TCD: Critical Tool in Critical Care

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42nd Annual Meeting of the American Society of Neuroimaging


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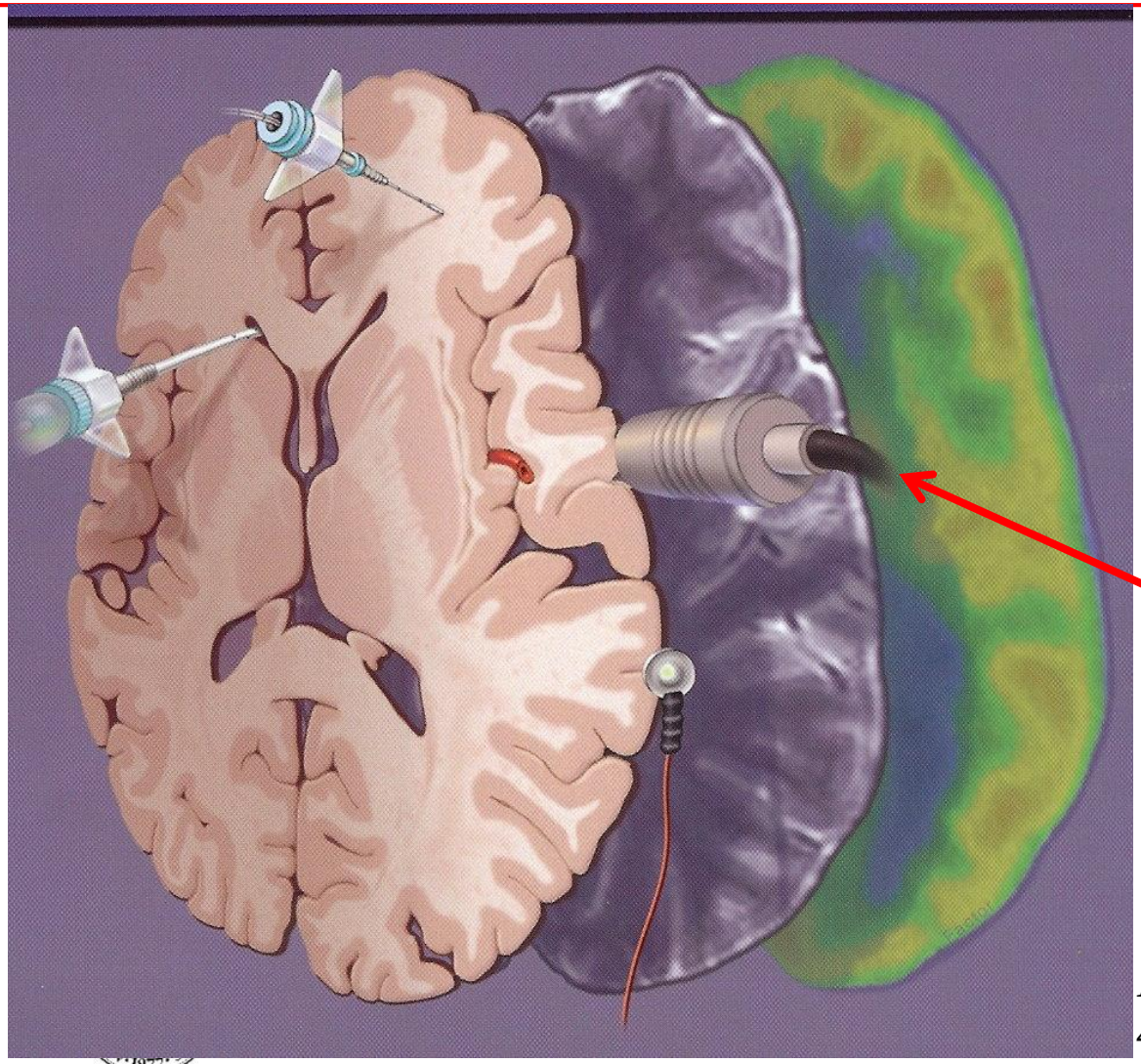
Multimodality Monitoring



- MAP
- SaO2
- ECG
- Et-CO2
- CVP
- Urine output
- ICP
- CBFV/**TCD**
  - PbO2
  - cEEG
  - CT/MRI Perfusion

Specific TCD Applications for Neuro-ICU (NCCU) or CCU

- Vasospasm diagnosis/monitoring and treatment effect evaluation after TBI, SAH, intracranial hemorrhage, tumor resection
- Stroke diagnosis/monitoring and treatment effect evaluation
- PFO screening for cryptogenic stroke and risk assessment
- Emboli and Fat emboli monitoring
- Septic patients evaluation
- CEA/CAS effect evaluation
- Neuroradiology test-occlusion (pre, during and post)
- Neuroradiology stenting (pre, during and post)
- Pre- and Post-treatment AVM evaluation
- Diagnosis and monitoring of intracranial hypertension
- Brain Death

VASOSPASM

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

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!

Role of TCD: Vasospasm

- When performed in isolation, the contribution of TCD to improving patient outcome has not been established in the prospective studies. Nevertheless, *TCD is a standard of care for patients after SAH*
- TCD can easily identify onset and time-course of posttraumatic vasospasm and augments neurological examination after SAH, TBI, etc.
- TCD can evaluate effect of treatment, especially after endovascular interventions for vasospasm treatment

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

2011 AHA/ASA Metrics for Measuring Quality of Care in Comprehensive Stroke Centers

- Among different measures for Comprehensive Stroke Centers is:

  Median frequency of noninvasive monitoring for surveillance for vasospasm in patients with aneurysmal SAH during the period between three and 14 days after SAH

Consensus Summary Statement of the International Multidisciplinary Consensus Conference on Multimodality Monitoring in Neurocritical Care

Le Roux P et al, 2014

- Recommend TCD monitoring to predict angiographic vasospasm after aneurysmal SAH
- Suggest that trends of TCD can help predict delayed ischemic neurological deficits due to vasospasm after aneurysmal SAH

Factors influencing TCD data interpretation

- Patient age
- The presence of moderate to severe anemia (Hct <27)
- Impaired CBF autoregulation (passive CBFV variation with MAP changes)
- Hyperemia induced by triple-H therapy

INTRACRANIAL HYPERTENSION

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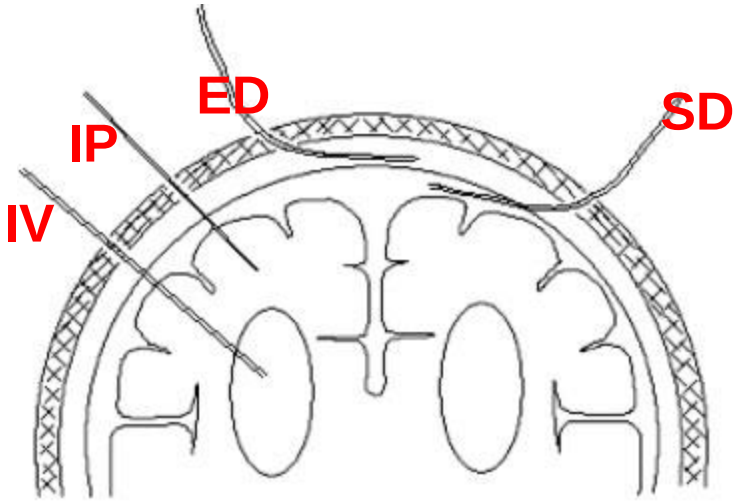
ICP Monitoring Methods



- **ED Probe**
  - Limited accuracy
  - Relatively delicate

- **SD 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

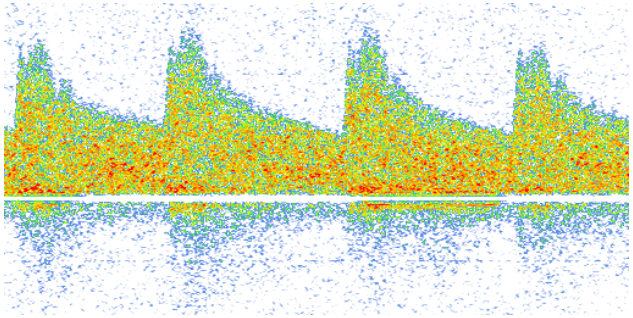
- **I/P Probe**
  - Measures local pressure
  - Drift of zero over time

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 field hospital or during medevac
- Must use physical findings
  - Neurologic deterioration
  - Unilaterally dilated pupil
  - Hemiparesis
  - Posturing

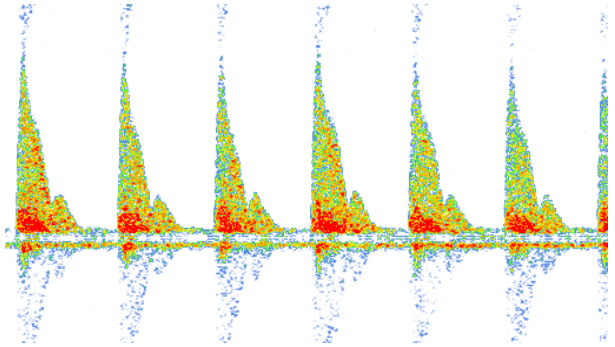
Representative Morphology of TCD Wave-Form

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



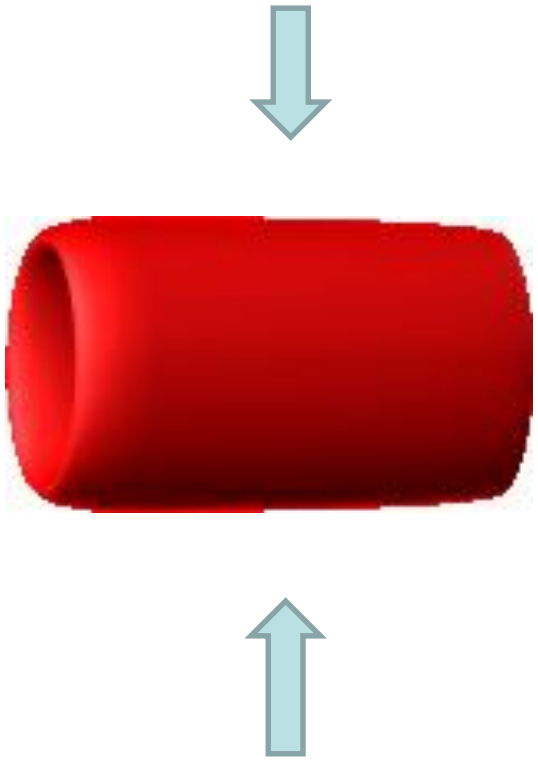
- **Low peripheral resistance and PI less than 1**

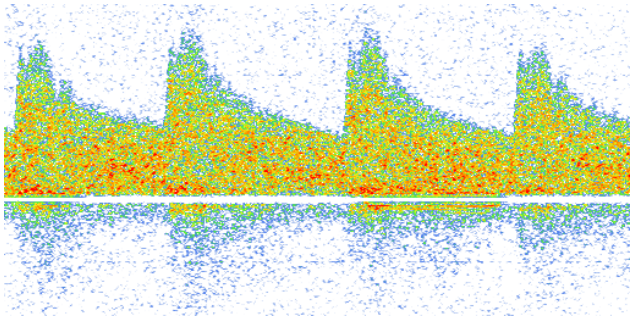
- OA



- **High peripheral resistance and PI more than 1**

TCD for non-invasive ICP evaluation

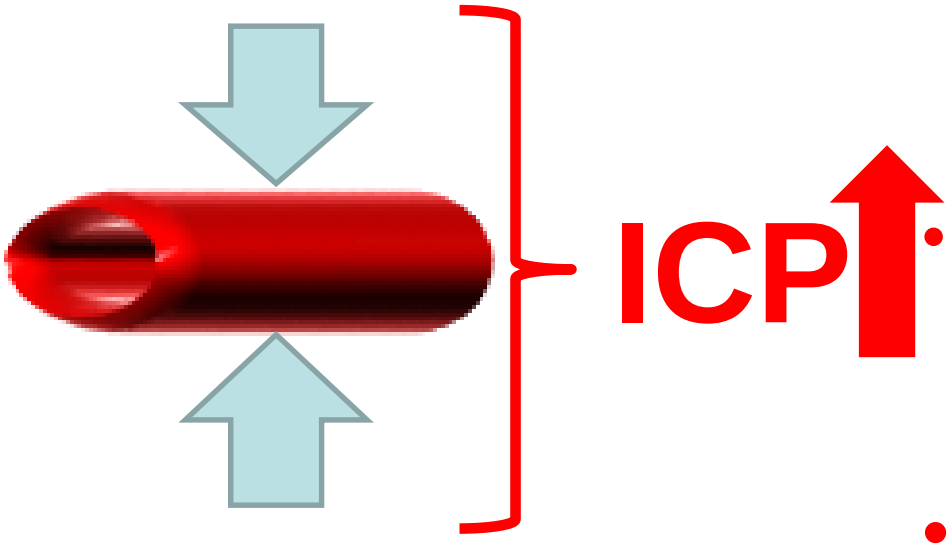


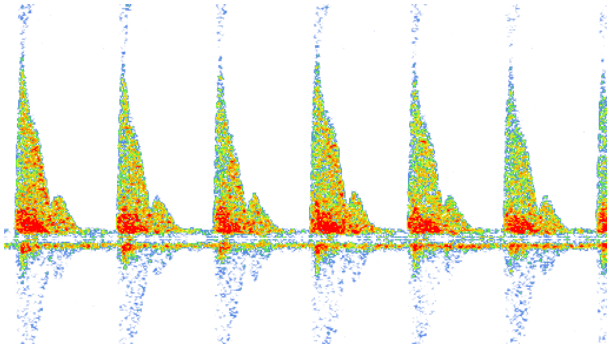


Normal ICP

- **Low resistance**
- **PI less than 1**

TCD for non-invasive ICP evaluation





The earliest sign of increased ICP is increased PI

- **High resistance**
- **PI more than 1**

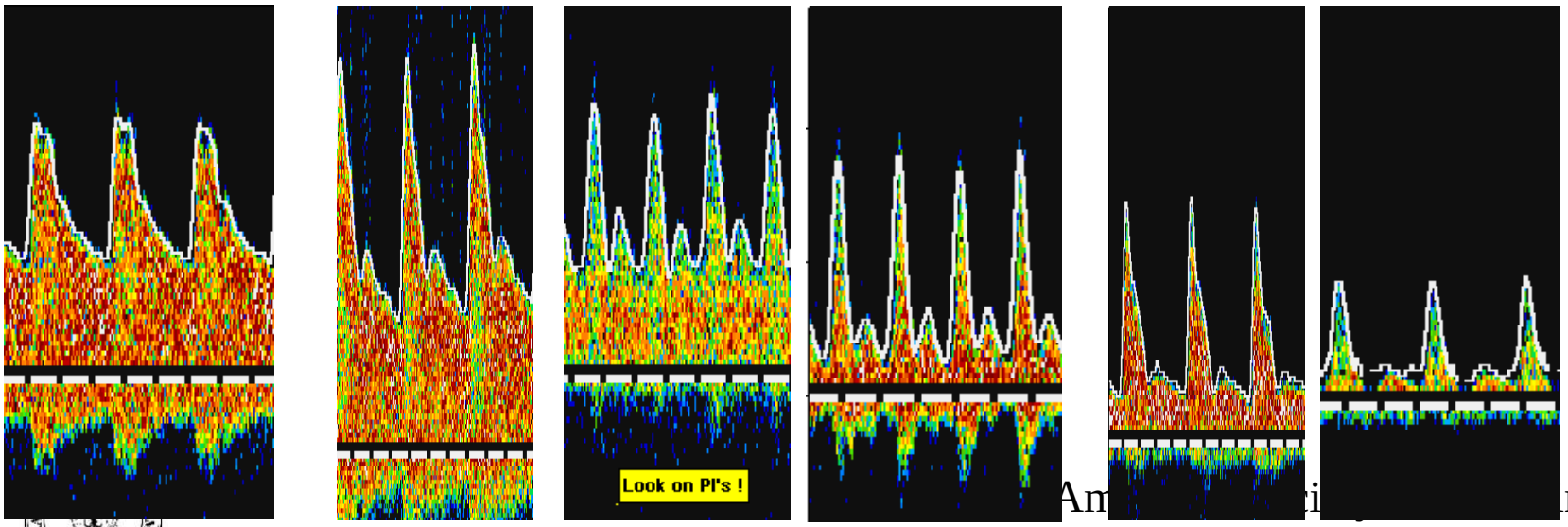
TCD wave-form changes with development of intracranial hypertension

Moreno et al, 2000; Belner et al, 2004; et al, 2005; Splavski et al, 2007; Melo et al, 2011; de Riva et al, 2012, Cardim D et al, 2019 and many others

PI ≥ 1.25 (Bouzat et al, 2011, 2016)
PI ≥ 1.26 could reliably predict CSF-P ≥ 20 cm H20 or 14.7 mmHg (Wakerley et al, 2015)

Normal ICP

ICP 20 mm Hg and higher

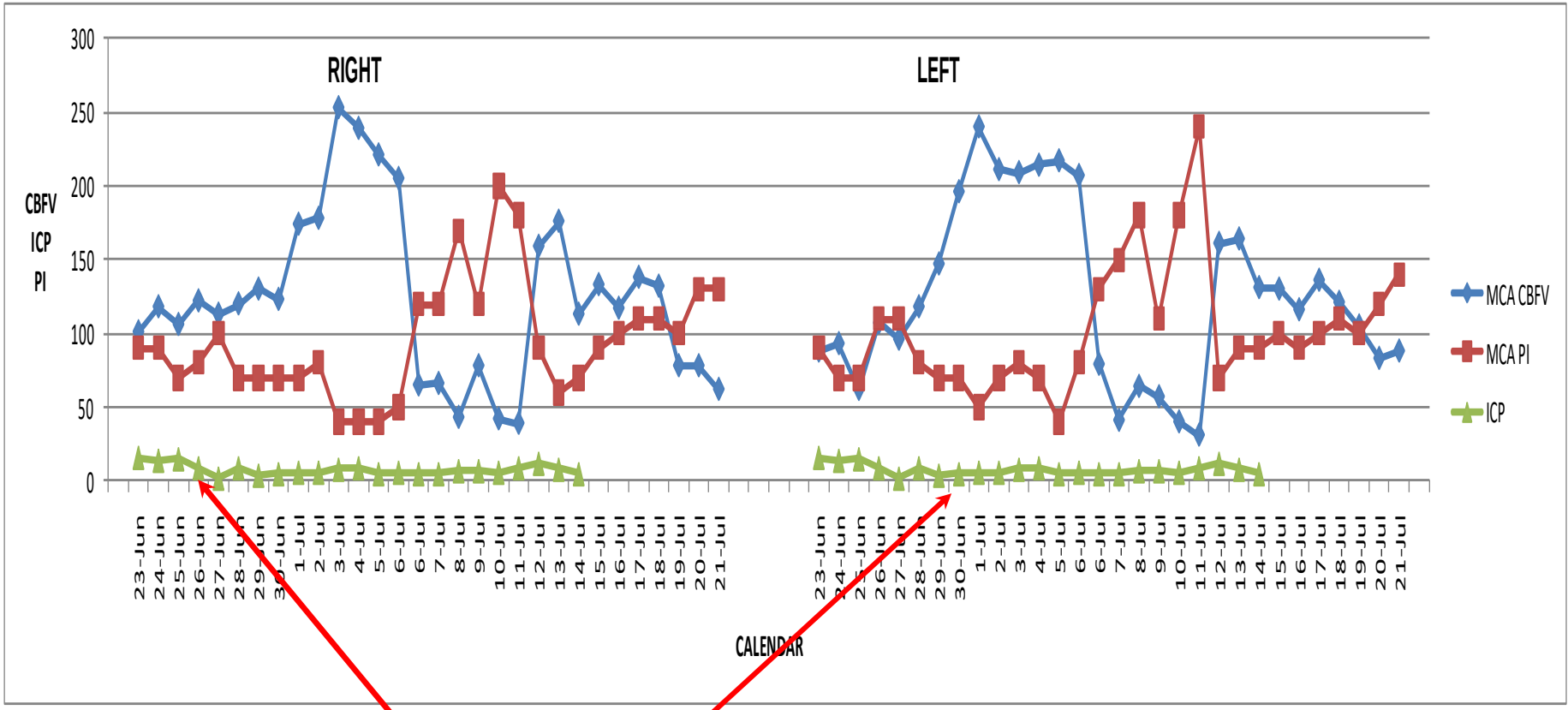


TCD & ICP

- 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**

Patient with GSW

Trend shows almost direct inverse relationship between CBFV and PI



Epidural ICP monitor

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 and ICP (cont.)

- This non-invasive and simple procedure must be engaged in the daily management of patients when one can suspect development and/or onset of intracranial hypertension

- Pulsatility Index (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*

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,…

Role of TCD: Intracranial hypertension evaluation

- TCD wave-form changes indicates abnormally high ICP, especially after 20 to 30 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, PaCO2 and cardiac output must be within the normal limits

TCD AND ACUTE STROKE

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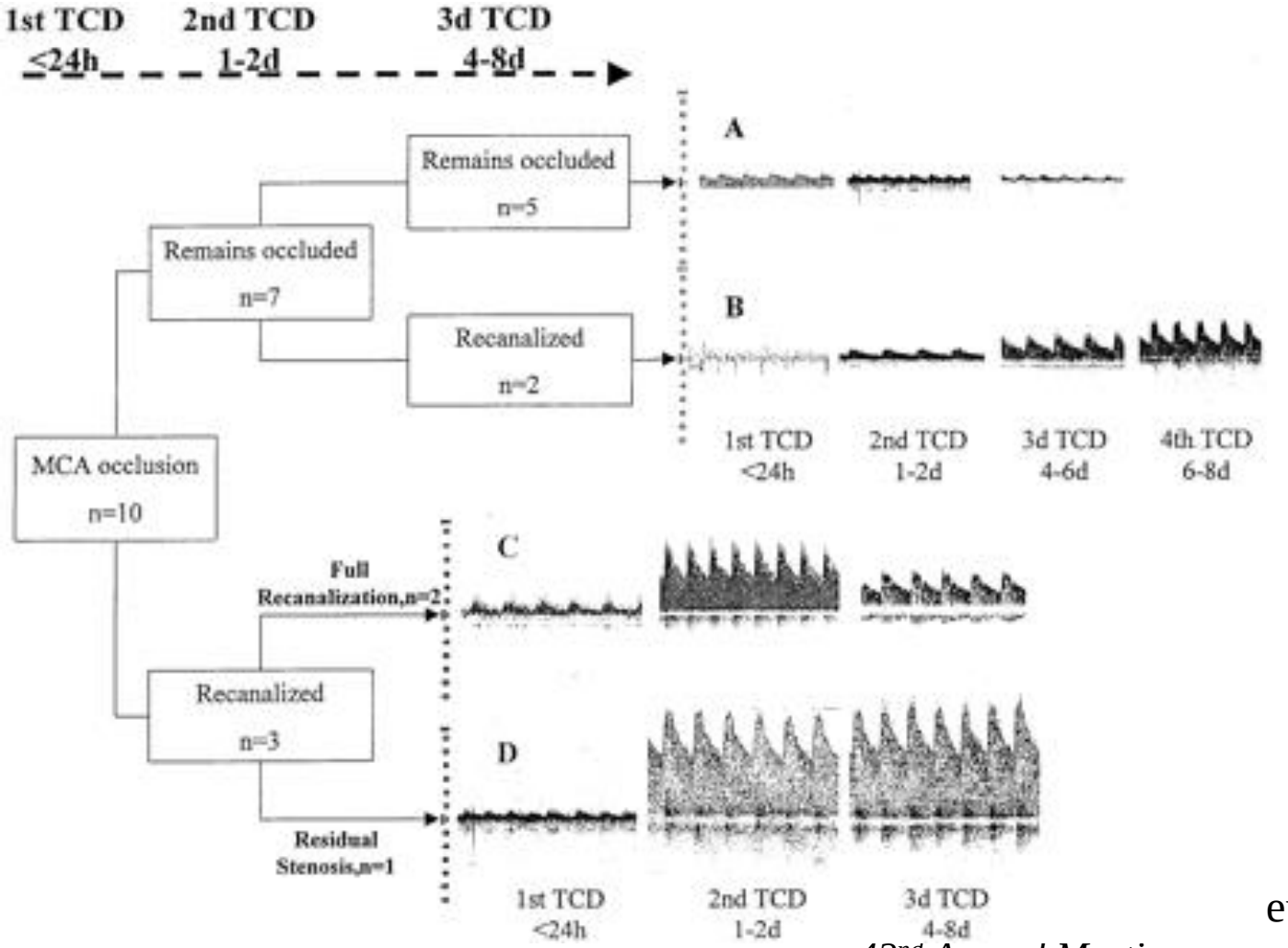
TCD and Acute Stroke

- 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

Hemodynamic studies in early ischemic stroke

Akopov et al., Stroke, 2002



Role of TCD: Acute Stroke/TIA

- 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 can identify hemodynamically significant abnormalities and lesions of the brain vasculature
- TCD is an accurate indicator of blood flow status and may be as reliable as angiography and correlated well with MRI, MRA, DSA, and CTA at a **fraction of the cost and no risk** for patients
- TCD could identify the active source of embolism in a very cost-effective manner. Detection of emboli may deliver clues for identification of the true, embolically active lesion

Role of TCD: Acute Stroke/TIA

- TCD can be performed rapidly and effectively in acute setting (ER, OR, ICU) or done longitudinally to evaluate progression and/or regression of disease

- TCD allows **rapid, non-invasive and cost-effective** manner evaluation of the blood flow status in basal cerebral arteries and offer new insight into the process of acute stroke and provide guidance for and monitoring of therapeutic interventions

MONITORING OF ACUTE STROKE TREATMENT

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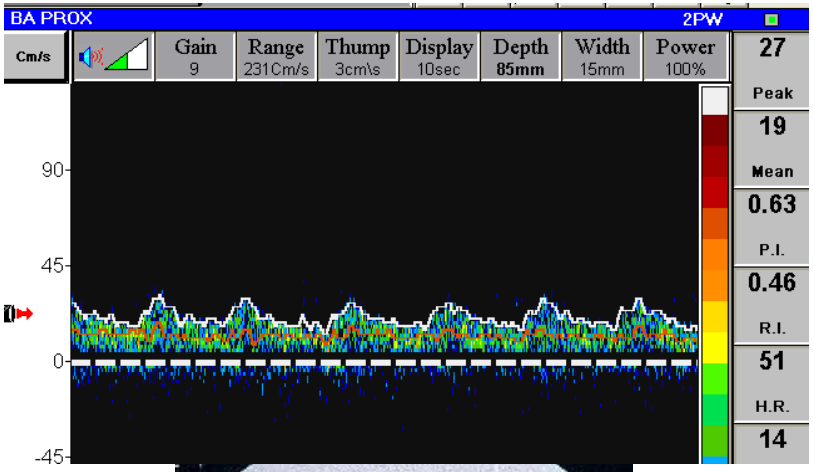
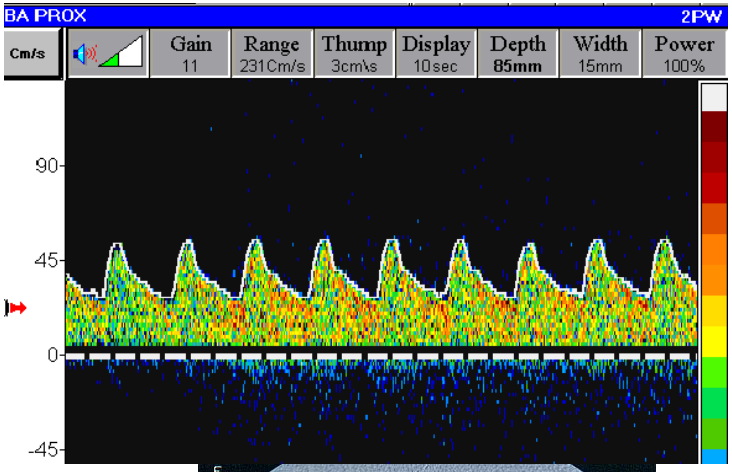
Angiography & TCD for patient with BA thrombosis



Before tPA



After tPA

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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 month
  - Patent MCA facilitates more aggressive therapeutic interventions such as induced hypothermia or decompressive craniotomy

Role of TCD: Monitoring of acute stroke treatment

- Outcome prediction/prognosis
- Treatment monitoring
- Treatment effect evaluation

TCD AND EMBOLI, INCLUDING FAT EMBOLI AND RISK EVALUATION

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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, complications of cardiac surgery, complications after different type of endovascular interventions, angiography, dialysis, etc.

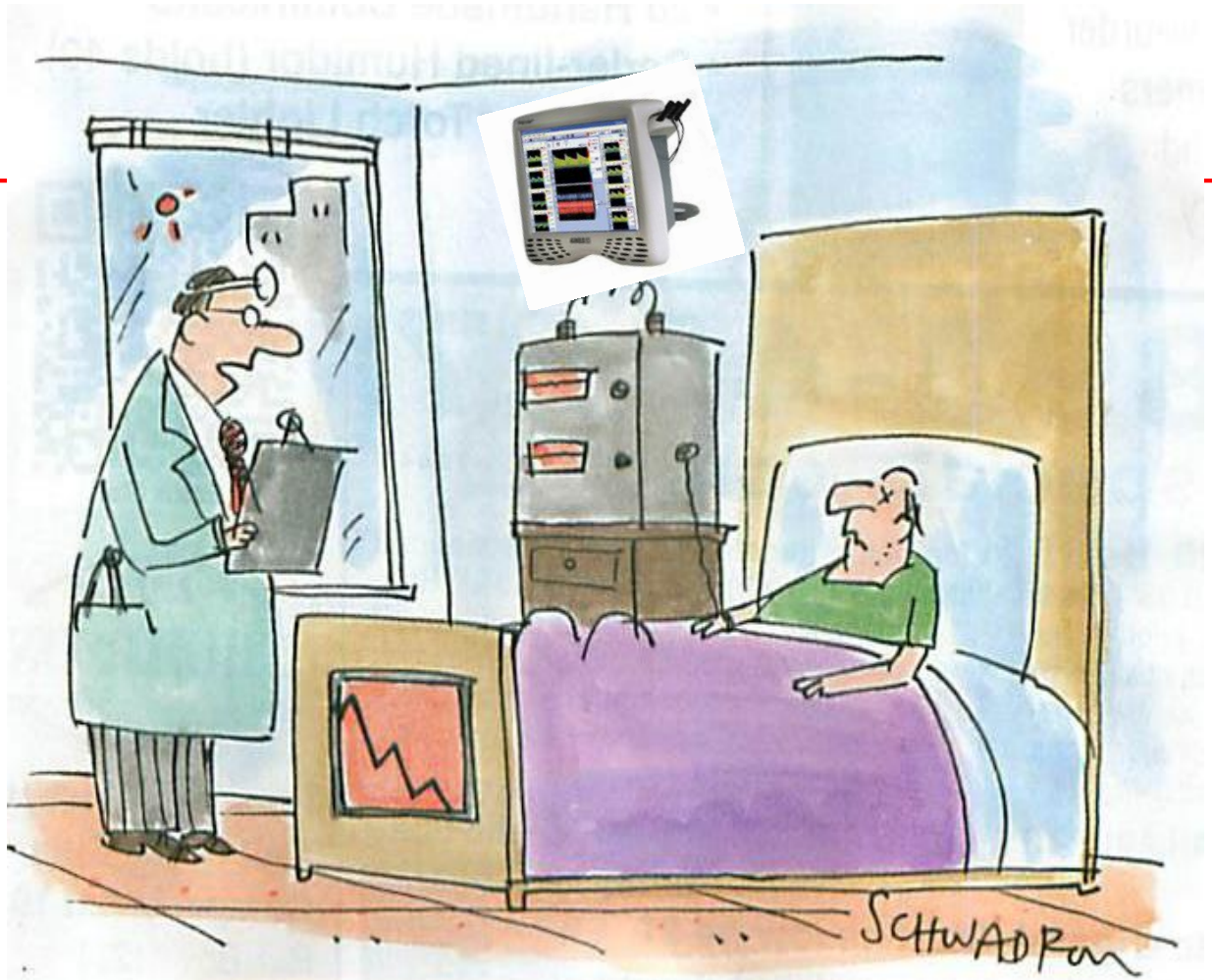
Role of TCD: Emboli Monitoring

1. Quantitative count of emboli
2. Localization of the embolic source responsible of stroke
3. Identification of high-risk patients for stroke and TIA recurrence
4. Monitoring of the therapy effectiveness
5. Monitoring of cardiovascular surgery
6. Monitoring different type of invasive procedures

Role of TCD: Emboli Monitoring

- Emboli monitoring: surrogate marker for plaque activity and risk of macroembolism
- Challenges of differentiation of embolic material

TCD AND BRAIN DEATH



"The monitors all show that you're dead…but to be sure, we'll need to run some more tests."

The Washington Post

December 23, 2015

"Terminal Wean" at Tomball Regional Medical Center (Tomball, TX)

March 2018. Brain Death: 'Miracle' child Trenton McKinley comes to life from brain injuries after parents sign organ donation papers

- Trenton McKinley, 13, from Mobile, Alabama, was so close to death after the brain trauma from a freak utility vehicle accident that his parents signed papers to donate his organs to five separate children needing transplants.
- In the days following the accident he remained brain dead and barely breathing on a life support machine.
- Doctors told his parents Trenton would "never be normal again" and they made the difficult decision to turn his life support off and signed papers to donate his organs as he was a match for five seriously ill kids
- However, a day before his life support was due to be turned off the young lad started showing signs of brain activity and movement, defying the odds

Brain Death: 'Miracle' child Trenton McKinley comes to life from brain injuries after parents sign organ donation papers

Diagnostic Accuracy of Transcranial Doppler for Brain Death Confirmation: Systematic Review and Meta-Analysis

Chang JJ et al, AJNR Am J Neuroradiol. 2016

- Case series studies have generally reported good correlations between TCD confirmation of cerebral circulatory arrest and clinical confirmation of brain death. The purpose of this study is to evaluate the utility of TCD as an ancillary test in brain death confirmation.
- **MATERIALS AND METHODS:** A systematic review of the literature and a diagnostic test accuracy meta-analysis to compare the sensitivity and specificity of TCD confirmation of cerebral circulatory arrest, by using clinical confirmation of brain death as the criterion standard.
- **RESULTS:** We identified 22 eligible studies (1671 patients total), dating from 1987 to 2014. Pooled sensitivity and specificity estimates from 12 study protocols that reported data for the calculation of both values were 0.90 (95% CI, 0.87-0.92) and 0.98 (95% CI, 0.96-0.99), respectively
- **CONCLUSIONS: The results of this meta-analysis suggest that TCD is a highly accurate ancillary test for brain death confirmation. However, TCD evaluates cerebral circulatory arrest rather than brain stem function, and this limitation needs to be taken into account when interpreting the results of this meta-analysis**

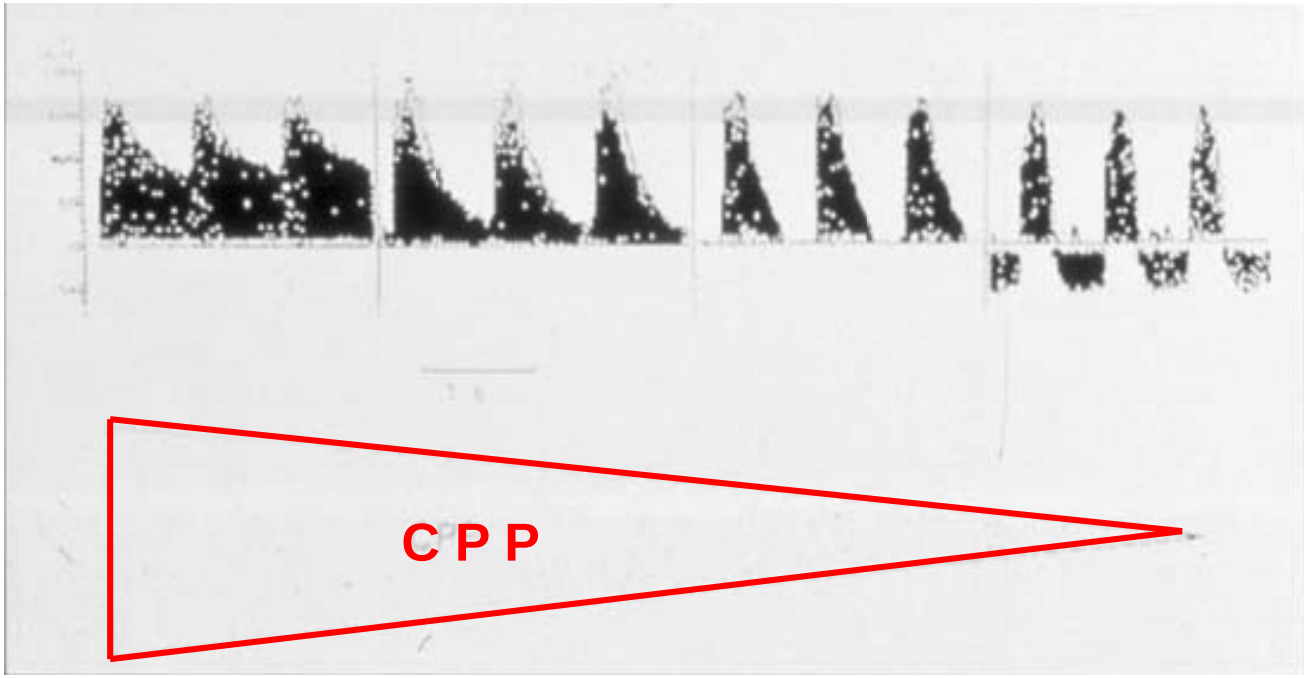
Doppler and Duplex Sonography for the Diagnosis of the Irreversible Cessation of Brain Function ("Brain Death"): Current Guidelines in Germany and Neighboring Countries

Walter U et al, Ultraschall in Med, 2016

- After EEG, TCD and TCCS are the most commonly used ancillary methods worldwide and regardless of geographical region
- TCD is even mandatory in 5% of countries but is used optionally in the USA
- In Germany, TCD is the most frequently used method for determining cerebral circulatory arrest, ***ahead*** of CTA and selective DSA
- TCD of only the bilateral MCAs and the BA is required in Holland, Poland, and Latin America in agreement with the recommendation of a N. American group of experts*, while bilateral examination of the MCA, ICA, and VA is required in Germany, Austria, the Czech Republic, and Japan (with additional examination of the BA being required in the Czech Republic)

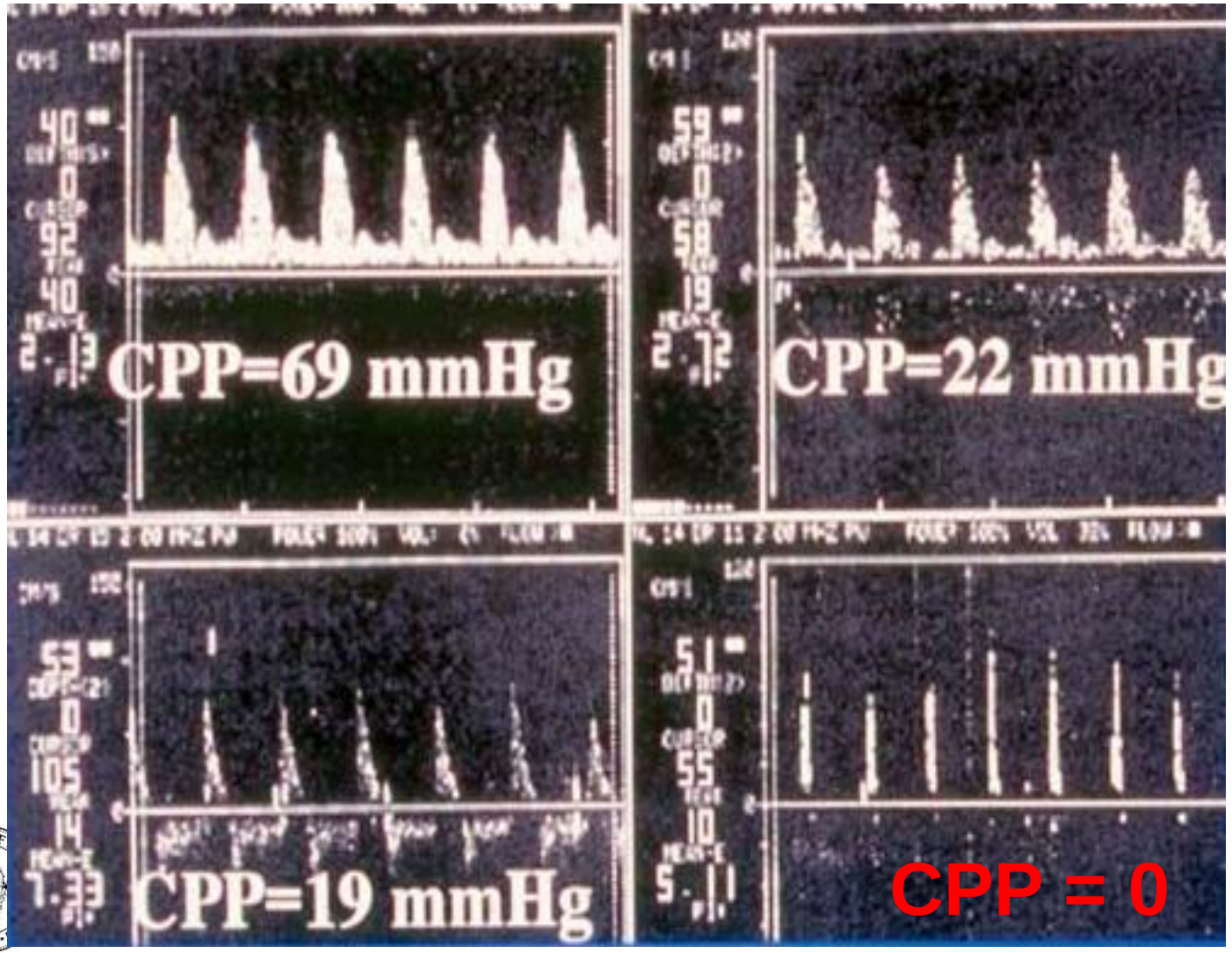
  * *Alexandrov et al. Practice standards for transcranial Doppler (TCD) ultrasound. Part II. Clinical indications and expected outcomes. J Neuroimaging 2012*

TCD wave form progression from intact CBFV to circulatory arrest



Hassler et al., 1988

TCD pattern in Brain Death



Role of TCD: Brain Death

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

TCD AS A CRITICAL TOOL IN CRITICAL CARE: SUMMARY

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What TCD Service Could Achieve

- Immediate bed-side results
- Provides accurate blood flow velocity information for determination of disease severity
- Detects even minimal cerebral hemodynamic 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

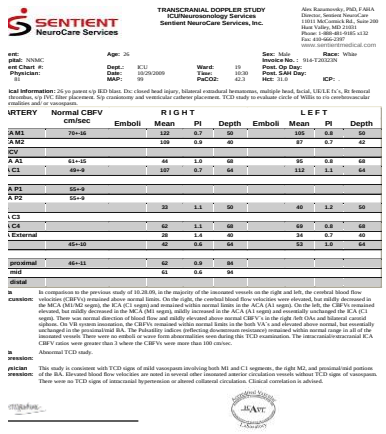
- The economic effect is clear. In a climate where doing more with less is imperative, any service/methods that increases productivity without compromising quality will positively impact Patient Outcome and success of the Hospital

Tele-TCD – Anytime, Anywhere…

Step 7. Provider sends f/u or questions/info to group

Step 1. Deployed Provider e-mails/calls for tele-TCD mentoring and consultation

Step 6. SNS emails/faxes recommendation and TCD report to the deployed Provider



SENTIENT NeuroCare Services

TRANSCRANIAL DOPPLER STUDY
ICU/Neurosonology Services
Sentient NeuroCare Services, Inc.

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Fax: 1-866-284-9185
www.sentientmedical.com

Age: 26
Sex: Male
Race: White
Dept.: ICU
Ward: 19
Date: 10/29/2009
Time: 10:30
MAP: 99
PaCO2: 42.3
Hct: 31.0
Invoice No.: 914-T26U2N
Post. Op Day:
Post. SAH Day:
ICP:

Clinical Information: 26 yo patient s/p IED blast. Dx: closed head injury, bilateral extradural hematomas, multiple head, facial, UE/LE fx's, Rt femoral thrombus, s/p IVC filter placement. S/p craniotomy and ventricular catheter placement. TCD study to evaluate circle of Willis to r/o cerebrovascular emabilies and/ or vasospasm.

ARTERY	Normal CBFV cm/sec	RIGHT Emboli	Mean	PI	Depth	LEFT Emboli	Mean	PI	Depth
A M1	70+-16		122	0.7	50		105	0.8	50
A M2			109	0.9	40		87	0.7	42
ICV									
A A1	61+-15		44	1.0	68		95	0.8	68
t C1	49+-9		107	0.7	64		112	1.1	64
A P1	55+-9								
A P2	55+-9								
			33	1.1	50		40	1.2	50
t C3									
t C4			62	1.1	68		69	0.8	68
t External	28		38	1.4	40		34	0.7	40
	45+-10		42	0.6	64		53	1.0	64
proximal	46+-11		62	0.9	84				
mid			61	0.6	94				
distal									

is cussion: In comparison to the previous study of 10.28.09, in the majority of the intracranial vessels on the right and left, the cerebral blood flow velocities (CBFVs) are unchanged. On the right, the intracranial CBFV velocities are elevated, and mildly increased in the MCA (M1/M2 segm), the ICA (C1 segm) and remained within normal limits in the ACA (A1 segm). On the left, the CBFVs remained elevated, but mildly decreased in the MCA (M1 segm), mildly increased in the ACA (A1 segm) and essentially unchanged the ICA (C1 segm). There was normal direction of blood flow and mildly elevated above normal CBFV's in the right M6 O/As and bilateral carotid siphons. On VB system insonation, the CBFVs remained within normal limits in the both VA's and elevated above normal, but essentially unchanged in the proximal/mid BA. The Pulsatility indices (reflecting downstream resistance) remained within normal range in all of the insonated vessels There were no emboli or wave form abnormalities seen during this TCD examination. The intracranial/extracranial ICA CBFV ratios were greater than 3 where the CBFVs were more than 100 cm/sec.

is session: Abnormal TCD study.

ysician session: This study is consistent with TCD signs of mild vasospasm involving both M1 and C1 segments, the right M2, and proximal/mid portions of the BA. Elevated blood flow velocities are noted in several other insonated anterior circulation vessels without TCD signs of vasospasm. There were no TCD signs of intracranial hypertension or altered collateral circulation. Clinical correlation is advised.

Neil M. Nussbaumer, M.D., Ph.D., F.A.H.A

Step 5. SNS Neurologist retrieves and reviews Tele-TCD report

Step 3. Tele-TCD is performed by deployed provider under SNS tele-mentoring

Step 2. Tele-consultation request E-mailed /called to Neurosonologist

Step 4. Creates TCD report and sends to Neurologist on-call

Step 8. Copy furnished to specialty group (Neurology, Neurosurgery and/or Neurointensivist) confirms tele-TCD consultation is answered and enables collaboration

TCD as a Modality

- Will be very good, reliable and accurate , if:
  - **Dedicated Personnel**
  - **Daily Monitoring of the Technical Performance Quality**
  - **Quality of Interpretation**

Questions?

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