GREENVILLE HEALTH SYSTEM

Understanding the Basics of TCD

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Disclosures

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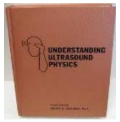
- Paid consultant, Arbor Pharmaceuticals
- Understanding Ultrasound Physics by Edelman was used as a reference for much of the physics



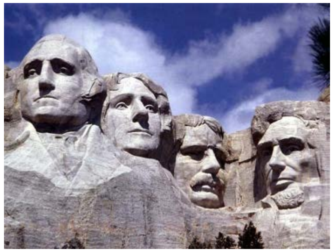
- Board member of the American Society of Neuroimaging
- Many of the slides have been adapted from slides presented at the American Society for Neuroimaging Annual Meetings by my mentors

Andrei Alexandrov

Zsolt Garami

Chuck Tegeler

Alex Razumovsky



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www.googleimages.com, accessed 9/8/2014

Objectives

- Review the basic principles of transcranial Doppler ultrasound (TCD)
- Discuss how TCD velocities are obtained
- Describe factors that increase and decrease TCD mean velocities
- List other pieces of information obtained from a TCD examination

Sound Waves (Acoustic Waves)

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- Mechanical wave carrying energy
- Can't travel in a vacuum, requires a medium to travel in
- Longitudinal waves (particles move in same direction that wave propagates)
- Travel in a straight line
- Molecules of the medium alternately compressed and rarified (stretched apart)
- *Acoustic properties*-effect of medium on sound wave
- *Biological effects*-effect of sound wave on the medium

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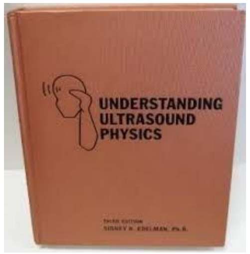

3 Acoustic Variables

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- <u>Pressure</u> (concentration of force in an area: *Pascals*)
- <u>Density</u> (concentration of mass in volume: *kg/cm3*)
- <u>Distance</u> (measure of particle motion: *cm, m, etc.)*

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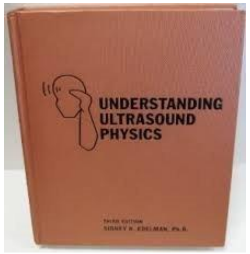
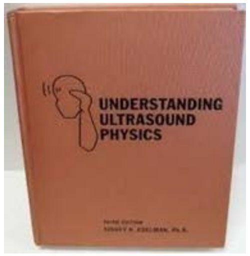


7 Acoustic Parameters

- *Period*
- *Frequency*
- *Amplitude*
- *Power*
- *Intensity*
- *Wavelength*
- *Propagation speed*



7 Acoustic Parameters

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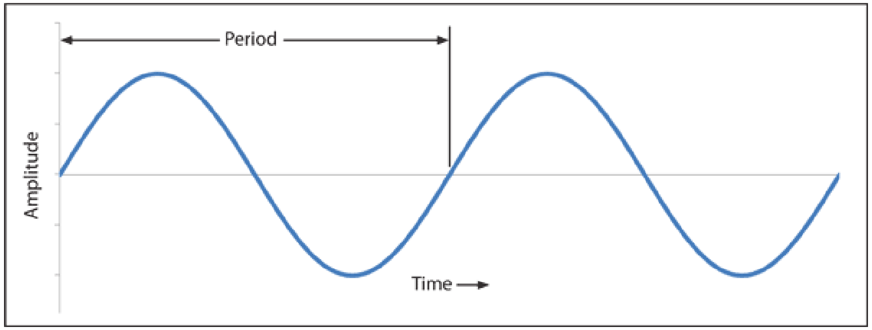
- ***Period* (T)**
  - Time from start of one cycle to start of next
  - Units of time (s, ms, etc.)
  - Determined by source not medium
  - Not adjustable (determined by the transducer used)
  - $T = 1/f$



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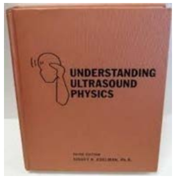

7 Acoustic Parameters

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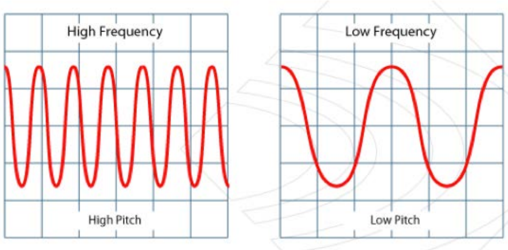
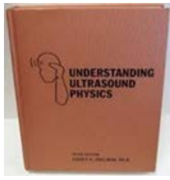
- ***<u>Frequency</u>*** *(f)*
  - Cycles per second (1 cycle/sec = 1 Hz)
  - Typically 2-10 MHz (2-10 million cycles/sec)
  - Determined by source not the medium
  - Not adjustable (determined by transducer used)
  - Affects penetration and image quality
  - Audible sound 20 Hz-20 kHz
  - Ultrasound greater than 20 kHz

https://www.google.com accessed 9/8/2016





7 Acoustic Parameters

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- ***Amplitude***
  - Measure of size of wave
  - Can have units of any of the acoustic variables
    - Pressure (Pa)
    - Density (g/cm3)
    - Distance (cm)
  - Determined by source, decreases as it travels through a medium
    - Rate of decrease is determined by the source and the medium
  - Initial amplitude can be increased by increasing the gain
  - Can be expressed in decibels (dB)

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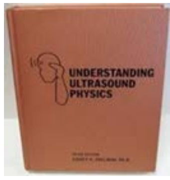

7 Acoustic Parameters

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- ***Power***
  - Rate of energy transfer (watts)
  - Power proportional to amplitude squared

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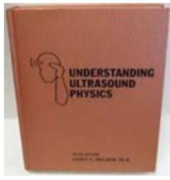

7 Acoustic Parameters

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- ***Intensity***
  - Concentration of energy in the beam
  - Intensity (Watts/cm^2) = $\frac{\text{Power (Watts)}}{\text{area (cm}^2\text{)}}$
  - Initial intensity is set by the source
  - Intensity changed as sound propagates
  - Can be adjusted by sonographer
  - Intensity proportional to power proportional to amplitude squared

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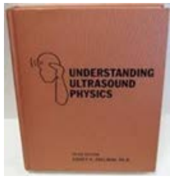
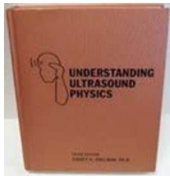


7 Acoustic Parameters

- ***Wavelength*** (λ)
  - Distance of one cycle
  - Measured in length units (m, cm, etc.)
  - Only parameter determined by both the source and medium
  - Not adjustable as determined by frequency of probe
  - In a given medium λ and *f* are inversely related
  - $\lambda\ (\text{mm}) = \dfrac{1.54\ \text{mm}/\mu\text{s}}{f\ (\text{MHz})}$
  - 1 MHz probe has a λ of 1.54 mm



Key facts

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- Higher frequency transducer produce shorter wavelength sound which creates superior image quality (better axial resolution)

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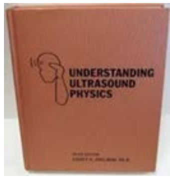

7 Acoustic Parameters

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- ***<u>Propagation speed</u>***
  - Distance that sound wave travels through a medium in 1 second
  - Velocity the wave travels at within a medium
  - Determined by the medium
  - **1540 m/s in soft tissue and blood**
  - Speed of sound in body 500 m/s to 4000 m/s depending on tissue (medium)

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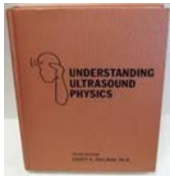

Key facts

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- Speed of sound through a medium is the same regardless of the source
- Speed of sound is only determined by the medium (stiffness proportional to speed)
- Speed of sound through soft tissue (liquid) is 1540 m/s
- Speed of sound through lung is less (because contains gas)
- Speed of sound through bone is more (solid)
- ***Solid faster than liquid faster than gas***

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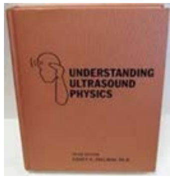
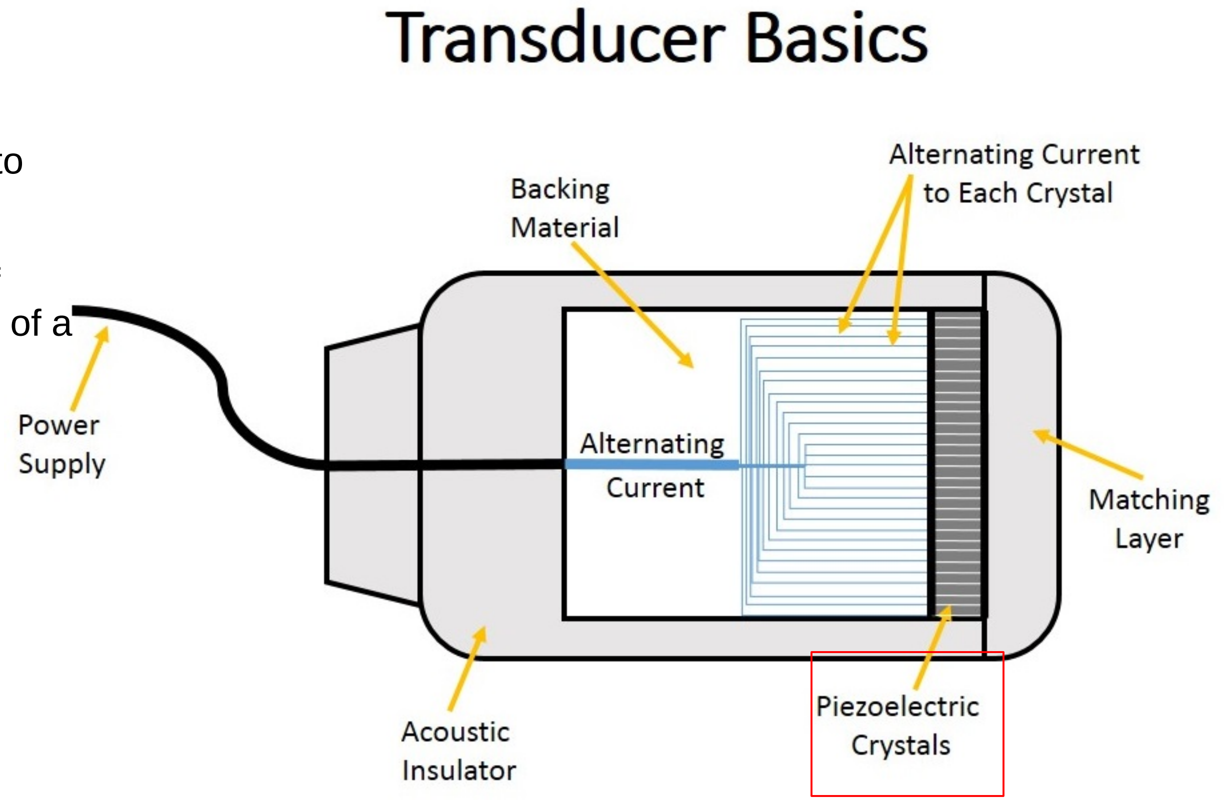


Components of a Transducer

Piezoelectric crystal

Electrical current applied to piezoelectric crystal causes it to deform and vibrate

Vibration causes production of electromotive force in the form of a mechanical wave



https://www.google.com accessed 9/8/2016

Principles of TCD

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- Blood flow velocity through a cross sectional area of a particular vessel (cm/s)
- Blood flow velocity is directly related to Doppler shift
    - If you measure the Doppler shift you can derive the blood flow velocity
        - Transcranial Doppler ultrasound can accomplish this

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Ultrasound Physics

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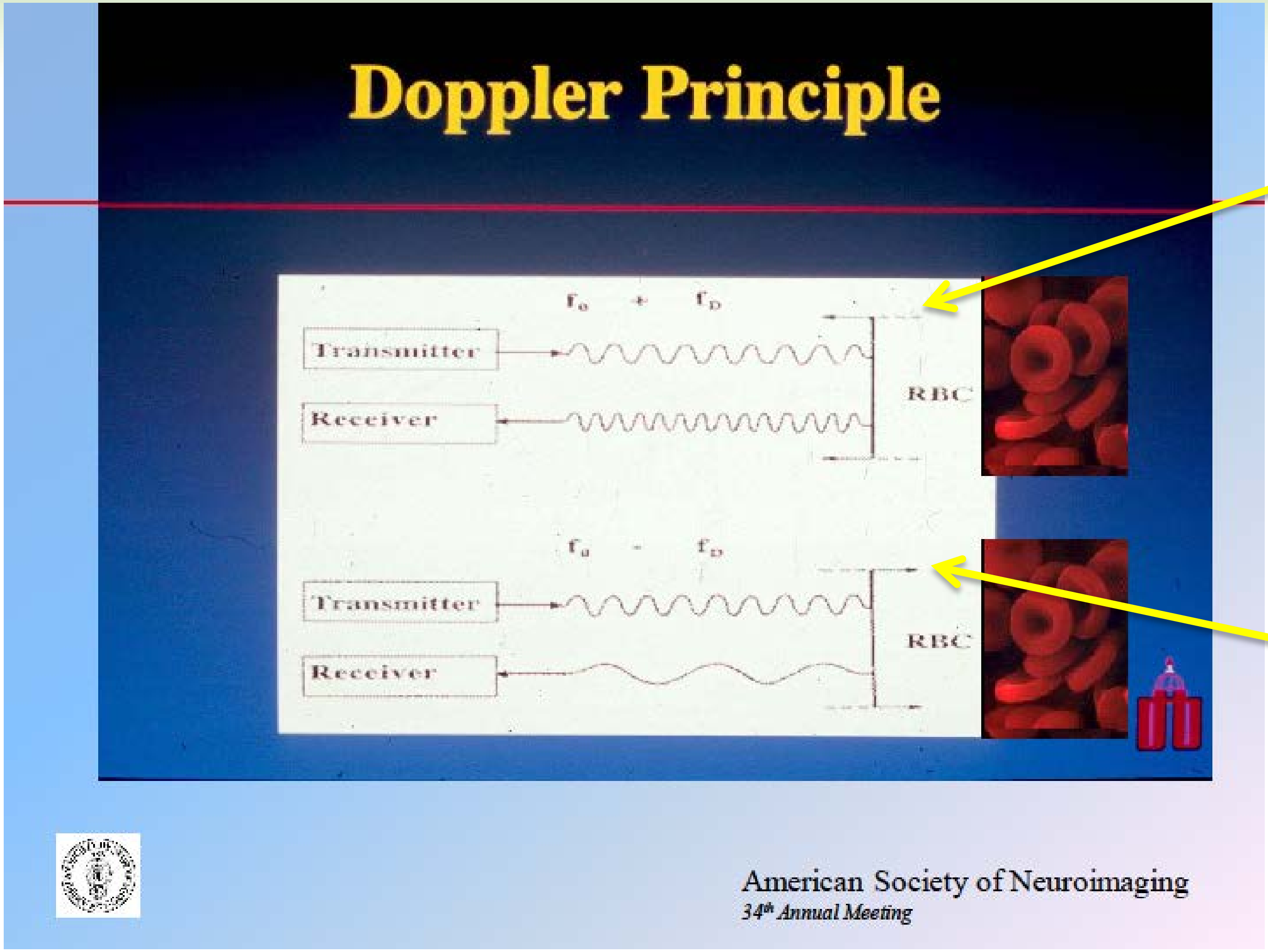

Blood towards probe

(+) Doppler Shift

Above baseline

Blood away from probe

(-) Doppler Shift

Below baseline

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Adapted from Alex Razumovsky, PhD

Insonation of Brain

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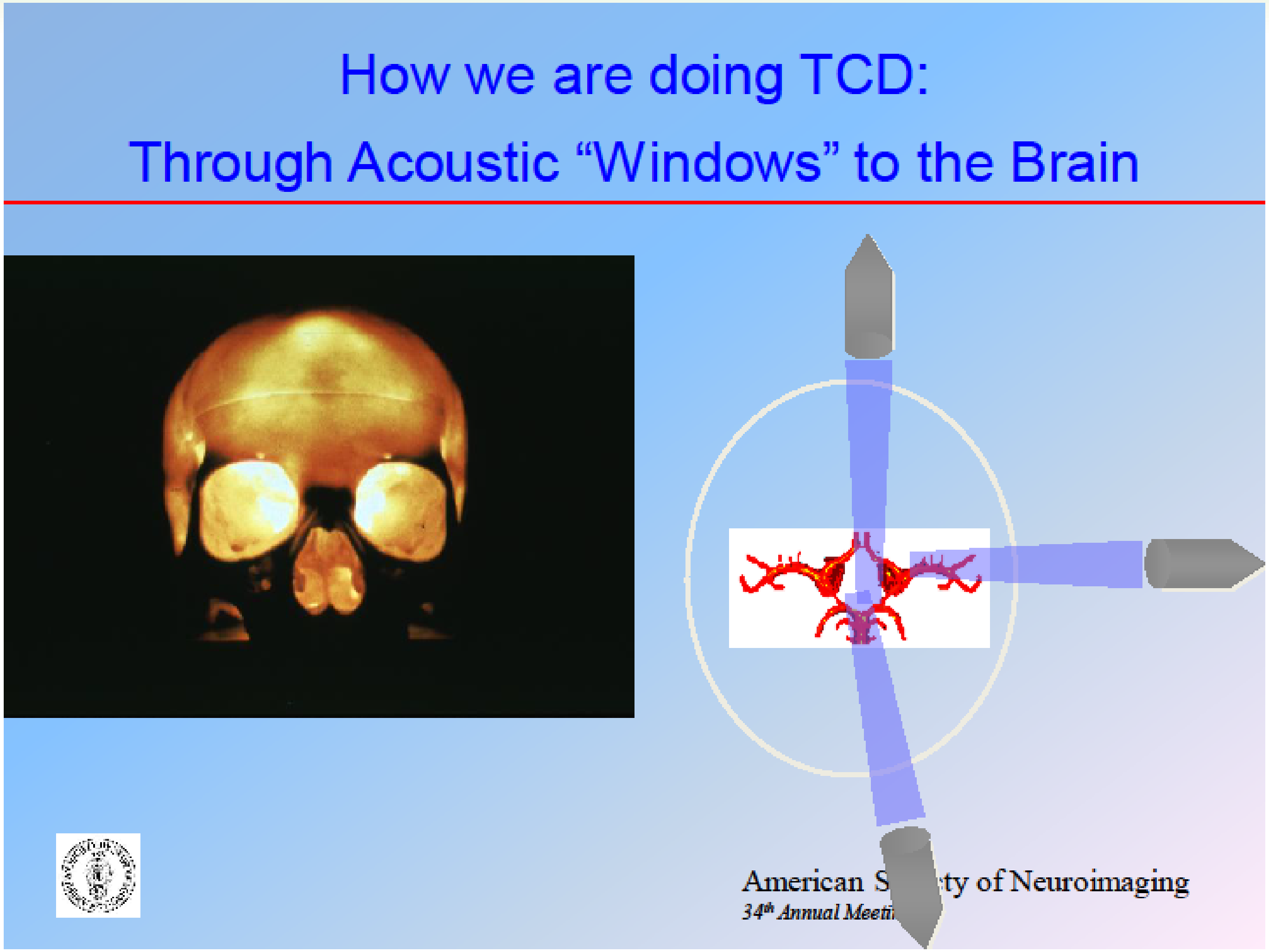

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Slide courtesy Alex Razumovsky, PhD

Transcranial Doppler Ultrasound

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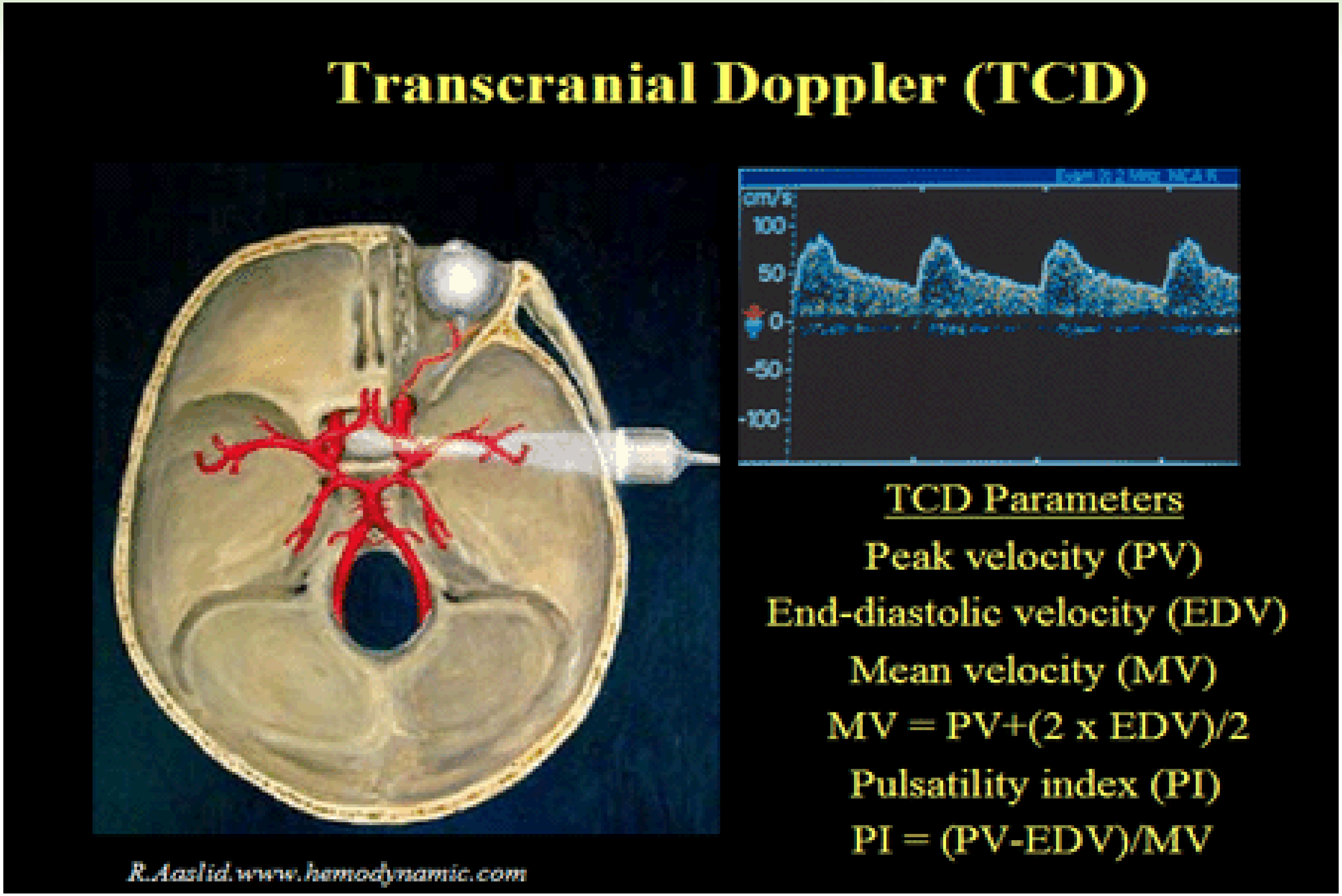


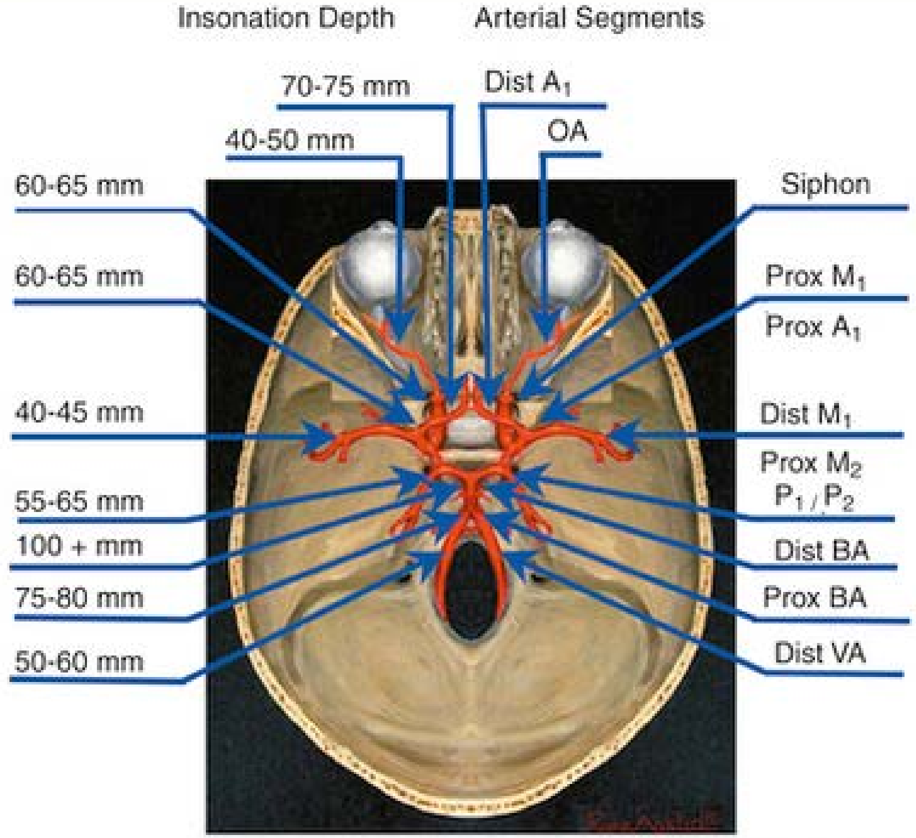
Identifying the Insonated Vessel

Need to know

1. Approach (transtemporal, suboccipital, or opthalmic)

2. Depth

3. Direction



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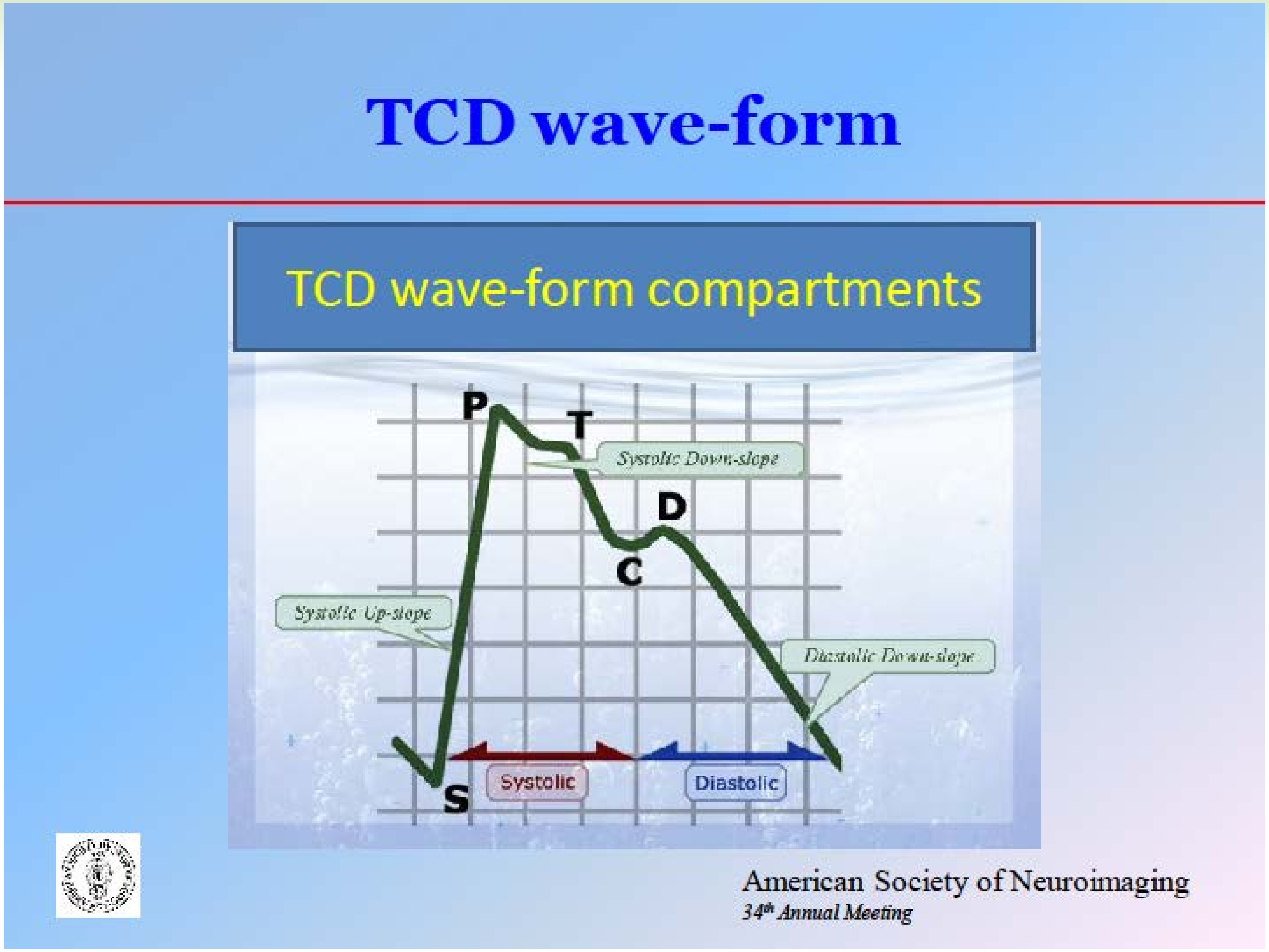
Alexandrov, A and Balucani, C. Role of
ultrasound in carotid occlusive disease Cerebrovascular Diseases 27 Suppl 1(1):9-18.
February 2009

TCD Wave



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TCD Spectra

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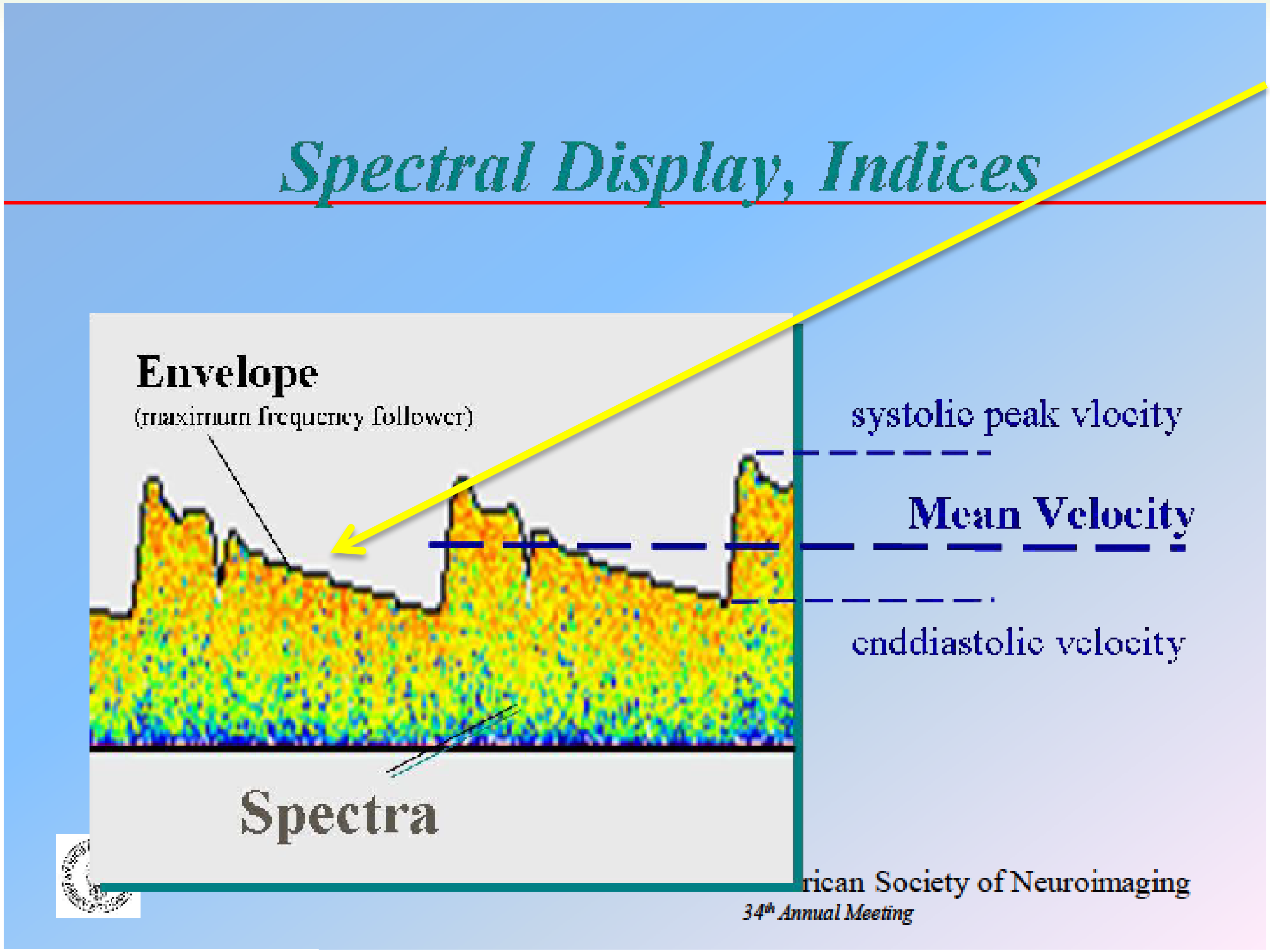

Normal systolic deceleration is due to intact cerebral autoregulation

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Slide courtesy Alex Razumovsky, PhD

Factors that Effect TCD Velocities

Cause ↑ Velocities

1. Vasospasm
2. Intracranial atherosclerosis/↑age
3. Hyperemia
4. Hypercapnea
5. Altered collaterals
6. Rewarming after hypothermia
7. Meningitis
8. Inhaled anesthetics
9. Sickle cell anemia
10. Pre-eclampsia

Cause ↓ Velocities

1. Increased ICP
2. Hypocapnea (hyperventilation)
3. Post-stenotic lesion (other side of Spencer's Curve)
4. Hypotension
5. Hypothermia
6. Anesthetic induction agents except ketamine
7. Hepatic failure
8. Brain death
9. Pregnancy

Spencer's Curve

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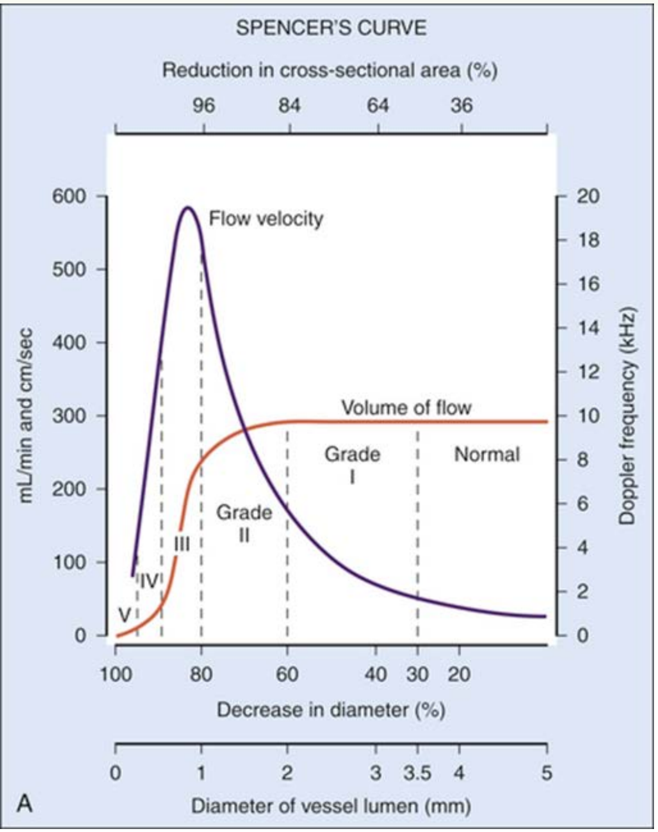

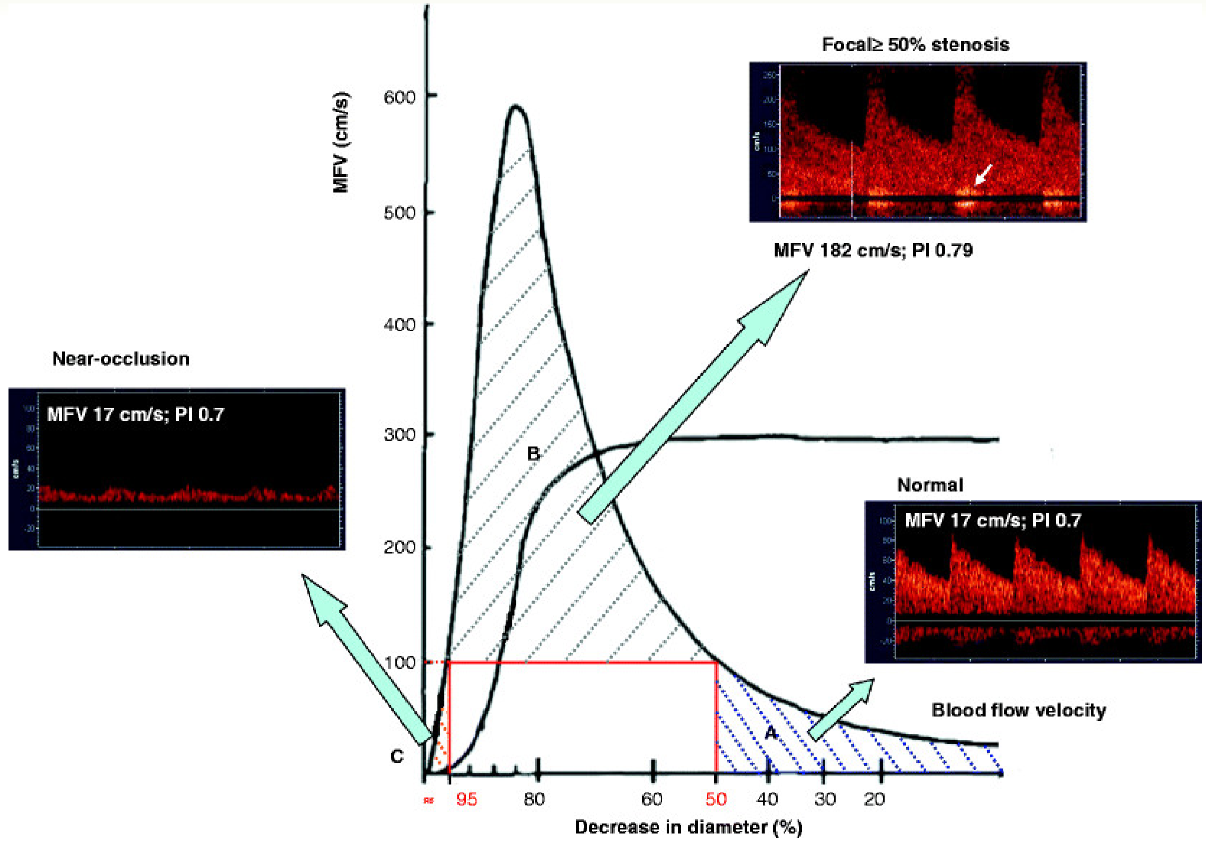

Alexandrov, A and Balucani, C. Role of ultrasound in carotid occlusive disease (2016)

50% reduction doubles velocity
70% reduction quadruples velocity

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https://www.researchgate.net/figure/226282579_fig2_Figure-5-05-The-Spencer's-curve-This-hemodynamic-model-is-frequently-used-to-interpret, accessed 9/8/2016

Pulsatility Indices

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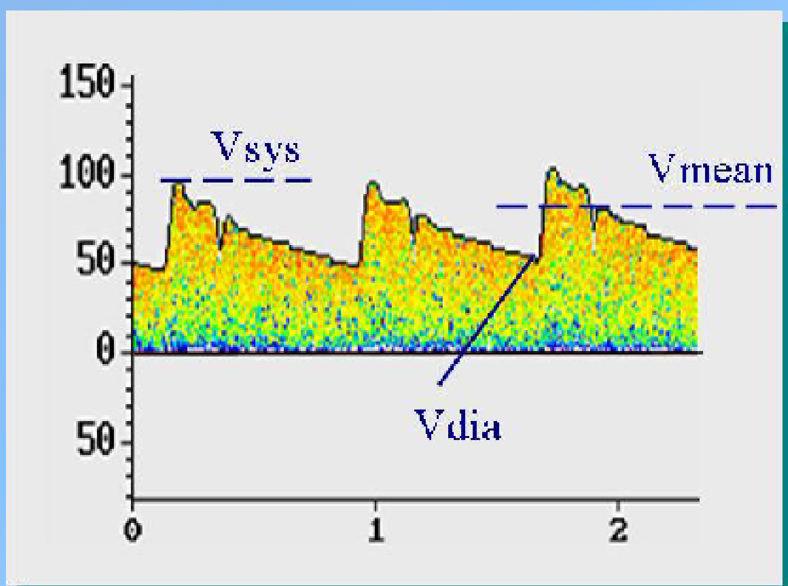
Pulsatility Indices



Gosling's Pulsatility Index

$$PI = \frac{Vsys-Vdia}{Vmean}$$

Pourcelot's Resistance Index

$$RI = \frac{Vsys-Vdia}{Vsys}$$

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Slide courtesy Alex Razumovsky, PhD

PI

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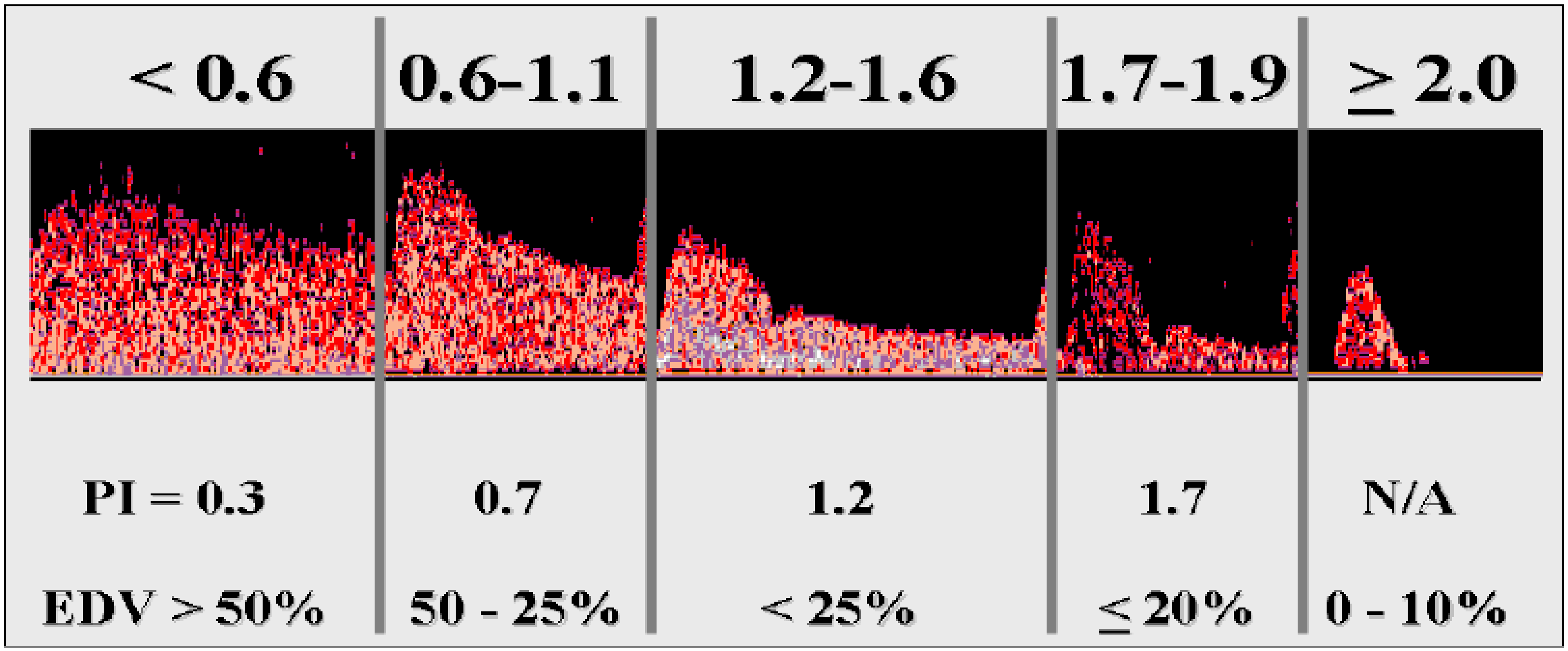

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Slide courtesy Andrei Alexandrov

TCD use in Carotid Occlusive Disease

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- Allows for evaluation of:
  - Collateral flow
  - Cerebral embolism
  - Poor vasomotor reserve i.e. progression of carotid stenosis

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Waveform Morphology

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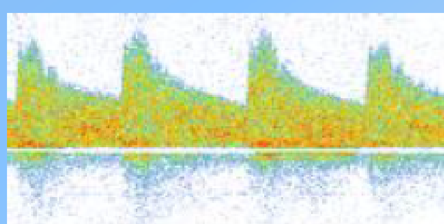
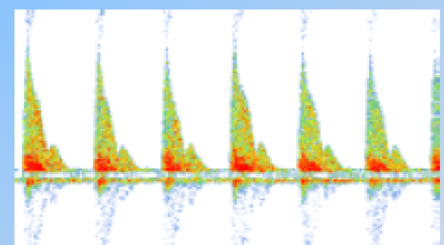
Typical morphology of TCD wave-form

- MCA (M1 and M2 segm)
- ICA (C1, C3 and C4 segm)
- ACA (A1 segm)
- PCA (P1, P2 segm)
- VA's and BA



- **Low peripheral resistance/Low PI**

- OA



- **High peripheral resistance/High PI**

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TCD use in Carotid Occlusive Disease

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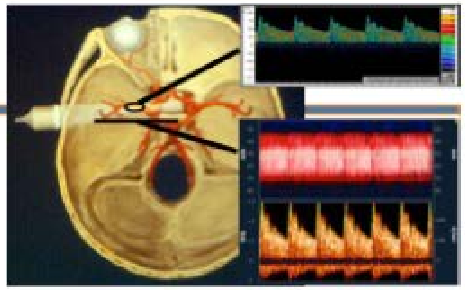
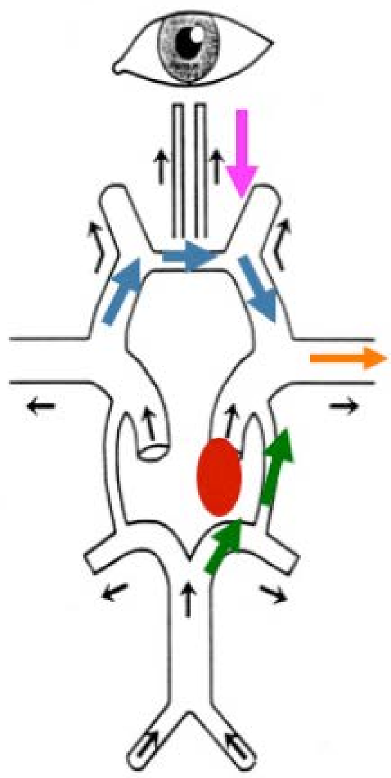
TCD evaluation in CAS





- Collateral flow

OA- purple
ACOM - blue
PCOM - green

Slide courtesy Z. Garami, MD

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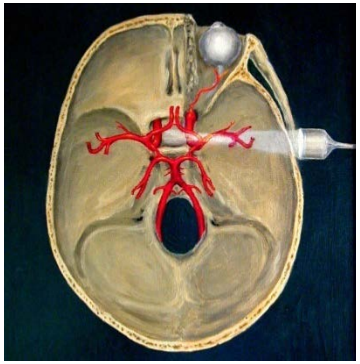
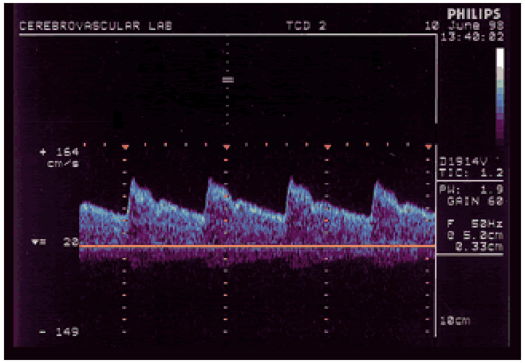
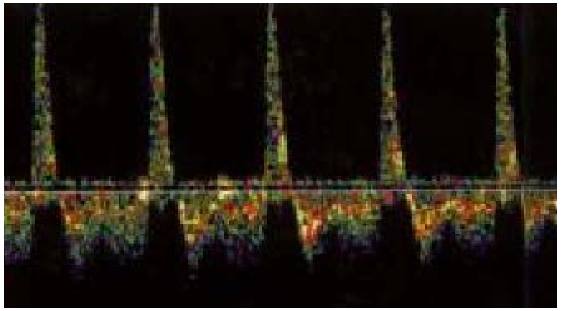
Subarachnoid Hemorrhage

- Detection of vasospasm
  - Clinical exam (usually somnolence or non-focal symptoms), not very sensitive
  - Daily TCD (non-invasive, 90% sensitivity, often precedes clinical vasospasm)
  - TCD or CTA can be used to screen for “plasty-able” lesions







Images from 1. http://www.spencertechnologies.com/products.html#thumb 2. www.viswiki.com/en/Transcranial_doppler,
3. http://depts.washington.edu/uwtcdlab/images/tcd/tcd3_lg.gif all accessed on 1/24/2010 4. Cerebrovascular Ultrasound in Stroke Prevention and

Data on TCD Monitoring

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TCD monitoring

The probability (%) to that TCD is normal and the patient does not have DCI is high → GOOD SPECIFICITY, FEW FALSE-NEGATIVE TESTS, HOWEVER NPV varies substantially depending on the vessel studied

TABLE 3. Individual Trial Results and Meta-Analyses

										Likelihood Ratio	
Reference	True Positive Angio+ TCD+	False-Positive Angio− TCD+	True Negative Angio− TCD−	False-Negative Angio+ TCD−	No. Patients/No. Tests	Sensitivity	Specificity	PPV	NPV	Positive Test	Negative Test
Middle cerebral artery											
Burch[21]	15	3	45	24	49/87	38%	94%	83%	65%	6.2	0.7
Kyoi[27]	10	0	7	1	18/18	91%	100%	100%	88%	14.0	0.1
Langlois[28]	11	0	97	4	56/112	73%	100%	100%	96%	140.9	0.3
Lennihan[29]	6	1	58	1	41/66	86%	98%	86%	98%	50.6	0.1
Sloan[34]	17	0	5	12	34/34	59%	100%	100%	29%	7.0	0.4
Random effects (95% CI)						67% (48–87)	99% (99–100)	97% (95–98)	78% (65–91)	17 (5–56)	0.4 (0.2–0.7)
Anterior cerebral artery											
Kyoi Kikuo[27]	9	2	5	2	18/18	82%	71%	82%	71%	2.9	0.3
Lennihan[29]	2	0	51	13	41/66	13%	100%	100%	80%	16.3	0.9
Wozniak[40]	9	13	24	41	49/87	18%	65%	41%	37%	0.5	1.3
Random effects (95% CI)						42% (11–72)	76% (53–100)	56% (27–84)	69% (43–95)	1.7 (0.6–4.9)	0.9 (0.6–1.3)
Internal carotid artery											
Burch[21]	11	4	42	33	84/90	25%	91%	73%	56%	2.9	0.8
Posterior cerebral artery											
Wozniak[40]	11	19	42	12	47/84	48%	69%	37%	78%	1.5	0.8
Basilar cerebral artery											
Sloan[35]	10	6	23	3	42/43	76.9%	79%	63%	88%	3.7	0.3
Vertebral cerebral arteries											
Sloan[35]	7	6	42	9	42/64	43.8%	88%	54%	82%	3.5	0.6

Angio indicates angiography, the gold standard; TCD is the diagnostic test.

Lysakowski C et al *Stroke* 2001; 32:2292–2298

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Slide courtesy Mauro Oddo, MD

AAN recommendations on use of ancillary testing

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Transcranial Doppler Ultrasonography

Transcranial Doppler (TCD) is only useful if a reliable signal is found. The abnormalities should include either reverberating flow or small systolic peaks in early systole. A finding of a complete absence of flow may not be reliable owing to inadequate transtemporal windows for insonation. There should be bilateral insonation and anterior and posterior insonation. The probe should be placed at the temporal bone, above the zygomatic arch and the vertebrobasilar arteries, through the suboccipital transcranial window.

Insonation through the orbital window can be considered to obtain a reliable signal. TCD may be less reliable in patients with a prior craniotomy.

AAN Clinician Guideline Supplement: Ancillary Testing; Update: Determining Brain Death in Adults. 2010.

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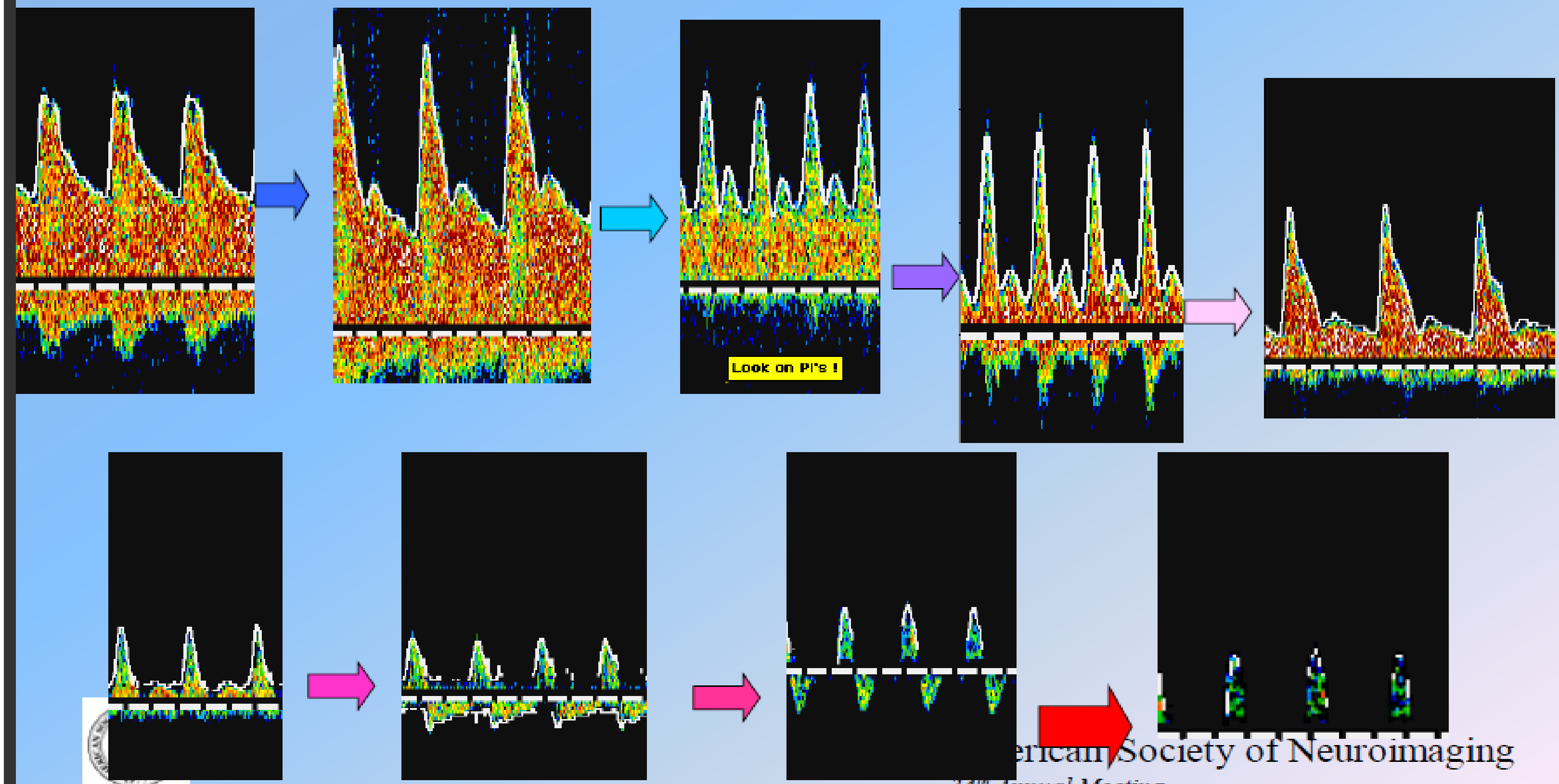
TCD wave form progression from intact CBFV to circulatory arrest



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