ASSESSMENT OF LOWER EXTREMITY PERFUSION: WHAT DO THE TEST RESULTS MEAN?

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Objectives

- What are the non-invasive tests for lower extremity PAD and how should we interpret them?

- What do the results mean for the patient and how should we use them to treat the patient?

Purpose of Noninvasive Arterial Testing

- Objectively confirm presence of PAD/ arterial ischemia
- Provide quantitative and reproducible physiological data concerning its severity
- Document location and hemodynamic significance of individual arterial lesions
- Monitor the progression of disease and impact of revascularization
- Monitor for restenosis after revascularization

- Comprehensive evaluation of PAD requires integration of Clinical (history and physical exam), Physiologic, and Anatomic (Imaging) information

Noninvasive Arterial Testing

- Direct
  - Duplex scanning of arteries (patency and flow in individual vessels)

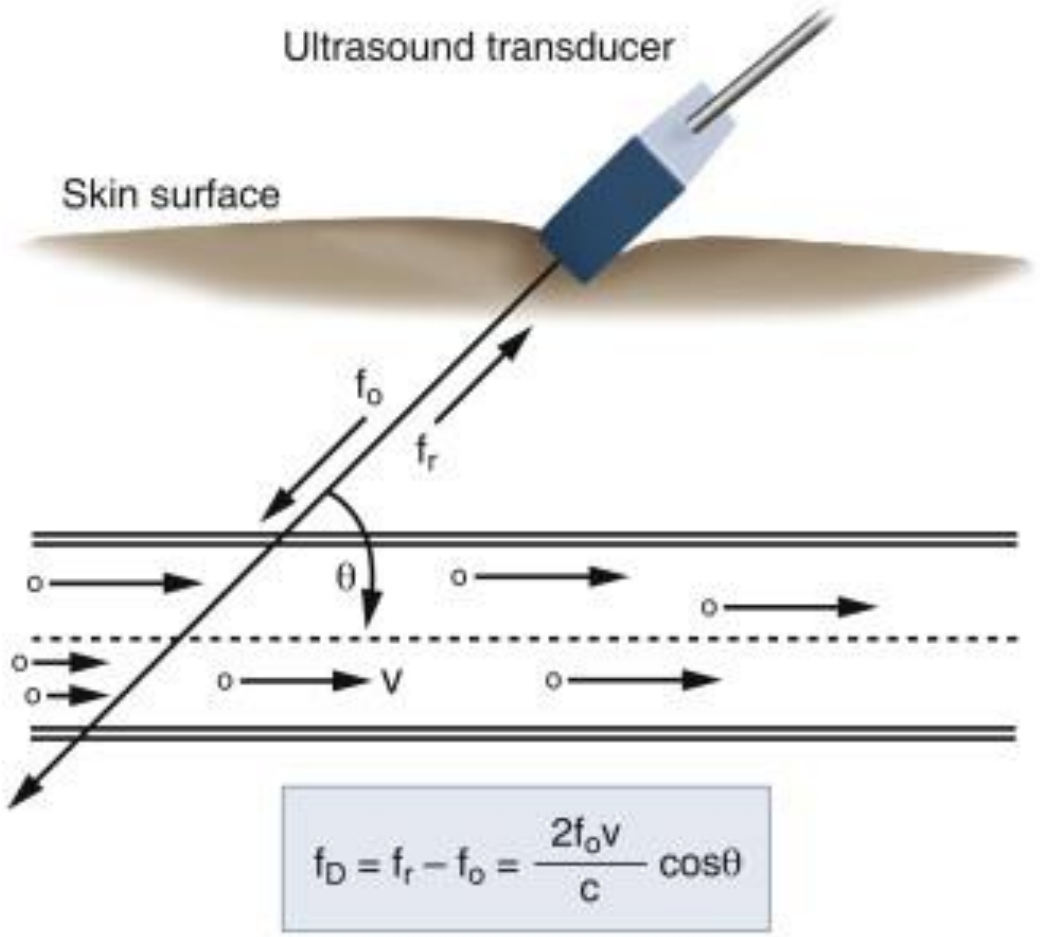
- Indirect
  - Provide crucial physiologic information about the perfusion of the whole limb
  - Use inference from accessible vessels to estimate degree of stenosis and disease
  - Analysis of velocity waveforms, pressure measurements, plethysmography

Non-Invasive Physiologic Vascular Testing

- “Pencil” Doppler
- Ankle-brachial indices
- Segmental pressures
- Toe-brachial indices
- Pulse volume recordings
- Exercise Stress Testing
- Duplex Imaging
- Transcutaneous Oxygen Tension
- Other

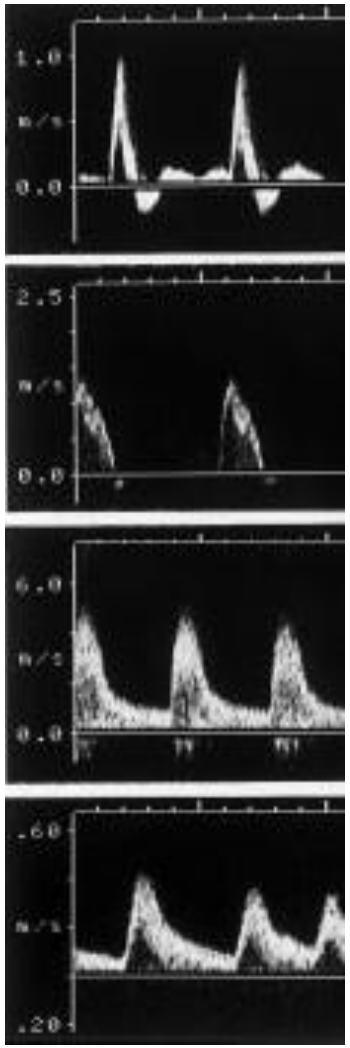
Doppler Ultrasound

- Detect blood flow velocity
- Hand-held continuous wave doppler detect frequency shifts, amplify it, and send it speakers
- Velocity of blood flow is proportional to frequency shifts and is heard a change in pitch of the audio signal



Doppler Analysis

- Aural Qualitative Interpretation (Bedside)
  - Absence of flow
  - ↑pitch= ↑ velocity= luminal narrowing
  - normal triphasic signal vs. dampened monophasic waveform (downstream from a significant stenosis)
- Quantitative Analysis
  - Spectrum analyzers



•Triphasic: normal artery

•Biphasic: mild stenosis, mildly increased velocity

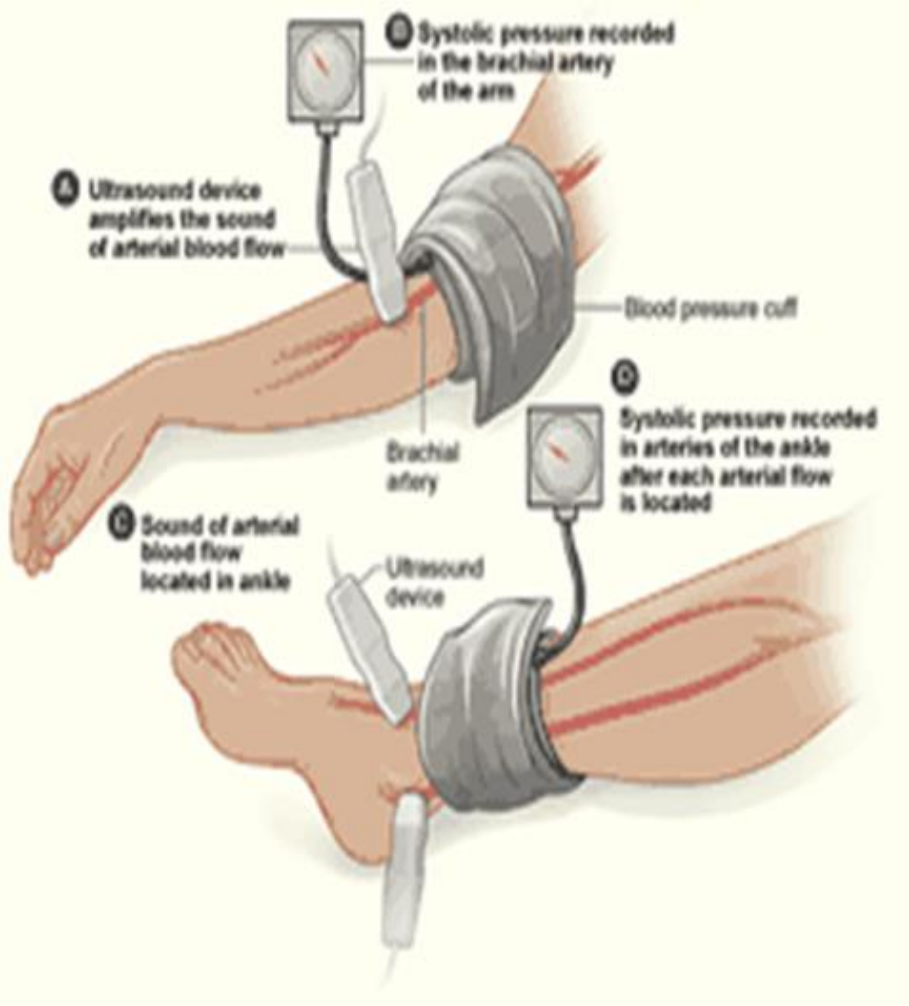
•Monophasic: tight stenosis, greatly increased velocity

•Dampened monophasic: distal to tight stenosis, reduced velocity

Pressure: Why it measures “perfusion”

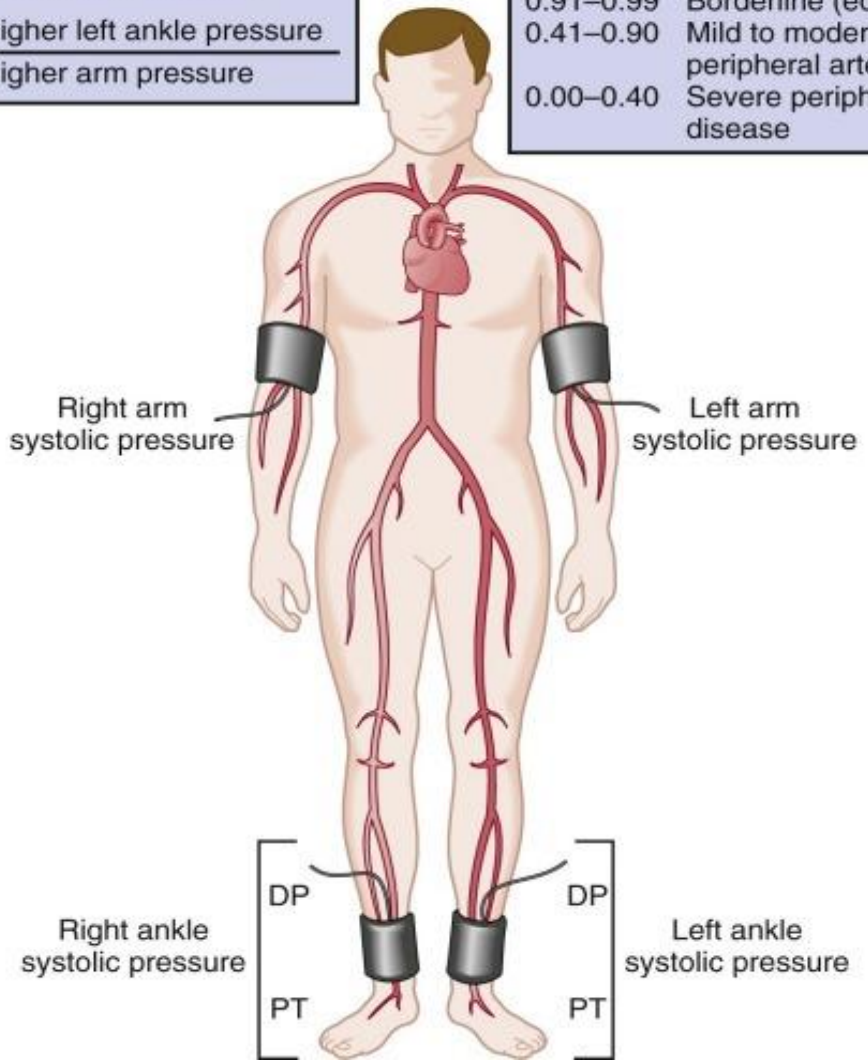
- Perfusion = Blood Flow (volume of blood/time/tissue mass)
- Flow is more difficult to measure than pressure
- Pressure differentials drive flow
- Pressures are an acceptable surrogate for flow

Ankle Brachial Index



Right ABI	Higher right ankle pressure / Higher arm pressure
Left ABI	Higher left ankle pressure / Higher arm pressure

Interpretation of ABI	
>1.30	Noncompressible
1.00–1.29	Normal
0.91–0.99	Borderline (equivocal)
0.41–0.90	Mild to moderate peripheral arterial disease
0.00–0.40	Severe peripheral arterial disease



Ankle–Brachial Index: Rationale

- Rationale:
  - Accounts for normal variation in central pressure throughout the day
    - Normalized value less variable than the central pressure alone
  - SD for ABI =0.07 → Change of .15 is significant
  - More accurate assessment of the leg: allow ankle pressure could reflect hypotension or PAD

Ankle Brachial Index: Limitations

- The absolute perfusion pressure is an important indicator of critical ischemia at a single point in time
- Significant bilateral subclavian or axillary artery occlusive disease may result in a falsely elevated ABI
- Chronic renal failure or diabetes: medial calcinosis of the popliteal and tibial arteries
  - Falsely elevated ABI
  - TBI/PVR useful
- Improper cuff size
- Although very sensitive(90%) and specific (90%), may not detect subclinical PAD

ABI and Extent of PAD

- ABI > 0.5: Single Vessel Disease
- ABI <0.5: Multilevel disease

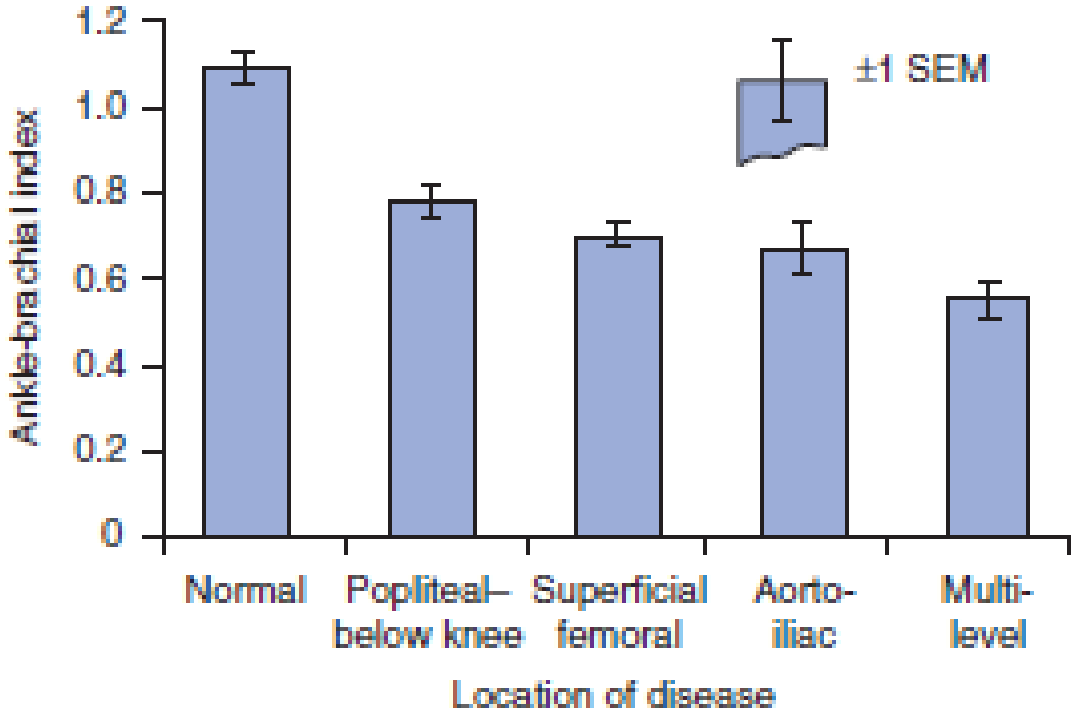
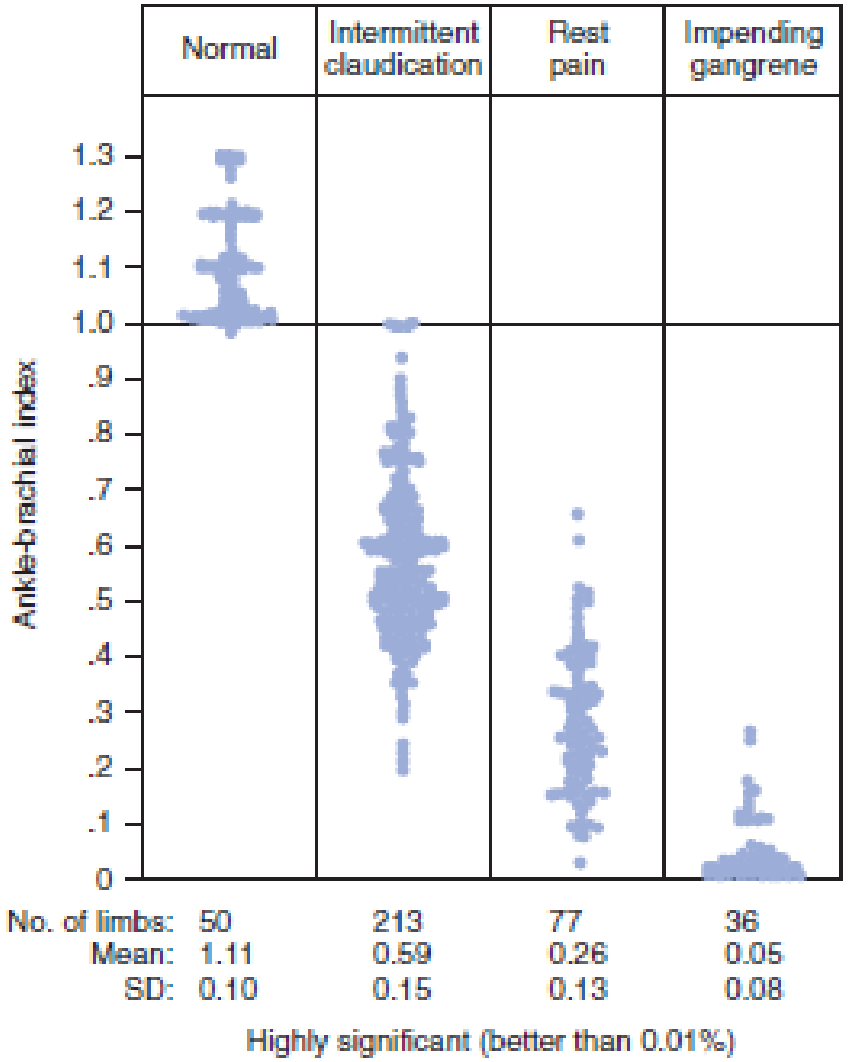


Figure 14-5 Resting ankle-brachial index (ankle systolic/arm systolic) measured in normal limbs and in limbs with arterial obstruction localized to different anatomic levels. SEM, standard error of the mean. *(Modified from Strandness DE Jr, Sumner DS. Hemodynamics for Surgeons. New York, NY: Grune & Stratton; 1975; data from Wolf EA Jr, Sumner DS, Strandness DE Jr. Correlation between nutritive blood flow and pressure in limbs of patients with intermittent claudication. Surg Forum. 1972;23:238.)*

Ankle-Brachial Indices and Clinical Symptoms



Functional Impairment	ABI
Noncompressible	>1.2
Normal	0.9-1.2
Claudication	0.7-0.9
Rest Pain	0.4-0.7
Tissue Loss	<0.4

Variability in correlation of ABI to symptoms given other patient comorbidities

Prognostic Value of the ABI for the Limb

- Limb Outcome in CLI

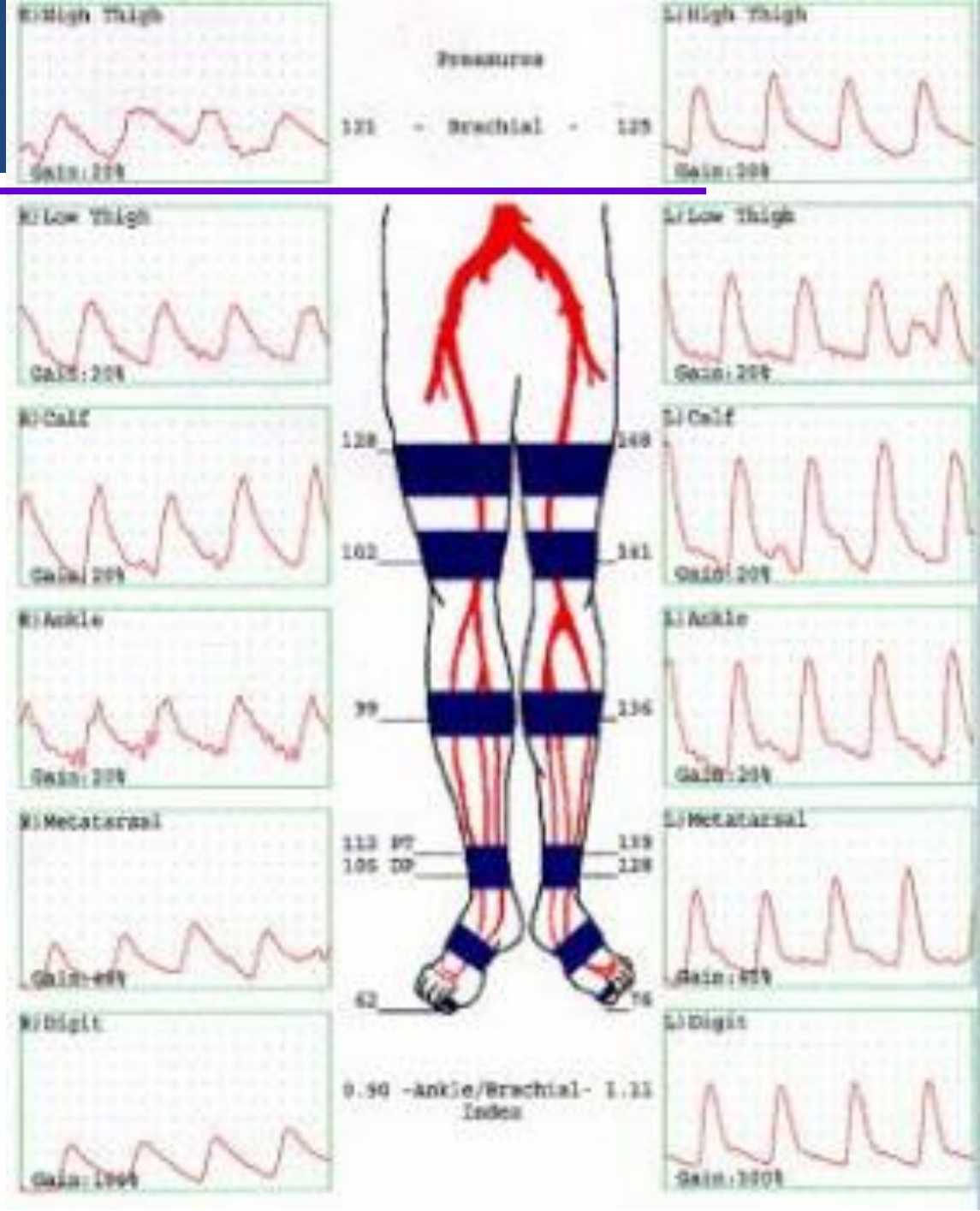
  Pressure required for healing of tissue loss

  - >60 mmHg in non-diabetics
  - >80 mmHg in diabetics
  - Interpret ABI with caution in patients with tissue loss
    - Index may seem adequate but pedal disease/ inaccurate angiosome perfusion may limit healing

- Limb Outcome in Claudicants
  - ABI > 0.5 infrequently associated with progression to CLI over 6 years
  - ABI < 0.5 and DM most frequently associated with progression from claudication to CLI

Segmental Pressures

- Determining level of disease with serial BP cuffs
- Gradients >20mmHg suggest significant obstruction
- Does NOT assess non-axial arteries
  - Normal gradients may be found in pts with disease if collaterals are large.
- Decrease in pressure ≥20mmHg signifies disease
  - ≥40 usually indicates occlusion
- Duplex mapping more commonly used



Segmental Pressures

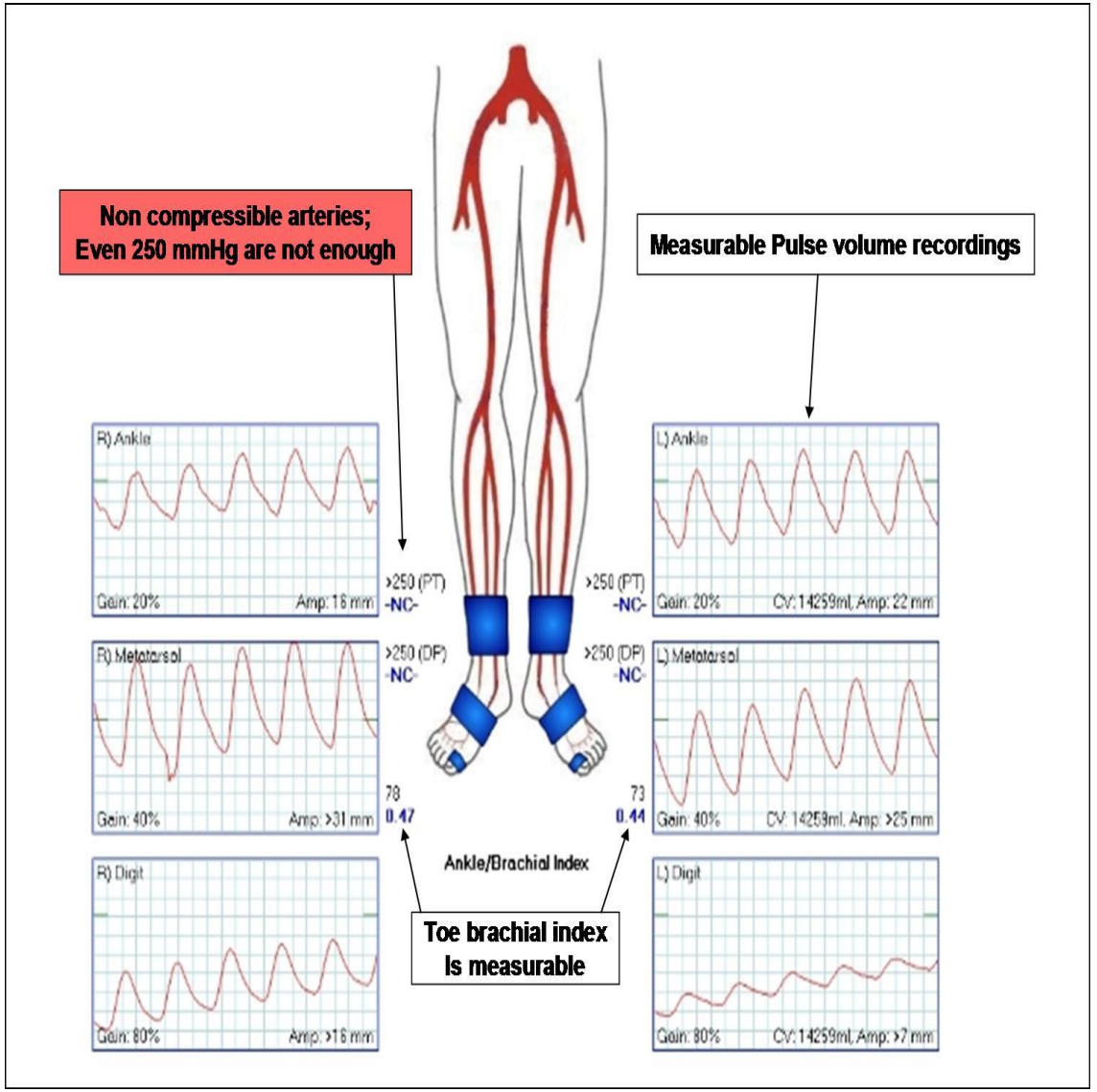
	Normal	Iliac	SFA	Iliac and SFA	Below Knee
Arm	120	120	120	120	120
Upper Thigh	160	110	160	110	160
Above Knee	150	100	100	70	150
Below Knee	140	90	90	60	140
Ankle	130	80	80	50	90

Digital (Toe) pressures

- Useful in patients with pedal artery occlusive disease or highly calcified vessels (incompressible)
- Normal digital waveforms/pressure in patients with calcified proximal vessels -> minimal restriction to blood flow
- Obstructive digital waveform/reduced pressure in presence of normal ankle pulses -> pedal artery occlusive disease or atheroembolism

Toe Pressures

- Pressures of 30 mmHg and lower associated with ischemic symptoms
- Foot lesions heal when pressure >30-40mmHg
- TBI
  - Less than 0.7 = abnormal
  - 0.2 to 0.69 = moderate arterial disease
  - Less than 0.2 = severe disease

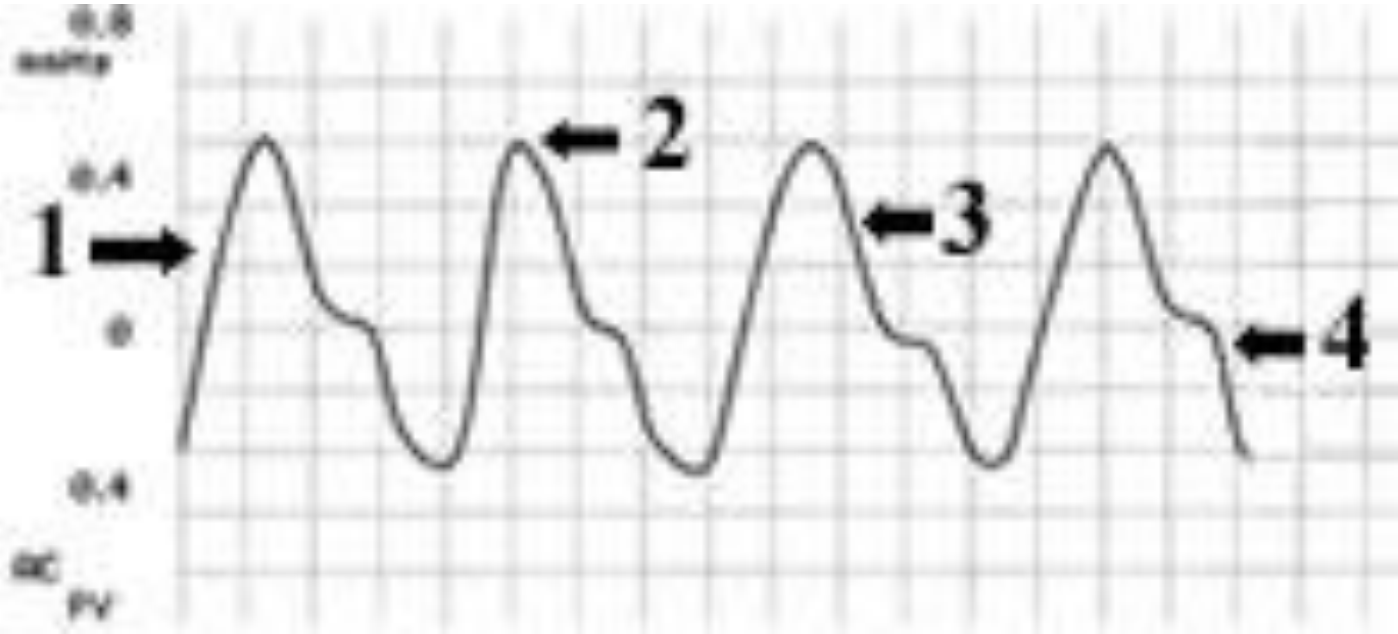


Plethysmography

- Based on detection of volume changes in the limb in response to arterial inflow
- Can be modified to produce pulse waveforms and determine digital pressures
- 3 types
  - Mercury strain gauge plethysmography
  - Air plethysmography (pulse volume recordings)
  - Photoplethysmography

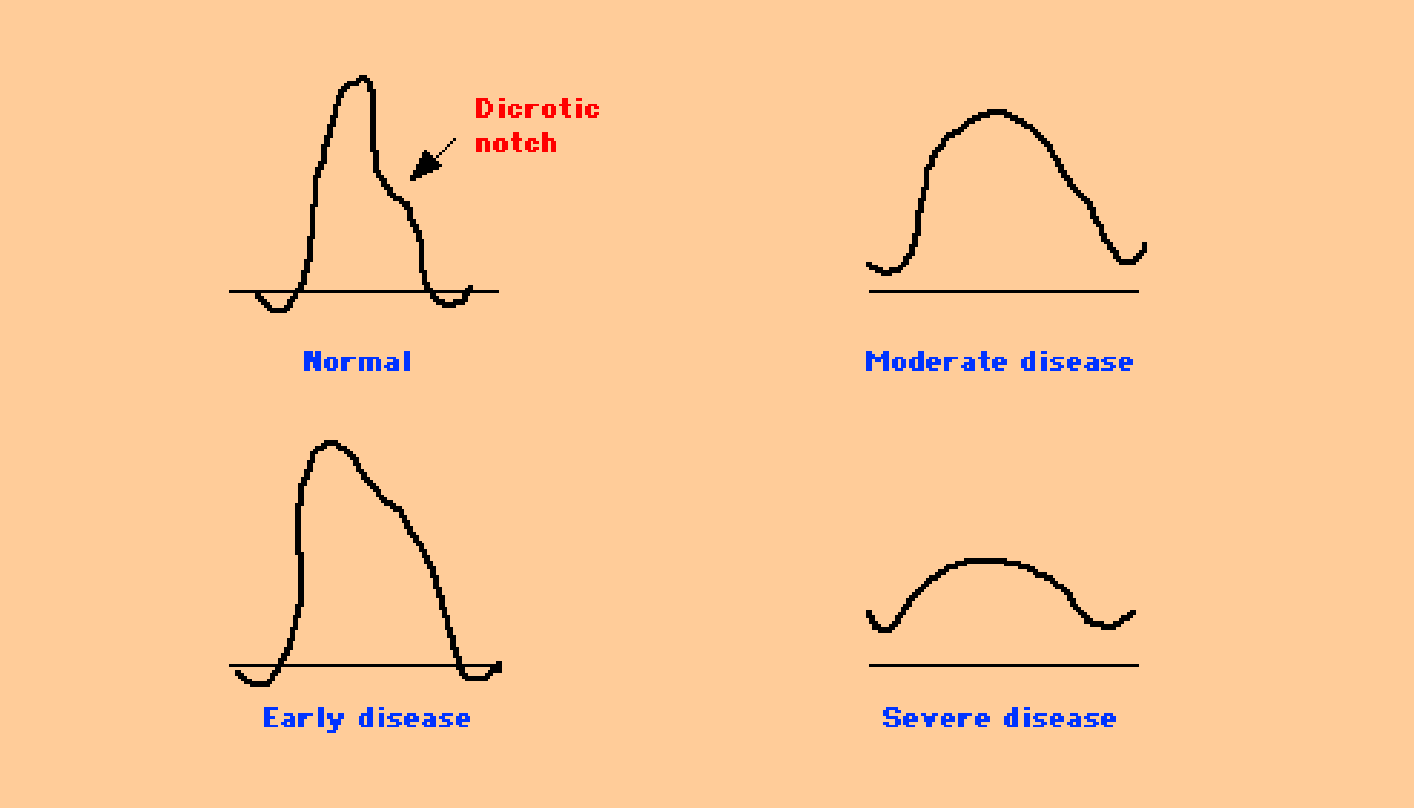
Air Plethysmography (Pulse Volume Recordings)

- Obtained with partially inflated segmental blood pressure cuffs that detect volume changes sequentially down a limb
- Normal pulse volume waveform:
  1. Sharp systolic upstroke
  2. Peak
  3. Downstroke
  4. Dicrotic notch



Pulse Volume Recordings

- Less affected by Arterial calcification
- More accurate with segmental pressures
- Small changes in limb volume that result from pressure changes with each pulsation are recorded as arterial contours

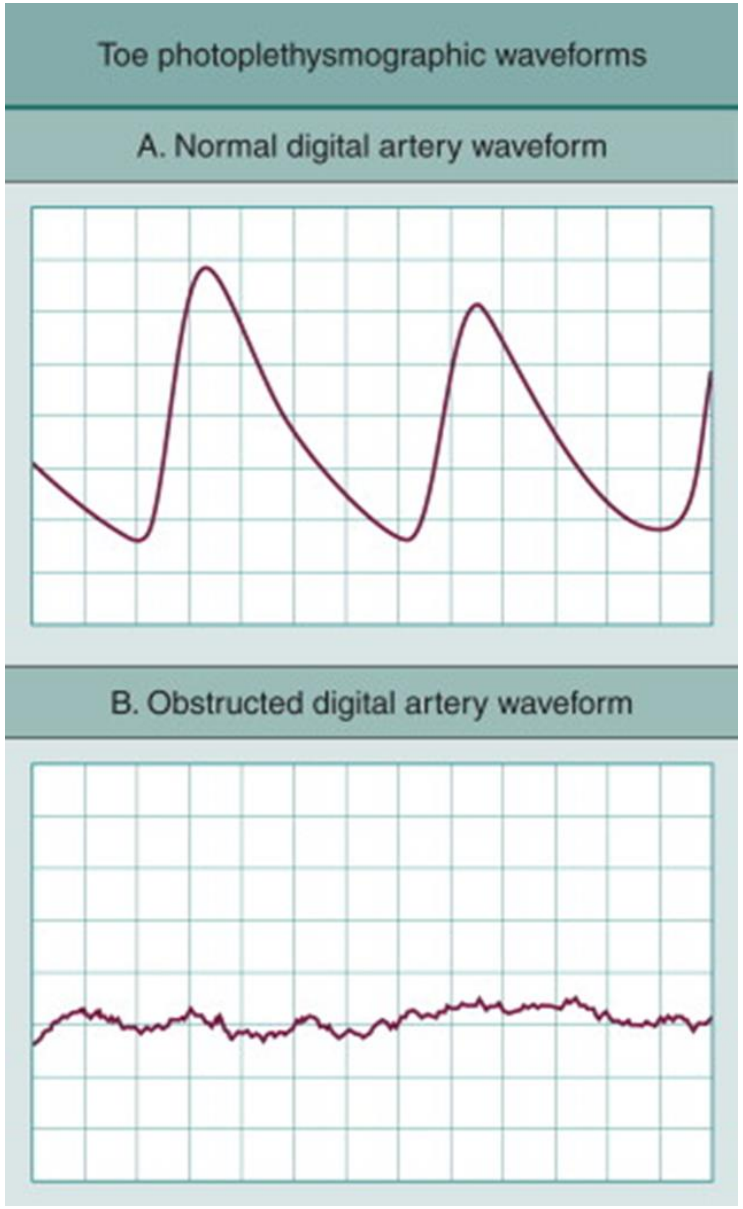


Air Plethysmography (Pulse Volume Recordings)

- Qualitative evaluation based on shape of curve
- Quantitative interpretive criteria not in widespread clinical use
- Lack of reliable, reproducible, quantitative data limits utility of PVR

Photoplethysmography

- Not a method to record volume change
- Photoelectrode detects changes in cutaneous blood flow
- Combination with pneumatic cuffs detects digital systolic pressures



Exercise Testing

- Patients with mild-moderate disease often have normal flow rates at rest.
- Exercise induces vasodilatation and increases flow, “unmasks” flow limiting lesion
- Measurement of Doppler-determined pressures can be combined with treadmill exercise testing
- Useful in a patient with symptoms of claudication who has palpable pedal pulses at rest and a normal or near-normal ABI

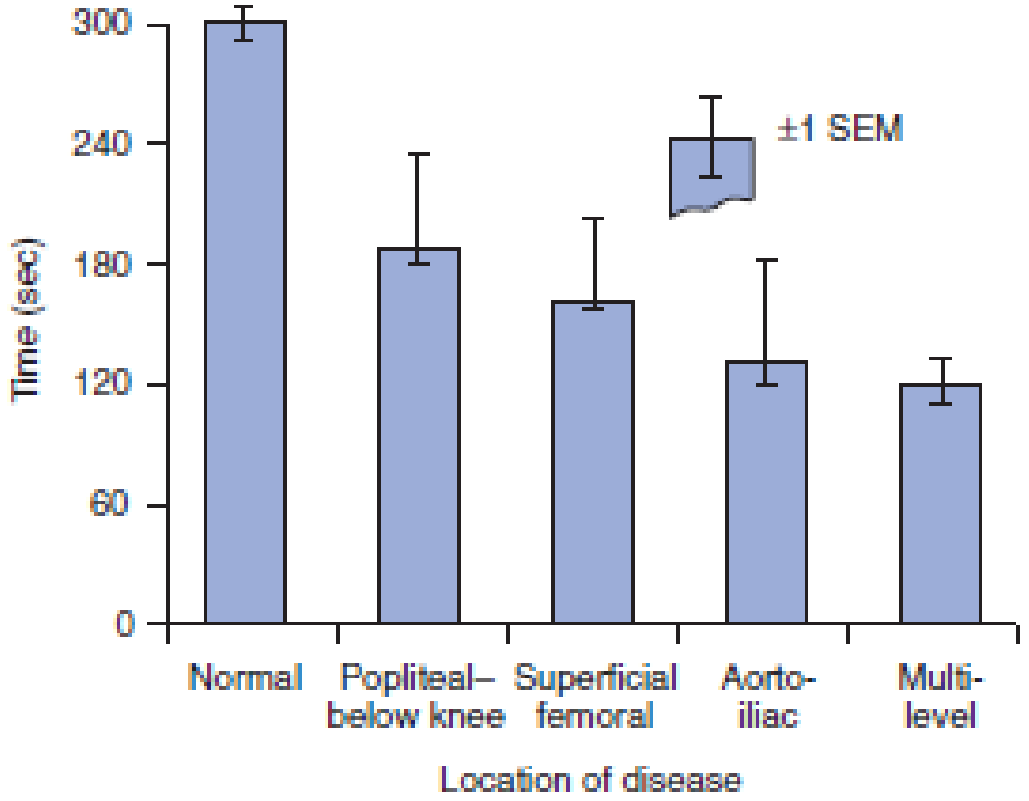
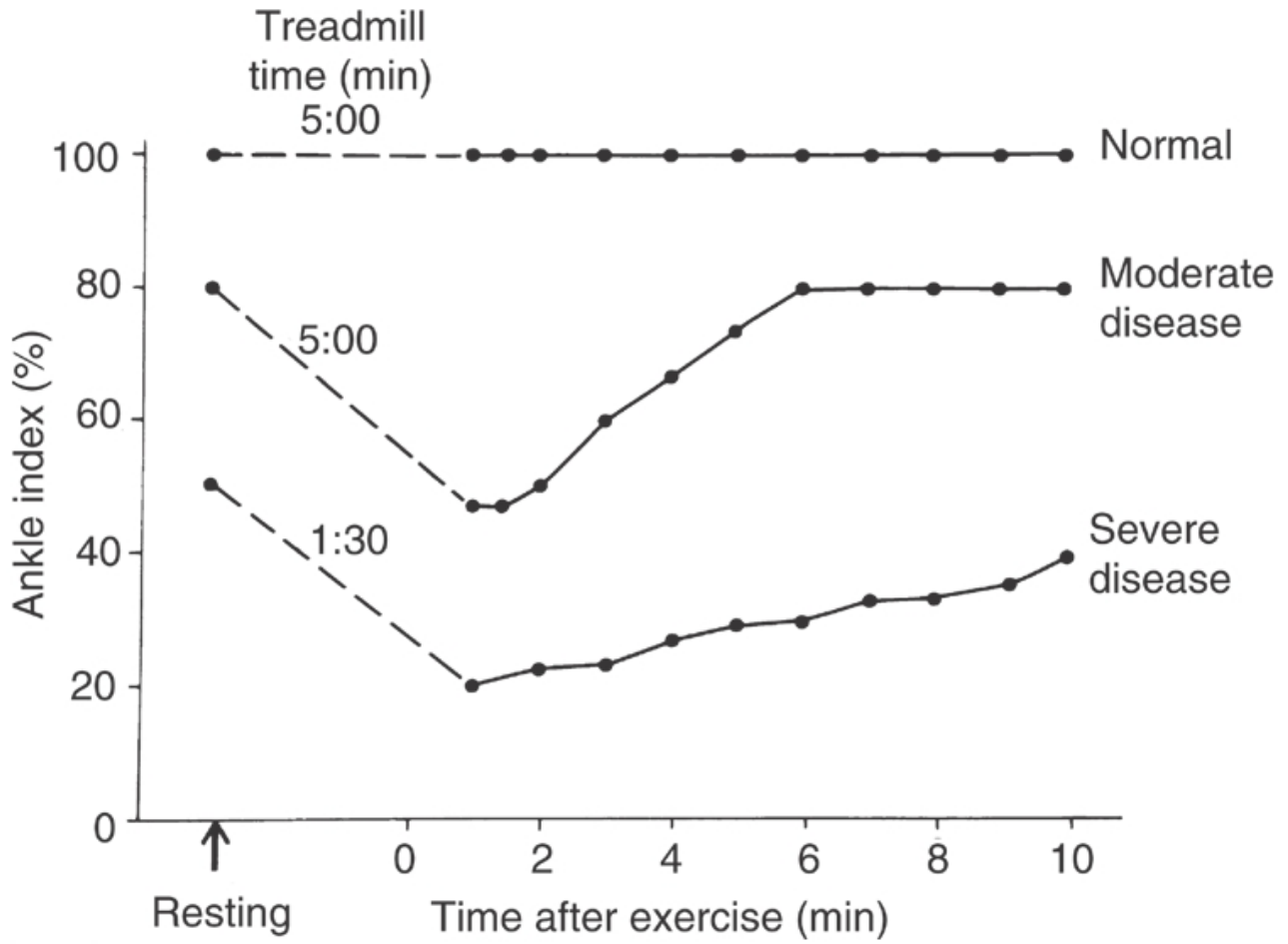


Figure 14-11 Treadmill walking times in patients with occlusive arterial disease. Normal subjects can almost always exceed 5 minutes (300 seconds). The treadmill is set at 2 miles per hour and a 12% grade. SEM, standard error of the mean. *(Modified from Strandness DE Jr, Sumner DS. Hemodynamics for Surgeons. New York, NY: Grune & Stratton; 1975.)*

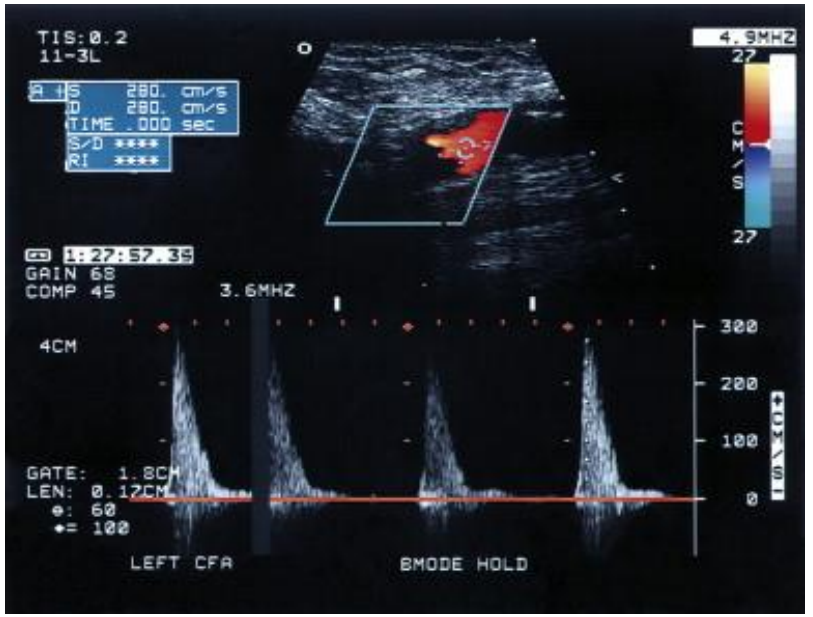
Exercise Stress Testing

- Pre and Post exercise ABIs compared
- Criteria for a positive exercise treadmill test
  - Decrease in absolute ankle pressure of 20 mm Hg
  - Decrease in ABI of 0.2 in symptomatic extremity
- Patients with claudication secondary to arterial insufficiency show a significant decrease in the post-exercise ABI



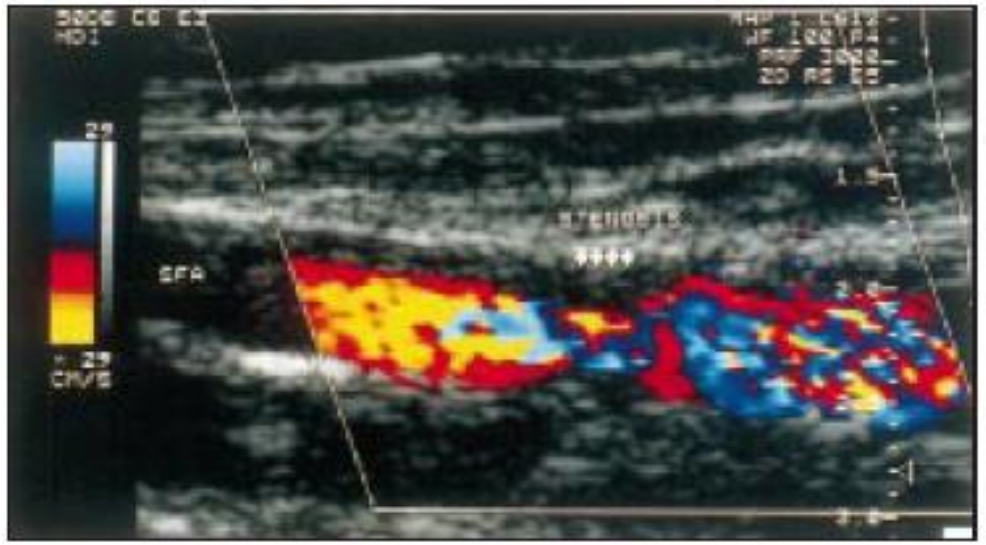
Peripheral Arterial Duplex

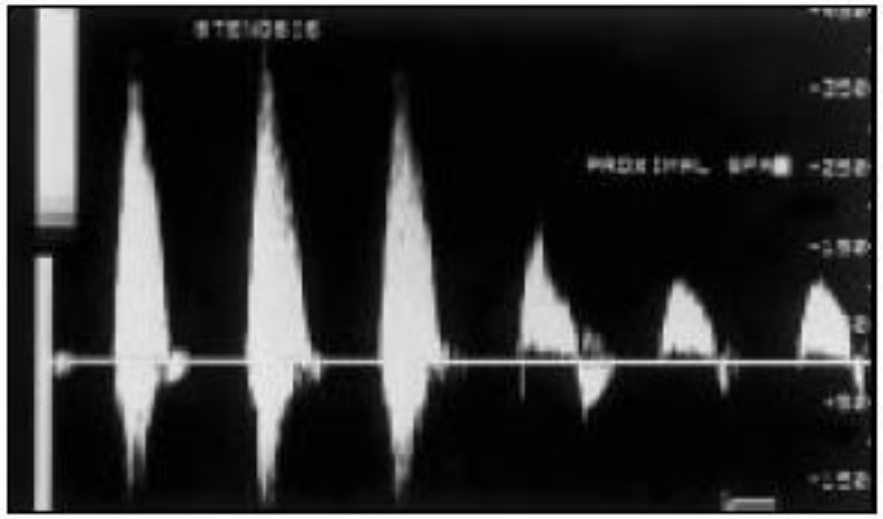
- Blood flow and anatomic Information
  - Blood flow=Pulsed Doppler spectral analysis
  - Anatomic=B-mode and color Doppler imaging
- Sensitivity (vs. angio) excellent
  - 90% at the iliac artery to 70% at the popliteal artery
  - 80-90% sensitivity for tibioperoneal arteries
- Sensitivity not influenced by the severity of atherosclerotic disease



Lower Extremity Occlusive Disease

- Maximum velocity at stenosis compared to velocity proximal to stenosis
- PSV ratio 1.5-2 / 1 = 30-49% stenosis
  2-4 / 1 = 50-75 % stenosis
  > 4 / 1 = > 75 % stenosis
- Occlusion characterized by gradual fall in velocity and absence of waveform





Transcutaneous Oxygen Tension ($tcPO_2$)

- Reflect metabolic state of target tissue
- Quantifies)2 molecules transferred to skin after heating
- Values > 55 mm hg are considered normal
- Patients with CLI: tcPO2 20-20 mmHg
- Wound healing requires tcPO2 > 40 mm Hg
- most helpful in severe ischemia
  - not impact by calcification (DM)
- determining level of amputation
  - Measured dorsum of foot, 10 cm below and 10 cm above knee
- Response to hyperbaric therapy (100% O2 inhalation)
- Influenced by many factors (age, weight, temp, edema, ect..)
- Time consuming

Other non-invasive tests of microcirculation

- Laser Doppler
- Vasoreactivity
- Capillaroscopy
- pulp skin flow
- iontophoresis

- None routinely utilized

Rutherford Classification of Chronic Limb Ischemia

Table II. Clinical categories of chronic limb ischemia*

Grade	*Category*	*Clinical description*	*Objective criteria*
0	0	Asymptomatic—no hemodynamically significant occlusive disease	Normal treadmill or reactive hyperemia test
	1	Mild claudication	Completes treadmill exercise†; AP after exercise >50 mm Hg but at least 20 mm Hg lower than resting value
I	2	Moderate claudication	Between categories 1 and 3
	3	Severe claudication	Cannot complete standard treadmill exercise† *and* AP after exercise <50 mm Hg
II*	4	Ischemic rest pain	Resting AP <40 mm Hg, flat or barely pulsatile ankle or metatarsal PVR; TP <30 mm Hg
III*	5	Minor tissue loss—nonhealing ulcer, focal gangrene with diffuse pedal ischemia	Resting AP <60 mm Hg, ankle or metatarsal PVR flat or barely pulsatile; TP <40 mm Hg
	6	Major tissue loss—extending above TM level, functional foot no longer salvageable	Same as category 5

AP, Ankle pressure; *PVR*, pulse volume recording; *TP*, toe pressure; *TM*, transmetatarsal.
*Grades II and III, categories 4, 5, and 6, are embraced by the term chronic *critical* ischemia.
†Five minutes at 2 mph on a 12% incline.

Hemodynamics and Probability of

Corollary:

A broad range of perfusion deficits may be limb-threatening in specific circumstances, depending on severity of tissue loss and concomitant factors

The utility of a single threshold value for “critical limb ischemia” in the presence of tissue loss is questioned

Andersen CA J Vasc Surg 2010; 52:Suppl S

The Society for Vascular Surgery Lower Extremity Threatened Limb Classification System: Risk stratification based on Wound, Ischemia, and foot Infection (WIfI)

Joseph L. Mills, Sr, MD,[a] Michael S. Conte, MD,[b] David G. Armstrong, DPM, MD, PhD,[a] Frank B. Pomposelli, MD,[c] Andres Schanzer, MD,[d] Anton N. Sidawy, MD, MPH,[e] and George Andros, MD,[f] on behalf of the Society for Vascular Surgery Lower Extremity Guidelines Committee, *Tucson, Ariz; San Francisco and Van Nuys, Calif; Brighton and Worcester, Mass; and Washington, D.C.*

- **W**ound: extent and depth
- **I**schemia: perfusion/flow
- **F**oot **I**nfection: presence and extent

Excluded: acute limb ischemia, emboli/"trash foot", trauma, vasculitides, pure venous ulcers, neoplastic disease, radiation

J Vasc Surg 2014; 59(1) 220-34

Wound Grade – *Clinical Category*

Grade	Clinical Description
0	Ischemic rest pain; Pre-gangrenous skin change, without frank ulcer or gangrene (Pedis or UT Class 0)
1	Minor tissue loss: small shallow ulceration) < 5 cm^2 on foot or distal leg (Pedis or UT Class 1); no exposed bone unless limited to distal phalanx
2	Major tissue loss: deeper ulceration(s) with exposed bone, joint or tendon, ulcer 5-10 cm^2 not involving calcaneus – (Pedis or UT Classes 2 and 3); gangrenous changes limited to digits. *Salvageable with multiple digital amps or standard TMA ± skin coverage*
3	Extensive ulcer/gangrene > 10 cm^2 involving forefoot or midfoot; full thickness heel ulcer > 5 cm^2 + calcaneal involvement. *Salvageable only with complex foot reconstruction, nontraditional TMA (Chopart/Lisfranc); flap coverage or complex wound management needed*

Ischemia Grade – *Noninvasive Assessment*

Grade	ABI	Ankle SP	TP
0	≥ 0.80	≥ 100 mm Hg	≥ 60 mm Hg
1	0.60-0.79	70-99 mmHg	40-59 mm Hg
2	0.40-0.59	50-69 mm Hg	30-39 mm Hg
3	< 0.40	< 50 mm Hg	< 30 mm Hg

ABI=ankle brachial index; SP= systolic pressure; TP=toe pressure

FI: FOOT INFECTION: SVS Grades 0 (none), 1 (mild), 2 (moderate), 3 (severe)

Grade	Clinical Description	IDSA	IWGDF Class
0	wound without purulence or manifestations of infection	uninfected	1
1	>2 manifestations of infection (erythema or purulence, pain tenderness, warmth or induration) any cellulitis or erythema extends < 2cm around ulcer; infection is limited to skin or subcutaneous tissues; no local complications or systemic illness	mild	2
2	Infection in patient who is systemically and metabolically stable but has ≥1 of the following: cellulitis extending 2cm, lymphangitis; spread beneath fascia; deep tissue abscess; gangrene; muscle, tendon, joint or bone involvement	moderate	3
3	Infection in patient with systemic or metabolic toxicity	severe	4

Risk of amputation	*Proposed clinical stages*	*WIfI spectrum score*
Very low	Stage 1	W0 I0 fI0,1
		W0 I1 fI0
		W1 I0 fI0,1
		W1 I1 fI 0
Low	Stage 2	W0 I0 fI2
		W0 I1 fI1
		W0 I2 fI0,1
		Wo I3 fI0
		W1 I0 fI2
		W1 I1 fI1
		W1 I2 fi0
		W2 I0 fI0/1
Moderate	Stage 3	W0 I0 fI3
		W0 I2 fI1,2
		W0 I3 fI1,2
		W1 I0 fI3
		W1 I1 fI2
		W1 I2 fI1
		W1 I3 fI0,1
		W2 I0 fI2
		W2 I 1 fI0,1
		W2 I2 fi0
		W3 I0 fi0,1
High	Stage 4	W0 I1,2,3 fI3
		W1 I1 fI3
		W1 I2,3 fI2,3
		W2 I0 fi3
		W2 I1 fI2,3
		W2 I2 fi1,2,3
		W2 I3 fI0,1,2,3
		W3 I0 fI2,3
		W3 I1,2,3 fI0,1,2,3

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Stage 1
- Minimal ischemia; no/minor TL
- Not in strict “CLI” definition

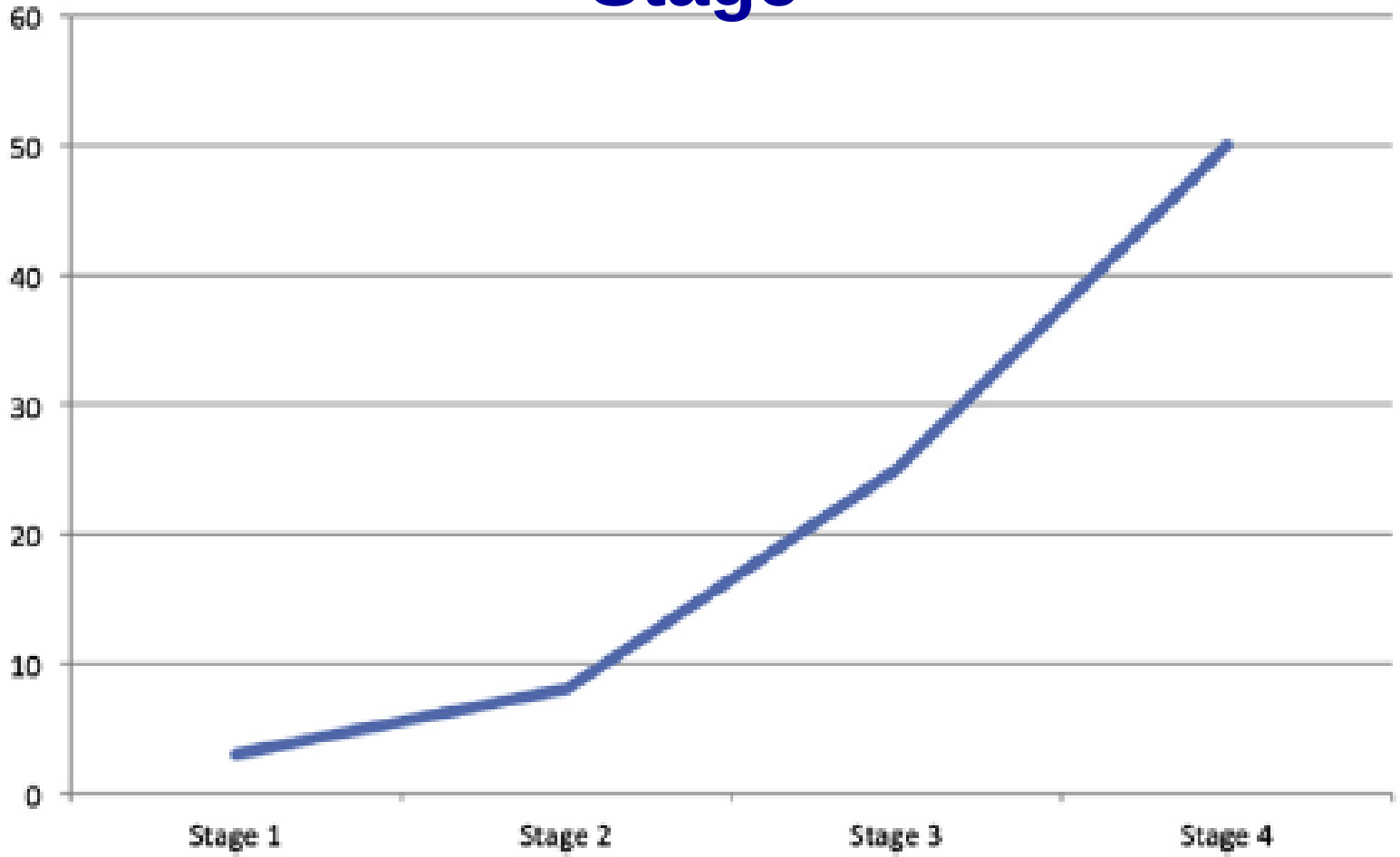
Stage 2
- Stage 1 with more infection
- Rest pain without infection
- Minor tissue loss/ mod infection

Stage 3
- Range of tissue loss/ischemia
- Mild to mod infection

Stage 4
- Advanced in one or more categories

- <u>Stage 5 : unsalvageable foot</u>

Estimated 1-Year Amputation Risk by Stage



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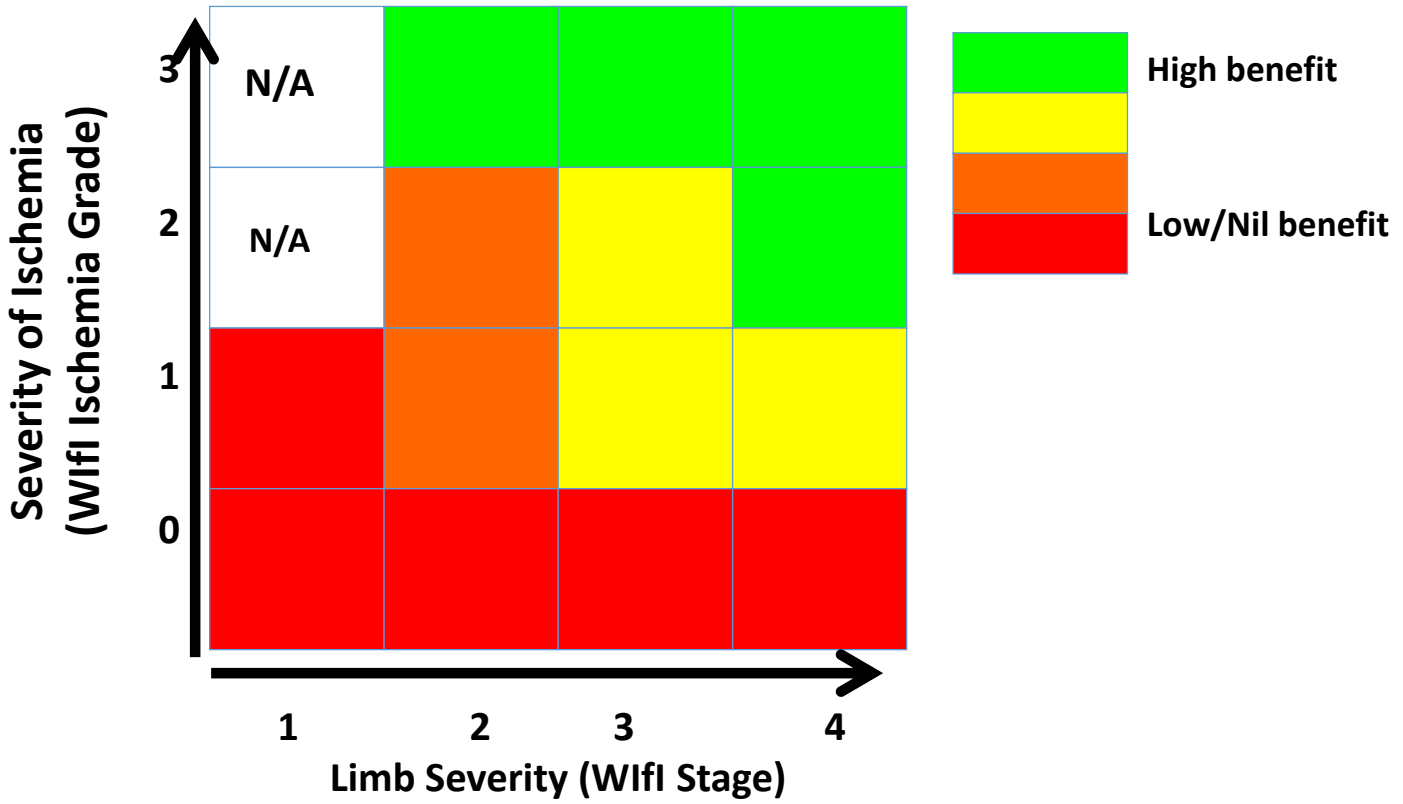
Risk of amputation versus WIfI Stage: Compilation of published data

Study (year): # Limbs at Risk	Stage 1	Stage 2	Stage 3	Stage 4
Cull (2014):151	37 (3%)	63 (10%)	43 (23%)	8 (40%)
Zhan (2015): 201	39 (0%)	50 (0%)	53 (8%)	59 (64%)*
Darling (2015): 551	5 (0%)	111 (10%)	222 (11%)	213 (24%)
Causey (2016): 160	21 (0%)	48 (8%)	42 (5%)	49 (20%)
Beropoulis (2016): 126	29 (0%)	42 (2%)	29 (3%)	26 (12%)
Ward (2016): 98	5 (0%)	21 (14%)	14 (21%)	58 (34%)
Darling (2017): 992	12 (0%)	293 (4%)	249 (4%)	438 (21%)
Robinson (2017): 262	48 (4%)	67 (16%)	64 (10%)	83 (22%)
Mathioudakis (2017): 279	95 (6.5%)	33 (6%)	87 (8%)**	64 (6%)***
N = 2820 (weighted mean)	291 (**3.2%**)	728 (**6.8%**)	803 (**8.5%**)	998 (**24%**)
Median (% 1 year amputation)	**0%**	**8%**	**8%**	**22%**

Benefit of revascularization varies with severity of limb threat and ischemia



Limb staging and appropriateness of revascularization

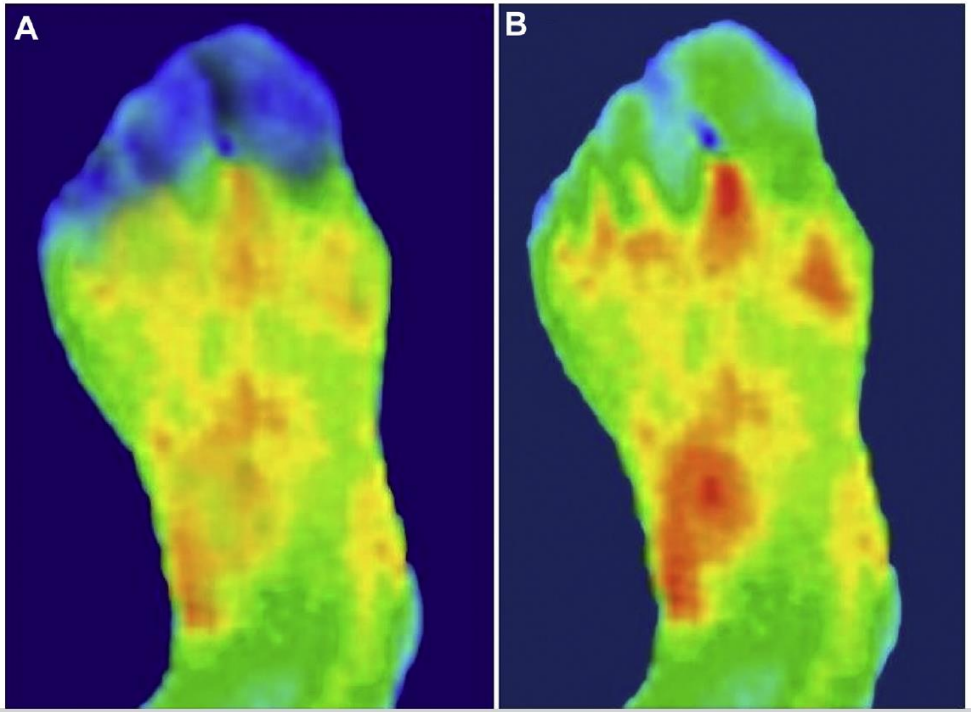
- CLTI represents a range of limb severity and ischemia as described in WIfI staging.
- Severe ischemia (WIfI ischemia grade 3) mandates revascularization for limb salvage
- With increased stages of limb threat (WIfI stages 3, 4) moderate degrees of ischemia (grades 1, 2) may be appropriate to address
- Low risk limbs (WIfI Stage 1) should be treated with wound care; revascularization should be reserved for failure to heal (50% within 4-6 weeks) or clinical signs of deterioration
- Not indicated for Ischemia grade 0

Assessment of lower extremity ischemia using smartphone thermographic imaging

Peter H. Lin, MD,[a,b] *and* Marius Saines, MD,[b] *Houston, Tex; and Los Angeles, Calif*

ABSTRACT

Conventional diagnostic modalities for assessing arterial circulation or tissue perfusion include blood pressure measurement, ultrasound evaluation, and contrast-based angiographic assessment. An infrared thermal camera can detect infrared radiation energy from the human body, which generates a thermographic image to allow tissue perfusion analysis. We describe a smartphone-based miniature thermal imaging system that can be used as an adjunctive imaging modality to assess tissue perfusion. This smartphone-based camera device is noninvasive, simple to use, and cost-effective in assessing patients with lower extremity tissue perfusion. Assessment of patients with lower extremity arterial ischemia can be performed by a variety of diagnostic modalities, including ankle-brachial index, absolute systolic ankle or toe pressure, transcutaneous oximetry, arterial Doppler waveform, arterial duplex ultrasound, computed tomography scan, arterial angiography, and thermal imaging. We herein describe a noninvasive imaging modality using smartphone-based infrared thermography. (J Vasc Surg Cases and Innovative Techniques 2017;3:205-8.)



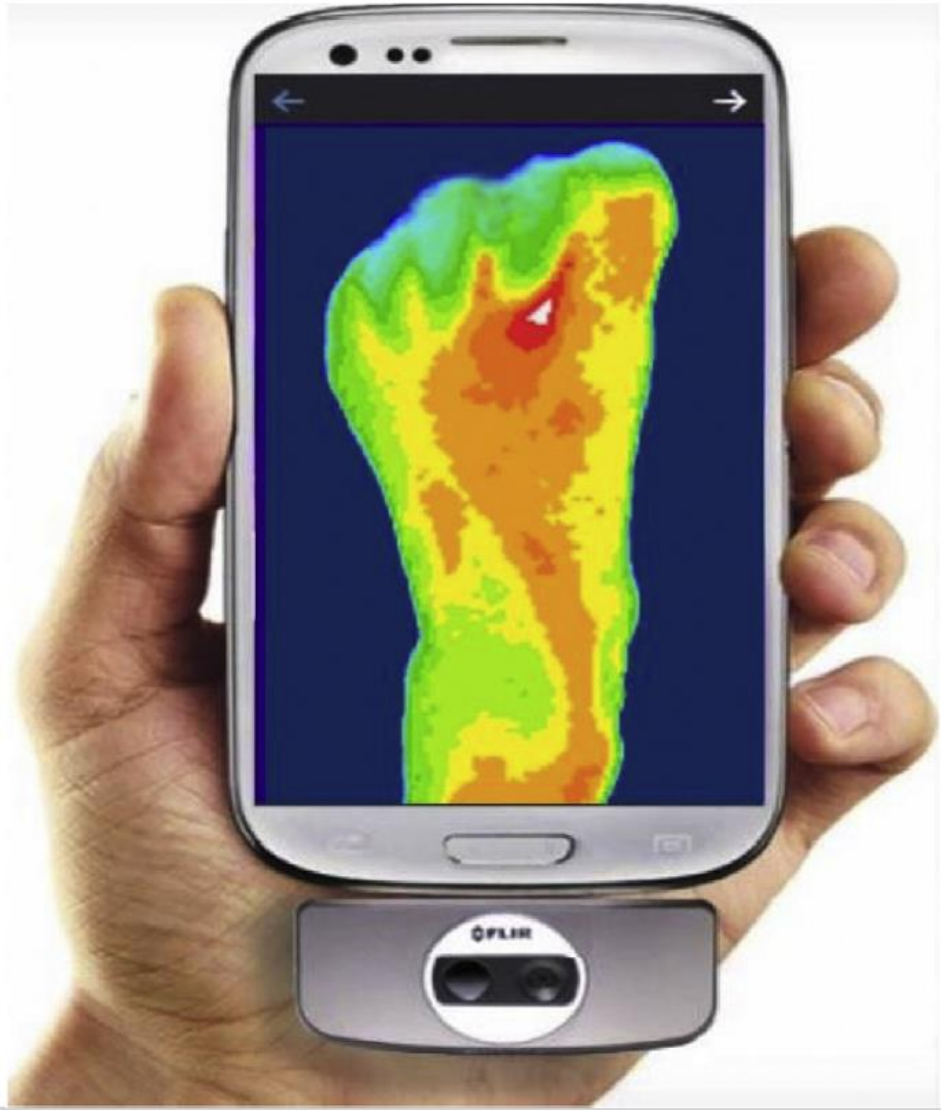


Fig 2. A, Preoperative infrared thermography in a patient (patient 2) with ischemic rest pain in the left foot and toes. **B,** Postoperative infrared thermography after femorotibial artery bypass demonstrated significant improvement in tissue perfusion in the toes.

Conclusions

- Noninvasive testing plays a crucial role in evaluation of PAD
- Guides further invasive testing and treatment
- Important to utilize both indirect (physiologic) and direct (duplex) testing to understand the pathophysiology of each patient
- Interpretation of the tests is not necessarily “cookbook” or algorithmic….comprehensive evaluation of PAD requires integration of clinical, non-invasive physiologic, and anatomic information