Specific TCD clinical applications for patients with traumatic brain injury

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DISCLOSURES

FTE, Private Practice for profit

American Society of Neuroimaging
38th Annual Meeting

TBI: SCOPE

- Every 21 seconds, one person in the US sustains traumatic brain injury (TBI)
- An estimated 5.3 million Americans – little more than 2% of the US population – currently live with disabilities resulting from brain injury
- Each year, 80,000 Americans experience the onset of long-term disability following TBI

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TBI

- Of the 1.4 million who sustain a TBI each year in the United States:
  - 50,000 die;
  - 235,000 are hospitalized;
  - 1.1 million are treated and released from an emergency department.[1]
- The number of people with TBI who are not seen in an emergency department or who receive no care is unknown

[1] Langlois JA, Rutland-Brown W, Thomas KE. Traumatic brain injury in the United States: emergency department visits, hospitalizations, and deaths. Atlanta (GA): Centers for Disease Control and Prevention, National Center for Injury Prevention and Control; 2006.

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What causes TBI?

- The leading causes of TBI are:
  - Falls (28%);
  - Motor vehicle-traffic crashes (20%);
  - Struck by/against events (19%);
  - Assaults (11%).[1]
- Blasts are a leading cause of TBI for active duty military personnel in war zones.[2]

[1] Langlois JA, Rutland-Brown W, Thomas KE. Traumatic brain injury in the United States: emergency department visits, hospitalizations, and deaths. Atlanta (GA): Centers for Disease Control and Prevention, National Center for Injury Prevention and Control; 2006.
[2] Defense and Veterans Brain Injury Center (DVBIC). [unpublished]. Washington (DC): U.S. Department of Defense; 2005

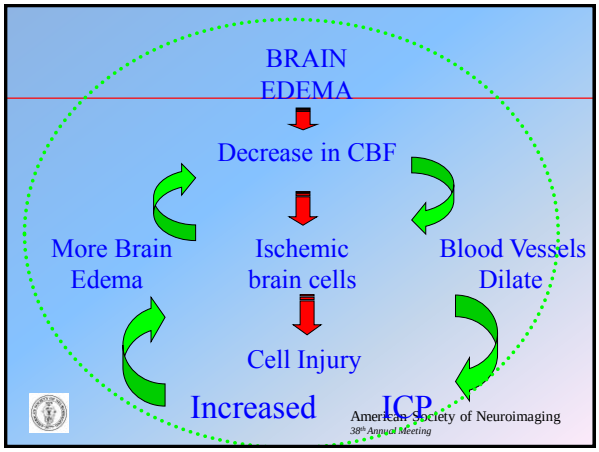
Who is at highest risk for TBI?

- Males are about 1.5 times as likely as females to sustain a TBI
- The two age groups at highest risk for TBI are 0 to 4 yo, 15 to 19 yo and older than 75 yo
- Falls are the leading cause of TBI in the elderly
- Certain military duties (e.g., paratrooper) increase the risk of sustaining a TBI.
- African Americans have the highest death rate from TBI

Traumatic Brain Injury. THE COST

- The cost of TBI in the US is estimated to be $48.3 *billion* annually
- Hospitalization accounts for $31.7 billion, and fatal brain injuries cost the nation $16.6 billion each year

TBI PATHOPHYSIOLOGY



TBI: Pathophysiology

Primary Injury:
- Contusions/Hemorrhages
- Diffuse Axonal Injury (DAI)

Secondary Injury (Intracranial) occurs hours to weeks/years after injury:
- Blood Flow and Metabolic Changes
- Cerebral Ischemia
- Traumatic Hematomas
- Cerebral Edema
- Hydrocephalus
- Increased Intracranial Pressure/Herniation
- PTSD?

TBI NEUROMONITORING

Balancing Multisystem Interactions

TBI & TCD

Cerebral Ischemia due to the onset of Posttraumatic Vasospasm

Increased Intracranial Pressure

POST TBI VASOSPASM

Clinical Significance

- 41% of patients who died from TBI had PTV (MacPherson et al., 1973)
- 24% with massive tSAH developed ischemic symptoms in contrast to 3% of patients with mild tSAH (Taneda et al., 1996)
- Ischemic symptoms accompanying arterial VSP following tSAH are comparable to those found following aneurysmal SAH

TCD Criteria for diagnosis of vasospasm

Mean CBFV (cm/s)	MCA/ICA ratio (Lindegaard Ratio)	Interpretation
<100	< 3	Nonspecific
100-140	3-6	Mild
140-200	3-6	Moderate
>200	>6	Severe

TCD criteria for vasospasm (mean CBFV)

- Newell D et al, 1990 — 120 cm/sec = significant VSP on DSA
- Mascia L et al, 2003 — TCD, threshold value of 100 cm/s for DSA VSP and 160 cm/s for clinical VSP detection
- Krejza J et al, 2005 — 94 cm/sec with TCCS and DSA
- Razumovsky A et al,, 2013 — 100 cm/sec with TCD

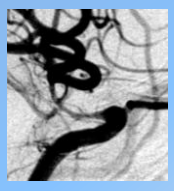
TCD and Vasospasm

- The Role of TCD Monitoring in the Diagnosis of Cerebral Vasospasm after SAH (Vora et al NS 44:6:June'99 1237-1248 Alberta Canada, University of Alberta Hospital)
  - MCA CBFV >200 cm/sec, PPV 87%
  - MCA CBFV <120cm/s, Negative PV 94%

Positive Predictive Values

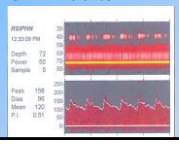
- Need 80% PPV prior to more invasive testing
- Need 90% NPV before repudiating the need for further treatment
  - Only values <120 or >200cm/s
  - Values between 140 and 200cm/s "No better than a coin toss" 50% PPV
  - EXCEPTION TCD CBFV 160-199 cm/s with >40cm/s difference between sides!
  - No criteria for elderly

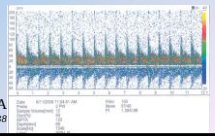
25 yo, closed TBI, no SAH



CBFV 120 cm/s

CBFV 57 cm/s

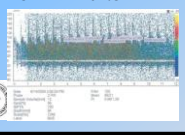


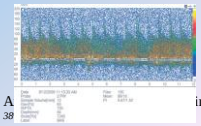


25 yo, closed TBI, no SAH

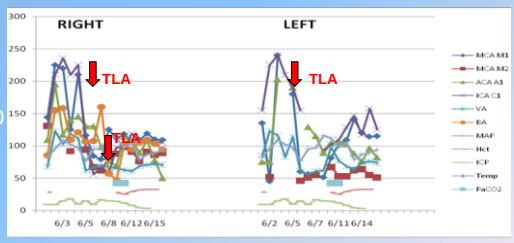
CBFV 112 cm/s

CBFV 89 cm/s





25 yo, closed TBI, no SAH



Calendar

Role of TCD: Post TBI vasospasm

- The incidence of vasospasm after TBI is similar to that following aneurysmal SAH but seems also could start later (up to 10 days) and be longer
- Because vasospasm is a significant event in a high proportion of patients after severe TBI, close TCD monitoring is recommended for the treatment of such patients

Role of TCD: Post TBI vasospasm

- 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
- TCD waveform appearance either regionally, or globally may be clinically significant

Role of TCD: Post TBI vasospasm

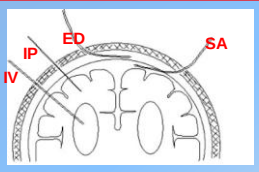
- Vasospasm following TBI is a very important source of morbidity and mortality. Too often, the first sign is a neurologic deficit, which may be too late to reverse.
- TCD assists in the clinical decision-making regarding further diagnostic evaluation and therapeutic interventions.
- As TCD-defined vasospasm preceded the neurological deficit in 64%, earlier intervention might reduce the incidence of vasospasm-related stroke in military hospitals with similar practice patterns

POST-TBI INTRACRANIAL HYPERTENSION

ICP and TBI

- High ICP causes drop in CPP
- High ICP lead to ischemia and further physical injury to the brain, if cerebrovascular autoregulation is impaired
- High ICP can trigger a vicious cycle in which increased ICP will further exacerbate brain injury
- Ample clinical evidence links increased ICP to poor outcome
- ICP is monitored in only a small fraction of those patents that could potentially benefit from the measurement

ICP Monitoring Methods



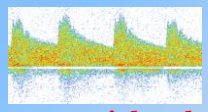
- **ED Probe**
  - Limited accuracy
  - Relatively delicate
- **SA Probe**
  - Limited accuracy
  - High failure rate
  - Periodic flushing necessary
- **IV catheter "Gold Standard"**
  - Most invasive method
  - High infection rate
  - May be difficult to insert
  - Simultaneous CSF drainage and ICP monitoring not possible
- **I/P Probe**
  - Measures local pressure
  - Drift of zero over time

Intracranial Pressure

- Normal <15 mm Hg
- ICP >20-25 mm Hg
  - Increases morbidity and mortality
- ICP monitoring rarely available in the ED or in military/civilian hospital or during MedEvac
- Must use physical findings
  - Neurologic deterioration
  - Unilaterally dilated pupil
  - Hemiparesis
  - Posturing

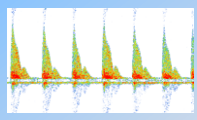
Typical morphology of TCD wave-form

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



- **Low peripheral resistance/Low PI**

- OA



- **High peripheral resistance/High PI**

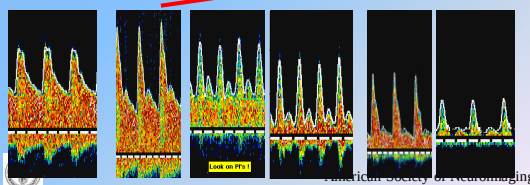
TCD wave-form changes with development of intracranial hypertension

Moreno et al, 2000; Belner et al, 2004; et al, 2005; Splavski et al, 2007; Melo et al, 2011; de Riva et al, 2012 and many others

PI ≥ 1.25 (Bouzat et al, 2011)
PI ≥ 1.26 could reliably predict CSF-P ≥ 20 cm H_2O or 14.7 mmHg (Wakerley et el, 2015)

ICP 20 mm Hg and higher

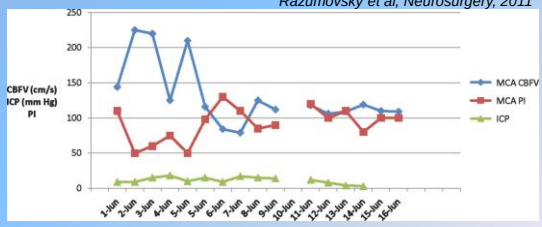
Normal ICP



Patient with GSW

Trend shows almost direct inverse relationship between CBFV and PI but epidural ICP values normal

Razumovsky et al, Neurosurgery, 2011



Transcranial Doppler to screen on admission patients with mild to moderate traumatic brain injury

Bouzat et a, Neurosurgery, 2011

- In patients with no severe brain lesions on CT following mild to moderate TBI, TCD on admission, in complement with brain CT scan, could accurately screen patients at risk for secondary neurological deterioration (edema, herniation, hydrocephalus) within first week after TBI

TCD and ICP

- Numerous data shows a highly significant correlation between TCD PI and ICP independent of intracranial pathology.
- Accordingly, in patients with suspected increase in ICP or where an increased ICP has to be excluded, PI may be of guidance and repeated PI measurements might prove a useful tool in neurointensive care or out-patient settings.

TCD in the management of TBI

- This non-invasive and simple procedure must be engaged in the daily management of TBI patients
- PI measurements permit the early identification of patients with low CPP/high ICP and high risk of cerebral ischemia. *In emergency situations it can be used alone when ICP monitoring is contraindicated or not readily available*

Role of TCD: Intracranial hypertension evaluation

- TCD wave-form changes indicates abnormally high ICP, especially after 20 mm Hg
- TCD changes may alarm Neuro-ICU personnel and may indicate malfunctioning of ICP probe
- Abnormally globally decreased pattern of the CBFV's in parallel with increased PI's indicate onset of diffuse intracranial hypertension
- Sudden onset of asymmetrical CBFV's and PI's changes may indicate potential mid-line shift
- *TCD quantitative and qualitative analysis must be taken into account for evaluation of intracranial hypertension, however, MAP, $PaCO_2$ and cardiac output must be within the normal limits*
- TCD is valid in predicting the patient's outcome

Role of TCD: Traumatic Brain Injury

- CBFV's often increased in patients with TBI due to the posttraumatic vasospasm
- TCD waveform changes can signal significant ICP changes
- TCD ultrasonography is valid in predicting the patient's outcome

Mild TBI

TCD measure of persistent CVR abnormality in service members with chronic mTBI

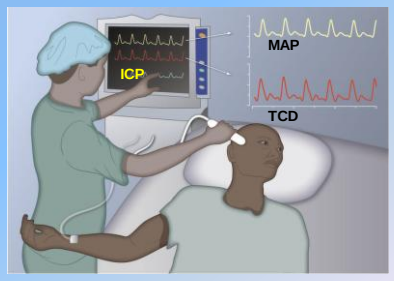
DeGraba et al, 2014

- Sixty-four of 145 subjects (44.1%) had abnormal BHI's indicating impaired cerebral vascular reactivity. Prevalence of Abnormal BHI per age (in 10 year increments) were: 20-29 (n=24) was 47.1%, age 30-39 (n=21) was 50.0%, and age ≥ 40 (n=18) was 42.9%.
- The abnormal BHI group had significantly higher scores on the PCL-M (PTSD Symptom Checklist-Military Version) than the Normal BHI group suggesting higher levels of PTSD in those with abnormal BHIs.
- TCD in patients with chronic post-concussive syndrome (PCS) revealed a high prevalence of cerebral autonomic disturbance. This autonomic disturbance is correlated with increased PCL-M. Therefore, these autonomic disturbances may be associated with post traumatic stress or may be an independent entity of PCS that overlaps with PTSD.

FUTURE DEVELOPMENTS

From Lundberg ICP: Computational Physiology and Modeling ICP

From Kashif et al. Sci Transl Med, 2012



From Lundberg ICP: Computational Physiology and Modeling ICP

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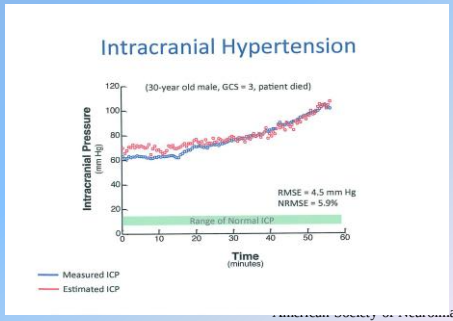


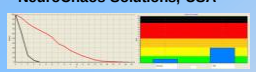
Non-Invasive ICP monitoring would enable

- Triage at the point of contact
  Battlefield, football field, ambulance, ER…
- In-time and evidence-based application of therapy
  Titrate therapy to ICP targets
- Long-term monitoring
  Without the risk of infection or damage to vital brain structures
- Expansion of patient pool for which monitoring might be beneficial
  Mild and moderate TBI, migraines, pediatric patients,…

New Developments

HeadSense Medical, Ltd, Israel

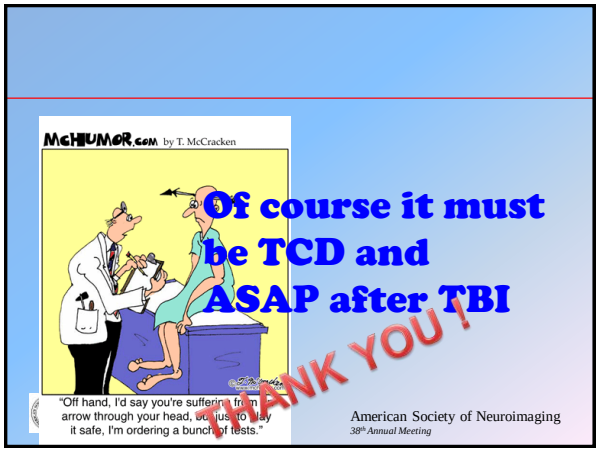
NeuroChaos Solutions, USA



Changes in the multiscale complexity of the dynamics of CBFV may indicate an abnormal state of the brain

Neural Analytics, USA

RapidICP takes TCD to the next level by leveraging advanced waveform analytics and a patient database for machine learning.


McHUMOR.com by T. McCracken
"Off hand, I'd say you're suffering from an arrow through your head, but just to play it safe, I'm ordering a bunch of tests."
Of course it must be TCD and ASAP after TBI
THANK YOU !
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