**Transcranial Doppler Ultrasonography: Clinical Applications and Interpretations**

How we are doing TCD:
Through Acoustic “Windows” to the Brain

Current TCD instruments

*Sonara, CareFusion*
*Neurovision 500P, Multigon*
*ST-3, Spencer Techn*
*Easy-DOP, DWL*
*Doppler Box, DWL*

TCD Variables

Transcranial Doppler (TCD)

- Peak velocity (PV)
- End-diastolic velocity (EDV)
- Mean velocity (MV)
- Pulsatility index (PI)
- PI = (PV - EDV)/MV
Where we are measuring CBFV: Through the Circle of Willis

- BA proximal
- BA mid
- BA distal
- VA’s

Transcranial Doppler Ultrasonography: Clinical Applications

- Extracranial arterial disease
- Vasomotor reactivity
- Intracranial arterial disease
- Acute cerebral ischemia/TIA
- Emboli
- Right to Left cardiac shunts
- Intensive Care
  - Vasospasm after SAH, TBI, tumor resection
  - AVM
  - Increased ICP and cerebral circulatory arrest
- Perioperative
- Periprocedural

Arterial Stenosis

- Arterial significant:
  - Modification of normal flow disturbances
  - CBFV increase
  - Local pressure drop
  - Decreased volume of flow
  - Modification of waveform
  - Evoking of collateral effects
- Tissue significant:
  - Reduction of regional perfusion
  - Reduction of oxygen and substrate delivery
  - Ischemic symptoms and functional incapacity
  - Infarction and stroke

Extracranial Disease
Carotid obstruction effect and TCD

- Mild to moderate stenosis < 75%: TCD is essentially normal
- Stenosis more than 75%: TCD wave form changes may include:
  - Decreased CBFV
  - Delayed systolic upstroke time
  - Decreased Pulsatility Index

Collateral Pathways

Collateral Pathway: via ACommA

- In the ACA
  - The contralateral ACA CBFV is approximately doubled
  - The ipsilateral ACA CBFV increase is approx. 50% with retrograde flow direction

Collateral Pathway: via ext. CCA

- In the OA
  - Retrograde OA flow direction when cross flow through the AComA is inadequate
  - The degree of collateralization through the OA ranging from flow confined to the cavernous portion, to flow extending to the distal MCA branches
Collateral Pathway: via PCommA

- **In the BA**
  - VA’s and BA CBFV’s increased and BA CBFV
  - A marked increase of BA CBFV after compression of the non-occluded CCA
  - An evident side-to-side asymmetry of the CBFV of the PCA’s

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Collateral Pathways

- Determination of altered collateral flow represent the most reliable indicator of CCA lesion by TCD
  - Collateralization through the AComA (sensitivity – 93%, specificity – 100%)
  - Collateralization through the PComA (sensitivity – 87%, specificity – 96%)
  - Collateralization through the OA (sensitivity – 95%, specificity – 100%)

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Anatomic Variants

<table>
<thead>
<tr>
<th>Variant</th>
<th>Incidence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classic Circle of Willis</td>
<td>18-20</td>
</tr>
<tr>
<td>Hypoplasia of A1</td>
<td>9-40</td>
</tr>
<tr>
<td>Hypoplasia of ACommA</td>
<td>13</td>
</tr>
<tr>
<td>Hypoplasia of PComA</td>
<td>22-53</td>
</tr>
<tr>
<td>Hypoplasia of P1</td>
<td>15-40</td>
</tr>
</tbody>
</table>

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Circle of Willis: Variants
Vasomotor (VMR) or Cerebrovascular Reactivity (CVR)

Increased CO2 causes a dilatation of the resistance vessels and results in:
- Increased CBF/CBFV
- Decreased Pulsatility Index

Decreased CO2 causes a constriction of the resistance vessels and results in:
- Decreased CBF/CBFV
- Increased Pulsatility Index

Physiologic Testing of CVR

- During the ischemia, the compensatory mechanism of vessel dilatation (cerebrovascular reactivity - CVR) is nearly or already exhausted
- During maximal dilatation of the resistance vessels in order to counterbalance a critical drop of perfusion pressure, the cerebral arterioles are no longer able to react to CO2 stimuli

Impaired CVR: Why it is important?

- CVR testing is mainly directed toward management of patients with asymptomatic carotid artery stenosis because it is still very controversial topic
- The actual benefit of CEA/stenting in asymptomatic patients, in terms of prevention of annual disabling stroke vs. the risk of angiography, stenting or surgery, may not justify its introduction into routine clinical practice. However, the benefit of intervention could be significantly increased in a subgroup of patients with high predisposition to develop cerebrovascular event
Physiologic Testing of CVR with Breath-Holding Index (BHI). Protocol

- 2 MHz PW TCD probes bilaterally with helmet with any modern TCD machine
- Before the BHI test, the procedure must be explained to the patient in detail: "Please, breathe normally, then take a normal breath and hold for 30 seconds, until I say okay, thereafter you are allowed to breathe again normally"
- Careful instruction provided to patient to avoid or minimize a Valsalva maneuver during the breath-holding
- In cases where breathing was started earlier than 30 sec, we need to repeat the test and reported loudly the time each 5 seconds that elapsed from the beginning. It will facilitate the cooperation during the procedure

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BHI (Normal)

<table>
<thead>
<tr>
<th>Time in sec</th>
<th>Right MCA</th>
<th>Baseline</th>
<th>Left MCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>BH start</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>BH end</td>
<td>↑</td>
<td></td>
<td>↑</td>
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</tbody>
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BHI Impaired

<table>
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<th>Time in sec</th>
<th>Right MCA</th>
<th>Baseline</th>
<th>Left MCA</th>
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<tr>
<td>BH end</td>
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<td>↑</td>
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</tbody>
</table>

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BHI Exhausted

<table>
<thead>
<tr>
<th>Time in sec</th>
<th>Right MCA</th>
<th>Baseline</th>
<th>Left MCA</th>
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<tr>
<td>BH end</td>
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Role of TCD: Physiologic Testing of CVR

- CVR evaluation of asymptomatic or symptomatic patients with less than 70% of stenosis could provide valuable information to help make decision about preventive CEA/stenting

Role of TCD: Extracranial carotid disease

- Detects impaired cerebral perfusion/emboli/presence or absence of altered collateral circulation
- Evaluates cerebrovascular reactivity (CVR) and reveals exhausted CVR. Helps to define more accurately patients for preventive CEA/stenting
- Provides follow-up after medical/surgical or endovascular treatment

Information from CMS

- January 1, 2005 effective CPT code (93890) for cerebral vasoreactivity evaluation with TCD

Transition of TCD wave form from normal to complete steal effect
80-90% stenosis of the brachiocephalic trunk

Right carotid siphon  Right MCA

Right VA

Role of TCD: Subclavian Steal

- Detects abnormal changes in Doppler spectrum waveform (systolic deceleration, alternating flow, retrograde flow) in the VA, and/or VA’s, and/or BA
- Indicates low pressure in the BA
- Raises option of subclavian bypass surgery

VB insufficiency

- Bow hunter’s syndrome (BHS) is characterized by transient VB ischemia brought on by head turning, but reports in the literature are rare
- Identification of diminishing blood flow velocities by TCD can be performed accurately at the bedside, and such findings are associated with clinical symptoms.

VB ischemia and head turns
Head Turns

- Provocative maneuvers with head turns
- In normals BA CBFV decrease is no more than 20%

Role of TCD: VB Insufficiency

- TCD will be helpful to determine the cause of symptoms
- TCD will eliminate the vascular component if there will be no significant proximal BA CBFV changes observed during head turns

Intracranial Arterial Disease
Criteria for abnormal TCD diagnosis of Intracranial Arterial Stenosis

- An MCA, ICA and ACA stenosis were considered if CBFV > 80 cm/s
- ICA siphon stenosis if CBFV > 65 cm/s
- BA and VA stenosis if CBFV > 60 cm/s

Intracranial Arterial Stenosis

<table>
<thead>
<tr>
<th>Normal CBFV</th>
<th>Stenotic CBFV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left MCA (M1 segment)</td>
<td>Right MCA (M1 segment)</td>
</tr>
</tbody>
</table>

MCA CBFV and Risk of Stroke

*Bos et al., 2007*

- Rotterdam population based study (1997-1999)
- Participants were 61 years or older and free from previous stroke (n= 2002)
- Average follow up 5.1 years
- First-ever stroke, death
- MCA CBFV was measured

MCA CBFV and Risk of Stroke

*Bos et al., 2007*

- Over five years of follow-up, there were 122 strokes, of which 89 were ischemic strokes.
- Individuals with MCA CBFV in the highest tertile had a 1.75-fold higher risk of stroke and a 2.21-fold higher risk of ischemic stroke than individuals with CBFV in the lowest tertile, the investigators report.
MCA CBFV and Risk of Stroke
Bos et al., 2007

• In this population-based study in stroke-free subjects aged 61 years and over, strong, significant, and independent association between MCA CBFV measured with TCD and the risk of stroke, particularly ischemic stroke, was demonstrated.

• Risk of stroke increased strongly with increasing MCA CBFV as measured with TCD in the general population.

TCD as a Screening Tool

• This is the first study that assessed TCD clinical/prognostic value in the large group of general population (n=2002).

• This paper basically suggests TCD screening because it offers the promise of early disease identification and in the future will allow individuals to receive preventive medicine.

Rt CCA injection

CBFV’s Gradient
Virtual “Neurosonoangiology”?

<table>
<thead>
<tr>
<th>NORMAL</th>
<th>ABNORMAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (mm)</td>
<td>CBFV (cm/s)</td>
</tr>
<tr>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>42</td>
<td>42</td>
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<tr>
<td>52</td>
<td>50</td>
</tr>
</tbody>
</table>
Vascular Dementia (VaD) and Alzheimer Disease (AD)

- VaD and AD are the most common causes of age-associated dementia. Alzheimer’s is a disease that attacks the brain. Every 72 seconds in USA someone is diagnosed with AD (http://www.alz.org).
- The Am. Alzheimer’s Assoc. estimates that about 4.5 million currently suffer from AD. As the world’s population grows older, the prevalence of AD is expected to increase up to 16 million in the USA by the middle of the 21st century.
- In 62% of elderly persons in the USA dementia could be the direct result of stroke.

Cerebrovascular Disease (CVD) may worsen the dementia of AD

- CVD is highly heterogeneous but can culminate in vascular cognitive impairment, VaD and AD.
- The diagnosis cerebrovascular lesions should be considered in the presence of dementia, clinical, neuroradiological and neurosonologic (TCD & carotid duplex) signs of CVD.

Why TCD is needed for VaD and AD

- TCD is needed for VaD and AD to establish presence/absence of the CVD.
- TCD will detect the abnormal changes in intracranial circulation due to the presence of the extracranial lesions.
- TCD allows examination of the intracranial vessels, previously available only by angiography which carries a risk of mortality and morbidity.

Atherosclerosis of cerebral arteries in AD

- 20 autopsy cases (10 normal elderly and 10 AD).
- 370 arterial sections were measured.
- Circle of Willis in the normal elderly showed a statistically significant lower index of stenosis compare to AD.
- All arteries in the AD cases showed extensive atherosclerotic lesions.
Atherosclerosis of cerebral arteries in AD
Roher et al., Stroke, 2004

• Atherosclerotic lesions in the circle of Willis and large leptomeningeal vessels found to correlate with AD
• The atherosclerotic lesions extended into the large cerebral arteries compromising cerebral perfusion

Atherosclerosis and AD
Honig et al., Neurology, 2005

• Cross-sectional data from the USA National Alzheimer’s Coordinating Center database
• 1,054 individuals, 921 AD, 133 normal
• 9% of the individuals had clinical history of stroke during life, but 33% had evidence of cerebral infarcts at postmortem
• The presence of large-vessel CVD, or atherosclerosis, was strongly associated with an increased frequency of neuritic plaques

Am J Geriatr Psychiatry, 2006
Position Statement of the American Association for Geriatric Psychiatry Regarding Principles of Care for Patients With Dementia Resulting From Alzheimer Disease
C. G. Lyketsos, et al.
There is now strong evidence that brain vascular disease plays a role in the progression of AD in two ways:

1. First, brain vascular disease may add to the cognitive impairment of dementia for a given amount of Alzheimer pathology in the brain.
2. Second, brain vascular disease has been implicated as a factor in the development of the Alzheimer pathology.

Therefore, the management of vascular brain disease and its associated risk factors is now part of the care for disease treatment for AD.

Cerebral emboli in dementia

Purandare et al, Int J Geriatr Psychiatry 2005

- 41 patients with dementia (24 AD and 17 VaD), 16 controls
- Cerebral emboli were detected in 11 (27.5%) dementia patients compared with one (7%) control
- Cerebral emboli were being most frequent in VaD compared to controls
- Cerebral emboli and venous to arterial circulation shunt more frequent in dementia, which suggest paradoxical cerebral embolization as a potential mechanism for cerebral damage.

Role of TCD: Intracranial stenosis

- Detects stenosis of intracranial vessels
- Provides longitudinal follow up and monitor effects of treatment (medical, endovascular)
- TCD accurately, noninvasively and inexpensively evaluate intracranial circulation without adverse side effects or discomfort for patient

Acute Cerebral Ischemia/TIA: Diagnosis
AHA, Statistical Update

- **2007**: On average, every 45 sec, someone in the United States has a stroke
- Each year, about 700,000 people experience a new or recurrent stroke. About 500,000 of these are first attacks and 200,000 are recurrent attacks

- **2008-2011**: On average, every 40 sec, someone in the United States has a stroke
- Each year, about 795,000 people experience a new or recurrent stroke. About 610,000 of these are first attacks and 185,000 are recurrent attacks

AAN 2004: Established Effectiveness for TCD

TCD and Acute Stroke

5th and 6th World Stroke Congresses

- Stroke pattern imaging (CT/CTA & MRI/MRA) alone cannot identify stroke mechanism/s
- The lack of correlation between initial clinical presentation and imaging findings further justifies obtaining appropriate studies to define information about cerebrovascular hemodynamics
- Detailed and complete (extra with carotid and intracranial with TCD ultrasound) analysis of vascular condition is mandatory

TCD and Acute Stroke

- Different stroke therapies may offer a benefit for one mechanism but for other others
- If the mechanism can be determined in the first few hours after stroke, then patients with different stroke subtypes could be selected for specific therapies in clinical practice
Grading of TCD signals

Burgin et al., Stroke, 2000

<table>
<thead>
<tr>
<th>Signal Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO SIGNAL</td>
<td>No signal present</td>
</tr>
<tr>
<td>MINIMAL SIGNAL</td>
<td>Presence of flow signal with no end diastolic flow</td>
</tr>
<tr>
<td>BLUNTED SIGNAL</td>
<td>Presence of flow signal with no end diastolic flow and positive end diastolic flow</td>
</tr>
<tr>
<td>DAMPENED SIGNAL</td>
<td>Pulsatile flow with normal flow acceleration and decreased mean CBFV (≥30% difference between hemispheres)</td>
</tr>
<tr>
<td>STENOTIC</td>
<td>Presence of flow signal with focal decreased mean CBFV and positive end diastolic flow</td>
</tr>
<tr>
<td>NORMAL</td>
<td>Normal TCD signal</td>
</tr>
</tbody>
</table>

Criteria for localizing arterial occlusion

Dampened Signal

Pulsatile flow with normal flow acceleration and decreased mean CBFV (≥30% difference between hemispheres)

Blunted Signal

Delayed flow acceleration with stepwise maximum flow arrival during mid to late systole, compared to contralateral side and focal decreased mean CBFV and positive end diastolic flow

Minimal Signal

Presence of flow signal with no end diastolic flow and with increased PI
Criteria for localizing arterial occlusion

Absent Signal

- No detectable flow at appropriate depths of insonation for the artery in question

Criteria for localizing arterial occlusion

CBFV Asymmetry

- A side-to-side difference greater than 30% considered abnormal
- Moderate CBFV decrease with CBFV asymmetry more than 21%
- Major CBFV decrease with a significantly reduced CBFV lower than 30 cm/s

Virtual “Neurosonoangiological” representation of impaired CBFV: mid-distal MCA occlusion

- DEPTH 56 mm
- DEPTH 48 mm
- DEPTH 52 mm
- DEPTH 46 mm

TCD and CTA

Tsivgoulis et al, 2007

- A total of 132 patients underwent emergent neurovascular assessment with brain CTA and TCD.
- Compared with CTA, TCD showed 34 true-positive, 9 false-negative, 5 false-positive, and 84 true-negative studies (sensitivity 79.1%, specificity 94.3%, positive predictive value 87.2%, negative predictive value 90.3%, and accuracy 89.4%).
- In 9 cases (7%), TCD showed findings complementary to the CTA (real-time embolization, collateralization of flow with extracranial internal carotid artery disease, alternating flow signals indicative of steal phenomenon).
- Bedside TCD examination yields satisfactory agreement with urgent brain CTA in the evaluation of patients with acute cerebral ischemia. TCD can provide real-time flow findings that are complementary to information provided by CTA.
TCD and CTA

Tsivgoulis et al, 2007

TCD study was done at 10:30 A.M

MRI/MRA was done at 12:58 P.M.

MRI/MRA was done at 12:58 P.M.
Angiography performed at 6 P.M.

Role of TCD: Acute Stroke

- TCD within 24 hours of symptoms onset improves the early accuracy of stroke subtype diagnosis, especially in patients with large artery atherosclerosis
- Early detection may also affect therapeutic strategies in patients with acute/subacute cerebral ischemia or extra- or intracranial lesions (symptomatic or asymptomatic)

Role of TCD: Acute Stroke/TIA

- TCD has been confirmed and validated with other imaging modalities (MRI, MRA, CTA, DSA) and has been combined with other modalities acutely
- TCD can be performed rapidly and effectively in acute setting (ER, OR, ICU) or done longitudinally in the in- or out-patient setting to evaluate progression/regression of disease

Role of TCD: Acute Stroke/TIA

- TCD can identify hemodynamically significant abnormalities and lesions of the brain vasculature
- TCD can monitor in real time and assess embolization of the brain because TCD is the only one gold standard allowing detection of emboli in vivo
- TCD is an accurate indicator of blood flow status and may be as reliable as angiography at a fraction of the cost and no risk for patients

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Acute Cerebral Ischemia/TIA: Monitoring

MCA Occlusion and tPA Treatment

Monitoring of MCA reperfusion
Alexandrov et al., 2003

Hemodynamic studies in early ischemic stroke
Akopov et al., Stroke, 2002

- 47 acute stroke patients
- Three serial TCD (24 hrs, 24-48 hrs, between 4 and 8 days); Single MRA
- Serial TCD studies revealed an evolution (improvement or deterioration) of intracranial hemodynamics in 34%. Single MRA study may not demonstrate dynamic changes
- Serial TCD studies is a useful, inexpensive adjunct to MRA study, transforming the static MRA picture of cerebral perfusion into a dynamic evaluation of cerebral circulation

13:02  Time  13:38
Hemodynamic studies in early ischemic stroke
Akopov et al., Stroke, 2002

Angiography & TCD for patient with BA thrombosis

Can early Neurosonology Predict Outcome in Acute Stroke?
Stolz et al, Stroke, 2008

- MCA occlusion associated with a significantly increased risk for a fatal course
- Patients with patent MCA were more likely to clinically improve within 4 days
- Full recanalization within 6 hrs after symptoms onset was highly significantly associated with clinical improvement within 46 hrs

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Role of TCD: Monitoring of acute stroke treatment

- TCD could be ideal to guide aggressive treatment
- TCD can help in the primary and repetitive diagnosis of the vessel occlusion by indicating whether the lesion is present at all, still present or already re-canalized
- TCD can confirm the clinical diagnosis, can be done repetitively and close to the anticipated time of fibrinolysis
Role of TCD: Monitoring of acute stroke treatment

- A confirmatory TCD before angiography is the key to prevent exogenous fibrinolysis, which bears a high risk of intracranial bleeding.
- A noninvasive bedside and expeditious TCD able to add key prognostic information in patients with a similar clinical presentation:
  - MCA occlusion predicts death or disability at 3 months.
  - Patent MCA facilitates more aggressive therapeutic interventions such as induced hypothermia or decompressive craniotomy.
- TCD provides important information on prognosis in patients with acute stroke.

Role of TCD: Monitoring of acute stroke treatment

- Serial rapid measurements of cerebral hemodynamics with TCD offers new insight into the process of diagnosis of acute stroke and provides guidance for and monitoring of therapeutic interventions.

TIA

Heart Disease and Stroke Statistics—2010 Update

- The incidence of TIA in the United States has been estimated to be 200,000 to 500,000 per year, with a population prevalence of 2.3%, which translates into million people.
- Approximately half of all patients who experience a TIA fail to report it to their healthcare providers.
- Approximately 15% of all strokes are heralded by a TIA.
- One third of episodes characterized as TIA according to the classic definition (ie, focal neurological deficits that resolve within 24 hours) would be considered infarctions on the basis of diffusion-weighted magnetic resonance imaging findings.

TIA

Heart Disease and Stroke Statistics—2010 Update

- In population-based studies, the age- and gender-adjusted incidence rates for TIA range from 68.2 to 83.0 per 100,000. Men and blacks have higher rates of TIA.
- After TIA, the 90-day risk of stroke is 3.0% to 17.3% and is highest within the first 30 days, with half occurring within the first 48 hours after a TIA.
- Within 1 year of TIA, up to one fourth of patients will die.
- Individuals who have a TIA have a 10-year stroke risk of 18.8% and a combined 10-year stroke, MI, or vascular death risk of 42.8% (4%/year).
**Role of TCD: TIA**

- TCD can discover brain embolization
- TCD can detect intracranial stenosis
- TCD can identify presence of altered collateral
- TCD can recognize asymmetric brain perfusion
- TCD CVR testing can illuminate compromised CBF autoregulation

**CLOT-BUST Trial**

Alexandrov et al., 2004

- 126 patients with MCA occlusions on pre-bolus TCD were randomized to tPA or tPA+2 hrs TCD (bolus within 3 hrs of onset)
- Symptomatic hemorrhage 4.8% in both groups
- Primary combined end-point within 2 hours (complete recanalization on TCD or dramatic clinical recovery (total NIHSS 3 points or less OR decrease in NIHSS score by 10 points or more) 30% vs. 49%, p=0.02
- A trend was observed towards better outcome at 3 months (not a primary end-point).

**Sickle Cell Disease**

- Sickle cell is in many nationalities:
  - African Americans,
  - Africans,
  - Arabs,
  - Greeks,
  - Italians,
  - Latin Americans, and those from India
**STOP Trial**

- Children with SCD who had been found to be at high risk for stroke on the basis of elevated CBFV greater or equal 200 cm/sec
- Two abnormal comparable TCD’s are needed to identify patients at higher risk of stroke (CBFV greater than 200 cm/sec on two separate occasions)
- If CBFV is equal or greater than 170 cm/sec – conditional
- TCD screening recommended

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**CEREBRAL VASCULOPATHY OUTCOME AFTER STEM-CELLTRANSPLANTATION FOR SICKLE CELL DISEASE**

Verlhac et a, 2007

- 87 consecutive patients transplanted
- between 11/1988 and 12/2004 (40 F, 47 M)
- 14 French centers
- Mean age: 9.5 y (2 to 22 years)
- Median Follow-up: 6 y (range 2-18 years)

- 56 had a cerebral vasculopathy
- 36 overt stroke
- 10 abnormal TCD without stroke with abnormal conventional arteriography or MRA(n=6) or with normal angiography but persistent abnormal TCD despite chronic transfusions (n=4).
- 5 out of 10 had silent infarcts
- 10 silent infarcts with severe anemia and/or cognitive deficiency and normal TCD

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Abnormal TCD at the age of 4. Mild MCA stenoses on MRA in 2001. No change in 2003. Rapid TCD normalisation following transplantation whereas chronic transfusions had failed to revert to normal velocities

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**CEREBRAL VASCULOPATHY OUTCOME AFTER STEM-CELLTRANSPLANTATION FOR SICKLE CELL DISEASE**

Verlhac et al, 2007

- High risk of early complications
  - Seizures
  - PRES with a slightly higher rate than in others diseases
  - SCT 4.2-7.2% (Reece 1991, Bartynski 2004)
- Effective prevention of:
  - A first stroke
  - stroke recurrence
  - Silent infarcts
  - Stabilization of stenoses
  - Normalization of high CBFV's

- As it was shown that abnormal CBFV’s precede:
  - arterial stenoses, it is likely that SCT has prevent constitution of severe stenoses in these children.
- On the other hand arterial occlusion and cerebral infarcts did not change. Even parenchymal atrophy progressed.
- Transplantation should be proposed earlier before stroke and its sequellae when abnormal CBFV’s are detected by TCD
- A strategy based on early and regular TCD and aggressive therapeutic strategies can efficiently prevent stroke, reducing the risk from 11% to less than 2%
TCD and Emboli

- Etiology of stroke is embolic in 32%
- TCD technique is the “gold” standard to detect emboli in real-time while emboli going through the cerebral circulation
- TCD emboli monitoring could be useful for patients with stroke, TIA, potential cardiac sources of emboli, etc.

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

- The Asymptomatic Carotid Embolism Study (ACES) was a prospective observational study in patients with asymptomatic carotid stenosis of at least 70% from 26 centers worldwide.
- To detect the presence of embolic signals, patients had two 1 h TCD recordings from the ipsilateral middle cerebral artery at baseline and one 1 h recording at 6, 12, and 18 months. Patients were followed up for 2 years.
- The primary endpoint was ipsilateral stroke and transient ischemic attack.
Asymptomatic embolisation for prediction of stroke in the Asymptomatic Carotid Emboli Study (ACES): a prospective observational study

Hugh S Markus, et al., Lancet Neurol 2010; 9: 663–71

482 patients were recruited, of whom 467 had evaluable recordings.

Embolic signals were present in 77 of 467 patients at baseline or 16.5%.

The hazard ratio for the risk of ipsilateral stroke and TIA from baseline to 2 years in patients with embolic signals compared with those without was 2.54 (95% CI 1.20–5.36; p=0.015). For ipsilateral stroke alone, the hazard ratio was 5.57 (1.61–19.32; p=0.007). The absolute annual risk of ipsilateral stroke or TIA between baseline and 2 years was 7.13% in patients with embolic signals and 3.04% in those without, and for ipsilateral stroke was 3.62% in patients with embolic signals and 0.70% in those without.

The hazard ratio for the risk of ipsilateral stroke and TIA for patients who had embolic signals on the recording preceding the next 6-month follow-up compared with those who did not was 2.63 (95% CI 1.01–6.88; p=0.049), and for ipsilateral stroke alone the hazard ratio was 6.37 (1.59–25.57; p=0.009). Controlling for antiplatelet therapy, degree of stenosis, and other risk factors did not alter the results.

Role of TCD: Emboli

- Emboli monitoring: detection of emboli represent a marker for plaque activity and risk of macroembolism
- Detection of asymptomatic embolisation on TCD can be used to identify patients with asymptomatic carotid stenosis who are at a higher risk of stroke and transient ischaemic attack, and also those with a low absolute stroke risk
- Assessment of the presence of embolic signals on TCD might be useful in the selection of patients with asymptomatic carotid stenosis who are likely to benefit from endarterectomy

Information from CMS

- January 1, 2005 effective CPT code (93892) for continuous emboli monitoring w/o intravenous injection of bubbles

Right-to-Left Cardiac Shunt
TEE or TCD?
Initial Diagnosis of PFO

Information from CMS

• January 1, 2005 effective CPT code (93893) for “Bubble-TCD” test for Right-to-Left shunt detection with intravenous bubbles injection
**TCD in the ICU**

- **Diagnosis:**
  - Acute Stroke
  - Vasospasm
  - Vasomotor Reactivity
  - Intracranial Hypertension
  - Brain Death

- **Monitoring treatment effect:**
  - SAH
  - Endovascular Intervention (TLA)
  - Stroke
  - Thrombolysis
  - CEA
  - Test-occlusion
  - AVM

**TCD test in patient immediately and few days later after SAH**

- Baseline TCD
- Five days later

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**Guidelines for the Management of Aneurysmal SAH**

*Stroke Council, AHA, 1994*

- **Summary and Recommendations:**
  1. SAH is a medical emergency…
  2. CT scanning for suspected SAH is strongly recommended…
  3. Selective cerebral angiography to document…
  4. TCD is recommended for the diagnosis and monitoring of vasospasm, although the cerebral angiography may be required for definitive diagnosis

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**Role of TCD: SAH**

- Elevated CBFV’s in asymptomatic patients warrant meticulous observation in some closely supervised setting until CBFV’s begin trend downward
- Elevated CBFV’s in a particular vascular territory can focus subsequent neurologic examinations to detect subtle changes earlier in their clinical course
Role of TCD: SAH

- In symptomatic patients, elevated CBFV’s most likely represent significant vessel narrowing and may obviate the need for cerebral angiography. At this point, triple-H therapy can be initiated or advanced.
- Asymptomatic patients w/o elevated CBFV’s probably can avoid additional angiography. However, we need to consider patient’s age because elderly patient’s could develop vasospasm in normal or slightly abnormal CBFV’s range.

Role of TCD: SAH monitoring

- It is useful to perform TCD test on admission (or ASAP after surgery) and perform daily TCD studies when patient is in the ICU.
- The frequency with which TCD should be performed may be guided by patient clinical presentation, knowledge of risk factors for vasospasm, early clinical course.
- TCD studies should be performed after endovascular treatment to identify patients with recurrent vasospasm.

Role of TCD: SAH Monitoring

- The presence and temporal profile of CBFV’s in all available vessels must be detected and serially monitored.
- The pattern of CBFV’s elevation may indicate the need to follow patient carefully for evidence of deficits related to specific vascular territory.
- Waveform appearance either regionally, or globally may be clinically significant.

Intracranial Hypertension and Brain Death
Transcranial Doppler Ultrasonography Elucidates Symptomatic Cavum Septum Pellucidum Cyst: Case Report  
Bell et al, JVNI, 2010

- We are judging quantitative and qualitative TCD wave form morphology changes
- These changes usually will be obvious after ICP will be more 30 mm Hg
- However, one condition must be full filled if you would be using TCD wave from changes to predict intracranial hypertension: MAP, cardiac output and PaCO2 are normal and not different significantly compared to the previous day
Role of TCD: Intracranial Hypertension

- Quantitative (CBFV; PI) and qualitative (TCD wave-form) analysis of the data
- Reliably determines onset of abnormally high ICO, especially if you have chance to do serial TCD examinations
- Useful non-invasive adjunct tool for intracranial hypertension determination in the ICU/ER settings

TCD wave form progression from intact CBFV to circulatory arrest

ICP & TCD pattern changes
TCD pattern in patient with brain stem stroke and clinical diagnosis of brain death

<table>
<thead>
<tr>
<th>TBI Type</th>
<th>PTV %</th>
<th>High ICP %</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHI</td>
<td>13/14.4</td>
<td>12/13.3</td>
</tr>
<tr>
<td>CHI/ED</td>
<td>12/13.3</td>
<td>9/10</td>
</tr>
<tr>
<td>PHI</td>
<td>21/23.3</td>
<td>16/17.7</td>
</tr>
<tr>
<td>PHI/ED</td>
<td>11/12.2</td>
<td>12/13.3</td>
</tr>
<tr>
<td>Total</td>
<td>57/63.3</td>
<td>49/54.4</td>
</tr>
</tbody>
</table>

Role of TCD: Increased ICP/Brain Death

- Quickly detects dramatically increased ICP
- Confirm brain death in comatose patients
- Reliably determines arrest of cerebral circulation which can shorten observation time for organ retrieval in patients with brain death

Wartime TBI

- Traumatic brain injury (TBI) is associated with the severest casualties from Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF). Consequences of neurotrauma are cerebral vasospasm and intracranial hypertension.
- From Oct. 1, 2008 AMEDD TBI program initiated TCD ultrasound service for TBI patients who were presented for care at the National Naval Medical Center and at the Walter Reed Army Medical Center.
- This prospective study evaluated all inpatient TCD studies related to battle injury from OIF and OEF.
**Perioperative and Periprocedural Monitoring**

- The MCA on the side of CEA is the artery usually monitored by TCD because it is most likely affected by carotid blood flow.

**CEA TCD Monitoring**

- Embolism is a principal cause of CVA from CEA.
- Hypoperfusion and hyperperfusion are also important causes.
- TCD provides information that allows prompt identification and treatment of these three major causes of stroke from CEA.

**TCD Bilateral Probe-holder**

- Spencer, 1997

**TCD monitoring and causes of stroke from CEA**

- Embolism is a principal cause of CVA from CEA.
- Hypoperfusion and hyperperfusion are also important causes.
- TCD provides information that allows prompt identification and treatment of these three major causes of stroke from CEA.
Role of TCD: CEA

• TCD provides continuous noninvasive monitoring of the right and left MCA CBFV’s and immediately detects changes in cerebral perfusion during CEA manipulation (cross-clamping)
• Malfunction of the shunt (twisting or compression) can be promptly detected by TCD and corrected

Role of TCD: CEA

• TCD monitoring provides the opportunity to assess the rate of microemboli to the brain in patients before, during or after CEA to verify whether these phenomena have ceased after procedure. If not, the pharmacological intervention can be instituted
• If CBFV is markedly decreased from the baseline level after CEA, intraluminal complications can be suspected and exploration of the arteriotomy can be immediately carried out
**Role of TCD: CEA**

- Patients with a relative hyperemia after shunt insertion/CEA (100% or greater increase in CBFV MCA) can be identified and pharmacological intervention can be instituted if necessary.

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**Neuroradiology: Test-Occlusion**

- Arteriogram of a giant aneurysm of the ICA
- MCA CBFV during test-occlusion

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**Role of TCD: Neuroradiology (Test-Occlusion)**

- Patients with giant intracranial aneurysms (not accessible with direct surgery/coiling) and vascular tumors (cervical cancer) may undergo temporary/permanent occlusion of the internal carotid artery, to determine brain tolerance to exclusion of that vessel if it must be sacrificed.

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**Role of TCD: Neuroradiology (Test-Occlusion)**

- TCD Monitoring of the ipsilateral MCA CBFV during test-occlusion determines the percent change in CBFV during balloon inflation and documents the collateral pathways patency/absency.
- This information compliments the balloon occlusion procedure and can help in identifying the patients who are at risk for hemodynamic stroke following ICA permanent occlusion.
Role of TCD: AVM

- TCD study can provide two different types of clinical information: the diagnosis and anatomical localization of AVM
- TCD can be useful addition to CT-scanning and for planning the angiography
- TCD offers the prospect of reducing the number of X-ray exposures required in follow up
Intraoperative microvascular Doppler (20 MHz)

**BEFORE ANEURYSM CLIPPING**

![Doppler waveform before clipping](image1)

**AFTER ANEURYSM CLIPPING**

![Doppler waveform after clipping](image2)

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**AVM: Intraoperative**

![Microvascular Doppler probe and waveform](image3)

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**Periprocedural Monitoring**

- Cerebral angiography and cardiac catheterization are occasionally complicated by stroke, presumably because of dislodged embolic materials from the cardiac chambers, aortic plaques, or the catheter tip itself.

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**Cerebral emboli during left heart catheterization**

*Lund et al., European Heart Journal 2005*

- Clusters of MES entering the brain a few seconds after initiation of ventriculography

- MES detected by multifrequency (2.0 and 2.5 MHz) TCD, passing through the MCA during left heart catheterization

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Cerebral emboli during left heart catheterization
Lund et al., European Heart Journal 2005

- Post-catheterization cerebral DWI showing a new brain lesion in both (A) the right frontal lobe and (B) the left cerebellar hemisphere of the same patient.

SCIPION: Silent cerebral infarct after cardiac catheterization as detected by DW-MRI: a randomized comparison of radial and femoral arterial approaches

- Cerebral microembolism detected by TCD occurs systematically during cardiac catheterization, but its clinical relevance remains unknown. Studies suggest that asymptomatic embolic cerebral infarction detectable by DW MRI might exist after percutaneous cardiac interventions with a frequency as high as 15 to 22% of cases.

A prospective multicenter trial to assess the rate of silent cerebral infarction after cardiac catheterization and to compare the impact of the arterial access site, comparing radial and femoral access, on this phenomenon.

This prospective study will be performed in patients with severe aortic valve stenosis. To assess the occurrence of cerebral infarction, all patients will undergo cerebral DW-MRI and neurological assessment within 24 hours before, and 48 hours after cardiac catheterization and retrograde catheterization of the aortic valve.

- A subgroup will be monitored by TCD M-mode during cardiac catheterization to observe CBFV and MES. Neuropsychological tests will also be recorded in a subgroup of patients before and after the interventional procedures to assess the impact of silent brain injury on potential cognitive decline.

- The primary end-point of the study is a direct comparison of ischemic cerebral lesions as detected by serial cerebral DW-MRI between patients explored by radial access and patients explored by femoral access. Secondary end-points include comparison of neuropsychological test performance and number of MES signals observed in the two groups.
Potential Role of TCD: Emboli Monitoring during Cardiac Catheterization

- At the end of SCIPION Trial:
  - Using serial DW-MRI, silent cerebral infarction rate will be defined and the potential influence of vascular access site will be evaluated.
  - Silent cerebral infarction might be a major concern during cardiac catheterization and its potential relationship to cognitive decline needs to be assessed.
  - TCD utilization during these procedures would be warranted

Periprocedural Monitoring

- There are no standards to determine the accuracy of TCD during cerebral or cardiac angiography
- Data supporting the use of TCD come from small case series
- TCD ultrasonography is considered an investigational technique for monitoring during angiography

Parametric perfusion imaging with contrast enhanced ultrasound in acute stroke
Weismann et al., Stroke, 2004

Large area in the territory of the Rt MCA shows increased TTP (compare with C) (TTP – time-to-peak). Severely decreased intensity of perfusion is noted in large area in the territory of the Rt MCA

TTP parameter image of Lt hemisphere is shown for comparison, PPI parameter image of Lt hemisphere is shown for comparison

Medicare Policy

- Currently Medicare in State of Maryland is establishing the coverage for codes 93886, 93888, 93890, 93892 and 93893 for 112 ICD-9 Codes that supports medical necessity
- Covered from 282.60 Sickle-Cell anemia, 346.20 variants of migraine, 437.0 Cerebral atherosclerosis and other generalized ischemic cerebrovascular disease, and many-many more – total 112 ICD-9 Codes
What TCD Service Could Achieve

- Immediate bed-side results
- Provides accurate blood flow velocity information for determination of disease severity
- Detects even minimal cerebral hemodynamics changes
- Ideal modality for following disease progression, therapeutic, radiological or surgical revascularization, stages of recovery and long-term therapeutic effects

What TCD Service Could Achieve

- Accurate, cost-effective method for diagnosis of intracranial disease and effect of extracranial disease on cerebral circulation
- The economic effect is clear. In a climate where doing more with less is imperative, any service/methods that increases productivity without compromising quality will positively impact Patient Outcome and success of the Hospital/Private Practice

TCD Advantages

- Rapid assessment of cerebral vasculature, provides physiological and hemodynamics data
- Quantitative
- Repeatable
- Changes often precede clinical symptoms
- Changes precede angiographic narrowing

TCD Advantages

- No contraindications
- Portable
- Non-invasive
- Safe and not painful
- Cost-effective alternative to radiographic choices
TCD “Disadvantages”

- Operator dependent
- N. American medicine relies on imaging very broadly vs. physiological data interpretation
- Neuroimaging modalities utilization and overutilization
- Absence of structured teaching

TCD as a Modality

Will be very high-quality, reliable and accurate, if:

- Dedicated Personnel
- Daily Monitoring of the Technical Performance Quality
- Quality of Interpretation