Monitoring of Cerebral Blood Flow

Transcranial Doppler
Laser Doppler Flowmetry
Thermal dilution method (Hemedex)
Doppler Principle

- The ultrasound signal is reflected and backscattered from moving objects (e.g. blood cells) with a positive or negative frequency shift.
- The faster the blood cells are moving the larger the frequency shift.

Christian Doppler, Prague, 1842
Doppler Formula

Doppler Frequency Shift:

\[ f_d = \frac{2f_t v \cos \beta}{v_0} \]

Velocity:

\[ v = \frac{v_0 f_d}{2f_t \cos \beta} \]

simplified:

\[ v = f_d \times \frac{1540\text{m/s}}{2 \times 2\text{MHz} \times 1} \]

- \( f_d \): Doppler frequency shift
- \( f_t \): ultrasound frequency, e.g. 2MHz
- \( v \): velocity of the moving blood cells
- \( v_0 \): velocity of ultrasound in tissue (1540 m/s)
- \( \beta \): angle of insonation

The Doppler frequency shift is the only variable in the above shown formula, therefore we have a linear relationship between blood flow velocity and Doppler frequency shift.
Thanks to Dr.DJ Kim
Doppler System

Audio Doppler Signal:
- Doppler signal
- time signal
- audio output
- difficult to analyze

Spectral Display:
- frequencies and velocities
- spectral display
- parameters like envelope, PI
- easier to analyze
**Spectral Display, Indices**

- **Envelope** (maximum frequency follower)
- **Systolic peak velocity**
- **Mean Velocity**
- **Enddiastolic velocity**

**Spectra**
Pulsatility Indices

Gosling’s Pulsatility Index

\[ PI = \frac{V_{sys} - V_{dia}}{V_{mean}} \]

Pourcelot’s Resistance Index

\[ RI = \frac{V_{sys} - V_{dia}}{V_{sys}} \]
Investigation of ICA
Cerebrovascular Laboratory

Thanks to Dr. P. Smielwski
Testing of Cerebrovascular Reactivity using TCD

Acetazolamide test

• Inhibitor of carbonic anhydrase in red cells.
• Intravenous administration of 1 g of acetazolamide causes normally 30%-60% increase in CBF.

• Advantages:
  – does not change ABP,
  – does not require patient’s co-operation.

• Disadvantages: 2-h duration of action.

Thanks to Dr.P.Smielwski
Acetazolamide test

Reactivity = \frac{\Delta FV}{FVbas}

Normal values: 30-60% (Sullivan et al., 1987)

Thanks to Dr. P. Smielwski
CO$_2$ reactivity test

- Change in CO2 concentration of the inspired gas
- Breath holding
- Manipulation of ventilation in sedated patients

Thanks to Dr. P. Smielwski
**CO₂ Reactivity**  Methods of assessment

Change in FV to change in PaCO₂ ratio

Reactivity = \( \frac{\Delta FV}{\Delta CO₂} \cdot \frac{1}{FV_{bas}} \)

Normal values: 24 + 4.1 %/kPa

Thanks to Dr. P. Smielwski
CO₂ Reactivity

Methods of assessment

Linear regression

Reactivity = Slope of regr.

Normal values:
24 + 4.1 %/kPa
Transient Hyperaemic Response Test

Definition

Carotid compression

Transient hyperaemic response ratio

$$THRR = \frac{FVS_{\text{hyperaemia}}}{FVS_{\text{baseline}}}$$

Thanks to Dr. P. Smielwski
Transient Hyperaemic Response Test

THRT Positive
Intact Autoregulation

THRR = 1.45

THRT Negative
Impaired autoregulation

THRR = 0.95

Thanks to Dr. P. Smielwski
Transient Hyperaemic Response Test
repeated at different CO₂ levels

- **Normocapnia**
  - THRR 1.18
  - THRR 1.19

- **Hypercapnia**
  - THRR 1.05
  - THRR 1.04
  - THRR 1.37
  - THRR 1.46

- **Hypocapnia**

Thanks to Dr. P. Smielwski
Brain monitoring on NCCU
Continuous monitoring of CBF: ‘Hyperaemic’ waves of ICP
PI is a useful index of decreasing CPP
Refractory intracranial hypertension:
Multimodal CBF monitoring

**Figure 8-8** Recording of events characterized by intracranial hypertension in a head-injured patient receiving intensive care. Using multimodality monitoring makes it possible to identify the cause of this increase. Increase in intracranial pressure (ICP) (plateau wave [P]) is secondary to a fall in cerebral perfusion pressure (CPP), as the blood velocity (FV), the jugular bulb oxygen saturation values ($S\text{J}_{O_2}$) and cortical blood flow (LDF, in arbitrary units) also fall, indicating hypoperfusion. Repetitive vasogenic waves of ICP (B waves [B]) are secondary to fluctuations of cerebral blood flow as $S\text{J}_{O_2}$, and FV, and LDF increase and decrease in phase with ICP.
Figure 1 Basic operating principles of laser Doppler flowmetry. A laser beam is directed to an area of tissue. Upon contact with red blood cells in the target tissue, light waves are reflected and scattered, resulting in broadening of the light wave frequency, which is detected and received by a photodector.
Clinical monitoring of rCBF using LDF
Experimental monitoring

Group A (Naïve ICP)

Group B (ICP 20 mmHg)

The LLA is the intersection of the two best-fit lines with the lowest residual error squared taken from plots of CBF against CPP.
LDF flux during plateau elevation of ICP
‘Pulse wave’ of LDF flux
LDF during refractory elevation of ICP
Hemedex- rCBF measurement using thermal dilution method
Changes in Hemedex CBF related to changes in EtCO2

Thanks to Dr A. Oshorov
Slow waves in Hemedex CBF and ICP

CBF (ml/min/100g)

ICP (mmHg)

Cross-spectrum

Coherence ICP-CBF
Head injury - CBF fluctuates independently on CPP
But not always: example of homogenous Lassen’s curve; 3 days monitoring, TBI

Thanks to Dr. N. De Riva Solla
Calibration gaps - main source of variation in measured CBF
Typical...

Thanks to Dr. N. Der Riva Solla
Message to take home

TCD- non-invasive, indirect and difficult in continuous monitoring
TCD- information included in mean velocity and waveform
TCD- very good dynamical response

LDF- invasive, indirect
LDF- rarely used in clinical practice
LDF- biological zero

Hemedex- invasive, direct
Hemedex- lot of fluctuations which seem to be artificial

New technique: DCS
Based on NIR
monitoring, absolute
non-invasive CBF?