Neurovascular Course
TCD Portion

Welcome to Winston-Salem, NC, WFUSM, and the Center for Medical Ultrasound

Course Overview
- Schedule
- Sign slips for CME
- Introductions
- Textbooks
- Food, restrooms, bookstore, phones
- Applications for ASN, NSRG, AIUM
- Special needs

Transcranial Doppler
Principles and Techniques

Charles H. Tegeler, MD
McKinney-Avant Professor of Neurology
Director, Comprehensive Stroke Center
Director, B-Mode Ultrasound Center
Director, Neurosonology Lab
WFUSM

TCD Principles and Techniques
- Review of Doppler principles and physics
- Pertinent anatomy
- Basic TCD methods
- Transcranial Color Duplex

Transcranial Doppler
- Low frequency Doppler (2 MHz)
- Penetrate thin portions of skull/foramina (temporal, orbital, suboccipital)
- Provides Doppler data/hemodynamic info
- Done with blind probe or color duplex
- Study of large arteries at base of brain
Sound

- **Sound is a wave**: Propagating variations in acoustic variables of pressure, density, particle motion and temperature
  - Waves transmit energy from one place to another
  - Sound waves require a medium to travel through - Sound cannot pass through a vacuum

Describing a Wave

- **Frequency**
- **Wavelength**
- **Period**
- **Amplitude**
- **Intensity**
- **Propagation Speed**

Frequency

- The number of complete cycles (variations) in one second
- Expressed in hertz (Hz) and megahertz (MHz)
- Human hearing: 20Hz to 20 kHz
  - < 20 Hz = infrasound
  - > 20 kHz = ULTRASOUND

Propagation Speed

- Speed of the sound wave as it travels
  - Independent of the frequency and amplitude of the wave and determined by the stiffness and density of the medium
  - In general, sound travels slowest in gaseous media, faster in liquid, and fastest in solids.
- Average speed of sound in soft tissues is 1540m/s or 1.54mm/μs
  - Speed of sound in air = 330m/s

Ultrasound Transducers

- Devices which produce ultrasound via the piezoelectric effect
  - Electrical energy causes the crystal or ceramic material to contract and expand, creating a sound wave
  - Sound energy received by the transducer makes the crystal vibrate, which can then create an electrical current to be analyzed

Transmission/Reflection Scattering

- Sound waves propagate in one direction in homogeneous media
- At boundary zones between different media and in heterogeneous media, the wave is scattered
Transmission/Reflection Scattering
• Reflection occurs at smooth interfaces (rare in living tissues)
• Scattering/transmission depends on difference in acoustic impedance
• Can be physiological interface, as with boundary layer separation in flowing blood
• Beam bent/refracted if not perpendicular

Ultrasound Doppler Ultrasonography

Doppler Principle
• Christian Andreas Doppler – 1842 – described basis for color shifts in double stars
• Change in echo frequency produced by a moving reflector is called the Doppler shift
  Doppler shift = reflected frequency - transmitted frequency
• Directly related to the speed of the reflector/scatterer and the transmitted frequency
• Inversely related to the angle of insonation

Vascular Doppler
• Blood cells/components act as moving scatterers (reflectors)
• Imparts frequency shift to scattered Doppler beam (higher or lower)
• Instrument can determine magnitude of Doppler shift in cycles/sec (Hz)
• With AOI can get velocity (cm/s); provides common language across labs/instruments
Doppler Angle of Insonation

- Doppler Beam
- Angle between the Doppler beam and the direction of the scatterer/reflecter; Flow direction for vascular Doppler

Pulsed Wave Doppler

- A transducer emits short pulses of sound at a fixed rate (PRF) and then waits for the echo before emitting the next pulse
- “Range-gate” to sample at specific depths
- To evaluate the Doppler shift of the echoes accurately, there must be at least 2 pulses for each cycle of the DFS

Doppler Spectral Analysis

- Higher frequency shift/velocity in systole; lower diastole
- If plug flow, or single giant red cell would see single tracing over cardiac cycle

Doppler Spectral Analysis

- Normal vessels have laminar flow
- Multiple speeds & directions of flow in any sample volume

Doppler Spectral Analysis

- At any point in time, there is a spectrum of different speeds and directions of flows (frequency shifts or velocities)

Spectral Analysis

- RBC’s within vessels move at a variety of speeds, which creates a ‘spectrum’ of DFS’s when sampled by Doppler instrument
- This spectrum of velocities is displayed as a band (envelope) of velocities over time
  - > variety of velocities = broader envelope
  - Turbulent flow
Doppler Spectral Analysis
FFT Spectral Display

Vascular Doppler
Spectral Analysis Parameters for TCD
- Flow direction
- Time averaged mean max velocity
- Peak systolic velocity
- End-diastolic velocity
- Turbulence/spectral broadening
- Pulsatility

Aliasing
- If the DFS is high, there may no longer be 2 pulses for each cycle of the DFS
  - Creates erroneous display of the Doppler information (as with wagon wheels appearing to go backwards in the old western movies)
- Occurs when the DFS > 1/2 PRF
  - Nyquist limit

Selected Hemodynamic Principles
Classic Factors Affecting Flow
- Pressure difference
- Resistance
  - Tube/stenosis length
  - Fluid viscosity
  - Radius (residual lumen)
- Brain tries to maintain flow
- Rich potential for collateral flow

Fluid Dynamics
Flow Rate = Pressure/Resistance
- The PRESSURE DIFFERENCE between two points causes blood to flow from the high pressure area to the low pressure area.
- Resistance impedes flow.

[Diagram of pressure gradient with arrow and symbols]
Flow depends upon resistance

- Tube length: ↑ length = ↑ resistance
- Fluid viscosity: ↑ viscosity = ↑ resistance
- Radius of vessel: ↓ radius = ↑ resistance

Hemodynamic Effect Of Stenosis

Hemodynamic Effect of Stenosis

Circle of Willis

Temporal cutaway: Transtemporal window
TCD Acoustic Windows
Transtemporal

TCD Acoustic Windows
Transorbital

TCD Acoustic Windows
Transorbital and Suboccipital

TCD: Vertebral Artery

TCD: Basilar Artery

TCD: Ophthalmic Artery

TCD: Intracranial ICA Siphon

Circle of Willis

TCD Vessel Identification

- Depth
- Flow Direction
- Direction/angulation of transducer
- Spectral appearance
- Context (other vessels)
- Compression tests
**Expected Values for TCD**

<table>
<thead>
<tr>
<th>Artery</th>
<th>Depth (mm)</th>
<th>Flow Direction</th>
<th>MFV (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCA</td>
<td>45-60</td>
<td>Toward</td>
<td>40-80</td>
</tr>
<tr>
<td>ACA</td>
<td>60-70</td>
<td>Away</td>
<td>35-60</td>
</tr>
<tr>
<td>ICA (C1)</td>
<td>60-70</td>
<td>Toward</td>
<td>Variable</td>
</tr>
<tr>
<td>PCA (P1)</td>
<td>60-65</td>
<td>Toward</td>
<td>30-55</td>
</tr>
<tr>
<td>OA</td>
<td>40-55</td>
<td>Toward</td>
<td>15-30</td>
</tr>
<tr>
<td>Siphon (C4)</td>
<td>65-70</td>
<td>Toward</td>
<td>40-70</td>
</tr>
<tr>
<td>VA</td>
<td>60-75</td>
<td>Away</td>
<td>25-50</td>
</tr>
<tr>
<td>BA</td>
<td>&gt;75</td>
<td>Away</td>
<td>25-60</td>
</tr>
</tbody>
</table>

TCD Compression Tests

B-Mode Imaging

Principles and Application

- “Brightness”-Mode
- Returning, scattered echoes stored in gray scale memory; strong scatterers bright white, weaker ones shades of gray
- Multiple B-Mode scan lines put together across a scan plane create gray-scale, 2-dimensional image
- Update many times/sec (frame rate) for “real-time” imaging as with television (30/sec) the vessel wall, plaque and soft tissues

B-Mode Imaging

- Provides ultrasonic picture of tissues, vessels, plaque (not true anatomic image)
- Best to use ultrasonic terms to describe
- Transducer frequency and focusing determine resolution
- Higher frequency, higher resolution
- Higher frequency, greater attenuation, less working depth

B-mode Imaging

- Scan line swept across plane of tissue to give 2-D image
- Mechanical sector (single transducer moved across plane, fires multiple scan lines)
- Arrays (linear, phased) with multiple transducer elements/channels are electronically steered across the plane to collect multiple scan lines
B-Mode
Real Time Imaging
• Static 2-D image updated many times per second so appears to be moving in real time
• Rate of updates is Frame Rate
• Television updated 30 times/sec
• Provides ultrasound view of moving targets as with pulsing vessels, moving plaques
• Typical B-Mode movement not quantitative

Duplex Sonography
• Combines PW Doppler & B-mode imaging
• Image guided placement of sample gate
• Angle correction
• Option for color flow imaging
• Overcomes pitfalls of stand alone tests
• Expect 90% sens/spec for tight stenosis

Duplex Doppler
ICA Tight Stenosis

Color Flow Imaging
Underlying B-mode Image

Color Flow Imaging CCA
Transcranial Color Duplex Imaging

Circle of Willis

- Visual assistance windows
- Visual display and ID of vessels
- More accurate angle of insonation
- Safe noninvasive imaging
- Potential for Power Doppler, contrast, and 3-D reconstructions
Power Doppler

- Encodes the intensity (amplitude) of the Doppler shifts from the area sampled, and superimposes this upon the gray scale image
  - Not angle dependent and free of aliasing
  - Increases sensitivity to slow flow

Carotid Protocol & Techniques

Key Elements of Protocol - Doppler

- Color/Power Doppler imaging during collection of velocity data helps identify flow, high velocity jets, and accurate AOI
- Helpful with large or complex plaques to show lumen and surface features
- Also helpful with vertebral and sampling most distal ICA segments
Power M-mode TCD

Embolus Detection

Embolus Detection

TCD Embolus Detection
Initial Animal Studies

TCD New Developments
TCD Protocol

Key Aspects

- Windows: temporal, sub-occipital, orbital
- Sample volume: 10-15 mm
- Segments (23): MCA (Prox, Dist), ACA, PCA (P1, P2), C1, Ophthalmic, ICA Siphon (C2, C4), Vertebral, Basilar (Prox, Mid, Distal)
- Parameters: Depth, Flow Direction, Velocity (mean, systolic, diastolic), PI