Demystifying Arterial Physiologic Testing

Rob Daigle, BA, RVT, FSVU, FSDMS

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Observations

- Many radiology-based labs avoid physiologic testing because they are unfamiliar with the instrumentation and methods.
- Physiologic testing is the most economical, efficient method to DX Peripheral Arterial Disease (PAD).
- IAC Vascular Accreditation requires ABIs and segmental PVR, CW Doppler.

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Arterial Physiologic Testing

Purpose:

1. Is there PAD?

   - Pulse palpation and Pt. History are often unreliable.

2. If disease is present, how severe?
3. If arterial disease is present, is it causing the symptoms?
4. What is the "region" of disease?

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Physiologic Testing Limitations

- Cannot differentiate arterial stenosis from occlusion
- Cannot Identify the specific location of obstructive disease
- Cannot detect mild disease

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Manifestations of PAD:

Mild Disease

- Asymptomatic at rest and with exercise
- Can be source of emboli?
- Exercise = some decrease in ankle pressure

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Moderate Disease

- Asymptomatic at rest
- Pain, fatigue, weakness in calf, thigh or buttock when walking
- Claudication- “to limp”
- Relieved by rest
- Exercise = significant decrease in ankle pressure

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Severe Disease

- Night pain in feet- toes
  - Relieved by dependency
- Dependent rubor
  - Redness, light purple or deep red-violet color that develops on the foot when it hangs in a dependent position

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Severe Disease

- Ischemic rest pain (in feet and toes)
- Ulceration
- Tissue necrosis
- Gangrene

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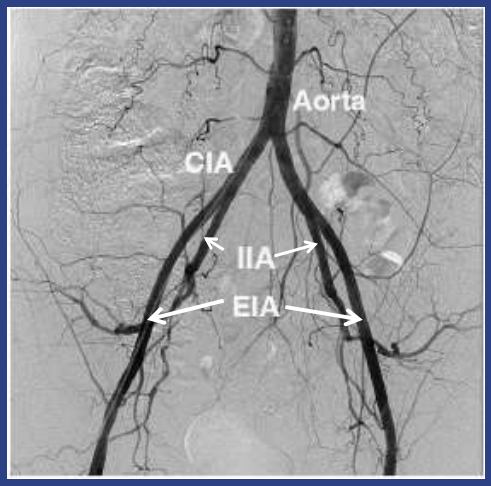
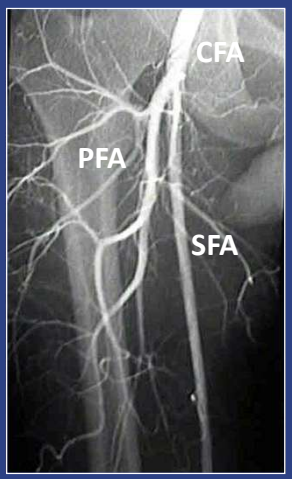
Anatomy Review





Fukuda K (2017) Angiography and Endovascular Therapy for Aortoiliac Artery Disease... InTech. http://dx.doi.org/10.5772/67178.

Images by R. Daigle

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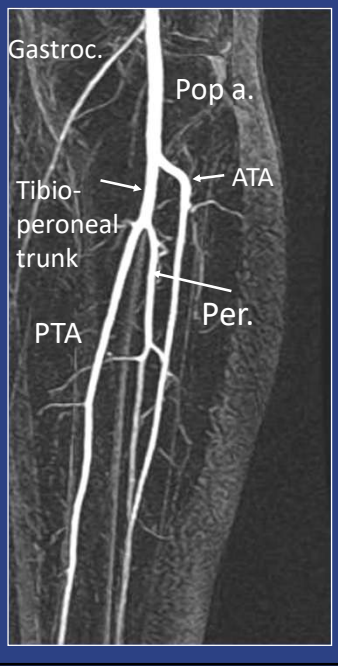

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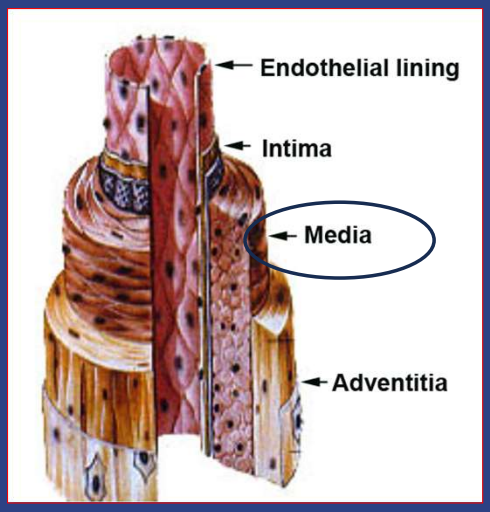
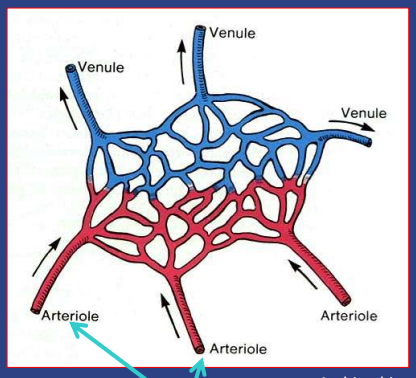
Arterial Wall Anatomy



Fox, Stuart I. Human Physiology 4th . Ed.
Brown Publishers

Capillary bed



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Arterioles

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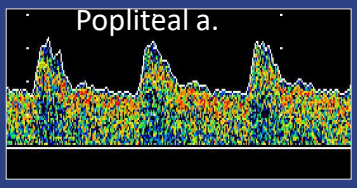
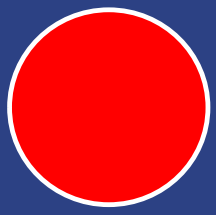
Arterioles and Flow



Vasoconstriction at rest



Vasodilation during exercise

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Indirect Physiologic Tests

1. Pressure assessment
   - ABI and/or segmental pressures
2. Volume plethysmography
   - Pulse volume recording (PVR) (VPR)
   - Photoplethysmography (PPG)
3. Doppler waveform analysis
4. Exercise stress test

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Protocols

1. Traditional, full segmental study at 3-4 sites
   a. Developed before duplex imaging, MRA, CTA
   b. Knowledge necessary for RVT, RVS, VS, RPVI certification
2. Abbreviated, efficient, cost effective protocol.
   - Eliminates redundancy

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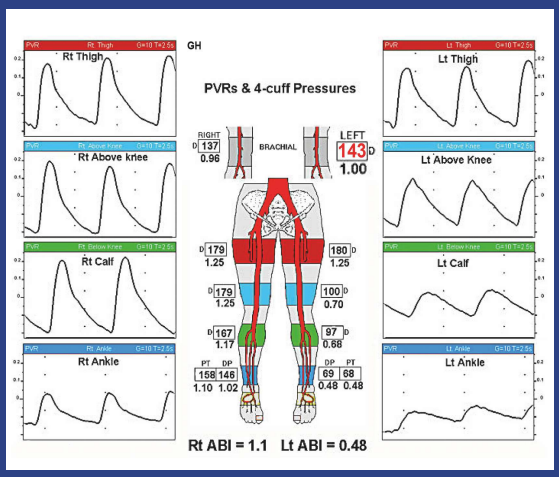
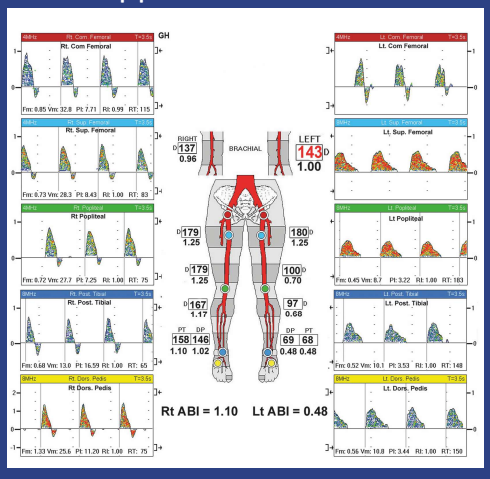
Examples of Full Segmental Studies

PVR's & 4-cuff Pressures



CW-Doppler & 4-cuff Pressures



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Limited, Bilateral Physiologic Study

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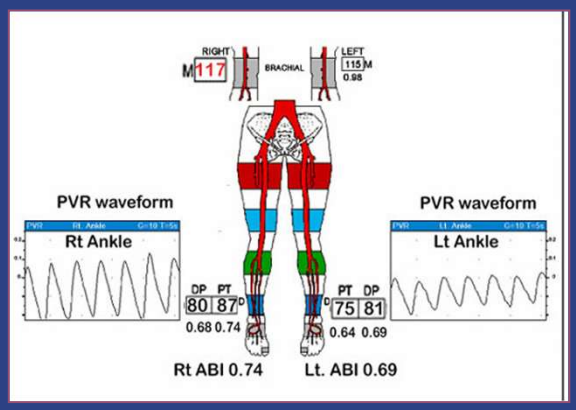

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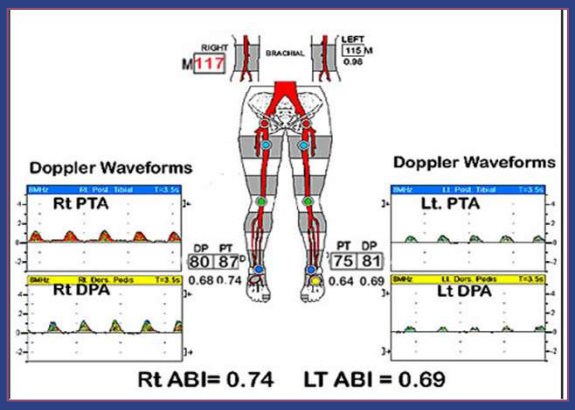

ABI with PVR waveforms

ABI with Doppler waveforms

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1. Pressure Assessment -Principle:

- In a normal individual in a supine position, ankle systolic pressure is ≥ brachial pressure
- 10 -12 cm wide blood pressure cuffs are applied to arms and ankles
- Use an 8-10 MHz CW-Doppler

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Obtain bilateral arm systolic pressures and compare

- A pressure gradient of 20 mmHg or greater suggests subclavian artery disease on the lower side

Brachial systolic pressures: Abnormal on Left

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Obtain Bilateral Ankle Pressures

Doppler Pressure Sites

- Posterior Tibial Artery (PTA)
- Dorsalis Pedis Artery (DPA

No waveform is recorded, only the pressure value.

Doppler is used as a "stethoscope"

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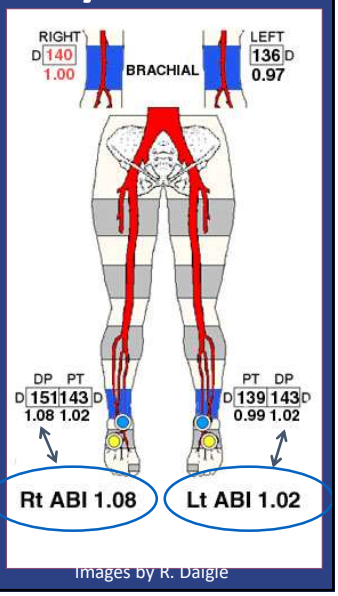
The Ankle/Brachial Index (ABI)

- Bilateral ankle pressures divided by the higher brachial pressure
- The higher of the 2 ankle ABIs is reporting as the ABI
- e.g., Rt. DPA is 1.08, the Rt. PTA is 1.02, so the **Rt. Ankle ABI is 1.08**



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Resting (ABI) Values*

> 1.35 = calcific medial sclerosis

> 0.90 -1.34 = normal

< 0.90 = abnormal or (borderline normal)

< 0.8 = probable claudication

< 0.5 = multi-level disease or long segment occlusion

< 0.3 = ischemic rest pain

* General correlation-varies by patient.

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Resting ABIs - Comments

- ABI is the best, quantitative method for detecting hemodynamically significant PAD, and it's easy.
- However, Medicare considers the ABI (without waveforms) to be "part of the physical exam" and is not reimbursable.

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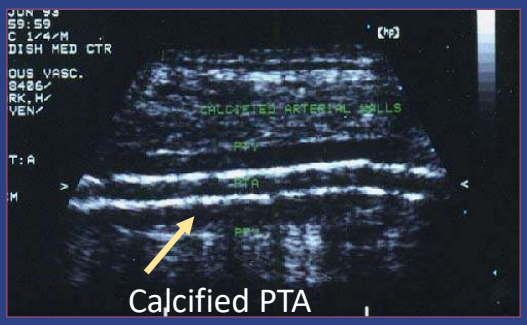
Calcific Medial Sclerosis

The bane of pressure measurements

- Incompressible tibial arteries
- Or, ABI > 1.35



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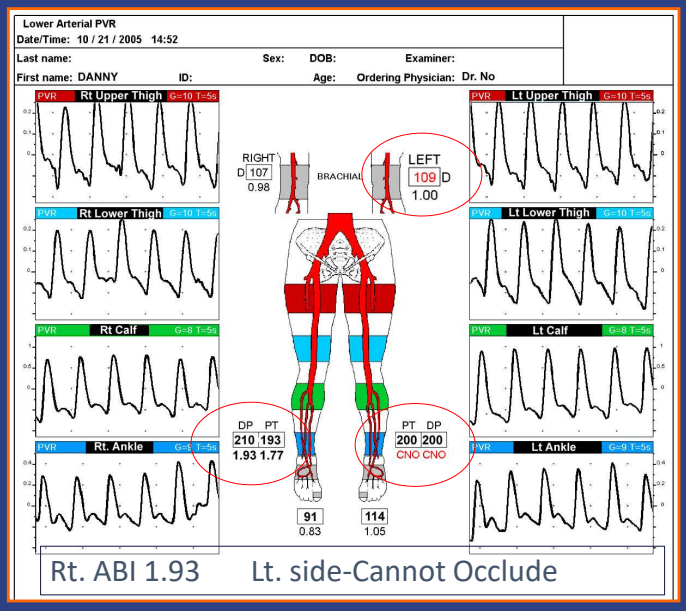
Calcified Tibial Arteries



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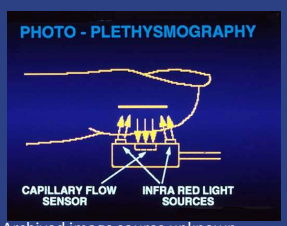
TBI- If ankle pressures are unobtainable

- Obtain toe pressures, or rely on ankle waveforms
- Toe/Brachial Index (TBI)
  - Normal > 0.75
  - Abnormal < 0.66



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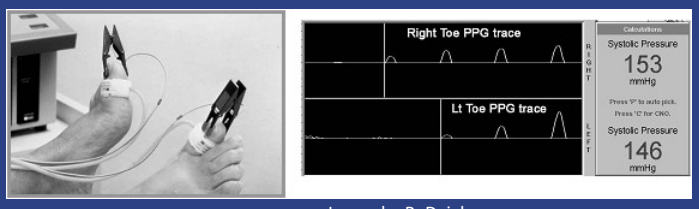
Toe Pressures obtained with PPG



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Comments- Additional Pressures?

- If ABIs are abnormal, there is "Aorto-Tibial" disease.
- If ABIs are normal, there is no need to acquire segmental pressures (thigh and calf)
- If Abnormal, segmental pressures (and waveforms) may identify the region of PAD

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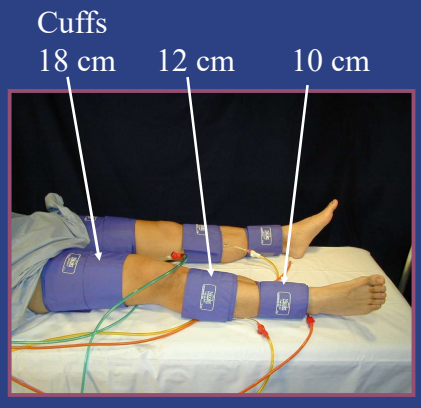
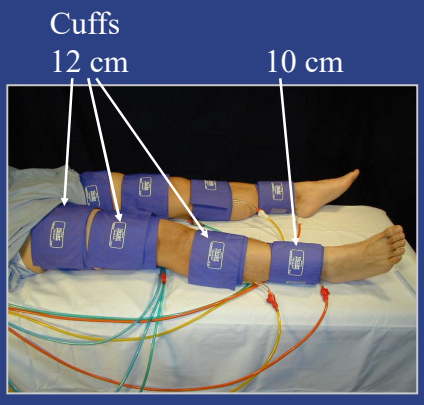
Segmental Pressures:

3 and 4-cuff methods



1 large thigh cuff



2 narrow thigh cuffs

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Segmental Pressures

- 20 mmHg drop between segments = PAD
- Thigh interpretation is a confusing mess.
- Thigh pressures are not “patient friendly”
- Identify “inflow” disease with waveforms (PVR or Doppler)
- Skip thigh pressures!

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2. Pulse Volume Recording (PVR)

- AKA: Volume Plethysmography, VPR
- “The measurement of a volume change in a limb or organ.”
- Cuff placement: thigh, calf, ankle, metatarsal (optional), great toe (optional)

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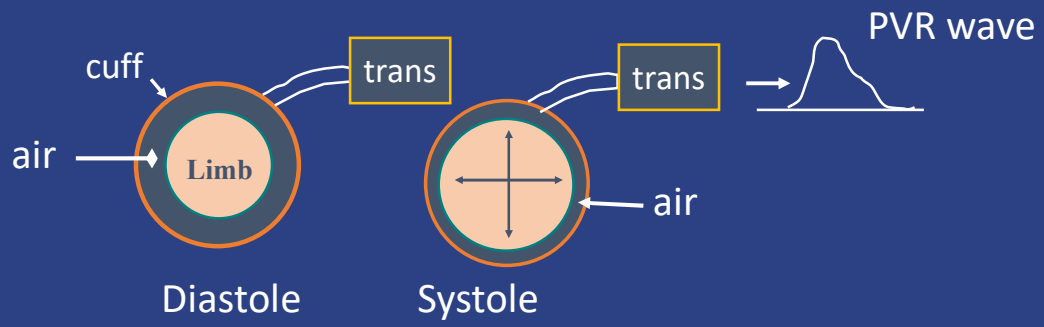
Pulse Volume Recording

- Limb volume increases in systole
- Air is displaced within a cuff
- Instantaneous pressure change is recorded.



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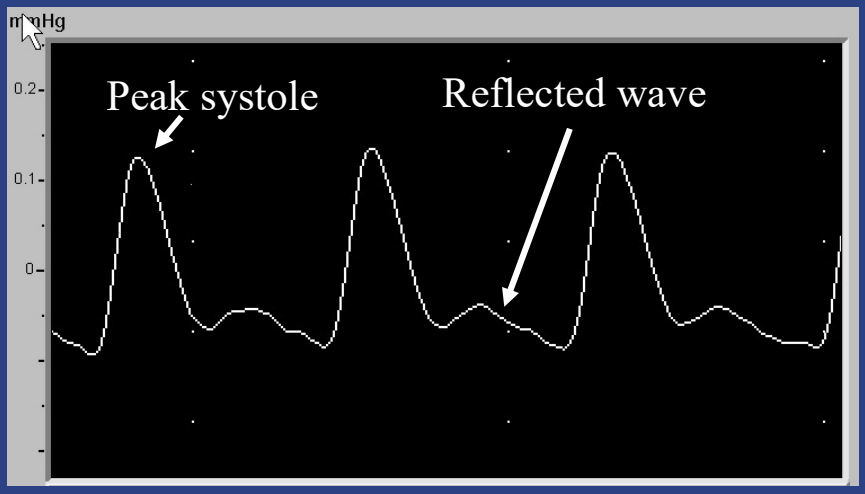
Normal PVR



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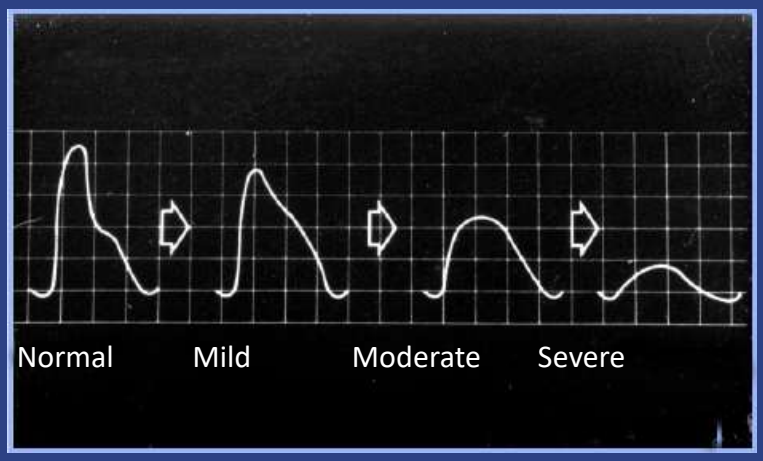
PVR Waveforms

Waveform morphology changes with disease severity



Kempczinski, RF, Yao, JT. Practical Noninvasive Vascular Diagnosis, 2nd ed. Year Book Medical Publisher Chapter 9, P.140

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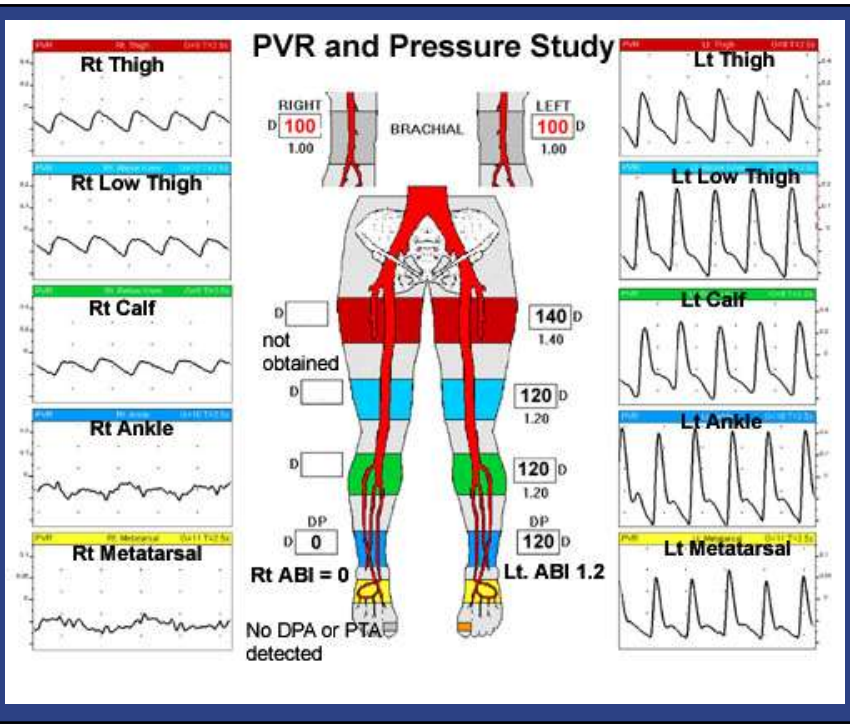

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PVR Interpretation

- Normal at upper thigh= no significant inflow disease.
- Abnormal upper thigh PVR indicates:
  - Inflow disease (Aortoiliac or CFA)
  - or, although less likely, PFA disease
- PVRs represent inflow to cuff region, pressures reflect status under the cuff.

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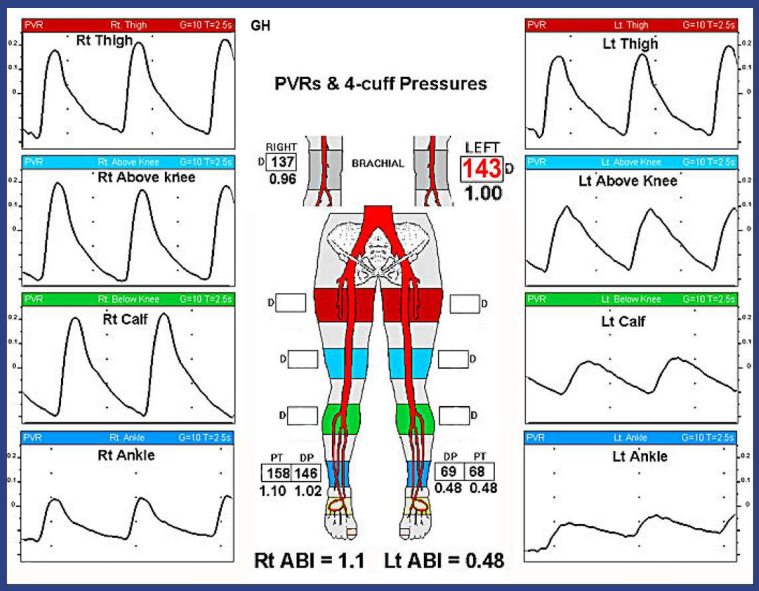
ABI and PVR Study



Lt. Femoro-Popliteal Disease

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PVR Advantages

- Easy to learn and to perform
- Assessment of global limb perfusion
- Metatarsal and toe evaluation
- Not affected by calcified arteries
- It's hard to screw it up

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PVR Limitations

- Tremor - motion
- Distal disease with proximal obstruction
- Subjective interpretation
- Atrial Fib.

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3. CW-Doppler Waveform Analysis

- CW Doppler transducer 4 MHz (deep) or 8 MHz (superficial)
- Transducer 45 – 60ºangle to skin and pointed along vessel long axis
  - Obtain and record waveforms from CFA, SFA, POP, PTA, DPA

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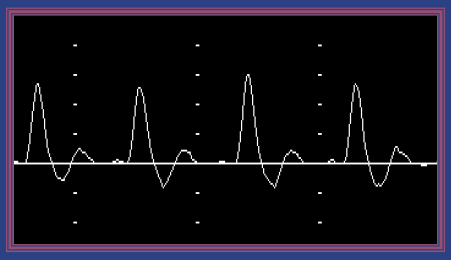
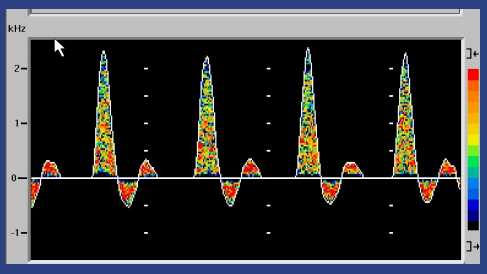
Doppler Waveform Analysis:

Analog, zero-crossing detector; most common method.



FFT color spectrum analyzer-CW Doppler. Less common.



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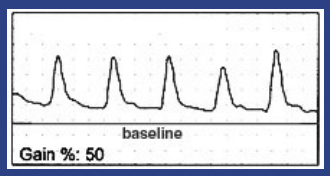
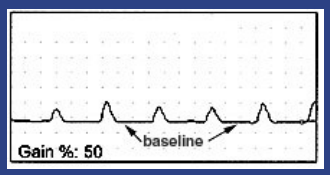
Doppler Waveforms- Old Nomenclature

Normal: "triphasic", "multiphasic"

Moderate disease: "biphasic"



Severe disease: "monophasic"



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New Nomenclature- Peripheral Arterial Waveforms – from SVU & SVM

Consensus Statement from the Society for Vascular Medicine and Society for Vascular Ultrasound, published in 2020 *

~~Triphasic~~ ~~Biphasic~~ Monophasic-changed

* Esther ES, Sharma AM, Scissons R, et. al. Interpretation of Peripheral Arterial and Venous Doppler Waveforms: A Consensus Statement From the Society for Vascular Medicine and Society for Vascular Ultrasound. J Vasc Technol. 44(3) 118–143, 2020 DOI: 10.1177/1544316720943099

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New Nomenclature

- Multiphasic with high-resistance
- Monophasic with low-resistance
- Monophasic with intermediate resistance
- Monophasic, low-resistance, and delayed rise time
- Monophasic without diastolic flow

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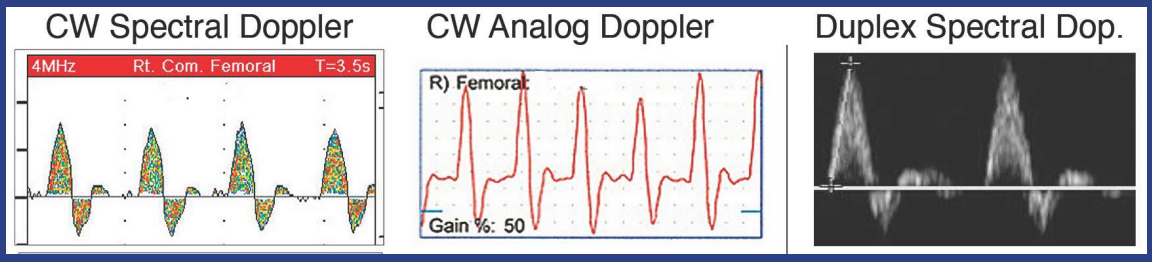
1. Multiphasic with High-Resistance



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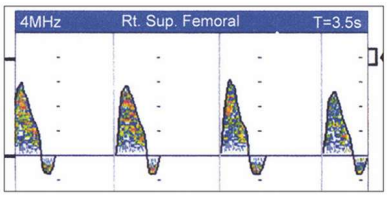
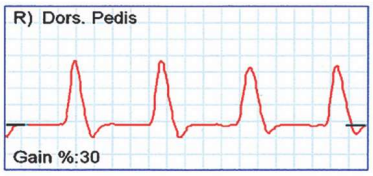
1. Multiphasic with High-Resistance

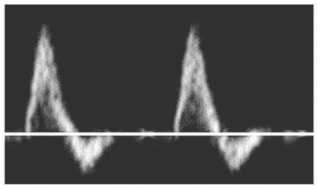
CW Spectral Doppler



CW Analog Doppler



Duplex Spectral Dop.



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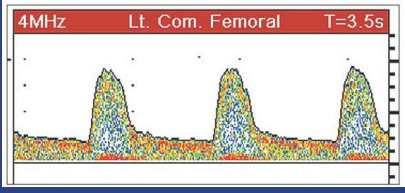
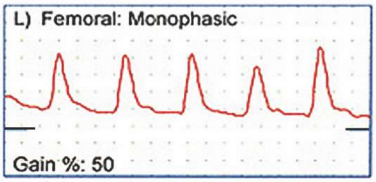
2. Monophasic with Low-Resistance

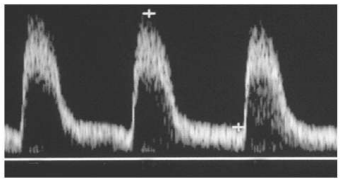
CW Spectral Doppler



CW Analog Doppler



Duplex Spectral Dop.



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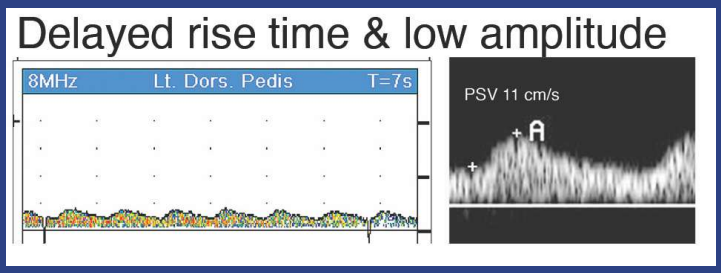
3. Monophasic, Low-Resistance, Delayed Rise Time



Severe Proximal
Obstructive Disease

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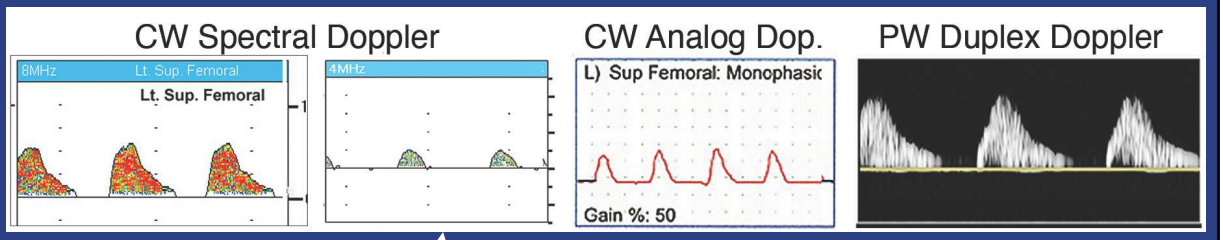
4. Monophasic without Diastolic Flow



Comment on Low Amplitude

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”Distal (resistance) Dictates Diastole”

Phil Bendick, PhD

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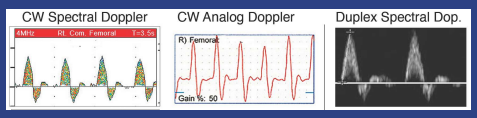
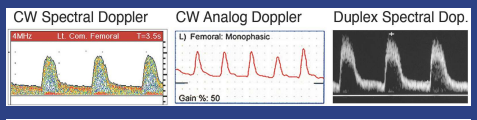
Rob’s Alternative Nomenclature

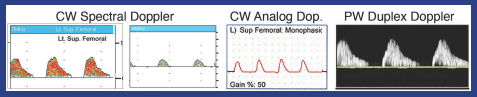
For CW Doppler Lower Extremities

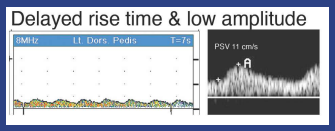
Normal Multiphasic



Abnormal, or Atypical







All Images by R. Daigle

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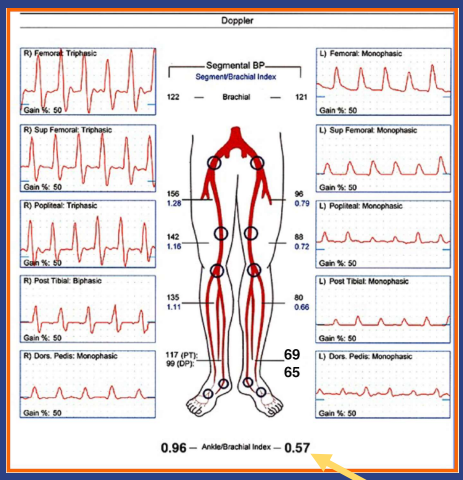
Segmental Study with Pressures and Doppler Waveforms



Study courtesy of Parks Medical Electronics

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Doppler Waveforms: Limitations

- Requires SKILL
- Junk signals
  - Obesity, scar tissue, occluded artery
- Venous interference (averaged signal)
- Subjective interpretation
- Usually no reason to perform DW and PVRs

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4. Exercise Stress Testing, Purpose:

- Differentiate true vascular claudication from "pseudo-claudication"
- Differentiate borderline normal from abnormal
- In patients with combined neuropathy and vascular disease, determine which condition is limiting walking.

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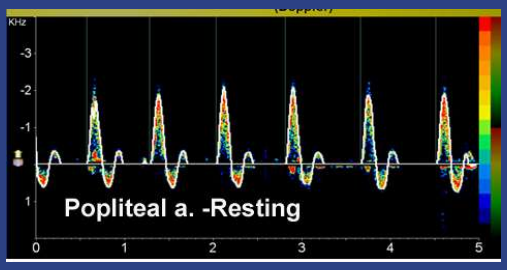
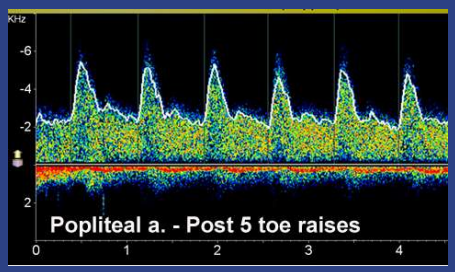
Popliteal Flow with 5 Toe Raises





R ↓ x Q ↑ F ankle P no change

Modified Poiseuille's Equation

All Images by R. Daigle

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Patients with Occlusive Disease

- During exercise, arteriolar vasodilation occurs
- Little or no increase in distal volume (collaterals are too small)
- Decrease in distal pressure

$$R \downarrow \times Q_{\text{no change or decrease}} = {}_{\text{ankle}}P \downarrow$$

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Post -Treadmill Serial Pressures

Manifested in intermittent CLAUDICATION (muscle ischemia)

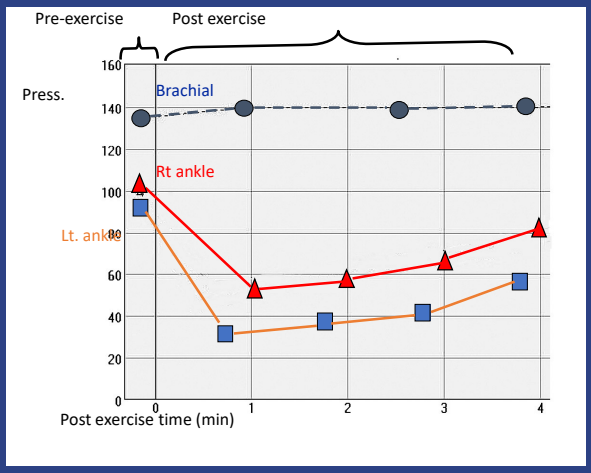

Image by R. Daigle

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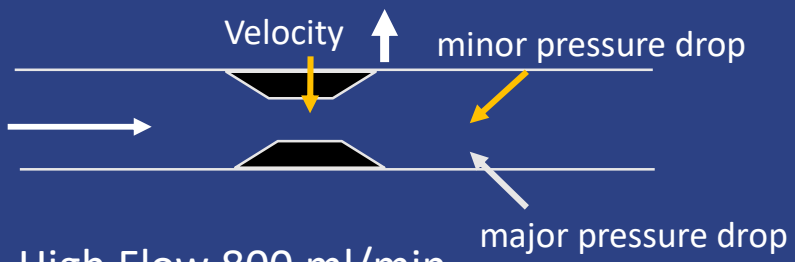
Poiseuille's law

Blood volume change over stenosis impacts distal perfusion

1. Low Flow e.g., 50 ml/min



2. High Flow 800 ml/min

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Candidates for Exercise

1. Intermittent claudicators
2. ABI 0.85 - 0.5 (arbitrary)
3. If resting study is normal, but patient has claudication, perform exercise
4. Borderline normal resting exam

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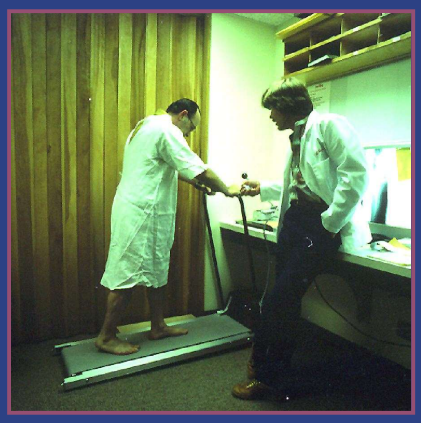
Treadmill Stress Test:

- Treadmill speed = 1.5 or 2 mph
- 5-10% grade- 5 minutes
- Note -the time of onset of claudication, and maximal walking time.
- Post-exercise ankle pressures- ASAP



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Post-treadmill Criteria for PAD

- A pressure decrease of ≥ 30 mmHg
- An ABI decrease of ≥ 20%
- Post-exercise ankle pressure of 60 mmHg or less confirms a vascular cause for claudication

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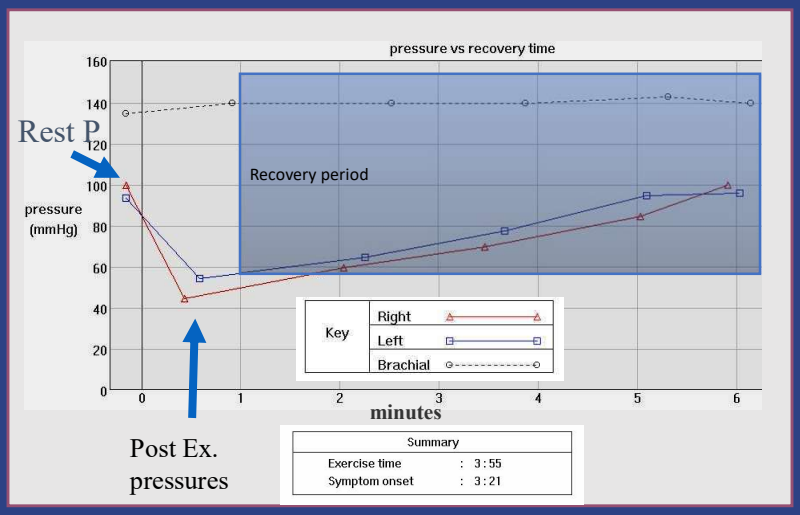
Post-Exercise Serial Pressures



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Contraindications for Treadmill Exercise

- Questionable cardiac status
- Resting ischemia (ABI ≤ 0.3)
- Ischemic ulceration
- Poor ambulators, poor gait, or balance disorder
- Normal resting study with resting symptoms (but no claudication)

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Toe Raises (Heel Lifts)

- Substitute for treadmill
- Toes raises for 1 minute
- Leave cuffs in place
- Obtain 1 set post-exercise ankle pressures and compare to resting pressures

Toe raises

Images source unknown

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Physiologic Testing Limitations

- Detects only hemodynamically significant disease
- Usually cannot distinguish stenosis from occlusion
- Region, but not site of disease
- Not good for aneurysmal disease
- Not good for bypass graft follow-up

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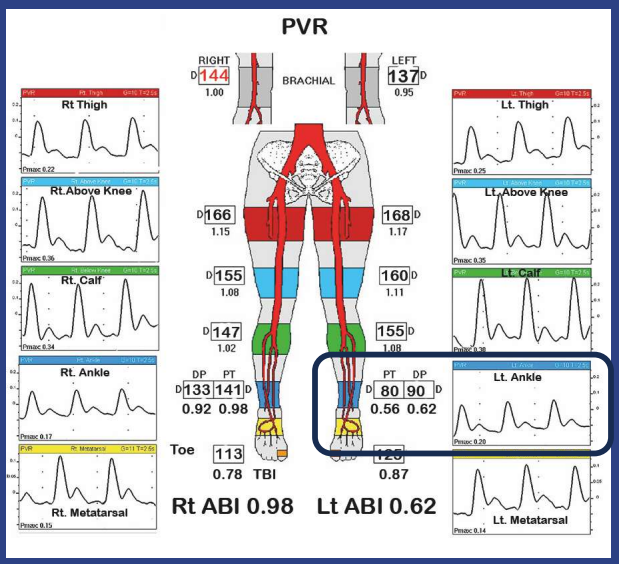
Check for Mismatched Data at Ankle Level

- If ankle pressures are low but waveforms are normal; pressures should be repeated



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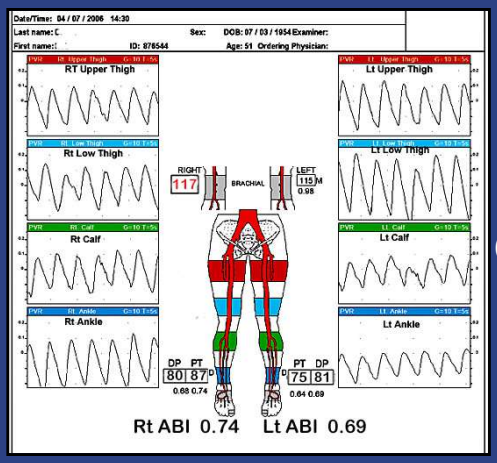
Recommended Protocol:
Segmental PVR with ABIs



Optional -toe pressures

CPT code 93923

Aorto-iliac disease bilaterally

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Add Exercise Stress Test in Appropriate Patients

CPT Code 93924
Bilateral study with motorized treadmill exercise test

CPT Code 93923
Bilateral study with "provocative" functional maneuvers

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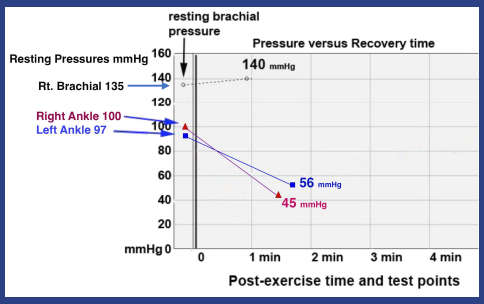
Post-Treadmill Exercise Data

- Bilateral ABIs
- Time
- Serial measurements (only if required)



Post-exercise ankle pressure ≤ 60 mmHg confirms a vascular etiology for claudication

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Thoughts on physiologic testing of lower extremities for PAD

- Remember the testing purpose(s)
  - PAD present?
  - Severity?
  - Symptomatic?
  - Region?
- There is a tendency to “over-read” physiologic arterial studies. Not necessary!

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Thoughts on physiologic testing of lower extremities for PAD

- Physiologic testing should be performed prior to color duplex imaging.
- Some physicians may prefer MRA over color duplex imaging
- Physiologic testing is very good at detecting symptomatic PAD

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FAQ

- Can I take pressures over a distal limb bypass graft?
  - *NO! but PVRs are OK.*
- Should I obtain serial post-exercise pressures with toe raises.
  - *NO. One (post) ABI is sufficient.*
- Are serial post-treadmill exercise pressure measurements necessary?
  - *Maybe-Technically yes for 93924 reimbursement, otherwise NO.*

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FAQ

- Post-treadmill exercise, what pressures should be first?
  - *Ankle on symptomatic limb, other ankle, then one brachial. Use the same resting data arteries.*
- Can PPG or Oscillometric devices be used for ABI's.
  - *Not for reimbursable CPT codes 93922-24. Also, oscillometric methods are inaccurate for low limb pressures.*

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