Arterial Physiologic Testing: 
Is It Worth the Effort? 
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INDIRECT Vascular Ultrasound Procedure 
What Is Physiologic Testing? 

• Direct: Image based, site-specific assumptions, e.g. Duplex 
• Indirect: Non-image based, Indirect / physiologic assumptions 

Arterial Physiologic Testing Equipment 

• CW / PW Doppler 
• PVR 
• Limb Pressures 
• PPG 
• OPG 
• APG 
• TcPO2 
• Laser Doppler 
• Temperature
Primary Features: Pressures / CW Doppler / PVR / PPG

• Primary Use—UE/LE peripheral arterial disease (PAD) evaluations
• Secondary Use—TOS / Raynaud’s / LE Vein Reflux / Steal / Allen Test
• Multimodality Console—Testing, Printer, DICOM and Report Functions

What Can Physiologic Tests Do...That Duplex Can't

Obvious Questions ...Obvious Answers

• PAD diagnostic algorithms do NOT start with duplex
• Duplex vs Physio...Physiologic much less costly
• Duplex vs Physio...Physiologic are easier learn/operate
• Time vs Reimbursement...Physiologic exams are most cost effective

Arterial Physiologic Testing—What It Does

 Defines Global versus Focal Hemodynamics

• Duplex Equipment
  → Provides site-specific (focal) hemodynamic data
• Physiologic Equipment
  → Reflects global hemodynamics (Pressure / PVR)
  □ Primary + Secondary vessels evaluated beneath cuff
THE Lower Extremity Global Hemodynamic Indicator

Ankle-Brachial Index (ABI)

* Ratio to express global hemodynamic status of lower extremity
  -- Highest Systolic Brachial / Ankle (PT / AT / DP) Pressure (mmHg)
  -- Example: Highest Brachial: 100·90 Ankle mmHg PT = 0.90 ABI

Lower Extremity Global Hemodynamic Indicator

Reflects Clinical Presentation...and...Functional Severity

<table>
<thead>
<tr>
<th>Clinical Presentation</th>
<th>Disease Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>Normal 0.97—1.25</td>
</tr>
<tr>
<td>Claudication</td>
<td>Mild 0.75—0.96</td>
</tr>
<tr>
<td>Mild</td>
<td>Moderate 0.50—0.74</td>
</tr>
<tr>
<td>Moderate</td>
<td>Severe &lt; 0.50</td>
</tr>
<tr>
<td>Severe</td>
<td>Critical &lt; 0.30</td>
</tr>
<tr>
<td>Rest Pain</td>
<td>Calcified 1.40</td>
</tr>
</tbody>
</table>

* Clinical and Disease Severity categories vary—"In General":
  -- 1.00 = Normal 0.90—1.00 = Borderline < 0.90 = Abnormal
  -- ABI: > 0.50 = Single Level < 0.50 = Multi-Level PAD
  -- ABI: < 0.20 = Limb threatening with impending tissue death

Functional Severity...Example

Duplex--It’s BAD...BUT...HOW Bad?

* What is the clinical presentation of this patient?
  -- Claudication
  -- Rest Pain
  -- Impending Tissue Death
**Functional Severity...Example**

**Duplex—It’s BAD...But...HOW Bad?**

- **Significant Right SFA Stenosis**
- **Occlusion Left Mid-SFA**

<table>
<thead>
<tr>
<th>Right</th>
<th>Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT = 0.56</td>
<td>PT = 0.42</td>
</tr>
<tr>
<td>DP = 0.69</td>
<td>DP = 0.34</td>
</tr>
<tr>
<td>530/22 cm/sec</td>
<td>0 cm/sec</td>
</tr>
</tbody>
</table>

- **Stenosis Ratio:** 7.2
- **Absent Doppler Signal**

* Yes...PAD (LT > RT)...but impending tissue death...NO !
* Right: Clinical=Moderate claudication / Disease Severity=Moderate
* Left: Clinical=Severe claudication / Disease Severity=Severe

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**ABI—Defines Global Hemodynamics...And MORE**

**The Great Predictor**

* **Ankle-Brachial Index (ABI):**
  - Surrogate marker of atherosclerosis elsewhere in body
  - Predictor of future cardiovascular events and mortality

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**ABI—Defines Global Hemodynamics...BUT**

**Should We Report Highest...or...Lowest ABI?**

- ABI used to detect PAD...
- PAD considered major indicator for coronary heart disease

*Alternative Ankle-Brachial Index Method Identifies Additional At-Risk Individuals*


Reporting ONLY highest ABI may incorrectly classify at-risk cardiovascular patients as “Normal”...report **both** posterior tibial and dorsalis pedis ABI
Is It Real…Or…Something Else?

**Functional Severity—Treadmill Testing**

- **Differentiates**
  - "True" (PAD) Claudication
  - "Pseudo" (Musculoskeletal / Neurogenic)
- **Fixed Load Treadmill Exam**
  - 2mph…12% grade…Max 5-min; or, intolerable symptoms
- **Variable Load Treadmill Exam**
  - 0-2 min 1mph 0% grade 2-4 min 1.5 mph 3% grade
  - 4-6 min 2mph 2% grade 6-10 min 2mph 12% grade

*Provide pre-treadmill instructions; monitor patient closely:
ANY indication of cardiac problem—chest pain/SOB—STOP exam
* Document…If / When / Where…symptoms occur on extremity(s)
* Consult MD—Rest pain; Amputation; Walking disability; Ulcer
* Monitor Post-X (10 min Max)—Use highest PRE-exercise PT or DP

**Pre-Exercise ABI**
Right: PT = 1.16
Left: PT = 1.13

**Post-Exercise ABI**
Right: PT = 1.41
Left: PT = 1.20

* NORMAL—NO drop (typically increased) ankle pressures / ABI
* NOTE: Controversy—Use ABI…or…absolute Pre/Post ankle pressure?

**Pre-Exercise ABI**
Right: PT = 0.82
Left: PT = 0.57

**Post-Exercise ABI**
Right: PT = 0.29
Left: PT = 0.13

* ABNORMAL—Significant pressure / ABI decrease (> 0.15)
  -- ABI Return to Baseline…2-6min = Single level…>10min = Multi-level
Arterial Wall Calcification: Non-Diagnostic ABI

• ABI in patients with diabetes is unreliable—usually attributed to medial calcinosis, which stiffens arteries and makes them poorly compressible

• Abnormal /Falsely elevated ABI varies by author—typically ≥1.3 or ≥1.4

• Toe arteries less prone to medial calcinosis and toe-brachial index (TBI) surrogate for ABI in patients with medial calcinosis/falsely elevated ABI

ABI Global Hemodynamics—Exception To Rule

Arterial Wall Calcification

Pressure / ABI Variations

* Wall calcifications would need similar alignment for similar pressures

* Wall calcification realignment variations cause pressure / ABI variability

Toe Brachial Index (TBI)—ABI Surrogate

Relationship To Peripheral Arterial Disease (PAD)

TBI

Normal  ≥ 0.80
Borderline  0.60—0.79
Abnormal  < 0.60
Claudication  0.20—0.50
Rest Pain  < 0.20

• Protocol ...typically digital pressure cuff + PPG or PVR sensor
  – Primary technical problem—No digital waveform—No TBI

• TBI relationship to PAD varies by author—abnormal generally < 0.60

• Absolute toe pressure < 30 mmHg good indicator wound will not heal
### Toe Brachial Index (TBI)

**Protocol**

- **TBI:** Toe systolic pressure ÷ Highest brachial pressure

  - Digital pressure cuff placed around proximal phalanx of toe
  - PPG sensor positioned on plantar pad of the distal phalanx
  - Cuff inflated supra-systolic pressure, until pulsations disappear
  - Systolic toe pressure is the initial reappearance of pulsatile flow

### Absolute Systolic Pressure: Calf, Ankle, Toe

**Predictor of Wound Healing Potential**

- **Non-Diabetic:** ankle pressure > 60 mmHg suggests rest pain unlikely
  -- < 35 mmHg ankle pressure suggests rest pain is likely present

- **Diabetic:** ankle pressure > 80 mmHg suggests rest pain is unlikely
  -- < 40 mmHg ankle pressure suggests rest pain is likely present

- **Ischemic foot ulcers are unlikely to heal with absolute ankle pressure < 40-50 mmHg in NON-diabetics and < 80 mmHg in diabetic patients**

- **Calf pressures > 65-70 mmHg typically sufficient to heal BK amputation**

### Transcutaneous Oximetry (Tcp02)

** Defines Cutaneous Tissue Perfusion / Healing Potential **

- **Tcp02**
  - Reflective of oxygen supply at skin level
  - Useful for treatment decisions in diabetic patients with foot ischemia and non-diabetics with chronic ischemia
  - Severe limb ischemia—Tcp02 value LESS than 20 mmHg
  - Inadequate tissue perfusion to support wound healing
    -- Tcp02 values LESS than 30 mmHg
Mr. Digital-Know-It-All

Arterial Photoplethysmography (PPG)

• Extremity Obstructions, Embolic events, Vasospasm and Impingement impact microvasculature of upper and lower extremity digits

• PPG: Primary method for determining hemodynamic impact to digits

• PPG: Not true plethysmography device—does not measure changes in volume
  -- Phototransistor measures light (infrared) intensity variations associated with perfusion changes within tissue capillaries

Mr. Digital-Know-It-All

PPG / PVR Waveforms: Normal / Abnormal

• Obstructive arterial disorders impacting digital hemodynamics are readily defined with arterial photoplethysmography (PPG)

  NORMAL
  • Dicrotic notch—present
  • Downslope curve TOWARD baseline
  • Sharp systolic upstroke (~1/5th sec)
  • Rapid diastolic deceleration

  ABNORMAL
  • Dicrotic notch—absent
  • NO inward downslope curve
  • Delayed systolic upstroke
  • Prolonged diastolic deceleration

Evaluating Digital Hemodynamic Impairment

PPG Finger Pressure + Waveform Analysis

<table>
<thead>
<tr>
<th>Abnormal DBI</th>
<th>Normal DBI</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.80</td>
<td>≥ 0.80</td>
</tr>
</tbody>
</table>

Abnormal

Brachial-Digit Difference: ≥30 mmHg

Digital Brachial Index (DBI): Digit Brachial Pressure

NOTE: Controversy—calculate DBI with ipsilateral...or...highest brachial?
Mr. Digital-Know-It-All

PPG Waveforms—Vasospasm

Primary Raynaud’s / TOS  Secondary Raynaud’s

* Intermittent vasospasm—anacrotic notch (“nipple peak”) or “dual peak”—commonly noted in primary Raynaud’s and TOS
* Long term vasospasm can produce digital arterial obstructions

Evaluating Hemodynamic Impact At Digital Level

Palmar Arch Patency—Allen Test

* Palmar Arch Patency—Allen Test
  → Helps define patency of deep/superficial palmar arch
  → Often combined with PPG analysis for digital obstruction
  → Common requirement prior to creating hemodialysis fistula
  → Crucial prior to radial artery harvest for coronary bypass graft

Palmar Arch Patency

Allen Test: Protocol and Interpretation

* Digit location varies—thumb, 1st, 2nd, 5th—obtain baseline PPG amplitude
* Verify Radial AND Ulnar location—compress simultaneously—PPG Flatline
* With Radial compression ONLY—PPG Flatline—ULNAR artery is dominant
* With Ulnar compression ONLY—PPG Flatline—RADIAL artery is dominant
* NO significant amplitude change—Radial or Ulnar compression—NORMAL
**Thoracic Outlet Syndrome (TOS) Manuevers**

- **Documenting using slow (2–5 mm/sec) chart speed...easier to evaluate**
  - Secure PPG with tape and practice maneuver with patient
  - Obtain baseline height...perform maneuver...end maneuver...verify
  - Perform basic maneuvers...ALWAYS include symptomatic maneuver

- **NEGATIVE:** No change (or increase)...PPG waveform amplitude

- **POSITIVE:** Significant decrease or flatline...PPG waveform amplitude
Impingement Disorders—Popliteal Entrapment

- Popliteal Entrapment—uncommon compression disorder of popliteal artery by adjacent gastrocnemius muscle and/or tendon structures
  - Chronic microtrauma that can lead to early arteriosclerosis and/or thrombus formation resulting in distal ischemia

- Patients typically young—<30 yo; 15:1 male tendency; bilateral 20-66%

- Young male athletes with calf claudication—2/3rds may have PopEntrap

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Popliteal Entrapment Maneuvers

- Interpretation
  - Document using slow (2–5 mm/sec) chart speed...easier to evaluate
    - Secure PPG with tape...practice maneuver with patient
    - Obtain baseline height...perform maneuver...end maneuver...verify
  - NEGATIVE: NO change (or increase)...PPG waveform amplitude
  - POSITIVE: Significant decrease or flatline...PPG waveform amplitude

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Evaluating Hemodynamic Impact At Digital Level

Dialysis Access Steal

- ALL dialysis access grafts steal arterial flow from native artery
- Steal occurs because of high vascular resistance in outflow bed (muscle) versus much lower resistance in dialysis access graft

- 4-Levels of Dialysis Steal
  - Level 1: Asymptomatic
  - Level 2: Pain with exertion or during dialysis
  - Level 3: Pain during rest
  - Level 4: Tissue necrosis
PPG—Dialysis Steal Evaluation

Protocol / Interpretation

- Two Protocol Variations—both evaluate amplitude changes
  - Method-1: slow chart speed (2-5 mm/sec)...obtain baseline amplitude
  - Method-2: normal 25 mm/sec chart speed...obtain baseline amplitude

- Interpretation: PPG Steal Evaluation WITH Dialysis Compression
  - Insignificant = NO significant amplitude / waveform change
  - Significant = Major amplitude INCREASE / improved waveform contour

Questions—Answers—Tips—Comments—Controversy

Tip

How To Minimize PVR Waveform Cuff Artifact

- Minor extremity tremors are magnified with direct table contact
- Wrap pool noodle in exam table sheet—elevate heels/cuffs off table
Question / Answer

Does ICAVL Require Segmental Pressures AND Waveforms?

* NO…unless YOU want both as part of your protocol
  (Arterial Section: 3.4.1.8)

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Question / Comment

Can We Perform CW Doppler AND PVR On Arterial Exams?

* Sure…but you can only charge 93923…ONCE
  HOW would you use this data?
  What reference shows improved outcomes?

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Question / Controversy

What's Better—CW Doppler…or…PVR?

* PVR Waveforms
  - Less known…“doesn’t look like Doppler”
  - Specific waveform calibration parameters
  - Simple to obtain…interpretation variability

* Doppler Waveforms
  - Easier to relate—“looks like duplex”
  - Multiple technical issues…operator dependent
  - Longer learning curve…conflicting definitions
Controversy / Comment
Doppler Waveforms Are Easier To Understand Than PVR

MULTIPHASIC
Kupper (Burnham), 1984
TRIPHASIC
Zierler, Duplex Scanning in Vasc Ultrasound, 2010
BIPHASIC
Zierler, Vascular Surgery, 2005
MONOPHASIC
Zwiebel / Pellerito, Intro Vasc Ultrasonography, 2005
SHARP MONOPHASIC
Spronk S. J Vasc Surg, 2005

* Same waveform...5-definitions—is this easier to understand ?
* Beware...tri-, bi-, monophasic definitions are not standardized !!!

Question / Answer
Do You Need Treadmill For LE Exercise Exams?

* No...you can have patient walk...perform toe-ups, foot dorsiflexion...or reactive hyperemia...BUT
  -- If you charge 93924...you must use treadmill

Question / Controversy
Are Segmental Blood Pressures Worthwhile ?

Lower extremity arterial evaluation:
Are segmental arterial blood pressures worthwhile?

Segmental thigh/calf/ankle waveform analysis in combination with ABI was was more accurate than segmental waveforms + thigh/calf pressures and ABI

When compared to objective waveform characterization, brachial to thigh cuff differences had significantly lower Sensitivity, Specificity, Positive (PPV), Negative Predictive Values (NPV) and overall Accuracy

Comparison of subjective vs objective lower extremity arterial plethysmographic waveform analysis for identifying hemodynamically significant inflow disease: Scissons R, Comerota A. SVU National Conference, 2013
How Can You Make Analyzing Physiologic Exams Easier?

1) Review pressure / waveform exam separately
   -- Pressures: >20mmHg differences (one level to next; side to side)
   -- Waveforms: Significant changes (slow acceleration; low amplitude)

2) Use 4 Disease Categories: Inflow; Outflow; Runoff; Multi-Level
   -- Reconcile differences; base final decision on criteria with best correlation [pressures; waveforms; waveforms+pressures+ABI]

   • INFLOW (CFA or above)
     -- Thigh Pressure
     -- Thigh PVR / CFA CW-Waveform

   • OUTFLOW [AKA—Femoropopliteal]
     -- Calf Pressure
     -- Calf PVR / PopA CW-Waveform
     -- Calf PVR waveform augmentation

   • RUNOFF [AKA—Outflow; Tibioperoneal]
     -- PT / DP Ankle Pressure
     -- Ankle PVR / PT-DF CW-Waveform

What's Easiest Way To Define Level of Disease With PVR?

Waveform "Pattern" Recognition

* Waveform pattern recognition easiest..."best" method harder to answer
**Controversy: "Objective" PVR Waveform Analysis**

What's Easiest Way To Define Inflow Disease With PVR?

- Thigh PVR Waveform: 46 (non-diabetic) extremities
  - Acceleration Time: start of systole to mid-peak systole
  - Downslope Curvature: In/Even/Out bow from waveform baseline
- Positive Predictive Value—79%  Negative Predictive Value—96%

- < 50% Inflow
  - 0.28 sec acceleration time; inward downslope curvature
  - < 0.28 sec acceleration time; even downslope curvature
- ≥ 50% Inflow
  - > 0.28 acceleration time; outward or even downslope curvature

Comparison of subjective vs objective lower extremity arterial plethysmographic waveform analysis for identifying hemodynamically significant inflow disease

Scissons R, Comerota A. SVU National Conference, 2013

**Conclusions**

**Physiologic Testing**

- Physiologic Testing
  - Indirect / Non-imaging vascular ultrasound procedure
  - Reflects global hemodynamic condition of extremity

- Physiologic Testing Data
  - Provides digital hemodynamic information
  - Used as surrogate marker for atherosclerosis elsewhere in body
  - Helps define O2 supply at skin level and wound healing potential
  - Helps evaluate vasospastic, impingement and digital steal disorders

- Physiologic Testing
  - In most instances it is more cost effective than duplex
  - In given instances it cannot be supplemented by duplex
  - In given instances it provides more information than duplex