Vascular Surgery Exam Prep

Editors: Adam Johnson, MD, MPH; Matt Smith, MD, PhD; and Audible Bleeding

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The content was developed here by the Audible Bleeding Team to accompany our board review podcast episodes.

Usage

This is not a comprehensive textbook but instead an outline of the most high yield information to help guide board preparation.

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Cerebrovascular

07 Jan 2019: *Adam Johnson, MD, MPH; Nicole Rich, MD, MPH; Kevin Kniery, MD, MPH*

Available Guidelines

Society for Vascular Surgery clinical practice guidelines for management of extracranial cerebrovascular disease[1]

Presentation and Diagnosis

1. **What is the definition of crescendo TIAs?**

   Frequent repetitive neurological attacks without complete resolution of the deficit between the episodes, producing the same deficit but no progressive deterioration in neurological function If a progressive deterioration then it is a stroke in evolution.

2. **Who needs to be screened?**

   Only 15% of stroke victims have a warning TIA before a stroke so waiting until symptoms occur is not ideal. The purpose of carotid bifurcation imaging is to detect "stroke-prone" carotid bifurcation plaque and identify a high-risk patient likely to benefit from therapy designed to reduce stroke risk.

   The absence of a neck bruit does not exclude the possibility of a significant carotid bifurcation lesion - focal ipsilateral carotid bruits in symptomatic patients has a sensitivity of 63% and a specificity of 61% for high-grade carotid stenosis (range, 70%-99%).

   Screening of the general population is not indicated. Screening should be considered for patients with:

   - Evidence of clinically significant peripheral vascular disease regardless of age

- Patients aged >65 years with a history of one or more of the following atherosclerotic risk factors:
  - CAD
  - Smoking
  - Hypercholesterolemia
- In general, the more risk factors present, the higher the yield of screening should be expected.
- The benefit of prophylactic treatment of high grade stenosis is estimated at a 1-2% stroke reduction risk per year.[2]
- Keep in mind that intervention (CEA/CAS) has only demonstrated a benefit in asymptomatic patient with life expectancy greater than 3 years.[3–5]

3. **US findings that confirm disease**
   - 50-69% stenosis of ICA - Low sensitivity for 50-69% stenosis - a negative ultrasound in symptomatic patients necessitates additional imaging
     - PSV 125-229 cm/sec
     - EDV 40-100
     - Internal/Common Carotid PSV Ratio 2-4
   - 70-99% stenosis of ICA
     - PSV >/= 230 cm/sec
     - EDV >100 (EDV > 140 cm/sec most sensitive for stenosis >80%)
     - Internal/Common Carotid PSV Ratio > 4
   - Velocity-based estimation of carotid artery stenosis may need to be adjusted in certain circumstances
     - Higher velocities in women than in men
     - Higher velocities in the presence of contralateral carotid artery occlusion.
   - High carotid bifurcation, severe arterial tortuosity, extensive vascular calcification, and obesity may also reduce the accuracy of DUS imaging
4. **Other Imaging Modalities**
   - CTA
     - Pro - fast, sub-millimeter spatial resolution, visualize surrounding structures
     - Con - cost, contrast exposure

- MRA
  - Pro - no contrast administered; analyze plaque morphology
  - Con - Does not visualize calcium in plaque; overestimates the degree of stenosis (False positive for 50-69% to be read as >70%)
- Catheter-based digital subtraction imaging (DSA)
  - Still considered by many the gold-standard imaging modality
  - Reserved for individuals with conflicting less-invasive imaging or those considered for CAS
  - Con - cost and risk of stroke

Management

Optimal medical therapy

Hypertension

- Lowering blood pressure to a target <140/90 mmHg by lifestyle interventions and anti-hypertensive treatment is recommended in individuals who have hypertension with asymptomatic carotid atherosclerosis or those with TIA or stroke after the hyper-acute period.
- Each 10-mm Hg reduction in blood pressure among hypertensive patients decreases the risk for stroke by 33%.

Diabetes

- Glucose control to nearly normoglycemic levels (target hemoglobin A1C <7%) is recommended among diabetic patients to reduce microvascular complications and, with lesser certainty, macrovascular complications other than stroke.

Lipid abnormalities

- Risk of stroke decreased by >15% for every 10% reduction in serum LDL in patients with known coronary or other atherosclerosis
- Statin agents are recommended targeting LDL of 100 mg/dL, for those with coronary heart disease or symptomatic atherosclerotic disease, and LDL of 70 mg/dL for very high-risk persons with multiple risk factors
- High dose statin therapy in patients with TIA/stroke reduce future rates of stroke or cardiovascular events but not overall mortality at 5 years.[6]

Smoking - Physician counseling is an important and effective intervention that reduces smoking in patients by 10% to 20%

Antithrombotic therapy - There is no evidence to suggest that antiplatelet agents other than aspirin have improved benefit in asymptomatic patients with carotid atherosclerosis

Carotid endarterectomy

Timing

- Recommendations on when to operate after a stroke
  - Acute stroke with a fixed neurologic deficit of >6h duration - When the patient is medically stable, treatment in less than or equal to 2 weeks after the stroke is preferable.[7,8]
  - Consider urgent intervention in a medically stable patient with mild-moderate neurologic deficit, if there is a significant area of ischemic penumbra at risk for progression
  - Stroke in evolution (fluctuating / evolving neuro deficit) or crescendo TIA (repetitive transient ischemia w improvement between events) - If neuro status is not stabilized by medical intervention consider urgent CEA
  - CEA is preferred to CAS based on an increased embolic potential of carotid lesions that present in this fashion.[9]
  - Management of acute stroke[10]
    - <4.5hrs from onset of symptoms - tPA unless contraindication
      - Age >80 and diabetes are contraindication to tPA after 3hrs.
      - Other contraindications - high BP, intracranial hemorrhage, recent stroke or head trauma, spine/brain surgery within 3mo, GI bleed within 21d
    - <6hr from onset of symptoms - catheter directed therapy
- What is the only emergent indication for CEA?
  - Crescendo TIAs or a stroke in evolution with a surgically correctable lesion that is identified

Intraoperative Techniques

- General concepts
  - Patch angioplasty or eversion endarterectomy are recommended rather than primary closure to reduce the early and late complications of CEA (GRADE 1, Level of Evidence A).
- Neuromonitoring/Shunting options during a carotid endarterectomy

  - Local anesthesia with direct neuro monitoring - the patient is awake and moving to command throughout the case. Though improved neuromonitoring has not been shown to reduce MI rate with CEA
  - Stump pressure Clamp the inflow and place butterfly attached to a-line tubing into the internal carotid If stump pressure is > 40 mmHg can proceed, if < 40 place shunt
  - EEG Neuromonitoring - EEG tech places neuromonitoring, monitored by intraop tech and neurologist remotely, generally clamp ICA for 3 minutes before proceeding, if any deficits unclamp, await normalization of EEG then proceed
  - Non-selective shunting - shunt all carotids
- Techniques to reach internal carotid lesions that are high?
  - Nasotracheal intubation will help extend the neck to reach higher lesions
  - Divide posterior belly of digastric to reach high lesions with care to watch for glossopharyngeal
  - Styloidectomy
  - Mandible subluxation with assistance from ENT if previous techniques fail.
- What is the best technique for a patient with a kinked internal carotid artery?
  - Eversion carotid endarterectomy will allow you to reduce the redundancy
  - Otherwise, no advantage has been shown between eversion or patch, both can be shunted
- Discuss nerve injuries – where you would encounter these and what deficit would be seen
  - Hypoglossal Just above the bifurcation of the carotid artery Will see tongue deviation to the side of injury
  - Glossopharyngeal High dissections under digastric Difficulty swallowing, aspiration risk, can be devastating
  - Vagus Adjacent and lateral to carotid, injury occurs with carotid clamping, Hoarseness is noted as RLN is a branch off of vagus
  - Marginal Mandibular (Off of facial nerve) Retraction at the angle of the jaw for high dissections Leads to the corner of lip drooping, can be confused with a neuro deficit following the case

Postoperative Complications

- What to do if neuro deficits following your carotid endarterectomy
  - If in OR – perform duplex, if normal open wound and shoot cerebral angiogram
  - If in Recovery or on the floor – many would consider CTA first vs duplex to look for thrombosis
- Risk factors and how to manage hyperperfusion syndrome?
  - Defined as an ipsilateral headache, hypertension, seizures, and focal neurological deficits can present 2-3 days out from surgery
  - Patients with uncontrolled hypertension are at risk for hyperperfusion syndrome, clinical practice guidelines by SVS recommend strict BP control following CEA, maintain a pressure less than 140/80
- High risk groups
  - ESRD patients have higher rates of perioperative stroke, but also have higher rates of stroke if not revascularized.[11]

Long term complications and follow up

- Recommend f/u US at </=30 days. >/= 50% stenosis requires further imaging.
- Contralateral stenosis
  - The risk of progression for moderate stenosis at the initial surveillance to severe stenosis can be as high as five times
  - Requires post-operative surveillance.

Carotid Artery Stenting

- In patients aged >70 undergoing CAS the risk of stroke was the highest, presumably due to calcific disease in the arch
  - Lesion-specific characteristics are thought to increase the risk of cerebral vascular events after CAS and include a “soft” lipid-rich plaque identified on noninvasive imaging, extensive (15 mm or more) disease, a pre-occlusive lesion, and circumferential heavy calcification
  - This can be reduced, but not eliminated, by using flow-reversal embolic protection rather than distal filter protection
- Limited data on CAS in asymptomatic patients - currently is not supported by guidelines or considered reimbursable
- Consider CAS in symptomatic patients with >50% stenosis who are poor candidates for CEA due to severe uncorrectable medical comorbidities and/or anatomic considerations

  - Ipsilateral neck dissection or XRT - equivalent periprocedural stroke rate to CEA, but increased later stroke rate. CEA higher rates of cranial nerve damage (9%).[12]
  - Contralateral vocal cord paralysis
  - Lesions that extend proximally to the clavicle or distal to C2
- Transfemoral Approach vs Transcarotid approach
  - ROADSTER Trial - single arm study with flow reversal for cerebral protection. Suggest lower rates of post-op stroke
- Post-op follow up - Dual-platelet therapy should be continued for 1 month after the procedure, and aspirin should be continued indefinitely
  - In stent restenosis (>50%) - repeat angioplasty or stent have low incidence of periprocedural stroke but failed to improve long term stroke/death/MI or patency rates.[13]

Management of uncommon disease presentations

- Occluded Carotid What to do for occluded carotid?
  - Leave it alone
- What if occluded carotid is still causing TIAs?
  - External carotid endarterectomy and ligation of internal
  - The addition of oral anticoagulation is likely to reduce the rate of recurrent CVA
- What if the patient has severe vertebrobasilar insufficiency and carotid artery disease?
  - Should undergo carotid revascularization first to improve flow
  - Vertebrobasilar insufficiency characterized by dizziness, ataxia, nausea, vertigo and bilateral weakness.[14]
- What about tandem lesions in the carotid in a symptomatic patient, carotid bulb and carotid siphon lesion (high ICA)? How should you treat this?
  - Treat carotid bulb first, likely the embolic source
- Carotid artery dissection
  - Patients with carotid dissection should be initially treated with antithrombotic therapy (antiplatelet agents or anticoagulation) (GRADE 1, Level of Evidence C).
  - Indications for endovascular treatment of carotid artery dissection[15–17]
    * Ongoing symptoms on best medical therapy

        - Contraindication to antithrombotics
        - Pseudoaneurysm
- Simultaneous coronary and carotid disease
    - Patients with symptomatic carotid stenosis will benefit from CEA before or concomitant with CABG. The timing of the intervention depends on the clinical presentation and institutional experience (GRADE 1, Level of Evidence B).
    - Patients with severe bilateral asymptomatic carotid stenosis, including stenosis and contralateral occlusion, should be considered for CEA before or concomitant with CABG (GRADE 2, Level of Evidence B)
    - Patients undergoing simultaneous CEA/CABG demonstrate highest mortality.[18]

Prospective Trials - MUST READS

1. Asymptomatic Carotid Atherosclerosis Study (ACAS)
    - Compared medical management with CEA in asymptomatic patients with $> 60\%$ stenosis
    - 5-year stroke and death rate was 5.1% vs 11%
    - In women, the benefit of CEA was not as certain as 5y stroke and death rates were 7.3% vs. 8.7%
    - This was pre statin and clopidogrel era
2. North American Symptomatic Carotid Endarterectomy Trial (NASCET)[19]
    - Compared medical management vs CEA for symptomatic patients with moderate (50-69%) and severe stenosis (>70%)
    - Only moderate impact for patients with moderate stenosis (50-69%)
    - Symptomatic patients with >70 % stenosis benefited from CEA, at 18 months 7% major stroke in surgical arm, and a 24% stroke rate in medical arm. 29% reduction in 5-year risk of stroke or death
        - Patients with severe >70% stenosis had such a dramatic effect the trial was stopped early for this subset and all referred for endarterectomy
    - No benefit is shown in symptomatic patients with $< 50\%$ stenosis
    - European studies have shown similar results
        - ACST = ACAS

  - ECST = NASCET.

3. Carotid Revascularization Endarterectomy versus Stenting Trial (CREST)
   - Compared CEA vs. CAS in both symptomatic and asymptomatic patients.
   - Composite endpoint of 30-day stroke, MI, death equivalent between CEA and CAS
   - CAS had a significantly higher incidence of stroke and death than CEA and CEA higher incidence of MI
     - Follow up at 10 years demonstrated no difference in composite stroke/MI/death but increased rate of stroke/death in stented patients likely attributable to increased periprocedural stroke.[20]
   - Subanalyses identified that older patients (>70y) had better outcomes after CEA than CAS, the QOL impact of stroke was more significant than that of MI, and anatomic characteristics of carotid lesions (longer, sequential, remote) were predictive of increased stroke and death after CAS
   - Unfortunately, this study provides a benchmark to strive for, but no other large trials have achieved these results.
4. ROADSTER
   - Single arm feasibility trial of transcarotid carotid stenting
   - The results of the ROADSTER trial demonstrate that the use of the ENROUTE Transcarotid NPS is safe and effective at preventing stroke during CAS. The overall stroke rate of 1.4% is the lowest reported to date for any prospective, multicenter clinical trial of CAS.
5. Trials to look out for in the next few years
   - CREST-2 - multicenter, randomized controlled trial is underway that is evaluating revascularization against modern intensive medical management
   - ACT-1 and ACST-2- the role of intervention in asymptomatic patients, designed to compare the early and long-term results of CEA vs CAS and best medical management
   - ROADSTER-2 - TCAR

Upper Extremity and Thoracic Outlet

21 Jan 2021: *Kush Sharma, MD and Ashraf Mansour, MD*

Anatomy/ Exposure of Vessels

What are the zones of the upper extremity?[21,21]

Division of the upper extremity into three zones:

1. Intrathoracic zone including aortic arch, innominate artery, subclavian artery bilaterally, innominate veins, and SVC
2. Thoracic outlet (base of neck to the axilla including the subclavian, proximal vertebral, proximal axillary arteries/veins)
3. Axilla to fingers (the arm)

What are some common exposures for major upper extremity arteries?

Right Subclavian Artery: Medial sternotomy (proximal) or right supraclavicular area (mid/distal)

Left Subclavian Artery: Anterolateral thoracotomy in emergent setting for proximal left subclavian artery control. When third space sternotomy, supraclavicular incision with thoracotomy "trap door" exposure

Supraclavicular incision: After division of the platysma and clavicular head of the SCM, fat pat of varying thickness contains the omohyoid muscle. This should be divided and placed superiorly/laterally. At this point, the anterior scalene muscle is exposed medially with phrenic nerve running in lateral to medial direction. Division of anterior scalene for carotid/subclavian bypass should be performed as close to the first rib as possible. After this is performed, the subclavian artery is exposed.

Axillary Artery: Infraclavicular exposure below middle 1/3rd of clavicle. Pec major split and pec minor freed at lateral wound. Axillary vein followed by deep

and superior to get to artery

Anatomically bound by the first rib proximally and the lateral edge of the teres major muscle distally. For exposure of the first part of the axillary artery, the ipsilateral arm is abducted approximately 90 degrees and horizontal skin incision 2 cm below the middle third of the clavicle. Underlying pec major is split by bluntly separating the fibers and followed by exposing the tough clavipectoral fascia. At the lateral wound, the pec minor can be freed and laterally retracted. The axillary vein is first structure encountered in the sheath and the artery lies just superior and deep to the vein. Make sure to avoid nerves of brachial plexus that lie deep to first part of axillary artery and are at risk for injury during blind placement of occluding arterial clamps.[22]

What steps are involved for brachial artery exposure?

Brachial artery: incision between biceps/triceps on medial arm (avoid basilic vein damage in subcutaneous and deep to the fasia at medial biceps. Median nerve seen and retracted. Two brachial vein are paired adjacent to artery.

Superficial location makes it vulnerable to injury and accounts for most vascular injuries of upper extremities. Brachial artery exposure involves a 5-8 cm longitudinal incision in the groove between the biceps/triceps muscles on the medial aspect of the arm. In the lower half of the arm, take care to avoid basilic vein damage in the subcutaneous tissue. Neurovascular bundle exposed by incising the deep fascia at the medial border of the biceps muscle, which is retracted anteriorly. After retracting basilic vein into posterior wound ,brachial sheath is opened and median nerve is most superficial structure and retracted. The artery lies deep to the nerve and surrounded by two brachial veins. Posteriorly, is the presence of the ulnar nerve.

Brachial Artery bifurcates at the radial tuberosity into radial/ulnar branches. After the bifurcation and immediately after its origin, the ulnar artery gives off a short common interosseous branch, which bifurcates at the hiatus in the proximal interosseous membrane. Exposure of brachial artery in the antecubital fossa requires a transverse skin incision 1 cm distal to the midpoint of the antecubital crease. After deepening, avoid injury to subcutaneous veins and mobilize the basilic vein medially. Medial antebrachial cutaneous nerve should be protected. Divide the bicipital aponeurosis and after division, exposure of the brachial artery is present, which is flanked by two deep veins and crossing branches. Isolation of brachial artery requires ligation and division of these crossing vein branches.

Radial artery at the wrist with 2-3 cm longitudinal incision generally between radial artery and cephalic vein. Radial artery was exposed by incising the antebrachial fascia just medial to the radius. Two veins accompany the artery and should be dissected away during arterial isolation. The superficial radial nerve and its medial/lateral branches course between the cephalic vein and radial artery in the area.

Exposure of the ulnar artery is by coursing beneath the superficial flexor muscles in the proximal forearm, emerging near the ulnar border at the point midway between the elbow and the wrist. In the distal forearm, the ulnar artery course just beneath the antebrachial fascia and is easily exposed through a longitudinal incision placed radial to the flexor carbi ulnaris. The palmar branch of the ulnar nerve courses the superficial to the antebrachial fascia and should be preserved during arterial exposure

What common aberrant upper extremity/arch anatomy is important to be aware of?

- Bovine arch with left common carotid/left subclavian have common origin
- Vertebral artery directly off the aortic arch
- Aberrant right subclavian where innominate becomes right CCA and right subclavian distal to last branch on left side passing behind esophagus to supply the right arm

Epidemiology, etiology, and diagnostic evaluation

How does evaluation of upper extremity ischemia differentiate from lower extremity ischemia?[23]

- Upper extremity ischemia <5% of patients with limb ischemia and in contrast to lower extremity, atherosclerosis is not a major contributor to upper extremity ischemia
- Vast majority of cases caused by autoimmune/connective tissue disorders

How can upper extremity disease be classified?

Anatomic Location:

- Large vs. Small Vessel

Disease Process:

- Vasospastic or occlusive. Vasospastic disease is more responsive to pharmacologic management while occlusive requiring endovascular/surgical management.

How should patients be evaluated who have concern for upper extremity disease?

Diagnostic Evaluation

1. Detailed H+P evaluation (pulse palpation, auscultation at supraclavicular/infraclavicular fossa may reaveal a bruit concerning for subclavian artery stenosis, upper extremity neurovascular/skin exam)

2. Brachial/forearm blood pressures and if suspected claudication, measured at rest and 2-5 minutes after exercise. Look for a gradient of >20 mmHg is considered significant
3. Some or all of 6 P's of acute limb ischemia with symptoms occurring within 14 days are deemed acute
4. Doppler insonation of radial, ulnar, palmar, and digital arteries
5. Vascular Lab Evaluation
    1. Segmental Pressure Measurements
    2. Duplex Ultrasound (look for large vessel occlusive disease)
6. Other Imaging
    1. CTA/MRA
7. Clinical Lab tests
    1. Inflammatory disorders-CBC, ESR, ANA, RF
    2. Hypercoagulable screening

Operations/Procedures

What are some indications for carotid-subclavian bypass?

1. Atherosclerosis
2. Staged revascularization prior to TEVAR for aneurysmal disease requiring coverage of the LSA

How does the exposure differentiate in transposition vs bypass?

Exposure (Transposition vs Bypass)

- Arterial transposition via a short, transverse cervical incision above the clavicle between two heads of SCM (bypass is lateral to entire SCM)
- Sub-platysmal flaps created and avoid EJ vein damage
- Omohypoid divided between heads of SCM and IJ mobilized laterally (bypass IJ is mobilized medially to expose CCA and care must be taken to avoid phrenic nerve in more lateral approach)
- CCA is reflected medially with vagus nerve
- On the left side, the thoracic duct is identifiable and divided followed by dividing the vertebral vein
- Subclavian artery and proximal branches identified (anterior scalene is in lateral dissection)

What are some common complications after carotid subclavian bypass in order of highest to lowest incidence?

Complications[24]

1. Phrenic nerve palsy (most common) - most often managed conservatively.
2. Recurrent laryngeal palsy
3. Lymphatic leak
4. Neck hematoma

When carotid-subclavian bypass compared to transposition?

1. Vertebral artery takes origin from the subclavian artery in a very proximal position or is dominant over the contralateral side, then bypass preferred.[25]
2. For coronary-subclavian steal with patent internal mammary artery to coronary artery bypass graft, then Bypass (a carotid-subclavian transposition requires a more proximal clamp with occlusion of inline antegrade flow to the coronary bypass during the procedure)[26]

Vaso-occlusive disease

What are causes and symptoms associated with subclavian/axillary occlusive disease?[27]

- Etiology: Atherosclerosis is the most common cause of subclavian/axillary occlusive disease. Left SCA > Right involvement. Less common causes include Takayasu disease, giant cell arteritis, or arterial TOS
- Symptoms: Upper extremity arm/hand ischemia or neurologic symptoms due to subclavian-vertebral steal. Because significant collaterals, minimal pain on exertion even with subclavian occlusion

What are causes and symptoms associated with brachial/forearm occlusive disease?

- Etiology: MCC of brachial artery occlusion is cardiac origin embolus. Atherosclerosis RARELY affects the brachial artery. Distal axillary/proximal brachial stenosis can be from repetitive trauma from crutch use.
- Forearm occlusive disease can be seen in advanced ESRD/DM where calcific atherosclerosis of radial/ulnar arteries is present. Less common causes include Beurger disease or Raynaud Phenomenon

How/when is upper extremity occlusive disease treated?

- SCA Occlusive Disease

  - Endovascular with balloon expandable stent via femoral or ipsilateral brachial artery.

    @*chatterjeeAngioplastyAloneAngioplasty*2013; @*bradaricEndovascularTherapyStenoOccl*

    Preferred in:

    * Short segment or ostial disease with adequate distance to the vertebral artery origin.
    * History of neck surgery or radiation.

  - Surgery:

    * Bypass from aortic arch through median sternotomy
    * Ipsilateral CCA to subclavian artery (bypass or transposition)
    * Contralateral CCA (anterior or retropharyngeal)

- Brachial/forearm Occlusive disease

  - Endovascular: PTA evidence is anecdotal with stents for lesions unresponsive to PTA or dissection following angioplasty
  - Surgery:

    * GSV vein bypass remains standard for revascularization with bypasses to superficial or deep palmar arch have good patency rates. Tunneling is subcutaneous if to distal ulnar or superficial palmar arch whereas anatomical to distal radial artery over the anatomic snuffbox

Vasospastic Disorders

What is Raynaud's and what causes it?[23,28]

- Exaggeration of normal physiologic response with episodic pallor or cyanosis of the fingers caused by small digital artery vasoconstriction occurring in response to cold or emotional stress. There is an abnormality with sympathetic nervous system, resulting in a multifactorial problem involving a combination of vascular, neural, and humoral factors.

What are the subtypes of Raynaud's phenomenon and what is the underlying pathology?

- Primary: Raynaud's disease-idiopathic form that is a benign process not associated with structural vascular change. Triggers include (cold, emotional stress, caffeine) resulting in digital smooth muscle contraction and temporary digital hypoperfusion.

- Secondary: Fixed vascular obstruction to blood flow decreasing threshold for cold induced vasospasm or progress to tissue loss. Diseases associated include mixed connective tissue disease, SLE, and rheumatoid arthritis, and scleroderma (accounts for 80-90% of cases). In setting of lower digital blood pressure, symptomatic digital ischemia or tissue loss under low stress conditions. With cold/emotional stress, vasoconstrictive response of digital artery smooth muscle further causes arterial closure and resultant symptoms

What are diagnostic criteria for Raynaud's?

- Clinical (Progression of ischemia with white -> blue -> red finger discoloration. Episodes can be self-limited and may last from less than a minute, but generally not longer than 10-20 minutes
- Qualitative testing for severity of cold sensitivity in Raynaud's syndrome can be useful. Most basic test is cold sensitivity and recovery after ice water immersion. >10 minutes return to baseline pressure concerning for Raynaud's
- Segmental pressures with finger systolic blood pressure can differentiate purely vasospastic vs occlusive disease. Difference of more than 15 mm Hg between fingers or absolute finger pressure <70 mm Hg may indicate occlusive disease
- Serologic evaluation (ANA/RF)

What are appropriate treatments for Raynaud's phenomenon?

1. Medical-cold/tobacco avoidance. Calcium channel blocker (nifedipine) has been the most effective and losartan has also been beneficial. Fluoxetine (SSRI). Other drugs include alpha blocker, sildenafil, reserpine, cilostazol, captopril. NOT GOOD OUTCOMES IN PATIENTS WITH ARTERIAL OBSTRUCTION
2. Surgical-thoracic sympathectomy (used for treatment of digital artery vasospasm/digital ischemic ulceration). For vasospasm, thoracic sympathetcomy is initially successful, but symptoms return generally within 3-6 months.
3. Immunosuppression/immunomodulation for connective tissue disorders associated with secondary Raynaud phenomenon

Ergotism

What is Ergotism?[29]

- Etiology: Ergot is a parasitic fungal disease that has a particular prevalence for infecting rye plants and ergot alkaloids have been linked to epidemic poisonings that manifested as ergotism from consumption of rye

- Modern day is rare

What causes Ergotism and how do patients present?

- Ergotamine is chemically like endogenous catecholamines/indolamines and when applied clinically, it behaves as an agonist to alpha-adrenergic, sertoninergic, and dopaminergic receptors. Despite limited bioavailability, vasocontrictive effects have been reported to last for 24 hours or longer
- Gangrenous-mild limb pain followed by burning pain/shooting and
- Convulsive-heaviness in limbs and head associated with diarrhea. Could result in tonic-clonic spasms

How can you diagnose Ergotism and what is the process for treating this disease?

Upper extremity ischemia (i.e. digital ulceration) in the setting of ergot alkaloid use (typically for migraines)

Treatment:

- Volume expansion and IV heparin as anticoagulation
- IV infusion of nitroprusside, nitroglycerin, ilioprost or combination
- Infusion of Ca 2+ channel blockers
- Surgical: for thrombosis, consider thrombolysis

Buerger's Disease

How is Buerger's disease categorized?[27]

- Non-atherosclerotic, segmental, inflammatory disease of small/medium sized arteries in distal extremities of tobacco users distinct from either atherosclerosis of immune arteritis

What clinical criteria can help diagnose Buerger's?

- Smoking history, onset before 50 years, infrapopliteal arterial occlusions, upper limb involvement, absence of atherosclerotic risk factors besides smoking

What is important about diagnosing Buerger's

- Typically a diagnosis of exclusion
- Must rule out proximal embolic source, trauma, local lesions (eg pop entrapment or cystic adventitial disease), autoimmune disease, hypercoagulable status, atherosclerosis

What physical exam and non-invasive/invasive imaging findings of Buerger's?

- Distal, but not proximal arterial disease (palpable brachial/popliteal but absent/reduced at ankle or wrist)
- DBI<0.6 and flat/reduced digital waveforms
- CTA/MRA/DSA-characteristic corkscrew collateral

What is the mainstay treatment in Buerger's disease?

1. Smoking cessation! Only treatment to improve symptoms and reduce amputation risk if achieved before onset of gangrene or tissue loss. Important to remember following treatments will likely fail without smoking cessation.
2. If smoking cessation does not improve, medical management with antiplatelet agents, immunomodulators, vasodilators, anticoagulants
3. Endovascular-distal small vessel intervention
4. Surgical-upper extremity autogenous vein bypass-limited success due to poor outflow
5. Sometimes can consider upper extremity sympathectomy, but unproven benefit
6. Amputation-reported in 30-40% who are followed longer than 5 years

Large Artery Vasculitis

What are common characteristics for patients who are suspected to have a large vessel vasculitis?[30]

- Affect aorta and major branches
- Present with non-specific heterogenous symptoms making the diagnosis challenging. Most commonly, they present with systemic or constitutional symptoms (fatigue, fever, weight loss, arthralgias)
- Frequently, diagnosis made with presence of constitutional symptoms, elevated inflammatory markers, and dedicated imaging (MRA, CTA, DUS, or PET)

How can you differentiate takayasu arteritis vs giant cell arteritis?

1. Takayasu arteritis
    1. Aorta and primary
    2. Young patients <20 years and female in 80-90% of cases, Asian populations
    3. Criteria (ACR)
        1. Onset <40 years
        2. Claudication of an extremity

3. Decreased brachial pulse
4. >10 mmHg SBP between arms
5. Bruit over subclavian arteries or aorta
6. Arteriographic evidence of narrowing/occlusion in aorta/primary branches/or large upper/lower extremity arteries

2. Giant cell arteritis
    1. Aorta and main branches, but pre-dilection for carotid artery branches
    2. Diagnosis:
        1. Age at disease onset > 50 years
        2. New headache
        3. Temporal artery abnormality
        4. Elevated ESR (>50)
        5. Abnormal artery biopsy (gold standard test)
    3. Other symptoms include jaw pain with mastication or visual changes
    4. Associated with Polymyalgia rheumatic, characterized by morning stiffness in shoulders/hips occurring in 40-50% of patients
    5. Arteriography/MRA/CTA/PET may be used to assess large vessel involvement

How should patients be monitored with active large artery vasculitis?

- Lab data tracked at least monthly for 6 months with close follow-up to ensure appropriate response to medical treatment and enable physicians to assess for adverse effects of medical treatment
- Repeat tests after remission reached and imaging choice to evaluate large vessels (DUS/CTA/MRA)

What is the medical treatment for GCA and when do you consider surgical treatment?

- Medical-steroid therapy. In as many as 50% of patients who have a large vessel vasculitis refractory to glucocorticoid therapy alone, patients will trial immunomodulators or cytotoxic truxs (ie methotrexate, azathioprine, mycophenolate, tocilizumab, or leflunomide)
- Intervention-once remission, treatment of symptomatic arterial lesions should be considered and as many as 50-70% with large vessel vasculitis will require intervention.

  - Endovascular-angioplasty/stent/stent graft for large vessel vasculitis have all been described, however higher restenosis in endovascular compared to open treatment
  - Open Surgery (gold standard)-lesions are long, fibrotic and therefore less amenable to endovascular treatment. Bypass grafts from aorta-CCA are the most common (CEA should be avoid due to pathology involved)
    * Upper extremity bypass with autogenous vein to the brachial artery
    * Aortic aneurysms should be managed with open surgery

Aneurysmal Disease

How are subclavian aneurysms caused and how can they present?[31]

Etiology/Pathology:

- Degenerative (atherosclerotic or due to aberrant right subclavian with degenerative changes in proximal subclavian known as "Kommerell diverticulum")
- Traumatic (blunt, penetrating, iatrogenic with attempted catheter placement)
- Thoracic outlet obstruction

Presentation

- Exam-pulsatile supraclavicular mass or bruit, absent/diminished pulses, signs of microembolization ("blue finger")
- Most discovered incidentally, however referred chest, neck, shoulder pain, upper extremity ischemia due to thromboembolic phenomenon, brachial plexus compression, hoarseness from right recurrent laryngeal nerve compression
- Dysphagia from esophageal compression in aberrant right subclavian artery

What are diagnostic studies and treatment modalities for subclavian aneurysms?

- CXR-mediastinal mass may suggest neoplasm
- MRA/CTA important to delineate extent of aneurysm and proximity to ipsilateral vertebral artery

Treatment:

- Open Repair-resection/endoaneurysmorrhaphy with end to end (small aneurysms) or interposition prosthetic graft

  - Proximal-median sternotomy with supraclavicular fossa extension for adequate proximal control for right side, however supraclavicular with left anterolateral thoracotomy for left subclavian aneurysm
  - Mid-Distal-supraclavicular/infraclavicular generally adequate for control where again resection of the clavicle may be needed

- Endovascular Repair-transbrachial/transfemoral approach with covered stent
  - Must consider vertebral artery origin. Can cover vertebral artery if contralateral vertebral artery is patent and of adequate size, however posterior circulation stroke may occur when the contralateral vertebral artery is highly stenotic, hypoplastic or occluded.
- Hybrid Repair-embolization/coils of proximal subclavian artery combined with subclavian transposition or carotid-subclavian bypass
- For aberrant subclavian artery aneurysm, resection or exclusion of the aneurysmal artery with vascular reconstruction of the subclavian artery is recommended. Especially in the setting of dysphagia lusoria, subclavian artery reconstructed by interposition graft where proximal anastomosis is on ascending aorta. Alternatively, left posterolateral thoracotomy for proximal aneurysm resection and right supraclavicular incision for reconstruction of subclavian artery by end to side to the right CCA has been reported.

How are axillary aneurysms caused and how can they present?

Etiology/Pathology:

- Blunt/penetrating trauma
- Congenital (infrequently reported)
- Post-traumatic axillary aneurysms (repeated abduction/external rotation downward toward humeral head in baseball pitchers)

Presentation:

- Exam-pulsatile supraclavicular mass or bruit, absent/diminished pulses, signs of microembolization (“blue finger”)

What are diagnostic studies and treatment modalities for axillary aneurysms?

Diagnosis:

- Ultrasound
- CTA/MRA of upper extremity

Treatment:

- Open Repair-resection with interposition vein grafting or prosthetic if inadequate vein is present.

- Endovascular repair-covered stent graft can be placed with occasional embolization with micro coils to isolate sac and prevent retrograde endoleaks

How are brachial aneurysms caused and how can they present?

Etiology/Pathology:

- False aneurysms secondary to repetitive trauma
- Iatrogenic complications
- IV drug abuse (infected pseudoaneurysms in antecubital fossa)
- Connective tissue disorders (ex. type IV Ehlers danlos)

Presentation:

- Exam: pulsatile mass
- Local pain or symptoms of median nerve compressions
- Hand/digital ischemia from thrombosis/distal embolization

What are diagnostic studies and treatment modalities for brachial aneurysms?

Diagnosis:

- Duplex Ultrasound
- CTA/MRA of upper extremity may be needed to delineate extent of aneurysm

Treatment:

- Open Repair (preferred)-resection with patch or interposition vein grafting
- Endovascular repair-rare and generally in a traumatic setting
- Iatrogenic injuries-due to access and nonoperative treatment for small/asymptomatic pseudoaneurysms that are likely to thrombose spontaneously. Direct suture repair with evacuation of hematoma is possible. Thrombin injection is less favorable due to location and short neck.

Occupational Vascular Disease

There are some occupational vascular disorders than contribute to vascular disease in the upper extremity. Hand arm vibration syndrome and hypothenar hammer are of particular importance. Can you talk to us about the key information from these syndromes?[32]

Hand-Arm Vibration Syndrome

Etiology:

- Vibrating handheld machines (eg pneumatic hammers and drills, grinders, and chain saws)
- Linear relationship between exposure over years and onset of this syndrome
- Exact mechanism unknown, but thought that endothelial damage with sympathetic hyperactivity -> finger blanching attack

Presentation:

- Various stages seen where early results in slight tingling/numbness and lateral, the tips of one or more fingers experience attacks of blanching that is usually precipitated by cold
- Blanching typically lasts 1 hour and terminates with reactive hyperemia, but prolonged exposure can cause bluish black cyanosis of fingers

Diagnosis

- Detailed history with use of vibrating tools/symptoms of Raynaud phenomenon
- Objectively: cold induced ischemia with recording time until digital temperature recovers
- Digital occlusion with noninvasive digit pressures or duplex scanning

Treatment

- Avoidance of vibratory tools
- Nifedipine (Ca2+ channel blocker) in advanced cases
- IV prostanoid (ie prostacyclin) for digital gangrene
- Surgery-cervical sympathetectomy or digital sympathectomy rarely needed

Hypothenar hammer syndrome

Etiology:

- Repetitive use of palm of hand in activities that involve pushing, pounding, twisting
- Name comes from reports of mechanics, factory workers, carpenters or laborers who habitually use there hands as a hammer are ad risk for disease
- Repetitive trauma leads to thrombotic occlusion, aneurysm formation or both

Presentation:

- Asymmetrical distribution involving dominant upper extremity where cyanosis and pallor can occur and digits affected are ulnar distribution in nature
- Cool/mottled digits or severe cases with ischemic ulcers

Diagnosis:

- Duplex ultrasound
- CTA or MRA
- Arteriography (gold standard) with corkscrew pattern typically in affected vessels

Treatment

- Conservative-smoking cessation/hand protection/cold avoidance
- Medical-calcium channel blockers/antiplatelet
- Surgical (severe digital ischemia/aneurysm)-ligation if adequate collateral or interposition vein graft

Environmental Exposures

Exposure to what environmental agents can result in upper extremity ischemia?

Acrosteolysis

- Exposure to polyvinyl chloride can result in ischemic hand symptoms similar to those of Raynaud syndrome
- Angiography-damage to digital arteries with multiple stenosis/occlusions or hyper vascularity adjacent to areas of bone resorption
- Treatment-supportive

Electrical burns

- <1000 V cause injuries limited to immediate skin/soft tissue, however >1000 V cause damage from entry to exit point
- Results in arterial necrosis with thrombus or bleeding and gangrene of digits develop
- Initially can be occlusion/thrombosis or spasm, however later damage can cause aneurysmal degeneration
- Treatment-dependent on soft tissue/bone injuries as well. Can have reconstruction with free flap due to local vascular damage or occlusion of major artery requiring bypass grafting

Extreme thermal injuries

- Workers at risk with chronic exposure to cold (slaughterhouse, canning factory, and fisheries)
- Raynaud syndrome symptoms due to vasomotor disturbances in the hands when exposed to extreme chronic thermal trauma
- Treatment-Supportive

Sports Medicine

How can athletes specifically be affected by upper extremity ischemia?

Overview

- Athletes who engage in strenuous or exaggerated hand/shoulder activity may be susceptible to upper extremity ischemia from arterial injury manifested by Raynaud syndrome, symptoms of sudden arterial occlusion or digital embolization

Vascular Trauma-Upper Extremity

This is discussed in detail here: @ref(vascular-trauma), **so we will go over some important specifics for upper extremity vascular injury.**[33]

What is the mechanism and management of upper extremity axillary artery trauma?

Mechanism and Pattern

- Predominantly in penetrating trauma with equal incidence in proximal/middle/distal divisions and brachial plexus injury in >1/3rd of arterial injury

Diagnostic Considerations

- Physical exam with deficiencies in upper extremity pulses/ischemic changes, but may not be present given collateral flow from axillary artery to upper extremity
- High index of suspicion with location of injury proximity to course of axillary artery
- Upper extremity Doppler or CTA if patient is stable for diagnosis

Surgical Considerations

- Primary repair or treated with interposition graft
- If hemodynamically stable, can consider covered stent based on location to thoracic outlet via femoral/brachial approach

What is the mechanism and management of upper extremity brachial artery trauma?

Mechanism and Pattern

- Frequently associated with humerus fractures/elbow dislocation
- Penetrating trauma

Diagnostic Considerations

- Pulse deficit in majority (>75% of cases)
- Upper extremity Doppler of CTA

Surgical Considerations

- Given course, can be extensively mobilized and repaired in end-to-end fashion in 50% of cases. Otherwise, treatment with an interposition graft

What is the mechanism and management of upper extremity radial/ulnar artery trauma?

Mechanism and Pattern

- Associated with significant soft tissue pattern

Diagnostic Considerations

- Pulse deficit in >80% of patients
- Doppler based Allen test-confirm radial/ulnar contribution to palmar arch

Surgical Considerations

- If Allen test reveals a patent palmar arch, the injured artery can be ligated
- If palmar arch is not patent in the absence of contribution of the injured artery, it should be repaired
- If both are damaged, preference to ulnar artery as dominant contribution to hand
- Generally, repair can be done in an end to end fashion given mobility of the vessel

Compression Syndromes

The main syndromes are quadrilateral space syndrome and humeral compression of the axillary artery. What important information here do our listeners need to know?

Quadrilateral space syndrome

Anatomy:

- Bordered by teres minor superiorly, humeral shaft laterally, and teres major inferiorly, and long head of triceps muscle medially
- Posterior humeral circumflex artery and axillary nerve in space

Pathophysiology

- Compression of posterior humeral circumflex occurs with abduction/external rotation
- Typically seen with chronic overhand motion athletes (pitchers/volleyball players)
- Vascular-repetitive mechanical trauma to posterior circumflex humeral artery
- Neurogenic-fixed structural impaction of quadrilateral space by fibrous bands or space-occupying lesions

Presentation

- Muscle atrophy, paresthesias, poorly localized shoulder pain and pain in quadrilateral space

Treatment

- Medical: Oral anti-inflammatory medications, PT, limitation of activities
- Surgery: decompression with neurolysis/excision of fibrous bands or other space occupying lesions

Humeral head compression of axillary artery

Anatomy:

- 3rd portion of axillary artery compressed by head of humerus

Etiology/Pathophysiology:

- Arm is abducted and externally rotated with downward compression of humeral head to axillary artery

Presentation:

- Arm fatigue, loss of pitch velocity, finger numbness, Raynaud, cutaneous embolization

Diagnosis:

- Provocative maneuvers with impedance of flow through axillary artery on ultrasonography

- Arteriography with rest and provocative position

Treatment:

- Supportive with avoidance of throwing motion
- Surgical-saphenous vein patch for no improvement or structural injury may require resection with saphenous vein bypass anatomically or extra-anatomic tunneling above pec minor

Thoracic Outlet Syndrome

27 Nov 2019: *Nedal Katib, Prince of Wales, Sydney Australia*

Thoracic Outlet Syndrome = A constellation of signs and symptoms relating to the compression of the neurovascular structures that occurs as these structures travel between the thoracic aperture and the upper limb.

Types: Neurogenic, Venous and Arterial

- vTOS – 2-3%
- aTOS – 1%
- nTOS – >95%[34]

Anatomy

Understanding the anatomy of what is collectively referred to as the thoracic outlet is the best way to thoroughly appreciate this topic.

Anatomy from anterior to posterior

- Subclavian vein
- Phrenic nerve
- Anterior scalene muscle attachment to the first rib
- The subclavian artery
- The brachial plexus
- The middle scalene muscle.

Three spaces where the neurovascular structures are at risk of compression:

1. Interscalene Triangle
2. Costoclavicular Passage [22]
3. Subcoracoid Space[22]

Interscalene Triangle:

Appreciating the attachments of the Anterior and Middle Scalene Muscles on the first rib becomes important in the diagnosis of the various types and also the ultimate surgical management of the compression.

Anterior Scalene:

Attachments: Anterior Tubercles of the four 'typical' cervical vertebrae (3-6) AND the scalene tubercle on the upper surface of the first rib.

- Phrenic nerve runs along anterior scalene muscle and injury can cause ipsilateral diaphragm paralysis.

Middle Scalene:

Attachments: The posterior tubercles and intertubercular lamellae of all the cervical vertebrae AND the Quadrangular area between the neck and subclavian groove of the first rib.[35]

- Long thoracic nerve runs along middle scalene muscle and injury can cause winged scapula.

The First Rib:

- The broadest and flattest of the ribs and is an 'Atypical Rib.'
- The upper surface of the first rib has the scalene and quadrangular tubercles for attachments of the anterior and middle scalene muscles respectively. There are also three grooves for the Subclavian Vein, artery and the Lower Trunk of the Brachial Plexus.
- The Inferior Surface is smooth and inferior and medially has an attachment for the suprapleural membrane, Sibson's fascia AKA scalenus minimus, which is tethered to the C7 vertebrae.
- This is the passage of the subclavian vein largely as it emerges through the tight space created by the clavicle, the subclavius muscle and the costoclavicular ligament and also more posteriorly this can also compress the artery and nerves as the space can also be narrow in relation with the scapula and subscapularis.[22]

Subclavius Muscle:

- Attached to the costochondral junction of the first rib and is inserted into the subclavian groove on the inferior surface of the clavicle.[35]
- This space is best appreciated by intimate knowledge of three things:
  - The Coracoid Process and its attachments
  - The Pectoralis Minor Muscle
  - The Clavipectoral Fascia

The Coracoid Process:

- Arising from the Scapula as a 'process,' this broad-based bony landmark offers attachment to muscles and ligaments.
- The relevant attachments being the pectoralis minor muscle occupying the medial border for about 2cm behind its tip. The tip itself having a medial and lateral facet for the short head of biceps and the coracobrachialis muscles respectively.

Pectoralis Minor Muscle:

Attached to the bone of the third, fourth and fifth ribs AND the medial border of the coracoid process.

Clavipectoral Fascia:

A sheet of fascial membrane that fills the space between the clavicle and pectoralis minor splitting and encompassing the subclavius muscle. Its superior portion is what can be thickened and become a tight band referred to as the costocoracoid ligament.

Phrenic Nerve Anomaly:

The Phrenic Nerve normally runs anterior to the Subclavian Vein. A rare anomaly is the nerve compressing the vein anteriorly and in very rare circumstances due to the timing of development can run through the vein itself.

Anomalous anatomy can also cause TOS especially when patients have a Cervical Rib and anomalous first ribs or a congenital band attaching to the first rib.

- Incidence of anomalous first ribs and cervical ribs is 0.76% and 0.75% respectively.
- Incidence of bands are as high as 63% in the general population.[34]

nTOS

- Scalene Triangle compression – most common cause of brachial plexus and neurogenic TOS
- Cervical Rib and Anomalous First Rib

aTOS

- Cervical Rib and Anomalous First Rib
- Scalene Triangle compression

vTOS

- Costoclavicular Passage
- Subcoracoid Space

Diagnosis and Evaluation

Patient History

- Identify symptoms and thoroughly interrogate timing
- Exclude history of trauma
- Associated symptoms like headache, visual disturbance, neurology in the upper limb
- Exclude Carpal Tunnel and Antecubital Tunnel Syndromes if symptoms are isolated to the arm or forearm or hand
- Patients with vTOS may present acutely and have acute or subacute Upper Limb DVT
- Patients with aTOS need to be investigated and assessed urgently given risk of ischemia.

Clinical Examination

Provocative maneuvers are largely used for nTOS. While these are described and mentioned in most texts their utility largely is beyond the scope of a vascular surgeon's assessment and diagnosis of nTOS.

Adson Test

- Extended abducted and externally rotated arm – palpate radial pulse
- Rotate and laterally flex the neck to the ipsilateral side while inhaling deeply.
- A positive test results in reduction or complete obliteration of radial pulse

Roos Test / EAST test

- Patient seated and both arms abducted 90 degrees and externally rotated and elbows flexed at 90 degrees.
- Open and close hands for 3 minutes or until pain or paraesthesia sets in.

Elveys Test

- Abduct both arms to 90 degrees with elbows extended and dorsiflex both wrists.
- If pain is elicited as wrists dorsiflexed then test is positive.
- A further manoeuvre is then performed, laterally flex the head on each side, if pain is elicited on the contralateral side to which the head is flexed then test is positive.[34]

Non-invasive imaging or vascular lab studies

- DBI
- Arterial Duplex
- Venous Duplex
- CT – CTV commonly performed in acute upper limb DVT and suspicion of vTOS
- CTA for the evaluation of aTOS and excluding other causes of embolisation
- MRI – for further evaluation of the anatomy and related neurovascular compression
- Electromyography and Nerve Conduction Studies for nTOS

Paget Schroetter Syndrome

- First defined by Hughes in 1949 in reference to Sir James Paget who in a hundred years earlier defined acute arm swelling and pain as possibly related to vasospasm and then von Schroetter who in 1884 attributed to the presentation to subclavian and axillary vein thrombosis.[36]
- Now vTOS and Paget Schroetter Syndrome are used synonymously.
- Paget Schroetter Syndrome accounts for 10-20% of all upper extremity deep vein thrombosis.[37]

Rib Resection approaches

	Advantages	Disadvantages
Tran saxillary	Cosmetically more appealing as it has a limited hidden scar	• Difficult to visualize the anatomy, dependent on good assistance • Risk of injury to T1 nerve root, phrenic nerve, long thoracic, brachial plexus , subclavian vein and arterial with limited exposure to repair • Not able to approach cervical ribs, scalene triangle or patch vein.

	Advantages	Disadvantages
Suprac lavicular	• Good for scalene triangle access and debulking and cervical rib resection • Required for aTOS if arterial reconstruction necessary	• Unable to decompress venous compression or visualize vein adequately • Cosmetically less appealing
Infrac lavicular [@ siracuseI nfraclavi cularFirs tRib2015]	• Good access for venous decompression • Allows for excision of subclavius muscle and costoclavicular ligament	• Unable to expose subclavian artery or decompress brachial plexus. • Difficult to access most posterior aspect of rib • Cosmetically less appealing
Parac lavicular	• Useful if mixed etiology TOS to adequately decompression all neurovascular structures	• Requires two incisions one above and below the clavicle

Post operative complications

- Post operative patients with hemodynamic instability and ipsilateral effusion on xray should go back to OR for exploration and hemorrhage control.[38]
- Chyle leak often managed with adequate drainage and medium chain fatty acid diet.

vTOS

Demographics

- Incidence: 2/100,000 persons
- Age: 18 years to 30 years[39]
- M>F

Presentation

- Upper Limb edema, pain and cyanosis. Edema affects the shoulder, arm and hand and characteristically non pitting.

- Collateral vein dilatation over the shoulder, neck and anterior chest wall to accommodate for the increased venous hypertension.[36]
- Pain on exertion of the upper limb described as stabbing, aching or tightness.
- The reported incidence of PE following Upper Limb DVT is <12%.[36]

History

- A differential diagnosis for Upper Limb DVT
  - vTOS
  - Congenital Phrenic Nerve anomaly
  - History of Fracture, Clavicular Fracture and malunion
  - Repetitive arm provocative manoeuvres, check occupation and history of body-building
    - Pectoralis Minor Hypertrophy.
- Exclude Pulmonary Embolism
- Exclude Venous Gangrene and Phlegmasia of the upper limb

Goals of therapy for vTOS

Limited evidence due to lack of RCT's. Majority of evidence based on retrospective studies.

- Prevent immediate risk
- Return patient to unrestricted use of the affected extremity
- Prevent recurrence of thrombosis without the need of long-term anticoagulation
- Prevent long term Post Phlebitic Limb Syndrome

Initial management strategy

- As per ACCP Guidelines: Initial management is anticoagulation regardless of etiology.[40]
  - The limitations of anticoagulation alone are that the slow recanalization of the thrombus may lead to eventual valvular damage and intravenous scarring.[37]
  - Thrombolysis has been considered superior to anticoagulation alone in minimizing valvular damage due to residual clot.[41]
  - Systemic Lysis – non favored due to risk of intracranial hemorrhage.[42]

  - Catheter Directed Lysis (CDT) – carries a lower risk of intracranial hemorrhage.
  - Patient should be maintained in a compression sleeve until definitive decompression can be performed.
- Optimal timing of CDT
  - Within 14 days of onset of thrombosis. Excellent results have been reported following CDT if initiated before 14 days.[43]
- Surgical indications for vTOS
  - After initial management patients are generally divided into two groups, unsuccessful or successful thrombolysis.
  - Persistent stenosis or signs of extrinsic compression, on venography, has generally been perceived as a significant risk of recurrent thrombosis.
  - Surgery for vTOS remains to be mainly Rib Resection and decompression of the subclavian vein with or without venolysis and patch plasty either surgical or endovenous.
  - Surgical treatment of severe resistant subclavian vein stenosis in the setting of vTOS is rib resection by paraclavicular approach and vein patch plasty.

    @*melbyComprehensiveSurgicalManagement*2008

  - Venous occlusion in vTOS may be treated with jugular turn down or venous bypass to IJ of SVC if patients remain symptomatic.[44]

Controversy around vTOS

- There is a lack of consensus around the necessity of surgical rib resection, the timing and the requirement for vein patch plasty.
- Options post recanalization:
  - Deferring surgical decompression for 1-3 months after thrombolysis to allow for healing of the venous endothelium and resolution of the acute inflammatory process.[36]
  - Decompression during the same admission, as the thrombolysis, with the main benefit being to reduce the risk of re-occlusion.[36,45]
  - Post decompression venography and treatment 2 weeks post rib resection may help to prevent recurrence and long term vein patency.[46]

Landmark papers regarding vTOS and what are the take home messages

1. Lugo J et al – Acute Paget Schroetter syndrome: does the first rib routinely need to be removed after thrombolysis? Annals of Vascular Surgery 2015[47]
    1. Systematic literature review analysis. Patients divided into three groups
        1. First Rib resection (FRR) – n=448
        2. First Rib resection and endovenous venoplasty (FRR and PLASTY) n=68
        3. No further intervention after Thrombolysis n=168
    2. Symptom relief after initial follow up more likely in FRR (95%) and FRR and PLASTY (93%) compared to no rib removed (54%) – $p<0.0001$
    3. Results showed superior patency with FRR and PLASTY and FRR compared to anticoagulation alone.
    4. Conclusion was that patients are more likely to experience greater long-term results with FRR compared to no FRR.
2. Sajid MS et al – Upper limb vein thrombosis: a literature review to streamline the protocol for management. Acta Haematology 2007[48]
    1. a comprehensive review identifying the key papers on this topic and allows for a clear view of the best management strategy.
3. Vemuri, C., Salehi, P., Benarroch-Gampel, J., McLaughlin, L. N., & Thompson, R. W. (2016). Diagnosis and treatment of effort-induced thrombosis of the axillary subclavian vein due to venous thoracic outlet syndrome. *Journal of Vascular Surgery: Venous and Lymphatic Disorders*, *4*(4), 485–500.[44]
    1. Comprehensive summary of management strategy for effort induced thrombosis.

aTOS

Presentation

- Most common: Hand ischemia due to arterial compression or microembolization with subclavian artery aneurysm and pulsatile supraclavicular mass[49]
- Less common: Exertional pain, unilateral Raynaud's Phenomena, retrograde embolisation and neurological symptoms
- Clinical Examination

  - Audible Bruit / Palpable thrill over the supraclavicular fossa
  - Pulsatile mass
  - Distal ischemic lesions in the distal hand – Splinter hemorrhages
  - Positive Adson Test
- Differential Diagnosis
  - Trauma
  - Primary and Secondary Raynaud's Phenomena
  - Small Vessel Vasculitis
  - Connective Tissue Disorders
  - Thromboangiitis Obliterans
  - Arterial Embolisation – Aortic or Central Source
  - Radiation Arteritis
  - Atherosclerotic / Dissection causes
- The different anatomical abnormalities causing aTOS[49]
  - Cervical Rib (60%)
  - Anomalous First Rib (18%)
  - Fibrocartilaginous band (15%)
  - Clavicular Fracture (6%)
  - Enlarged C7 transverse process (1%)

Scher Staging of aTOS

- Stage 0: Asymptomatic
- Stage 1: Stenosis of Subclavian Artery with minor post stenotic dilatation with no intimal disruption
- Stage 2: Subclavian artery aneurysm with intimal damage and mural thrombus
- Stage 3: Distal embolisation from subclavian artery disease

Diagnosis

Most useful studies are pulse volume recordings (PVR) and duplex to identify aneurysm or sites of embolization. Stress test is not reliable for diagnosis.[50,51]

Management considerations with aTOS

- Symptomatic patients are generally indicated for treatment. Unlike asymptomatic patients in whom it may be appropriate to manage conservatively.[49]
- Supraclavicular rib resection is the most suitable for adequate arterial reconstruction. Transaxillary has been argued to offer more complete rib resection however arterial repair is not possible in this approach.
- Subclavian artery repair is necessary in Scher Stages 2 and 3 and in some cases 1. Arterial repair with conduit either GSV, Femoral Vein or prosthetic have been described. Ringed PTFE offers good patency and resistance to kinking in this functional anatomical location.

nTOS

Demographics

Neurogenic TOS is largely a clinical diagnosis with symptoms and signs pertaining to nerve compression most commonly the lower trunk of the brachial plexus.

- F>M – 70% Female
- Ages 20-40
- Occupational Exposure
- Trauma history

Presentation of nTOS

- Symptoms[52,53]
  - Paraesthesia (98%)
  - Trapezius pain (92%)
  - Neck, shoulder or arm pain (88%)
  - Supraclavicular pain with or without occipital headache (76%)
  - Chest pain (72%)
  - Weakness
  - Swelling
- Positional Effects
  - Reproducible exacerbation of symptoms
  - Lying supine with arms overhead
  - Overhead activities -occupational or recreational

- Weakness and Muscle Atrophy
  - Hypothenar atrophy
  - Drop-off in athletic performance
  - Inability to carry out activities of daily living

The role of the Vascular Surgeon with nTOS

Often these patients have already seen multiple specialists and physiotherapists.

- Exclude other causes
- Confirm diagnosis – Neurophysiologic Tests (EMG and NCS)
- Seek alternate opinion
- Trial of Physiotherapy and non-operative management - patients should be evaluated and undergo a 6 week course of physical therapy. This physical therapy focuses on scalene and pectoralis stretching improving mobility of the shoulder and strengthening the arm. Many improve with physical therapy.[54]
- Anterior scalene lidocaine block may provide temporary symptom relief (~7 days) and may help identify those patients most likely to benefit from surgical decompression.[55,56]
- Botulinum injection may give an average of 6 weeks of relief.[55]
- Be selective in patients who may require surgery

Surgery with Rib resection often is accomplished with transaxillary or supraclavicular approach, particularly if scalenectomy or cervical rib resection is necessary.

Abdominal/Iliac/Peripheral Aneurysms

30 Mar 2021: *Mia Miller, MD and Julie Duke, MD; University of Minnesota*

Pathogenesis, presentation and risk factors

What is an abdominal aortic aneurysm (AAA)?[57]

- Defined as a localized dilation of an artery to a diameter greater than 50% (1.5x) of its normal diameter. It is generally accepted that >3cm in adults is considered aneurysmal for the abdominal aorta.
- AAAs can be described as:
  - Infrarenal – distal to the renal arteries with normal aorta between the renal arteries and the aneurysm origin.
  - Juxtarenal – aneurysm extends to the renal arteries but does not involve them
  - Pararenal – aneurysm involving the origin of at least one of the renal arteries
- Estimated 1.1 million Americans have AAAs, which equates to a prevalence of 1.4% in 50-84 year old general population.
- AAAs are 3-7x more prevalent than thoracic aortic aneurysms and can co-exist with other aneurysms throughout the arterial vascular system like popliteal artery aneurysms.
  - In a 10-year review originating from Ireland, 50% of patients that presented with unilateral popliteal artery aneurysms had associated AAA. In patients with bilateral popliteal aneurysms, 63% of those had associated AAA.[58]
  - Conversely, if a patient is first found to have a AAA, there is an 11% chance of having associated popliteal artery aneurysms >15mm.[59]

  - Another study showed a rate of femoral-popliteal aneurysms in AAA patients is approximately 14%.[60]
  - This association stresses the importance of a good physical exam when evaluating a patient with a AAA and is commonly tested on exams.

What is the pathogenesis of an abdominal aortic aneurysm?[57]

- More than 90% of AAAs are associated with atherosclerosis.
- Other causes include cystic medial necrosis, dissection, Marfan's syndrome, Ehler's-Danlos syndrome, HIV and syphilis.
- Elastin and collagen are the major structural proteins responsible for the integrity of the aortic wall and defects in these cause degeneration and further aneurysmal change.
- For example, a mutation in fibrillin in Marfan's syndrome causes elastin fragmentation and pathological remodeling of the wall of the artery to form cystic medial degeneration.
- Several investigations have also shown that upregulations of metalloproteinase activity, specifically MMP-2 and MMP-9, have an essential role in aneurysm formation. Imbalances between aortic wall proteases and antiproteases cause degradation of the extracellular matrix and loss of structural integrity of the aortic wall.
- Increased thrombus burden is associated with wall thinning, medial loss of smooth muscle cells, elastin degradation, adventitial inflammation and aortic wall hypoxia which all increase the rate of AAA growth.

What are the risk factors for AAA occurrence and growth?[57]

- Risk factors for AAAs are similar to the risk factors for occlusive atherosclerosis and include age, tobacco use, hypertension, male gender and hypercholesterolemia.
- It has been found that diabetes is protective for AAA progression and rupture.
- Cigarette smoking is the single most important modifiable risk factor to prevent occurrence and growth of AAAs. Smoking increases the rate of growth by 35% for abdominal aortic aneurysms.
- Medical therapy has been studied with disappointing results. Beta-blockers and ACE/ARB inhibitors have been studied but have not shown any effect on growth of AAAs.
- Fluoroquinolones
  - In a recent study just published in JAMA Surgery this January, the group at UNC showed an increased short-term risk of developing an

aortic aneurysm with fluoroquinolone use.[61]

- They reviewed all prescription fills for fluoroquinolones or comparative antibiotics from 2005-2017.
- This included >27 million US Adults aged 18-64 years old with no history of aneurysms.
- 18% of the prescriptions were fluoroquinolones.
- Fluoroquinolones were associated with increased incidence of aortic aneurysms. Compared to the other antibiotics, fluoroquinolones were associated with a higher 90-day incidence of AAA and iliac aneurysms as well as more likely to undergo aneurysm repair.
- They recommended that fluoroquinolone use should be pursued with caution in all adults, not just high risk individuals, and they recommended broadening of the warnings from the FDA.

- Fluoroquinolones playing a role in dissections and aneurysm formation is often a highly tested question

What is the dreaded complication of AAA?[57]

- Aneurysm rupture is the fear with a diagnosis of AAA. The risk of rupture increases yearly as the aneurysm expands. Once an aneurysm develops, it tends to enlarge gradually yet progressively. This is an important concept to grasp for testing.
- Growth rate
  - For smaller aneurysms (3-5cm in size), the growth rate is approximately 2-3mm/year
  - For larger aneurysms (>5cm), the growth rate is higher at 3-5mm/year.
- Rupture risk (historically):
  - 4 - 5.4cm -> 0.5-1%.
  - 6 - 7cm -> 10%
  - 7 – 8cm -> 19-35%
- Newer data suggests the true rupture risk per year is decreasing with time.
- In a study from the UK published in JVS in 2015, the rupture risks were far lower than previously reported and what is documented in most textbooks.[62]
  - This systematic review of more recently published data mostly from 1995 to 2014 included a total of 11 studies reviewing 1514 patients. The cumulative yearly rupture risks identified in this study were as follows:

    * 5.5 - 6 cm -> 3.5%
    * 6.1 - 7 cm -> 4.1%
    * >7 cm -> 6.3%
  - Previously published data with meta-analyses from 1970s-1990s reported rupture rates of 3.3%, 9.4% and 24%, respectively, compared to 3.5%, 4.1% and 6.3% in the most recent data.
- Factors that increase the risk of rupture other than the size of the aneurysm are smoking, COPD, hypertension, transplant recipient, and rapid enlargement (defined as 1 cm/year or more).

Evaluation and Diagnosis

What is the work up for a AAA?[57]

- 75% of all infrarenal AAAs are asymptomatic when first detected and often incidentally discovered on unrelated imaging.
- Symptoms - Some patients may report symptoms such as abdominal, flank or back pain from pressure on adjacent somatic sensory nerves or overlying peritoneum. Tenderness by itself is not a reliable indicator of impending rupture. Other symptoms include thrombosis and distal embolization.

Imaging

- Ultrasound, when feasible, is the preferred imaging modality for aneurysm screening and surveillance.
  - The Society for Vascular Surgery (SVS) recommends a one-time ultrasound screening in men and women ages 65 to 75 years with either a history of smoking or a family history of AAA, as well as men and women over the age of 75 with a smoking history in otherwise good health who have not previously undergone screening.[63] Recommended intervals for surveillance imaging:
    * 2.5 – 2.9 cm -> 10 years
    * 3 - 3.9 cm -> 3 years
    * 4 - 4.9 cm -> 1 year
    * 5 - 5.4 cm -> 6 months
  - It is important to note that these screening guidelines are Level 2, Grade C evidence from the SVS.
  - Traditionally, once duplex reveals an aneurysm 5cm in size, an initial CTA is performed and patients are followed with additional CT scans to assist with operative planning.

- CT Angiograms are helpful in operative planning and determining candidacy for EVAR. You can assess the relationship of the aneurysm to the renal arteries, assess the access vessels, and measure seal zones
  - The maximum aneurysm diameter derived from the CTA should be based on outer wall to outer wall measurement perpendicular to the path of the aorta (the centerline of the aneurysm).
- MRA is recommended for patients with renal insufficiency who cannot tolerate iodinated contrast.

Management

What are the indications for repair?[57]

- The current recommendation to repair a fusiform aneurysm is 5.5cm for men (Level 1, Grade A evidence), 5.0cm for women as they have a higher risk for rupture, and rapid growth (>5mm over 6 months).[63]
- For saccular aneurysms, the SVS practice guidelines recommend elective repair (Level 2, Grade C evidence).[63]
  - Studies show equivalent wall stress in saccular aneurysms at much smaller sizes when compared to fusiform aneurysms. This has led to the notion that they have a higher rupture risk at smaller sizes.
  - A study published in Annals of Vascular Surgery in 2016 showed a significant portion of ruptures <55mm in size were saccular in nature.[64]
    - Specific size guidelines for repair are currently lacking because of their infrequent presentation.

What are the options for repair, and how do you choose?[57,65]

- Two options: open repair and endovascular aortic aneurysm repair (EVAR).
  - When attempting to decide between the two, one must consider the patient's perioperative risk as well as the patient's anatomy, which will be reviewed further here.
- When reviewing the patient's risk for surgery, there are many tools to assist, which are outlined in the Society for Vascular Surgery's practice guidelines.
- The VSGNE or Vascular Study Group of New England developed a risk prediction model for mortality which can assist in your decision making. This is endorsed by both SVS and the Vascular Quality Initiative.
  - This risk model looks at open vs endovascular repair and further delineates infrarenal vs suprarenal clamps

  - It includes aneurysm sizes with 6.5cm as the cut off.
  - It includes age above or below 75yo.
  - Gender and comorbidities are included like heart disease, cerebrovascular disease and COPD.
  - An important risk factor is also renal function which is delineated by creatinine at 1.5-2 or >2.
  - Each of these risk factors is assigned a point grading.
  - These points are added together and they place the patient on a spectrum of mortality risk. Depending on the amount of points accumulated, the risk is divided into low, medium, high or prohibitively high-risk groups
  - This is something that can help both the patient and physician in deciding on surgery and how to proceed.

- Recent studies have shown that decreased aerobic fitness and high frailty score predicted increased morbidity and mortality after open aneurysm repair.
- High-risk patients are defined by the following in the SVS guidelines:
  - Unstable angina or angina at rest
  - Congestive heart failure with EF $<$ 25-30%
  - Serum creatinine level $>$ 3 mg/dL
  - Pulmonary disease manifested by room air PaO2 $<$ 50 mmHg, elevated PCO2, or both.
- To help delineate a patient's risk, a preoperative workup is necessary. The SVS practice guidelines recommend the following:[63]
  - Determine if the patient has an active cardiovascular condition. Coronary artery disease is responsible for at least 50% to 60% of perioperative and late deaths after operations on the abdominal aorta, therefore, it is important for patients to undergo cardiac evaluation prior to surgery.
    * Unstable angina, decompensated heart failure, severe valvular disease, significant arrythmia -> Cardiology consultation (Level 1, Grade B)
    * Significant clinical risk factors such as coronary artery disease, congestive heart failure, stroke, diabetes mellitus, and chronic kidney disease -> Stress test (Level 2, Grade B)
    * Worsening dyspnea -> Echocardiogram (Level 1, Grade A)
    * All patients undergoing EVAR or open repair require EKG

    - In patients capable of moderate physical activities, such as climbing two flights of stairs or running a short distance (MET >= 4), there is no benefit in further testing.
    - If coronary intervention is required, this takes precedence over aneurysm repair.
  - History of COPD
    - Pulmonary function test with ABG (Level 2, Grade C)
    - Smoking cessation for at least 2 weeks prior (Level 1, Grade C)
    - Pulmonary bronchodilators at least 2 weeks before aneurysm repair (Level 2, Grade C)

- In patients who are deemed high risk, EVAR is the most attractive option in anatomically suitable patients
- Morbidity and mortality rates are lower for EVAR than open repair in the short term. This is illustrated in multiple studies.
  - The EVAR-1 trial, a randomized prospective UK study including 1082 patients, compared EVAR with open AAA repair in patients who were fit enough to undergo open surgical repair from 1999-2003. The 30-day mortality rate was reduced in the EVAR group (1.7% vs 4.7%), although secondary interventions were more common in the EVAR group (9.8% vs. 5.8%).[66]
  - The DREAM trial, a multicenter randomized trial from 2000-2003, compared open repair with EVAR in 345 patients with a reduction in operative mortality (4.7% vs 9.8%) with the majority of complications accounted for by pulmonary issues.[67]
- This early survival benefit with EVAR over open repair disappears by the third postoperative year.
  - The Open vs Endovascular Repair (OVER) trial included 881 patients from 42 VA centers randomized to either EVAR or open repair. This demonstrated that perioperative mortality was improved in the EVAR group (0.5% vs 3.0%), yet no statistically significant difference was seen in mortality at 2 years (7.0% vs 9.8%).[68]
  - Late mortality seems to be higher in EVAR due to ruptures from endoleaks that do not occur in open repair.[69]
- Reviewing the anatomic criteria for traditional EVAR may rule out EVAR as an option in some patients. These criteria vary slightly depending on the particular device being used.
  - Neck

    * A neck length of at least 10-15mm from the renal arteries to the aneurysm start with a diameter of 18-32mm.
    * It is important that the neck is relatively free of thrombus or calcification to decrease the risk of endoleaks.
    * More complex options like fenestrated EVAR are available for shorter necks but will not be discussed in this review.
  - Angulation
    * Neck angulation should be < 60 degrees for current devices
  - Access vessels
    * Access vessels must be adequate for delivery of the device depending on the sheath size required (6-8mm)
  - Aortic bifurcation
    * The aortic bifurcation must be >20mm in size to accommodate the graft opening to full caliber
  - Iliac landing zone
    * Adequate seal zone in the distal common iliac arteries of 10-15mm in length and diameter of 7.5-25mm.
    * If covering the hypogastric arteries is necessary unilaterally to obtain a seal, you can embolize the hypogastric artery (to prevent retrograde flow) and extend the graft into the external iliac artery.
    * If this is an issue bilaterally, an iliac branch device can assist in maintaining perfusion into the hypogastric arteries.

EVAR

Can you briefly go over the steps of an EVAR?[57]

- EVAR now accounts for approximately 70-80% of elective abdominal aortic aneurysm repairs and 65% of iliac aneurysm repairs in the United States and many other countries.
- Performed in the operating room or IR suite with a fixed or portable C-arm
- Anesthesia
  - Regional block, local anesthesia or general anesthesia depending on surgeon preference and patient risk
- Groin access and short sheath placement
  - Percutaneous - Closure devices are introduced prior to inserting the large sheaths containing the stent-grafts

  - Cut-down

- Pigtail catheter is used to perform an aortogram of the abdominal aorta and iliac arteries
- The renal artery orifices are marked. If there is any concern about good visualization, IVUS (intravascular ultrasound) can be used to assist.
- Systemic heparin is given
- Bilateral femoral sheaths are exchanged over a stiff wire for the necessary sheaths required for the device size chosen.
  - Main trunk and ipsilateral limb sheath on one side
  - Contralateral limb sheath on the other side
- The main body is positioned in the proximal neck and a repeat angiogram is commonly performed to confirm the positioning of the device at the desired level just below the lowest renal artery. It is best to position the main body so that the gate is directed at the simplest angle to cannulate.
- The main body is deployed to the point where the gate is opened
- Contralateral limb gate cannulation is performed using a wire and directional catheter.
- Once in the gate, a pigtail catheter is formed within the main body and must be able to spin freely 360 degrees to confirm placement within the endograft
- The contralateral limb is introduced and deployed taking care to preserve flow to the internal iliac artery.
- The remainder of the main body is deployed and iliac extensions deployed if required.
- The stent graft is ballooned at the neck, within the gate, at the bifurcation, and distal iliac seal zones.
- An aortogram, usually multiple in different views, is performed to exclude any endoleaks.
- The sheaths are removed, and the groin sites are closed using Perclose devices if performed percutaneously, or primary repair if open cutdown performed.
- Check pedal signals at the end of the case to ensure no thromboembolic events or femoral artery access injuries have occurred. If there is concern, an ultrasound duplex can be performed intraoperatively.

You mentioned endoleaks, can you discuss the complications specific to EVAR and the management?[57]

- Many of the cardiopulmonary complications inherent with open repair do not occur with EVAR as there is no aortic cross clamping.
  - In a study from Mayo clinic evaluating elective infrarenal AAA repairs from 1999 to 2001, Elkouri et al found that cardiac and pulmonary morbidity after EVAR was drastically reduced compared to open repair (11% vs 22% and 3% vs 16%, respectively).[70]
- Risk of ischemic colitis remains as the IMA is covered with EVAR. It is lower than with open repair but remains 1-2%.
- Renal insufficiency may occur secondary to contrast administration in a patient with underlying chronic kidney disease. Thromboembolic events may occur from thrombus-laden aortic necks with wire and device manipulation to the renal arteries as well.

Endoleaks

Defined as persistent blood flow within the aneurysm sac following EVAR.

1. Type I
   - A leak at the graft ends secondary to inadequate seal proximally (1a) or distally (1b)
   - If identified intraoperatively, Type I endoleaks require attention with further balloon angioplasty, proximal or distal extension, or endoanchors.
   - If seen in follow up surveillance, intervention is necessary.
2. Type II
   - Sac filling secondary to retrograde filling via a branch vessel off of the aneurysm sac such as a lumbar artery or the IMA
   - If identified intraoperatively, this typically does not need to be addressed in the OR.
   - Typically, type II endoleaks spontaneously thrombose and therefore can be observed.
   - If the leak persists for $>$ 6 months with sac enlargement $>$5mm, intervention is recommended. Several techniques exist to eliminate type II endoleaks, most frequently embolization.
   - It is common to continue monitoring even if there is persistent flow as long as there is no aneurysm sac growth.
3. Type III
   - Separation of graft components

- Usually identified in follow-up surveillance and necessitates intervention.

4. Type IV
    - Secondary to a porous graft which typically does not occur any longer as endograft material and devices have improved. If seen, no intervention is needed at the time, and they usually thrombose on their own.
5. Type V
    - Increasing aneurysm sac size with no identifiable endoleak. Commonly referred to as endotension.
    - Usually necessitates graft explantation and open repair or re-lining of the graft.

Open Repair

Now we can move onto open repair. Describe an open infrarenal aneurysm repair.[22,57]

- After thorough preoperative evaluation and clearance, the patient is taken back to the operating room. An epidural may be placed preoperatively depending on institutional preference. The patient is intubated, and arterial and central venous catheters are placed. The abdomen is prepped from chest to bilateral thighs.
- A cell-saver should be available to optimize resuscitation during the procedure due to expected large amounts of blood loss. Balanced resuscitation to prevent coagulopathy is important with significant blood loss.
- Exposure
    - Trans-peritoneal or retro-peritoneal. First we will describe the most common approach: trans-peritoneal.
- Surgical steps
    1. Mid-line laparotomy, transverse or chevron-style incision
    2. A retractor system such as an Omni, Bookwalter or Balfour retractor is used to assist in exposure depending on physician preference.
    3. The transverse colon is retracted cephalad, and the small bowel is retracted to the patient's right to expose the aorta. The duodenum is mobilized and the ligament of Treitz is divided. The posterior peritoneum is opened along the anterior wall of the aorta.
    4. The aneurysm sac is now in view and careful dissection proximally for clamp site is achieved. Identification of the left renal vein crossing the aorta is key and can be divided if necessary.

5. Identification of the renal arteries proximally is required if there is a plan for suprarenal clamping.
6. Isolate bilateral common iliac arteries for distal clamp site. Use caution when dissecting the fibro-areolar tissue overlying the left common iliac artery as it contains nerves that control sexual function. Damage can result in retrograde ejaculation.
   - You can avoid nerve injury with mobilization of the sigmoid colon medially and identifying the iliac bifurcation distally, thus avoiding transecting the tissue overlying the left common iliac artery.
   - If the iliac arteries are severely calcified and pose risk for injury with clamping, intraluminal balloon catheters can be inserted for distal control instead.
   - Also, you must be cognizant of the location of the ureters crossing over the iliac bifurcation to prevent injury.
7. After proximal and distal clamp sites have been identified, systemic heparin is administered by anesthesia.
8. Clamp the distal vessels first to prevent distal embolization.
9. Open the aneurysm sac in a longitudinal fashion toward the patient's right to avoid the IMA and clear the sac of thrombus. Extend proximally to normal aorta and then t off the incision on the aortic wall.
   - Some physicians prefer to transect the aortic wall as opposed to leaving the posterior wall intact for the anastomosis.
10. Lumbar arteries on the posterior wall are ligated using figure-of-eight sutures.
    - Back-bleeding lumbar vessels can be the source of significant blood loss.
11. Graft
    - A tube graft or bifurcated graft depending on the patient's anatomy and aortic diameter is chosen. Dacron or PTFE grafts are most common, and the choice depends on physician preference. This is anastomosed proximally in a continuous fashion.
    - Once complete, the graft is flushed forward to flush out any thrombus. The graft is then clamped and the aortic clamp removed to test the anastomosis. Repair if needed.
    - The distal anastomosis is completed to the aorta or bilateral iliac arteries depending on extent of the aneurysm.

- The graft is flushed forward prior to completion to remove any thrombus within the graft. The anastomosis is completed and clamps removed.

12. Hypotension may occur at this point from re-perfusion of the lower extremities and pelvis. Anesthesia should be notified that unclamping will occur soon prior to completion of the distal anastomosis to allow for fluid resuscitation in preparation.
    - The graft can be slowly unclamped or partially clamped to assist with blood pressure management during this time. You can also place manual pressure on the iliac arteries or femoral arteries to slowly release flow and avoid significant hypotension.
13. Next, the IMA must be addressed. The IMA orifice is identified within the aneurysm sac.
    - Chronically occluded or pulsatile back bleeding -> ligate.
    - Anything between occlusion and strong pulsatile back bleeding requires further evaluation. This should be performed at the end of the case after the internal iliacs have been reperfused. Methods to measure perfusion:
        * Place vessel loops or micro bulldog on IMA and assess the sigmoid colon. If there is a poor doppler signal on the antimesenteric border of the sigmoid colon, the IMA should be reimplanted.
        * Insert blunt-tip needle through the IMA orifice and pull vessel loop around needle to secure and connect to a transducer. Pressure less than 35 mmHg requires reimplantation.[71]
    - The Carrel patch technique involves excising a circular button of the aortic wall around the IMA and anastomosing it to the graft wall.
    - Newer studies have shown that IMA reimplantation does not eliminate the risk of ischemic colitis after open AAA repair. In a study out of George Washington University in DC published in JVS in 2019, there was still significant risk of ischemic colitis rates with IMA reimplantation.[72]
        * Using NSQIP data collected prospectively and studied retrospectively
        * Out of 2397 patients undergoing AAA from 2012-2015, 135 patients (5.6%) had ischemic colitis.
        * 672 patients were evaluated further after exclusion criteria applied (suprarenal clamp, emergent or ruptured, occluded mesenteric vessels)

        * Of these, 637 patients had IMA ligation, 35 had IMA reimplantation
        * Reimplantation was associated with - More frequent return to the OR (20% vs 7.2%), Higher rates of wound complications (17.1% vs 3%), Higher rates of ischemic colitis (8.6% vs 2.4%)
      - Difficult to interpret impact of revascularization of IMA on ischemic colitis rates, due to selection bias, but should be noted that patients who require revascularization still may experience colon ischemia.

    14. To finish, the aneurysm sac is then closed over the graft to protect the viscera, and the retro-peritoneum is reapproximated. Occasionally, a vascularized omental pedicle flap may be used to separate the graft from the duodenum to prevent an aorto-enteric fistula if the peritoneum cannot be closed securely.

- Steps for the retro-peritoneal approach:
  - Positioned semi-lateral with the left side up with bilateral groins exposed for femoral artery access. This is done in a lazy lateral position where the patients upper body is near complete lateral but the hips are rotated to the patient's left in attempt to keep both groins in the field in case they need to be accessed.
  - An oblique incision extends from the left 11th intercostal space or tip of the 12th rib to the edge of the rectus abdominus muscle, through the external and internal oblique muscles, transversalis fascia until you are just superficial to the peritoneum. Using blunt finger dissection, the peritoneum is dissected from the abdominal wall posteriorly over the psoas muscle until the aorta is reached.
    * Benefits include less postoperative ileus, less intraoperative hypothermia, lower IV fluid requirements, and less post-op respiratory compromise.
    * A disadvantage is the difficulty addressing the right iliac artery from this approach.

Complications

What are some of the complications with open aortic aneurysm repair?[57]

- Myocardial dysfunction which is usually secondary to cardiac ischemia or hemorrhage.
- Abdominal compartment syndrome secondary to coagulopathic bleeding postoperatively or third spacing of fluids can cause abdominal compartment syndrome requiring emergent laparotomy. Unexplained oliguria, difficulty

maintaining adequate ventilation, and hypotension with significant abdominal distension is concerning for abdominal compartment syndrome. A sustained bladder pressure > 20 mmHg with associated organ dysfunction (elevated peak airway pressures, new onset acute renal failure) is indicative of abdominal compartment syndrome.

  - Abdominal compartment syndrome can still occur after EVAR during an aortic rupture, therefore, one must keep a heightened suspicion for this in the post-operative period.

  - It is important to note that a patient with a soft abdominal exam can still have abdominal compartment syndrome particularly with an enlarged body habitus.

- Renal failure can occur due to suprarenal aortic clamping, atheromatous embolization or hypotension causing acute tubular necrosis (ATN).

- Postoperative ileus is common. Duodenal obstruction from dissection of the ligament of Treitz can mimic a gastric outlet obstruction.

- Ischemic colitis of the left colon and rectum is the most serious gastrointestinal complication, and the incidence ranges from 0.2 - 10%.

  - 3-4x more common after operations for occlusive disease than aneurysmal disease.

  - It is important to study the collateral pathways on the preoperative CT scan and the patient's history to assist in surgical decisions regarding IMA reimplantation including:

    * Stenosis/occlusion of the SMA

    * Previous colectomy

    * Hypogastric artery occlusion

  - Earliest manifestation is postoperative diarrhea, especially bloody diarrhea.

  - Sigmoidoscopy is needed for diagnosis.

    * Mild colon ischemia with patchy mucosal involvement should be treated with bowel rest, fluid resuscitation and antibiotics. Transmural necrosis requires emergent operation with colon resection. Patients can be left in discontinuity or an end colostomy performed depending on stability.

    * The mortality rate with colon ischemia after aneurysm surgery is about 25% but reaches over 50% if bowel resection is required.[73] This is a very heavily tested topic for both general surgery and vascular surgery boards.

- Distal ischemia from embolization downstream can lodge in larger vessels or cause microembolization, colloquially known as "trash foot."
- Infection is rare but can be associated with graft-enteric fistula which is another highly tested topic.

Postoperative Surveillance

What is the post-operative surveillance required for open and endovascular approach, and how do they differ?[57]

- That is a great question because it highlights why open repair has continued to be so important, especially for young, healthy patients.
- Post-operative surveillance is necessary in the immediate post-operative period for open repair to evaluate incisions. Follow-up is only needed every 5-10 years, unless the patient becomes symptomatic.
- In contrast, EVAR patients require a strict postoperative surveillance regimen to allow for detection of endoleaks, aneurysm sac expansion, stent fracture, limb kinking and material fatigue.
  - CT scans at 1-, 6- and 12-month intervals initially then annually are recommended which raises concerns related to cost, cumulative radiation exposure, and contrast administration.
  - Some physicians may elect to use ultrasound for surveillance with CTA prompted if an endoleak is identified or the sac is enlarged, particularly in patients with stable aneurysms.
  - The long-term follow-up is often inconsistent and a study of 19,962 Medicare beneficiaries undergoing EVAR from 2001 to 2008 showed that 50% of patients were lost to annual imaging follow-up at 5 years after surgery.[74]
- Some patients will elect for open repair to avoid frequent surveillance if they are a candidate for both, while other patients will select endovascular management to avoid the short-term effects like longer hospitalizations, post-operative pain, and longer recovery time to baseline functioning in open surgery.

Ruptured Aneurysms

Although elective repair is important, can you touch on the management of a ruptured AAA (RAAA) as our last topic of the session?[57,75]

- Ruptured AAAs have declined secondary to improved medical management, decreased rates of smoking and superior diagnostic imaging and surveillance.

- Traditionally, it has been taught that 50% of ruptured AAAs die in the field and of those remaining, 50% will die in the hospital. With time, the in-hospital mortality rate has decreased.
  - In one study out of Finland, of 712 patients with ruptured AAAs from 2003-2013, 52% died prior to arrival to the hospital. Of those that were offered surgery, 67% of patients were alive at 30 days indicating a mortality rate of 33%.[76]
- Diagnostic triad on presentation:
  - Pain, syncope and known or palpable AAA.
- When a ruptured AAA is suspected or diagnosed, permissive hypotension is key in the initial management before surgery.
  - Allowing systolic arterial pressures of 50-70 mmHg as long as the patient is mentating appropriately.
  - Limits internal bleeding which further limits loss of platelets and clotting factors.
- Initial management involves many considerations like patient stability, patient's anatomy and the surgeon's experience with either open or endovascular repair.
- Due to the developments of endovascular techniques, it is ideal to have a CTA prior to the operating room to determine if the patient is a candidate for an EVAR.
- There are two options for expedient aortic control in an unstable patient with a ruptured aneurysm.
  - Open supraceliac aortic clamping
    - Achieved by retracting the stomach caudally, entering and dividing a portion of the gastrohepatic ligament, reaching under and medial to the caudate lobe, dividing the pars flaccida, and identifying the spine. The aorta lies to the patient's left of the spine and is bluntly dissected anteriorly and laterally for aortic clamp placement.
    - Another method of supraceliac exposure and control is to mobilize and reflect the left lobe of the liver, sweep the esophagus to the patient's left, divide the right crus of the diaphragm and bluntly dissect both sides of the aorta then apply the clamp.
    - A nasogastric tube can help identify the esophagus when placing this clamp to ensure the esophagus has been swept to the patient's left and protected.

        * The clamp should be moved down to the desired position for repair (supra or infrarenal depending on anatomy of the aneurysm neck) to decrease ischemia time to visceral vessels as soon as possible.

    - Percutaneous occlusive aortic balloon

        * Gain percutaneous access and place an occlusive aortic balloon for stabilization in the distal thoracic aorta. This will require a long support sheath, usually 12fr in size, to prevent distal migration of the occlusive balloon.

- EVAR has been used increasingly to treat ruptured AAAs and offers many theoretical advantages over open repair.
- Less invasive, eliminates risk of damage to periaortic and abdominal structures, decreases bleeding from surgical dissection, minimizes hypothermia and third space losses, and lessens the requirement for deep anesthesia.
- EVAR has been deemed superior to open repair for the treatment of RAAA in many studies.
    - In a study out of UVA published in JVS in August 2020, they looked at ruptures in the VQI database from 2003-2018. This resulted in 724 pairs of open and endovascular pairs after propensity matching.[77]

        * There was a clear advantage of endovascular compared to open repair in patient's with suitable anatomy.

        * Length of stay was decreased with 5 vs 10 days in open. 30 day mortality was much lower at 18% vs 32%. Major adverse events like MI, Renal failure, leg ischemia, mesenteric ischemia, respiratory complications were much lower in the EVAR group at 35% vs 68% in the open group.

        * All cause 1 year survival was much higher with EVAR at 73% vs 59% in the open group.

- Despite improved RAAA results with EVAR, conversion from EVAR to open AAA repair appears to have the most unfavorable outcomes in terms of mortality.
    - Conversions can be early or late and are due to access-related problems, errors in endograft deployment, graft migration, persistent endoleak, graft thrombosis, or infection.
    - In a study evaluating 32,164 patients from NSQIP with 300 conversions (7,188 standard open repairs and 24,676 EVARs), conversion to open repair was associated with a significantly higher 30-day mortality than standard open repair (10% vs 4.2%) and EVAR (10% vs 1.7%). In addition, conversion patients compared to standard open patients were more likely to undergo new dialysis (6.0% vs. 3.5%), cardiopulmonary

resuscitation (5.3% vs. 1.9%), postoperative blood transfusion (42.3% vs. 31.6%), and have a myocardial infarction (5.0% vs. 2.2%).[78]

Lower Extremity Occlusive Disease

Pathophysiology

24 Aug 2020: Nedal Katib and Danielle Bajakian

What is Peripheral Arterial Disease (PAD) and what does it encompass?

Peripheral Arterial Disease encompasses extremity arterial disease but generally is used to describe lower limb arterial occlusive disease. PAOD is a more specific term and this encompasses atherosclerotic disease of the lower limb arteries.

The disease has various presentations on a spectrum of asymptomatic disease to intermittent claudication and finally chronic limb threatening ischemia (CLTI) formerly known as Critical Limb Ischemia (CLI)[79]

What is the underlying pathophysiology of PAOD?

The underlying pathophysiology which results in occlusive arterial disease of the lower limb has somewhat evolved over the last 50 years. While atherosclerosis remains, the main pathological process resulting in occlusive disease, smoking related atherosclerosis has in the last 30 years been confounded with the rising incidence of diabetes and in addition an aging population with progressive arterial disease.

Atherosclerosis, in summary, begins with an injury to the intimal lining of the arterial wall, which can result from smoking, hypertension or advanced age and ultimately a chronic inflammatory reaction resulting in plaque build up and calcification that may result in progressive stenosis and occlusion or plaque rupture with acute occlusion.

What are the risk factors for atherosclerosis?

Modifiable:

1. ***Smoking***

- The **most significant modifiable risk factor** for developing peripheral arterial disease
- Causes Endothelial dysfunction by reducing nitric oxide and triggering reactive-oxygen species[80]
- Causes a prothrombotic environment by causing an increase in thromboxane A2 and decreasing Prostacyclin thus overall resulting in an increased prothrombotic environment for platelets.
- Smoking has a stronger association with Intermittent claudication than with Coronary Artery Disease![81]

2. ***Diabetes , Metabolic Syndrome and Insulin Resistance***
   - Diabetes Mellitus, after smoking, is the most significant modifiable risk factor for developing peripheral arterial disease. Both insulin resistance and hyperinsulinemia are independent risk factors for developing peripheral arterial disease.
   - The Odds Risk for developing PAD in patients with DM ranges from 1.89 to 4.05.
   - An increase in HbA1C by 1% correlates with a 28% increase risk of developing PAD.[82]
3. ***Hypertension***
   - The **most common** cardiovascular risk factor worldwide.
   - The Incidence of PAD increases to 2.5-fold in patients with Hypertension.[83]
4. ***Dyslipidemia***
   - A strong association has long been identified as a risk factor for cardiovascular disease.
   - 25% cardiovascular event reduction for each 39 mg/dL (1mmol/L) reduction in LDL.[84]

Non Modifiable:

1. **Age**
   - Age is identified as a risk factor for PAD regardless of gender.
   - Prevalence of PAD increases with age: 15% $>$ 70 years of age.
2. **Gender**
   - The Framingham Study has found that the risk of developing PAD is doubled in men.
3. **Ethnicity**

- The MESA study showed a higher prevalence of PAD (ABPI <0.9) in African Americans compared to Whites. 7.2% versus 3.6%.[85]
- Cross Sectional analysis 6653 subjects all with ABPI assessment revealed a prevalence of PAD (<0.9) of 4%. Non-Hispanic Whites: 3.6%, Asian: 2%, African American: 7.2% and Hispanic: 2.4%. (p<0.01)[86]

What are the some of the major population-based trials looking at the natural history?

1. The Framingham Heart Study: The original Cohort from the town of Framingham, n=5183 patients followed over time for over 30 years. There have been multiple subsequent recruited populations since. The majority of information we have about risk factors related to cardiovascular health comes from this study.[87]
2. The Rotterdam Study: 1990, Longitudinal Study, >7000 particpants.
3. CVHS – 1989-1999 Longitudinal Study : n>5000 Multicentre Study.
4. MESA – Cross Sectional analysis 6653 subjects all with ABPI assessment revealed a prevalence of PAD (<0.9) of 4%. Non-Hispanic Whites: 3.6%, Asian: 2%, African American: 7.2% and Hispanic: 2.4%. (p<0.01)[86]
5. The Edinburgh Study: The EAS began as a cross sectional study of 1592 men and women in Edinburgh with the goal of examining the frequency of risk factors for peripheral arterial disease. The subjects were followed over 20 years.[88]

How does Diabetes confound the clinical picture of PAOD?

- Increasing Incidence of Diabetes world-wide.[89]
  - 2.8% in 2000, 4.4% in 2030
  - 25% of patients with diabetes develop a DFU at some stage in their lives
  - Limb Loss every 20 seconds world-wide to Diabetes

What's the pathophysiology of Diabetes and PAOD[90]

- Sensory Neuropathy, Motor Neuropathy and Autonomic Neuropathy
- Structural and Gait abnormalities
- Arterial disease
  - Large Vessel
  - Small Vessel
  - Both

Given this diverse and confounding pathology the normal progressive history of PAD is somewhat different. What's most concerning is the neuropathy resulting in initial presentation being ulceration. This results in a lack of a 'safety net' where presenting with progressive claudication allows for a period of detection, management and and risk factor modification before they develop tissue loss and are at risk of amputation.

Since 2014 and the publication of WIfI a lot has changed in the way we view PAD leading up to last years new Global Vascular Guidelines on CLTI, which as a term has replaced CLI.[91,92]

Intermittent Claudication

What is Intermittent Claudication and the classic patient presentation?

The original population studies we mentioned determined the epidemiology and natural history of Intermittent Claudication based on historically validated and widely accepted questionnaires, namely the Rose[93] (which later was adopted by the WHO) and subsequently the Edinburgh questionnaire.[94]

All questionnaires are based on a number of key diagnostic clinical factors that define claudication, they are:

- Onset
- Calf involvement
- Reproducibility
- Relief with Rest
- Not occurring at Rest

The progression historically graded by Fontaine (1954)[95] followed by the Rutherford Grading System (1986, Revised 1997)[96]

Rutherford et al. Ad Hoc Committee on Reporting Standards, SVS/North American Chapter ISCVS:

Grade/Category	Clinical Description
0/0	Asymptomatic -no haemodynamic significant occlusive disease
I/1	Mild Claudication
I/2	Moderate Claudication
I/3	Severe Claudication
II/4	Ischaemic Rest Pain
III/5	Minor Tissue Loss
III/6	Major Tissue Loss

What is involved in the work up of patients with PAOD/Intermittent

Claudication?

History / Clinical Examination

SVS Guidelines:

"We recommend using ABI as the first-line non-invasive test to establish a diagnosis of PAD in individuals with symptoms or signs suggestive of disease. When the ABI is borderline or normal (>0.9) and symptoms of claudication are suggestive, we recommend an exercise ABI."

Grade 1 Level of Evidence A

- ABPI
- Exercise ABPI
- Ultrasound

What is an ABPI and how is it measured?

The AHA came out with guidelines on how to perform an ABI and to standardise the method to allow for more comparable results from studies.

Divide the higher of the PT or DP pressure by the higher of the right or left Brachial SBP *(Class 1 Level of Evidence A)*[97]

Sensitivity and Specificity both >95% (when ABPI cut off </=0.9 – in detecting >/= 50% stenosis)[98,99]

Interpreting ABPI
>1.4
>0.9-1.39
0.5-0.9
0.0-0.5

What is Exercise ABPI studies?

Constant Load Testing – (unlike the Graded Test – Bruce Protocol)

Walking distance has been shown to correlate with level and severity of POAD.[100]

What is the ultrasound duplex criteria for defining PAOD?

Stenosis Category	Peak Systolic Velocity	Velocity Ratio	Distal Artery Spectral Waveform
Normal	<150	<1.5	Triphasic, Normal PSV

Stenosis Category	Peak Systolic Velocity	Velocity Ratio	Distal Artery Spectral Waveform
30-49%	150-200	1.5-2	Triphasic, Normal PSV
50-75%	200-400	2-4	M onophasic, reduced PSV
>75%	>400	>4	Damped, m onophasic, reduced PSV
Occlusion	No Flow – B -mode, Terminal Thump		

Adapted from[101]

What Guidelines are there pertaining to PAD Management.

SVS Guidelines (2015)

- The SVS published the SVS practice guidelines for atherosclerotic occlusive disease of the lower extremities:**Management of asymptomatic disease and claudication**. *Conte and Pomposelli et al. JVS 2015*[102]

Other Guidelines:

- TASC 1 -2
- European Guidelines (2017)
- AHA Guidelines (last update 2016)

What is the initial management of Asymptomatic Patients with PAD?

1. Smoking Cessation – Multidisciplinary comprehensive smoking cessation interventions – repeatedly until tobacco use has stopped (Grade A – 1)
2. Intervention is not only not recommended, but invasive treatment is recommended against, in the absence of symptoms (Grade A -1)

How can we medically (non-invasively) manage Asymptomatic PAOD based on the SVS Guidelines?

- Anti-platelet Therapy
  - The Aspirin for Asymptomatic Atherosclerosis Trial – n=3350, aspirin versus placebo. 8 years follow up no difference in events[103] – therefore benefit unknown
- Statin Therapy
  - The Heart Protection Study[84] - this study looked at Statins in patients with PAD but not completely asymptomatic, they had other risk factors such as diabetes, IHD, cerebral disease or hypertension. Without these risk factors Statin therapy benefit unsure.

  - However, the AHA from the Framingham Study does recommend using Statins if 10-year risk based on risk calculators >7.5% (which would be positive if PAD present).

- Exercise and Limb Function
  - No clear evidence that physical therapy improves QoL
- Surveillance
  - No benefit from US surveillance, unclear benefit of ABPI surveillance.

Management

How can we medically manage Intermittent Claudication based on the SVS Guidelines?

- Smoking Cessation – Multidisciplinary comprehensive smoking cessation interventions – repeatedly until tobacco use has stopped (Grade A – 1)
- Dyslipidaemia: Statin Therapy Recommended – most recent evidence on lipid therapy has suggested focussing on reducing 10-year cardiovascular event risk rather than specifically reducing lipid levels. (Grade 1-A)
- Statin Therapy – Aspirin therapy (75-325mg daily) is recommended to reduce cardiovascular events in patients with PAD (Grade 1-Level A)[104]
  - There is evidence that Clopidogrel 75mg compared to Aspirin is better in event reduction (CAPRIE)[105]– replacing Aspirin with Clopidogrel Grade 1-Level B)
- Diabetes Mellitus – Optimisation of HbA1C < 7% (Grade 1-Level B)
- Hypertension – Indicated B-Blockers for hypertension (Grade 1-Level B) (there's no evidence that Beta Blockers worsens IC)
- Homocysteine – Recommendation against Folic Acid and Vit B12 (Grade 2 – C)

To improve Limb Function in patients with IC:

- Cilostozol use – IC without CHF – 3-month Trial (Grade 2 - A)
  - If unable to tolerate Cilostozol – Pentoxifylline (400mg TDS) (Grade 2 – B)
  - Based on Meta-analysis 26 trials[106]
- Exercise Therapy
  - First Line Therapy recommended SEP: minimum three times / week (30-60 min/session) for at least 12 weeks (Grade 1 Level A)

  - Meta-analysis of 32 RCT's: Placebo versus exercise: Walking Time, Walking Ability, Pain Free Walking and maximum walking distance improves. BUT no difference in ABPI, Mortality or amputation.[107]
  - Meta- Analysis of 14RCT's: SEP better than Non-Supervised Programs.[108]

What is the management for patients with Intermittent Claudication?

- **Patient Selection for Intervention:**
  - 20-30% of patients with IC who adhere to risk factor modification will have progressive symptoms that will eventually be treated with intervention.
  - Patient selection should be based on QoL and functional impairment in an active person (loss of ability to perform occupation or that limits basic activities of daily living) rather than haemodynamic (ABPI or US) or anatomical disease progression/severity.
- **Always remember multifactorial causes of immobility – particularly in the elderly.**
  - SVS recommends that invasive therapy for IC have a >50% likelihood of sustained clinical improvement for at least 2 years.
- **Anatomical Selection:**
  - Aortoiliac Disease:
    * Previous TASC Classification has attempted to categorise anatomy of disease and subsequent recommendation of Endovascular versus open surgery. But as the authors of the SVS guidelines highlight, "improvements in technology and endovascular techniques have resulted in EVT replacing open surgical bypass as a primary treatment for both focal and advanced AIOD in many cases."
    * The majority of evidence is non randomized and meta analyses of non-randomized series.
    * Endovascular procedures over open surgery for focal AIOD causing IC. (Grade 1 Evidence B)
    * Endovascular interventions as first line for CIA or EIZ occlusive disease-causing IC. (Grade 1 Level B)
    * Hybrid recommended for Iliac disease involving CFA. (Grade 1 Level B)
    * Direct Surgical reconstruction (bypass, endarterectomy) in patients with reasonable surgical risk and diffuse AIOD not amenable to endovascular approach, after one or more failed

attempts at EVT, or combined occlusive and aneurysmal disease. (Grade 1 Evidence B)

- Infrainguinal Disease:
  - When you look at the historical data comparing all EVT together they are less durable than surgical bypass, especially when there's diffuse or long segments of occlusion/multilevel infra inguinal disease.
  - Most recommendations are based on low level evidence when comparing EVT versus Open Surgery
  - Focal + Not involving SFA origin = EVT (Grade 1 Level C)
  - SFA 5-15cm, self-expanding stent (with or without paclitaxel) (Grade 1 Level B) – NB: (This was in 2015 pre Katsanos Paper)
  - Recommend against infrapopliteal treatment for IC (Grade 1 Level C)
  - Initial Surgical Bypass (with vein: Grade 1 Level a): If
    - Diffuse FP disease
    - Small Calibre <5mm
    - Extensive calcification in SFA
    - Average or low operative risk (Grade 1 Level B)

Chronic Limb Threatening Ischemia

03 Jan 2021: ***Nedal Katib and Danielle Bajakian***

Since Our previous discussion of PAD how does this pathology then progress clinically into the more advanced stages?

The latter stages of both the Rutherford and Fontaine Classification systems highlight this progression, with the Rutherford classification of Stage 5 being specifically minor tissue loss with focal gangrene, and stage 6 as major tissue loss identified by speeding of gangrene beyond the Trans metatarsal level.

Rutherford et al. Ad Hoc Committee on Reporting Standards, SVS/North American Chapter ISCVS:

Grade/Category	Clinical Description
0/0	Asymptomatic -no haemodynamic significant occlusive disease
I/1	Mild Claudication
I/2	Moderate Claudication
I/3	Severe Claudication

Grade/Category	Clinical Description
II/4	Ischaemic Rest Pain
III/5	Minor Tissue Loss
III/6	Major Tissue Loss

What is Chrinc Limb Threatening Ischemia (CLTI), sometimes previously call Critical Limb Ischemia (CLI)?

In the last decade leading up to the recent Global Vascular Guidelines (GVG) published last year, the term (Chronic Limb threatening Ischaemia) CLTI has been gradually replacing CLI. The GVG mentions that their "promotion" of the term CLTI is partly due to terms such as "critical or severe limb ischemia" failing to "recognize the full spectrum and inter-relatedness of components beyond ischemia that contribute to major limb amputation. . . "

What was the original definition and threshold for CLI and how can we make sure we elicit the right symptoms from the patient?

John Cranley back in his publication in 1969 defined Ischemic Rest Pain as,

". . . pain that occurs in the toes or in the area of the metatarsal heads. Occasionally. . . in the foot proximal to the metatarsal heads. Elevation of the limb above or at the horizontal position aggravates the pain and pendency. . . brings relief. . . "[109]

Nocturnal Rest Pain: Worse due to horizontal positioning and systolic BP drop during sleep.

What aspects of the clinical assessment is important?

Clinical Assessment involves a full history (the differential mentioned above) and examination.

- Clinical Examination:
  - Bergers Test (Beurger 1908) / AKA Ratschows Test (Max-Ratschow-Klinic) identifies when there is critical ischemia without necrosis yet or gangrene, and is characterised by pallor when the leg is elevated above the level of the heart, which then turns red when hanging down over the edge of the bed. This redness is referred to as "Sunset appearance" and its due to abnormal autoregulation. Its been described that normally only a third of the capillary bed is open at any time but in a state of critical ischaemia because of the autoregulation being paralyzed a significantly higher portion of the capillaries open up.
  - The ischaemic Angle: A refinement to Berger's Test: The angle of elevation from the horizontal at which the Doppler Signal of the PT or DP disappears. This is also referred to as the 'pole test,' whereby the foot is raised alongside a calibrated pole marked in mmHg.

- Tissue Loss:
  - Gangrene Dry or Wet (infection)
  - Level of tissue Loss
  - Probing To Bone/ Exposed structures: Tendons, Soft Tissue, bone, Joint Capsule.
  - Examination of an Ulcer (may have many aetiologies) – important not only to identify extent of disease but also to exclude other aetiologies:
    - Such as Venous, Mixed, infective, autoimmune, inflammatory, malignancy or trauma.

What is the natural history of CLI and what do we know about its prognosis?

Fortunately, only a small portion of patients with Intermittent Claudication will go on to develop rest pain or tissue loss. Its estimated that anywhere between 5% -29% of patients with PAD or IC go on to develop CLTI over 5 years.

However, those that do develop CLTI, have a high risk of limb loss (greater than 20% annual risk) and a high mortality (10-15% annual risk), the majority of terminal events being related to cardiovascular events.

What has changed in the last few decades?

Prevalence of smokers-Ex and Current (decrease) and patients with diabetes(increase).

Estimated 4.4% of the world will have diabetes by 2030. 25% of patients with Diabetes will develop a foot ulcer.

Briefly outline the underlying pathophysiology associated with peripheral neuropathy in Diabetes?

The loss of the basic nociceptive mechanisms in the foot amongst diabetics, presents as a loss of protective sensation (LOPS).

Neuropathy can be divided into three types:

1. Sensory: “stocking-glove” distribution
2. Motor: Intrinsic muscle wasting – resulting in deformities
3. Autonomic: Sympathetic nervous system pathology

Along with Neuropathy, Diabetic Patients also have Structural deformities and Gait disturbances in addition to Angiopathy or small vessel disease.

There is often an overlap in the pathological processes in patients with CLTI or CLI.

What is the WIFI Classification?[91]

Interestingly in the original article by Bob Rutherford regarding Diabetes and PAD:

- "It was generally agreed that diabetic patients who have a varied clinical picture of neuropathy, ischemia and sepsis make the definition even more difficult and it is desirable that these patients be excluded... diabetic patients should be clearly defined as a separate category or should be clearly defined as a separate category."

Since then, the SVS, while acknowledging that we can no longer exclude these patients and treat them separately given the overlap, have decided that a new classification system is necessary, as one of the key authors (Joseph Mills) states:

- "We classify things into groups to differentiate, remember and compare, observe and predict their behaviour over time." –Joseph Mills

WIfI stands for: Wound, Ischemia and foot Infection. Most of the existing Vascular and non-Vascular classification systems don't include all three components or fail to stratify the degree of ischemia and presence of gangrene.

Principles of WIfI:

1. Grades, Classes and Stages – Each of the three categories (WIfI) have Grades 0,1,2,3: Resulting in 64 Classes.
2. Delphi Consensus – Clinical Stages 1 (Very Low),2 (Low), 3 (Moderate), 4 (High Risk/Benefit).
    1. What is the one-year risk of amputation with medical therapy alone?
    2. What is the potential benefit from successful revascularization?
3. Analogous to TNM Staging

"It is intended to be an iterative process with the goal of more precisely stratifying patients according to their initial disease burden, analogous to TNM cancer staging, but not to dictate therapy."

What about a differential diagnosis or other causes of similar pain as rest pain?

Acute Lower Limb ischemia is a different clinical picture, but there may some overlap with Acute on Chronic disease such as in the case of in situ thrombosis in the lower limb arterial system.

Other causes of ischemic pain include:

- Buergers Disease, or Thromboangiitis obliterans
- Scleroderma
- Fibromuscular dysplasia
- Popliteal Artery Entrapment

- Cystic Adventitial Disease
- Persistent Sciatic Artery Disease

What is the Rutherford Acute Ischemia Grading System?

Although Acute Ischemia is very different from chronic ischemia, patients with progressive chronic PAD can develop an acute picture whether from embolism or in-situ thrombosis secondary to plaque rupture. See @ref(acute-limb-ischemia) for more.

What are the recent CLTI Guidelines?

In 2019 the SVS, the ESVS and the World federation of Vascular Societies (WFVS) joined forces to put together the structure and funding of the Global Vascular Guidelines Initiative (GVG). Importantly all sponsorship was directly from the societies and any direct industry sponsorship or external sources were excluded. They put together a steering committee responsible for recruiting a large and diverse writing group and outlined the scope and developed the section briefs of the guideline.

They determined that:

"The term"critical limb ischemia" (CLI) is outdated and fails to encompass the full spectrum of patients who are evaluated and treated for limb-threatening ischemia in modern practice."

CLTI was promoted as the term of choice and was defined by the target population

The target population were:

1. Ischemic Rest Pain with confirmatory hemodynamic studies
2. Diabetic Foot Ulcer or any lower limb ulceration present for at least 2 weeks
3. Gangrene involving any portion of the lower limb or foot

Exclusion from the population:

1. Purely venous ulcers
2. Acute Limb Ischemia/acute trash foot/ischemia due to emboli
3. Acute Trauma or mangled extremity
4. Wounds secondary to non-atherosclerotic conditions

Methodology of the guidelines utilised the structure of GRADE.

They Highlighted particular important sections in the evaluation and management of patients with CLTI: namely Patient Risk stratification, Limb Assessment and Severity of Limb Threat and the development of a specific evidence-based revascularisation guideline in CLTI.

One think to notice (which the authors also highlight in the text body) is compared to most guidelines, unfortunately in this area, particularly when it comes to revascularisation, the level of evidence is generally LOW. Again, highlighting the importance of these guidelines in developing a standard approach and appropriately stratifying patients in not only management but ongoing research.

What clinical evaluation is necessary for the patient with CLTI?

In addition to the History and Examination, and the WIfI assessment mentioned above. For patients with diabetes and an ulcer a full assessment of neuropathy and a "probe to bone" test for any open ulcers is recommended as part of good practice.

We mentioned in our previous discussion the non-invasive methods of assessment for these patients. One additional point to make is the importance of TP and TBI in these patients.

It's been shown that, healing of an ulcer or tissue loss is unlikely if a patient's toe pressures are less than 55mmHg. And Toe Pressures have been validated in multiple studies to correlate with Amputation free survival and wound healing: Amputation Free Survival TP <30mmHg 2.13 HR (1.52-2.98). - (J.E. Wickstrom et al EJVS May 2017).

What are the recommendations for patients with CLTI when it comes to Medical Therapy and Risk Factor Modification?

- Treat all patients with CLTI with an Antiplatelet agent (Grade 1 Level A)
- Consider Clopidogrel as the single agent (**Grade 2 Level B**) – CAPRIE
- Moderate or High-intensity statin therapy to reduce all-cause and cardiovascular mortality (**Grade 1 Level A**)
- Control Hypertension to BP target <140mm Hg systolic and <90mm Hg diastolic in patients with CLTI (**Grade 1 Level B**)
- Offer Smoking Cessation interventions and ask all smokers or former smokers about status of tobacco use every visit (**Grade 1 Level A**)

What imaging assessment is required?

The CLTI Guidelines outlines an algorithm of attaining Arterial Anatomy Imaging. Starting with US and then depending on the information required, CTA, MRA or eventually digital subtraction angiography. They emphasize the importance of obtaining good quality imaging to appropriately stage and be able to compare the level and degree of disease.

What is the Global Limb Anatomic Staging System (GLASS)?[92]

Because the existing arterial anatomical staging of disease is very vague, and are "lesion focussed" and not all encompassing (beyond the concept of 'in-line pulsatile flow to the foot'), GLASS attempts to incorporate all aspects in its

staging to improve vascular care and evidence-based revascularisation (EBR) outcomes.

GLASS incorporates two novel and important concepts: The Target Arterial Path (TAP) and the estimated Limb-Based Patency (LBP) and it's a grading system based on anatomical and subjective assessment of calcification.

GLASS focusses on Infrainguinal disease, with the Aorto Iliac (AI) segment considered the inflow disease which includes the Common Femoral Artery and the Profunda Artery. Therefore, the GLASS grades assume the inflow vessels are treated and adequately 'dealt with.'

Infrainguinal disease assessment for Femoropoliteal (FP) and Infrapopliteal (IP) is based on length of disease and the extent of CTO's. The FP and IP GLASS Grades are then combined into Stages 1-3.

The calcification scale is a dichotomous subjective assessment of the degree of calcification and if there is >50% circumference of calcification, diffuse or bulky calcification or "coral reef" plaques, then there is an increase in the within-segment grade by one numerical value.

There is also mention of the Inframaleolar (IM) degree of disease (PO, P1-absent arch, P2-no target artery crossing into foot) which is not included in the GLASS staging given little evidence on the outcomes this difference makes on overall patency and limb salvage.

Once the GRADES (0-4) of FP and IP disease are determined then staging (1-3) can be performed based on the matrix or grid that is provided. Staging then allows for estimated Peripheral endo-Vascular Intervention outcomes (PVI) to be predicted, Immediate Technical Failure (ITF - <10% or < 20% or > 20%)) and 1-year Limb Based Patency (LBP - >70%, 50-75% or <50%).

What is the Target Arterial Path (TAP)?

"The selected continuous route of in-line flow from groin to ankle. The TAP typically involves the least diseased IP artery but may be angiosome based."

What revascularisation management strategies exist for CLTI?

The mainstay of management for patients with CLI or CLTI has always been based on the fundamental principle of limb salvage and given the high risk of limb loss in these patients there's been a low threshold to revascularize these patients if they have occlusive disease that is treatable. But strategy has varied significantly.

The CLTI Guidelines provide an approach to dealing with this complex condition on planning three aspects to each case:

1. Patient Risk Estimation
2. Limb Staging
3. Anatomic Pattern of Disease

What is involved with the Patient Risk Estimation?

Good Practice Statements (Recommendations section 6)

"Refer all patients with suspected CLTI to a vascular specialist for consideration of limb salvage, unless major amputation is considered medically urgent."

"Offer primary amputation or palliation to patients with limited life expectancy, poor functional status (e.g. non ambulatory), or an unsalvageable limb after shared decision-making."

Recommendation 6.3:

- Estimate periprocedural risk and life expectancy in patients with CLTI who are candidates for revascularization. **Grade 1 (Strong) Level of Evidence C (Low)**
- Average Surgical Risk: \<5% operative mortality and 2-year survival >50%
- Severe Surgical Risk: \>/= 5% operative mortality and 2-year survival </=50%

What is involved and recommended with the Limb Staging and recommendation for Management?

Use an integrated threatened limb classification system (such as WIfI) to stage all CLTI patients who are candidates for limb salvage. **Grade 1 (Strong) Level of Evidence C (Low)**

Perform urgent surgical drainage and debridement (including minor amputation if needed) and commence antibiotic treatment in all patients with suspected CLTI who present with deep space foot infection or wet gangrene. (Good Practice Statement)

Offer Revascularisation to all "average surgical risk patients" (\<5% operative mortality and 2-year survival >50%) with advanced limb-threatening conditions (e.g. WIfI stage 4) and significant perfusion deficits (e.g. ischemia grades 2 and 3). **Grade 1 (Strong) Level of Evidence C (Low)**

What is involved in the Planning of the Anatomic pattern of disease and its effects of revascularisation strategy?

The overall pattern of arterial occlusive disease is a dominant factor in guiding type of revascularisation and timing of such.

Do all patients require direct in-line flow to the foot as a primary technical outcome with revascularisation?

One important patient population to identify that do not necessarily require direct in line flow are those with rest pain "for which correction of inflow disease alone or treatment of FP disease even without continuous tibial runoff to the foot may provide relief of symptoms. This may also be the case in patients presenting with minor degrees of tissue loss."

What are some essential Key Factors to consider before deciding Open versus Endovascular according to the CLTI guidelines?

1. **The "availability of and quality of autogenous vein conduit"7**
2. **Patient overall risk (as mentioned above) and Limb Staging**
3. **The Target EndoVascular Intervention (TVI) outcomes**

What evidence do we have for deciding between Endo and Open? What is the BASIL trial?

The evidence is largely retrospective or non-controlled, industry sponsored and in overall quality poor. BASIL (Bypass versus Angioplasty in Severe Ischemia of the Leg) remains the only multicentre RCT (BASIL -2 and 3 underway) directly comparing an endo versus open strategy in CLTI and Infra-inguinal occlusive disease.

BASIL compared POBA and Bypass across multiple centres (27 centres, n=452, 1999-2004) in the UK. Primary endpoint was amputation-free survival.[110]

Major Findings:

1. At 6-months follow up: no difference in AFS.
2. Intention-To-Treat Analysis of overall follow up showed no significant difference in AFS and overall survival.
3. Amongst patients who survived >2 years, overall survival was better for those treated with Bypass as a first approach
4. Analysis to treat:
    1. Prosthetic Bypass Patients did very poorly (even compared to POBA)
    2. Patients who had bypass after failed POBA had significantly worse AFS compared to those treated with a bypass as initial treatment

Criticism:

1. Majority had POBA alone (not currently best endovascular option)
2. 25 % of Open Bypass were Prosthetic
3. The Technology and Technical Skill with growing operator experience in Endovascular has improved.

What is new with the future management guidance for CTLI? What is BASIL 2 and 3 and BEST-CLI?

BASIL 2: Infrapopliteal Disease: Vein Bypass First vs. Best Endovascular Treatment first

BASIL 3: PBA +/- BMS vs. DCB +/- BMS vs. DES

(Both Follow up 24-60 months, Primary Endpoint AFS)

BEST-CLI: Open Bypass versus Endovascular Intervention, Primary Endpoint: MALE-Free Survival. Major Above-the-Ankle Amputation, Major Bypass or Jump/interposition graft revision or the need for thrombectomy or thrombolysis (MALE).

Acute Limb Ischemia

17 Oct 2020: *Alex Forsyth and Sarah Carlson; Boston Univeristy*

What is acute limb ischemia and what does it encompass?

Acute limb ischemia is defined as any process that leads to an abrupt cessation of blood flow to a limb resulting in ischemia. There are a few causes, but the most common two are embolic and thrombotic.

- Embolic
  - Cardiac
    - Typically due to a fib
    - Arm ischemia is most commonly due to cardiac embolism
    - Endocarditis – as seen in IV drug users or patients with bacteremia from other causes
    - Cardiac tumors – such as atrial myxoma
  - Atherosclerotic (e.g. iliac disease embolizing downstream to the lower leg)
  - Paradoxical embolism (Thromboembolic venous system with PFO)
  - Aneurysm (e.g. thrombus from within an aortic aneurysm embolizing downstream to the leg)
- Thrombosis
  - Aneurysm
  - Bypass graft
  - Acute on chronic progression of atherosclerosis
- Dissection
- Thoracic outlet syndrome (in the upper extremity)
- Vasospasm (severe)

For clarification: (1) Acute on chronic progression of atherosclerosis: – e.g. once a chronic stenosis becomes critically tight, platelet thrombus can develop leading to an acute occlusion; or unstable plaque can "rupture" leading to an acute occlusion of a chronic lesion. And (2) Regarding aneurysms – especially small

aneurysms (such as popliteal) – these are less likely to rupture, but more likely to thrombose and cause an acute limb ischemic event.

Presentation and Diangosis

What is the patient presentation of ALI? Are there any differences for upper vs. lower extremity presentations?

Classically remembered by the 5 or 6 Ps depending on who you ask

- Pain: usually located distal to the occlusion and gradually increases in severity as the duration of ischemia continues. The pain may also decrease after a time due to ischemic sensory loss
- Pallor: the limb appears pale compared to the non ischemic limb. There is delayed capillary refill as well
- Poikiolothermia: (just a way to make "cold" into a "P" – really means cold limb) means literally the inability to regulate one's body temperature, or dependent on ambient temperature as cold blooded animals are. If there is no perfusion of warm blood to the limb, it acclimates to the ambient temperature.
- Pulseless: self explanatory, but a good thing to think about is if the contralateral limb has normal pulses, it suggests the absence of chronic limb ischemia and that an embolus or other cause of ALI.
- Paresthesia and Paralysis are the last two Ps. Paresthesias are an earlier sign of ischemic nerve dysfunction and paralysis is a later sign. In the lower extremity, ischemic changes often affect the anterior compartment first, and sensory loss over the dorsum of the foot is one of the earlier neurologic deficits in ALI

This is why a thorough physical exam is key; comparison of both limbs and a good pulse exam including handheld doppler exam. It can be difficult for a junior resident to tell whether a limb is acutely threatened, especially in patients with chronic disease where the presentation of an acute change can be more subtle. This is why the attending surgeon will always ask the consult resident "how is the motor and sensory function" in addition to the pulse exam... this helps us gauge the chronicity and therefore the urgency of intervention.

How is ALI classified?

From Rutherford RB, Baker JD, Ernst C, et al. Recommended standards for reports dealing with lower extremity ischemia: revised version. J Vasc Surg. 1997;26:517–538.[96]

Cl assification	Descripti on/prognosis	Findings	Doppler signals
Sensory loss	**Muscle weakness**	**Arterial**	**Venous**
I. Viable	Not immediately threatened	None	None
II. Threatened			
a. Marginally	Salvageable if promptly treated	Minimal (toes) or none	None
b. Immediately	Salvageable with immediate rev ascularization	More than toes, associated with rest pain	Mild, moderate
III. Irreversible	Major tissue loss or permanent nerve damage inevitable. Cyanosis may be present	Profound, anesthetic	Profound, paralysis (rigor)

What does the work up for an acute limb entail? How is the diagnosis made?

- The diagnosis can often be made on history, physical exam, and bilateral ABIs. Imaging can be done in patients in who the diagnosis is uncertain
- As with most urgent cases, the type of imaging done depends on the availability of at your institution, but generally imaging, such as a CT angiography or arteriography should be done on viable and marginally threatened limbs. Arteriography often can distinguish between embolic vs arterial thrombosis which may help to direct therapy.

The situation varies depending on how severe the presentation is and how quickly you can obtain imaging. Also depends on renal function and whether you want accept two contrast loads (CT followed by endovascular intervention). As a rule of thumb, if I can feel femoral pulses I would typically be more inclined to proceed with on-table angiogram without a CT scan. If femoral pulses are absent I would be more concerned about aortoiliac disease and I would prefer to have a CT scan so I know what I'm getting into in the operating room and can have a better plan.

In patients with severe renal insufficiency, MRA or MR time-of-flight can be helpful, but these studies usually take a little longer to obtain and may not be quickly available in an acute threatened limb situation.

Bedside ultrasound can also be very helpful even if you're not a certified ultrasonographer yourself, if you have access to color flow doppler US it can be very

helpful.

Management

What is normally done in the initial management of ALI?

- Anticoagulation - IV unfractionated heparin is immediately administered to prevent proximal and distal progression of secondary thrombus as long as heparin is not contraindicated. The dose should be titrated to maintain activated partial thromboplastin time between 50 and 80 seconds (2-3 times normal values)
- Supportive care (IV fluids)
- A full set of labs including serum chemistry panel with BUN and Cr, CBC, baseline coagulation studies should be obtained. Baseline plasma CPK can be helpful to follow for evidence of rhabdomyolysis after reperfusion

A good rule of thumb for IV heparin is to start with a bolus of 80-100 units/kg, and then drop at 18units/kg/hr – titrating to PTT at 2-3x normal

What are some of the options for treatment of ALI?

- Medical primarily with anticoagulation using heparin or a direct Xa inhibitor
- Open
  - Thrombectomy – balloon catheter based (Fogarty embolectomy balloon – Dr. Fogarty invented this while he was a medical student)
  - Bypass
  - Endarterectomy – not usually the go to but might be used for the common femoral
- Endovascular
- mechanical thrombolysis vs catheter directed
- Percutaneous thrombus aspiration – useful for small fresh thrombi such as after angioplasty, as distal diameter of the catheter tip limits the size of the thrombus that can be removed.
- Mechanical thrombolysis and aspiration are also useful for patients with contraindications for thrombolytic therapy, and also may allow for a lower dose of a thrombolytic agent, but risk damage to the arterial wall

Who gets which kinds of treatment? Who needs emergent treatment?

- Class I might just need medical therapy like anticoagulation and revascularization can be elective.
- Class IIb patients do not need immediate revascularization

  - If symptoms have been present for less than 2 weeks endovascular therapy is preferred
  - If more than 2 weeks or lytic therapy has failed then surgical intervention is preferred
- Class IIb need immediate revascularization. Historically surgical revascularization has been preferred because of its immediacy, but catheter directed thrombolysis and percutaneous mechanical thrombectomy have shortened time to revascularization.
- Studies:
  - STILE trial – one of the first large RCTs comparing catheter thrombolysis with open surgery; overall the study showed some short term benefit to open surgery however this can probably be attributed to a couple things: (1) in 28% of patients randomized to CDT they weren't able to get a catheter in place so these patients were considered treatment failures and crossed over to the surgery arm, and (2) patients with very long durations of ischemia – up to 6 months) were randomized, and when they looked at patients who had been symptomatic for less than 2 weeks, the thrombolysis patients actually did better.[111]
  - TOPAS trial – larger RCT which enrolled patients who had an acute arterial occlusion of less than 14 days; this showed no difference in mortality or amputation-free survival but higher major bleeding in the CDT group.[112]
  - Meta analysis released originally published in 2002 but updated in 2013 and 2018 demonstrated no difference in mortality or limb salvage between surgical and thrombolytic therapy, but endovascular demonstrated higher rates of complications including ongoing limb ischemia and bleeding within 30 days of treatment. Previously they had reported higher rates of stroke in the thrombolysis category but the most recent update is unable to support this finding[113]
    * All this to say, it is very reasonable to think about a cathter-directed therapy especially if the presentation is acute, less than 2 weeks or so. That said, there are certain anatomical locations that most surgeons would favor a simple open procedure – e.g. embolism to the common femoral or brachial arteries – these are typically pretty simple to treat with a cut down and balloon thrombectomy.
    * One thing it is important to consider when doing a therapeutic infusion is that you might place a tPA infusion catheter at time zero and then bring the patient back 24 hours later; patient needs to be advised that they'll need to lie flat for a day or even two days. Setting expectations with patients is important.

- Class III is usually treated with primary amputation because revascularization is unlikely to restore function to the limb and restoring bloodflow can cause the patient serious harm.

What are the risks of revascularization for a class III or prolonged ischemia?

- Myonephropathic metabolic syndrome: muscle cells undergo liquefactive necrosis due to ischemia. Potassium, myoglobin, lactic acid, and superoxide accumulate and can perfuse through the body or can have a sudden increase in the event of revascularization which leads to hyperkalemia, arrhythmias, pulmonary edema, metabolic acidosis, myoglobinuria, and can even cause sudden death from heart and/or renal failure.[114] Treatment of this is largely supportive with fluids

Compartment Syndrome

What is the pathophysiology and manifestations of compartment syndrome?

- Increased intramuscular compartment pressure results from increases in capillary permeability due to ischemic reperfusion. The increase in pressure leads to neuromuscular dysfunction and interferes with circulation. Irreversible damage occurs when pressures exceed 30mmHg in each compartment
- Clinically they can have neurological dysfunction with sensory motor deficits, but the most common presentation is a tense extremity with pain on passive movement of the muscles in the compartment, which is often dorsiflexion/plantar flection of the ankle. A sensitive indicator is loss of two point discrimination

How do you diagnose a compartment syndrome?

- Physical exam (tenderness, especially over anterior compartment), paresthesias, especially between first and second toes (anterior compartment: deep peroneal nerve – this is a VSITE favorite)
- Compartment pressures: how do you do this?
  - Need a needle to access the compartment and a pressure monitoring system (can be handheld Stryker kit, or just a hollow bore needle connected to an arterial pressure bag).
  - Normal compartment pressure is <10-20mmHg; greater than 30 is highly concerning. Probably even more accurate than an absolute number is comparing the compartment pressure to the mean arterial pressure or diastolic pressure. If the compartment pressure is within 40mmHg of the MAP (for example, MAP is 60 and compartment pressure is 25 – this is concerning) – OR – if the difference between

compartment pressure and diastolic pressure is less than 10 (for example, diastolic pressure is low at 30, and compartment pressure is 22).

If clinical suspicion of compartment syndrome is high, I tend not to be reassured by "normal" compartment pressures. It's relatively low risk to do fasciotomies, but the risk of limb loss is so high for a missed compartment syndrome... I would much rather err on the side of caution if there's any question.

Treatment is a fasciotomy – can you tell us a little about the types of fasciotomies?

- Forearm and upper arm fasciotomies are often performed by orthopedic or hand surgeons. The forearm fasciotomy includes dorsal and volar incisions to release the dorsal and volar compartment, and mobile wad while avoiding numerous superficial cutaneous nerves. The arm fasciotomy releases the medial, lateral, and deltoid compartments through medial lateral incisions
- Fasciotomies can be done in the thigh as well with a medial and lateral incision to release the lateral, medial and posterior compartment
- The most common type is a lower leg 4 compartment fasciotomy

How is a lower leg 4 compartment fasciotomy for the lower extremity performed?

1. A longitudinal incision is created between the fibular shaft and the crest of the tibia over the intermuscular septum and the anterior and lateral compartments are opened. If tissues are swollen occluding the view of the intermuscular septum, the perforating vessels can be followed down to it. Nerves including the peroneal nerve are most at risk near the fibular head
2. A second incision is created on the medial surface of the lower leg approx. 1cm posterior to the edge of the tibia to avoid the greater saphenous vein. The superficial posterior compartment is incised. The gastrocnemius-soleus complex is taken down from its attachments to the tibia in order to access the deep posterior compartment.
3. The incisions are made generously – sometimes the skin incision can be a little short of the fascial incision, but they should be nice and long in order to fully release the compartments
4. After hemostasis be sure to apply loose dressings, and the leg should be elevated to reduce edema that can complicate closure. Closure can be done in 48-72 hours but may be delayed and dressed with wound vacs to attempt primary closure. If primary closure is not possible, a split thickness skin graft can be used for closure

Who should a prophylactic fasciotomy be performed on?

- Patients with high occlusion and extensive ischemia,

- Acute ischemia of greater than 6 hours with few collaterals
- Patients with combined arterial and venous injury
- Patients who are obtunded making serial examination difficult

What is the prognosis for a patient with ALI? What are some patient factors that lead to a poor prognosis?

Amputation rates after acute limb ischemia are typically described in the 10-20% range, and mortality is also in the 10-25% range whether you're talking about surgery or catheter-directed procedures (that's excluding the patients who present with Rutherford class III and by definition have an unsalvageable limb). Many factors determine likelihood of amputation; typically, patients with more medical comorbid conditions tend to do worse as you might expect: baseline CAD, kidney disease and smoking are predictive of worse outcomes. There is a trend toward improved limb salvage rates (decreased amputation rate) over time, and I think this speaks to wider availability of different limb salvage techniques among vascular surgeons across the globe.

Mesenteric Disease

09 Apr 2020: *Matt Chia, MD and Nick Mouawad, MD*

Mesenteric vascular disease can be broken down into three disease states that we'll cover today. There's the arterial disease, which is clearly separated into acute mesenteric ischemia and chronic mesenteric ischemia. Then there is venous disease, which we'll touch on briefly. There are also a handful of somewhat related diseases that we'll also sprinkle into these discussions, like median arcuate ligament syndrome and SMA syndrome, but that's overall where we're headed.

Acute Mesenteric Ischemia

Presentation and diagnosis

Can you tell me about the classic presentation and approach to patients presenting with acute mesenteric ischemia?

These patients present with the sudden onset of abdominal pain. Nausea, vomiting, distention, and diarrhea (possibly bloody, described as "sudden and forceful evacuation") are the common symptoms. Pain out of proportion is the classic buzzword, and can be hidden on multiple choice tests with a pain score of 10/10 with only mild abdominal tenderness on physical exam.

Vitals typically normal, possible tachycardia.

Lab evaluation typically unremarkable. Leukocytosis, hemoconcentration, and acidosis (high anion gap) all are frequently found, but the absence of these definitely does **not** rule out acute mesenteric ischemia.

D-dimer has been proposed as a reasonable rule-out test for acute mesenteric ischemia.

How about radiology studies?

Plain film:

Frequently normal, may show ileus in the early stages. In late stage acute mesenteric ischemia, findings on plain film can include bowel wall edema (thumbprint-

ing) or pneumatosis.

CT angio:

Probably represents the most common diagnostic modality to diagnose acute mesenteric ischemia. CTA has the advantages of speed, availability, and non-invasiveness when compared to conventional angiography, and also allows for some assessment of the degree of bowel involvement.

Preferentially, a "negative" oral contrast agent would help prevent oral contrast from causing artifact or obscuring evaluation of the vessels, although the availability of these agents may limit their use.

How about mesenteric duplex (vascular lab studies)?

Mesenteric duplex has the advantage of being able to see the velocity of flow across a stenosis, giving you a good method of quantifying the significance of a stenosis. However, bowel gas often limits the acoustic windows for visualizing the mesenteric arteries, and so we usually will have patients fast for several hours before a study. Also, duplex is more sensitive for proximal disease rather than distal mesenteric involvement. For these reasons, mesenteric duplex is considered the gold standard for evaluating chronic mesenteric ischemia, but has no real role in the evaluation of acute mesenteric ischemia. Can you imagine, having a tech mash a transducer into a patient with acute abdominal pain?!

Management

What's your approach to the initial management of the patient?

1. Resuscitation. Fluids, fluids, fluids. These patients are really volume down, and are headed towards a profound distributive shock that will be worsened by your eventual plan for revascularization (think ischemia-reperfusion injury). Also look for electrolyte imbalances and correct those early.

2. Antibiotics. These patients are not usually septic on initial presentation, but are at high-risk, so broad-spectrum antibiotics with gut coverage (Gram negative and anaerobes) are standard of care.

3. Heparin. In the absence of a clinical contraindication, these patients should be systemically heparinized, with a bolus, as soon as the diagnosis is made.

Which blood vessel does acute mesenteric ischemia typically involve?

The SMA. This makes sense if you think of each mesenteric distribution. The celiac distribution has organs that have redundant blood supply (like liver and stomach). The IMA is frequently occluded in patients with AAA, but the patients are rarely ever symptomatic due to collateral flow. The hypogastrics (which ARE mesenteric vessels, especially in the situation of an occluded IMA) principally supply the rectum from a mesenteric standpoint.

For embolic pathology, the acute angle of the SMA seems to predispose it to capture emboli from above, but this is more theoretical than proven.

Tell me about the two main pathologies, and how they would differ in terms of the anatomy and operative findings.

So the two most common etiologies of acute mesenteric ischemia are embolism and thrombosis.

Embolism is the more common, where preexisting thrombus (think atrial fibrillation, mural thrombus from thoracic aneurysm, etc.) or plaques from atherosclerotic disease break off and lodge in the SMA. The classic operative finding is that an embolism lodges just distal to the middle colic artery, where there is a significant caliber change in the SMA. This is distal to the first few jejunal branches off of the SMA, leading to the classic sparing of the proximal jejunum and transverse colon. In other words, the mid to distal jejunum and all of the ileum will be ischemic, but other areas of the SMA territory are spared. Atherosclerotic debris is typically smaller, and results in smaller, more patchy areas of ischemia.

Thrombosis occurs primarily as a plaque rupture of preexisting atherosclerotic disease, resulting in acute thrombosis at the site of the disease. Thus the patients will often present with an acute-on-chronic symptomatology, having classic symptoms of postprandial abdominal pain, food fear, and weight loss, but with a sudden onset of severe symptoms. This frequently allows for the development of mesenteric collaterals, which may make the onset of acute symptoms more insidious than for embolic pathology. In the majority of situations, the atherosclerotic disease is most severe right at the origin (consistent with what we know about shear stress and branch points in blood vessels). This means that when the plaque ruptures, the entirety of the SMA occludes, leading to ischemia of the entire territory, as opposed to the jejunal-sparing distribution seen in embolic disease.

Describe the operative steps to getting exposure of the supraceliac aorta (or the celiac artery).

1. Divide triangular ligament to mobilize left lobe of liver
2. Divide gastrohepatic ligament to enter the lesser sac
3. Retract liver to right with a self-retaining retractor
4. Push esophagus left (use NGT to assist with identification)
5. Divide peritoneum overlying crura to identify celiac vessels
6. Typically trace common hepatic artery backwards to identify celiac artery
    - Watch out for the left gastric vein as it crosses the celiac artery as it drains the lesser curve of the stomach into the portal vein.

- About half of the time, the phrenic artery takes an origin from the celiac artery and must be controlled during exposure.

7. To expose the supraceliac aorta, divide the median arcuate ligament and separate the left and right crura from each other.

So through this kind of exposure, what mesenteric vessels do you get access to?

You can trace most of the proximal celiac distribution right at the origin, and through this exposure you get access to the origin of the SMA if you mobilize the superior border of the pancreas. The neck of the pancreas and the splenic vein cross the anterior of the SMA, obscuring the rest of the mid and distal SMA from the superior approach.

How about getting to the rest of the SMA?

There are a couple of places you can get exposure to the SMA.

Most commonly you'll hear it described at "root of the mesentery." Specifically, lifting up the transverse colon will stretch out its mesentery (i.e. transverse mesocolon). At the bottom, or "root" of the transverse mesocolon, a transverse incision is made. If the middle colic artery is palpable in the mesocolon, the incision can be made around it, and you can trace the middle colic backwards to the SMA. Usually you'll find the SMV first, and the SMA will be just to the left of it. Be sure to identify and preserve small jejunal branches during the dissection. If needed, careful dissection superiorly, going behind the inferior border of the pancreas can get a little more proximal exposure.

Alternatively, you can get to the SMA from a lateral approach, specifically from the left side. Begin by dividing the ligament of Treitz and mobilizing the 4th portion of the duodenum. The SMA is found in the tissues just cephalad to the duodenum. You can also improve your proximal exposure if needed by retracting the inferior border of the pancreas cephalad to the level of the left renal vein.

Other options include a retroperitoneal exposure, like you were preparing to treat a thoracoabdominal aneurysm. Additionally, the more distal SMA can just be identified in the small bowel mesentery.

So for the operative strategy for acute mesenteric ischemia, tell me about the general approach to the patient.

1. Resect frankly necrotic bowel and contain gross spillage. Once you revascularize the bowel, compromised-appearing bowel may improve and not need immediate resection. Thus the first step is only damage control, to remove anything completely unsalvageable that is making the patient sick, or anything causing gross contamination of the operative field. The key is you're not doing anything definitive with the bowel as your first step.

2. Revascularization. SMA embolectomy is the initial management of choice for embolic disease. Thrombotic disease, on the other hand, may be more

challenging to treat by embolectomy alone, and frequently are treated with a bypass. (More to come on these procedures).

3. Re-assess bowel viability. Clinical status permitting, 20-30 minutes should be taken to fully assess the results of the revascularization before proceeding with resection. Perfusion can be assessed by many methods, including clinically, by Doppler, pulse oximetry (a.k.a. photoplethysmography), fluorescein fluorescence, etc. The take home is to give the bowel enough time to be perfused before going ahead with resection.

4. Proceed with temporizing or definitive bowel repair. Resection, leaving in discontinuity, primary anastomosis, diversion, etc. All of these are options on the table, but the key here is that all of the previous steps occur before addressing the bowel.

5. Consider second-look laparotomy. Many times, bowel may look questionable even after revascularization and thorough re-assessment. To preserve the most bowel length, it may be reasonable to leave borderline bowel alone at the index operation and do a "second look" to fully reassess the bowel, especially after the patient has benefitted from aggressive resuscitation in the ICU.

Let's talk a little about the steps for an SMA embolectomy.

Typically, you'll expose at the root of the transverse mesocolon. After obtaining proximal and distal control, an arteriotomy is made, and embolectomy can be performed by passing Fogarty catheters in both a retrograde and antegrade fashion. The arteriotomy can be made transversely for an embolectomy, and thus could be closed primarily. A longitudinal arteriotomy may be advisable if you have a high suspicion that you'll need to do a bypass, and if not, may be closed with vein patch angioplasty (remember that the field is contaminated or dirty in many situations).

So if I'm gonna do a bypass, what are my options for conduit?

Yeah, so again, because the field is frequently contaminated or dirty, a good conduit is saphenous, followed by femoral vein. Thus every patient undergoing surgery for acute mesenteric ischemia should have both legs prepped out in the field. Prosthetic conduit has the advantages of being more resistant to kinking (externally reinforced), likely better patency than vein (although data are a little mixed), but in the situation of gross contamination may be less preferred than vein. Other less common options include cryo-preserved cadaveric homograft, or rifampin-soaked prosthetic.

And what are some of my options for constructing a bypass?

Short retrograde aorto-SMA bypass:

This bypass takes is origin off of the aorta just below the SMA, anastomosing typically end-side onto the SMA just below its origin in order to bypass ostial or very proximal disease. This is a relatively quick bypass, with only one field

of dissection directly from the aorta below the SMA onto the proximal-mid SMA. The length of the bypass is very short, limiting concerns with kinking or twisting of the bypass. However, this may not always be feasible, as SMA disease often coexists with significant aortic disease. Additionally, the other bypasses described have better reported patency.

Long retrograde R iliac-SMA bypass ("C-loop"):

This bypass originates from the right common iliac artery, which presents a number of distinct advantages over an aorto-mesenteric bypass. First, using the iliacs avoids the hemodynamic consequences of an aortic cross-clamp, which may be contraindicated depending on your patient's medical condition. Second, you can avoid showering, causing dissection, or otherwise injuring your clamp sites if you have significant disease in the mesenteric segment of the aorta, which is common in patients with chronic mesenteric ischemia. The graft should be tunneled in a gentle C-loop towards the SMA to avoid kinging or twisting. The proximal anastomosis is performed end-side on the iliac artery, and the distal can be performed either end-end or end-side depending on the anatomy of the disease. Especially when using prosthetic in a contaminated field, you can consider taking an omental flap to wrap or cover the prosthetic.

Antegrade supraceliac aorta-SMA bypass:

This bypass originates from the supraceliac aorta. If revascularization of both celiac and SMA is planned, a bifurcated graft can be selected. A side-biting aortic clamp can be used to mitigate the hemodynamic effect of an aortic cross-clamp. The tunnel to the SMA is created with gentle finger dissection in a retropancreatic plane, taking care to avoid injury to the SMV.

What other options have been described for treatment of acute mesenteric ischemia?

Retrograde open mesenteric stenting (ROMS)

So ROMS is a hybrid procedure involving an upper midline laparotomy that is used to evaluate the bowel. Through this incision, SMA exposure is obtained just as in a traditional open fashion at the root of the mesentery. The mid-SMA is then punctured under direct vision, and the area of disease is attempted to be treated from a retrograde approach back into the aorta. If bowel ischemia is found, the upper midline is easily lengthened into a traditional vertical laparotomy incision.

Endovascular treatment (percutaneous thrombectomy / thrombolysis / pharmacomechanical thrombect

Some authors have described completely endovascular approaches to treatment of acute mesenteric ischemia. However, the major limitation is the inability to assess the bowel. These patients are frequently those who are deemed to be lower-risk for frank bowel ischemia or perforation, but the rates of laparotomy and bowel resection after these treatments have been described at over 20%. Probably not your first answer for oral boards.

Rare Etiologies

What are some other, more rare etiologies of acute mesenteric ischemia?

Sure, so remember that embolism is the most common etiology of acute mesenteric ischemia, approaching half of these patients. The thrombotic etiology composes another quarter to a third of these populations. The other two etiologies to consider are non-occlusive mesenteric ischemia and mesenteric venous thrombosis.

Perfect, so how does a non-occlusive mesenteric ischemia (or NOMI) patient differ from what we've been talking about?

So NOMI patients typically do not have a focal lesion like you see with embolism or thrombosis. What happens to these patients is that classically they're pretty sick patients with some predisposing factors, most commonly ESRD. On top of that, there was some clear inciting hemodynamic event causing sustained hypotension, such as recently getting a session of hemodialysis or undergoing cardiopulmonary bypass. The presentation is more indolent and less obvious than embolic or thrombotic acute mesenteric ischemia, and the imaging findings are more consistent with a diffuse vasospasm and hypovolemia picture. Treatment is primarily conservative, with the emphasis on resuscitation and addressing whatever the underlying etiology is. Adjuncts to this include placement of infusion catheters into the affected vessel with infusions of vasodilators (most commonly papaverine) or prostaglandin.

How about mesenteric venous thrombosis?

This is the most rare and most difficult to diagnose. They have a very slow course, frequently with a lot of other workup already done. There's a wide variety of causes that have been reported, and any of the things that contribute to Virchow's triad have been reported (thrombophilia from coagulopathy or malignancy, venous stasis from abdominal hypertension or obesity, direct injury from trauma, surgery, or inflammation). The diagnostic test of choice is a CT venogram, which most commonly identifies thrombosis in the superior mesenteric vein (but can also involve the IMV, portal vein, or splenic vein). The treatment of choice is therapeutic anticoagulation.

Chronic Mesenteric Ischemia

Presentation and Diagnosis

How does chronic mesenteric ischemia differ in its presentation?

Chronic mesenteric ischemia is characterised by post-prandial abdominal pain, typically 30-60 minutes after eating (think after gastric emptying time). This pain is usually severe, crampy, and resolves after minutes to hours of time. The pain leads to food fear and eventual unintentional weight loss.

The clinical presentation here is key. Chronic mesenteric ischemia is pretty unlikely in patients who do not have this constellation of clinical symptoms, and it's really common for patients to be referred with imaging findings of elevated mesenteric velocities on duplex who have none of the clinical findings, and thus do not benefit from any intervention.

What are the duplex criteria for chronic mesenteric ischemia?

Yeah, so really the two vessels we're concerned with here are the celiac artery and the SMA. It's pretty rare that stenosis of the IMA results in clinically significant ischemia, and also pretty rare that isolated disease of either the celiac or the SMA would be enough to cause significant symptoms. Typically you see the classic symptomatology of chronic mesenteric ischemia in patients with occlusive disease in both the celiac and the SMA.

The key numbers to remember here are peak systolic velocities (that's PSV) of 200 cm/s for the celiac artery, and 275 cm/s for the SMA. These correspond to a stenosis of at least 70%. Remember, the **superior** mesenteric artery has **higher** velocity criteria, in case you forget. These classic numbers come from a study done in 1993, and many other studies have demonstrated other thresholds. Make sure to check with your friendly neighborhood vascular technician to see what the thresholds in your local lab are!

In addition to the PSV, you can also use the end diastolic velocity (EDV) to predict stenosis. For the EDV values in the celiac and the SMA, think approximately 50 cm/s predicts a stenosis of 50% (easy to remember, **50-50**).

You can also predict a higher degree of stenosis with EDV values. This is easy for the SMA, where an EDV of 70 cm/s predicts a stenosis of 70% (**70-70**). For the celiac, it's a bit higher, where an EDV of 100 cm/s predicts that same 70% stenosis.

So to review the numbers:[115–117]

- PSVs: 200 in the celiac or 275 in the SMA gives you 70% stenosis
- EDVs: 50s in the celiac or 50s in the SMA gives you 50% stenosis
- EDV #2: 100 in the celiac, or 70 in the SMA gives you 70% stenosis.

Final thought. When the celiac artery is severely narrowed or occluded, often you'll have retrograde flow coming from the SMA via collaterals (these are your pancreaticoduodenal arcades via the GDA). You can see this as backwards flow in the common hepatic artery, and this has 100% specificity for disease in the celiac artery.

Management

What's next in the approach to these patients?

Frequently they're going to get some kind of axial imaging, either CTA or MRA, to help plan for their revascularization, although this isn't strictly necessary. Often endovascular approaches are the mainstay of treatment. Remember that the angle of the SMA frequently favors a brachial approach, although you can also engage the SMA from a femoral approach with preformed catheters (think Sos, Cobra, etc) or steerable sheaths. Remember to watch out for median nerve compression from brachial sheath hematomas if you've opted for a percutaneous brachial approach, with a low threshold to evacuate the hematoma and perform median nerve decompression if the patient develops and symptoms in the median nerve distribution postoperatively. Also remember that a brachial sheath hematoma will not be easily palpable or visible at the skin level, so the neurologic exam postoperatively is key.

Any other technical tips for endo intervention on the mesenterics?

Most often balloon-expandable stents are selected for the mesenteric circulation. The precision of deployment and the increased hoop strength of a balloon expandable stent make them more favorable here over the radial force of a self-expanding stent. You can also flare the proximal end of a balloon-expandable stent into the aorta, making sure that you've really treated any ostial disease. Some authors advocate for use of embolic protection devices to prevent distal embolism, and other authors also advocate for the use of covered stents for the mesenteric circulation due to better patency.

How about open revascularization?

So we talked a lot about open revascularization earlier in the acute mesenteric ischemia segment. The techniques are broadly similar, with the exception that often for chronic mesenteric ischemia, frequently you'll be planning to revascularize both the celiac and the SMA. The approach for this is with a bifurcated graft from the supraceliac aorta, taking one limb down to the celiac artery, and the other limb tunneled in a retropancreatic fashion to the mid-SMA. Remember that this approach requires a supraceliac aortic cross clamp, which your patient may not be able to tolerate. Taking a retrograde bypass off of the common iliac artery as we previously described may be a better option for these patients. A further option that completely avoids a bypass is to go right for a trapdoor endarterectomy of the celiac artery and the SMA, allowing you to address coral reef or proximal/ostial disease (such as flush occlusions) that are difficult to treat endovascularly.

Median Arcuate Ligament Syndrome (MALS)

Can you tell me about median arcuate ligament syndrome and how that differs from chronic mesenteric ischemia?

Sure, so median arcuate ligament syndrome (MALS), which has many names (Dunbar syndrome, celiac axis compression syndrome, etc.) is a somewhat contro-

versial entity that occurs when repeated compression of the celiac artery occurs against the median arcuate ligament during respiratory variation. The thing you want to visualize here is that during full exhalation, the lungs are completely emptied, and the diaphragm moves up at a sharper angle. This angulation kinks off the celiac artery more severely, so velocities in **exhalation** are **higher** in MALS. However, these findings are common in asymptomatic patients, and so just like chronic mesenteric ischemia, the clinical presentation is key. They'll have a similar presentation as chronic mesenteric ischemia patients, with post-prandial pain, food fear, and weight loss, but often the symptomatology is a little more indolent in these patients. Because of this, these patients have frequently gotten the million dollar workup for nonspecific GI pain. The treatment of choice for suspected MALS is a laparoscopic median arcuate ligament release, frequently performed by a MIS/foregut surgeon. A key point here is that you don't want to be fooled into putting a stent in these patients before they've gotten their median arcuate ligament release, because the dynamic motion of the diaphragm is likely to crimp or bend the stent if that hasn't been treated yet. It may be that some patients benefit from endovascular treatment after release, though, as some think that the chronic damage from MALS can result in intimal damage/scarring that persists even after the extrinsic compression is treated by the median arcuate ligament release.

SMA Syndrome

What is SMA syndrome?

So SMA syndrome, also called Wilkie's Syndrome is a rare entity where the 3rd portion of the duodenum gets compressed between the SMA and the aorta, causing a functional gastric outlet obstruction. Patients are typically emaciated, having lost a significant amount of weight before their symptom onset. What's happened is they've lost the fat pat that normally surrounds the SMA, and so the angle between the SMA and the aorta becomes more acute, pinching off the duodenum. The treatment of choice here is enteral feeding with a nasojejunal tube or other surgically placed tube, because what really will help them here is weight gain. It's not really a mesenteric vascular disease, but it sometimes shows up on exams as a related entity.

Renal

29 Jun 2020: *Dr. Cullen McCarthy and Dr. Matthew Edwards; Wake Forest*

Pathophysiology

What is renovascular hypertension?

Hypertension as a result of progressive renal artery stenosis

- While renal artery stenosis is a relatively common finding in older patients with hypertension, it's relatively uncommon as the primary cause of hypertension.

What is ischemic nephropathy?

Decreased renal function and/or chronic kidney disease that results from atherosclerotic renal artery stenosis due to a reduction in glomerular filtration rate (GFR) and rise in creatine produced by any cause of diminished renal blood flow that threatens

Who is at risk for ischemic nephropathy?

Renal injury can develop in anyone with a kidney or kidney region beyond a critically stenotic artery

- Now, this is usually in patients with atherosclerotic disease, but any flow limiting lesion—such as coarctation of the aorta, mid-aortic syndrome, or fibromuscular dyplasia– can cause ischemic neuropathy OR renovascular hypertension.
- In terms of clinical practice, the prevalence of renovascular hypertension is probably less than 1 % in patients with mild hypertension but may be as high as 10 to 40 % in patients with acute (even if superimposed on a preexisting elevation in blood pressure), severe, or refractory hypertension.

That's the best you can do, 10-40%? That's a big window.

Yes, and it illustrates the biggest issue we have with renovascular disease. We know 5-22 % of patients 50 years or older who have advanced CKD have some

degree of renal artery stenosis and 23 to 54% of these patients have bilateral renal artery disease.

- Bilateral renal arterial stenosis is associated with more widespread atherosclerotic disease, higher serum creatinine levels, and higher mortality than unilateral disease
- Renal artery revascularization among patients in these studies infrequently produced a meaningful recovery of kidney function, which would have supported the diagnosis

So not everyone with flow limitations to their renal vascular will get renovascular hypertension or ischemic nephropathy?

Not at all, actually. Flow limiting lesions may be an "incidental" finding in patients who have CKD or hypertension that is caused by a separate disorder (eg, diabetic nephropathy and essential/primary hypertension).

- Because of this, it can be very difficult to distinguish between patient whose disease is induced by renal artery stenosis and those who have alternative causes of CKD or renovascular hypertension.

So you're telling me that we have no idea who has clinically significant disease and who doesn't?

No. Fortunately there are clinical findings that suggest that renovascular disease is an underlying cause:

- Recent or rapid development of severe hypertension.
  - Relatively specific for renovascular hypertension and is the strongest predictor of antihypertensive benefit from revascularization.
- Severe hypertension that may be treatment resistant.
  - Some patients with ischemic nephropathy are normotensive, which may be due in part to a reduced cardiac output
- Acute rise in serum creatinine following the administration of angiotensin-converting enzyme (ACE) inhibitors or angiotensin receptor blockers (ARBs).
  - Rise in serum creatinine is more common with agents that block the renin-angiotensin system than with other antihypertensive drugs because glomerular filtration rate (GFR) often depends upon the efferent arteriolar actions of angiotensin II in this setting.
  - More common with bilateral as compared with unilateral disease because there is hemodynamic compromise to the entire renal functional mass
  - This usually resolves after withdrawal of the drug.

  - Restoring the renal blood supply in such cases can recover the ability to use these drugs for blood pressure control.

- Significant variability of serum creatinine concentration that may be due to changes in volume status

- A rapid rise in arterial pressure associated with sudden development of left ventricular failure ("flash pulmonary edema").

  - This finding is more common with renal artery stenosis because bilateral disease is also associated with diuretic resistance and sympathetic adrenergic activation

- Deterioration of kidney function after placement of an endovascular aortic stent graft– IATROGENIC

So it matters which kidney is affected or if it's one or both?

Yes, effect of the stenosis may not be clinically apparent due to compensatory function of the unaffected contralateral kidney

- Most cases of renal artery stenosis affect one side much more than the other; one kidney is affected with the second kidney being essentially normal, hence the designation "unilateral" disease.

- Patients who are diagnosed with ischemic nephropathy usually have high-grade stenosis of both renal arteries or stenosis to a solitary functioning kidney.

  - It is this subpopulation of the disease that merits specific consideration because of its additional contribution to fluid retention, loss of kidney function, and congestive heart failure.

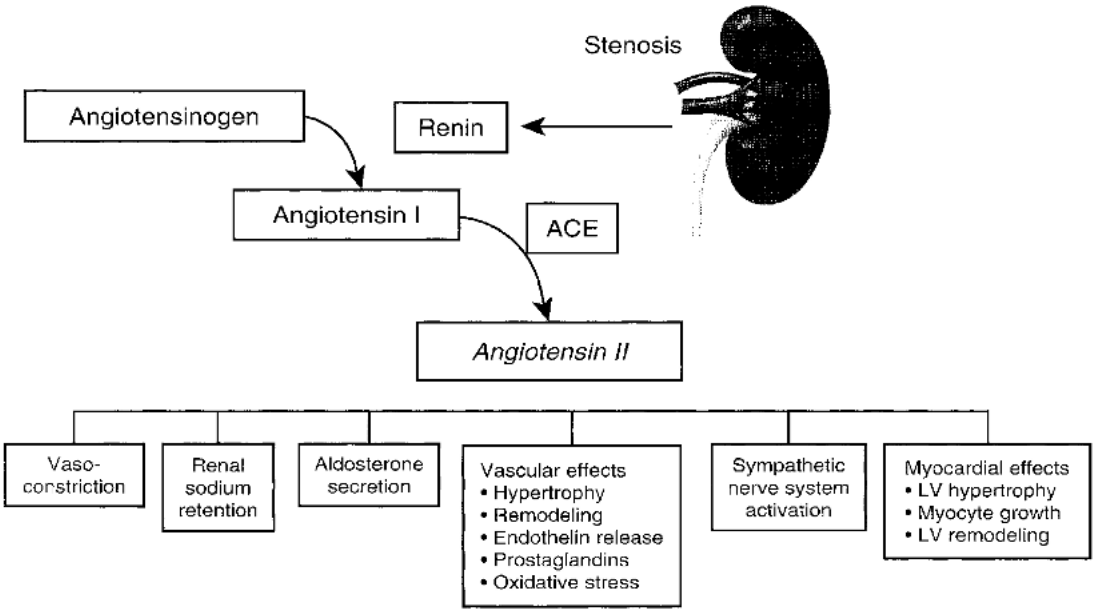
What are the pathophysiological mechanisms at play here?

Like we said, first you need a flow limitation. We mentioned several, but by in large There are two major causes of renal artery stenosis:

1. Atherosclerosis – you'll generally see this in patients over 45 years old, likely with known PVD/CAD—though it can occur as an isolated renal lesion—usually involving the aortic orifice or the proximal main renal artery.

2. Fibromuscular dysplasia – These patients are most often women under the age of 50 years and typically involves the mid- or distal main renal artery or the intrarenal branches.

   - Rarely iatrogenic from malposition or migration of endovascular aortic stent grafts over the renal orifices.



I think the flow limitation part has been well established. What next?

Renal (especially bilateral) hypoperfusion induces activation of the renin-angiotensin-aldosterone system which increases vascular tone and impairs sodium excretion resulting in expansion of the extracellular fluid volume.

Medical Management and Evaluation

Can't we just treat their hypertension and give these patients an ACE inhibitor at this point?

Sure. And oftentimes we do. In fact, many of these patients can be treated with medical therapy without loss of function or irreversible fibrosis, sometimes for many years

- Studies in human subjects demonstrate that, despite a moderate reduction in renal perfusion pressure (up to 40 %) and in renal blood flow (mean 30 %), glomerular filtration is reduced but tissue oxygenation within the kidney cortex and medulla can adapt without the development of severe

hypoxia.

- But this only works to an extent.

Explain that...

As the hypertension is treated, we're lowering the pressure gradient across the stenosis and can actually increase the degree of renal malperfusion and worsen the renal function.

- Oftentimes this loss of kidney function is a reversible consequence of antihypertensive therapy but it to some degree limits our ability to control the hypertension medically without causing further damage to the kidneys.... And it can also reflect progressive narrowing of the renal arteries and/or progressive intrinsic kidney disease as more advanced vascular occlusion, corresponding to a 70 to 80% narrowing of the renal artery, leads to demonstrable cortical hypoxia.

Can we tell who has cortical hypoxia through diagnostic tests?

A: To some degree. Cortical perfusion can be measured by blood oxygen level dependent magnetic resonance (BOLD-MR). Additionally, inflammatory markers sampled from renal veins of stenotic kidneys correlated strongly with the degree of hypoxia (as measured by BOLD-MR), particularly after correction of the stenosis with angioplasty

So we have a patient with evidence of malperfused kidneys, either through worsening renal function or uncontrolled hypertension, with known discrete stenoses, and we even got a BOLD-MRI which confirms it. Let's just revascularize them and be done with it?

Not so fast. Although vascular stenosis or occlusion can initiate these processes, long-standing ischemia causes parenchymal injury characterized by inflammation and fibrosis which eventually becomes an irreversible process. At some point, restoring renal blood flow provides no recovery of kidney function or clinical benefit.

So how can we determine who has CKD or hypertension due to renovascular stenosis that we can actually help?

This is probably the most important question since in this whole disease process.

- To start, if a patient has the clinical manifestations of ischemic nephropathy or renovascular hypertension as we discussed above, a presumptive diagnosis of ischemic nephropathy can be made if there is radiologic documentation of significant stenosis (usually more than 70 % luminal occlusion) of both renal arteries or of one renal artery to a solitary functioning kidney.

But how do we know the vascular occlusive disease posing critical hemodynamic limitation to kidney function?

- Generally, luminal occlusion of at least 60 to 75 % is required to limit blood flow and reduce perfusion pressure
- This degree of stenosis is usually associated with a measurable translesional "pull-back" pressure gradient of 10 to 15 mmHg.
- Doppler ultrasound criteria conventionally require peak systolic velocities above 180 to 200 cm/sec to identify more than 60 % luminal stenoses but identifiable levels of cortical hypoxia (measured by blood oxygen level dependent magnetic resonance BOLD-MR) are usually associated with translesional velocities above 385 cm/sec or reduction of single kidney glomerular filtration rate (GFR) in the range of 20 to 25 mL/min.

Most importantly: is the condition of the kidneys such that restoring renal blood flow is likely to benefit function?

Short answer, we still can't be certain.

Long answer, we can at least have some idea by considering the renal resistive index, the six-month trajectory of kidney function, and the size of the kidneys or by performing a kidney biopsy (which is not usually done).

- None of these factors predict the outcome of revascularization with certainty.
- Improved and validated methods to evaluate the salvageability of kidney function in this disorder

Let's go through some of these:

Renal Resistive index:

Some studies indicate that elevated resistive indices in segmental vessels (above 0.80) measured by duplex ultrasound denote poor prognosis for renal recovery while a low resistive index is a favorable sign.

Trajectory of kidney function

The most consistent predictor of good recovery of kidney function after revascularization has been a recent deterioration of kidney function (ie, in the prior six to twelve months).

Kidney size

Very small kidneys (less than 7 cm in longest diameter) are usually considered unlikely to recover after revascularization.

Kidney biopsy

Previous studies suggest that biopsy demonstrating preexisting atheroembolic changes and interstitial fibrosis indicate a limited potential for recovery.

- Biopsies are not usually performed.

Comparison of kidney morphology with kidney function

Some investigators have recommended assessing morphologic parameters, such as renal parenchymal volume and cortical thickness with MRI, and comparing these parameters with kidney function measured by radionuclide scanning

- In a stenotic kidney, apparently normal morphology combined with reduced function may indicate a "hibernating kidney" that could be salvaged with revascularization.

So how do we get a definitive diagnosis?

A definitive diagnosis is not usually made before revascularization. In practice, confirmation of the diagnosis is based upon stabilization or improvement of the GFR after successful revascularization.

Operative Managment

Now we think our patient's renal artery stenosis maybe is causing hypertension or decline in renal function and we can possibly reverse it... how do we treat it?

For starters, all of these patients should receive medical therapy to control their hypertension in addition to routine CKD care and surveillance. They need to be aggressively treated for secondary prevention of cardiovascular morbidity with aspirin, statins, cessation of smoking, and, in patients with diabetes, glycemic control.

Second, once diagnosis has been made we have 2 therapeutic alternatives... Which are?

First, medical therapy alone- this generally involves ACE-I or ARB and as we discussed.

Hemodynamically mediated acute kidney injury is the major limitation of ACE inhibitors and ARBs in patients with bilateral renal artery stenosis as lowering the systemic blood pressure is more likely to reduce the renal perfusion and thus the intraglomerular pressure below the limits of renal autoregulation... in turn lowering the GFR.

Okay, in other words we can have chronic normalization of the systemic pressure that might eventually lead to ischemic atrophy due to the reduced renal perfusion pressure distal to the stenosis? Any other concerns with medical management alone?

- We're addressing or prevention progression of stenosis in those with atherosclerotic disease.

Since this isn't a vascular medicine podcast, what's our other option?

Procedural intervention (open or endovascular) along with medical therapy.

Now you're talking. Who should we fix operatively?

Some but not all patients should undergo revascularization, Patient selection single most important factor.

Depends upon the hemodynamic severity and likely recoverability of kidney function

You mentioned recoverability before, can you once again touch on what helps us determine recoverability?

- Recoverability indicators–
  - A short duration of blood pressure elevation prior to the diagnosis of renovascular disease, since this is the strongest clinical predictor of a fall in blood pressure after renal revascularization
  - Failure of optimal medical therapy to control the blood pressure
  - Intolerance to optimal medical therapy (eg, deterioration of renal function during antihypertensive drug therapy)
  - Recurrent flash pulmonary edema and/or refractory heart failure
  - Otherwise unexplained progressive renal insufficiency, particularly if proteinuria is absent

But do we have any good data proving our interventions help?

This is where things can get muddy.

Early on, observational studies demonstrated a high rate of procedural success with percutaneous transluminal renal angioplasty (PTRA) and stent placement (~85%) in patients with ostial atherosclerotic disease, as well as a high rate of clinical success measured by improvements in blood pressure and kidney function in 50 to 75 % of subjects.

Anything better than observational studies?

Unfortunately, randomized trials showed no additional benefit from stenting when added to medical therapy with respect to blood pressure control, renal function, cardiovascular events, and mortality. But these studies have their own limitations.

The one we keep hearing about is the CORAL trial. Tell me about that.

- CORAL trial[118]
  - Cardiovascular Outcomes in Renal Atherosclerotic Lesions (CORAL) trial
  - 947 patients (80 % had unilateral disease) who met the following two criteria:
    * Unilateral or bilateral atherosclerotic renal artery stenosis >60 % if diagnosed with conventional angiography, peak systolic velocity

>300 cm/second if diagnosed by duplex Doppler ultrasonography, Luminal narrowing >80 % if diagnosed with magnetic resonance angiography or computerized tomography angiography (or >70 % with additional evidence of renal ischemia)

    - Systolic hypertension despite two or more antihypertensive medications and/or an estimated glomerular filtration rate (eGFR) <60 mL/min/1.73 m2 that was presumably due to the stenosis.
    - All patients received antiplatelet therapy plus best medical therapy including ARB
  - Revascularization had no additional effect on the primary outcome (a composite of cardiovascular or renal death, stroke, myocardial infarction, hospitalization for heart failure, a reduction in eGFR by more than 30 %, or end-stage renal disease) as compared with medical therapy alone (35.1 versus 35.8 %).
  - No effect on any of the individual components of the primary outcome.
  - Low procedural complication rate ~2%

Well, that sounds pretty convincing.

- Limitations on existing treatment data:
  - Considerable selection bias – For the most part, the patients enrolled in these trials did **not** meet the criteria for selecting patients likely to benefit from intervention (eg, short duration of blood pressure elevation, hypertension resistant to medical therapy, recurrent flash pulmonary edema):
    - CORAL[118]
      - Patients hospitalized for heart failure within 30 days of screening for the trial were excluded, thereby limiting the number of trial participants with recurrent flash pulmonary edema.
      - Mean number of antihypertensive medications used by CORAL participants at baseline was 2.1- many had not failed optimal medical therapy
      - More than 25 % had controlled blood pressure upon entry into the trial.
      - Mortality and event rates lower than in most previous registries, suggesting that many high-risk patients were not enrolled.
    - ASTRAL[119]
      - Large number of patients had stenoses that were probably not clinically significant (50 to 70 %), and patients were excluded

if their primary doctors felt that they "definitely" needed revascularization.

- Results of the trials differ substantially from observational reports of "high-risk" subsets
  - For the most part, patients selected by their treating clinicians to undergo revascularization have derived greater benefit from revascularization than did patients enrolled in the trials who were randomly assigned to revascularization

Endovascular Therapy

We've determined our patient is an appropriate candidate for intervention, and we don't fully buy into CORAL, what can we do?

- Percutaneous renal angioplasty/stentingin addition to medical therapy
  - Most commonly employed if technically feasible.
  - Most amenable lesions to angioplasty are those producing incomplete occlusion in the main renal artery.
    - Total occlusions and ostial lesions extending into aorta generally do not respond well to angioplasty alone due to elastic recoil.
  - Quick results: maximum antihypertensive response is generally observed at 48 hours after the procedure
    - But BP levels and antihypertensive drug requirements often change over subsequent weeks
  - In general, the effects of revascularization on blood pressure were greater in bilateral disease, but effects on renal function and mortality did not differ in those with bilateral as compared with unilateral stenosis .
  - Most atherosclerotic lesions are now treated with primary stenting to avoid rapid development of restenosis.
    - A higher initial primary success rate, defined as less than 50 % stenosis (88 versus 57 %).
    - At six months, a higher patency rate (75 versus 29 %) and a lower restenosis rate (14 versus 48 %).
    - Twelve patients assigned to PTRA alone underwent stenting because of treatment failure within six months. These patients had a similar blood pressure response as those initially treated with stenting.

What about complications?

- Complication rate with percutaneous transluminal renal angioplasty with or without stenting is between 5 and 15 %
  - Mostly minor: puncture site hematoma and renal artery dissection.
  - Serious complications more rare: renal artery thrombosis or perforation, AKI 2/2 atheroembolic disease (~1%)or radiocontrast agent injury.
  - Mortality exceedingly rare

Outcomes data

- In the correct patient population:
  - Unilateral disease
    - PTRA alone results in normalization of blood pressure (removal of antihypertensive drug therapy) ~8-20%
    - Some improvement 50-60%
    - Failure rate ~20-30%
    - Restenosis rate of 8 to 30 % at two years (without stent)
    - Better results with unilateral fibromuscular disease.
    - Less consistent for patients with chronic hypertension compared with patients who have an acute elevation in blood pressure
  - Bilateral disease
    - 25-30% will recover kidney function to a meaningful degree, sometimes avoiding progression to end-stage kidney disease (ESKD) and/or the need for renal replacement therapy.
    - ~50% will have little immediate change in kidney function but will "stabilize"
    - ~20% will have a progressive deterioration of kidney function, sometimes related to the procedure

Guidelines

- 2005 ACC/AHA guidelines on peripheral artery disease recommends that a stent be placed in patients undergoing PTRA for treatment of atherosclerotic renal artery stenosis[120]
  - PTRA without stent placement is rarely performed unless the anatomy precludes stenting.
  - POBA without stenting is generally less successful and associated with more complications (eg atheroemboli)

How durable is PTA/stenting?

- Restenosis
  - ~11-17%
    - 11-39% during the first one to two years
  - Detected as a rise in blood pressure requiring more intensive therapy
  - Angioplasty/stenting injures the vascular endothelium, which may result in restenosis.
  - Symptomatic stenosis leading to a rise in blood pressure or a fall in GFR are less common and are reported in 10 to 20 % of patients

How do you follow these patients after stenting?

- Follow-up of patients who have had a renal artery stent should include serial measurements of blood pressure and estimation of GFR.
  - Post-stent duplex ultrasound @2-4weeks with
  - Repeated examinations on a quarterly basis (not much data)
  - Patients who develop an increase in pressure or reduced GFR after stenting should undergo duplex ultrasonography to identify restenosis
  - Retreatment with angioplasty with or without repeat stenting can be attempted, but the restenosis rate after repeat angioplasty is increased.
    - Surgical reconstruction may be pursued in patients with recurrent episodes of restenosis and loss of kidney function.

Open Surgery

What about an open operation?

- Surgical revascularization used in addition to medical therapy
  - Less common since the widespread application of effective antihypertensive drug therapy and endovascular stents (mid 90s)

So who still gets open repair?

- Primarily for correction of complex vascular lesions and/or repeated episodes of in-stent restenosis

How do we do it?

- Involves bypassing the stenotic segment or of removing a small atrophic kidney with nearly complete arterial occlusion.
  - From the aorta or hepatorenal or splenorenal bypass to avoid diseased aorta.

  - Bilateral: either bilateral repair or unilateral repair with contralateral nephrectomy of a nonfunctioning, atrophic kidney.

How do outcomes compare to PTA/stenting?

- Equally or more effective than PTRA in the treatment of atherosclerotic disease, with cure of or improvement in the hypertension occurring in 80 to 95 % of patients.
  - Cure of hypertension after surgery is most likely in patients who have been hypertensive for less than five years
- Lack of complete response was usually associated with one of two factors:
  - Presence of underlying primary/essential hypertension
  - Development of intrarenal vascular disease due to exposure of the contralateral kidney to the elevated blood pressure.

Guidelines recommendations?

- 2005 American College of Cardiology/American Heart Association (ACC/AHA) guidelines[120]
  - Open surgery in patients with atherosclerotic renal artery stenosis largely restricted to those who have multiple small renal arteries, have early primary branching of the main renal artery, require aortic reconstruction near the renal arteries for other indications (eg, aneurysm repair or severe aortoiliac occlusive disease), or to avoid manipulation of a highly diseased aorta or failed endovascular stents (using specific surgical techniques, including splenorenal, ileorenal, or hepatorenal bypass procedures).

So why not do it instead of stent?

- In-hospital mortality: ~3-10 % in high volume centers
  - Risk factors diffuse atherosclerosis, advanced age, chronic kidney disease, heart failure, or chronic lung disease.
  - No deaths in 105 procedures for fibromuscular dysplasia (FMD).

Fibromuscular Dysplasia (FMD)

You mentioned FMD as a cause of renovascular hypertension, tell me more about that...

Fibromuscular dysplasia (FMD) is a noninflammatory, nonatherosclerotic disorder that leads to arterial stenosis, occlusion, aneurysm, dissection, and arterial tortuosity.

- Virtually always diagnosed radiographically – formerly pathologically, but rarely sent for specimen in modern diagnosis or treatment

How do we classify it?

- Most commonly classified by angiographic appearance:
  - Multifocal FMD (more common)
    - angiographic appearance of a "string of beads."
    - corresponds pathologically to medial fibroplasia, the most common histologic type, and to perimedial fibroplasia, which is less common.
  - Focal FMD (less common)
    - angiographic appearance of a "circumferential or tubular stenosis"
    - corresponds pathologically to intimal fibroplasia but medial hyperplasia and periarterial hyperplasia may also have a focal appearance.
  - These two different angiographic subtypes of FMD (multifocal and focal) have different phenotypic presentations and natural history
    - Is FMD is, in fact, a single disease?

Where does it occur?

- Has been observed in nearly every arterial bed
- Involvement of the renal arteries ~75-80%
- Involvement of the extracranial cerebrovascular arteries (eg, carotid and vertebral arteries) ~75%
  - 2/3 of patients have multiple arteries involved.

Who has FMD?

- ~90% of cases in adults are in women.
  - No female predominance among children with FMD.
- Mean age at diagnosis was 52 years, with a range of 5 to 86 years
  - In the past, it was believed that FMD was a disease of young women. However, older now know to make up a large proportion of affected
- 35-50% of cases in children and 5-10% of cases in adults under the age of 60 years with renovascular hypertension
- Often an incidental finding:
  - 4.4% of potential kidney donors had evidence of FMD.
  - CORAL trial:

    * FMD was discovered in 5.7% of the total study population (8.8% of enrolled females)

What causes FMD?

The etiology of FMD remains unknown, but some mechanisms have been proposed

- Genetics may play an important role in development
  - Some studies report autosomal mode of inheritance with variable penetrance
  - Potential association with a single nucleotide variant in the phosphatase and actin regulator 1 gene (PHACTR1)
  - Variant rs9349379 is also a risk locus for coronary artery disease, migraine headache, and cervical artery dissection.
- Predominance of young/childbearing age women hormonal influences are thought to play a role
  - Remains unproven.
- Mechanical factors such as stretch and trauma unproven.

Does FMD present differently that the atherosclerotic renovascular disease we talked about?

- Varies widely depending on artery affected and as it results from:
- Ischemia related to stenosis
- Dissection and occlusion of major arteries (renal infarction, stroke, myocardial infarction)
- Rupture of aneurysms
- Embolization of intravascular thrombi from dissection or aneurysms

What are the common presenting symptoms and signs

- Manifestations of renal FMD (eg, hypertension, flank pain) are more likely to occur in men, as are arterial dissections and aneurysms.
  - Most common presenting signs:
  - Hypertension – 67% (66% of women and 74 % of men)
- But overall hypertension is the most common manifestation of renal artery FMD in both genders
  - Flank pain and abdominal pain can result from ischemia, aneurysm rupture, or dissection of renal and mesenteric arteries, respectively.

Are these dissections common?

- High prevalence of aneurysm and/or dissection

  - Aneurysm (22%) and dissection (26%).
    * 34% of aneurysms were renal
    * 11% of dissections were renal
  - 42% had an aneurysm and/or dissection.

So should we screen for these dissections in a patient with known FMD?

- Every patient diagnosed with FMD should have one-time, head-to-pelvic CTA (or MRA) is an alternative.
  - CTA of the neck and head on one day followed one week later by CTA of the chest, abdomen, and pelvis

When should we suspect FMD?

- Hypertension (particularly in a woman under the age of 60 years) with findings that would prompt an evaluation for secondary hypertension:
  - Severe or resistant hypertension.
  - Onset of hypertension before the age of 35 years.
  - A sudden rise in blood pressure over a previously stable baseline.
  - A significant increase in the serum creatinine concentration after the institution of therapy with an angiotensin-converting enzyme (ACE) inhibitor or angiotensin receptor blocker (ARB) in the absence of an excessive reduction in blood pressure.
  - An epigastric/abdominal bruit.
- Renal artery dissection (or carotid, vertebral, coronary)
- Aneurysm in a visceral, carotid, vertebral, or intracranial vessel.
- Renal infarction.

How do we diagnose this and/or distinguish it from renovascular atherosclerotic disease?

- Confirmed by diagnostic imaging that reveals consistent findings
- Noninvasive imaging test is usually performed first. This includes CTA, MRA, and Duplex ultrasound.

Let talk about CTA...

- CTA is preferable due to higher spatial resolution than MRA, less dependence upon technical expertise, and a shorter scan time
- Excellent diagnostic accuracy for FMD of the main renal arteries, although the sensitivity decreases when FMD is only present in the smaller branch renal arteries.

- Multirow detector CT scanners, which offer more rapid image acquisition, variable section thickness, three-dimensional rendering, diminished helical artifacts, and smaller contrast requirements, may gain an increased role in the diagnosis and follow-up of renal artery FMD

What about MRA?

- Inconsistent detection of FMD and is performed if CTA is contraindicated
- The spatial resolution in the branch vessels is not adequate, and artifact may occur, suggesting "beading" when none is present.
- May miss mild FMD.
- Can be useful for detecting aneurysms and dissections

And finally, Duplex ultrasonography

- Detects elevated blood flow velocities in the mid and distal portions of the renal artery, most common locations for FMD.
- Increased peak systolic velocity, turbulent blood flow, and tortuosity of the mid and distal artery.
  - % diameter stenosis reports less helpful and usually inaccurate
- lowest spatial resolution of all of the cross-sectional imaging modalities
- most operator dependence
- first choice only in high-volume centers with extensive expertise in this technique

What about non invasive testing?

- DSA is performed in patients if there is a high clinical suspicion of FMD, and treatment with revascularization is planned if a stenosis is found.
  - Can improve visualization of the arteries by eliminating background soft tissue and bone and has higher spatial resolution than any of the other imaging modalities
  - Can measure the pressure gradient across the stenosis
    - Pressure decrease threshold of 10 % or more of the mean pressure should be used to decide whether a lesion is hemodynamically significant
    - IVUS and optical coherence tomography (OCT) can be helpful in determining if a dissection or intramural hematoma is present as well as help to determine if angioplasty has improved the stenosis.
  - Negative DSA excludes a diagnosis of FMD in the vascular bed that was imaged.

Any place for pathologic diagnosis in modern therapy?

- Histopathology (and histologic classification) is **no longer** part of the diagnosis.
  - Only in the rare patient who requires surgical revascularization or resection of an aneurysm.

So how do we treat this, what warrants intervention and are those interventions different than what we offer atherosclerotic disease of the renal arteries?

- All patients with FMD should be placed on antiplatelet therapy (ASA) unless otherwise contraindicated
- Antihypertensive therapy
  - Most patients will require antihypertensive therapy, even if they undergo revascularization.
  - Majority of patients with **focal** FMD have their blood pressure cured with angoplasty

But what about revascularization?

- Revascularization Goal: control of hypertension
  - BP can be controlled in most adults with multifocal FMD with a mean of two antihypertensive medications
  - Weigh risks and benefits in well controlled hypertension.
- **No** randomized trials comparing revascularization with medical therapy

Well then who do we treat?

- Recent-onset hypertension, with goal to cure hypertension.
- Resistant hypertension despite compliance with an appropriate three-drug regimen.
- Patients unable to tolerate antihypertensive medications or who are non-compliant with their medication regimen.
- Adults with bilateral renal FMD, or unilateral renal FMD to a single functioning kidney, and unexplained progressive renal insufficiency thought to result from renal artery stenosis
- Hypertensive children.
- may be at higher risk than adults for progressive renal parenchymal loss, and therefore could benefit from revascularization even if their hypertension can be well-controlled with one or two antihypertensive medications.

And what kind of results do we get with revascularization?

- Hypertension is cured or improved following revascularization in a large proportion of patients with FMD.

  - Much better than 2/2 atherosclerosis
  - Varies considerably from study to study, although hypertension control improves in most patients and depends in large part upon the definition of cure.
  - Not good data on stabilization of either GFR or renal size in patients with FMD.

What options do we have in terms of revascularization?

Angioplasty and open surgery

Do we have good results treating FMD with these?

- Improvement in blood pressure (including those with and without cure) was similar with PTA as compared with surgery (86 versus 88 %).
- Older age and longer duration of hypertension prior to revascularization were significantly associated with a lower cure rate.

How do these compare?

- PTA achieves similar technical success and is associated with a lower risk of adverse events in observational studies
- Most patients with FMD who are selected for renal revascularization have PTA rather than surgery
- Major adverse events were more frequent with surgery (15 versus 6 %).

So why choose open surgery?

- Cure rates were higher with surgery (54 versus 36 %).
- Surgery rather than PTA if PTA fails or if the arterial anatomy is not amenable to PTA
  - Patients with small renal arteries (<4 mm), with branch renal artery disease, or with extensive intimal fibroplasia.

So how do we perform Percutaneous transluminal angioplasty for FMD?

- Without stent placement... unlike PTA for atherosclerotic RAS

Why not place a stent?

- Patients do very well with angioplasty alone, no reason to place a stent.
  - Lesion is so fibrotic that the pressure gradient cannot be obliterated with an angioplasty, a stent will not correct this problem
    - Such patients should be referred for surgery.
- Usually have stenoses in the mid and distal portions of the artery rather than at the ostium or proximal portion (as occurs with atherosclerosis).

  - Should surgical revascularization become necessary due, for example, to in-stent restenosis, patients may require more complex branch repair to bypass the occluded stent since the stent often covers the renal artery up to the point of the first intrarenal branch.

Do we ever place stents?

- Stents placed when a dissection results from the performance of PTA or in the rare instance in which a perforation of the renal artery occurs during angioplasty.

And we're getting good outcomes with PTA alone?

- Technical (angiographic) success rates for PTA 83-100
- Rate of restenosis 12-34% over follow-up intervals of six months to two years
  - Difficult to determine if patients with FMD develop restenosis, or if the lesion was not completely treated correctly the first time.
  - Not necessarily associated with recurrent hypertension.

But generally we can achieve significant and sustained reductions in systolic blood pressure, diastolic blood pressure, serum creatinine, and number of antihypertensive agents.

- Systolic blood pressure response was better in patients with FMD affecting the main renal artery than in patients with branch vessel involvement.

Any specific technical tips?

- Cutting balloon angioplasty should be avoided
  - Increased risk of rupture
- Post angioplasty visual inspection alone is **not** accurate.
  - Measure pressure differential using a pressure guidewire, with a mean gradient of <5 mmHg across the treated segment suggesting a satisfactory result
    * Measure before and after angioplasty
  - Post-procedure renal duplex scanning
    * Degree of turbulence is less prominent, and velocity elevation in the mid-distal renal artery returns to normal.
  - Intravascular ultrasound or optical coherence tomography (OCT) is occasionally used to evaluate the elimination or reduction of various endoluminal defects.

What should we do if it doesn't work?

- If either has no improvement in blood pressure or an initial improvement followed by recurrence, repeat angiogram and PTA.
  - Restenosis may actually represent inadequate angioplasty during the first procedure
- Persistent HTN despite technically successful PTA suggests that the cause of hypertension is unrelated to fibromuscular disease or is related to small vessel disease within the kidney (nephrosclerosis) due to longstanding hypertension.

What kind of complications do we see after this?

- Mostly related to vascular access
- Rarely: renal artery perforation, dissection, or segmental renal infarction may occur.
- Decreasing over time- 16 % in 1998 to 3 % in 2001

Ok, lets switch gears to open revascularization?

- Aortorenal bypass with a saphenous vein graft is the most common technique
  - Artificial graft material used occasionally

For everyone? What about for pediatric patients?

- Pediatric patients: hypogastric artery grafts are used or else aortic reimplantation of the renal artery is performed because vein grafts become aneurysmal

How does this compare again to PTA?

- Similar success rates compared to PTA (82-89% patency) but with higher morbidity.
  - Perioperative mortality appears to be very low (~1.2%)
  - Usually limited to complex cases so success and complication would probably be higher if simpler cases were included.

What's Monitoring and follow-up look like for these patients?

- Medical management only:
  - Renal artery stenosis and kidney dysfunction may progress despite good blood pressure control
    - Mostly in patients with focal FMD and intimal fibroplasia
  - Every patient with FMD should have measurement of serum creatinine and renal artery duplex ultrasound every 12 months.

And After revascularization?

- Duplex ultrasonography and serum creatinine measurements performed on the first office visit post procedure, then every six months for two years, and then yearly, if stable.
- With worsening on new hypertension, or unexplained increase in the serum creatinine, he or she should be imaged at that time with duplex ultrasound (or CTA if the ultrasound is equivocal or poor quality).

Renal Artery Aneurysms

Ok, that's a pretty good review, but let's switch gears and talk about renal artery aneurysms

- Renal artery aneurysms are rare.
  - Autopsy studies have revealed an incidence of 0.01% to 0.09%.
  - Renal artery aneurysms are bilateral in about 10% of cases with more than 90% of true renal artery aneurysms being extraparenchymal.
- Females > males
  - Females and males equal with FMD excluded
- Most frequent site of involvement is primary bifurcation, intraparenchymal (<10%)
- Most are saccular
- Right slightly more common than left, bilateral 10%
- Size criteria currently controversial*
  - 2.5 common criteria for visceral arterial intervention, but paucity of data suggesting rupture risk drastically increases at this size
  - Many aneurysms with circumferential calcification which could offer protection against rupture
- The majority of renal artery aneurysms are asymptomatic, and less than 3% rupture.
  - Present with flank pain, hypotension
  - 10% mortality
  - 90% risk of kidney loss
- Although arteriosclerotic changes have been identified in most aneurysms in patients with multiple lesions, this is not a uniform finding, suggesting that arteriosclerosis may not be the most important factor in the genesis of renal artery aneurysms.

- More likely due to a congenital medial degenerative process with weakness of the elastic lamina.
- Fibromuscular dysplasia (FMD) is often a direct contributor to the development of an aneurysm.
  - Medial fibroplasia is typically associated with multiple stenoses and post-stenotic dilatation of the distal two thirds of the renal artery.
  - Renal artery aneurysms in association with FMD are generally only a few millimeters in diameter.
  - The typical angiographic appearance of a renal artery involved with medial fibroplasia is a "string of beads."
- The majority of renal artery aneurysms are saccular.
- A rare cause of renal artery aneurysms is Ehlers-Danlos' syndrome.
  - This disorder is associated with extreme arterial fragility and spontaneous rupture.
- Renal artery dissection caused by guide wires or catheters can occur, but is rare.
- In an elderly patient, observation of this aneurysm with Duplex surveillance is the appropriate treatment.
- For larger aneurysms in younger patients, aneurysmorrhaphy with primary repair or patching can be performed with low mortality.
  - Endovascular techniques such as coiling have been reported to be successful in treating these saccular aneurysms; however, covered stent placement may be difficult in the distal renal artery near potential branch points of the artery.

Thoracic Aorta

Aortic Dissection

01 Nov 2021: *Matt Spreadbury, MD; Adham Elmously, MD; Einar Brevik, MD and Joseph Lombardi, MD*

What is an aortic dissection?

It's when a tear occurs in the intima that results in separation of layers of the intima and media and allows blood to flow through the false lumen.

How common are they and how serious are they?

Acute dissections occur around 3/100000 - 2-3x more common than ruptured aortic aneurysm. For Type A dissections, early mortality 1-2% per hour - if untreated, 20% die within 6 hours, 50% within 24 hours, 70% first week.

Main cause of death in type A is aortic rupture into the pericardium, acute aortic regurgitation, and coronary ostia compromise. While patients with descending thoracic aortic dissections are more likely to die from end organ compromise due to obstruction of visceral or extremity vessels in the acute phase of the disease.

The time frame is also important.

- Hyperacute <24 hours
- Acute < 2 weeks
- Subacute 2 weeks – 3 months -> TEVAR
- Chronic >3 months -> Chronic aneurysmal degeneration/ partial false lumen thrombosis (highest risk) = operative treatment

When we think about aortic dissections there are a few classifications, how can we break it down?

Historically, there are the Stanford and Debakey Criteria.

Anatomical Stanford

- Type A - involves the ascending aorta, 2/3 (most common)

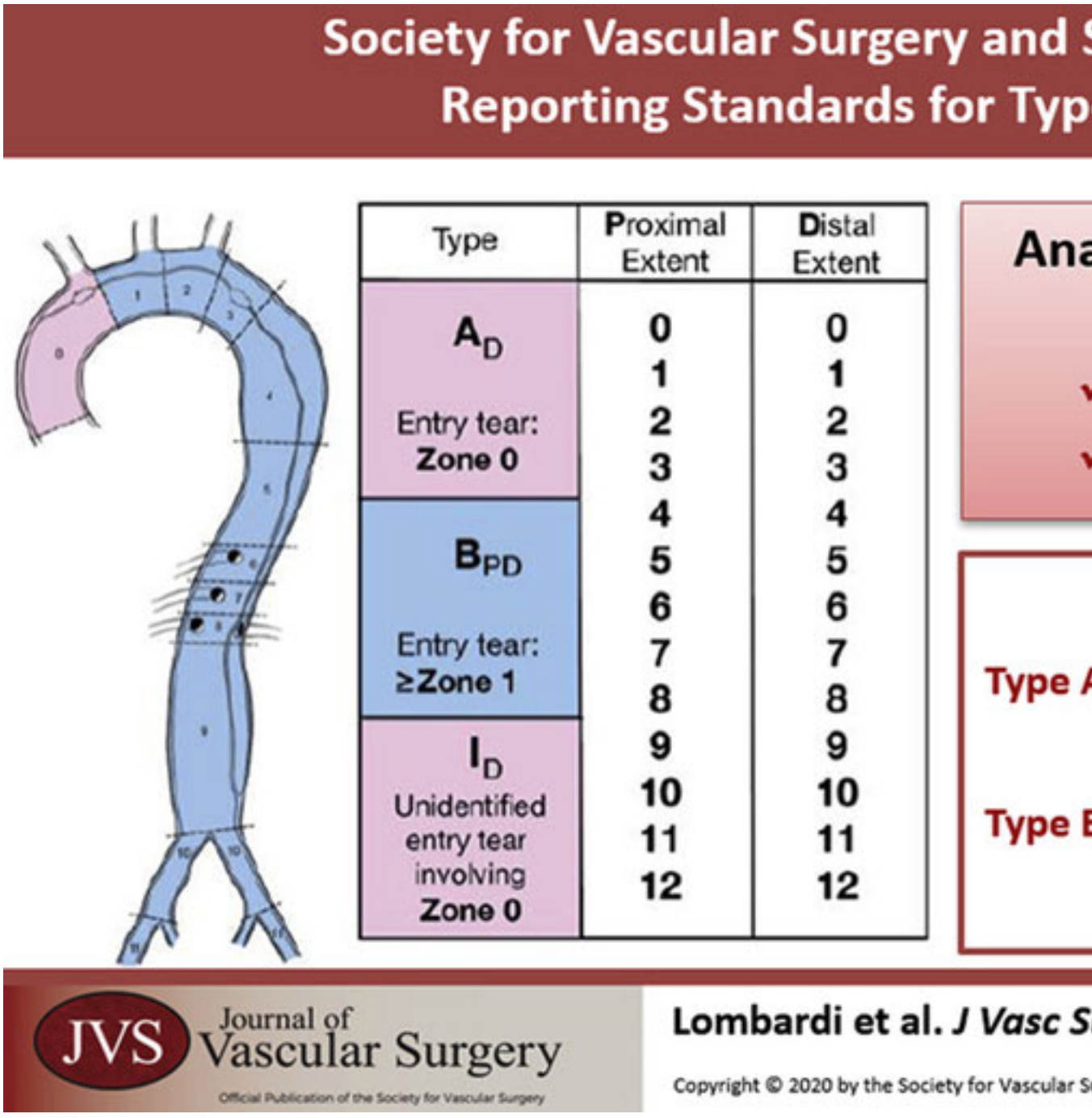
- Type B - arises from distal to L subclavian, 1/3

Debakey

- A
  - 1 - ascending + descending
  - 2 - ascending only
- B - distal or at the LSCA.
  - 3a - Descending aorta above diaphragm
  - 3b - Descending aorta above and below diaphragm

How about the new system proposed by Dr Lombardi, the SVS-STS classification system?

The new system published in 2020 keeps A and B and adds a number system which divides the aorta into zones from 0 proximaly to 12 distally in the mid SFA.[121]



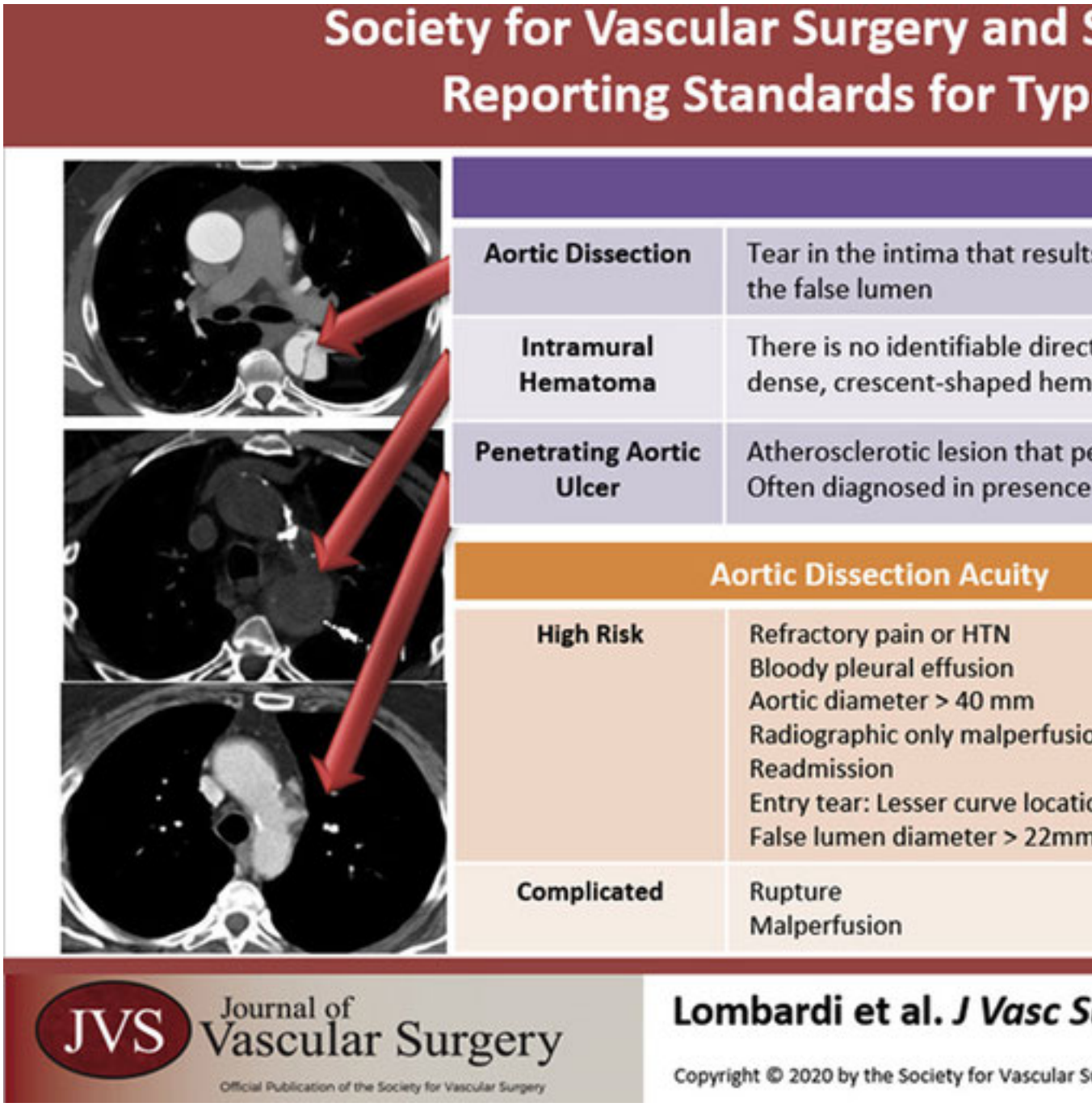
- Type A is now JUST the ascending aorta to the innominate, also called Zone 0.

- Type B is now an entry tear in Zone 1 or greater and distally to whichever zone the dissection lands in.

This anatomical classification is based on reading the CT angio. What else could we see on a CT angio that we have to know about?

So aside from the aortic dissection its self, you could see a bleb of contrast sticking out. That could be an penetrating aortic ulcer. That is an atherosclerotic lesion that penetrates the internal elastic lamina of the aortic wall.

Another key finding can be an intramural hematoma which is a hyperdense crescent shaped hemorrhage within the aortic wall. There is no identifiable direct communication between the true and false lumen. IMH are classified in the same way but with the abbreviation IMH p-d zones.



Whats the significance of these two in combination?

There is a higher chance of aortic rupture if a penetrating aortic ulcer is seen

with intramural hematoma.

When a patient presents with an aortic dissection how can we classify them clinically?

- Uncomplicated
  - Stable hemodynamics
  - No evidence of malperfusion
  - Pain controlled
- Complicated
  - End organ ischemia / malperfusjon
  - Rupture or impending rupture
- High risk
  - Uncontrollable pain / hypertension
  - Bloody pleural effusion
  - Aortic diameter >40mm / False lumen diameter > 22mm
  - Readmission
  - Radiographic only malperfusion
  - Entry tear on the lesser curve

What is the danger of a false lumen? How does it lead to symptoms and malperfusion? Likewise which arteries commonly branch off the true lumen?

The false lumen can lead to end organ ischemia as the intimal flap can cover the ostia of branching vessels. This can be a static or a dynamic obstruction.

Likewise it also leads to weakening in the wall of the aorta which can become a threatened rupture or rupture if the diameter of the false lumen is larger than 22mm.

The celiac trunk, SMA, right renal typicaly come of the true lumen. Left renal comes off the false.

Also the dissection most commonly goes down into the left common illiac rather than the right. You might be able to detect down stream effects of this on clinical exam with reduced left sided groin pulse.

What kind of patients get aortic dissections?

Hypertension (older patients) / cocaine or Meth (younger patients)

Marfans, loeys-Dietz, Ehlers danlos Type 4, Turners, Arteritis, Bicuspid aortic valve.

We also have a traumatic cause of aortic dissections. That being called blunt thoracic aortic injury:

- Grade 1: intima tear
- Grade 2: IMH
- Grade 3: Pseudo aneurysm
- Grade 4: Aortic rupture.

How do these patients present?

Signs and symptoms – Chest pain 90% tearing pain radiating between the shoulder blades.

Chest pain extending to the abdomen abdomen? Think mesenteric ischemia or aortic tear

Type A - Stroke 5-10%, Syncope 15%, tamponade, carotid dissection, paralysis.

Others: MI – Hypovolemic shock – leg ischemia

What is the workup?

Physical Exam – Asymmetric pulses / blood pressure differences / Diastolic murmur,

Investigations - CXR, EKG, D-dimer + Troponin, CTA, ECHO for type A.

The big distinction is to find out if this is a type A or type B because the treatment strategy is completely different.

- Type A need an emergent operation
- Type B starts with medical management, follow up CT angio +/- Trans esophageal echo in the OR. Reevaluate at 24 hours.

What are the details of Type A treatment?

Operative treatment. 30% op mortality. Cardiothoracics take the lead on this one. However vascular surgeons should be involved in the management of type A as after the repair, a type A can become a functional type B.

Type B is in the realm of vascular surgery. What is the first management step after we have diagnosed a type B dissection?

Invasive impulse therapy. That means redusing the force of transmitted impulse down the aorta. Blood pressure goals of 100-120mmHg. Hr $<$ 60bpm.

How would you achieve that?

Start with a beta-blocker (esmolol or labetalol) first then a vasodilator (nitroprusside). This is to stop the sympathetic surge after vasodialation that could increase pressure and thus tearing forces inside the aorta worsening the dissection.

Initial CT, 72 hours, 3 months x 4, q6 months x2, q12 month. (Descending thoracic aorta that dialates first.)

Why isnt open surgery indicated for type B dissections?

Open surgery is not recommended due to the high mortality 30% if < 48 hours. 18% if > 49 hours.

In the acute setting mortality can be up to 50% with a 20% paraplegia risk. Its been described as sowing tissue paper.

What is the management plan for a complicated Type B aortic dissection?

Start with invasive medical management and plan for TEVAR. The goal with TEVAR being to direct the blood flow into the true lumen and seal the entry tear. If there was a dynamic obstruction (flap occludes branching vessels.) Then TEVAR would reestablish the true lumen hence removing the dynamic obstruction. Endovascular fenestration can also equalise the pressure in the true and false lumen.[122]

For a static occlusion there could be a thrombus or stenosis in the branched vessel so a stent might be indicated.

What are the major risks of TEVAR in the management of Type B aortic dissections?

Retrograde type A (reported 2% in literature however it can be around 20% in some experiences), 5% paraplegia, and stent induced new entry.

Is there a role for TEVAR in uncomplicated type B dissections?

The INSTEAD and INSTEAD XL trials looked at uncomplicated Type B dissections. There was NO statistical difference at 2 years comparing OMT vs TEVAR but at 5 years there was good aortic remodelling and better long term survival in patients treated in the subacute stage.

Timing for TEVAR is a difficult choice. In chronic dissections the septum thickens leading to a potentially difficult TEVAR. Anecdotally TEVAR is best at 2w-3m.

Thoracoabdominal Aneurysms (TAAA)

02 Dec 2021: Mr. Mohamed Barkat, Mr. Nick Greaves, and Mr. Michael Jenkins

Resources

- Crawford Classification
- ESVS recommendation of management of Thoracic aortic pathologies
- Open Repair of Thoracoabdominal Aortic Aneurysm: Step-by-Step

- <https://www.circulationfoundation.org.uk>
- <https://www.bset.co.uk/>
- <https://www.vascularsociety.org.uk/>
- Yale Vascular Review Podcast Episode 1: Thoracoabdominal Aneurysms

Aortopathies

18 May 2020: *Dr. Anna Ohlsson and Dr Sherene Shalhub; University of Washington*

What are the common genetic aortopathies?

There are several well-known genetic disorders which account for genetic aortopathies. The most well-known are Marfan syndrome, Loeys-Dietz Syndrome, and Vascular Ehlers-Danlos Syndrome,

There are less commonly known ones such as Familial Thoracic Aortic Aneurysms and Dissections due to pathogenic variants smooth muscle cells genes such as *ACTA2*. There are others in which the causative gene is not known.

Why are they such a big deal?

These are cases in which the building blocks of the aortic wall are defective. What I mean by this, is that these patients have pathogenic variants in the genes that affect cell signaling or smooth muscle cell structure that lead to suboptimal composition of the aortic wall. These alterations ultimately lead to cystic medial necrosis in the aortic wall.

As such they are at more risk for aortic aneurysms and dissections that can lead to the premature death of the patient.

To put the frequency in perspective, Marfan syndrome occurs in 1:5000 of the population while Vascular Ehlers-Danlos syndrome (also known as VEDS) occur in 1:50000 of the population.

Let's dive into them then – what are the defining features of each and the high yield information?

The high yield information is being able to pair the genetic syndrome and phenotype with its associated genetic mutation. A useful exercise following this broadcast is to list the disorders in a table and write out their associated gene mutation, what protein defect or deficit occurs, the typical phenotype, and the common vascular pathology associated.

But before we dive in, I want you to keep in mind some of shared features. One is that the associated aneurysms and dissections tend to occur at younger ages and dissect at lower blood pressures than what we see with sporadic dissections (these are the dissections that are not familial or associated with a syndrome)

One is that these are inherited in an autosomal dominant matter but there can be variation in how the pathogenic variants are expressed among affected people and even within families. The other thing to remember, is that in roughly half of these cases, the affected patient is the first in their family to have a given pathogenic mutation. The flip side of this, is in half the cases, there is a family history of aortic aneurysms, dissections, and sudden death.

We will start with Marfan syndrome.

Marfan syndrome is caused by pathogenic variants in the *FBN1* gene (also known as fibrillin-1 gene). These variants lead to improper formation of the microfibrils that maintain elastin, a key component of the arterial wall.

These patients are prone to aneurysmal degeneration and dissections of the aortic root but can also dissect the descending thoracic aorta. They commonly have lens dislocations (ectopia lentis). They have common skeletal features such as

being tall, thin, with long arms and legs, scoliosis, pectus deformities (carnitatum or exicavtum), and club feet. They can also have a history of spontaneous pneumothoraces and mitral valve prolapse.

How is Marfan syndrome similar or different from the other genetically triggered aortopathies that you mentioned?

Loeys Dietz Syndrome is similar to Marfan syndrome in all the features including the aortic root aneurysms. They don't seem to have lens dislocation and they have other unique features such as bifid uvula or cleft palate, and hypertelorism (which is an abnormally increased distance between the eyes). What is different about Loeys Dietz Syndrome from Marfan syndrome is that they can have arterial aneurysms of other arteries instead of the aorta, such as the SMA, axillary, or other peripheral arteries.

Vascular Ehlers-Danlos syndrome has some shared features to Marfan Syndrome with both such as spontaneous pneumothoraces, but these patients tend to be short and can have easy bruising. They also have similar features to Loeys Dietz syndrome in terms of arterial aneurysms. Common features of VEDS would be thin translucent skin where you can easily see their veins, thin lips, thin bridge of the nose, large eyes, easy bruising, acrogeria – or an aged appearance of the hands

However, unlike Marfan and Loey Dietz, the majority of VEDS patients tend to not have aortic root aneurysms. One thing to remember about VEDS is that it is a *subtype* of Ehlers Danlos syndromes. It's very important to distinguish it from the other subtypes because most of the other 12 Ehlers-Danlos syndromes are not associated with arterial pathology. So people with vascular EDS are prone to arterial, uterine, and intestinal rupture and their average lifespan is 48 due to these highly morbid pathologies. 25% of patients with vEDS will have experienced some clinical manifestation by age 20, and that number is close to 90% by age 40.

I remember learning about classic Ehler's Danlos presenting with hypermobile skin and joints. Is this something you see with Vascular EDS as well?

Patient's with vEDS don't have the same hypermobile skin or joint laxity as we classically think of with classic Ehler's Danlos. In fact, some vEDS patients report losing confidence in their physicians who ask them about joint and skin hypermobility because it suggests to them that their doctor doesn't know about their disease process. These patients often know more than most of the doctors they meet about their condition, and it's a source of constant frustration for them. It can also be a problem if the severity of the disease is underestimated, as we discussed they can present much younger than most patients with highly morbid issues – like arterial rupture.

You mentioned arterial pathology in Loeys Dietz and VEDS. Can you tell me more about that?

In both types you can see subclavian, carotid, SMA, and iliac artery aneurysms and dissections, as well as less frequently vertebral, SFA, and popliteal aneurysms and dissections.

How do you diagnose these genetically triggered aortopathies?

There are clinical diagnostic criteria for each, but ultimately genetic and laboratory testing is very important for the final diagnosis.

Ghent's criteria is used to clinically diagnose Marfan's syndrome. The big ones are aortic root dilation, known family history of Marfan's or not, the diagnosis of ectopia lentis which clinically is manifested as iridonesis (lens shimmering). Additionally, genetic testing for pathogenic FBN1 variants is also diagnostic.

To date, there are 5 types of Loeys-Dietz as of last check. These are due to pathogenic variants in the TGF-B signaling pathway, such as TGF-beta receptors and SMAD3 genes.

Vascular EDS is caused by a mutation in the COL3A1 gene which encodes a defective type of III procollagen. The defect in the procollagen makes it unable to properly fold into a triple helix that forms the normal collagen structure. This causes the defective procollagen to be degraded intracellularly and as a result there is an overall deficit in type III collagen which is an important component of arterial walls and other structures. The confirmatory test for VEDS is collagen testing which can confirm the collagen III defect.

How would you manage these patients?

Medical optimization and surveillance is key to try to extend the time as much as possible before they get a dissection and avoid it if at all possible.

We start with lifestyle modification. Avoid "burst" exertions such as sprinting and weight-lifting. Anything that very strenuous. That's not to say that they

shouldn't exercise. Light exercise is encouraged, but this would be activities like light jogging, swimming laps, or biking.

In order to minimize aortic shear stress, a resting heart rate of under 70 beats per minute and an exercising heart rate under 100 should be the goal. This can be accomplished with beta blockers. Propranolol has been shown to significantly decrease the rate of aortic growth in Marfans patients with a baseline aortic root diameter under 4cm. There is research into the use of Losartan in murine models that suggests it inhibits TGF-beta in the aortic wall, which is an important pathway that contributes to the breakdown of the wall. However, randomized controlled studies have failed to show an increased benefit of Losartan over beta blockers in Marfans patients. ACE inhibitors are also being tested and are shown to decrease the risk of type b aortic dissection over 6 years.

In vascular EDS instead of propranolol, celiprolol has been studied by the French and shown to reduce vascular rupture from 50 down to 20% in vEDS, although the mechanism of this is not yet clear and does not appear to be necessarily the same as decreasing shear stress as in Marfan's syndrome. In general taking care of these patients involves trying to minimize complications from procedures and interventions. For instance, use ultrasound for any line that is necessary and avoid arterial lines, intramuscular injections, or other invasive lines if possible to minimize the chance of a complication. Patients are advised to wear medical bracelets notifying that they have vEDS.

We also discuss the importance of forming a care team based on their needs. This usually includes a cardiologist, a cardiac surgeon, a vascular surgeon, and a primary care physician.

What about surgical treatment for those who need it?

For patients with Marfan's, prophylactic surgery is recommended for aortic root dilation >5cm or thoracic aorta >5.5cm. Often times the thoracic and abdominal aorta are involved. Open and endovascular surgery are options for these patients. Open procedures often include open thoracoabdominal aortic aneurysm repairs, open cardiac surgery for arch replacement, or cervical debranching procedures. Endovascular procedures can include regular TEVARs or branched TEVARs which require extensive aortic coverage. Open surgery can be well tolerated and is ideal in the sense that you can replace the entire aorta which avoids the future complications from continued aneurysmal degeneration, loss of proximal or distal seal zones, or device issues that can plague endovascular methods. However open surgery, of course caries higher complication risk and morbidity up front and does share some complications with endovascular treatments as well. Sometimes these patients will have hybrid procedures and often their care will require multiple surgery teams including cardiac and vascular surgery. An important thing to be up front with all of these patients about is that this is a long term relationship with their surgeon, as they often require multiple staged procedures, things aren't fixed in one procedure, and even after they have been surgically addressed there is a lifetime of maintenance

and surveillance. Ultimately, the decision for open vs. endovascular approaches will vary between patients based on their specific anatomy and arterial issues, what their body can tolerate, and ultimately what their goals of care are.[123] Some may require having their entire aorta replaced, while others may only need ongoing medical therapy and surveillance and it's important to set expectations early.

What about VEDS, when surgery cannot be avoided? How do you mitigate the risk of complications?

The tissue is very fragile. So using instruments that are the least traumatic is key – like fogarty clamps for vessels. Sutures often must be pledgetted to reinforce them. Leave no tension on anastomoses or suture lines. Always keep a backup plan in mind– when arteries cannot be repaired, can they safely be ligated or embolized? Generally any large bore access for endovascular treatment is avoided because access site complications are high and can lead to devastating consequences. In situations of extremis, like a rupture, these patients' tissues have been known to completely breakdown. Try to avoid the worst case scenario, but of course sometimes it's the only option left to get out of the OR. Be upfront with the patient about how complications may arise, set expectations, and think about goals of care early.

We discussed earlier that these aortopathies can have shared phenotypic characteristics, some of which can be used in a clinical diagnosis, but are all of these genetic aortopathies syndromic?

Let's start by saying that all patients with Marfan syndrome and VEDS can have the syndromic features we just talked about. However, it's not always the case and the absence of these feature does not exclude the diagnosis. In fact, we recently treated a middle-aged woman with an aortic dissection who had Marfan Syndrome confirmed with genetic testing. She had been diagnosed prior to her dissection because her daughter had undergone genetic testing. However, on meeting her, I would not have guessed she had Marfan Syndrome, had I not known. She was average height, obese, and had no other relevant physical findings on exam or history.

This ties into another genetic aortopathy that we have not discussed yet which are the familial thoracic aortic aneurysms and dissections. They do not have any syndromic features. For example, patients with ACTA2 pathogenic variants that cause alpha actin mutations which again contribute to degeneration of the arterial wall. These patients tend to present 10 years younger than sporadic thoracic aortic aneurysms, generally in their late 50s compared to late 60s, and women seem to be less often effected than men.

Dr. Shalhub, I know vascular genetics is one of your passions. Is there anything else you want people to remember from this broadcast?

Don't forget the family. Once you've made the diagnosis in one of them, remember it is autosomal dominant, so it's important to make sure the family

understands and that they are set up with the appropriate care team and monitoring. They may not all develop the same medical issues, however as we discussed, ongoing medical management and lifestyle changes are the key.

LINKS:

VEDS Research Colaborative study:

https://www.vedscollaborative.org/get-involved

https://depts.washington.edu/vedscoll/

Venous Disease

28 Nov 2021: *Mr. Andrew Nickinson, Mr. Aminder Singh and Mr Manj Gohel*

- Chronic lower limb venous insufficiency
  - 02:55 - What is chronic venous insufficiency?
  - 10:09 - Approach to managing superficial venous reflux
  - 20:47 - The role of surgery in superficial venous reflux[124–126]
  - 27:31 - What is superficial venous thrombosis?
- Deep venous thrombosis[127]
  - 34:38 - Screening for malignancy and thrombophilias in patients with DVT
  - 40:33 - The role of compression in proximal DVTs
  - 42:17 - What is post thrombotic syndrome?
  - 46:42 - The evidence for catheter directed clot burden reduction in proximal DVT[128]
  - 52:17 - Management of phelgmasia
- Proximal deep venous outflow obstruction
  - 54:04 - The basics of proximal deep venous outflow obstruction
  - 57:30 - When to consider imaging the proximal deep veins in patients with symptoms of venous disease
  - 1:08:07 - Pelvic congestion syndrome
  - 1:11:15 - Training and service provision in venous interventions

Vascular Trauma

Peripheral

22 Sep 2019: *Kevin Kniery, MD, MPH; Todd Rasmussen, MD*

Abdominal Arterial

22 Dec 2019: *Kevin Kniery, MD, MPH; Adham Elmously, MD; Todd Rasmussen, MD*

Abdominal Venous

18 Jan 2020: *Kevin Kniery, MD, MPH; Adham Elmously, MD; Todd Rasmussen, MD*

Check out Dr. Rasmussen's book

https://www.elsevier.com/books/richs-vascular-trauma/9781455712618

https://www.amazon.com/Richs-Vascular-Trauma-Todd-Rasmussen/dp/1455712612

Cerebrovascular Trauma

25 May 2020: *Kevin Kniery, MD, MPH; Adam Johnson, MD, MPH; Nicole Rich, MD, MPH; Todd Rasmussen, MD*

EAST Blunt Cerebrovascular Injury Guidelines

https://www.east.org/education/practice-management-guidelines/blunt-cerebrovascular-injury

Check out Rich's Vascular Trauma

https://www.elsevier.com/books/richs-vascular-trauma/9781455712618

Endovascular Approaches

09 Feb 2021: *Kevin Kniery, MD, MPH; Marlin "Wayne" Causey MD; Todd Rasmussen, MD*

Seminal Papers in Blunt Thoracic Aortic Injury

- AAST 1997 Paper: https://pubmed.ncbi.nlm.nih.gov/9095103/
- AAST 2008 Paper: https://pubmed.ncbi.nlm.nih.gov/18545103/
- JVS 2011 Paper: https://pubmed.ncbi.nlm.nih.gov/20974523/
- Timing of repair of BTAI JVS 2020: https://www.jvascsurg.org/article/S0741-5214(20)31575-5/fulltext

Dr. Ben Starnes' podcast on Behind The Knife on BTAI: https://bit.ly/2LuycWq

Angioaccess

28 Mar 2020: *Young Lee, MD and Matthew Smeds, MD*

Management of Dialysis access is an important topic of discussion, not only because it is a significant part of board examinations, but also because healthcare costs continue to rise for ESRD patients, particularly during the transition from CKD to ESRD. This is attributed to use of dialysis catheters and frequent hospitalizations for arteriovenous access failures and related procedures.

The National Kidney Foundation-Dialysis Outcomes Quality Initiative (NKF-KDOQI) and SVS has provided guidelines in the follow areas:

- Timing of referral to access surgeons
- Operative strategies to maximize placement of autogenous AV accesses
- First choice for autogenous access
- Choice of AV access when a patient is not a suitable candidate for a forearm autogenous access
- The role of monitoring and surveillance of AV access management
- Conversion of a prosthetic AV access to a secondary autogenous AV access
- Management of nonfunctional or failed AV access

This brings us to the question, who needs dialysis access?

Patients should be referred to a vascular surgeon for access when their creatinine clearance is <25mL/min which is CKD stage 4. You want to provide adequate time for your autogenous access to mature, so the ideal time for access creation would be > 6 months for anticipated need of dialysis. This allows for time for any subsequent interventions if your access is not maturing.

Should prosthetic access also be placed several months before anticipated dialysis?

Prosthetic access patency is limited by duration of access placement, thus, if a patient requires prosthetic access, placement should be delayed until about 3-6 weeks before initiation of dialysis

For dialysis access creation, which site should be considered and used first?

Due to the easier accessibility and lower infection rates, upper extremity access sites are used first. Furthermore, you want to place your access as far distally in the extremity as possible to preserve the proximal arm for future accesses.

What are some important considerations in a patient's history when planning a dialysis access?

It is important to find out recent history of peripheral IV lines, sites of any indwelling catheters including pacemakers and defibrillators, as well as placement of previous catheters. Any previous access procedures should be identified. In additions, any history of trauma or surgery to the upper extremities is important to identify. Moreover, you also want to consider the patient's quality of life, thus, noting which extremity is dominant is important. If possible, you want to create your dialysis access in the nondominant arm so that when the patient is receiving dialysis multiple times a week, they are able to use their dominant arm during their dialysis sessions

As with any preoperative planning, physical examination is extremely important. Central venous stenosis can cause problems such as prolonged bleeding after dialysis sessions at the puncture site. What are some signs of central venous stenosis?

Unilateral arm swelling or edema and prominent venous collaterals are signs of central venous stenosis. Central venous stenosis can lead to venous hypertension which affects access patency and function, and also causes disabling edema. Beyond signs of central venous stenosis, when examining a patient, an Allen's test should always be performed to evaluate palmer arch patency.

Preoperative planning should also include arterial and venous assessments. What are your size requirements for the artery and the vein to be used in your dialysis access creation?

First, you want equal pressure gradients in bilateral upper extremities and the artery should be greater than or equal to 2mm. A venous duplex should also be done to evaluate for diameter, distensibility and continuity. A vein mapping is useful to determine the size of the patient's superficial veins at various points in the forearm and upper arm. The vein should be at least 2.5mm.

Autogenous access should always be considered first due to higher patency rates, lower infection rates, and longer duration of access survival. What are the different configurations of autogenous accesses?

The first and best option would be direct arteriovenous anastomosis. However, if that is not possible, then venous transposition should be considered next follow by venous translocation. Venous transposition is for deeper veins such as the basilic vein, which is transposed so the vein lies just below the skin for easier access for puncture during dialysis sessions. Transpositions are generally a

2-stage procedure in which the direct arteriovenous anastomosis is created during the first stage and once the vein has arterialized 4-6 weeks later, the second stage of transposition is done when the vein is easier to mobilize. Translocation procedures include harvesting the femoral or saphenous vein and using it as a conduit for AV access creation in the upper extremity.

When can a venous transposition be done in a one stage procedure?

When the vein is >4mm

It was mentioned earlier that the dialysis access should be created as distally as possible on the extremity. What are some of the most distal locations?

The snuffbox fistula, which is the posterior radial branch to cephalic direct access and Brescia-cimino-appel fistula which is the radial-cephalic wrist direct access are two of the most distal fistulas that can be created.

What are your arterial and venous options in the upper extremity?

In the forearm, you have your radial, ulnar, and brachial arteries and cephalic and basilic veins. In the upper arm, you have your brachial or proximal radial arteries and cephalic, basilic, brachial and axillary veins.

If you need to use a prosthetic graft, what would you use?

PTFE is the most common, they make tapered 4-7mm grafts to ensure the size of your arterial anastomosis isn't too large to minimize chances of steal.

The techniques of arteriovenous fistula creation are standard. Can you go through the techniques?

First the vein is identified and the distal end is transected and flushed with heparin. By flushing with the heparin, you are able to access the caliber and extent of the vein as well as identify any side branches

Then after distal and proximal control of your artery, a 4-6mm arteriotomy is made. The length is limited to decrease incidence of arterial steal. The artery is then flushed with heparin to avoid thrombosis during the anastomosis and an anastomosis is created between the side of the artery and the end of the vein. A 6-0 or 7-0 nonabsorbable continuous suture should be used to create the anastomosis to avoid future dilation of the anastomosis.

What are some other options if an access is not able to be created in the upper extremity?

Autogenous accesses can also be created in the lower extremity. Femoral artery to femoral vein or saphenous vein anastomosis can be created. Both veins have to be transposed. However, one must ensure that the ABI is normal because limb ischemia can be a devastating consequence. Furthermore, for morbidly obese patients, the excess pannus can hinder access in the groin region.

Access creation in the chest wall or cervical region is also possible with axillary artery to ipsilateral axillary vein loop access, axillary artery to contralateral axillary or jugular vein straight access (ie necklace access) and brachial artery to jugular vein straight access.

For patients with central venous stenosis or occlusion, what is another alternative upper extremity access creation?

For these patients, the hemodialysis reliable outflow (HeRO) device can come to the rescue. This device is composed of 2 components: a graft which is made of 6mm PTFE with a titanium coupler at one end, and a venous outflow component of a 19 Fr silicone catheter reinforced with a nitinol braid to prevent kinking. The graft portion is anastomosed to an artery, usually brachial, and is tunneled subcutaneously and the venous component is percutaneously placed into the right atrium via the IJ or subclavian vein. The two components are connected with a titanium coupler at the deltopectoral groove. If you need more immediate dialysis, the super HeRO comes to the rescue in which the graft portion is the early cannulation graft.

When is the newly created dialysis access ready for use?

A good way to remember this is the rule of 6's. it's ready to use when the Fistula is 6mm in Diameter, has a flow of 600ml/min, is 6mm from the surface of the skin and usually takes 6 weeks to mature. Prosthetic AV accesses can be used as early as 2 weeks postoperatively. If you use the early cannulation grafts, the access can be used as early as 24 hours after access creation. This is great because it offers the potential for avoidance of dialysis catheters in patients who need dialysis immediately.

What are some reasons why an access may fail to mature?

Sometimes your access may have arterial inflow stenosis. This is difficult to detect clinically because there will be a palpable thrill, however, due to the stenosis, the flow is not sufficient enough for dialysis. In the absence of arterial inflow issues, collateral or large venous branches can divert blood away from the main access channel resulting in insufficient flow.

If the newly created AV fistula is not maturing, what are some secondary procedures to help with maturation?

Open procedures include vein patches, interposition vein grafts, vein transposition to proximal arteries, branch ligations, and vein superficialization. Endovascular procedures include arterial and venous angioplasties.

Once a dialysis access is created, maintenance of the access is extremely important. The flow disturbances and hemodynamic changes associated with AV access creation causes intimal hyperplasia leading to venous outflow stenosis. This can ultimately lead to access thrombosis and failure. What are some methods of detecting access failure?

One way of detecting a well functioning access is a strong thrill at the arterial anastomosis which continues a few centimeters into the outflow vein. If you feel a pulsation near the venous outflow, then a stenosis or thrombosis is likely. If you feel a thrill distal to the area of pulsation, then you have likely localized your area of stenosis. It is important to note that you may feel a pulsation at a pseudoaneurysm independent of venous outflow issues.

Another way to detect stenosis is collateral veins or upper extremity edema. This is indicative of venous hypertension likely secondary to stenosis. You will typically see this in the shoulder area or anterior chest as a results of subclavian vein stenosis/thrombosis. Moreover, these high venous pressures as a result of the stenosis can result in excessive and prolonged bleeding after removal of needles from the dialysis puncture sites. This is often the first sign of elevated venous pressures.

What are some endovascular interventions for a failing access?

The most common intervention is a simple balloon angioplasty of the stenosed area. Insufflation times are generally up to 2-3 minutes. Treatment of stenosis 2/2 intimal hyperplasia often require high pressures of 20atm or more. However, this is a double edge sword because this can lead to trauma in the veins stimulating a further intimal hyperplasia process. Some advocate a cutting balloon before high pressure dilation. Stenting is also an option to treat residual stenosis or dissections after balloon angioplasty. Covered stents have shown good patency results.

If endovascular interventions fail, what are some open options for managing a failing access?

Generally an interposition graft or patch angioplasty is performed and the results of the two techniques are largely equivalent.

If an AV access has ultimately failed and thrombosed, what are your endovascular options at this point?

Some endovascular options are catheter directed thrombolysis with about 2-4mg of tPA injected into the clot, followed by balloon angioplasty (typically an 8mm by 8cm high pressure balloon). A mechanical thrombectomy device, such as angiojet, can also be used in combination to thrombolysis.

Alternatively, an open thrombectomy with a thromboembolectomy balloon and patch angioplasty of venous stenosis areas can also be used. Moreover, a hybrid approach of open thrombectomy with percutaneous interventions of venous stenosis areas has been described.

Earlier, you mentioned steal syndrome, can you explain to us what this is?

Steal syndrome is also known as Access Related Hand Ischemis = ARHI. It is an uncommon but devastating complication of access creation. All patients with arteriovenous fistulas have some degree of physiologic steal or reversal of flow in

part of the artery distal to the fistula. However, this is not sufficient enough to cause ischemia. Rather, ischemia results from inadequate collateral circulation and inability of peripheral arteries to meet the increased demand. Diseased vessels do not dilate and stenosis of arteries leads to decreased distal perfusion pressure. Furthermore, hypotension during dialysis further decreases perfusion causing symptoms. Steal can be limb threatening and is graded from 0 – 3. Grade 0 is no symptoms, Grade 1 is mild ischemia with signs of cool extremity and flow augmentation with access occlusion. Grade 2 is moderate/intermittent ischemia that is experienced only during dialysis and patients feel claudication. Grade 3 is severe, ischemic pain at rest with tissue loss.

What are some symptoms and signs of Steal syndrome?

Symptoms include coolness, parasthesias, rest pain, and weakness. Signs of steal include cool to touch, pallor, cyanosis, delayed capillary refill, absent pulses/signals, diminished sensation, weak grip, and in severe cases ulceration or gangrene. If the patient shows improvement with access compression, diagnosis is confirmed.

When is an intervention necessary to treat steal syndrome?

You do not need to intervene for grade 0 and 1. For grade 3 an intervention is mandatory. The goal of treatment includes symptom resolution and access preservation, and this is achieved by reducing access flow and increasing distal arterial flow.

What are your intervention options for resolving steal syndrome?

One simple option is banding to reduce access flow. This is done by suture plication, placement of single narrowing tie or wrap by constrictive cuff to cause a stenosis in the AV access near the arterial anastomosis. A minimally invasive approach is used by the MILLER banding which uses an endoluminal 4 or 5mm balloon as a sizer and a suture is placed around the access with the balloon inflated. This procedure increases arterial inflow towards the hand.

Revision using distal inflow (RUDI) involves ligation of the fistula at the arterial anastomosis and reestablishment of flow via a more distal artery by bypass or vein translocation. This allows for decreased flow through the access by reducing the fistula diameter and by taking inflow form a smaller vessel. However, ultimately, the fistula is placed at risk

Proximalizaiton of arterial inflow (PAI) involves ligation of AV anastomosis, and the inflow is moved to a more proximal level with a prosthetic interposition. Dialysis can be continue via the vein. The main advantage is the native artery's continuity.

Distal revascularization-interval ligation (DRIL) is ultimately considered the best option by many vascular surgeons due to the excellent results shown. There is an arterial bypass created originating proximal to the access and ending distal to the access, with ligation of the artery distal to the anastomosis. This prevents

retrograde flow from distal vessels and allows for a low resistance pathway for arterial supply to the hand.

Lastly for palmar arch steal syndrome from radio-cephalic av accesses, distal radial artery ligation (DRAL) can be performed to prevent reversal of flow in the palmar arch. However, the ulnar artery patency needs to evaluated first.

Steal syndrome is not the only complication of AV access creation. What are some other nonthrombotic complications?

Other nonthrombotic complications include pseudoaneurysms which is a result of trauma due to repeated punctures or poor technique and true aneurysms which is a result of hemodynamically significant stenosis. Both can lead to cannulation difficulties, increased risk of thrombosis, pain, bleeding and cosmetic deformities.

Prosthetic grafts can results in seroma from ultrafiltration of the graft and most resolve without intervention.

Most interestingly, access creation can result in neuropathy. It is important to note that over 2/3s of the patients have preexisting peripheral neuropathy. Neuropathy is also graded from 0-3, with 0 as asymptomatic, 1 as mild intermittent changes (pain, paresthesia, numbness with sensory deficit), 2 as moderate persistent sensory changes, and 3 as severe sensory changes with progressive motor loss (motion, strength, muscle wasting). Ischemic monomelic neuropathy is rare but occurs acutely after AV access creation. Within hours of surgery, patients develop acute pain, weakness, or paralysis of hand and forearm muscles with prominent sensory loss. However, the hand is warm with palpable pulse or audible signal in distal radial and ulnar arteries. It is important to note that pain out of proportion is what differentiates IMN from ARHI. Treatment is access ligation or emergent augmentation of flow.

Since we've beaten to death arteriovenous accesses, we are ready to focus our attention to a different type of dialysis access. We cannot forget about dialysis catheters. What is the difference between an acute and chronic hemodialysis catheter?

Chronic catheters have a subcutaneous cuff at the exit site and tunneled to the vein. This decreased infection rates and is less likely to become dislodged. Tunneled hemodialysis catheters can be used up to 12 months.

If catheters cause so much problems such as infection and central venous stenosis, what would be an indication for them?

The most common indication would be for urgent hemodialysis. But other indications include patient who are not operative candidates due to advanced comorbidities, or patients who are unable to have an AVF or AVG due to anatomic feasibility. Temporary dialysis access may also be needed in patients who have just had a peritoneal dialysis catheter placement or in chronic peritoneal dialysis catheter patients requiring abdominal or inguinal surgery.

Which site is the most ideal site for a hemodialysis catheter?

The right internal jugular vein is preferred because it has the best patency

Every procedure has potential complications. What are the immediate complications of catheter placement?

When placed in the internal jugular veins, there is always a chance of a pneumothorax or hemothorax. Wire embolism can occur is control of the wire is lost during the procedure. If the guidewire is placed too far, then there is always a chance of arrhythmia. Thus, the best place for the wire is through the IVC. With a left internal jugular vein approach, there is always a risk of thoracic duct laceration. If a leak is apparent, then the catheter needs to be removed immediately and a pressure dressing applied.

Vascular Lab

Endovascular

Vascular Access

29 Apr 2020: *Sammy Siada, MD and Rafael Malgor, MD*

Endovascular procedures are the cornerstone of any modern vascular surgery practice. Because most endovascular procedures are performed percutaneously using arterial or venous access, it is critical that vascular surgeons are facile with various techniques and devices used for endovascular access. Today we'll be discussing the various access sites, techniques for access, closure devices, and complications.

What factors play a role when choosing a site for access?

The factors to think about when thinking about which vessel to access are:

- The appropriateness of the access site the procedure performed
- Ability to obtain hemostasis at the conclusion of the procedure
- Ability to convert to open if necessary
- Effects of access on the tissues supplied by the accessed vessel and distal limb perfusion

What makes a vessel appropriate for access?

One of the most important factors when planning your access is the size of the vessel. The vessel needs to be able to accommodate the catheters and devices that will be used to perform the procedure. For instance, a brachial artery with less than 4mm diameter should not be accessed by a large bore sheaths, such as a 12Fr sheath.

The vessel also needs to be a in a location that can allow access to the target vessel of interest. Additionally, the vessel needs to have an area that is relatively healthy to access the vessel safely and minimize complications. Heavily calcified vessels especially those with anterior wall calcification might not be appropriate for access.

What about the ability obtaining hemostasis at the end of the procedure?

The ability to obtain hemostasis is critical to be able to perform endovascular procedures safely which is one reason why the common femoral artery is the most commonly accessed vessel.

Hemostasis is most commonly achieved through manual compression by compressing the artery against the femoral head. The brachial artery can also be compressed against the humerus, but because it's a more mobile vessel, compression is less effective and can lead to hematoma or pseudoaneurysm formation which may necessitate an operation to prevent compression of the median nerve

Patients who will need to be uninterruptedly anticoagulated peri and postoperatively pose a challenge to hemostasis. The use of closure devices is very important in these situations to prevent access bleeding.

A variety of closure devices can also be used to assist in hemostasis, each with their own inherent advantages and disadvantages. In general, closure devices are contraindicated in small diameter and heavily calcified vessels.

In any minimally invasive procedure, there is always a chance that you may need to convert to open. How does converting to open play a role in vascular access?

Conversion to open is uncommon with vessel access accounting for <5% of the cases. Sometimes a large sheath is accidentally pulled out and a cutdown becomes necessary to repair the artery. Closure devices aren't 100% effective in hemostasis and may also require a cutdown for definitive control if they fail, especially when obtaining large bore access.

This makes choosing the right vessel critical. For example, if a large sheath is accidentally pulled out of the CFA during an EVAR, the repair can be done through a straightforward groin cutdown. In contrast, the subclavian artery is rarely accessed percutaneously because converting to open would require a more challenging peri-clavicular incision or even a thoracotomy for repair.

Large diameter sheaths are often used, particularly in aortic procedures. These sheaths can be occlusive which can result in downstream tissue ischemia. What considerations should be taken when thinking about downstream tissue ischemia?

When performing diagnostic procedures using small diameter sheaths and catheters, anticoagulation may or may not be necessary depending on how diseased the access vessel is.

However, when using large devices (e.g. in EVARs), the sheaths can be partially or completely occlusive which mandates full anticoagulation to prevent thrombosis. The other thing to consider is the length of time that the sheath remains in the vessel as the leg can only tolerate ischemia for 4-6 hours. This is usually pertinent when performing complex endovascular aortic procedures.

To minimize downstream tissue ischemia, a large bore sheath should be pulled back to decrease the length of vessel obstruction by its shaft in order to unblock proximal vessel collateral branch vessels. For instance, when performing an aortic procedure through a femoral access attempt to pull the sheath back into the external iliac artery to increase distal limb perfusion through the internal to femoral artery collateral branch vessels.

The long story short is to be liberal with anticoagulation when there is reduced flow in the vessel such as the iliofemoral system during EVAR or tibial access

Do the principles that we've described also apply to veins?

The same principles apply but there are some notable differences between arterial and venous access.

Veins are a low-pressure system, so hemostasis is easier to achieve and hemorrhagic complications are much less common. However, this poses a challenge during access as there is less radial force keeping the vein open making the vein more susceptible to compression by the ultrasound probe and the needle.

If a large bore sheath is necessary to perform a venous procedure, a suture-mediated closure device can be utilized to achieve hemostasis especially in patients that will be kept fully anticoagulated

Additionally, a syringe may be needed to confirm access and can also prevent air embolism

Let's talk about accessing the common femoral artery. Why is the CFA the most common vessel used for access?

It is large caliber and can accommodate large sheaths up to 26-28 Fr. It also allows for a wide set of procedures and is ergonomically easy to work with given its location. It is relatively easy to hold manual pressure and if a conversion to open is needed, a femoral cutdown is relatively straightforward.

Where in the common femoral artery is the best spot to access?

The ideal puncture site is in the CFA in the medial third of the femoral head in between the inguinal ligament and the femoral bifurcation in the middle of the femoral head.

Accessing the vessel above the inguinal ligament makes compressing the artery very difficult which can lead to life-threatening retroperitoneal bleed.

A puncture that is too distal and into the SFA increase the risk of thrombosis or dissection causing acute limb ischemia as well as AV fistula formation between the superficial femoral and profunda femoris artery.

What are the different ways to obtain CFA access?

There are three different ways to access the CFA: manual palpation, fluoroscopic guided, and ultrasound guided.

With manual palpation, a finger is placed above and below the desired access point directly on the pulse and the needle is inserted in between the two fingers.

Fluoroscopic guidance uses bony landmarks relative to the position of the needle.

The standard of care in the modern era for obtaining CFA access is to use ultrasound guidance. Ultrasound allows visualization of the vessel and surrounding structures. PAD within the vessel can readily be identified with ultrasound, allowing safe access in a relatively disease-free part of the artery. Ultrasound also clearly shows the femoral bifurcation. Using ultrasound allows for subtle corrections in the angle of the needle and how it interacts with the surrounding tissues. It is rapid, real-time, inexpensive, and safe.

What anatomic considerations should be taken when accessing the CFA?

The CFA is the continuation of the external iliac artery as it courses under the inguinal ligament. It is about 5-8 cm in length and then bifurcates in to the superficial femoral and profunda femoris arteries

The inguinal ligament is a good external landmark to estimate where the CFA is. It is critical to emphasize that the inguinal ligament does not correspond to the groin crease and this is especially true in obese patients. An imaginary line is drawn from the ASIS to the pubic tubercle. The artery generally runs a third of the way from the pubic tubercle to the ASIS. A metallic instrument can be placed in this area to mark it externally and a fluoroscopic image can be obtained to identify the relation of the instrument to the medial third of the femoral head. This imaginary line also marks the superior-most extent of the access

The CFA is most often accessed in a retrograde fashion in between the inguinal ligament and femoral bifurcation. This allows for a multitude of potential diagnostic and therapeutic procedures in most parts of the body.

Can the CFA be accessed antegrade?

Yes. Sometimes antegrade CFA access is used when performing an intervention distal on the ipsilateral leg. The advantage of antegrade access is better pushability and torquability of wires, catheters, and sheaths when performing complex peripheral intervention where no other proximal procedures are needed.

Antegrade access is more challenging than retrograde access, however. This is particularly true in patients with a very short CFA, short distance between the inguinal ligament and the femoral bifurcation because the needle requires a steeper angle of entry to allow for cannulation well above the femoral bifurcation.

Obtaining antegrade access is especially difficult in obese patients and will usually require an assistant to retract the pannus to allow proper needle placement. I would say antegrade access is relatively contra-indicated in morbidly obese patients with large pannus. Ultrasound guidance remains key here as well.

What are some other commonly accessed arteries for endovascular procedures?

The tibial vessels can be accessed percutaneously for retrograde recanalization for severe LE PAD. It is usually performed using micropuncture kits which we will discuss a little later. It is usually done with ultrasound guidance and uses small sheaths and wires. The PT and AT are more commonly used because they are easier to access.

The radial artery is commonly used in coronary interventions and is increasingly being used by vascular surgeons. It is easily palpable over the distal radius and can be cannulated with ease. Hemostasis is straightforward using compression. In the rare setting of radial occlusion, the hand rarely becomes ischemic because most people are ulnar dominant. It can accommodate sheaths up to 6 French.

The brachial artery can be accessed percutaneously over the olecranon process with the arm supinated. Ultrasound guidance allows for visualization of the brachial bifurcation. It can accommodate 6-7 Fr sheaths. Hemostasis is critically important as bleeding can result in a hematoma that results in median nerve compression, which is a surgical emergency.

Let's not forget about venous access. What are some of the most commonly accessed veins?

The CFV is commonly accessed for procedures involving the IVC and iliac vessels and their branches for conditions such as May-Thurner, pelvic congestion syndrome, and IVC filter placement. Treatment of PE can also be performed through the CFV. The CFV can easily be compressed over the femoral head and is located medial to the CFA. Ultrasound guidance should be used to prevent arterial injury and backwalling.

The internal jugular vein can be accessed using US guidance (to prevent carotid injury; IJ is lateral to the carotid). IJ access is used most commonly for central venous catheters as well as IVC placement and filter retrieval. It is also an excellent access to treat pulmonary embolism via thrombolysis or thrombectomy. The IJ can be utilized to perform ovarian and internal iliac vein embolization. IJ is also the preferred access to perform TIPS, which is often of less interest to vascular surgeon.

The popliteal vein can be accessed with the patient in the prone position or the distal femoral vein in the supine position to diagnose and treat DVTs of the extremity veins. Ultrasound is also helpful to avoid arterial access and especially if the vein is thrombosed

Arm veins (cephalic/basilic) can be also readily accessed for vein mapping or fistula interventions.

Let's move on to access technique. Historically, there are two types of puncture needles: single-wall and double-wall. Can you talk about the differences?

Double wall needles were commonly used back in the day for femoral access. They have an outer hollow blunt-tipped needle and an inner sharp stylet. The needle was inserted through and through the artery and the stylet removed and the blunt hollow needle pulled back until blood is returned. These aren't favored anymore because they cause unnecessary backwalling of the artery. Double wall access kits are used in treating endoleaks from both a transcaval and translumbar routes to allow access into the aneurysm sack and needle removal to avoid puncturing the endograft.

Single wall needles are typically the choice for diagnostic procedures. 18-gauge needles accommodate an 0.035 in wire and 21 gauge accommodates a 0.018 in wire.

Can you describe the micropuncture technique for percutaneous access?

Micropuncture technique is the most commonly used method for percutaneous access nowadays. The advantage of the micropuncture technique is the use of a small needle which can be removed and repositioned with a negligible risk of bleeding and minimal amount of manual compression needed.

Ultrasound is used to cannulate the artery with a 21-gauge needle. It is best to visualize the needle entering the artery and to be intraluminal without being against the wall Blood return is then seen and a floppy tip micropuncture (0.018) wire is inserted under fluoroscopic guidance to make sure the wire passes into the vessel easily. A 4 Fr introducer sheath is placed over the wire gently to avoid kinking the wire. The inner cannula of the sheath is removed, and a 0.035 guidewire is placed under fluoroscopic guidance. It is important to remember that there are two types of introducer sheath depending on amount of subcutaneous scar tissue containing either a soft or a stiffened cannula. The 4 Fr is removed over the wire while holding manual pressure and desired sheath (usually 5 or 6 Fr) is placed for definitive access. The side port is then aspirated for arterial blood and flushed with heparinized saline.

With any invasive procedure, there are risks of complications. What are some of the complications of percutaneous vascular access?

Hematomas are the most common complication and have an incidence of about 3%. Most of these hematomas are clinically insignificant but retroperitoneal hemorrhage from a high puncture above the inguinal ligament can be life-threatening. These may require conversion to open and direct repair of the vessel or covered stent placement (especially if the puncture is above the inguinal ligament). Proximal balloon occlusion can be helpful to control hemorrhage while the vessel is being repaired.

Groin hematomas are not uncommon and are usually self-limiting. An expanding hematoma that is seen early can be treated with simple manual pressure at the bedside. If the hematoma is large and compressing surrounding structures or threatening skin integrity or if the patient is hemodynamically unstable, then

surgical evacuation may be necessary

Pseudoaneurysms are an uncommon complication with an incidence of about 0.6%. Most pseudoaneurysms are treated with ultrasound-guided compression or thrombin injection. Thrombin injection requires a narrow neck into the pseudoaneurysm. If the pseudoaneurysm is >2cm, compresses surrounding structures, threatens skin integrity, or has failed thrombin injection, then surgical repair is required.

Thrombosis of the CFA is a known complication but fortunately is rare with an incidence of 0.2%. This can result from manual compression of the CFA that has severe atherosclerotic disease or prior groin reconstruction. This generally requires a cutdown, endarterectomy, thrombectomy, and patch angioplasty.

Lastly, AV fistula can form and are usually between the femoral artery and vein with an incidence of 0.5-0.9%). These usually occur from a low puncture of the CFA bifurcation or profunda. They are usually asymptomatic and detected on exam (palpable thrill) and confirmed with duplex imaging. If the fistula is small, it generally can be observed with close duplex surveillance. If it enlarges or becomes symptomatic, then repair is indicated. Covered stent grafts can be placed with minimal morbidity, making this optimal for high risk patients. Open surgery also is highly successful. Deciding between non-operative, endovascular, or open treatment is up for debate and is up to the clinical judgement of the surgeon.

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