Continuous cerebral autoregulation monitoring

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20/10/2017

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Determinants of cerebral blood flow

Thanks to Joseph Donnelly
Determinants of cerebral blood flow

Cerebral perfusion pressure

*CPP = ABP - ICP

Thanks to Joseph Donnelly
Determinants of cerebral blood flow

Cerebrovascular resistance

\[ \text{CPP} = \text{ABP} - \text{ICP} \]
Cerebral Autoregulation

Ability of the brain to stabilise cerebral blood flow in spite of changes in cerebral perfusion pressure

Drawing by her daughter (age 7)
Cerebral Autoregulation

![Graph showing ABP and FV over time]

10 min
Autoregulatory curve

![Graph showing CPP, ICP, and FV over time]
Autoregulation in Head Injury is easily disturbed

“Minor head injury”: 28%

“Severe head injury”: 87%
Autoregulation in Head Injury

• Upper limit shifted to the left


• Lower limit shifted to the right


• Lower limit shifted to the right, upper limit shifted to the left

Autoregulation in Head Injury

Graph showing CBF (Cerebral Blood Flow) against CPP (Cerebral Perfusion Pressure). The graph illustrates the relationship between CBF and CPP with different levels of CPP indicated on the x-axis (50, 100, 150). The CBF is depicted on the y-axis.
Cerebral blood flow monitors

Laser Doppler Flowmetry
Thermal conduction (Hemedex)
Optical-ultrasound modulation (Ornim)

Bulk flow – Transcranial Doppler (TCD)
Regional Heterogeneity

CT

Scan 1
(CPP = 74 mmHg)

Scan 2
(CPP = 98 mmHg)

SROR

Regional or Global?

Autoregulation assessment

CO₂ reactivity test

CO₂ reactivity = \% change in FV / \% change in CO₂

Correction for changes in ABP?
Intervention-less autoregulation assessment

Mx: an index of autoregulation

Cerebral autoregulation impaired ($Mx > 0$): Cerebral autoregulation intact ($Mx \leq 0$):


ICP as a monitor of blood volume changes

Pressure-volume curve
Pressure reactivity

Poor brain vessel function

Arterial blood pressure

Brain vessels

Intracranial pressure
(Cerebral blood volume)

PRx \sim +1

Thanks to Joseph Donnelly
Pressure reactivity

Good brain vessel function

Arterial blood pressure  →  Brain vessels

Intracranial pressure (Cerebral blood volume)  

PRx ~ -1

Thanks to Joseph Donnelly
Pressure reactivity (PRx)
PRx correlates with PET-static rate of autoregulation

Figure 5: PET vs. PRx

Global SROR


SRoR = \( \frac{\text{% Change in CVR}}{\text{% change in CPP}} \)
PRx detects lower limit of autoregulation - piglet model
Continuous evaluation of PRx

Input signals ICP, ABP

10 sec window

Mean(ABP)

Mean(ICP)

ICP

5 min window

ABP

MAP

MICP

Correlation(MAP, MICP)

Output trend PRx
Why 10 second filter and 5 minute window?

10 sec moving average filter
Why 10 second filter and 5 minute window?

Piglet model

Modulated PEEP

Dr.K.Brady
Individual trends are most important

Severe head trauma patient after a road traffic accident.

Colour coded autoregulation (AR) index PRx
- AR intact
- AR impaired
Deterioration of PRx precedes refractory hypertension
TBI Mortality rate dramatically depends on PRx
Question

How to incorporate PRx into the clinical management protocol of TBI patients?
Modifying the cerebral perfusion pressure CPP

Cerebral perfusion pressure*

*CPP = ABP - ICP

Thanks to Joseph Donnelly
TBI guidelines 2016

- ICP < 22 mmHg
- CPP 60-70 mmHg
- Autoregulation status
Retrospective TBI studies: thresholds

Fig. 1. Mortality and persistent vegetative state (d/pvs) rate, rate of favorable outcome (g/m), and rate of severe disability (s.d.) expressed as a function of ICP.

Fig. 2. Mortality and persistent vegetative state (d/pvs) rate, rate of favorable outcome (g/m), and rate of severe disability (s.d.) expressed as a function of CPP.

Neurocrit care 2006
“The minimum level of CPP in this instance is greater than 70 mmHg and frequently higher, defined by individual circumstances that may occasionally require a level of 100 mmHg or more, but average 85 mmHg”
Individual Optimal CPP?

• SJO₂ and TCD

• Microdialysis
  Nordstrom CH *et al.*: Assessment of the lower limit for cerebral perfusion pressure in severe head injuries by bedside monitoring of regional energy metabolism. Anesthesiology 2003;98:809-14

• Brain Tissue Oxygen
‘Optimal’ Cerebral Perfusion Pressure

(529 head injuries, Addenbrooke’s Hospital)
Examine PRx-CPP curves in individual patients revealed varying CPP optimal values (the CPP value at which autoregulation was the strongest – i.e., the value of PRx was the lowest). In some patients, that value (named CPPOPT) was even outside of the CPP values observed.
Effects of cerebrovascular pressure reactivity-guided optimization of cerebral perfusion pressure on brain tissue oxygenation after traumatic brain injury*

*Crit Care Med 2010 Vol. 38, No. 5

Matthias Jaeger, MD; Markus Dengl, MD; Jürgen Meixensberger, MD, PhD; Martin U. Schuhmann, MD, PhD

Proof of concept: CPPopt = CBFopt
For the CPPopt assessment to be clinically useful it has to be obtainable from a period of hours rather than days.
TRACKING CPP OPT

9 hours
Missing CPPopt values

Why?
The shorter the calculation window the smaller the range of CPP probing the autoregulatory capacity.
Calculation of CPPopt from 4 hours long windows

- 560 patients examined
- 60% of monitoring time a value
- Only 70% U-shaped
- Sometimes unphysiologically high CPPopt values
Reasons for CPPopt value absence (‘low yield’)

Materials and methods

Main conclusions

1. Results show an association between absence of CPPopt and the following physiological and clinical variables:
   * absence of ABP slow waves
   * impaired autoregulation
   * status after decompressive craniectomy
   * not applying muscle paralytics
   * light or moderate sedation
   * high vasopressor use

Weersink et al. (2014)
Proposed CPP Opt based treatment algorithm

Start Treatment at Standard CPP Target of your Unit

Monitor Autoregulation for ~2 h

Decrease or increase CPP by 10 mmHg for ~2 h

CPP_{OPT} identified

Identify CPP_{OPT}

No CPP_{OPT} identified

Change Algorithm?

Monitor Autoregulation

Steiner LA et al, CCM 2002
CPPopt yield (%) with relation to the calculation window size

N = 35

N = 37
CPPopt yield (%) combined Window

N = 35

N = 37
U-curves could only be fitted for time windows of 2, 4, 6, 8, and 12 hours.

The CPPopt receive a weight (represented by line thickness) based on the goodness of fit of their U-shaped curve and the lower value of the LAx at CPPopt.

The highest weights are given to the 4-hour time window and LAx-20, LAx-30, LAx-60, and LAx-90.

The combined CPPopt is the weighted average of all CPPopts.
Multi-flexi window CPPopt algorithm in ICM+

\[
\text{weight} = \frac{1}{e^{\text{window length}}} \times \frac{1}{e^{\text{fit error}}} \times W_{\text{non-parabolic window}}
\]
PRx range matters
Multi-flexi window algorithm in ICM+

More stable and less likely to produce unphysiologically high values
Visualising time ‘landscape’ of cerebral autoregulation
Limits of autoregulation
Tracking the limits of reactivity
The milestones of CPPopt

- **1997**: Pressure reactivity index (PRx) [1]
- **2002**: Optimal cerebral perfusion pressure (CPPopt) [2]
- **2012**: Continuous automated CPPopt calculation [3]
- **2016**: CPPopt multi-window weighted approach [4]
- **2017**: Prospective randomised clinical trial starts (COGiTATE)
Welcome to the CPPopt website

Cerebral perfusion pressure (CPP) management based on cerebral autoregulation indices, such as cerebrovascular pressure reactivity (PRx) has the potential to provide a dynamic and personalised treatment target and subsequently improve patient outcomes. In literature, the term Optimal Cerebral Perfusion Pressure (CPPopt) was used to refer to this 'individual' treatment target as an example of autoregulation guided management.

Several successful research work has been performed to investigate retrospectively the patient’s outcome related to the deviation from CPPopt. Research fields include traumatic brain injury, intracranial hemorrhage, subarachnoid hemorrhage and monitoring of children/neonates.