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Transcranial Doppler Monitoring

Advanced Neurosonology Course

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Disclosures

- **Financial**
  NovaSignal: design and run device clinical trials
- **Unapproved Use of Devices**
  None

Transcranial Doppler Monitoring Studies

- **Ultrasound Physics of TCD monitoring**
  impedance, reflection, signal intensity
- **Technique and Evidence**
  - Microembolic Monitoring without Microbubble Injection (CPT 93892)
  - Microembolic Monitoring with Microbubble Injection (CPT 93893)
  - Vasomotor Reactivity (CPT 93890)
  - TBI/SAH Neurocritical Care Monitoring
  - Thrombolysis Monitoring
  - Intraoperative Monitoring
  - Rotational Vertebrobasilar Insufficiency Monitoring
- **Cases**

Physics of Embolic Monitoring

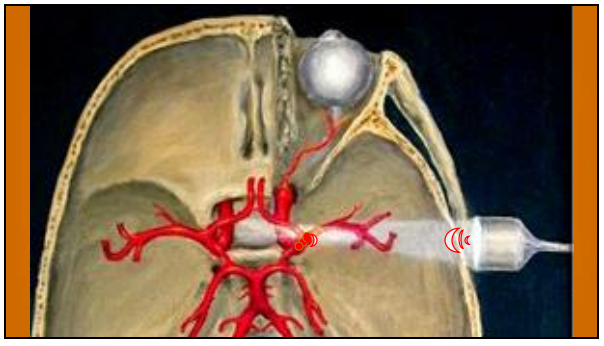
Physics

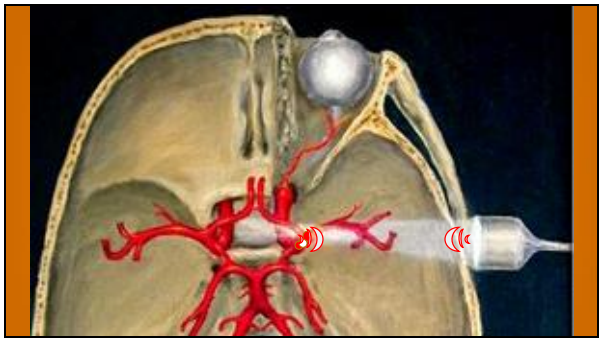
TCD Embolic Monitoring

- **Devices are calibrated to "expect" echoes reflecting off flowing blood**
  intensity reflection coefficient = reflected intensity/original intensity

  essentially unchanged over time when monitoring blood flow, unless…
- **Intensity of the reflection changes depending on the acoustic impedance**
  impedance (z) = density x propagation speed in the medium
  - particles (air, thrombi, etc) have very different density than RBCs and other blood elements

  when there is a dramatic difference in density, thereby impedance, the reflected intensity increases
  - IRC = $(z_2-z_1/z_2+z_1)^2$; smaller differences will make fractions, large differences will ~1
- **The result of an echo reflecting off particle/blood interface = intense signal**
  High Intensity Transient Signal (HITS) or Microembolic Signal (MES)





Physics

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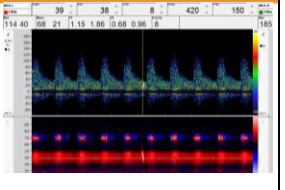
TCD Embolic Monitoring

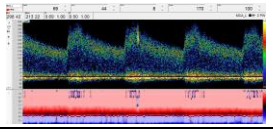
- **HITS/MES consensus criteria** [1,2]
  - Transient (<300ms)
  - Passage through time and space
  - High intensity (at least >3 dB above background)
  - Unidirectional
  - Characteristic "snap, tonal chirps or moans"

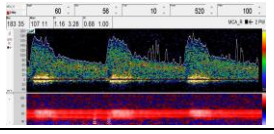


Embolic Monitoring Technique

Embolic Monitoring: Technique

- **Complete (93886)/Limited (93888)**
  - Always good to know the windows and hemodynamics
    - Pro tip: memorize/mark windows and probe position/angle
  - Billing requirement
- **Microembolic Monitoring without Microbubble Injection (93892)**
  - Headframe is applied, probe(s) are applied and affixed
    - Tight as tolerated for best signal
    - probes over the window, then angle for desired intercept
  - Looking for most coverage with Mmode; single gate less important





Bubble/RLS: Technique

- **Complete (93886)/Limited (93888)**
  - Always good to know the windows and hemodynamics
    - Pro tip: memorize/mark windows and probe position/angle
  - Billing requirement
- **Microembolic Monitoring with Microbubble Injection (93893)**
  - Headframe is applied, probe(s) are applied and affixed
    - Tight as tolerated for best signal
    - probes over the window, then angle for desired intercept
  - Patient has IV placed in right antecubital vein
  - Position the patient left lateral decubitus or sitting up
  - Mix up two doses of contrast: at rest & Valsalva
    - Air/saline/blood = 9 mL bacteriostatic saline, 1 mL air, +/- blood
  - Injection #1 at rest
  - Injection #2 with Valsalva
    - Inject → 0 or 5 seconds → Valsalva for 10 seconds (+/- calibrated 40 mmHg) → release
      - Want to see waveform dampening and mean velocity decrease at least 25% with Valsalva, practice beforehand if possible
  - Wait at least 1 minute (~ 1 full circulatory cycle) after each injection

Embolic Monitoring Evidence & Cases

Embolic Monitoring without Microbubble Injection

- **Many, many reports**
  atrial fibrillation, cardiac hardware, carotid stenosis, SAH, etc.
- **ACES**[4]
  asymptomatic emboli from asymptomatic carotid stenosis as a predictor of stroke/TIA
- **CARESS**[5]
  RCT of aspirin/clopidogrel vs aspirin to reduce HITS and stroke/TIA ipsilateral to recently symptomatic extracranial carotid stenosis
- **CLAIR**[6]
  RCT of aspirin/clopidogrel vs aspirin to reduce HITS and stroke/TIA ipsilateral to recently symptomatic intracranial stenosis

Embolic Monitoring

Asymptomatic embolisation for prediction of stroke in the Asymptomatic Carotid Emboli Study (ACES): a prospective observational study

Hugh S Markus, Alice King, Martin Shipley, Raffi Topakian, Marisa Cullinane, Sheila Reihill, Natan M Bornstein, Arjen Schaafsma

- **Prospective observational study of patients with asymptomatic carotid stenosis of 70% or greater by NASCET criteria to see if HITS = greater stroke risk**
  Two 1h studies of bilateral MCA at baseline (initial and 7d), 1h at 6|12|18mo; 77/467 had HITS
- **HITS = greater risk of ipsilateral stroke/TIA**
  Stroke/TIA within 2 years → HR 2.54
  Stroke within 2 years →HR 5.57
  Absolute risk of stroke/TIA within 2 years: 7.13% with HITS vs 3.04% without
  Absolute risk of stroke within 2 years: 3.62% with HITS vs 0.70% without
  HR of stroke/TIA (2.63) & stroke (6.37) at 6mo f/u for patients with HITS on their last recording
- **Detection of HITS can identify patients with significant asymptomatic carotid stenosis who are at particularly high or low risk for ipsilateral stroke/TIA**

Embolic Monitoring

Dual Antiplatelet Therapy With Clopidogrel and Aspirin in Symptomatic Carotid Stenosis Evaluated Using Doppler Embolic Signal Detection : The Clopidogrel and Aspirin for Reduction of Emboli in Symptomatic Carotid Stenosis (CARESS) Trial

Hugh S. Markus, Dirk W. Droste, Manfred Kaps, Vincent Larrue, Kennedy R. Lees, Mario Siebler and E. Bernd Ringelstein

- **RCT, double blind trial of aspirin vs aspirin/clopidogrel in recently symptomatic cervical carotid stenosis of ≥50% with HITS**
  - 1h study of bilateral MCA at baseline, 2d and 7d; 110/230 had HITS at baseline
- **Primary endpoint = HITS reduction at day 7 in DAPT vs monotherapy**
  - DAPT: 43.8% HITS+
  - Aspirin: 72.7% HITS+
  - DAPT vs aspirin: HITS hourly frequency reduced by 62.7% by day 2 and 61.2% by day 7
- **In patients with recently symptomatic ICA stenosis ≥50%, DAPT was better than aspirin alone at reducing asymptomatic embolization**

Embolic Monitoring

Clopidogrel plus aspirin versus aspirin alone for reducing embolisation in patients with acute symptomatic cerebral or carotid artery stenosis (CLAIR study): a randomised, open-label, blinded-endpoint trial

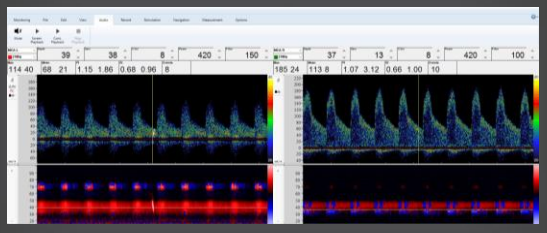
*Ka Sing Lawrence Wong, Christopher Chen, Jianhui Fu, Hui Meng Chang, Nijasri C Suwanwela, Yining N Huang, Zhao Han, Kay Sin Tan, Daya Ratanakorn, Pavittha Chollate, Yudong Zhao, Angeline Koh, Qing Hao, Hugh S Markus, for the CLAIR study investigators**

- **RCT of aspirin vs aspirin/clopidogrel for patients with symptomatic mostly (93%) intracranial atherosclerosis and HITS within 7d of symptoms**
  - TCD monitoring (30 min) at baseline, day 2 and day 7; 100 patients
  - Primary endpoint: proportion of patients with HITS at day 2
- **DAPT reduced HITS as compared to aspirin alone**
  - aspirin: 27/50; DAPT 14/45 (RRR 42.4%)
- **"clinical trials are now warranted to investigate whether this combination treatment also results in a reduction in stroke incidence"**

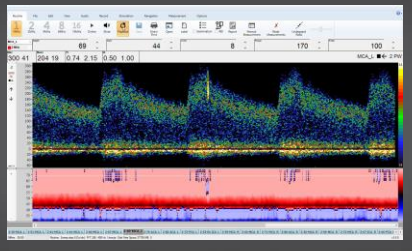
Embolic Monitoring: Bubble Study

- **screening for right to left shunt is important in patients with ESUS** [7]
  - overall OR of 2.9 of PFO in patients with "cryptogenic stroke" vs controls (5.1 age <55)
- **TTE or TCD recommended as screening tests** [8]
- **TCD much more sensitive as compared to TTE in a systematic review and meta-analysis** [9]
  - 35 studies, 3067 patients
  - TCD: 96.1% sensitivity, 92.4% specificity
  - TTE: 45.1% sensitivity, 99.6% specificity

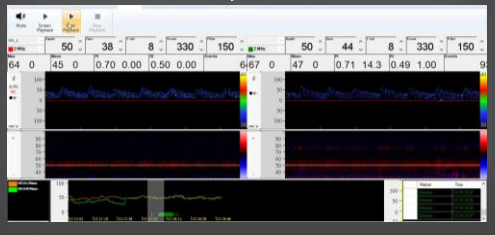
78F with L ICA stenosis



34F with aSAH



72M with “cryptogenic” stroke, “TTE –”



Physics of TCD Vasomotor Reactivity

Physics

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TCD Vasomotor Reactivity Testing

- **Cerebral arteries can be categorized into "conductance" and "resistance"**
  - large arteries, including Circle of Willis, primarily "conductance"
  - arterioles and capillaries are "resistance" arteries and responsive to metabolic, physical and neurological stimuli

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- **Vasomotor reactivity or reserve, can be tested**
  - the resistance vessels have "capacity" to respond to systemic insults (drop in CPP, etc) to maintain constant cerebral blood flow
  - severe proximal steno-occlusive disease can be a static trigger of vasodilatory response, thereby "exhausting" this capacity
- **TCD evaluates the mean velocity changes "upstream"**
  - The "action" is in the distal resistance vasculature, TCD measures mean velocity changes in the distal elements of the conductance vasculature
  - mean velocity changes by 3-4% for every 1 mmHg change in end-tidal CO_2

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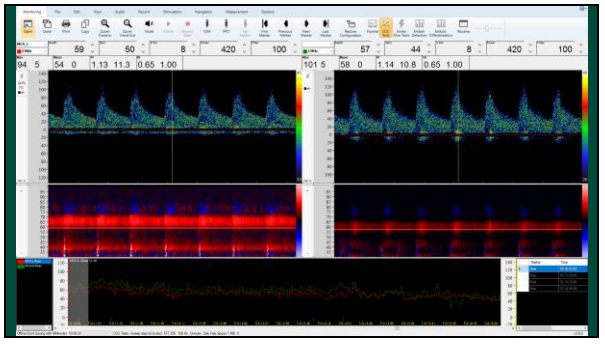
Vasomotor Reactivity Technique

Vasomotor Reactivity: Technique

- **Complete (93886)/Limited (93888)**
  - Always good to know the windows and hemodynamics
    - Pro tip: memorize/mark windows and probe position/angle
  - Billing requirement
- **Vasomotor Reactivity (93890)**
  - Headframe is applied, probe(s) are applied and affixed
    - Tight as tolerated for best signal
    - probes over the window, then angle for desired intercept
  - Looking for an optimized single gate signal, Mmode not so important
  - Multiple methods of providing vasomotor reactivity stimulus
    - acetazolamide [2]
    - Inhaled CO_2 [3]
    - Breath holding [4]
  - Allow at least several minutes of normal respiration before challenge
  - Use trending features of your device to mark start/end of stimulus
    - Pro tip: practice breath holding! Hold after normal inspiration, otherwise will be confounded by Valsalva
  - VMR = $\%\Delta = ((MV_{stim}-MV_{rest})/MV_{rest})*100$
  - BHI = $\%\Delta$ / s = $(((MV_{BH}-MV_{rest})/MV_{rest})*100)$/seconds breath held



Vasomotor Reactivity Evidence & Cases

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Vasomotor Reactivity

- **Many many reports**
  technique, extra- and intracranial stenosis/occlusion, migraine, concussion, etc.
- **Stroke risk** [15]
  impaired VMR (<20%) distal to carotid stenosis/occlusion is independently associated with ipsilateral ischemic stroke (HR 3.69)
- **Cognitive decline**
  asymptomatic severe carotid stenosis [16] and occlusion [17] with impaired VMR are associated with hemisphere-specific cognitive decline and bilaterally impaired VMR associated with global cognitive decline

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Cerebrovascular reactivity predicts stroke in high-grade carotid artery disease

- **systematic review and meta-analysis of individualized data**
  "To assess the usefulness of transcranial Doppler CO_2 reactivity for prediction of ipsilateral ischemic stroke in carotid artery stenosis."
- **Stroke risk**
  impaired VMR (<20%) distal to carotid stenosis/occlusion is independently associated with ipsilateral ischemic stroke (HR 3.69)
  as a continuous variable, every 10% drop in VMR → HR 1.69 for stroke
  No differences between recently symptomatic and asymptomatic stenoses
- **VMR is a useful predictor of ipsilateral stroke with carotid stenosis**
  should be studied whether treatment strategies based on VMR, particularly in asymptomatic stenosis, improves outcomes

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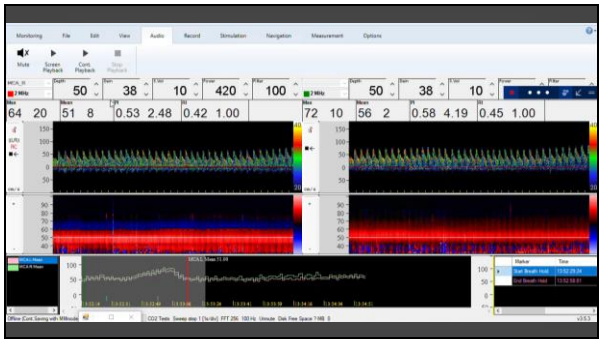
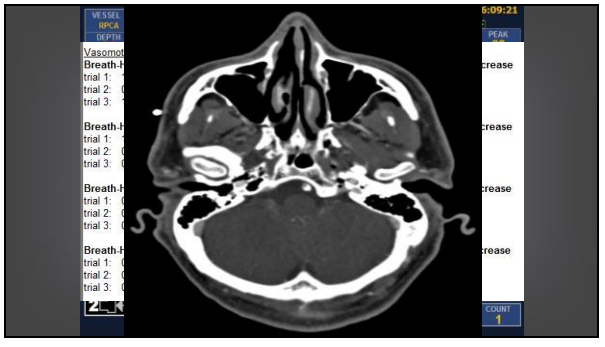
Severe carotid stenosis and impaired cerebral hemodynamics can influence cognitive deterioration

Carotid occlusion: Impact of cerebral hemodynamic impairment on cognitive performances

Giovanna Viticchi[1] | Lorenzo Falsetti[2] | Laura Buratti[3] | Maria C. Acciarri[3] | Andrea Emiliani[1] | Marco Bartolini[2] | Mauro Silvestrini[3]

- **Hypothesized that impaired VMR distal to carotid stenosis/occlusion impairs cognition**
  thinking of "risk" beyond ipsilateral stroke/TIA
- **Severe carotid stenosis**
  severe stenosis vs none → OR 4.16 for cognitive decline over 3y
  concomitantly impaired VMR ipsilateral → OR 14.66
- **Carotid Occlusion**
  "asymptomatic" carotid occlusion; 32 right and 29 left; impaired VMR → worse hemisphere-specific cognitive decline over 2y (Verbal Fluency for left, Colored Progressive Matrices and Complex Figure Copy Test for right)





Other Monitoring Techniques & Evidence

Physics of TCD in Critical Care "Multimodal" Monitoring

Physics

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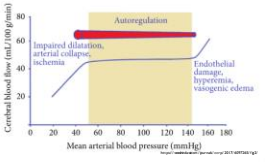
TCD in Critical Care Multimodal Monitoring

- autoregulation supports essentially constant CBF through vasomotor responses to fluctuations in ABP, ICP, CO_2, etc.
- Poor autoregulatory function ("pressure passive") is associated with poor outcome in severely brain injured patients [18]
  - "autoregulation-oriented therapy"
  - hypothesized that monitoring fluctuations in TCD and CPP could give a marker of autoregulation



Physics

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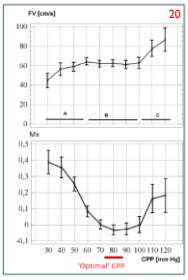
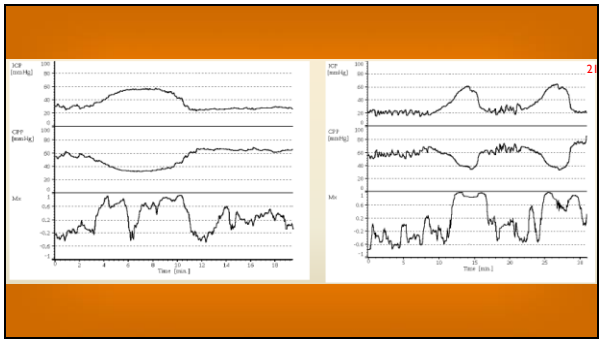
TCD in Critical Care Multimodal Monitoring

- There are many indices of cerebral autoregulation, generally measure a surrogate of CBF (TCD) or CBV (ICP) against "driving pressure" (MAP or CPP)
- Mx = correlation coefficient of FVm & CPP = an index of autoregulation
  - >0 autoregulation impaired; <0 autoregulation intact
  - thresholds for outcome prediction in severe TBI [19]
- Mx, among others, can be plotted with CPP to determine "CPP_{opt}"
  - Calculate the range of CPP at which a specific patient has autoregulatory capacity and is not pressure passive





Physics

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TCD in Critical Care Multimodal Monitoring

- **cerebral autoregulatory monitoring shifted to PRx = correlation coefficient of MAP & ICP** [22]
  - validated in experimental studies of the lower limit of autoregulation [23]
  - independent predictor of outcome in TBI
- **TCD parameters have returned, especially with robotic assistance** [24]
  - Derive fully noninvasive parameters with TCD and a noninvasive ABP monitor, including those that correlate with PRx [25]

Multimodal Monitoring

Multimodal Monitoring

- 30+ year literature of cerebral autoregulation measurement [26]
- M

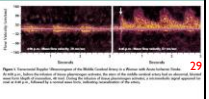

[24]

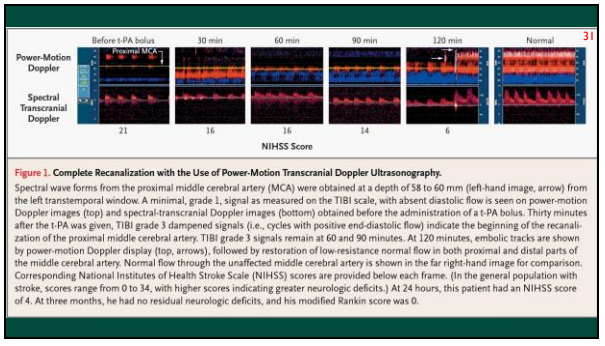

[27]

Thrombolysis Monitoring

Thrombolysis Monitoring

- Complete (93886)/Limited (93888) & Microembolic Monitoring without microbubble injection (93892)
- Shortly after tPA was approved for use there was an interest in monitoring real-time hemodynamics during infusion
  - Persistence of occlusion vs recanalization predicts outcome [28]
- Early report noted [30]
  - Outcomes tied to recanalization (full vs partial vs none)
  - Rate of recanalization and dramatic recovery with monitoring exceeded that of NINDS
    - improvement by ≥10pt/full recovery @ 24h
      - Alexandrov et al: 40%
      - NINDS: 27%
    - improvement by ≥4pt @ 24h
      - Alexandrov et al: 62.5%
      - NINDS: 47%


[29]



[31]

Figure 1. Complete Recanalization with the Use of Power-Motion Transcranial Doppler Ultrasonography.

Spectral wave forms from the proximal middle cerebral artery (MCA) were obtained at a depth of 58 to 60 mm (left-hand image, arrow) from the left transtemporal window. A minimal, grade 1, signal as measured on the TIBI scale, with absent diastolic flow is seen on power-motion Doppler images (top) and spectral-transcranial Doppler images (bottom) obtained before the administration of a t-PA bolus. Thirty minutes after the t-PA was given, TIBI grade 3 dampened signals (i.e., cycles with positive end-diastolic flow) indicate the beginning of the recanalization of the proximal middle cerebral artery. TIBI grade 3 signals remain at 60 and 90 minutes. At 120 minutes, embolic tracks are shown by power-motion Doppler display (top, arrows), followed by restoration of low-resistance normal flow in both proximal and distal parts of the middle cerebral artery. Normal flow through the unaffected middle cerebral artery is shown in the far right-hand image for comparison. Corresponding National Institutes of Health Stroke Scale (NIHSS) scores are provided below each frame. (In the general population with stroke, scores range from 0 to 34, with higher scores indicating greater neurologic deficits.) At 24 hours, this patient had an NIHSS score of 4. At three months, he had no residual neurologic deficits, and his modified Rankin score was 0.

Intraoperative Monitoring

Intraoperative Monitoring

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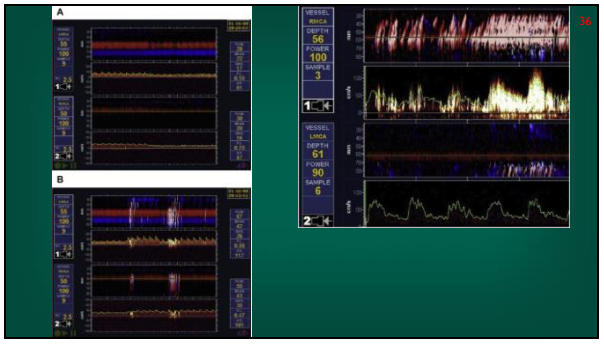
- **Reported with many procedures**
  - CEA, CAS, MT, CABG, orthopedic procedures
  - Practice-changing in CABG, making aortic filters standard to prevent HITS and subsequent post-op delirium [32]
- **Classic description defined CEA phases and risks** [33]
  - Preoperative (before anesthesia)
  - Dissection
  - Cross Clamping (including shunting, if performed)
  - Release of clamps
  - Closure
  - Recovery from anesthesia
  - Follow up
- **Best evidence in CEA**
  - Patients with perioperative CEA stroke are 4x more likely to have had a change in MCA FV change or HITS [34]
  - "virtually abolished intraoperative stroke" [35]



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Rotational Vertebrobasilar Insufficiency Monitoring

Rotational VBI Monitoring

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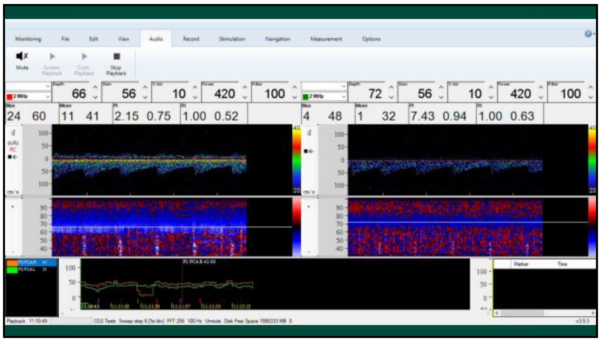
- **Complete (93886)/Limited (93888) +/- Vasomotor Reactivity (93890)**
  - No billing code for passive provocative maneuvers
- **Rotational vertebral artery compression, "Bow Hunter Syndrome" is a rare but potentially devastating cause of VBI** [37]
  - Classically diagnosed by dynamic DSA
- **TCD protocol as screen** [38]
  - Monitoring setup
  - Confirm PCAs are monitored by tapping VAs, evoked response
  - Passive provocative maneuvers
    - Rotation left, rotation right, maximal flexion, maximal extension
  - Looking for significant (>50% from baseline) drops in PCA MFV and reactive hyperemia with neutral head positioning
- **Series of TCD-identified rotational VBI tx** [39]
  - TCD identified the 16/100 referred with "real" VBI, got worked up and tailored surgical treatment



Summary

- **Transcranial Doppler Monitoring has myriad indications**
  - embolic monitoring distal to atherostenosis
  - bubble study
  - vasomotor reactivity distal to atherostenosis
  - TBI/neurocritical care (emerging)
  - operative monitoring
  - thrombolysis monitoring
  - rotational VBI
- **Safe, noninvasive, inexpensive means of getting real-time, continuous, reproducible hemodynamic data to inform clinical decision making**

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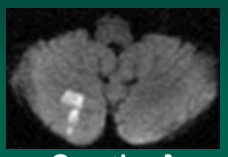

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