UNIVERSITY OF CAMBRIDGE

Continuous cerebral autoregulation monitoring

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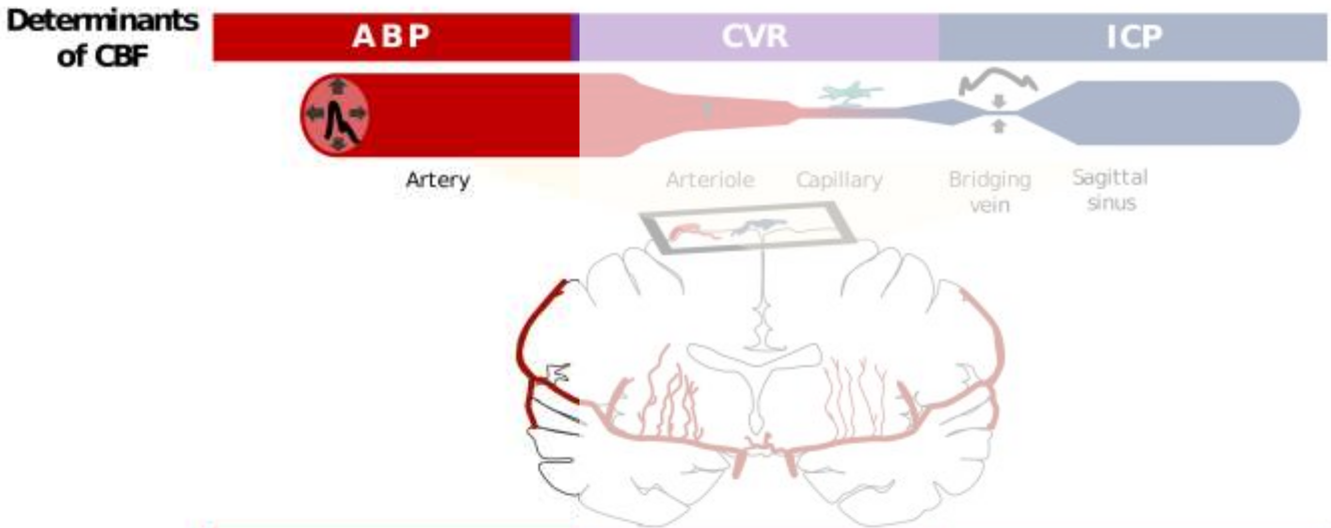
20/10/2017

Division of Neurosurgery, Department of Clinical Neurosciences

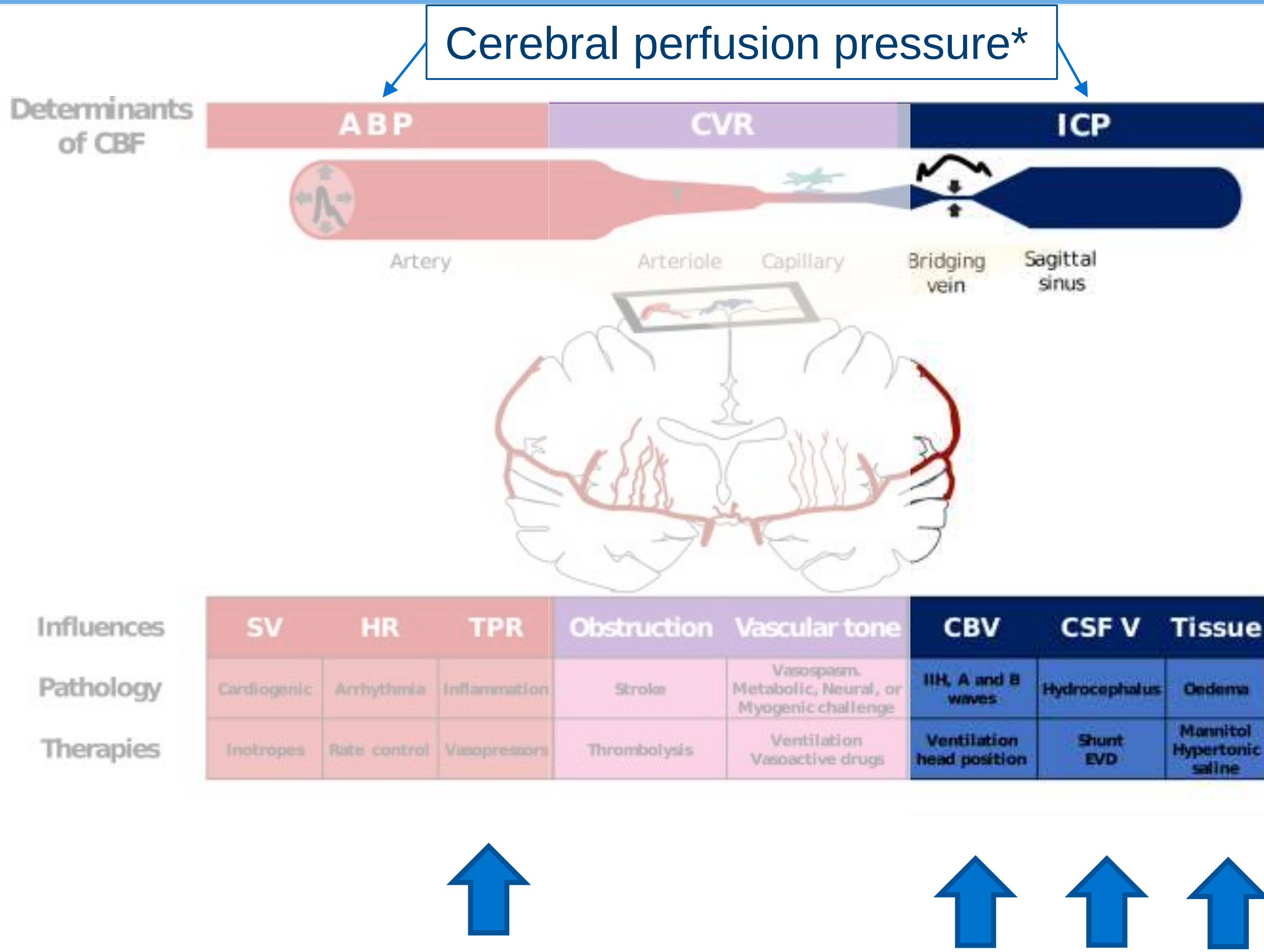
Determinants of cerebral blood flow



Influences	SV	HR	TPR	Obstruction	Vascular tone	CBV	CSF V	Tissue
Pathology	Cardiogenic	Arrhythmia	Inflammation	Stroke	Vasospasm. Metabolic, Neural, or Myogenic challenge	IIH, A and B waves	Hydrocephalus	Oedema
Therapies	Inotropes	Rate control	Vasopressors	Thrombolysis	Ventilation Vasoactive drugs	Ventilation head position	Shunt EVD	Mannitol Hypertonic saline

Thanks to Joseph Donnelly

Determinats of cerebral blood flow



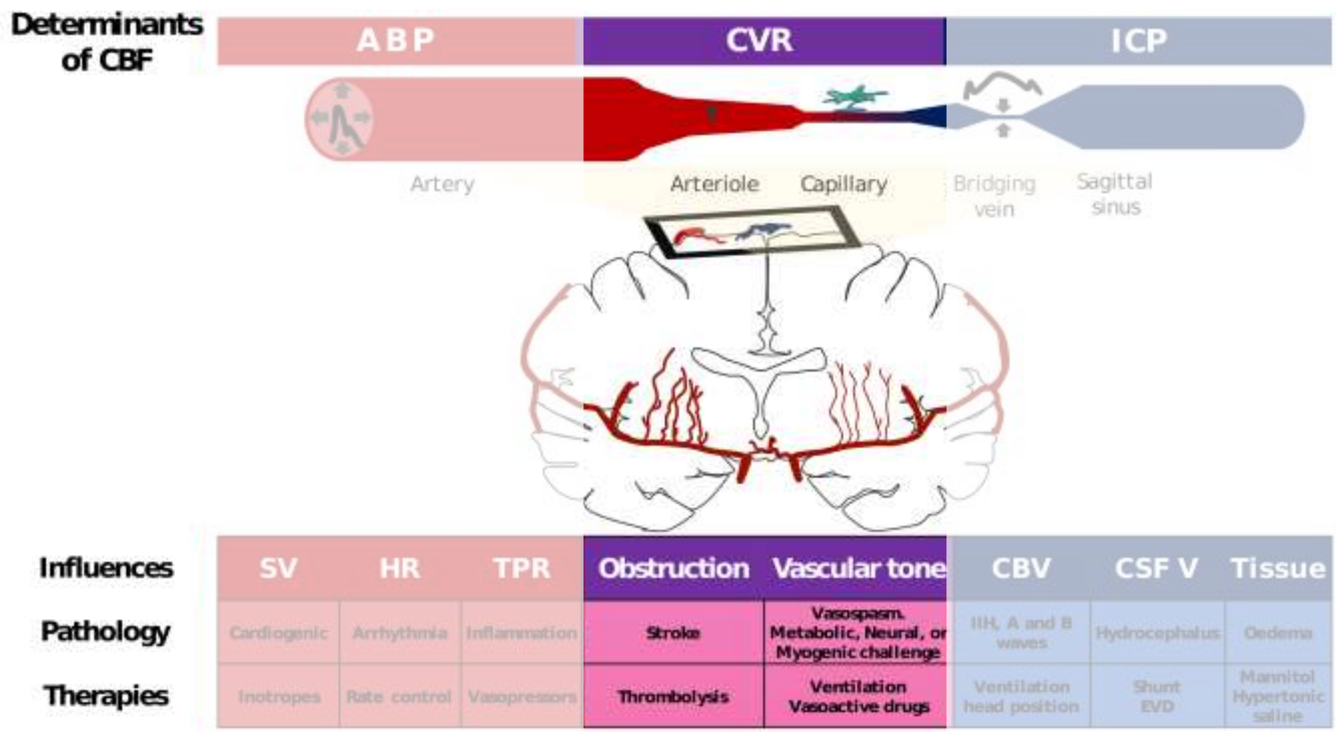
*CPP=ABP - ICP

Thanks to Joseph Donnelly

Determinats of cerebral blood flow

Cerebrovascular resistance

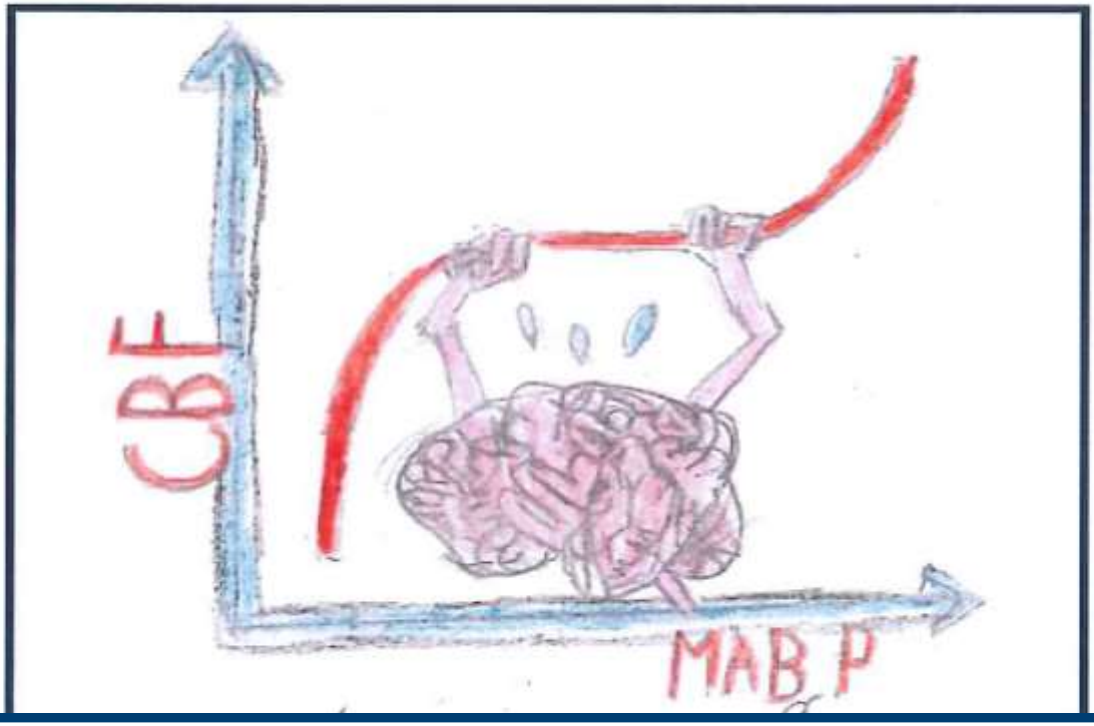
*CPP=ABP - ICP



Thanks to Joseph Donnelly

Cerebral Autoregulation

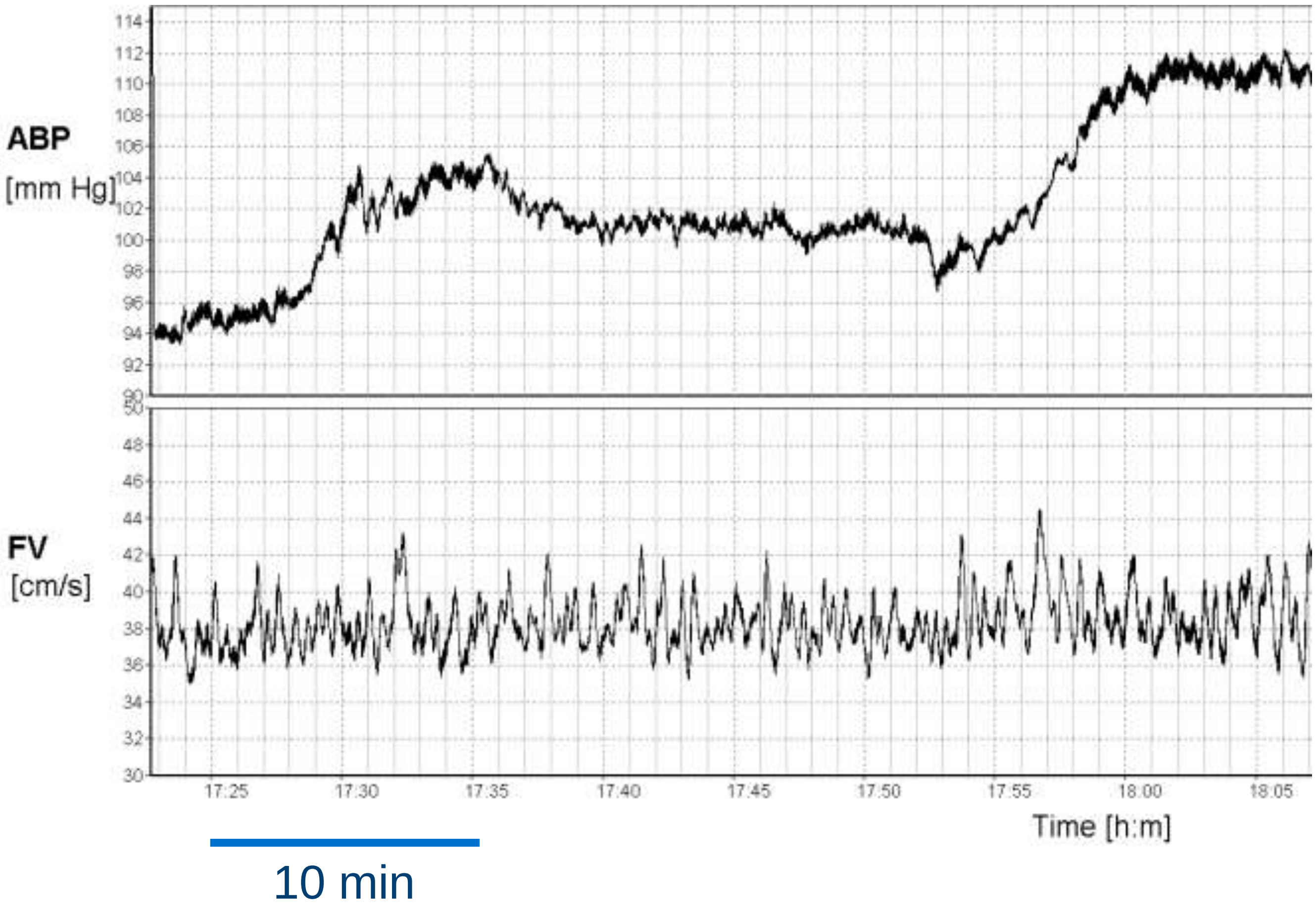
Ability of the brain to stabilise cerebral blood flow in spite of changes in cerebral perfusion pressure



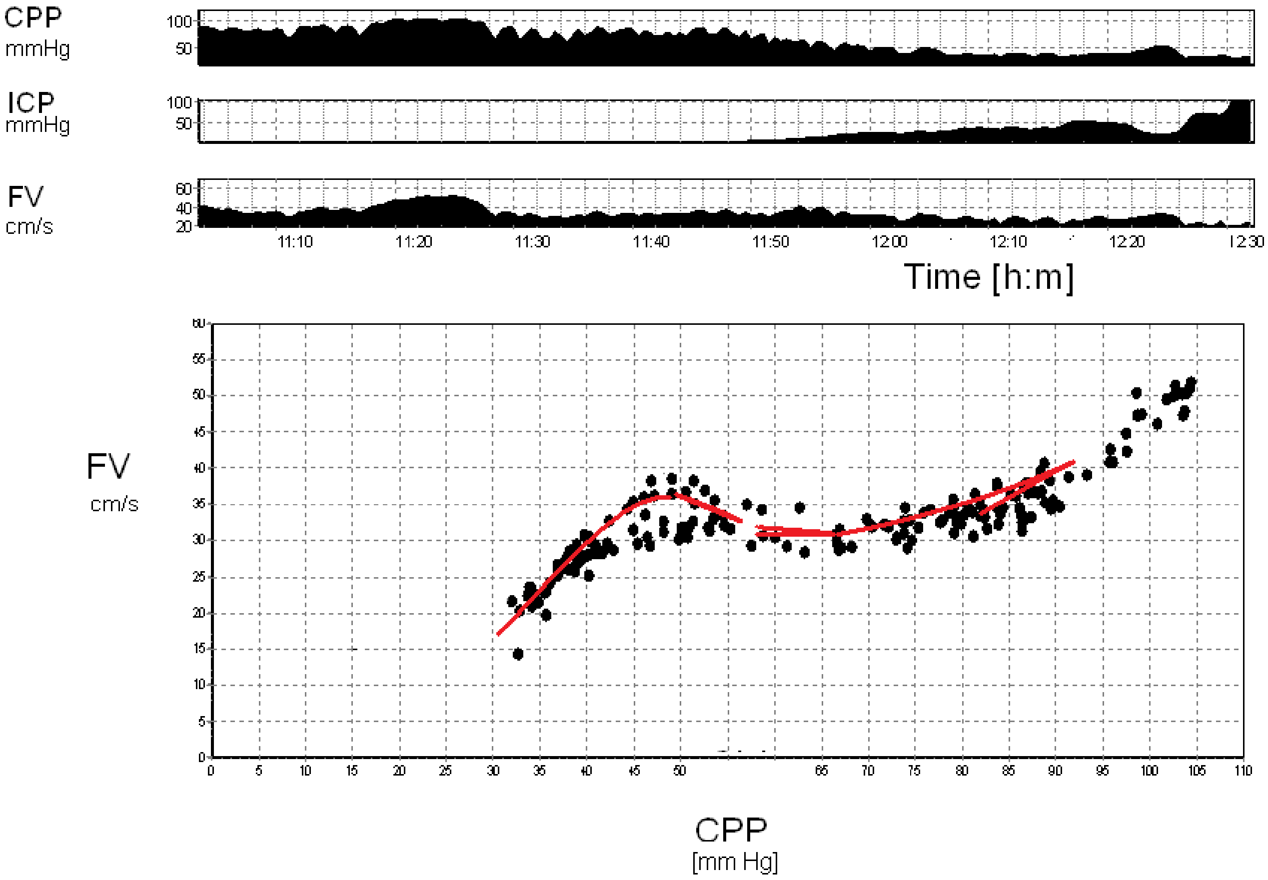
PhD thesis by Gitte Holst Hahn

Drawing by her daughter (age 7)

Cerebral Autoregulation



Autoregulatory curve



Autoregulation in Head Injury is easily disturbed

"Minor head injury": 28%
Jünger EC *et al*.: J Neurosurg 1997;86:425-32

"Severe head injury": 87%
Hlatky R *et al*.: J Neurosurg 2002;97:1054-61

Autoregulation in Head Injury

- Upper limit shifted to the left

  Hauerberg J, *et al*. The upper limit of cerebral blood flow autoregulation in acute intracranial hypertension. J Neurosurg Anesthesiol 1998;10(2):106-12

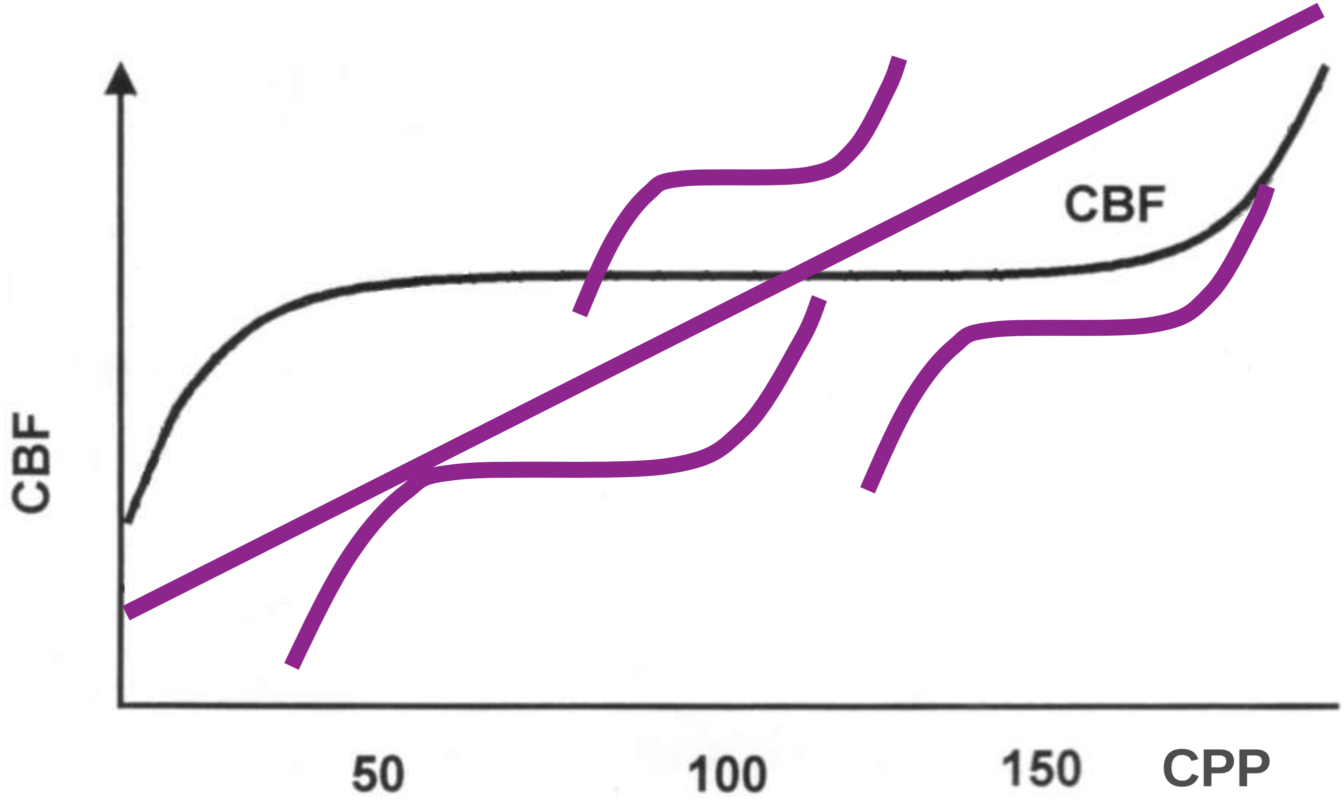
- Lower limit shifted to the right

  Cremer OL, *et al*. Cerebral hemodynamic responses to blood pressure manipulation in severely head-injured patients in the presence or absence of intracranial hypertension. Anesth Analg 2004;99(4):1211-7

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

  Steiner LA, *et al*. Continuous monitoring of cerebrovascular pressure reactivity allows determination of optimal cerebral perfusion pressure in patients with traumatic brain injury. Crit Care Med 2002;30(4):733-8.

Autoregulation in Head Injury



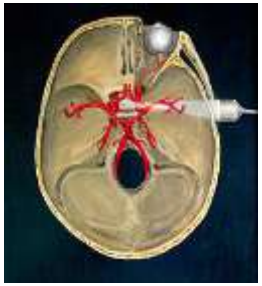
Cerebral blood flow monitors

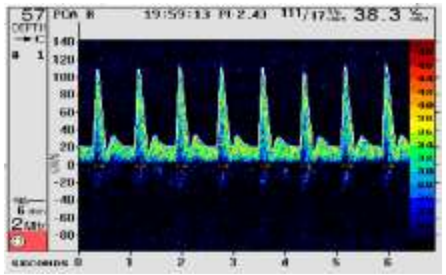
Laser Doppler Flowmetry

Thermal conduction (Hemedex)

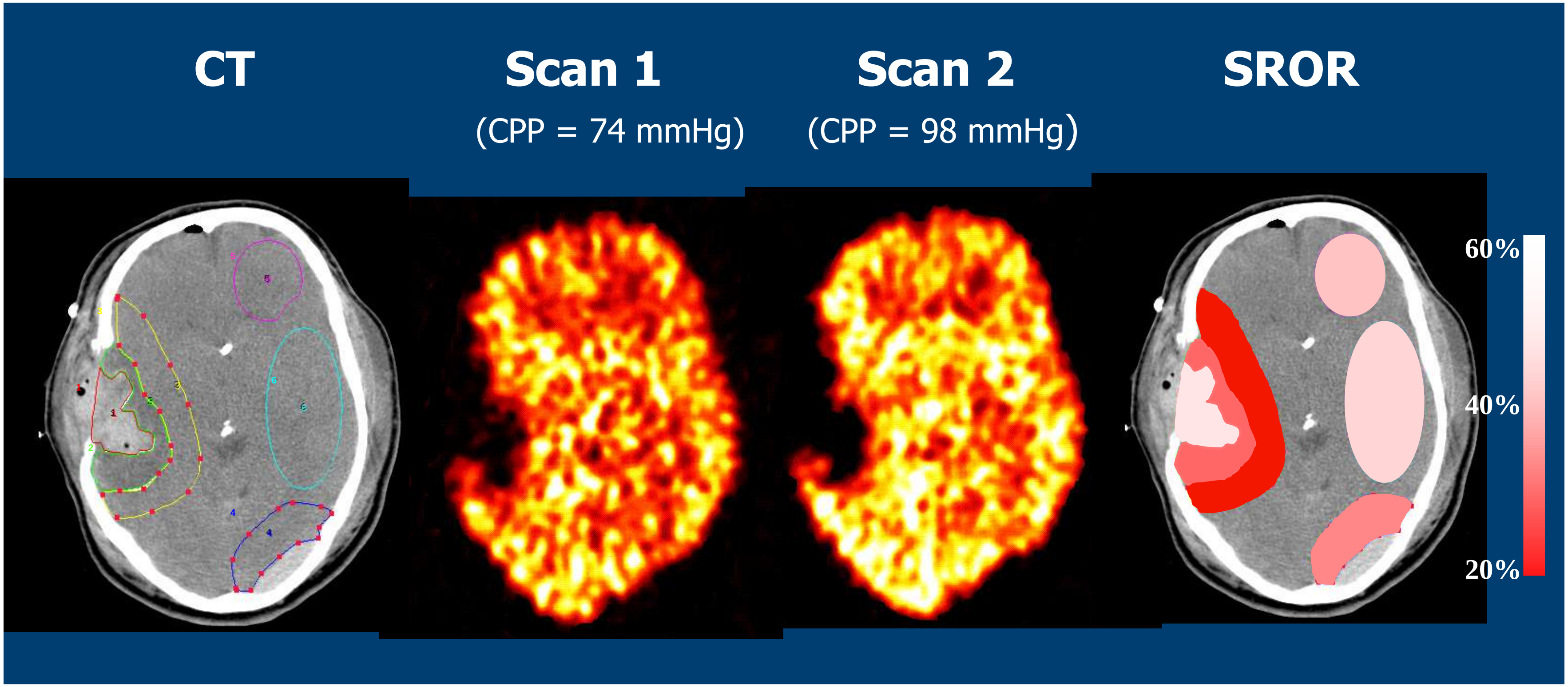
Optical-ultrasound modulation (Ornim)

Bulk flow – Transcranial Doppler (TCD)



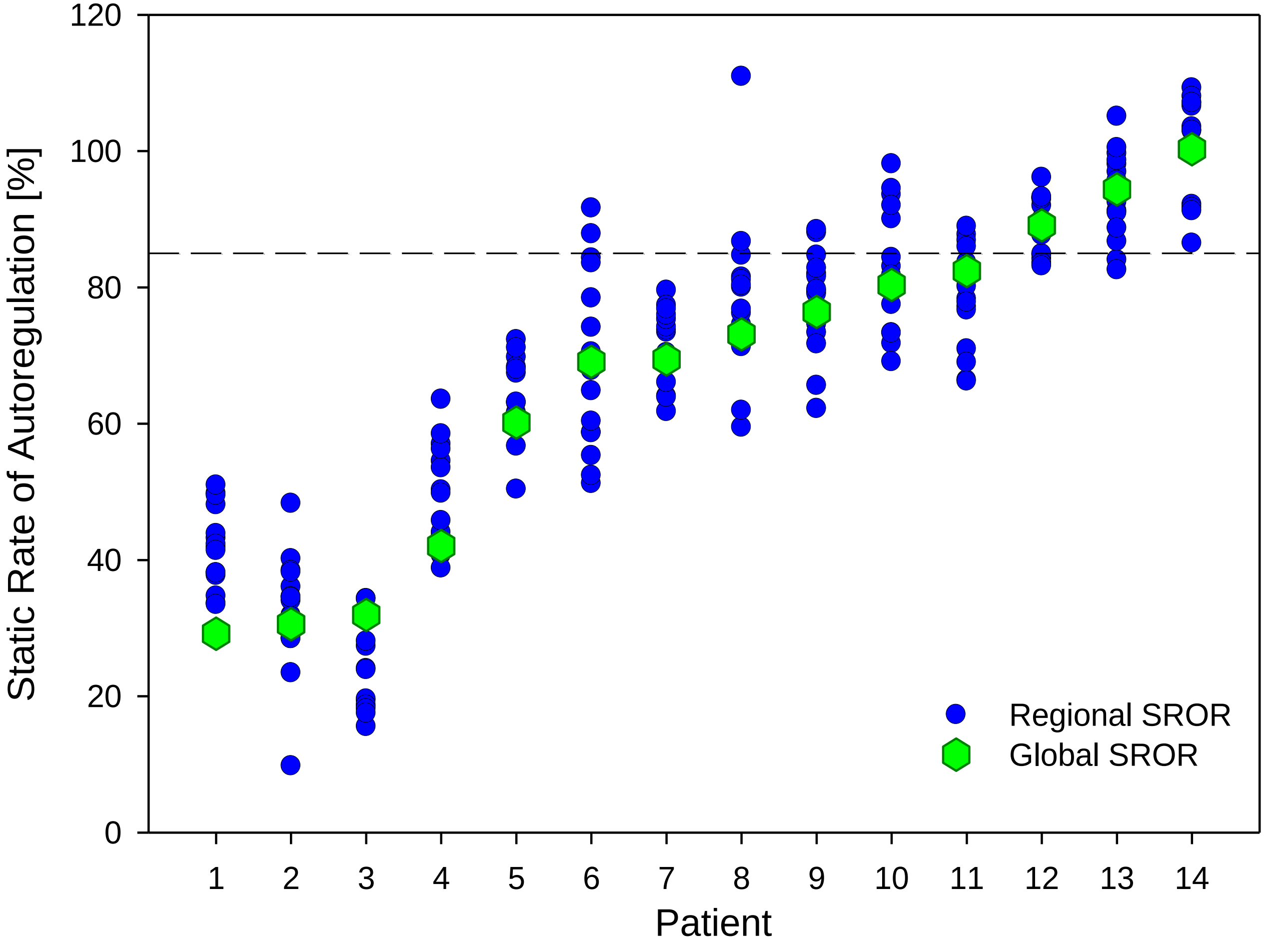


Regional Heterogeneity



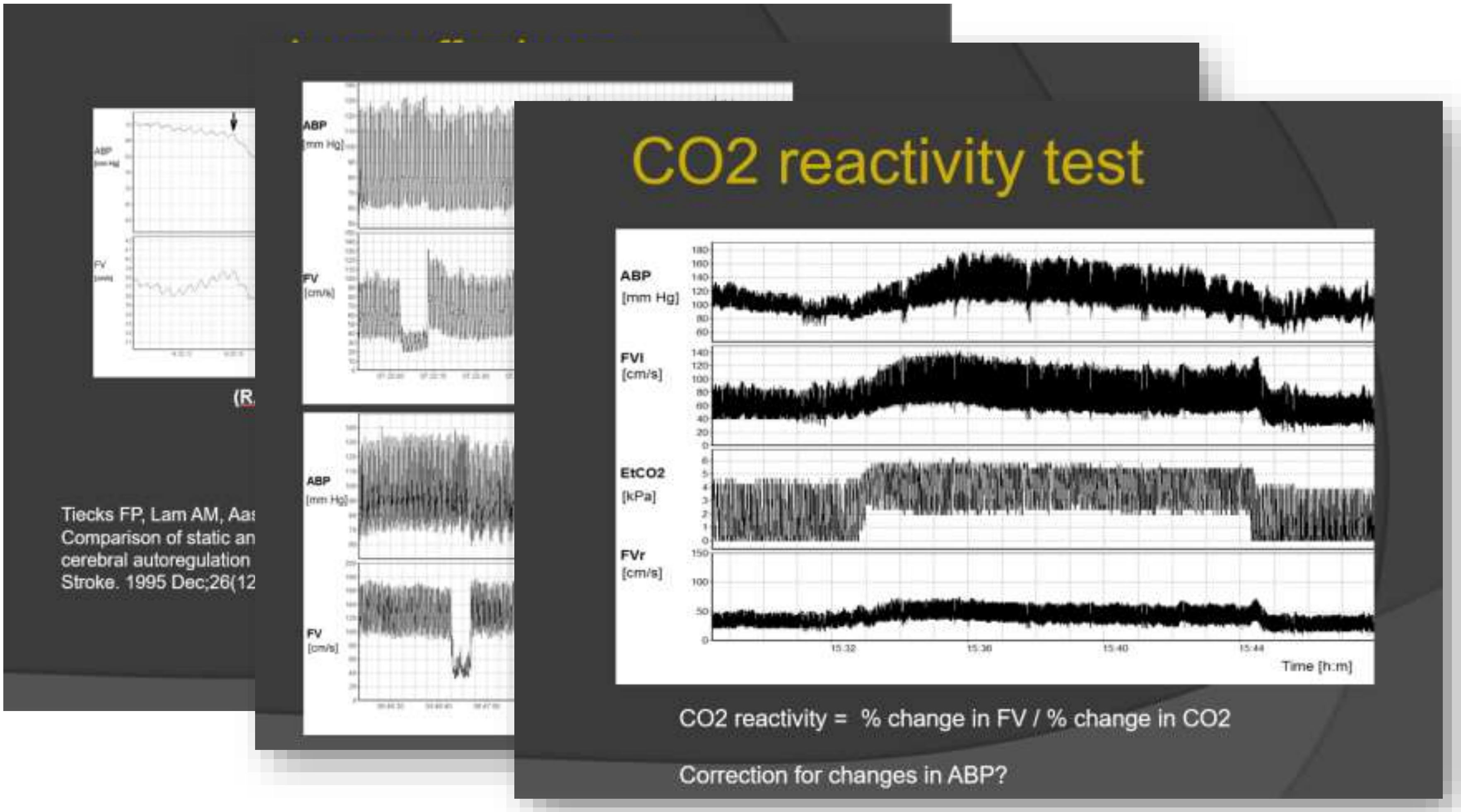
Steiner LA, *et al.* J Neurotrauma 2002;19:1301

Regional or Global?

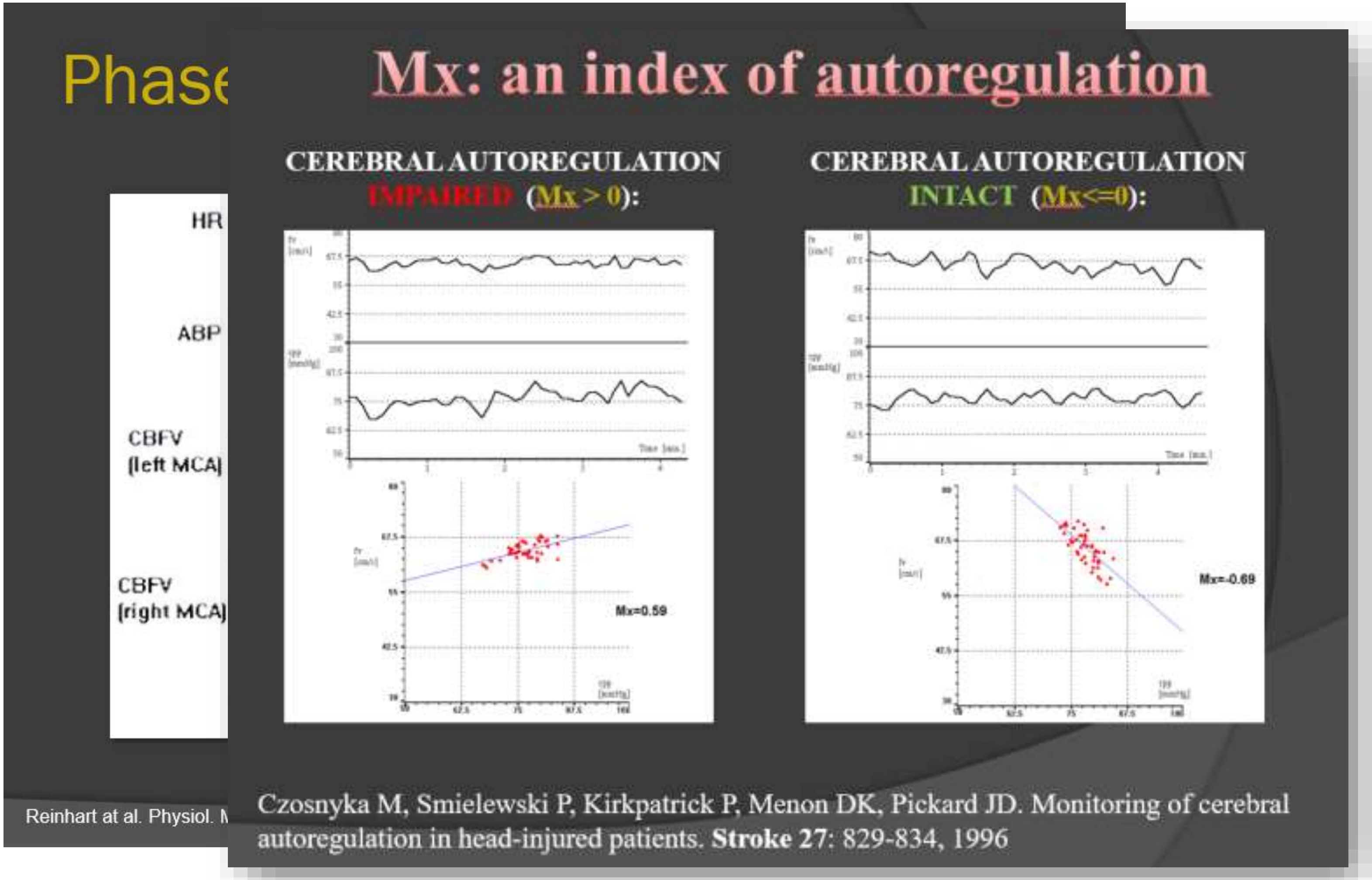


Steiner LA, *et al.* J Neurotrauma 2002;19:1301

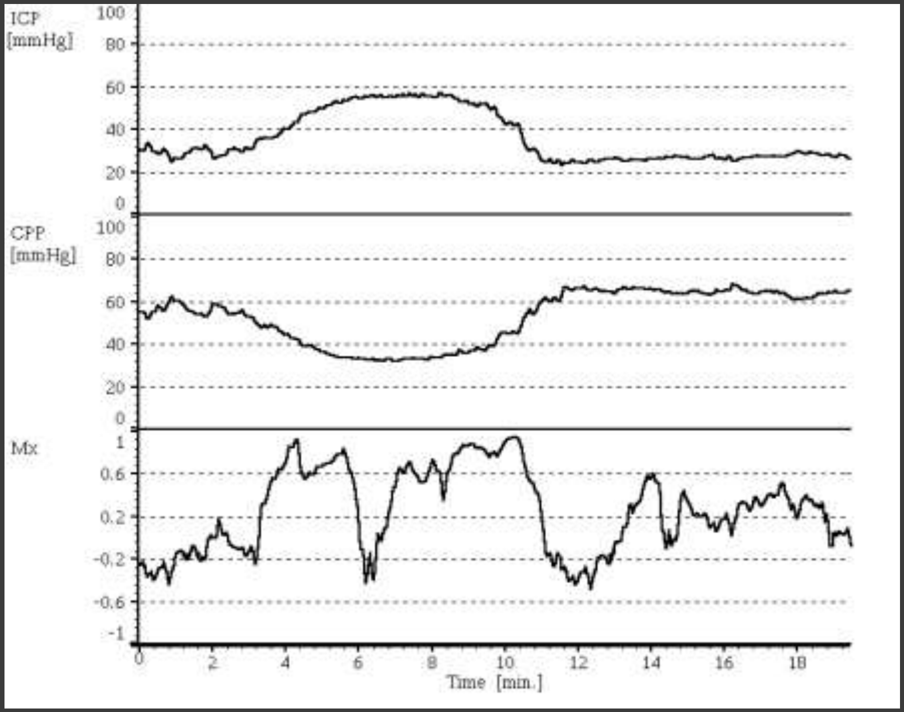
Autoregulation assessment

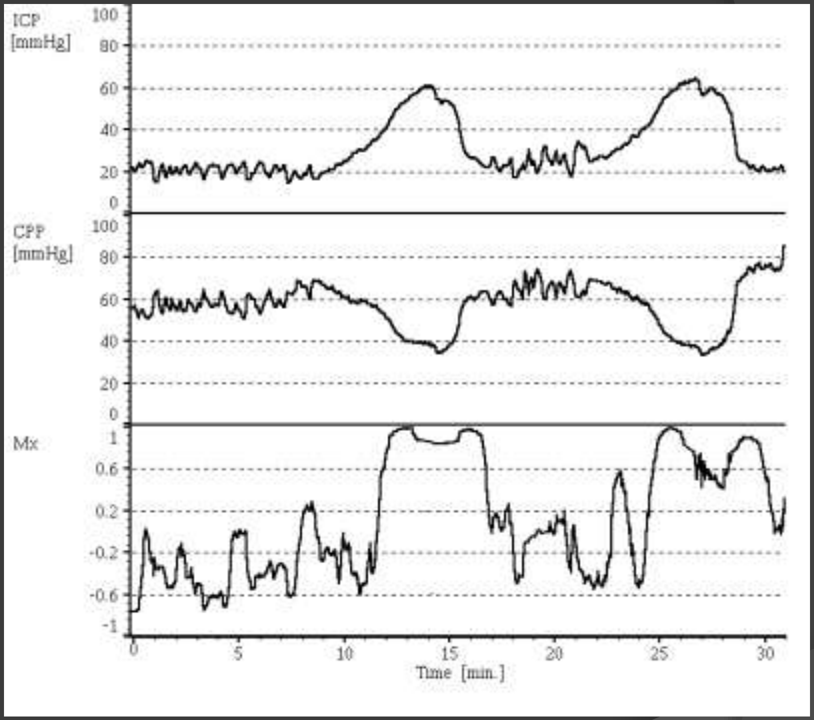


Intervention-less autoregulation assessment



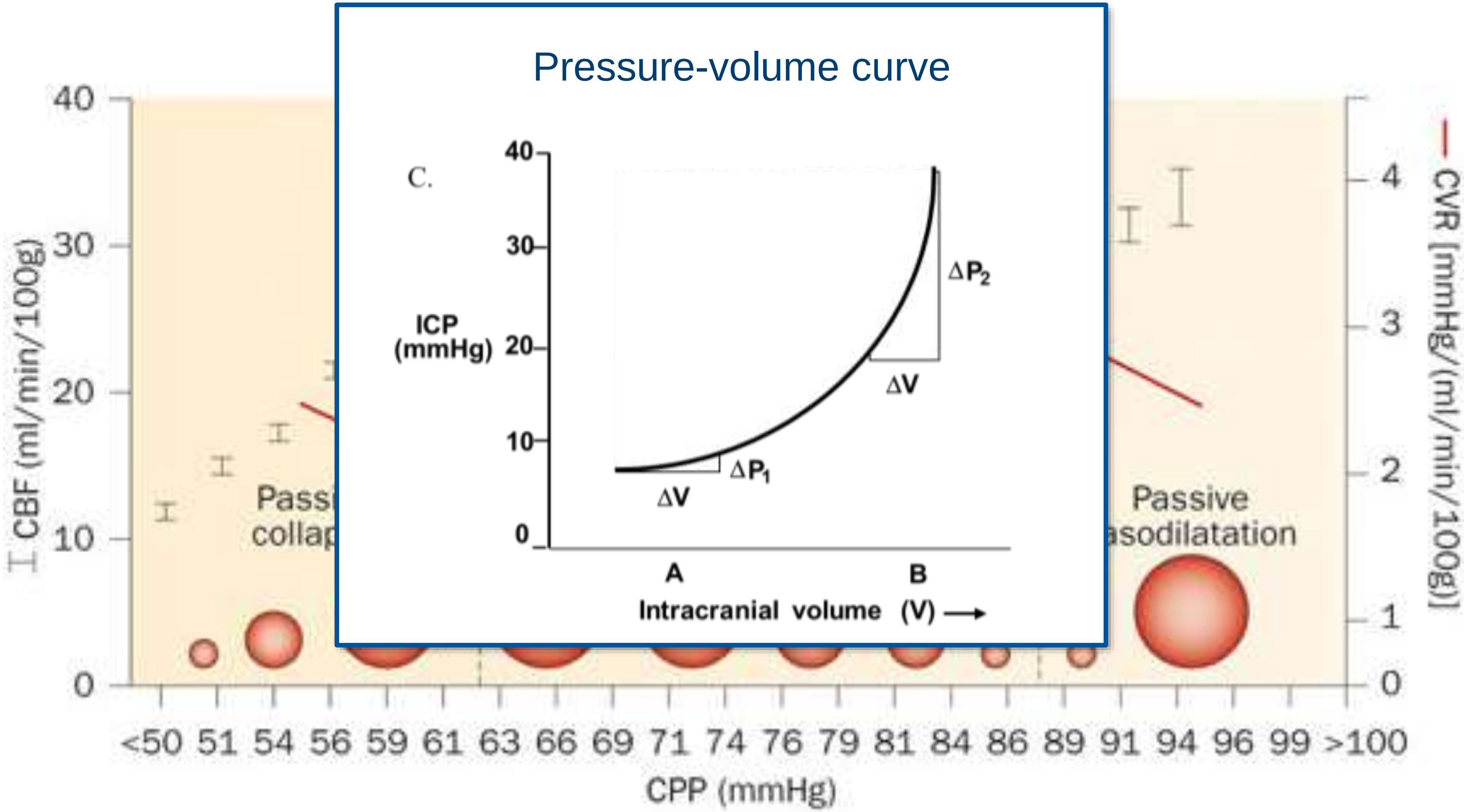
Monitoring of transient phenomena:
Positive Mx indicates loss of cerebral autoregulation at the top of plateau waves





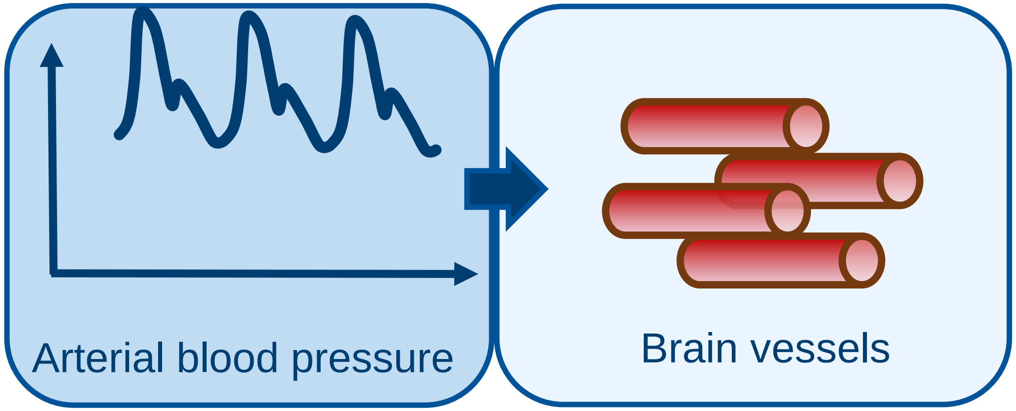
Czosnyka M, Smielewski P, Piechnik S, Schmidt EA, Al-Rawi P, Kirkpatrick PJ, Pickard JD: Hemodynamic characterization of intracranial pressure plateau waves in head-injured patients. J Neurosurgery 1999; 91:11-19.

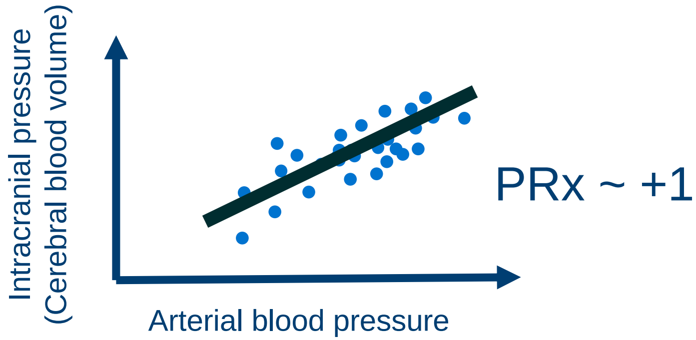
ICP as a monitor of blood volume changes



Pressure reactivity

Poor brain vessel function

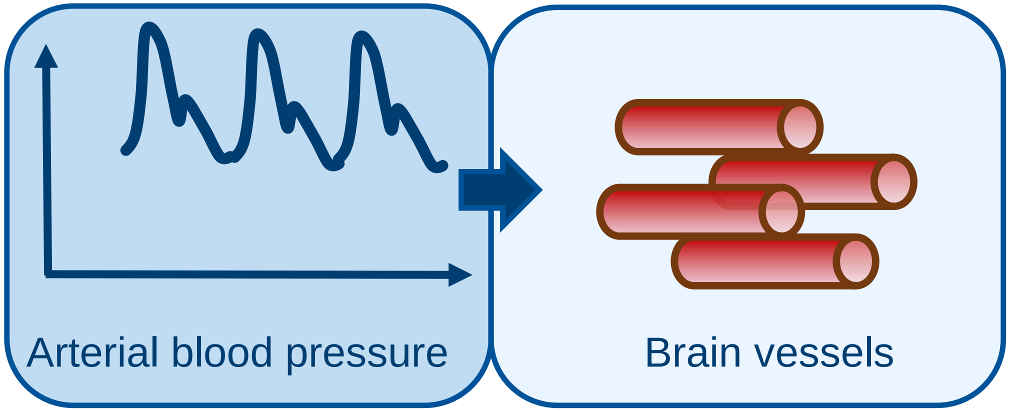


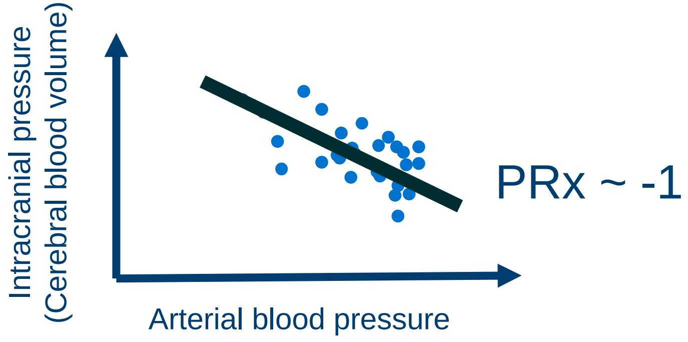


Thanks to Joseph Donnelly

Pressure reactivity

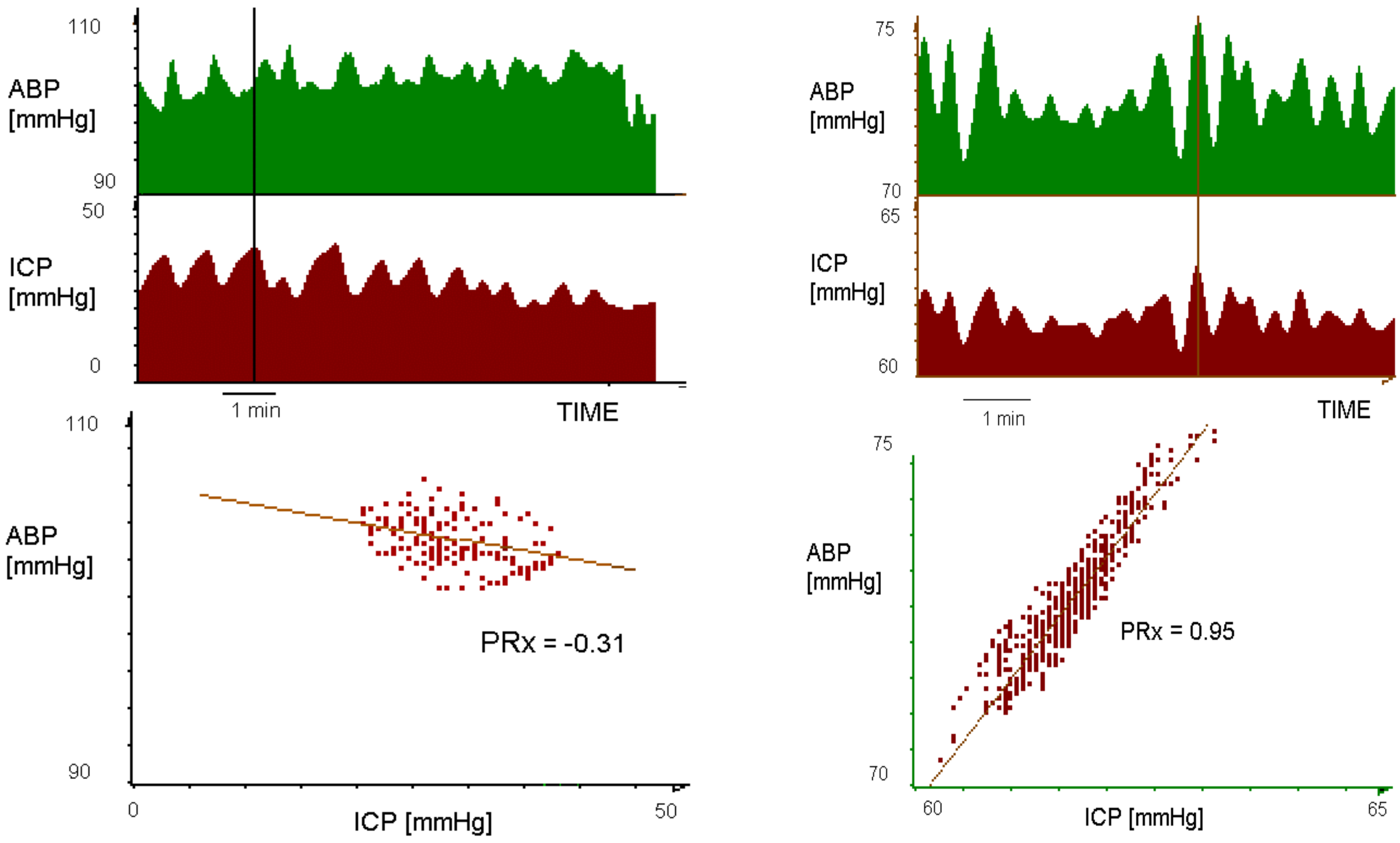
Good brain vessel function



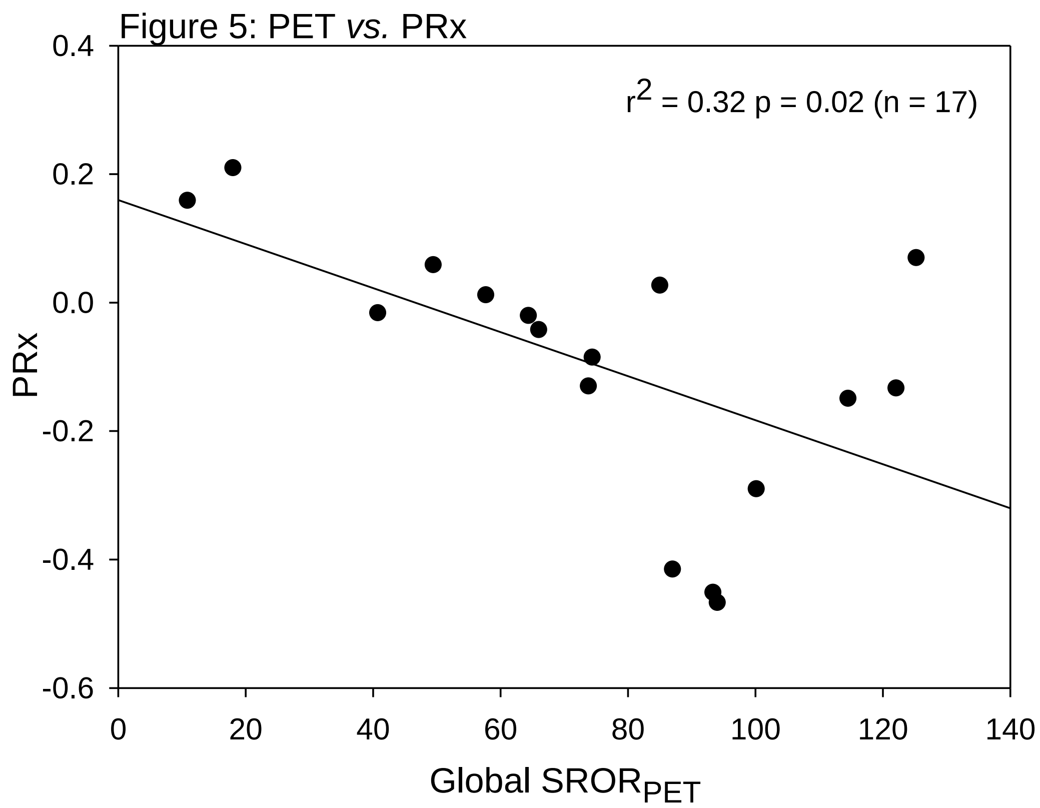


Thanks to Joseph Donnelly

Pressure reactivity (PRx)



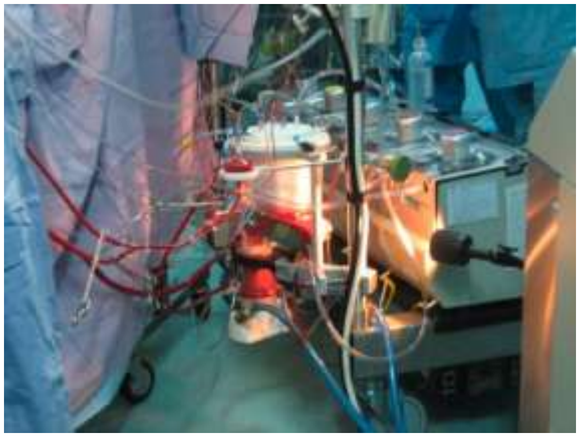
PRx correlates with PET-static rate of autoregulation

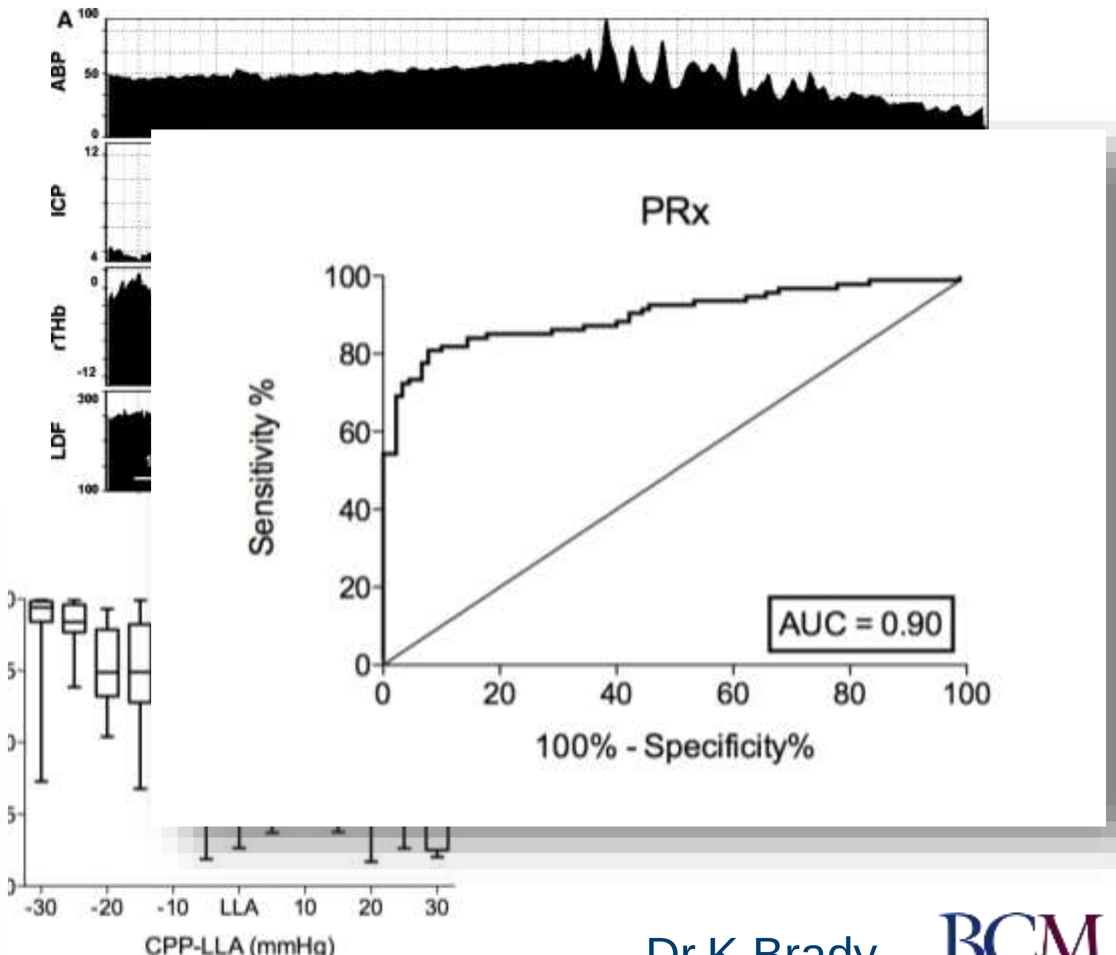


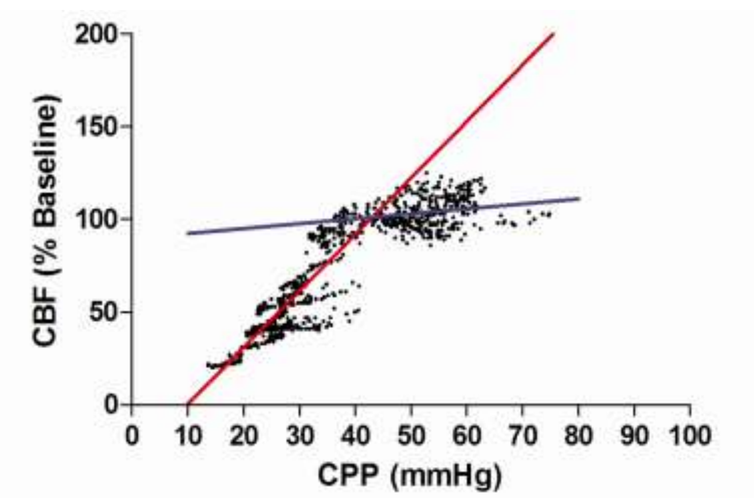
SRoR= % Change in CVR / % change in CPP

Steiner LA, et al. Assessment of Cerebrovascular Autoregulation in Head-Injured Patients. A Validation Study.Stroke. 2003 34:2404-2409

PRx detects lower limit of autoregulation- piglet model



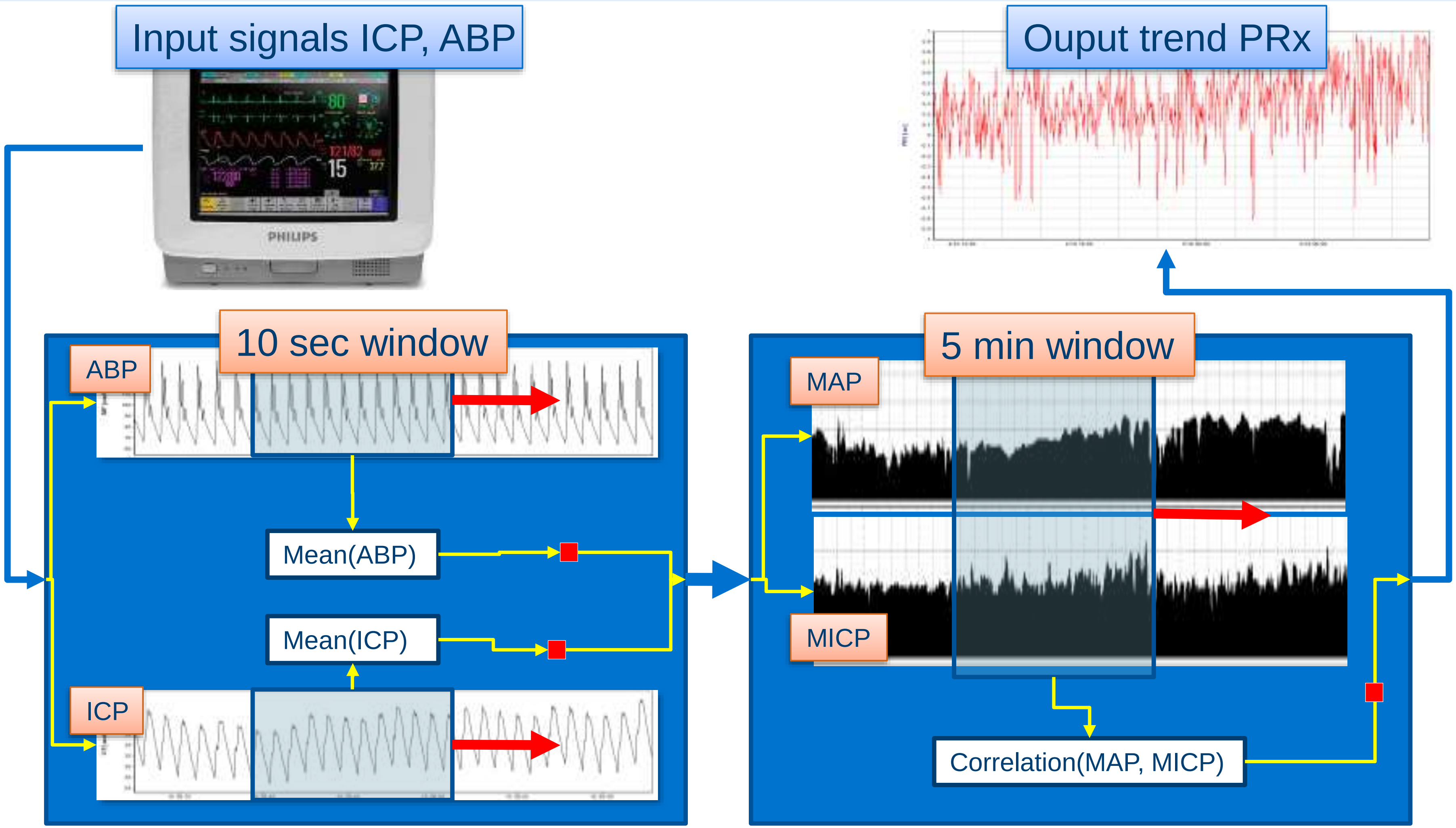




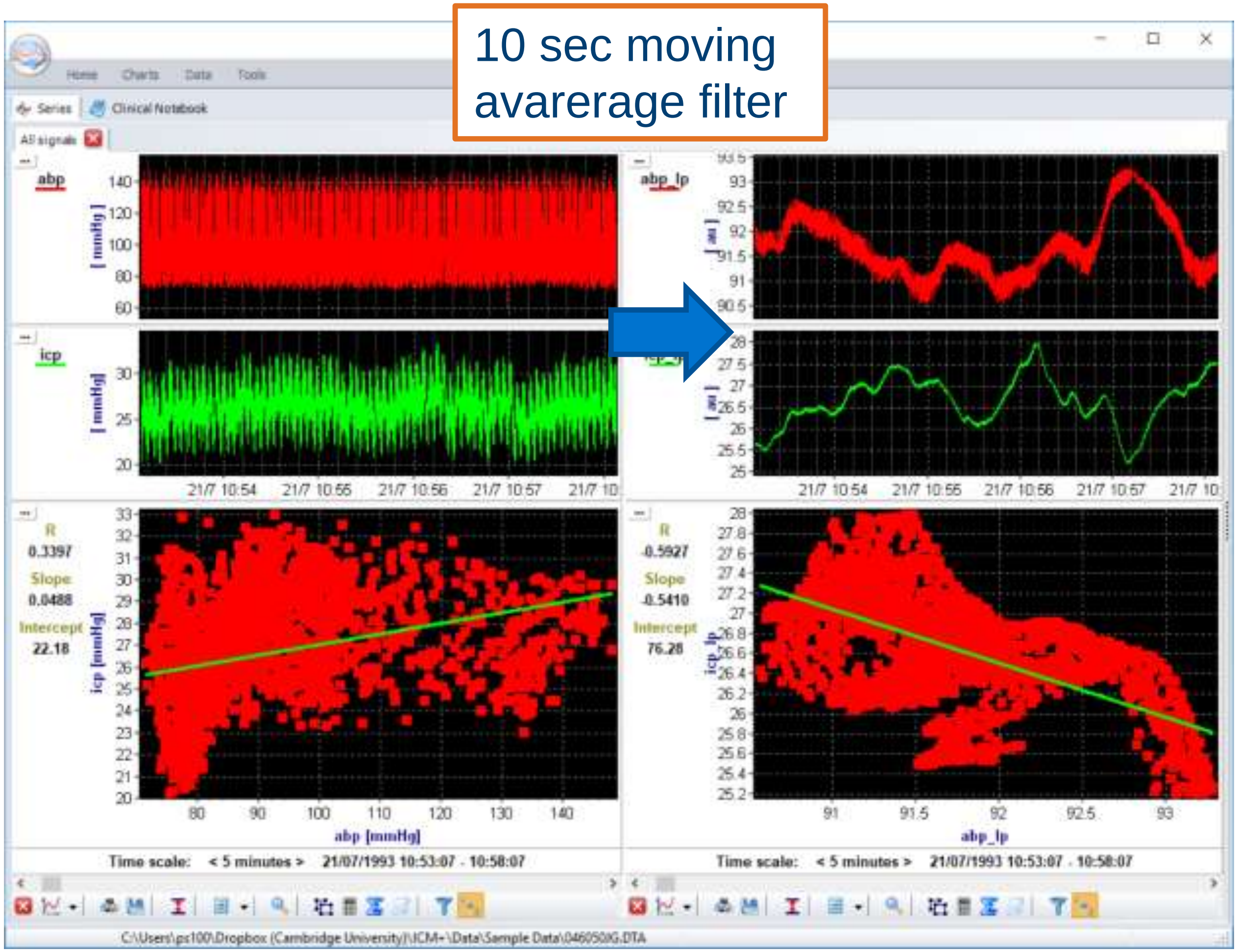
Dr.K.Brady

BCM
Baylor College of Medicine

Continuous evaluation of PRx



Why 10 second filter and 5 minute window?



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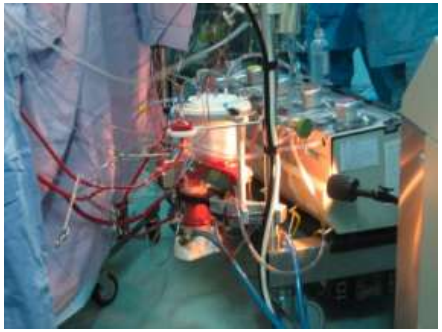
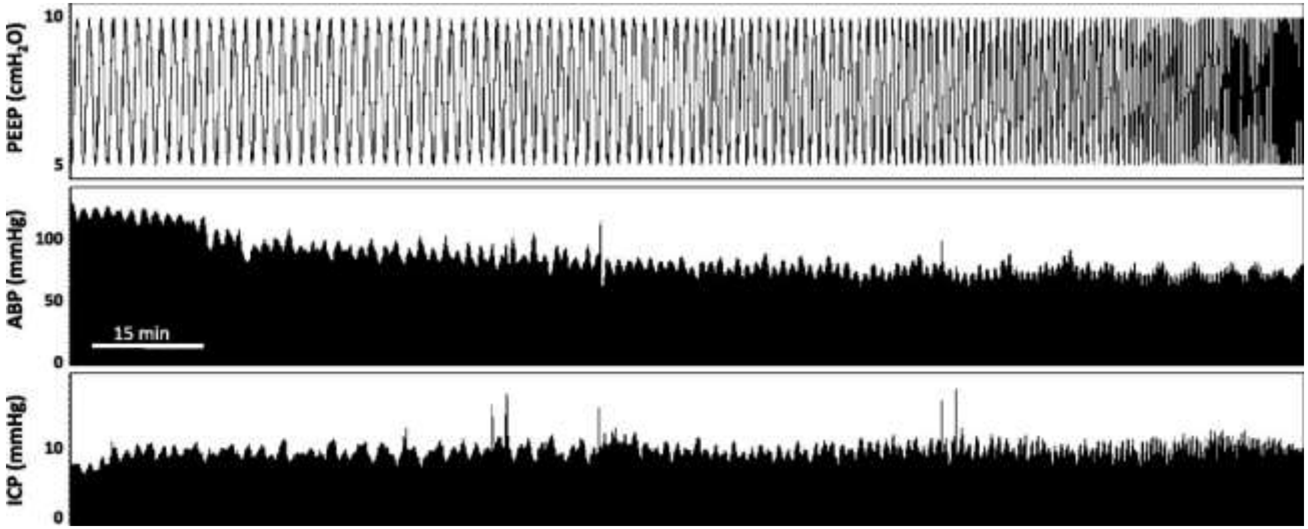
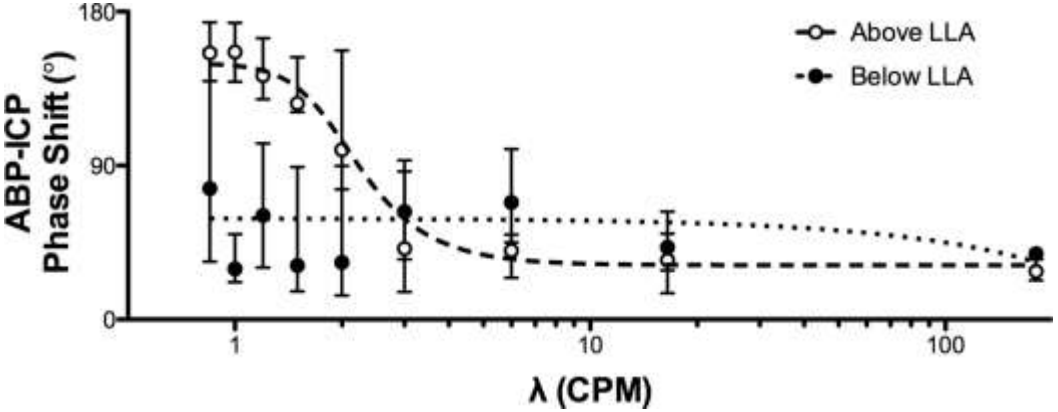




Piglet model

Modulated PEEP



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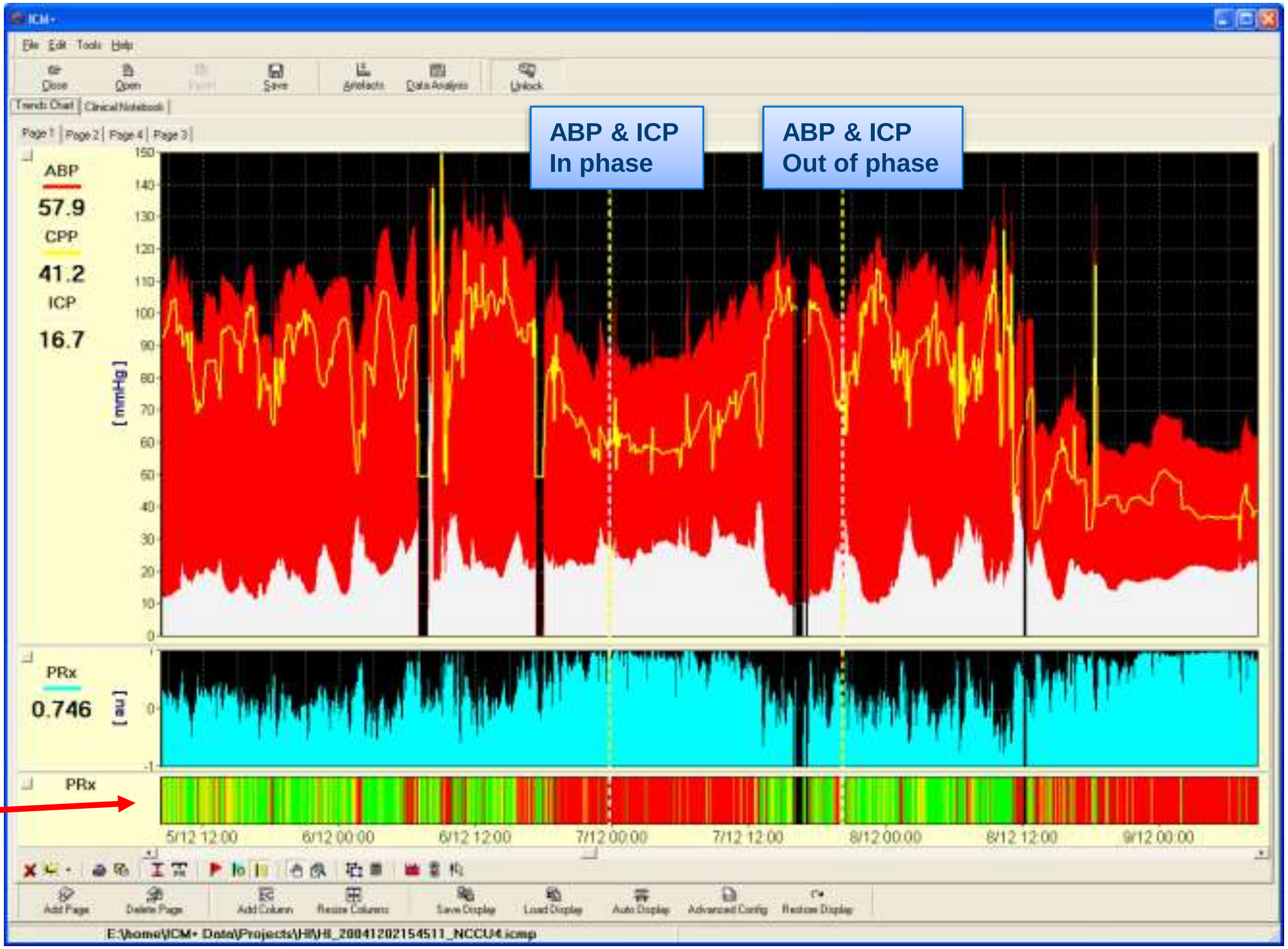
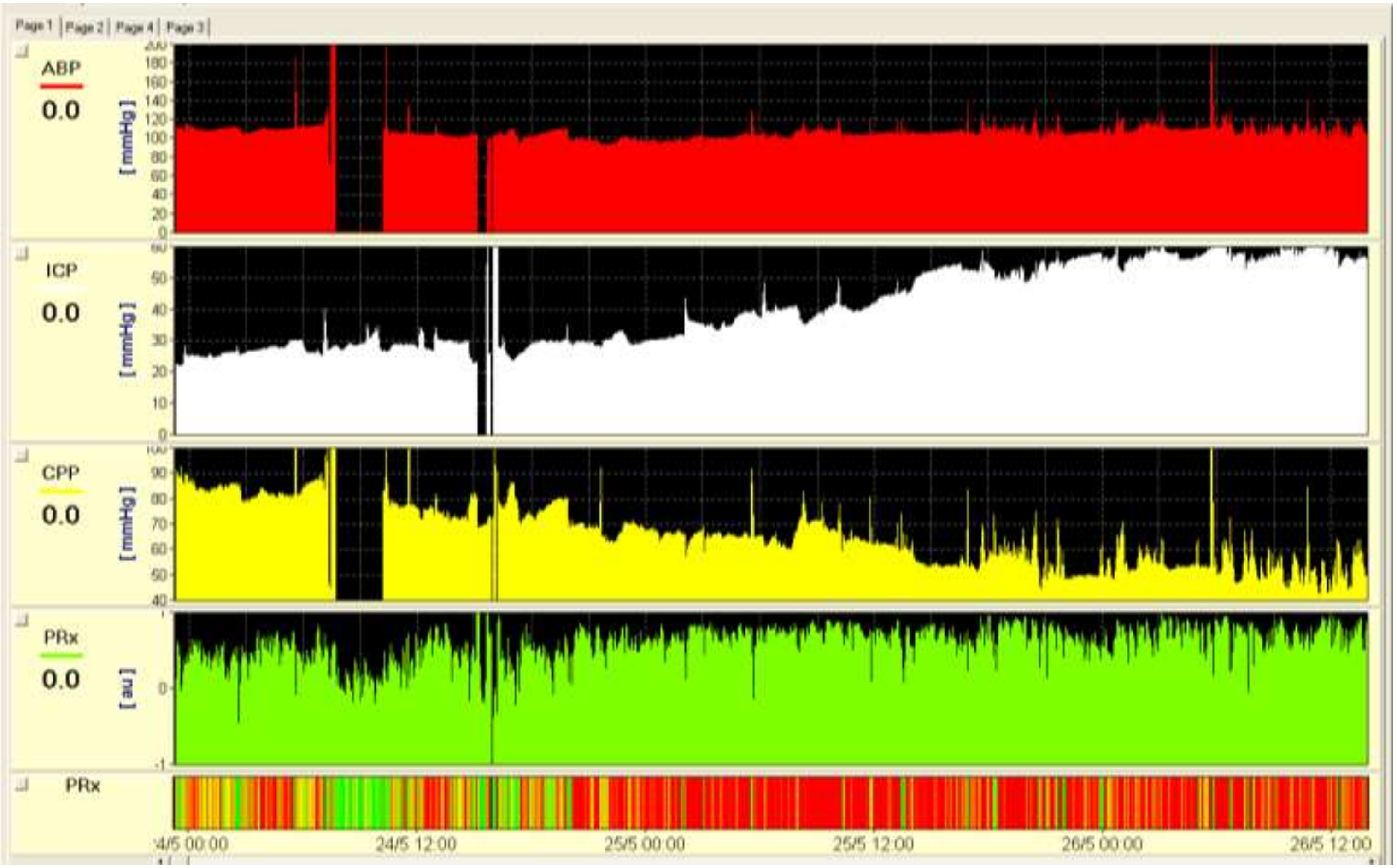
Individual trends are most important

Severe head trauma patient after a road traffic accident.

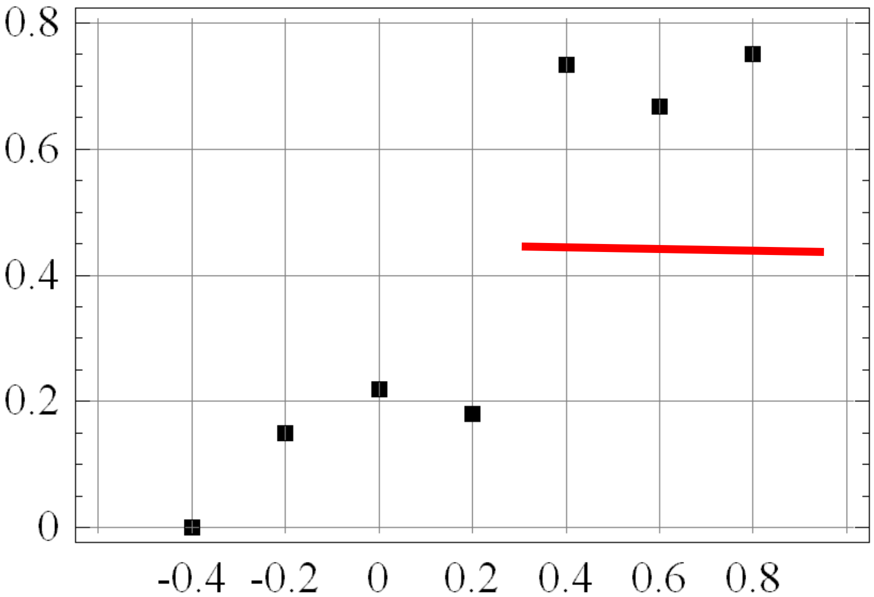


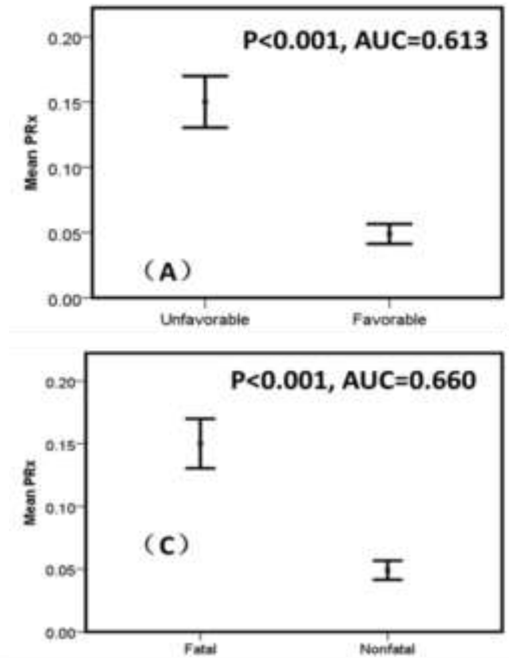
Colour coded autoregulation (AR) index PRx
- AR intact
- AR impaired

Deterioration of PRx precedes refractory hypertension



TBI Mortality rate dramatically depends on PRx





Neurocritical Care

ISSN 1541-6933/06/4:8–13
DOI 10.1385/Neurocrit. Care 2006;04:8–13

Original Article

Impact of Intracranial Pressure and Cerebral Perfusion Pressure on Severe Disability and Mortality After Head Injury

Marcella Balestreri,[1,2] Marek Czosnyka,[,1] Peter Hutchinson,[1] Luzius A. Steiner,[1,3] Magda Hiler,[1] Piotr Smielewski,[1] and John D. Pickard[1]*

[1]Academic Neurosurgical Unit Addenbrooke's Hospital, Cambridge, UK; [2]Policlinico San Matteo, University of Pavia, Italy; [3]Department of Anaesthesia, University Hospital Basel, Switzerland

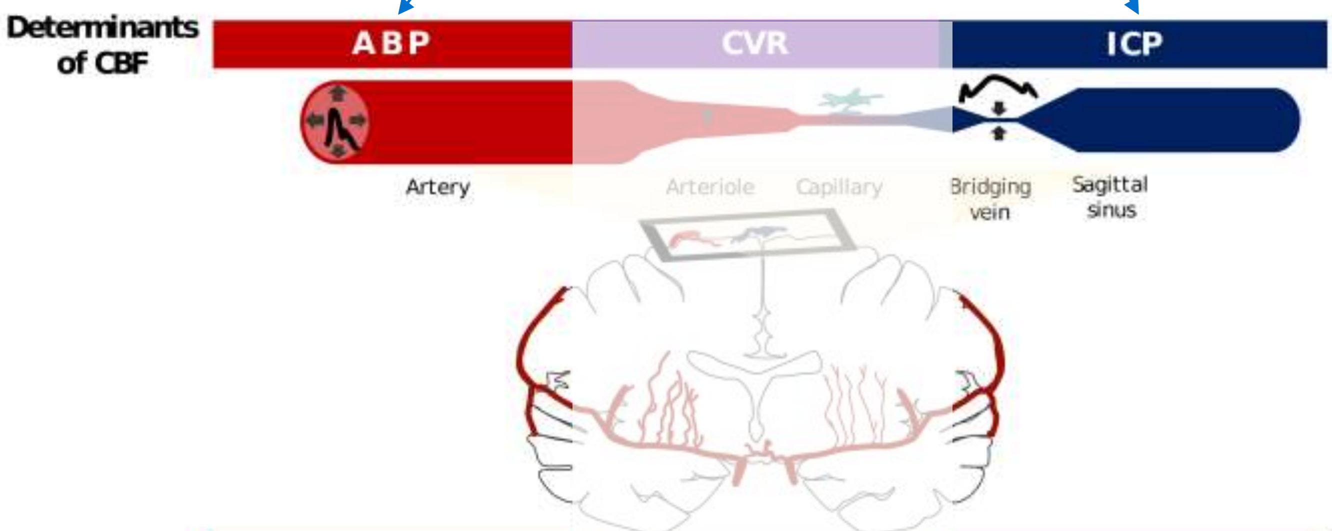
Question

How to incorporate PRx into the clinical management protocol of TBI patients ?

Modifying the cerebral perfusion pressure CPP

Cerebral perfusion pressure*

*CPP=ABP - ICP



Influences	SV	HR	TPR	Obstruction	Vascular tone	CBV	CSF V	Tissue
Pathology	Cardiogenic	Arrhythmia	Inflammation	Stroke	Vasospasm, Metabolic, Neural, or Myogenic challenge	IIH, A and B waves	Hydrocephalus	Oedema
Therapies	Inotropes	Rate control	Vasopressors	Thrombolysis	Ventilation Vasoactive drugs	Ventilation head position	Shunt EVD	Mannitol Hypertonic saline

Thanks to Joseph Donnelly

TBI guidelines 2016

Brain Trauma FOUNDATION

- ICP < 22 mmHg
- CPP 60-70 mmHg
- Autoregulation status

Retrospective TBI studies: thresholds

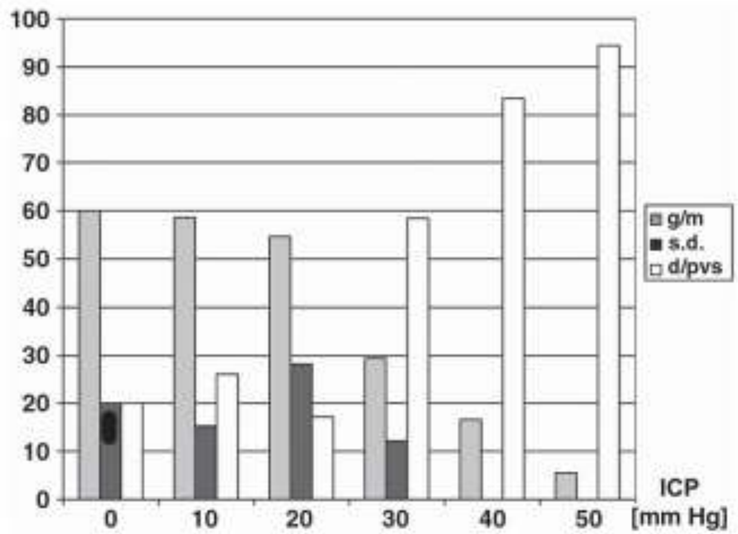


Fig. 1. Mortality and persistent vegetative state (d/pvs) rate, rate of favorable outcome (g/m), and rate of severe disability (s.d.) expressed as a function of ICP.

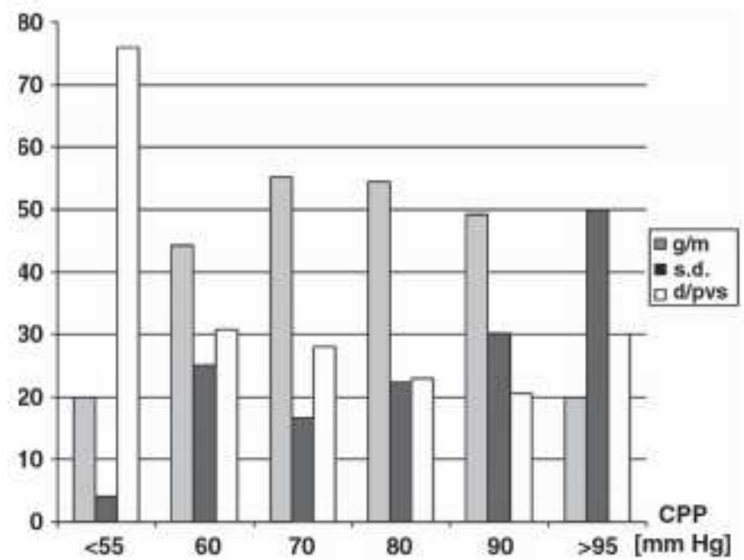


Fig. 2. Mortality and persistent vegetative state (d/pvs) rate, rate of favorable outcome (g/m), and rate of severe disability (s.d.) expressed as a function of CPP.

Neurocrit care 2006

Management of CPP - One Size Fits All?

Rosner MJ *et al.* J Neurosurg 83;1995:949-62

„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?

- SJO_2 and TCD

  Chan KH *et al*.: The effect of changes in cerebral perfusion pressure upon middle cerebral artery blood flow velocity and jugular bulb venous oxygen saturation after severe brain injury. J Neurosurg 1992;77:55-61

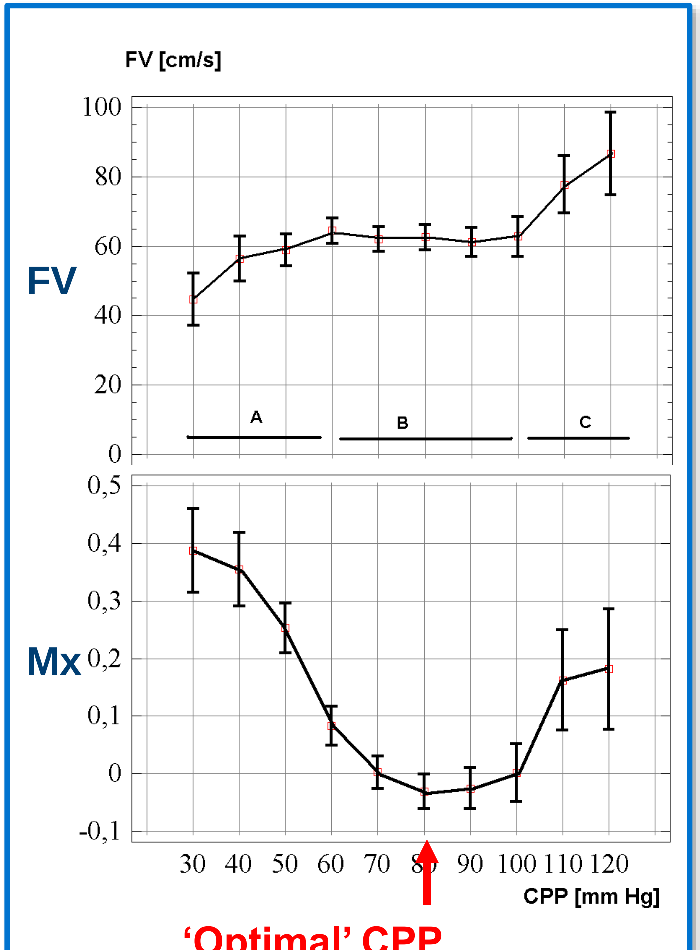
- Microdialysis

  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

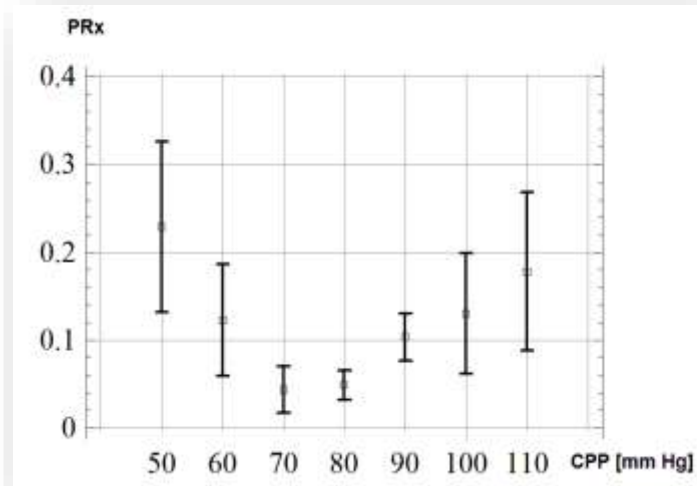
- Brain Tissue Oxygen

  Meixensberger J *et al*. Brain tissue oxygen guided treatment supplementing ICP/CPP therapy after traumatic brain injury. J Neurol Neurosurg Psychiatry. 2003;74:760-4

‘Optimal’ Cerebral Perfusion Pressure



(529 head injuries, Addenbrooke’s Hospital)



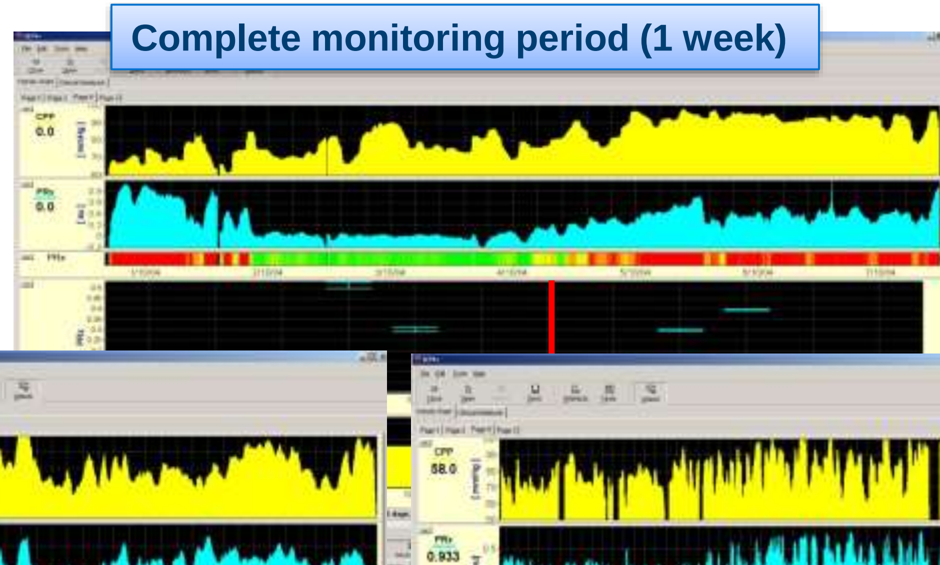
Feature Articles

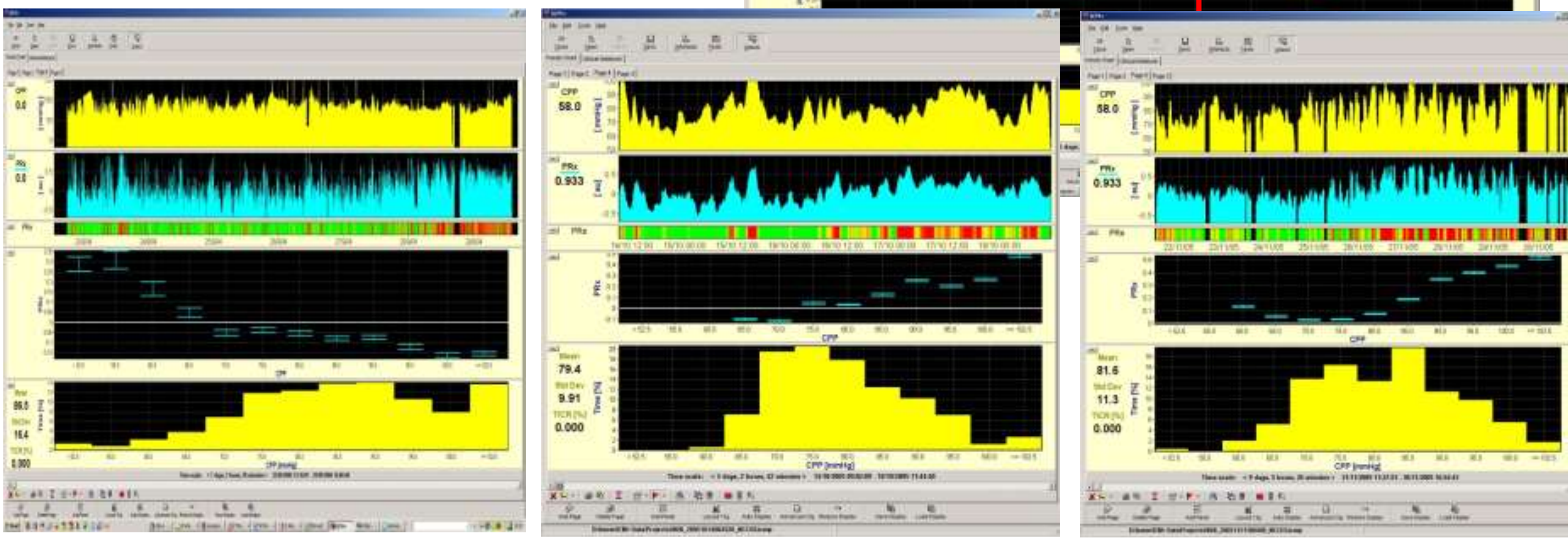
Continuous monitoring of cerebrovascular pressure reactivity allows determination of optimal cerebral perfusion pressure in patients with traumatic brain injury

Luzius A. Steiner, MD; Marek Czosnyka, PhD, DSc; Stefan K. Piechnik, PhD; Piotr Smielewski, PhD; Doris Chatfield, BSc; David K. Menon, PhD, FRCP, FRCA, FMedSci; John D. Pickard, MChir, FRCS, FMedSci

‘Optimal’ CPP in individual patients

Examining PRx-CPP curves in individual patients revealed varying CPP optimal values (the CPP value at which the 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.



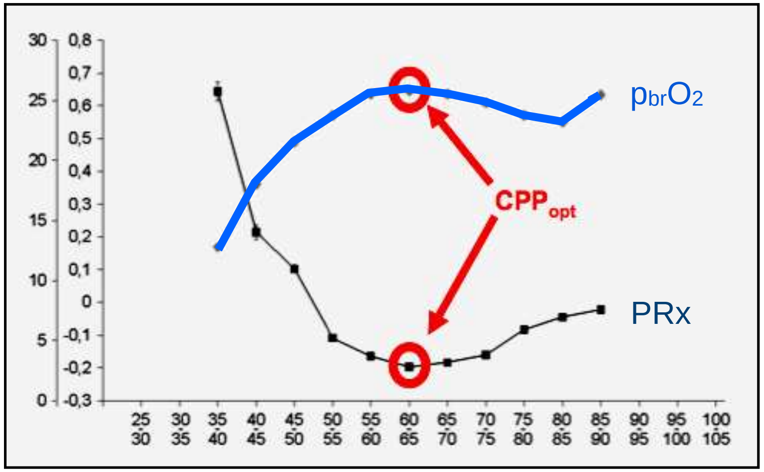


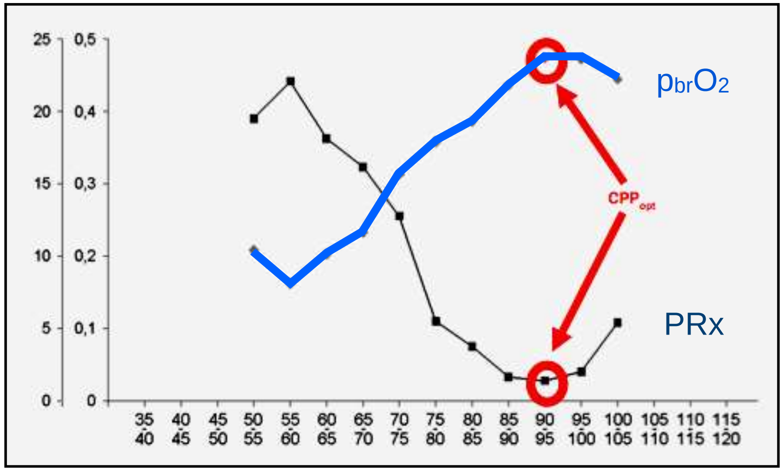
? CPPopt = good CBF ?

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

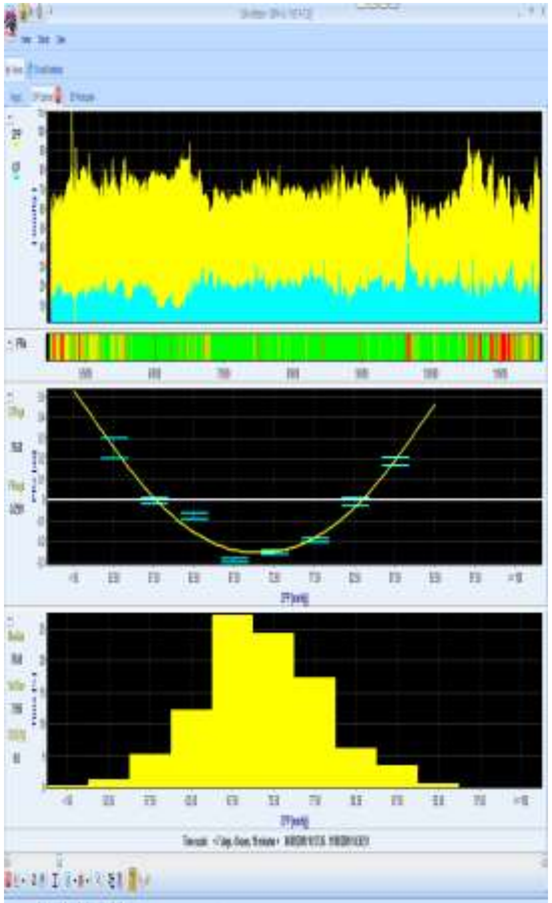




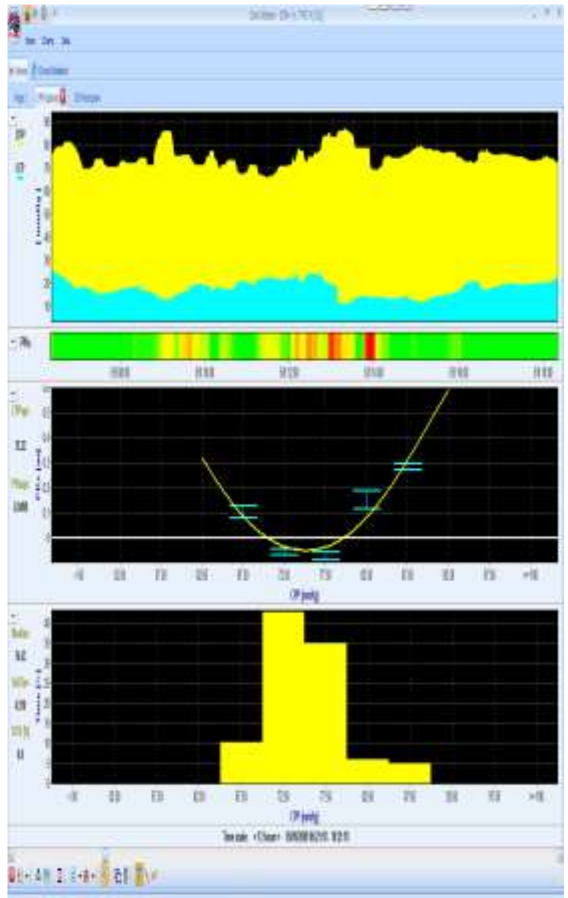
Proof of concept : CPPopt = CBFopt

For the CPPopt assessment to be clinically useful it has to be obtainable from a period of hours rather than days

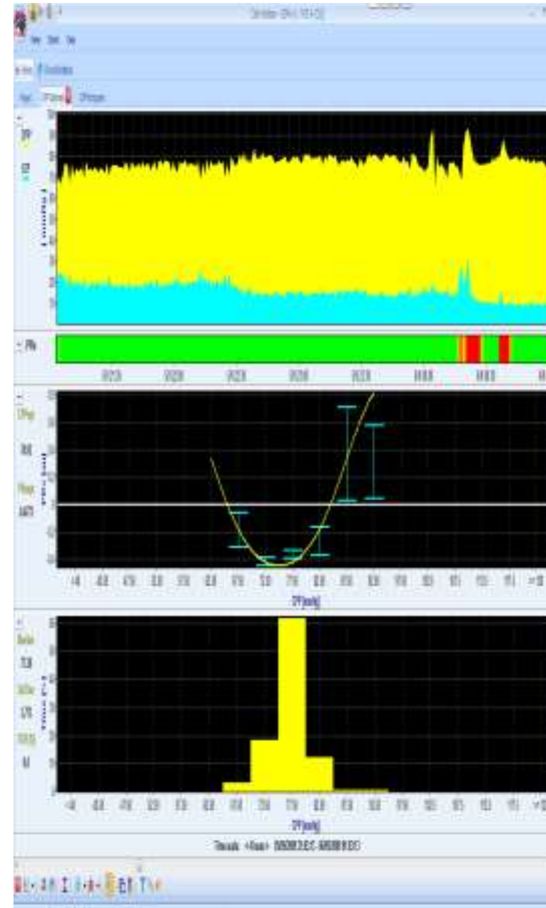
1 week



12 hours

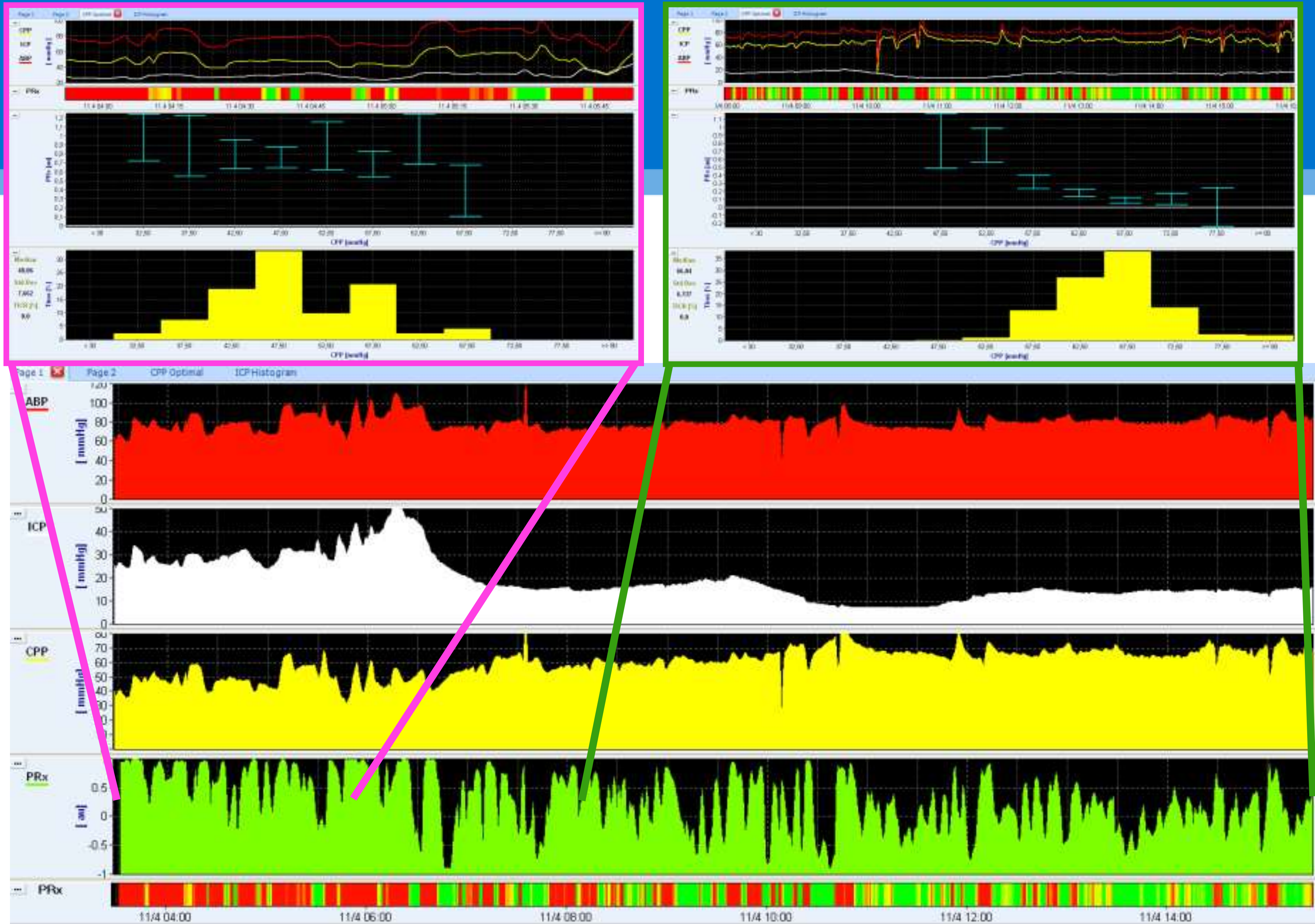


4 hours



TRACKING CPP OPT

Missing CPPopt values


Page 1
Page 2
CPP Optimal
ICP Histogram
ABP
[mmHg]
ICP
[mmHg]
CPP
[mmHg]
PRx
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PRx
11/4 04:00
11/4 06:00
11/4 08:00
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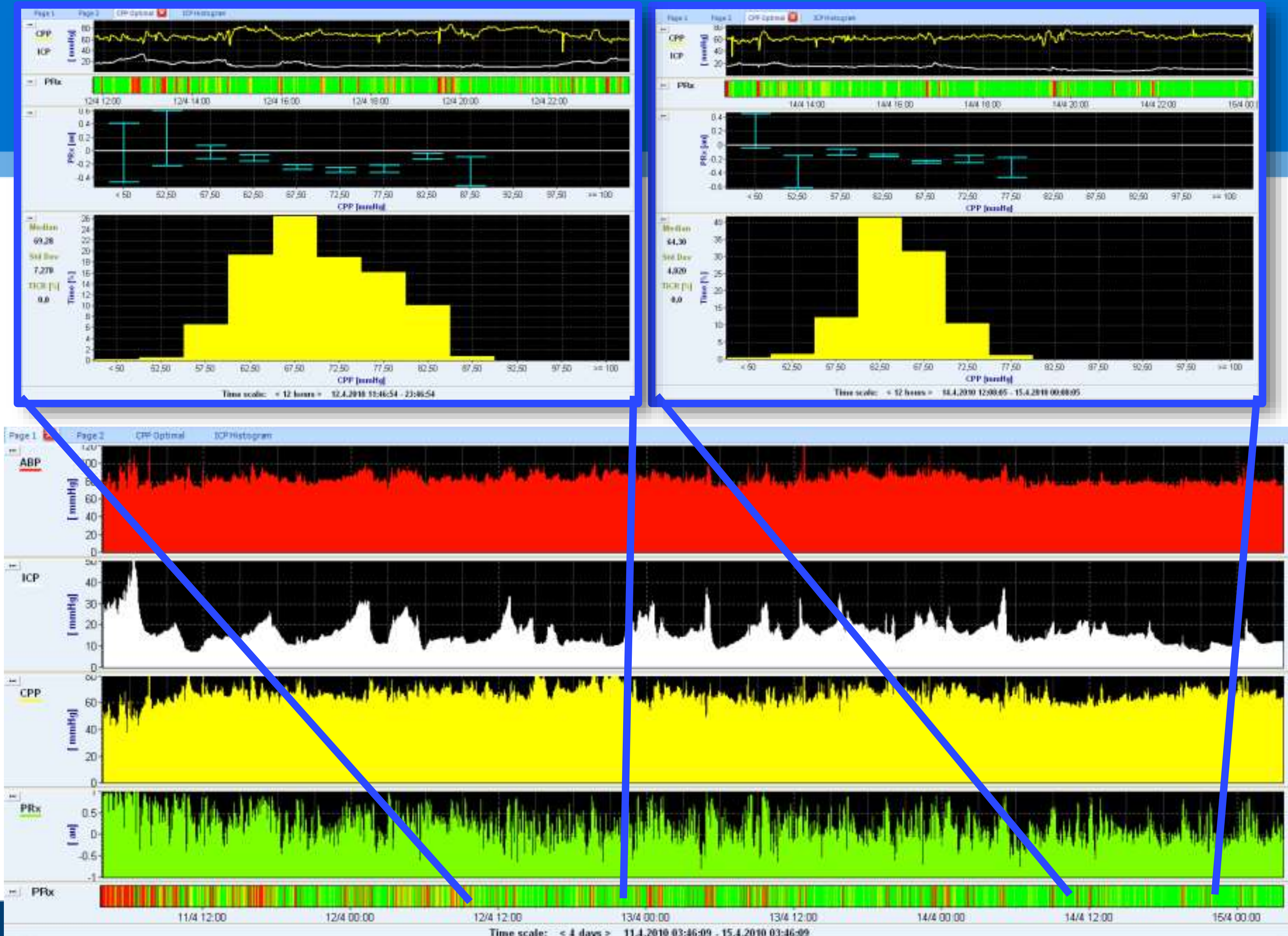
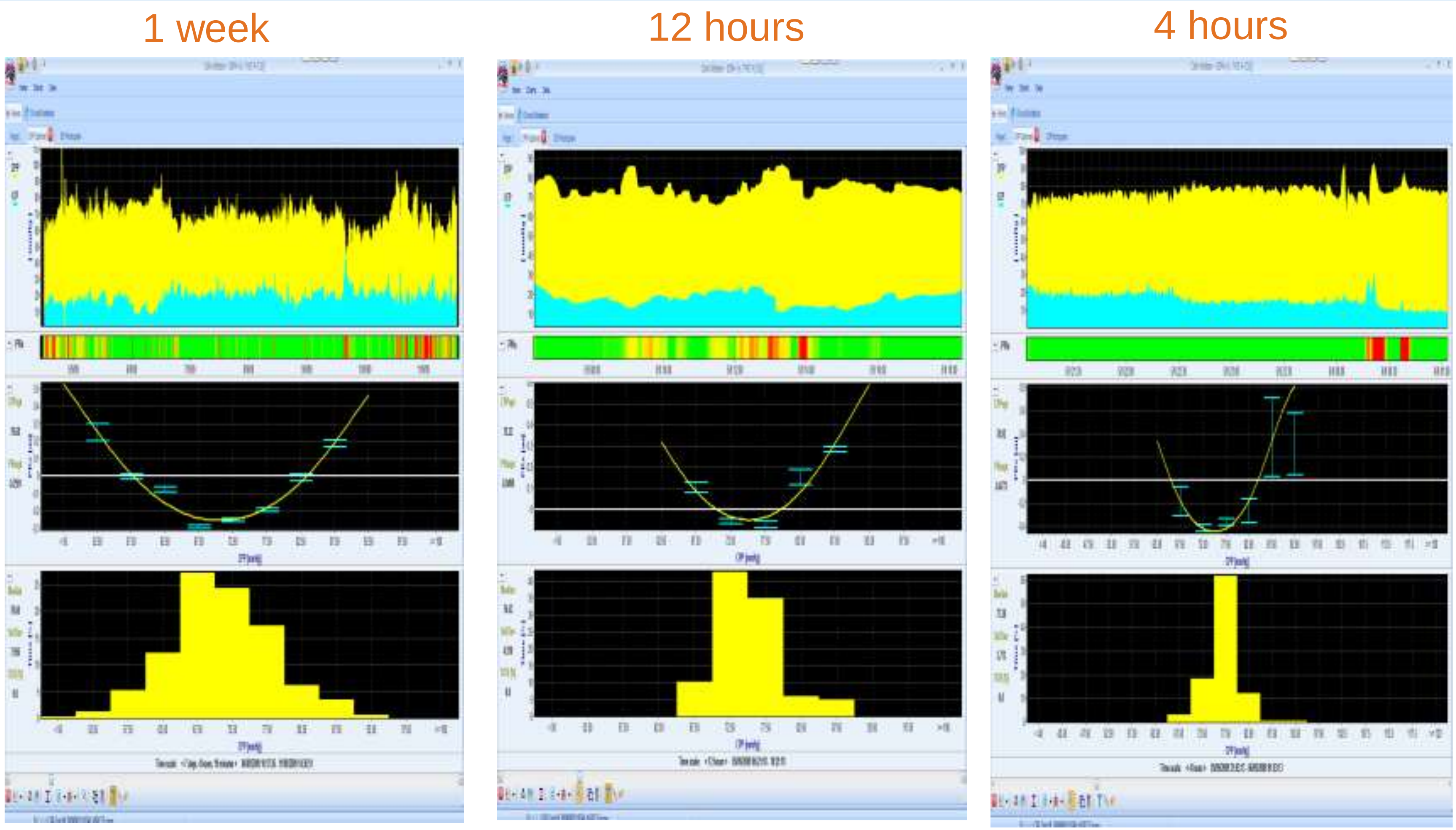


CAMBRIDGE

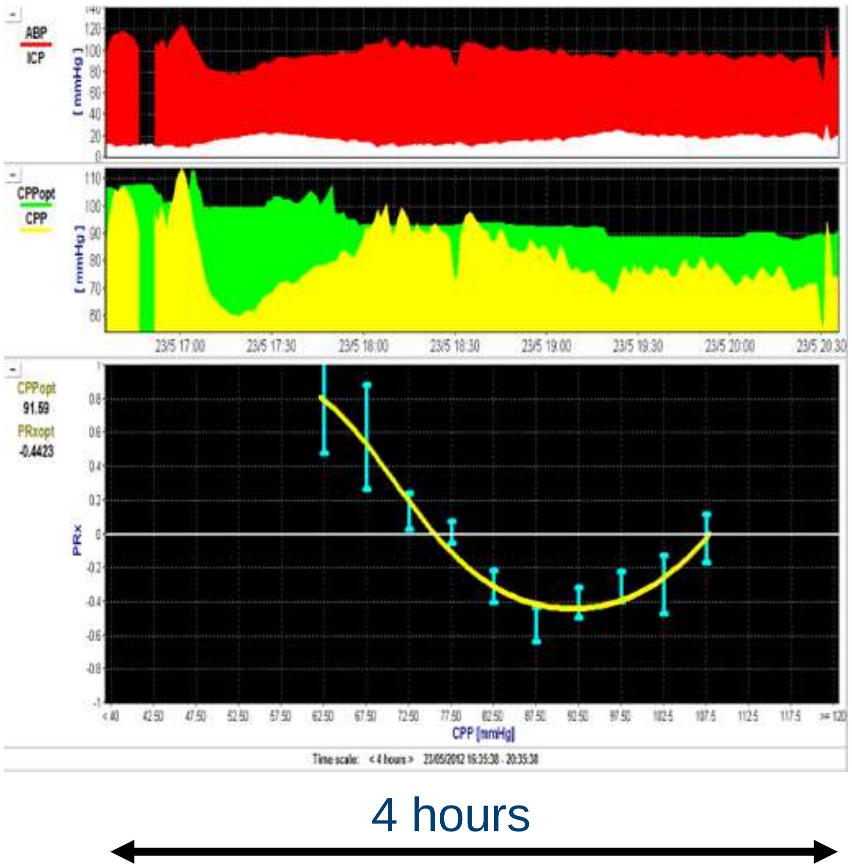
Brain Physics Lab

ICM+

The shorter the calculation window the smaller the range of CPP probing the autoregulatory capacity



Calculation of CPPopt from 4 hours long windows



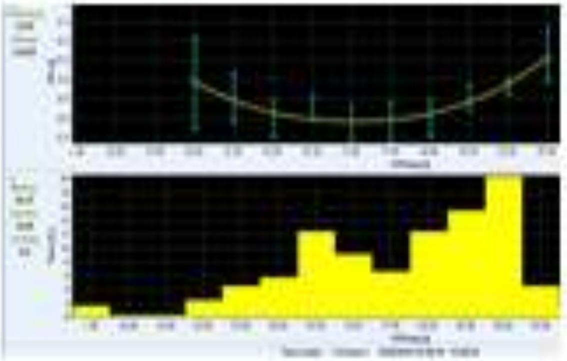
- 560 patients examined
- 60% of monitoring time a value
- Only 70% U-shaped
- Sometimes unphysiologically high CPPopt values

Reasons for CPPopt value absence ('low yield')

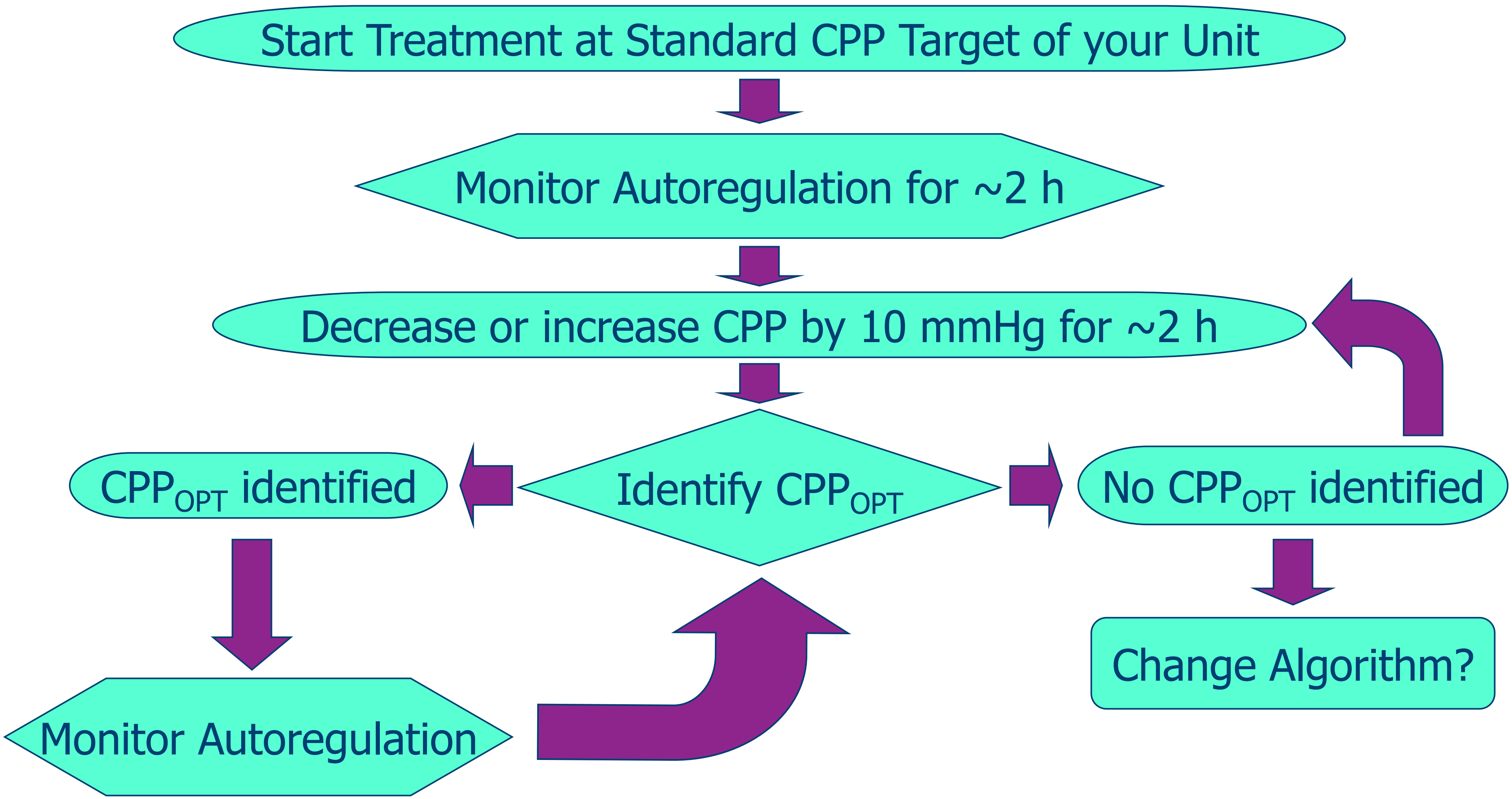
Materials and methods

Main conclusions

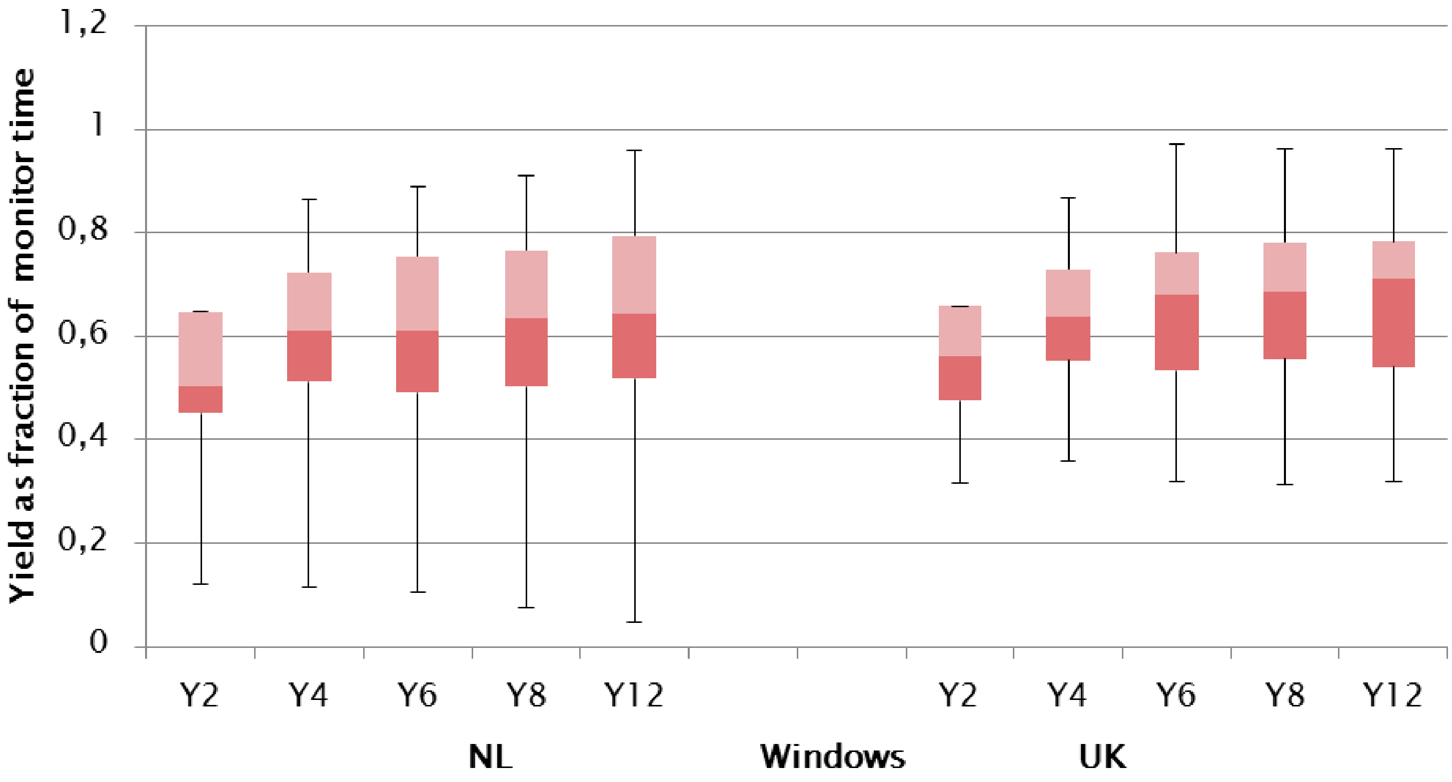
1. Results show an association between **absence of CPPopt** and the following physiological and clinical variables:
   - absence of ABP slow waves
   - impaired autoregulation
   - status after decompressive craniectomy
   - <u>not</u> applying muscle paralytics
   - light or moderate sedation
   -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



Proposed CPPopt based treatment algorithm



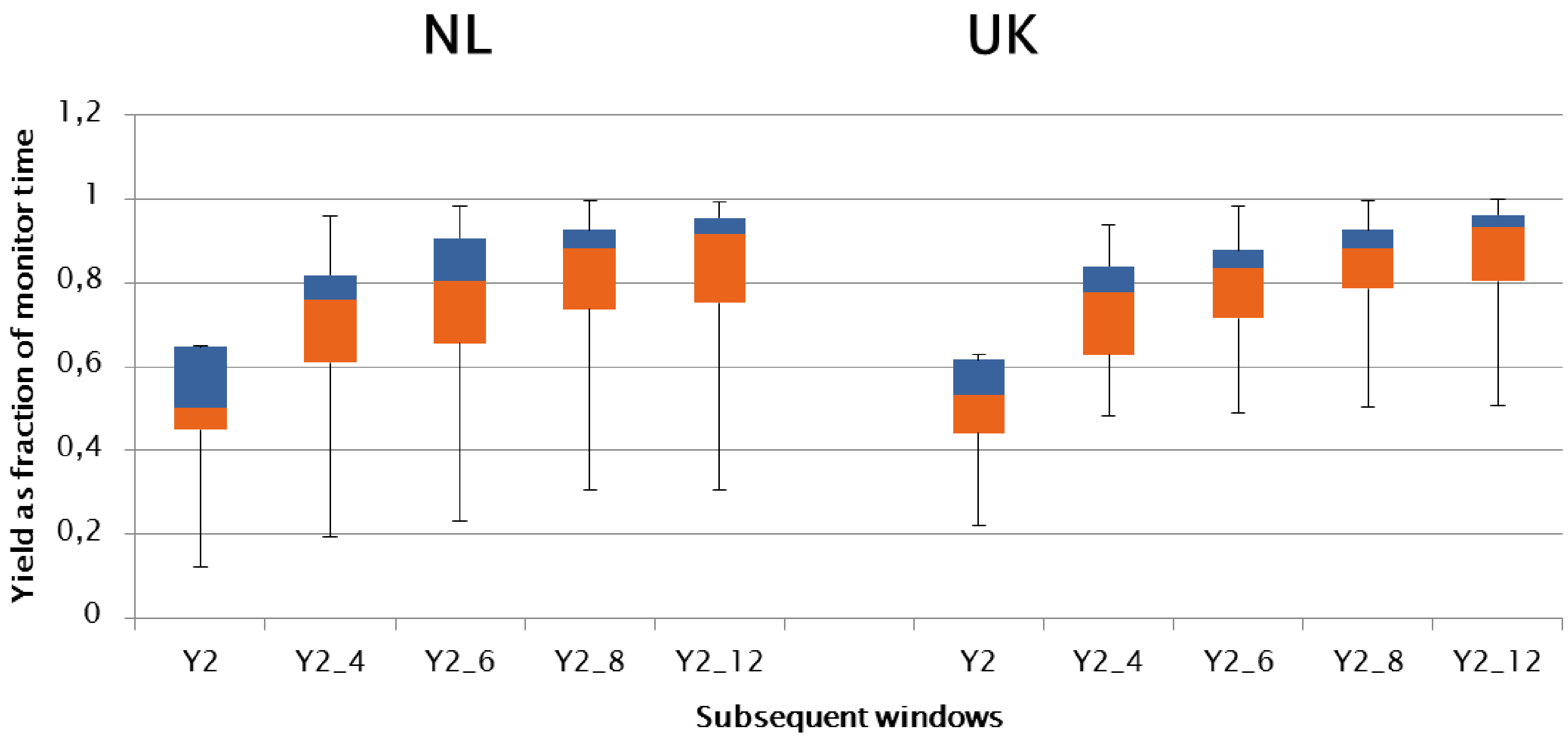
CPPopt yield (%) with relation to the calculation window size



N = 35

N = 37

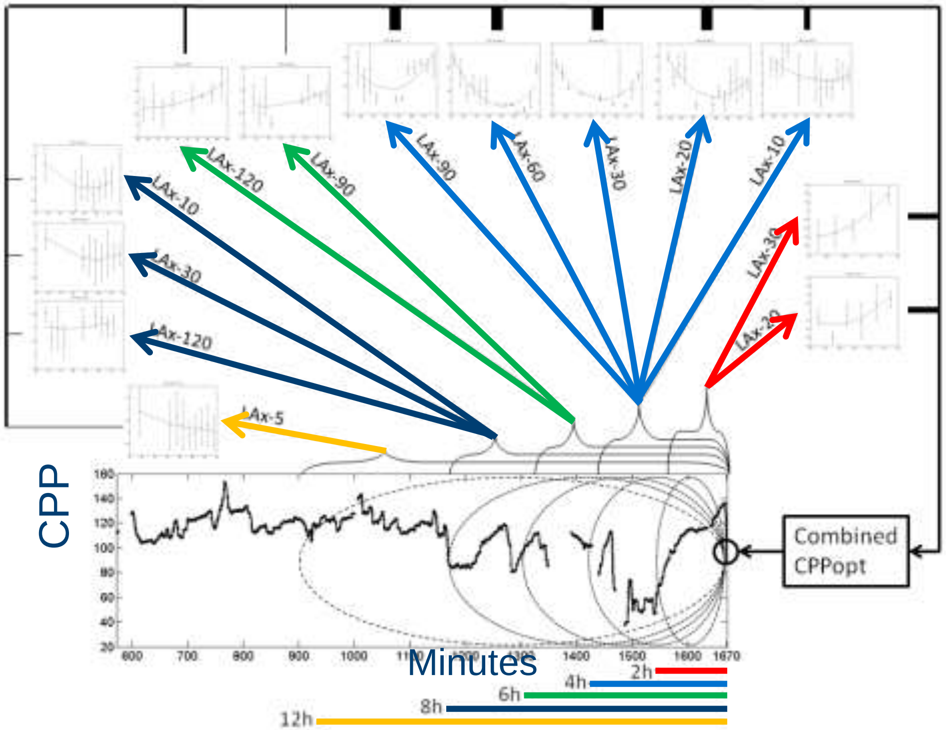
CPPopt yield (%) combined Window



N = 35

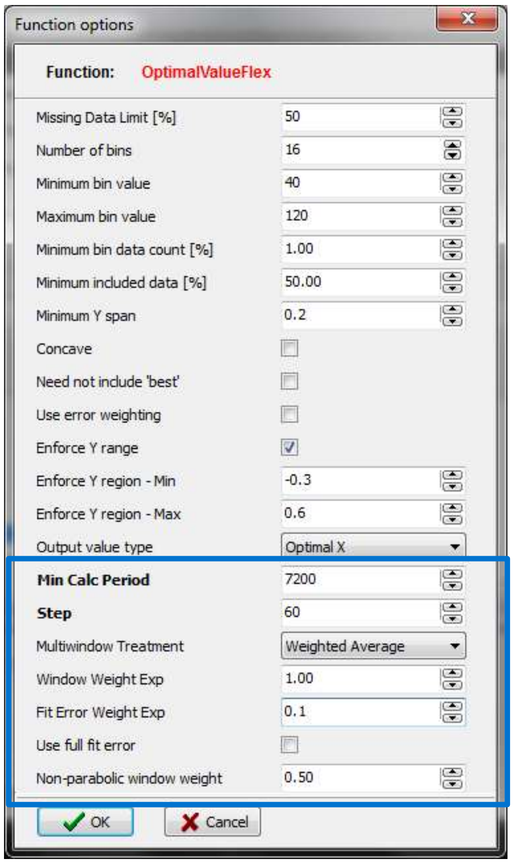
N = 37

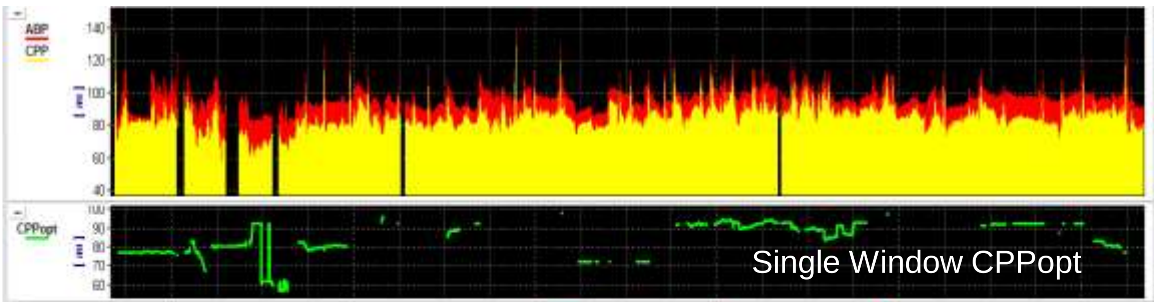
DATACAR



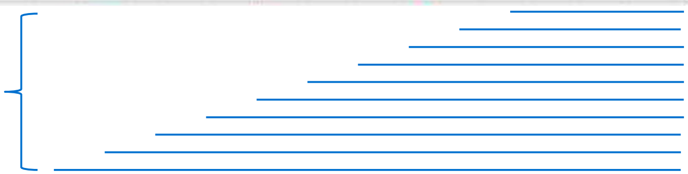
- U-curves could only be fitted for time windows of 2, 4, 6, 8, and 12 hours.
- The CPPopts receive a weight (represented by line thickness) based on the goodness of fit of their U-shaped curve and the lower value of the LAx at CPPopt.
- The highest weights are given to the 4-hour time window and LAx-20, LAx-30, LAx-60, and LAx-90.
- The combined CPPopt is the weighted average of all CPPopts.

Multi-flexi window CPPopt algorithm in ICM+



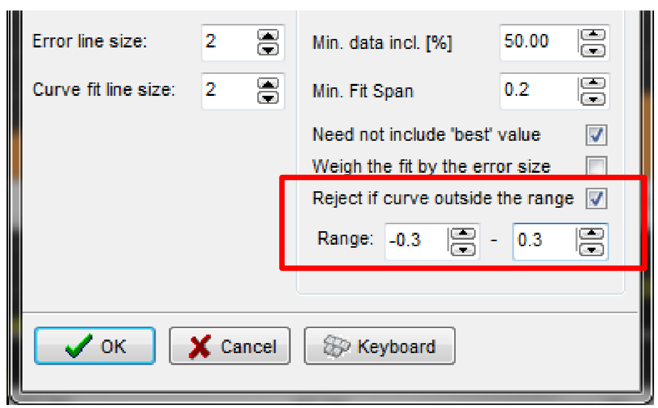


Multiple windows

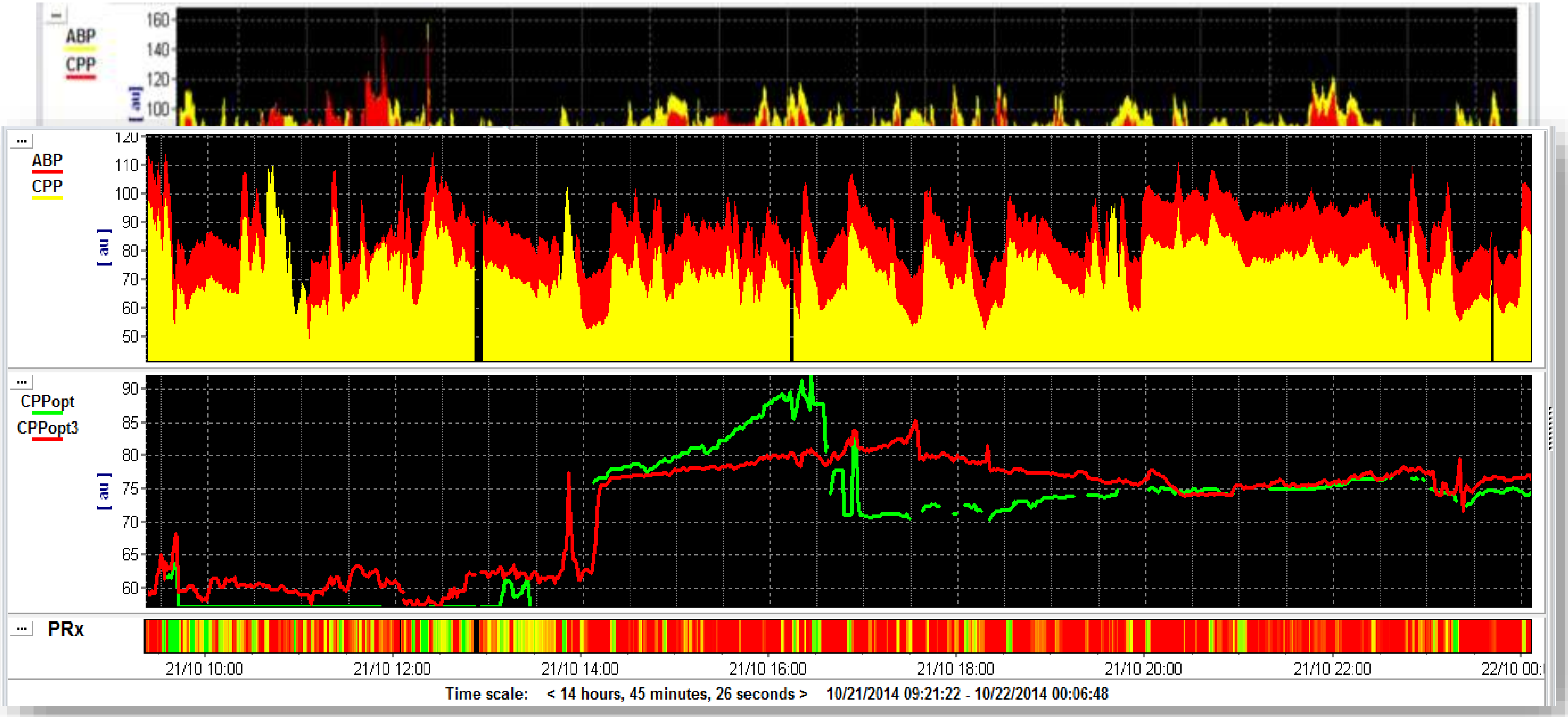


$$weight = \frac{1}{e^{window\ length}} \times \frac{1}{e^{fit\ error}} \times W_{non-parabolic\ window}$$

PRx range matters

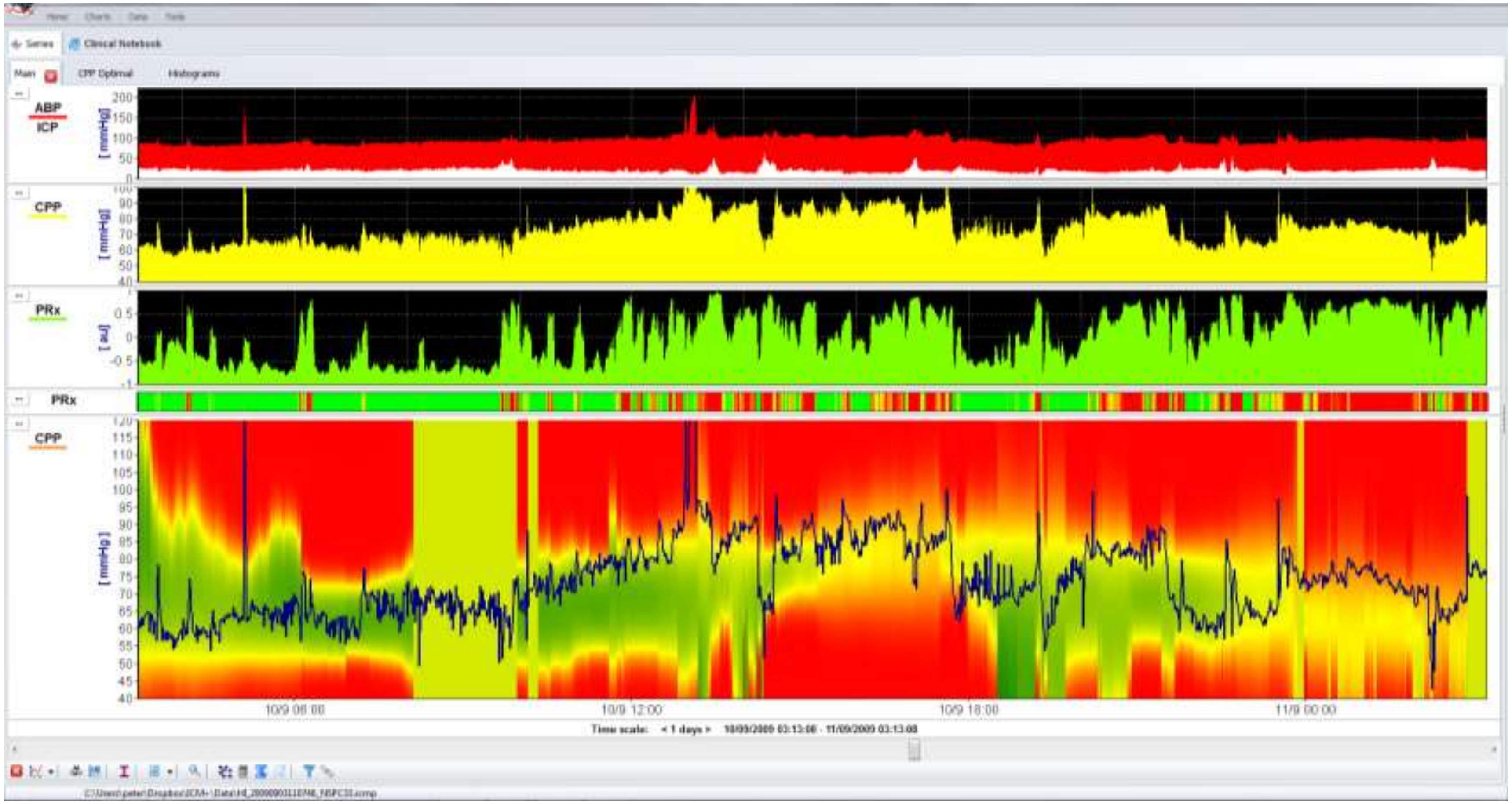


Multi-flexi window alorightm in ICM+

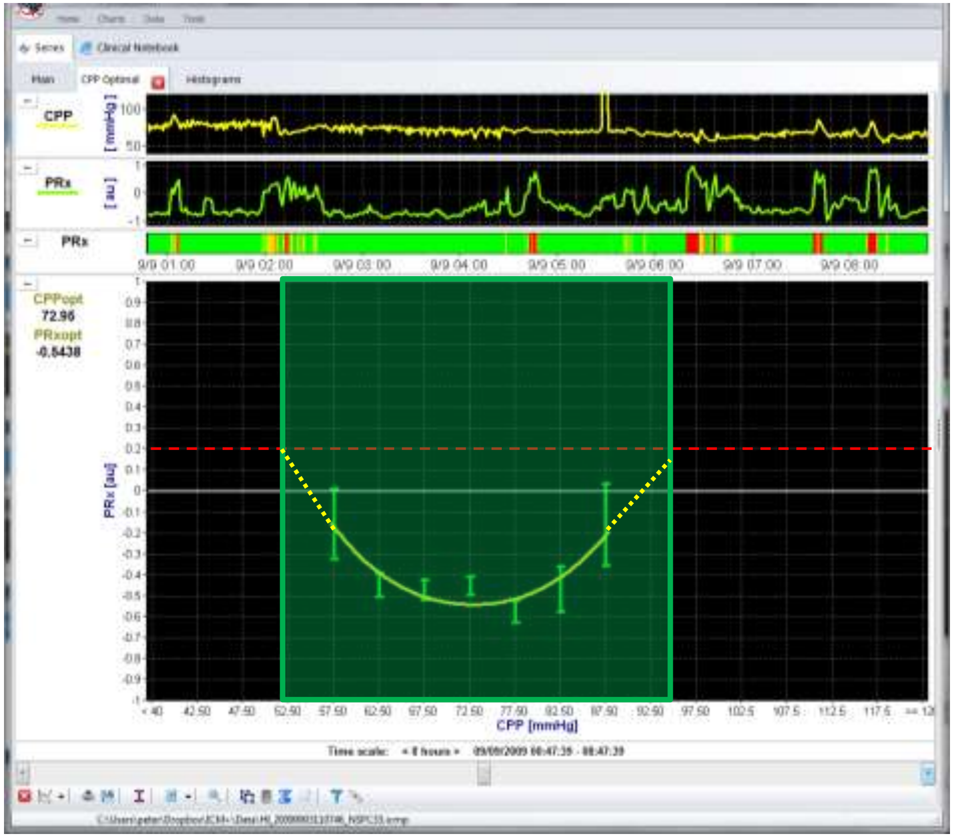


More stable and less likely to produce unphysiologically high values

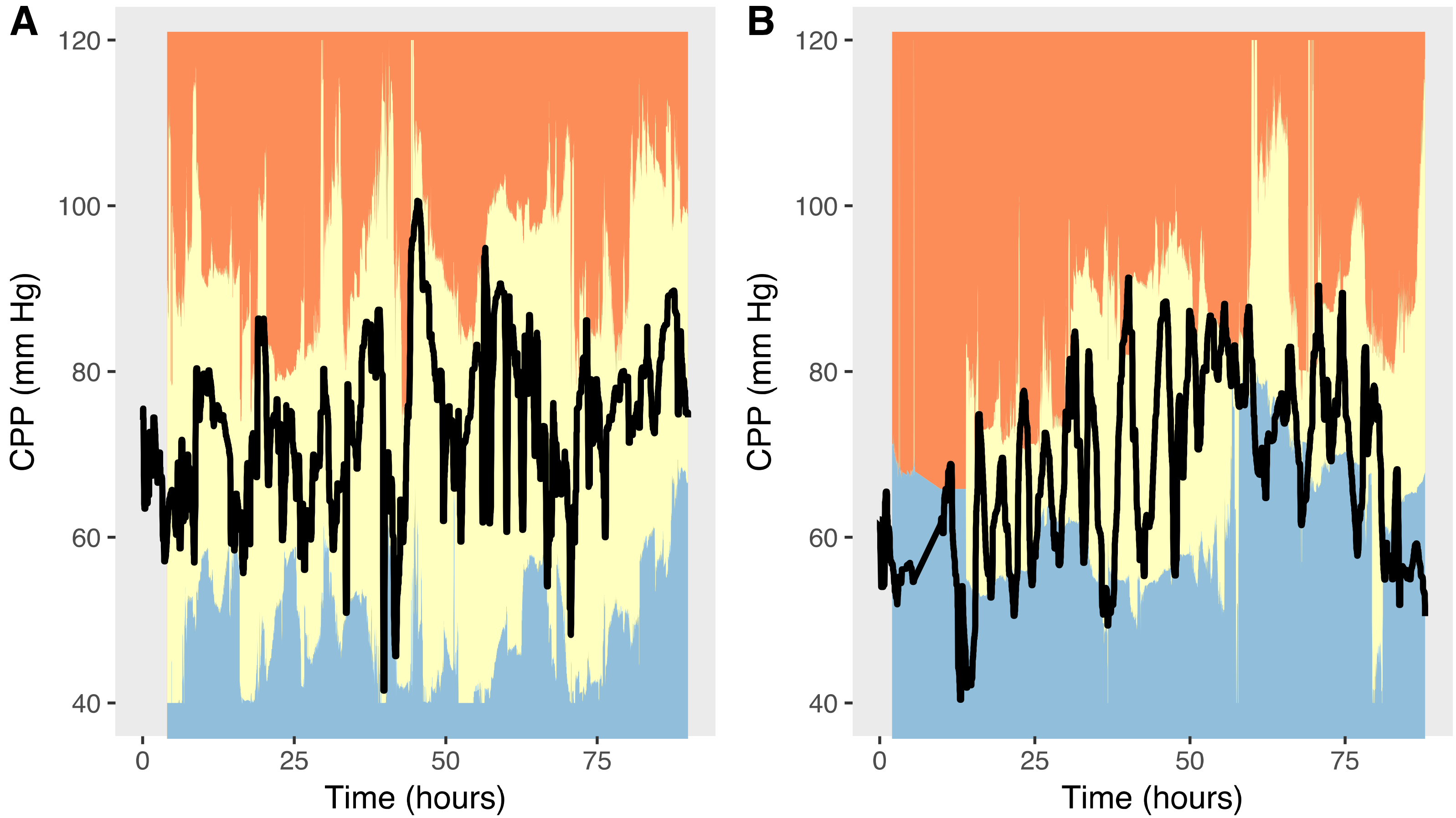
Visualising time ‘landscape’ of cerebral autoregulation



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)

Optimal Cerebral Perfusion P

cppopt.org

ICM+

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OPTIMAL CEREBRAL PERFUSION PRESSURE

CPPopt research website

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.

UPDATE!

COGiTATE augustus 2017

COGiTATE 70