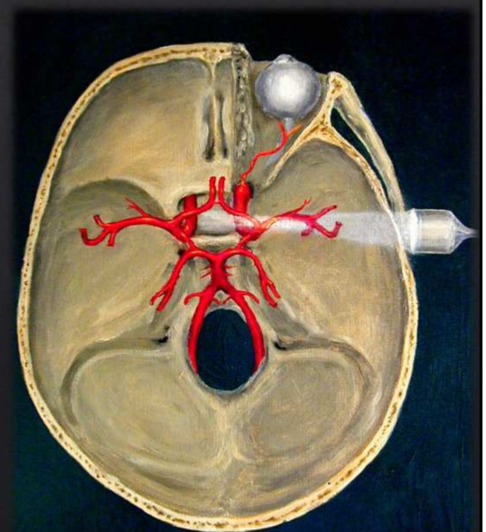
Cerebrovascular Intracranial: Transcranial Doppler

Sarah LaRose Michaud, RVT

Disclosures

- NONE

“Stethoscope for the Brain”



Real-time measures of neurovascular function

What is TCD used for?

Common Tests:

- Stenosis and collateral flow
- Vasospasm monitoring
- Emboli Detection aka “HITS” Study
- Emboli Detection with Microbubble Injection
- Vasoreactivity testing with CO_2
- Monitoring Sickle Cell patients
- Brain Death

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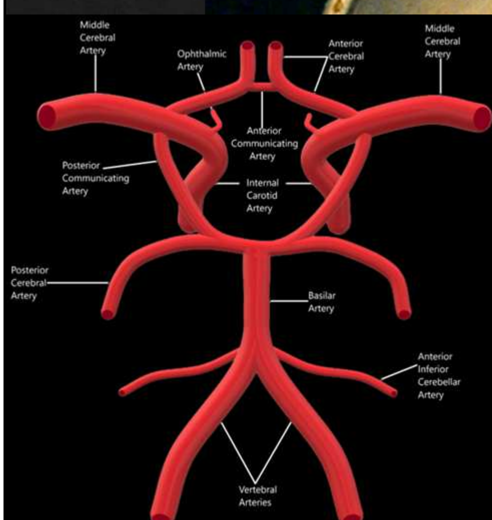
Ancillary Tests:

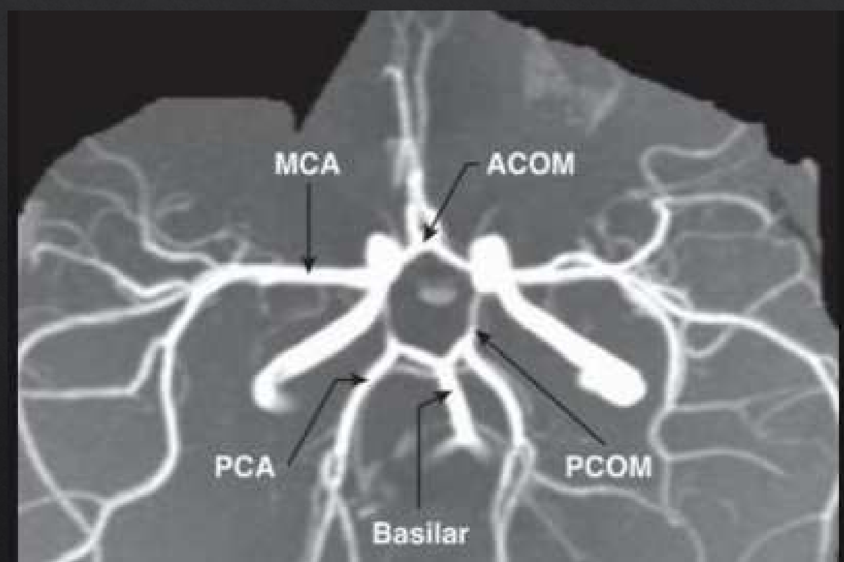
- Dynamic monitoring
  - Subclavian Steal, Head turning (such as for "Bow Hunter's Syndrome"), Sit-to-Stand, etc
- Evaluation of Arteriovenous Malformations
- Intraoperative monitoring such as during carotid endarterectomy
- Thrombolysis in Acute Ischemic Stroke
- Autoregulation and Neurovascular coupling (research focus)



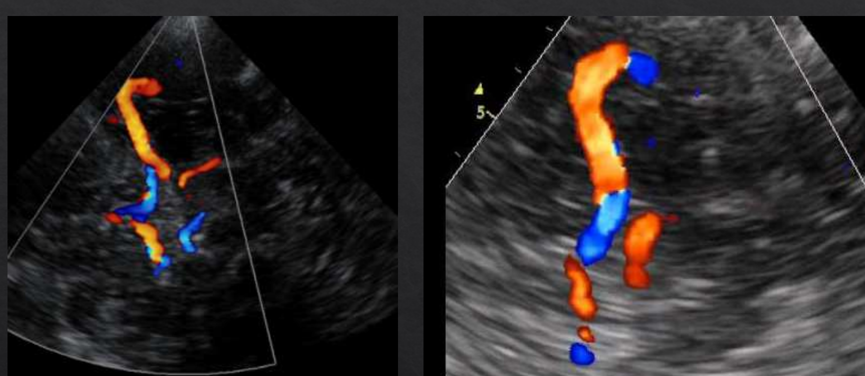
The Circle of Willis

An anastomotic ring at the base of the skull which connects the right and left hemispheres and the anterior and posterior circulations.

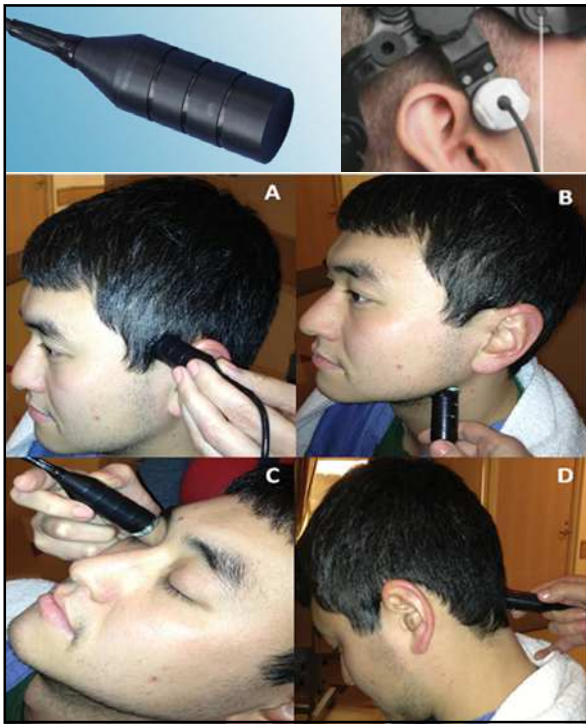
Only about 18-20% of people have a classic Circle



MRA

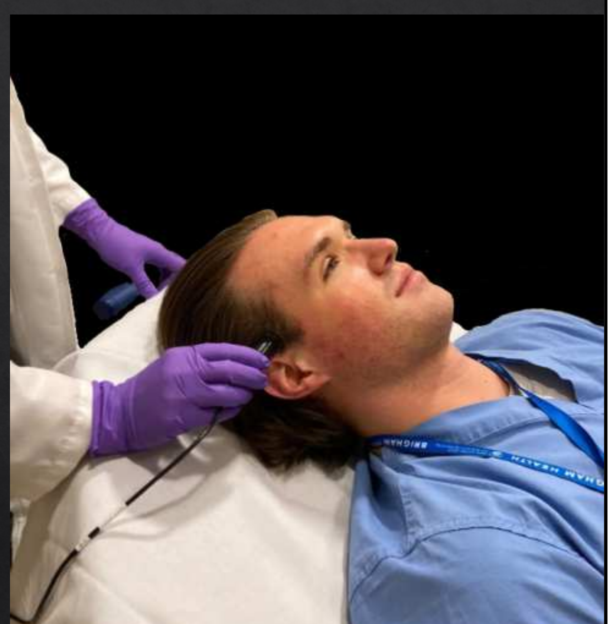


Transcranial Color-Coded Duplex Sonography (TCCS)



- 2 MHz Pulsed Wave Transducer
- Four “bone windows”
- <35% of energy penetrates the skull
- ~10-20% of the population does not have adequate temporal windows

Anchor your arm so you won’t drift



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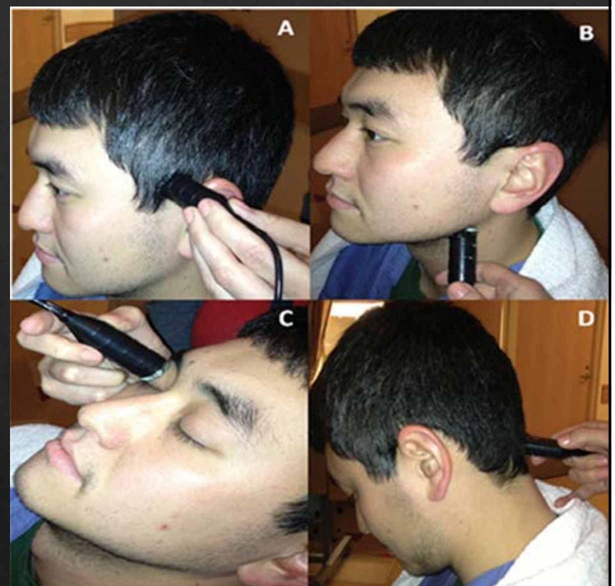
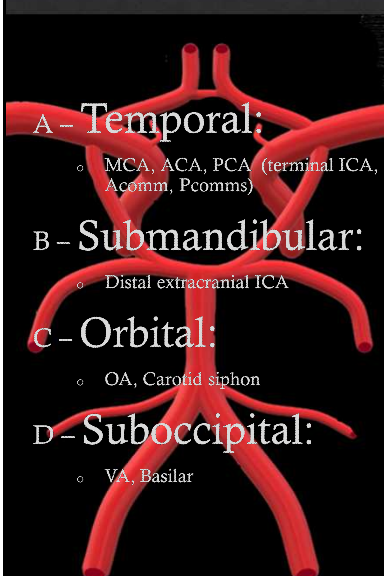


Fig. 2. Four acoustic windows commonly used in transcranial Doppler examination: transtemporal window (A), submandibular window (B), transorbital window (C), suboccipital window (D).

Four Insonation Windows

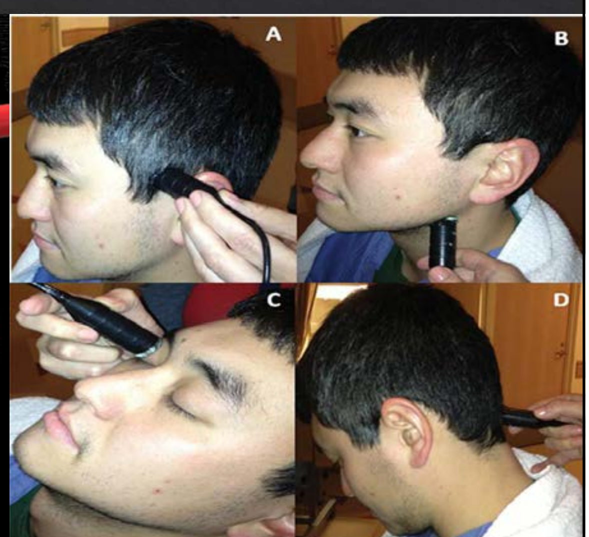


A – Temporal:
- MCA, ACA, PCA (terminal ICA, Acomm, Pcomms)

B – Submandibular:
- Distal extracranial ICA

C – Orbital:
- OA, Carotid siphon

D – Suboccipital:
- VA, Basilar



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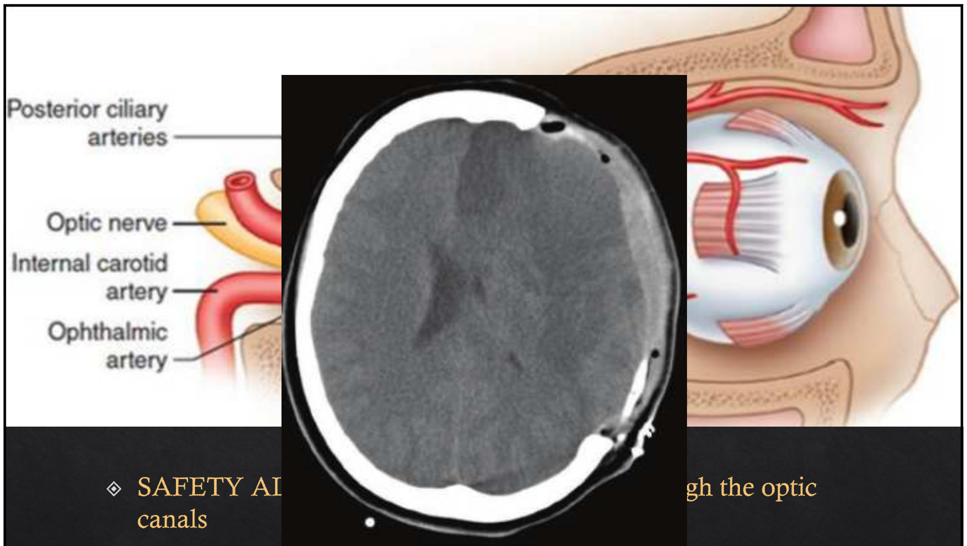
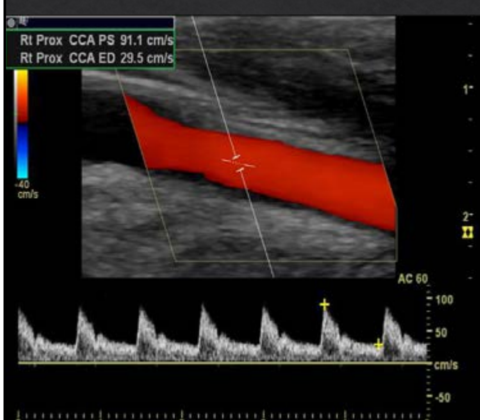


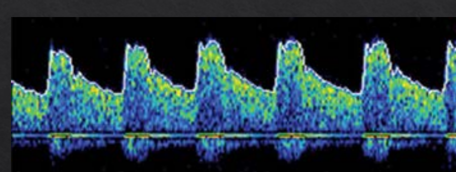
- SAFETY AI … gh the optic canals

Machine power MUST be reduced to 10% of its total possible output

Importance of the Angle of Insonation

Assumed angle of incidence of 0-30°





The Doppler shift: the difference in frequency between the beam transmitted into tissue and the echo produced by reflection from the moving red blood cells.

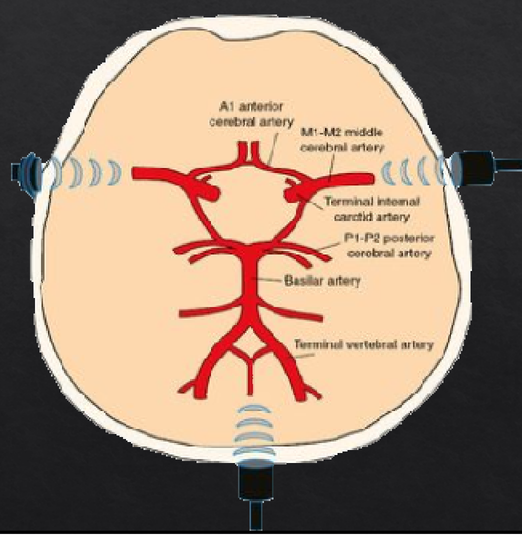
$$V = \frac{c \quad Df}{2\,F_0 \cos\theta}$$

- V = velocity of red blood cell
- C = ultrasound propagation speed in blood (approximately 1570 m/sec)
- Df = Doppler shift frequency (the received frequency)
- f0 = transmitted ultrasound beam frequency
- θ = angle between the ultrasound beam and the direction of red blood cell flow

- Frequency shift is proportional to both the velocity of the moving blood cells and the angle of incidence.

Reflector speed (cm/s) = $\dfrac{\text{Received frequency x propagation speed}}{\text{2 x transmitted frequency x Cos } \theta}$

- Cos 0° = 1
- Cos 90° = 0



Reflector speed (cm/s) = $\dfrac{\text{Received frequency x propagation speed}}{\text{2 x transmitted frequency x } \color{red}{\cos \theta}}$

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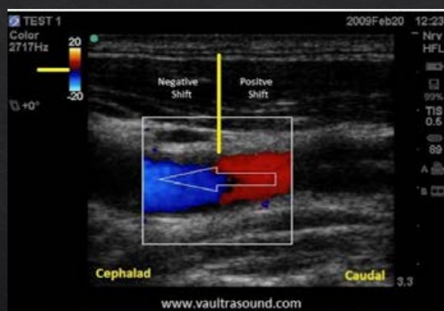
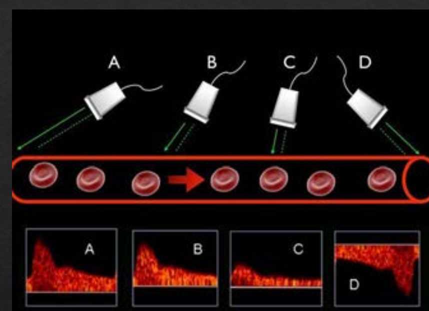
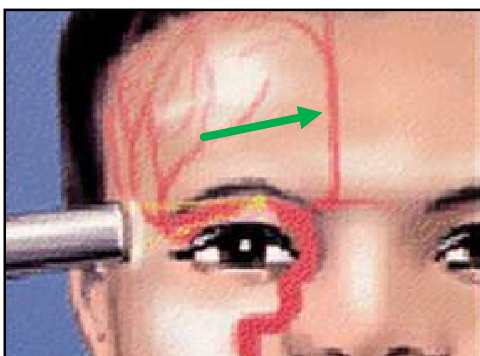
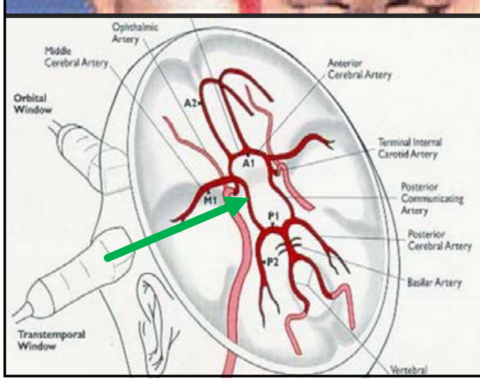




- Angle of insonation is assumed to be 0 - 30˚. If > 30˚ you will lose flow velocity in your measurement. At 90˚ you will not see any Doppler shift.

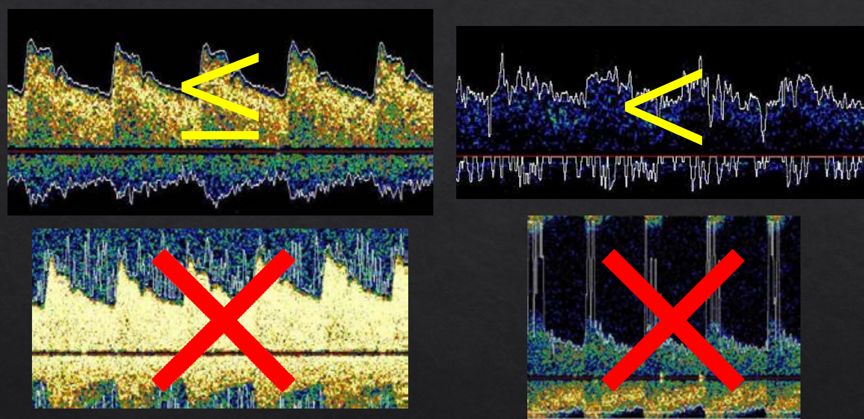




Due to vessel orientation, some vessels are impossible to insonate

Saqqur M, Zygun D, Demchuk A. Role of transcranial Doppler in neurocritical care. Crit Care Med. 2007 May

Calculated velocity is always ≤ true velocity



High velocity measurements always warrant further investigation

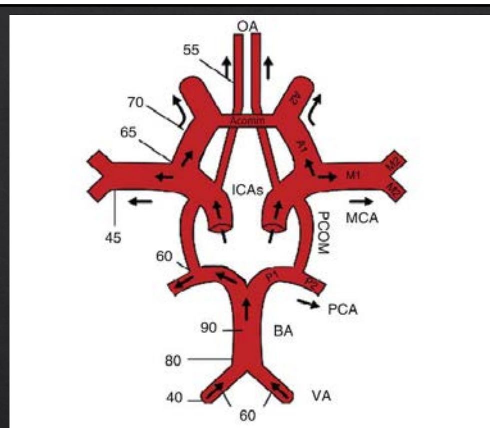
TCD Parameters

- Mean Flow Velocity (time-averaged mean)
  - (MFV = systolic + 2 x diastolic/3)
- Peak Systolic and End Diastolic Velocity
- Pulsatility Index (PI = Vsystole-Vdiastole/Vmean)
- Resistivity Index (RI = PSV-EDV/PSV)

Label	Depth	Mean	Max	PI	RI

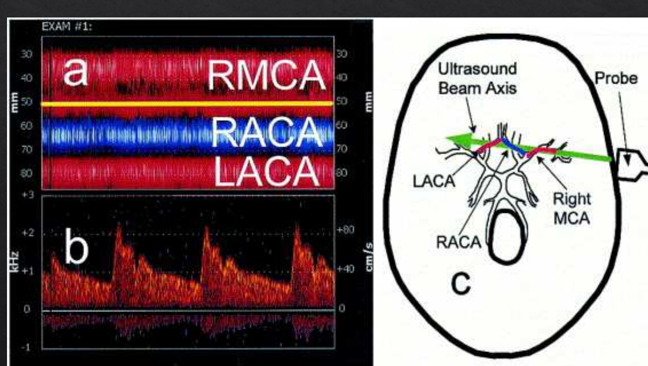
Vessel Identification

- Insonation Window, probe angle
- Sample volume depth
- Direction of blood flow (toward or away from transducer)
- Expected flow velocity and Pulsatility



Vessel	Insonation Window	Flow Direction	Depth (mm)	Mean FV (cm/s)
Middle Cerebral (MCA)	temporal	Toward	30-60	40-70
Anterial Cerebral (ACA)	temporal	Away	60-75	35-60
Posterior Cerebral (PCA)	temporal	P1 toward P2 away	55-75	30-55
Terminal ICA	temporal	Toward	60-70	30-50
Distal Extracranial ICA	submandibular	Away	40-60	30-60
Ophthalmic (OA)	orbital	Toward	35-55	15-30
Carotid Siphon	orbital	Bidirectional	55-80	35-60
Vertebral (VA)	suboccipital	Away	60-75	25-50
Basilar (BA)	suboccipital	Away	75-120	30-55

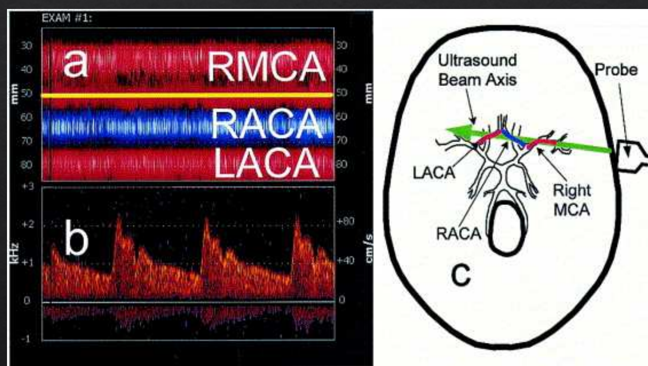
Vessel Identification - Continued



Picture from: Moehring M, Spencer M. Power M-mode Doppler (PMD) for observing cerebral blood flow and tracking emboli. Ultrasound in Medicine and Biology 2002. 28(1):49-57.

Vessel Identification - Continued

- Ability to trace the course of the artery
  - Take pictures in small 2-3mm increments
- Relation of one artery to another (find MCA and then use it as your "Home Base")
- DO NOT USE PRE-SETS!



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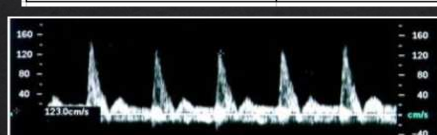
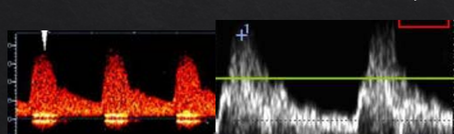
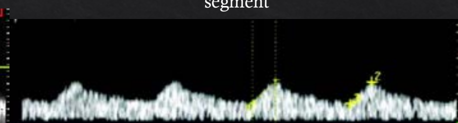


Proximal evidence of increased resistance distally

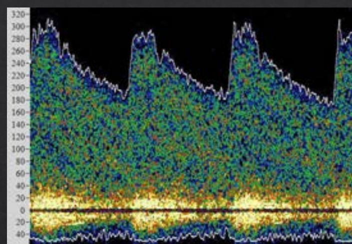
Focal increases in flow velocity within a stenotic segment

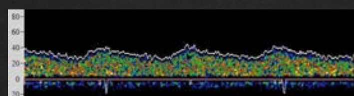


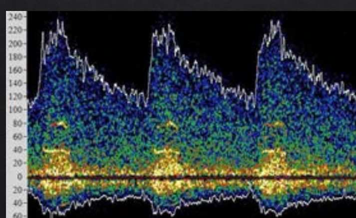
Stenotic and Post-stenotic turbulence



Blunted/tardus parvus post-stenotic slowing







Determining Degree of Stenosis

- acceleration of flow velocity through the stenotic segment
- decrease in velocity distal to the stenotic segment (post-stenotic dilation)
- disturbances in flow (i.e., turbulence and murmurs).
- side-to-side differences in mean flow velocity

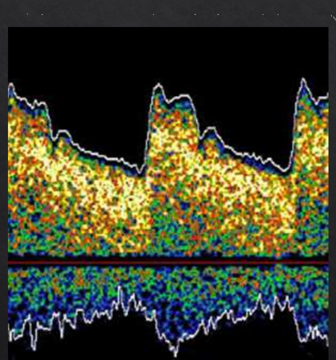
Stenotic Flow Velocity

Vessel	Mean FV	Peak
MCA	>100	>160
ACA	>90	>140
PCA	>55	>85
ICA (siphon)	>90	>135
VA	>60	>90
BA	>65	>100

Degree of Stenosis (in MCA)

	Normal	Mild	Moderate	Severe
Mean	<80	<120	120-140	141-200
Peak	<140	140-209	210-280	>280
MCA/ICA	<3.0	≤ 3.0	3.0 - 5.9	≥ 6.0

Typical Intracranial Hemodynamics



- The brain uses 20-25% of the total blood flow in the body.
- dilated vascular bed
- low resistance waveforms,

  low Pulsatility
  - Normal PI: 0.6-1.1

Pulsatility Index (PI= Vsystole-Vdiastole/Vmean)

- The pulsatility index is the difference between systolic flow velocity and diastolic flow velocity, divided by the time-averaged mean, and is an **estimation of vascular resistance distal to the site of insonation**

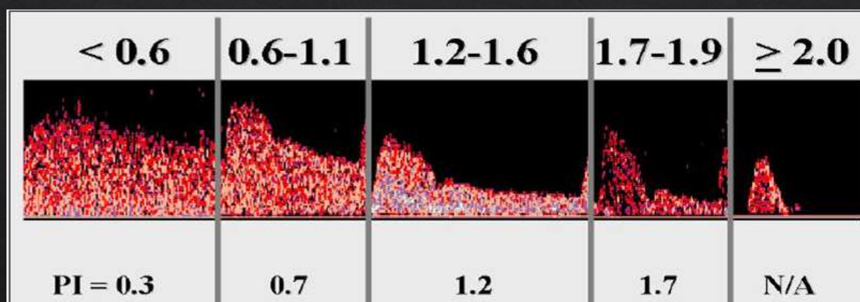
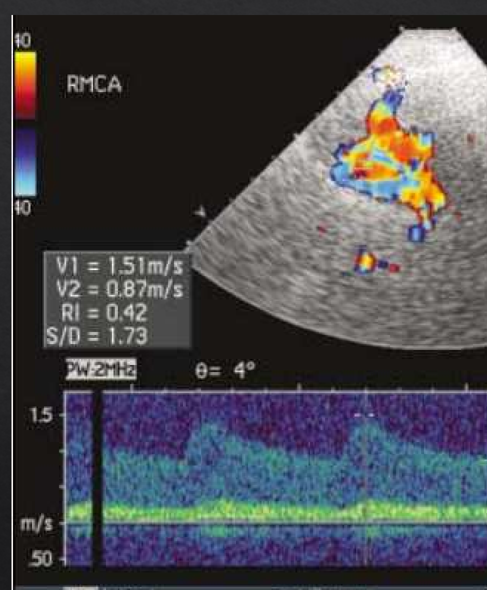


Image from https://slideplayer.com/slide/4898934/ University of Oklahoma Ryan Hakimi **2015 Introduction to Carotid and Transcranial Doppler Ultrasound**

Arteriovenous Malformations and PI

An abnormal tangle of blood vessels connecting arteries and veins, which disrupts normal blood flow and oxygen circulation.

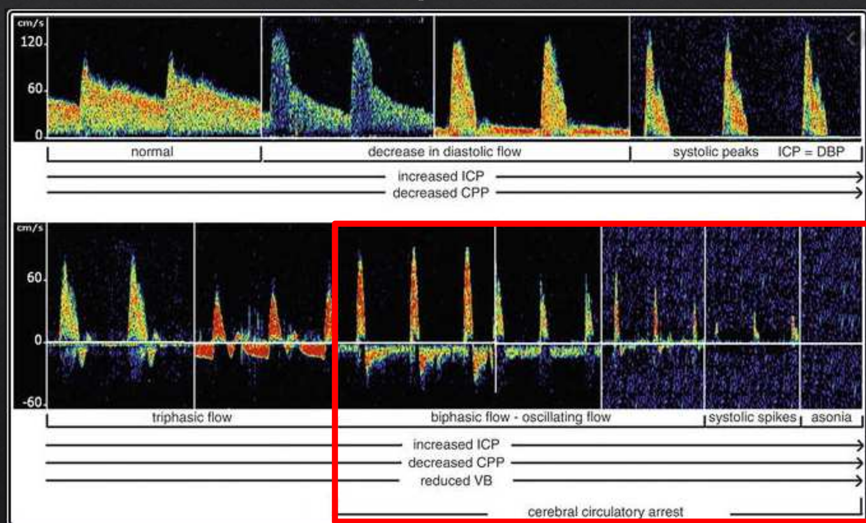
- High velocity, low Pulsatility, very low resistance
- PI < 0.5



Bartels, E. (2005), Evaluation of Arteriovenous Malformations (AVMs) With Transcranial Color-Coded Duplex Sonography.

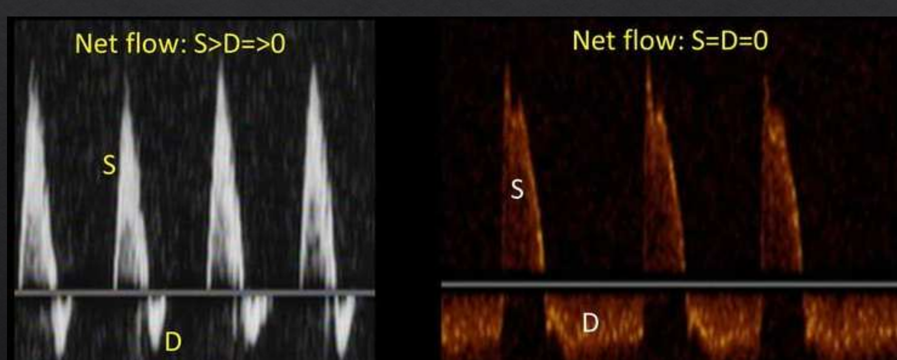
Brain Death

Small systolic spikes in early systole without diastolic flow or reverberating flow, indicating very high vascular resistance associated with greatly increased intracranial pressure are criteria supportive of the clinical diagnosis of brain death in a patient with adequate insonation windows and patent extracranial circulation.



Sawicki M., Wojczal J., Birkenfeld B., Cyrylowski L. (2014) Brain Death Imaging. In: Saba L., Raz E. (eds) Neurovascular Imaging.

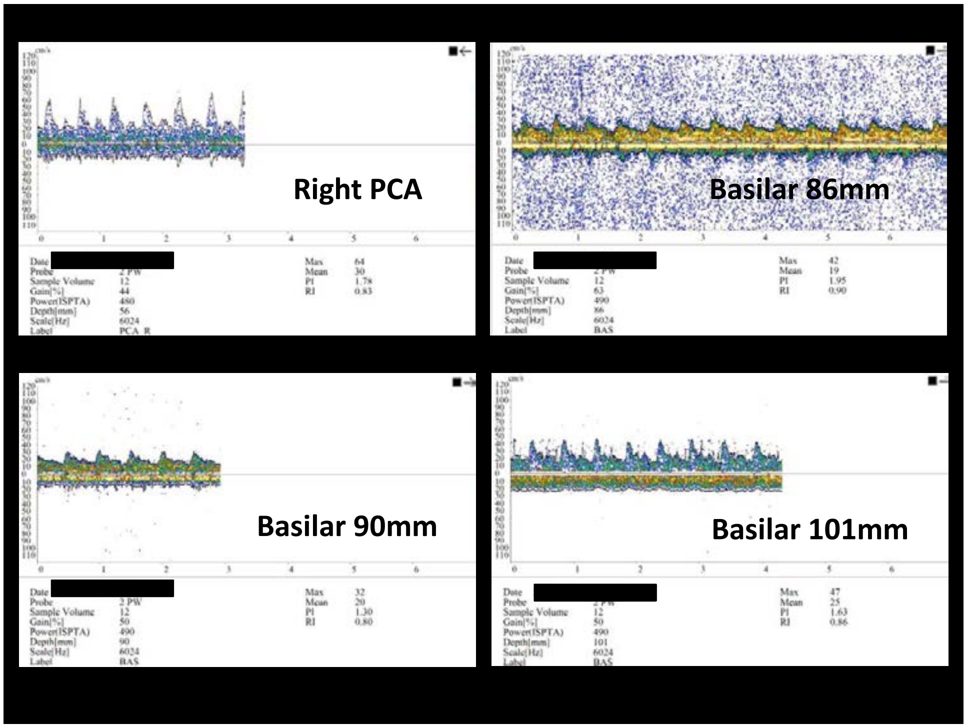
Brain Death

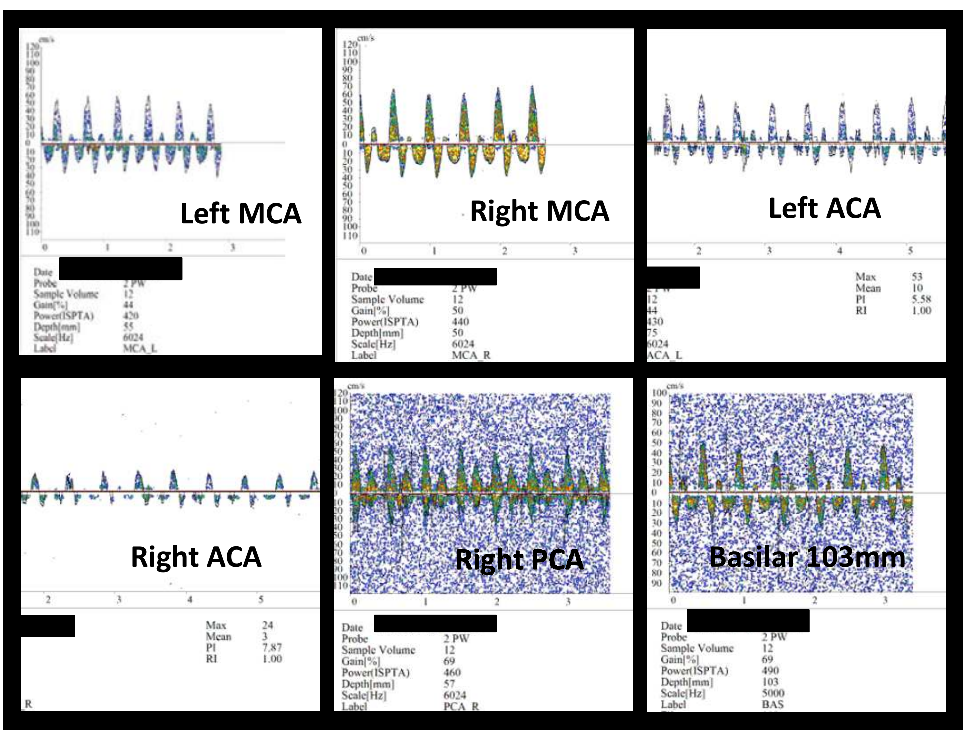


Blanco, P., Abdo-Cuza, A. Transcranial Doppler ultrasound in the ICU: it is not all sunshine and rainbows. *Crit Ultrasound J* **10**, 2 (2018). https://doi.org/10.1186/s13089-018-0085-4

Case Study – Brain Death

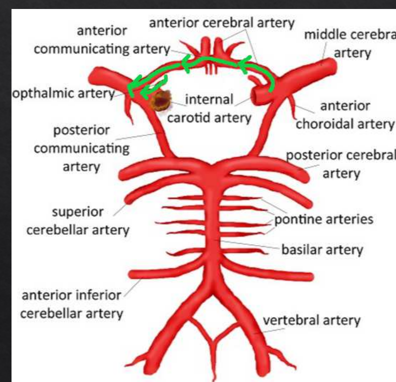
- 20-year-old male with asthma
- Anoxic brain injury after cardiac arrest
- Brainstem Function: +corneals + cough
- Progressing brain herniation
- Brainstem functions ceased day 12
- Electrolyte imbalance (hypernatremia)
- Family disagreements on goals of care
- Ancillary testing to help determine brain death

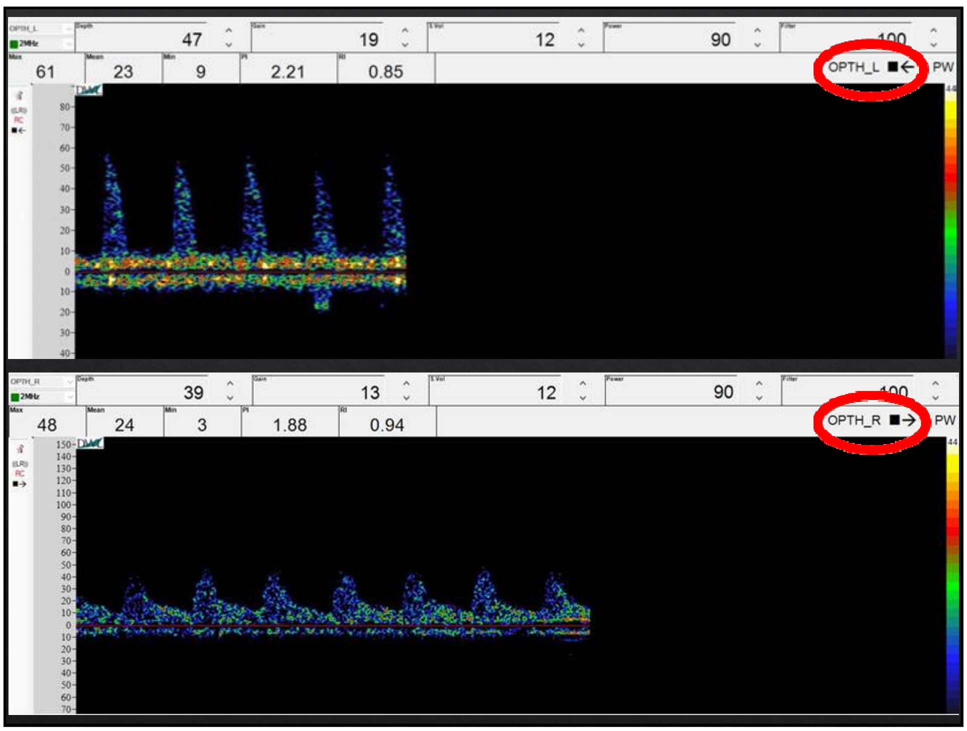

Right PCA
Basilar 86mm
Basilar 90mm
Basilar 101mm

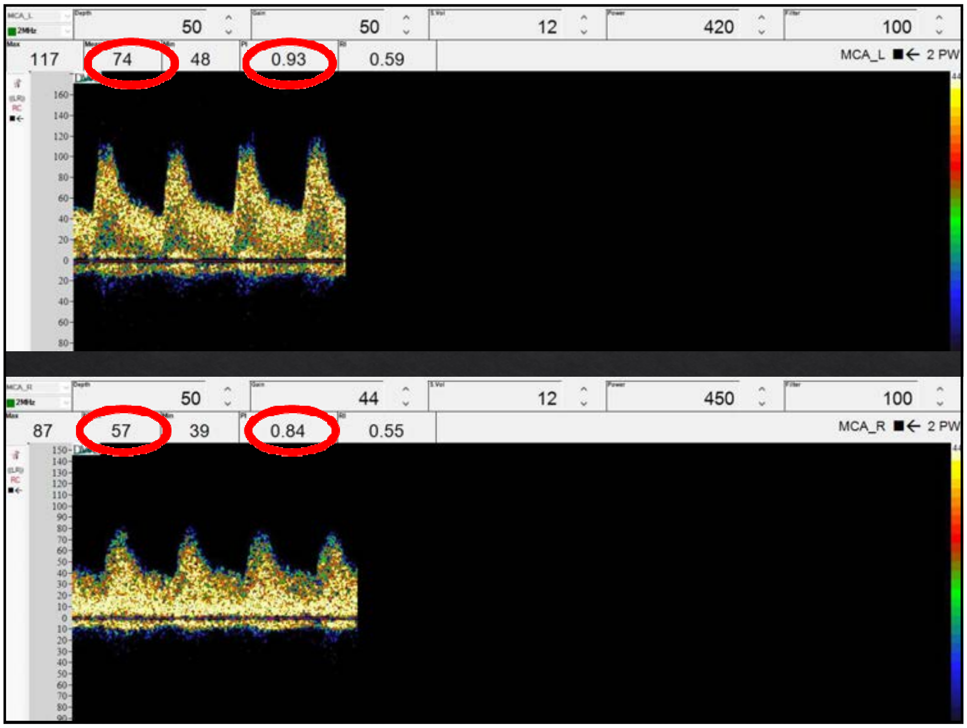

Left MCA
Right MCA
Left ACA
Right ACA
Right PCA
Basilar 103mm

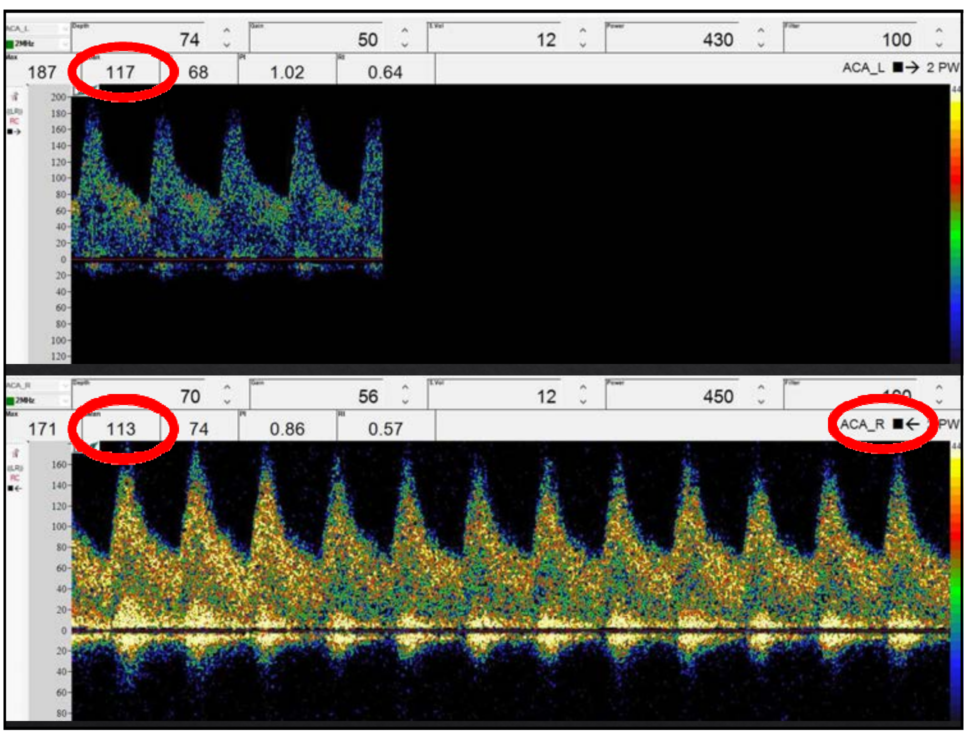
Case Study – Stenosis and Collateral Flow in an 72M with RICA Occlusion

- Carotid exam:
  - total occlusion of Right Internal Carotid
- TCD exam:
  - cross-collateralization from the Left to the Right through an active Acomm
  - External-to-internal collateralization






50
50
12
420
100
117
74
48
0.93
0.59
MCA_L
2 PW
50
44
12
450
100
87
57
39
0.84
0.55
MCA_R
2 PW


74
50
12
430
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187
117
68
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ACA_L
2 PW
70
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171
113
74
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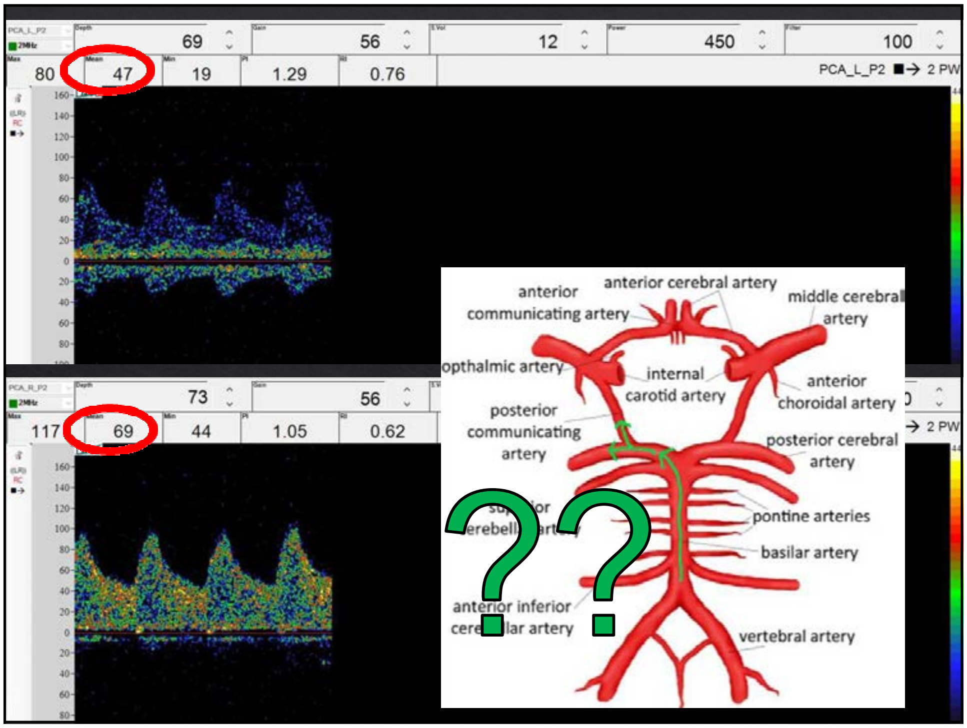
0.57
ACA_R
PW



69
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PCA_L_P2
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73
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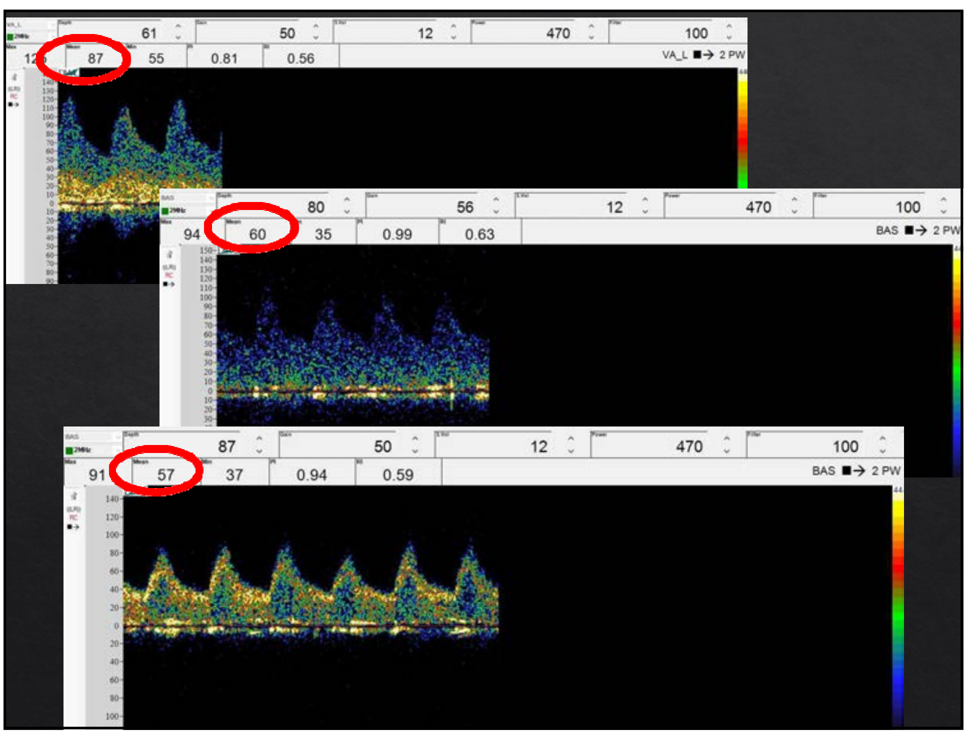
anterior cerebral artery
anterior communicating artery
middle cerebral artery
opthalmic artery
internal carotid artery
anterior choroidal artery
posterior communicating artery
posterior cerebral artery
pontine arteries
basilar artery
anterior inferior
vertebral artery
??



61
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470
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87
55
0.81
0.56
VA_L
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12
470
100
94
60
35
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BAS
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87
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57
37
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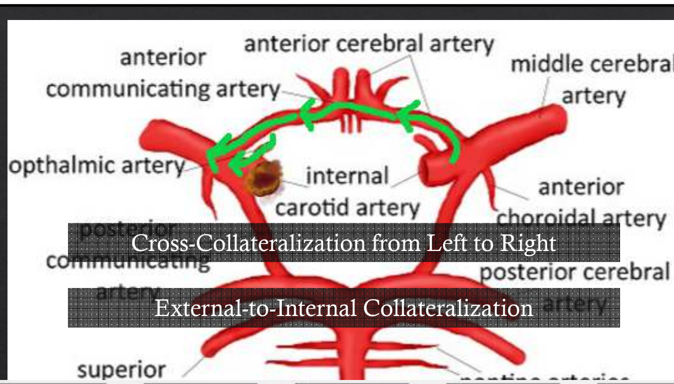
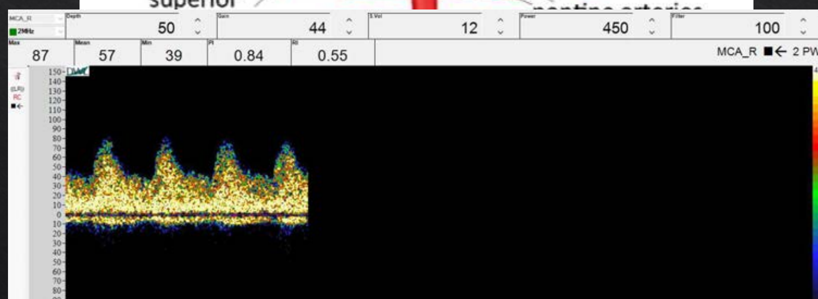
BAS
2 PW



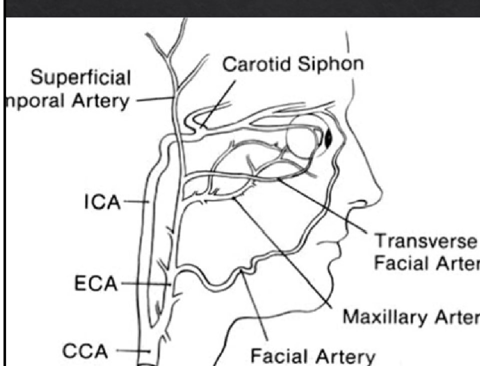
Cross-Collateralization from Left to Right

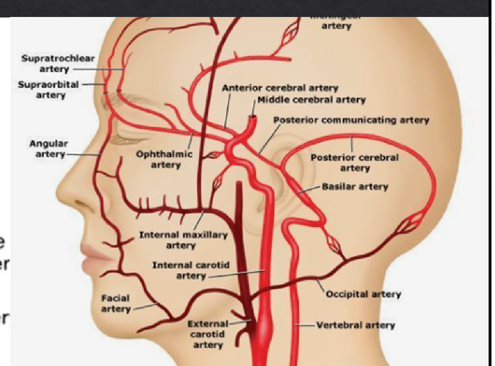
External-to-Internal Collateralization



Case Study – Stenosis and Collateral Flow with an Occluded ICA

External-to-Internal Collateralization

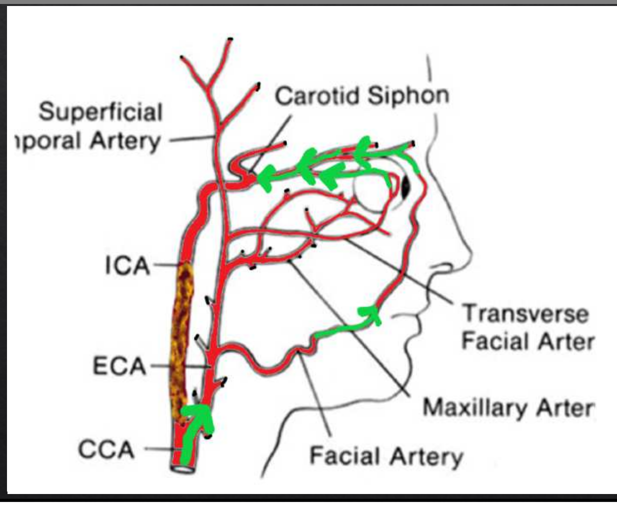


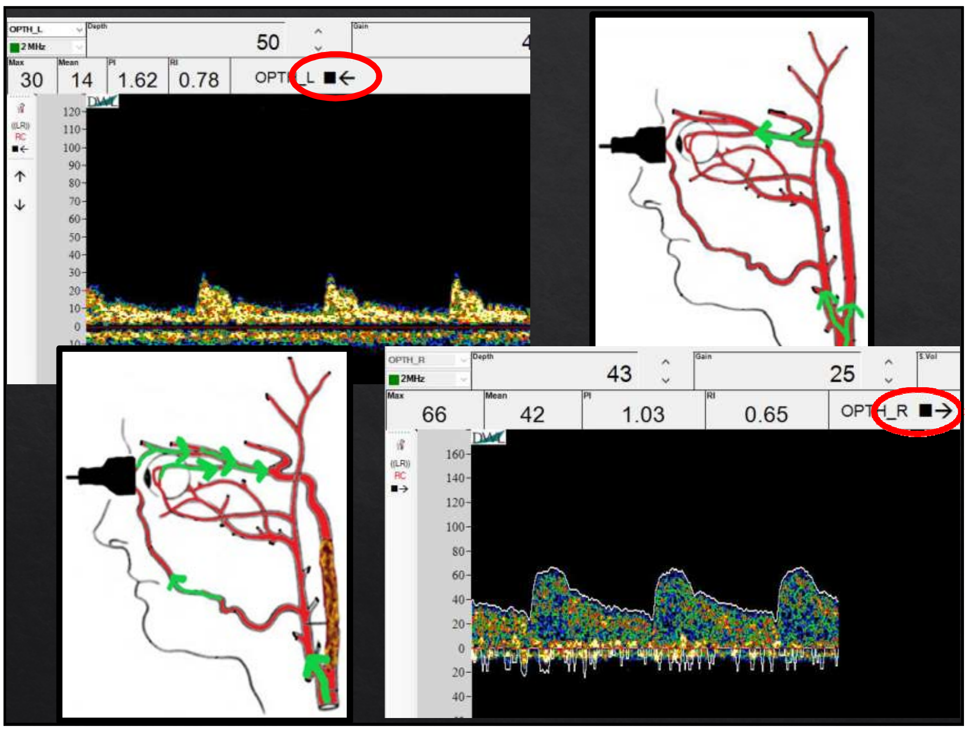


Images from: American Society of Radiologic Technologists

Case Study – Stenosis and Collateral Flow with an Occluded ICA

External-to-Internal Collateralization





Sickle Cell Anemia

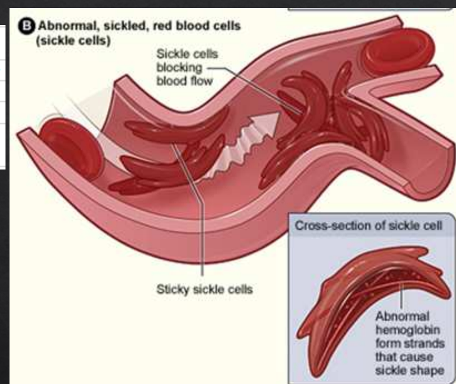
Stroke Prevention Trial in Sickle Cell Disease (aka the STOP trial)

Validated for children 2-16 years:

STOP Study for Sickle Cell Disease

Note: All values are Mean Flow Velocity (MFV) measurements

Vessel	Normal	Conditional	Abnormal
distal intracranial ICA & MCA	<170	170-199	>200

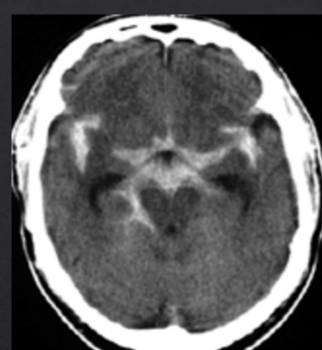


Other abnormal findings include:

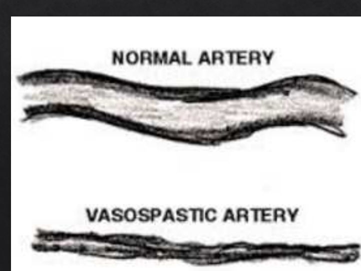
- low FV in MCA (<70cm/s)
- MCA ratio <0.5
- ipsilateral ACA/MCA ratio >1.2
- dampened waveform, turbulence, and musical harmonic murmurs

The National Heart, Lung, and Blood Institute (NHLBI)

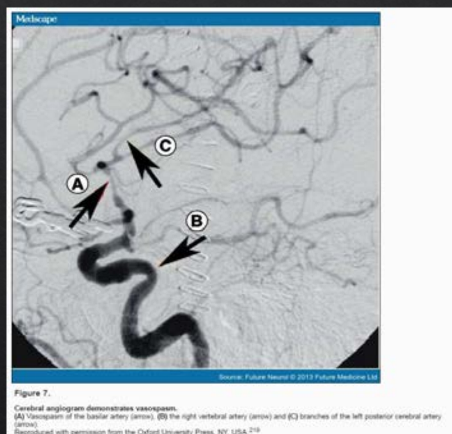
Vasospasm and SAH



- SAH is usually caused by spontaneous aneurysm burst and subsequent bleeding into subarachnoid space
- 2/3 of aneurysmal SAH develop vasospasm
- Usually develops between days 4-10 after bleed



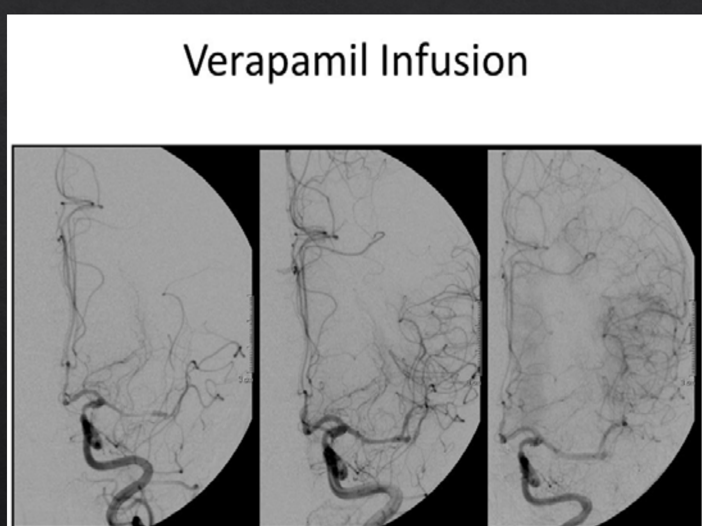
Angiogram
(the Gold Standard)



Computed Tomography Angiography (CTA)

Severe spasm can lead to ischemic stroke.

Intra-Arterial –Spasmolysis: direct infusion of a vasodilator to the site of spasm



TCD Diagnosis of Vasospasm

- Increases in Mean Flow Velocity, evidence of turbulence, Lindegaard Ratio

TCD Criteria for Vasospasm

Note: All values are Mean Flow Velocity (MFV) measurements

Vessel	Possible	Probable	Presumed/Definite
Terminal Internal Carotid Artery (ICA)	80	125	200
Middle Cerebral Artery (MCA)	120	150	>200
Anterior Cerebral Artery (ACA)	100	130	>150
Posterior Cerebral Artery (PCA)	80	120	>160
Verebral Artery (VA)	60	80	105
Basilar Artery (BA)	75	85	140

- Lindegaard Ratio – vasospasm vs hyperemia

LR = highest MFV in MCA/ highest MFV in EICA

LR < 3.0 indicates NO vasospasm
LR > 3.0 – 6.0 indicates mild vasospasm
LR > 6.0 indicates severe vasospasm

- Daily TCD exams to monitor for development of vasospasm
- highest **mean** flow velocities and LRs written in a flow chart
- Major changes prompt the care team to send patients for subsequent tests: CTA and Angiography.

Daily TCD Monitoring: **maximal Mean Flow Velocities (MFV in cm/s) and Lindegaard Ratios (LR = MFV MCA / MFV EICA)**

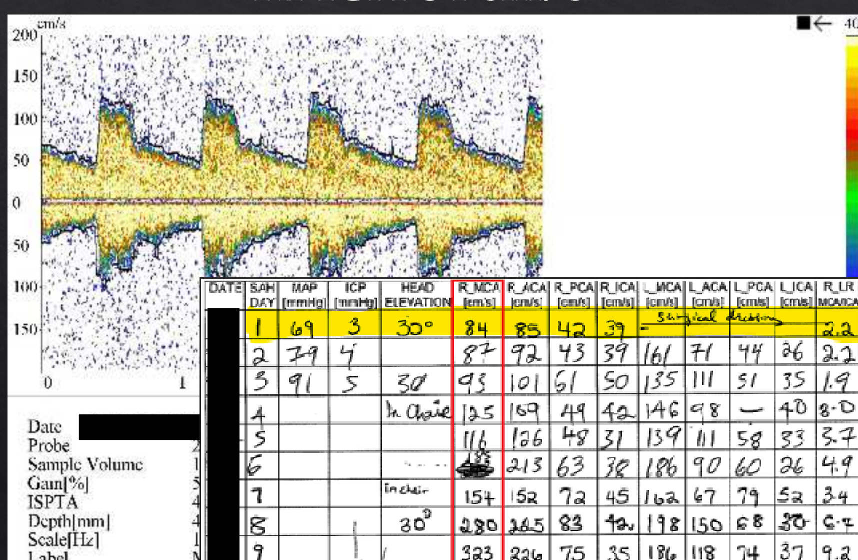
These values are preliminary. The final report will be available in EPIC and the raw TCD waveforms can be viewed in Visage

DATE	SAH DAY	MAP	ICP	R_MCA	R_TICA	R_ACA	R_PCA	R_EICA	L_MCA	L_TICA	L_ACA	L_PCA	L_EICA	R_LR MCA/ICA	L_LR MCA/ICA	tech	Notes

Case Study – SAH and Vasospasm Progression

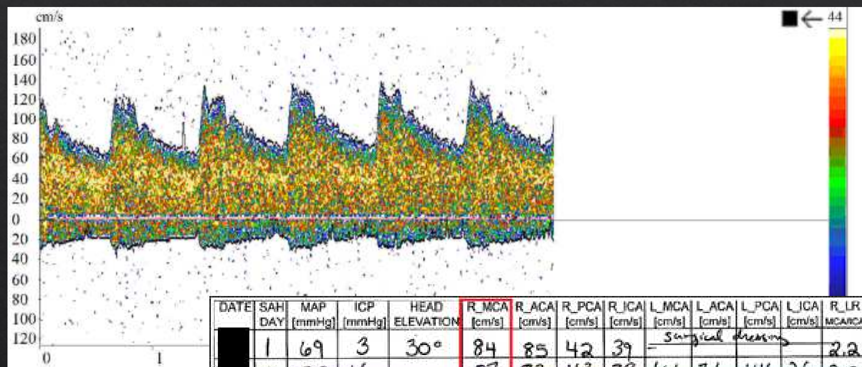
- 53M doing yard work
- Smoker, positive family history of ruptured cerebral aneurysms
- SAH from ruptured 9mm LMCA aneurysm
- EVD, craniotomy for clipping of the burst aneurysm, plus 2 other aneurysms that were found incidentally
- TCDs with progressively increasing MFVs

Post Bleed Day 1: highest MFV in RMCA 84 cm/s



DATE	SAH DAY	MAP [mmHg]	ICP [mmHg]	HEAD ELEVATION	R_MCA [cm/s]	R_ACA [cm/s]	R_PCA [cm/s]	R_ICA [cm/s]	L_MCA [cm/s]	L_ACA [cm/s]	L_PCA [cm/s]	L_ICA [cm/s]	R_LR MCA/ICA	L_LR MCA/ICA
[redacted]	1	69	3	30°	84	85	42	39	Surgical dressing				2.2	
	2	79	4		87	92	43	39	161	71	44	26	2.2	6.2
	3	91	5	30	93	101	61	50	135	111	51	35	1.9	3.9
	4			In Chair	125	169	49	42	146	98	—	40	8.0	3.7
	5				116	126	48	31	139	111	58	33	3.7	4.2
	6				[illegible]	213	63	38	186	90	60	26	4.9	7.2
	7			In chair	154	152	72	45	162	67	79	52	3.4	3.1
	8			30°	280	265	83	42	198	150	68	30	6.7	6.6
	9				323	226	75	35	186	118	74	37	9.2	5.0
	10		6		306	239	109	50	183	144	112	44	6.1	4.2

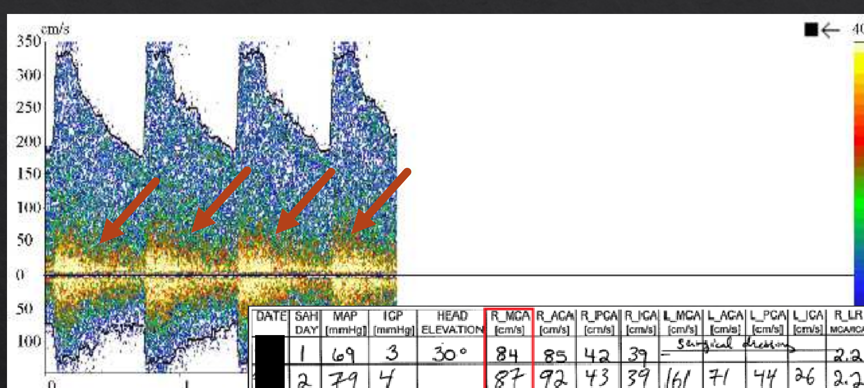
PBD 3: RMCA 93 cm/s



Date [redacted]
Probe 2 P
Sample Volume 12
Gain[%] 56
Power(ISPTA) 44(
Depth[mm] 54
Scale[Hz] 80(
Label MC

DATE	SAH DAY	MAP [mmHg]	ICP [mmHg]	HEAD ELEVATION	R_MCA [cm/s]	R_ACA [cm/s]	R_PCA [cm/s]	R_ICA [cm/s]	L_MCA [cm/s]	L_ACA [cm/s]	L_PCA [cm/s]	L_ICA [cm/s]	R_LR MCA/ICA	L_LR MCA/ICA
[redacted]	1	69	3	30°	84	85	42	39	Surgical dressing				2.2	
	2	79	4		87	92	43	39	161	71	44	26	2.2	6.2
	3	91	5	30°	93	101	61	50	135	111	51	35	1.9	3.9
	4			In Chair	125	109	49	42	146	98	—	40	3.0	3.7
	5				116	126	48	31	139	111	58	33	3.7	4.2
	6			- - - -	183	213	63	38	186	90	60	26	4.9	7.2
	7			in chair	154	152	72	45	162	67	79	52	3.4	3.1
	8		|	30°	280	225	83	42	198	150	68	30	6.7	6.6
	9		|	/	323	226	75	35	186	118	74	37	9.2	5.0
	10		6		306	239	109	50	183	144	112	44	6.1	4.2

PBD 8: RMCA 280 cm/s

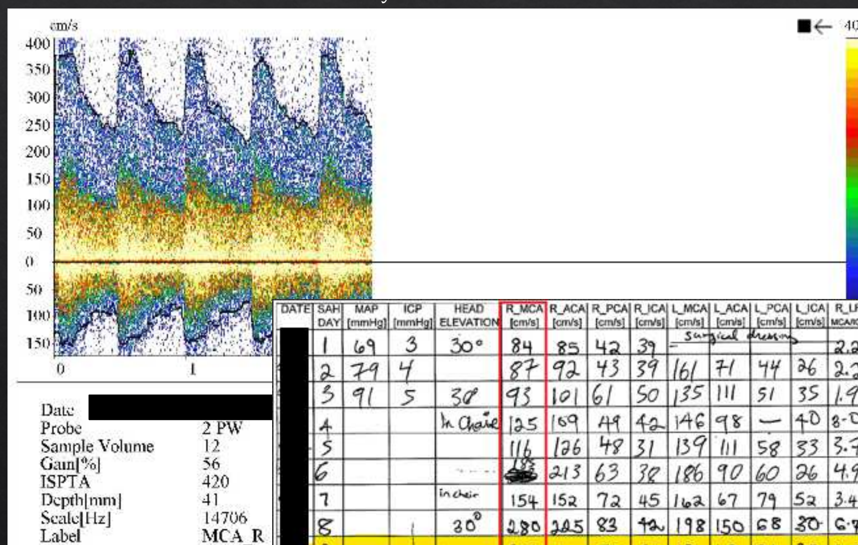


Date [redacted]
Probe 2 PW
Sample Volume 12
Gain[%] 38
ISPTA 420
Depth[mm] 51
Scale[Hz] 12500
Label MCA_

DATE	SAH DAY	MAP [mmHg]	ICP [mmHg]	HEAD ELEVATION	R_MCA [cm/s]	R_ACA [cm/s]	R_PCA [cm/s]	R_ICA [cm/s]	L_MCA [cm/s]	L_ACA [cm/s]	L_PCA [cm/s]	L_ICA [cm/s]	R_LR MCA/ICA	L_LR MCA/ICA
[redacted]	1	69	3	30°	84	85	42	39	Surgical dressing				2.2	
	2	79	4		87	92	43	39	161	71	44	26	2.2	6.2
	3	91	5	30°	93	101	61	50	135	111	51	35	1.9	3.9
	4			In Chair	125	109	49	42	146	98	—	40	3.0	3.7
	5				116	126	48	31	139	111	58	33	3.7	4.2
	6			- - - -	183	213	63	38	186	90	60	26	4.9	7.2
	7			in chair	154	152	72	45	162	67	79	52	3.4	3.1
	8		|	30°	280	225	83	42	198	150	68	30	6.7	6.6
	9		|	/	323	226	75	35	186	118	74	37	9.2	5.0
	10		6		306	239	109	50	183	144	112	44	6.1	4.2

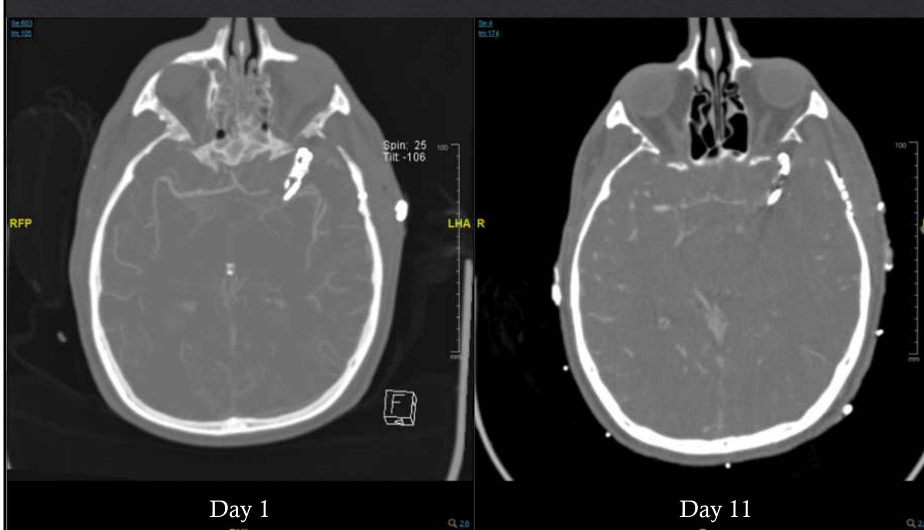
PBD 9: RMCA 323 cm/s

Post-bleed day 9 – scaled maxed out

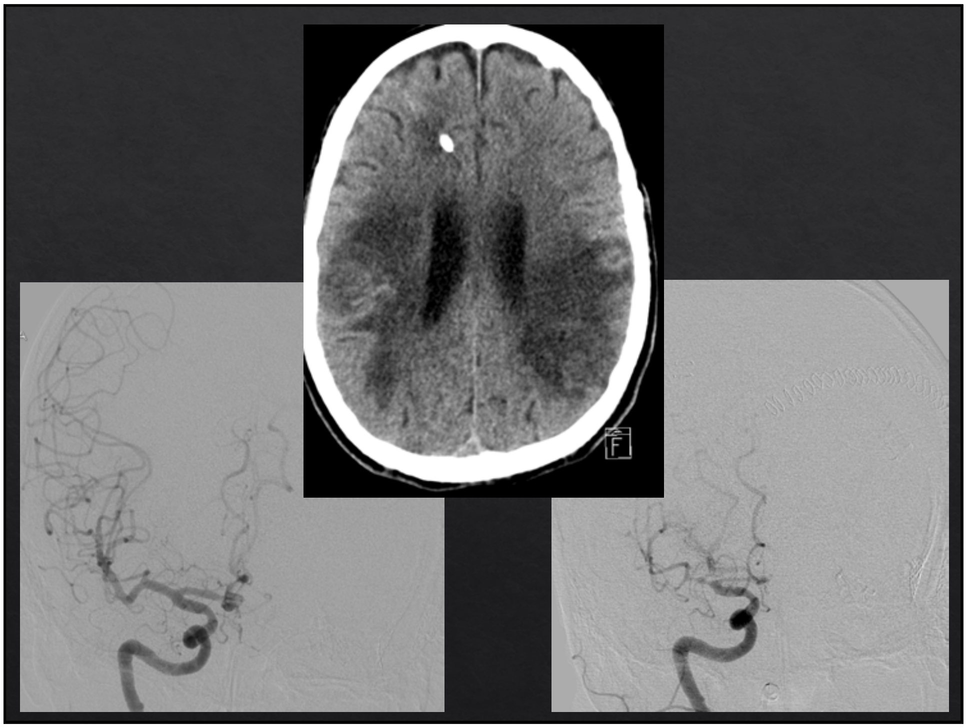


DATE	SAH DAY	MAP [mmHg]	ICP [mmHg]	HEAD ELEVATION	R_MCA [cm/s]	R_ACA [cm/s]	R_PCA [cm/s]	R_ICA [cm/s]	L_MCA [cm/s]	L_ACA [cm/s]	L_PCA [cm/s]	L_ICA [cm/s]	R_LR MCA/ICA	L_LR MCA/ICA
[redacted]	1	69	3	30°	84	85	42	39	surgical dressing				2.2	
	2	79	4		87	92	43	39	161	71	44	26	2.2	6.2
	3	91	5	30°	93	101	61	50	135	111	51	35	1.9	3.9
	4			In Chair	125	109	49	42	146	98	—	40	3.0	3.7
	5				116	126	48	31	139	111	58	33	3.7	4.2
	6				183	213	63	38	186	90	60	26	4.9	7.2
	7			in chair	154	152	72	45	162	67	79	52	3.4	3.1
	8			30°	280	225	83	42	198	150	68	30	6.7	6.6
	9				323	226	75	35	186	118	74	37	9.2	5.0
	10		6		306	239	109	50	183	144	112	44	6.1	4.2

CTA on PBD1 vs PBD11



Day 1 Day 11

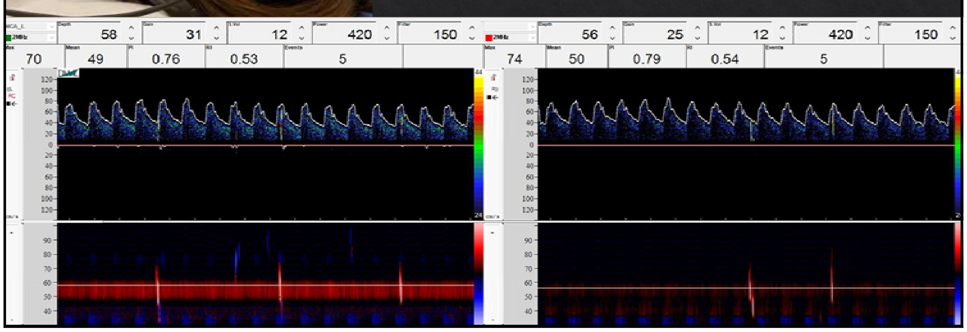


Emboli Detection

- Ischemic stroke, TIA, asymptomatic high-grade stenosis
- Microbubble Test for PFO diagnosis

Monitor "downstream" from the obstruction

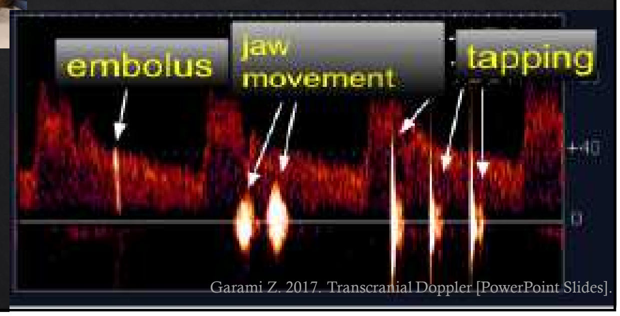
Turn down gain enough to allow visualization of embolic signals



Emboli Detection

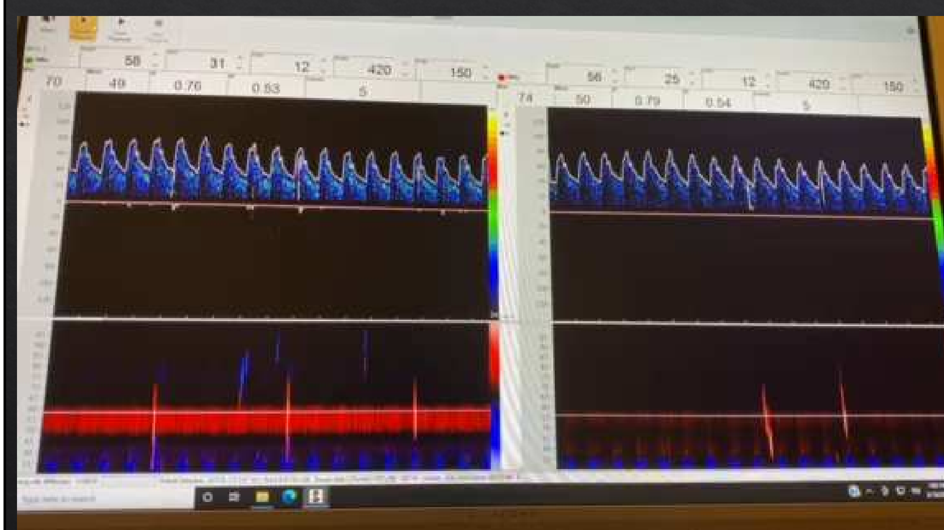
Microembolic Signals (MES) aka High Intensity Transient Signals (HITS)

- Random occurrence during cycle
- Brief duration (<0.1 second)
- High intensity (>3dB over background)
- Primarily unidirectional signals
- Audible component

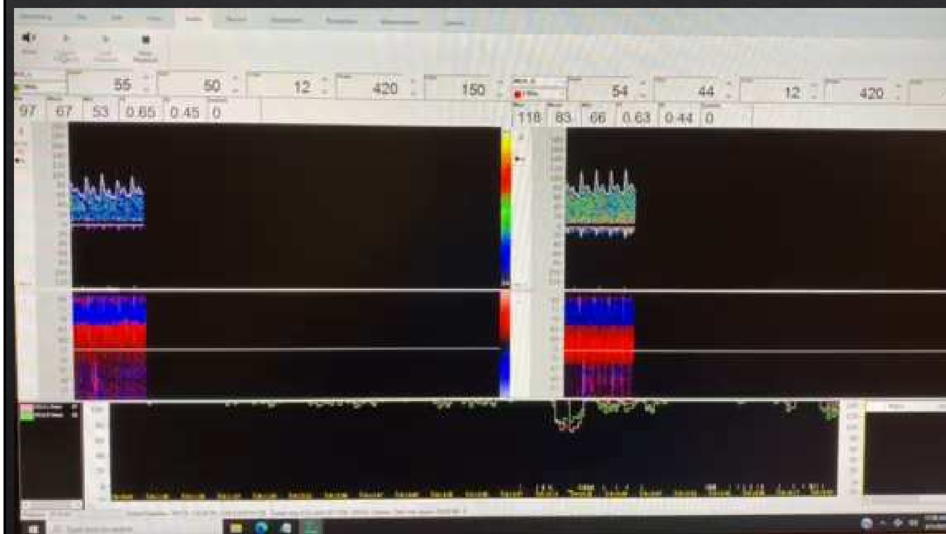


Garami Z. 2017. Transcranial Doppler [PowerPoint Slides].

Emboli Detection

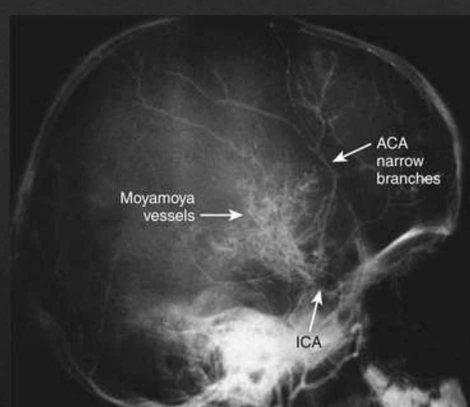


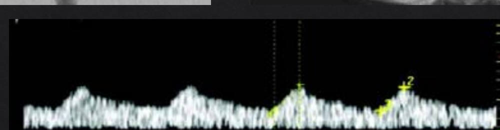
Emboli Detection - PFO



Cerebral Vasoreactivity Testing (CVR)

Vascular Reserve: Can the downstream vascular bed still dilate?





Picture from Neupsy Key https://neupsykey.com/surgical-treatment-of-moyamoya-disease-in-adults/#f0010

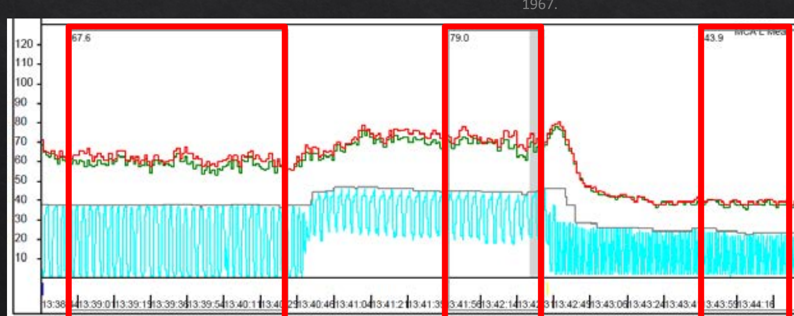
Cerebral Vasoreactivity Testing (CVR)

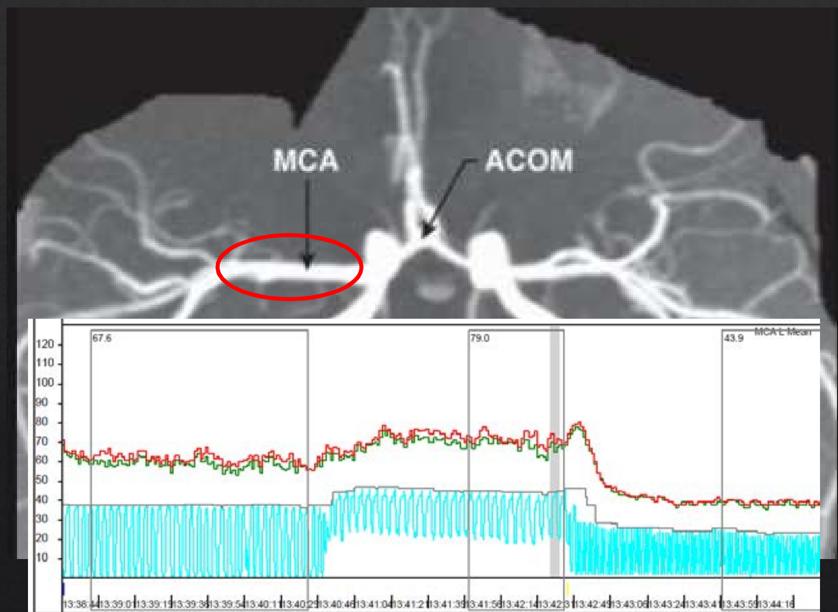
Baseline BP:		**MAP:**		**HR:**	
Left MCA MFV		**Right MCA MFV**		**EtCO2**	
Depth:		Depth:			
Hyper:		Hyper:		Hyper:	
RA:		RA:		RA:	
CO2:		CO2:		CO2:	
R:		R:			
CO2R:		CO2R:			
VMR:		VMR:			

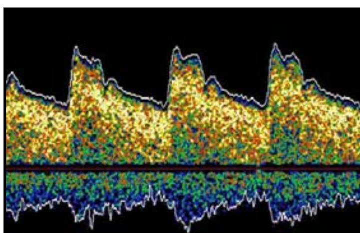
$$\frac{\%\Delta\ MFV}{\Delta\ etCO2} =$$

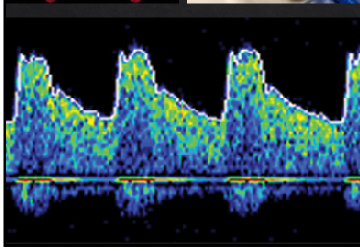
Hypercapnia	Hypocapnia	Interpretation
>10	>10	Normal
5-10	>10	Mild
5-10	5-10	Moderate
0-5	5-10	Severe
0-5	0-5	Critical
<0	any	Critical with Steal

Course of cerebrovascular reactivity in patients with carotid artery occlusions. B Widder, B Kleiser and H Krapf. Stroke. 1994 | Volume 25, Issue 10: 1963–1967.









An Essential Tool for Neurovascular Assessment

- Inexpensive
- Repeatable
- Non-invasive
- Real-time
- Portable

- Localize source of obstruction and embolization
- Aid in treatment evaluation and planning

References

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