Physiological Laboratory

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UNIVERSITY OF CAMBRIDGE enterprise

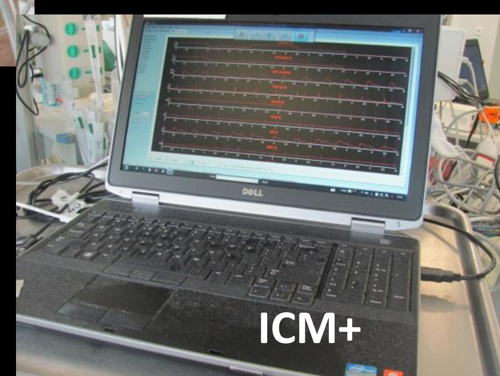
Brain Research Lab

Brain Physics Lab in Wrocław




BRAIN RESEARCH LAB

Multimodal monitoring in NCCU at the University Hospital in Wrocław



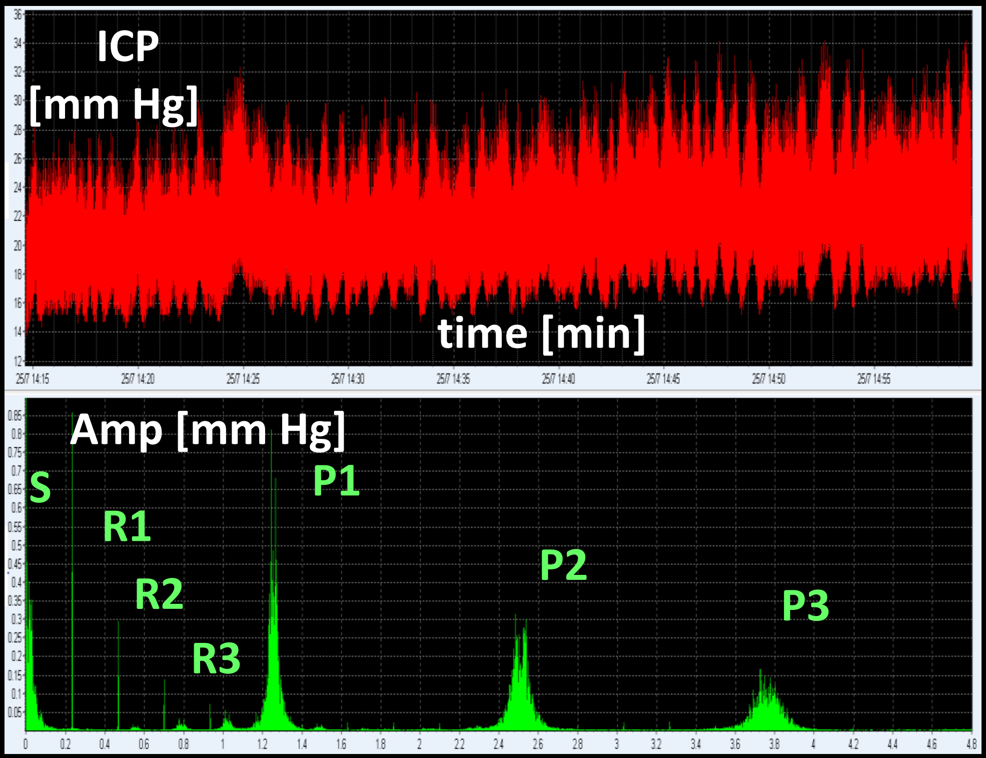
ICM+ class at the Wroclaw University of Science and Technology

Brain Research Lab

How I use ICM+ to teach biomedical engineering students

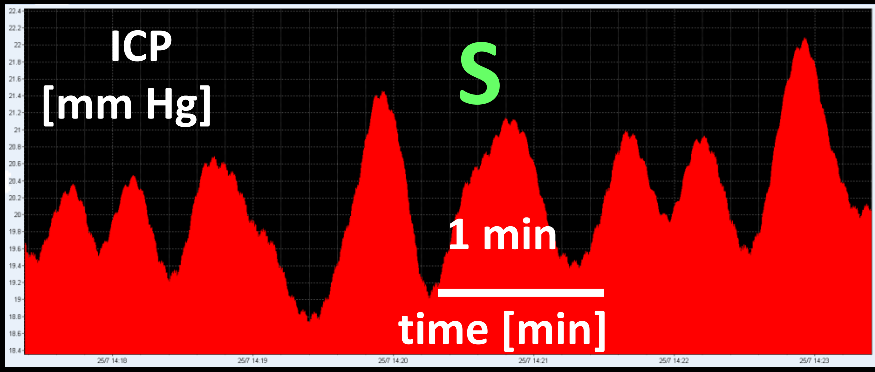
Task 1: Spectral analysis of ICP signal

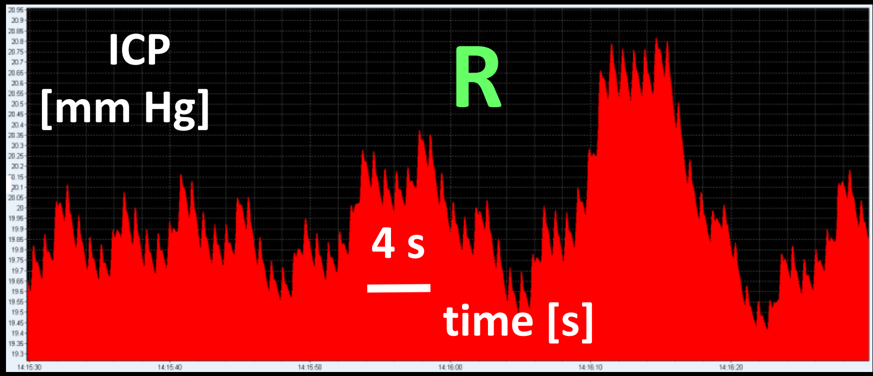
in frequency domain

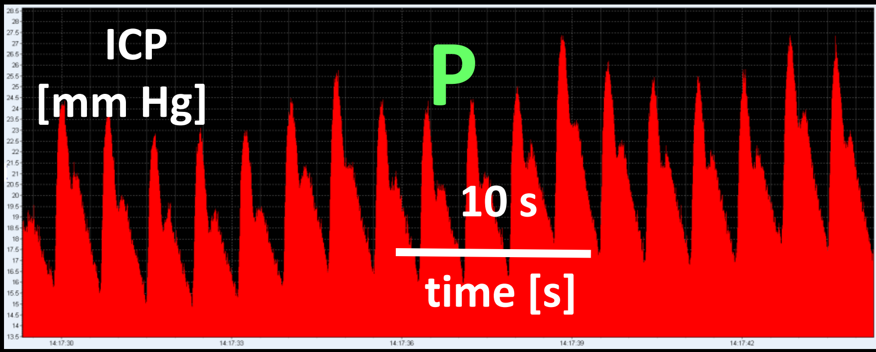


frequency [Hz]

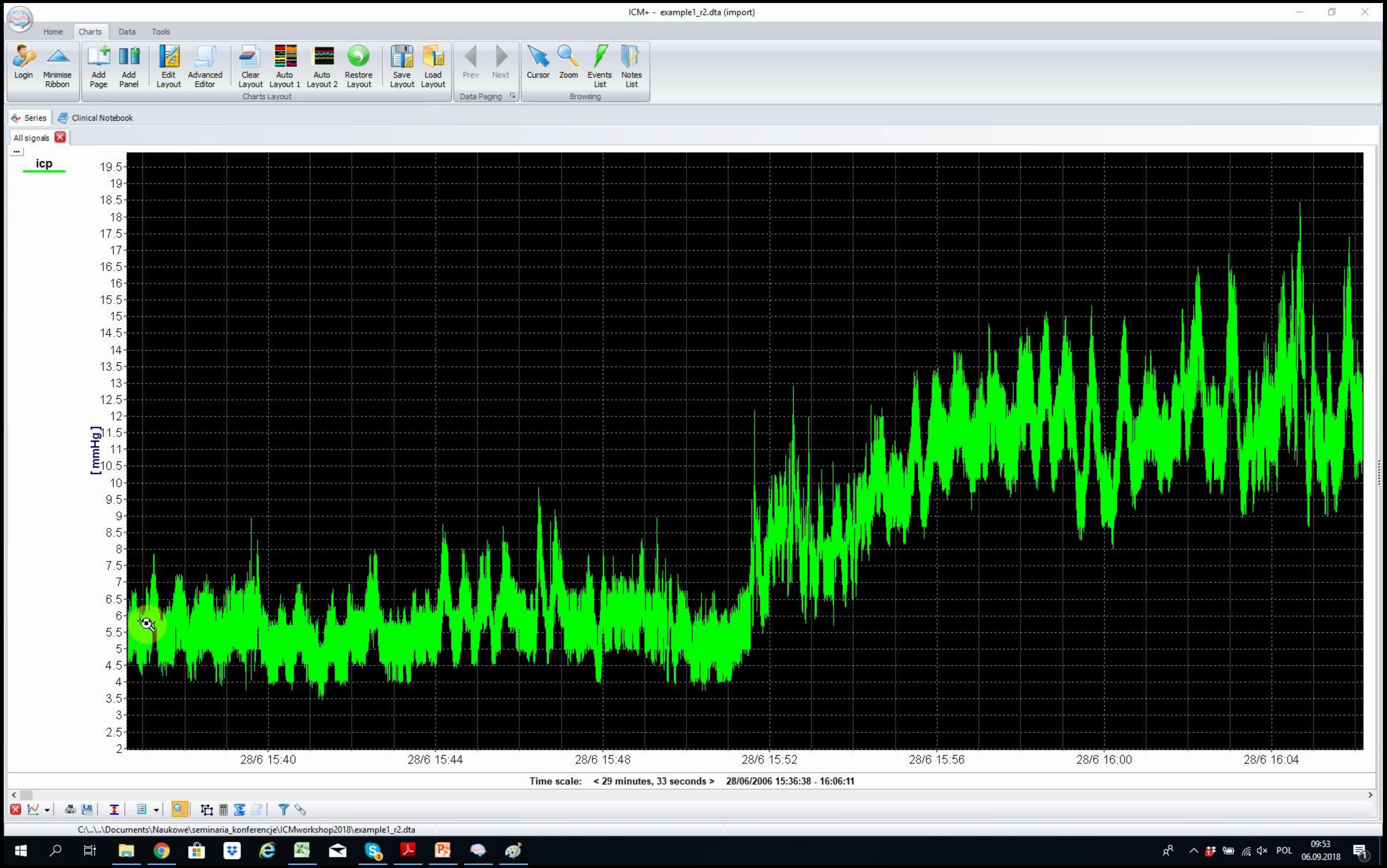
in time domain



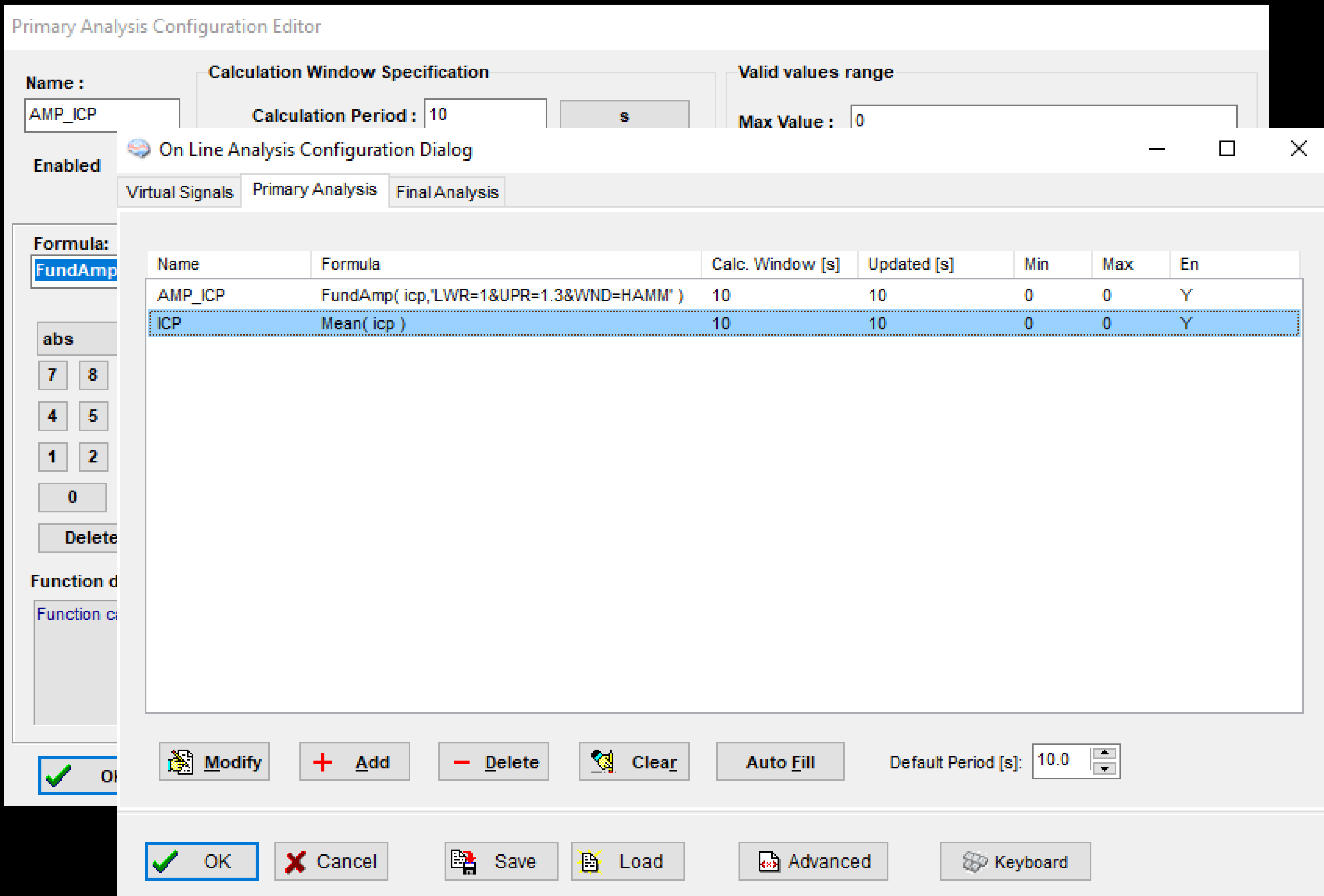




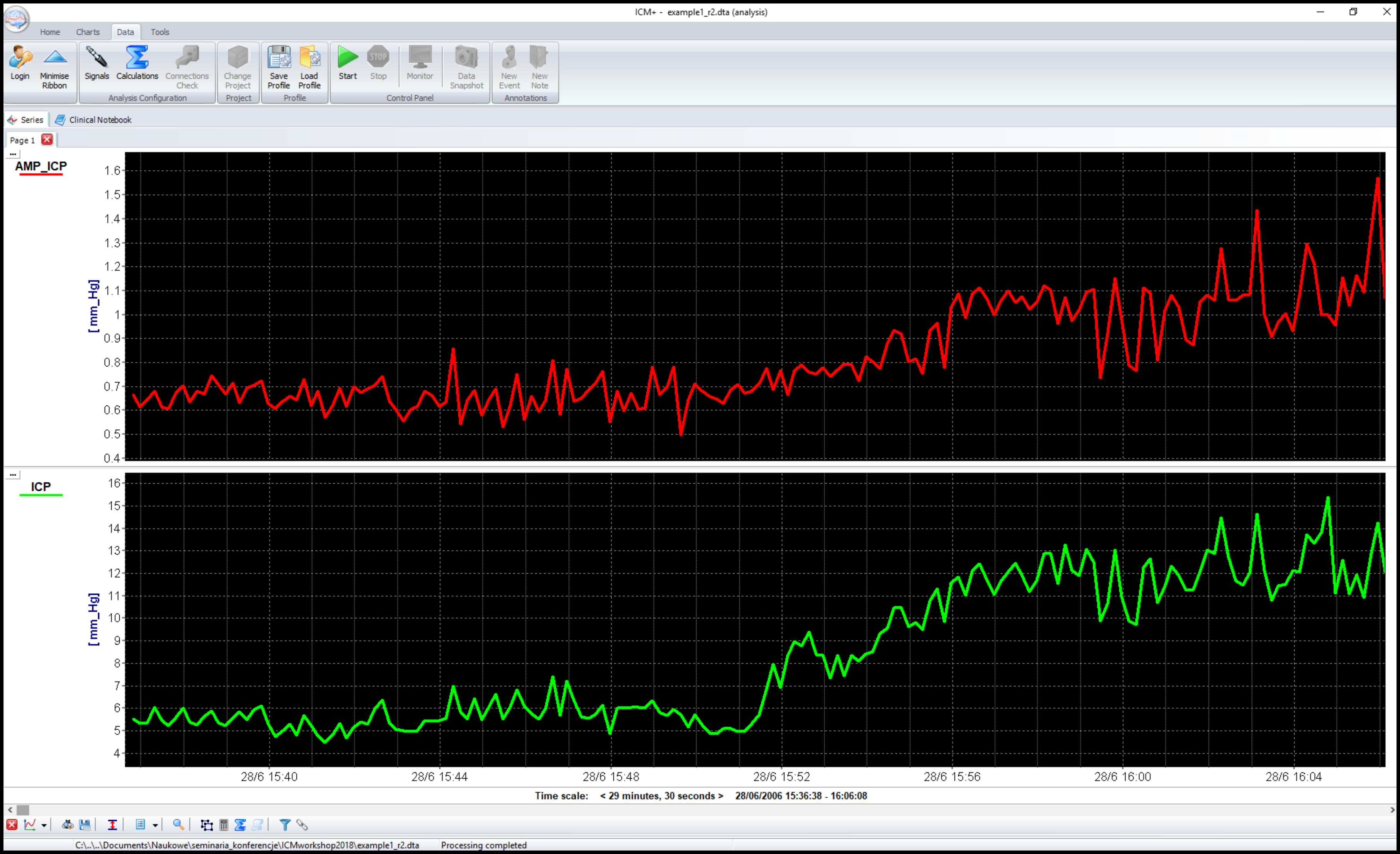
Spectral analysis using ICM+ chart tool



Spectral analysis using ICM+ configuration profile

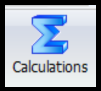


Spectral analysis using ICM+ configuration profile



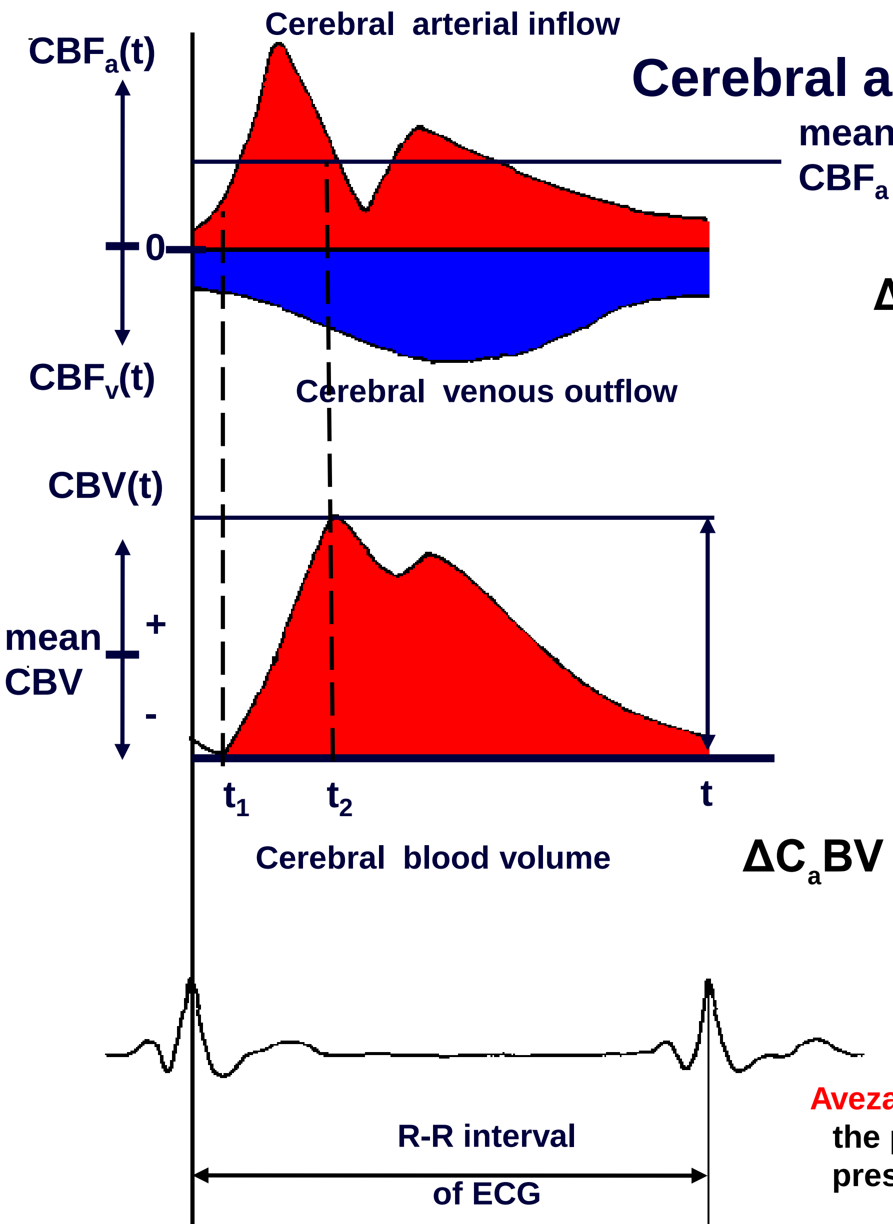
Short summary

- Fourier spectrum analysis reveals frequency compnents of a signal (e.g. ICP slow, respiratory and pulse waves)
- You can plot a spectrum chart of the signal and calculate aplitude of its frequency components using ICM+ tools 



- Amplitude of the ICP pulse waveforms increases with rising mean ICP during infusion test

Task 2: Cerebral arterial blood volume changes (ΔC_aBV)



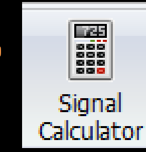
Cerebral arterial blood volume (C_aBV)

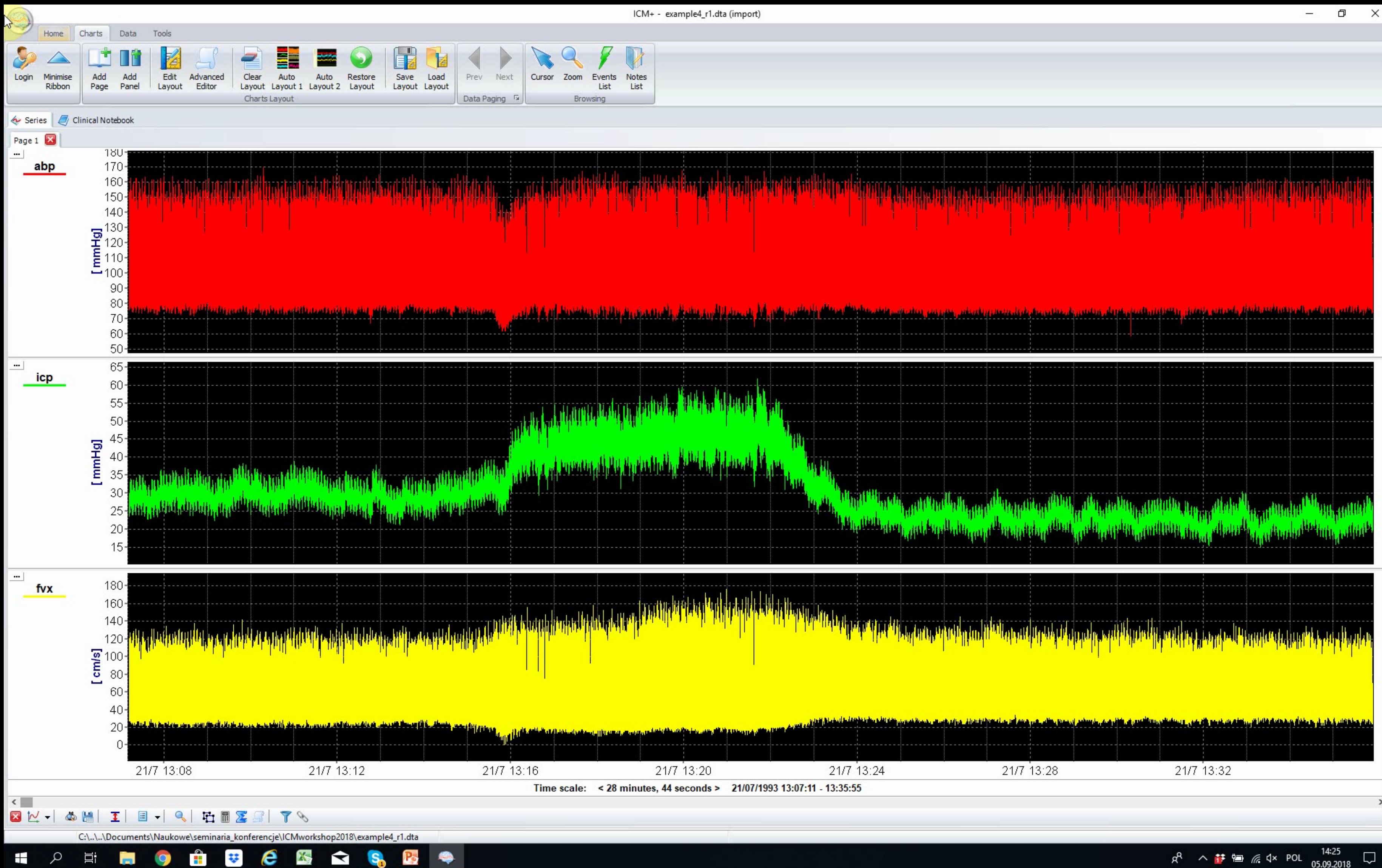
$$\Delta CBV = \int_{t_0}^{t} (CBF_a(s) - CBF_v(s))ds$$

$$\Delta C_aBV = S_a \int_{t_0}^{t} (CBFV_a(s) - meanCBFV_a)ds$$

Avezaat CJ, van Eijndhoven JH. (1986) The role of the pulsatile pressure variations in intracranial pressure monitoring. *Neurosurg Rev* 9:113-120

C_aBV estimation using a ICM+ signal calculator





CaBV pulsation
and shape of pulse waveform of ICP

JOURNAL OF NEUROTRAUMA 27:317–324 (February 2010)

DOI: 10.1089/neu.2009.0951

What Shapes Pulse Amplitude of Intracranial Pressure?

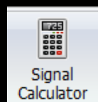
Emmanuel Carrera, Dong-Joo Kim, Gianluca Castellani, Christian Zweifel, Zofia Czosnyka, Magdalena Kasprowicz, Peter Smielewski, John D. Pickard, and Marek Czosnyka

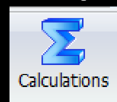
Abstract

The pulsatile component of intracranial pressure (ICP) has been shown to be a predictor of outcome in normal pressure hydrocephalus (NPH) and traumatic brain injury (TBI). Experimental studies have demonstrated that the pulse amplitude of ICP (AMP_{ICP}) is dependent on the mean ICP (mICP), and on the pulse amplitude of the cerebral arterial blood volume (AMP_{CaBV}), according to the exponential craniospinal compliance curve. In this study, we compared the influence of mICP and AMP_{CaBV} on AMP_{ICP} in patients with NPH (infusion study) and TBI (spontaneous recording). We retrospectively analyzed 25 NPH and 43 TBI patients with continuous monitoring of ICP and cerebral blood flow velocity (CBFV), as assessed with transcranial doppler. AMP_{CaBV} was extracted from the CBFV waveform. The influence of mICP and AMP_{CaBV} on AMP_{ICP} were determined using partial coefficients a, b, and c of the multiple regression model: $AMP_{ICP} = a * mICP + b * AMP_{CaBV} + c$. AMP_{ICP} was more dependent on mICP in NPH patients than in TBI patients (partial coefficient $a = 0.93$ versus -0.03; $p < 0.001$). On the contrary, AMP_{ICP} was more dependent on AMP_{CaBV} in patients with TBI than in those with NPH ($b = 0.86$ versus 0.10; $p < 0.001$). This study shows that AMP_{ICP} depends mostly on changes in mean ICP during cerebrospinal fluid (CSF) infusion studies in patients with NPH, and on changes in cerebral arterial blood volume (AMP_{CaBV}) in TBI patients. Further clinical studies will reveal whether AMP_{ICP} is a better indicator of clinical severity and outcome than mICP in TBI and NPH patients.

Key words: cerebral blood flow autoregulation; cerebral blood flow velocity; intracranial pressure; neurodegenerative disorders; traumatic brain injury

Short summary

- C_aBV has a pulstile component
- Amplitude of pulse changes in C_aBV can be calculated using ICM+ tools 

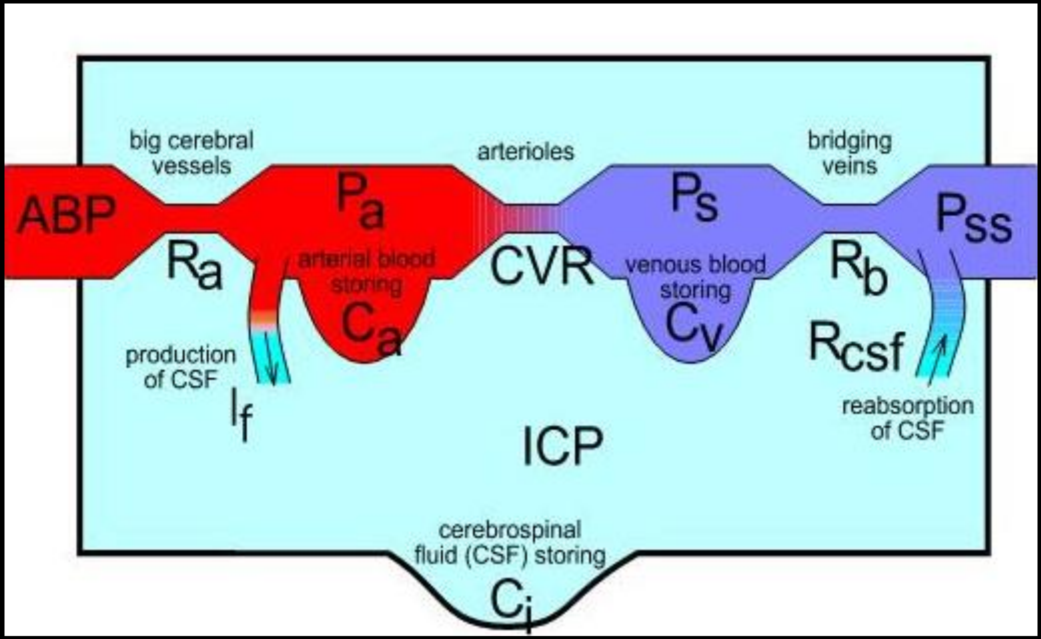


- ICP pulse waveform is shaped mostly by pulse changes of C_aBV during plateau waves in TBI

Task 3: Compartmental compliances of brain

Cerebral arterial compliance (C_a)

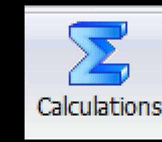
$$C_a = \frac{Amp_{C_a BV}}{Amp_{ABP}}$$

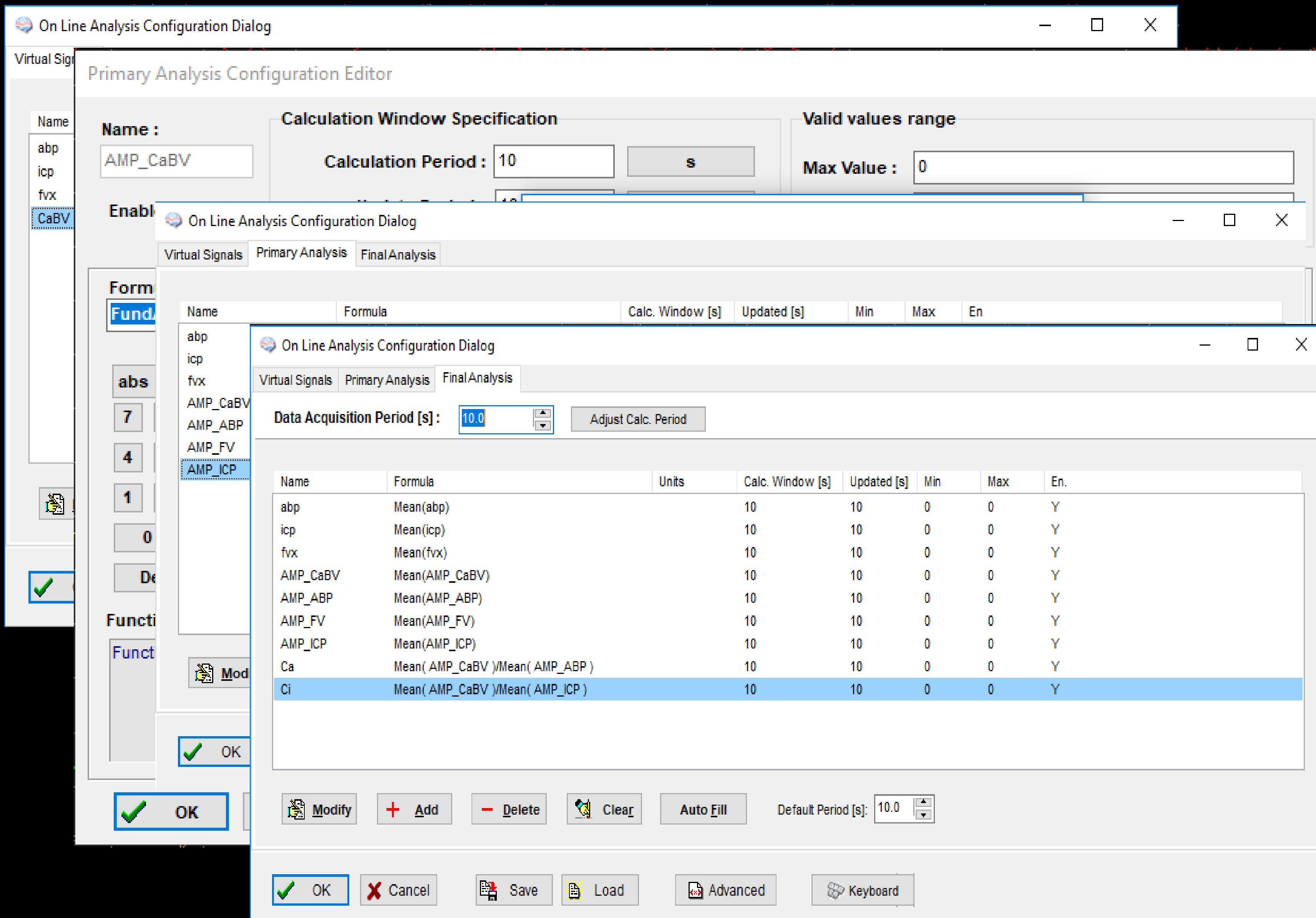


Cerebrospinal + venous compliance (C_i)

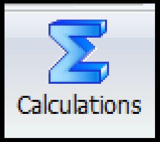
$$C_i = \frac{Amp_{C_a BV}}{Amp_{ICP}}$$

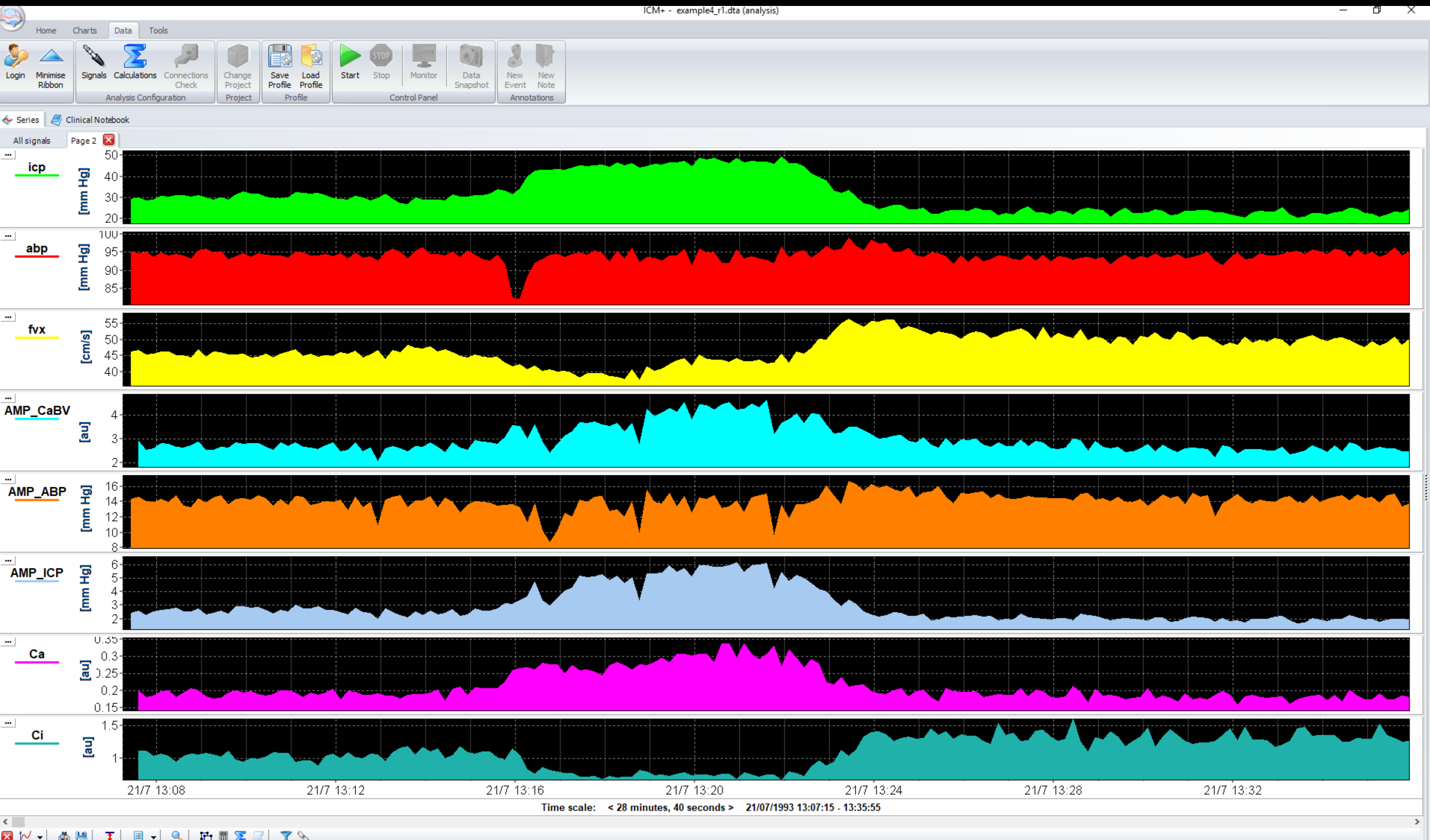
Task 3: C_a and C_i estimation using ICM+ configuration profile





Task 3: C_a and C_i estimation using ICM+ configuration profile





Relative changes in C_a and C_i during plateu waves

Physiol. Meas. **30** (2009) 647–659 doi:10.1088/0967-3334/30/7/009

The monitoring of relative changes in compartmental compliances of brain

Dong-Joo Kim[1,2], Magdalena Kasprowicz[3], Emmanuel Carrera[1], Gianluca Castellani[1], Christian Zweifel[1], Andrea Lavinio[4], Peter Smielewski[1], Michael P F Sutcliffe[2], John D Pickard[1] and Marek Czosnyka[1,5,6]

Abstract

The study aimed to develop a computational method for assessing relative changes in compartmental compliances within the brain: the arterial bed and the cerebrospinal space. The method utilizes the relationship between pulsatile components in the arterial blood volume, arterial blood pressure (ABP) and intracranial pressure (ICP). It was verified by using clinical recordings of intracranial pressure plateau waves, when massive vasodilatation accompanying plateau waves produces changes in brain compliances of the arterial bed (C_a) and compliance of the cerebrospinal space (C_i). Ten patients admitted after head injury with a median Glasgow Coma Score of 6 were studied retrospectively. ABP was directly monitored from the radial artery. Changes in the cerebral arterial blood volume were assessed using Transcranial Doppler (TCD) ultrasonography by digital integration of inflow blood velocity. During plateau waves, *ICP* increased ($P = 0.001$), *CPP* decreased ($P = 0.001$), *ABP* remained constant ($P = 0.532$), blood flow velocity decreased ($P = 0.001$). Calculated compliance of the arterial bed C_a increased significantly ($P = 0.001$); compliance of the CSF space C_i decreased ($P = 0.001$). We concluded that the method allows for continuous monitoring of relative changes in brain compartmental compliances. Plateau waves affect the balance between

Short summary

- Monitoring of the relative changes in compliances of arterial bed (C_a) and cerebrospinal space (C_i) is possible by using pulse waveforms of arterial and intracranial pressure and cerebral blood flow velocity
- C_a increases and C_i decreases during plateau waves

task 4: Cerebral arterial time constant (τ)

- ✓ **time to fill cerebral arterial bed with blood volume after a sudden change in ABP during one cardiac cycle**

$$\tau = C_a \cdot CVR$$

$$\frac{\text{mean}CPP}{\text{mean}CBFV \cdot S_a}$$

Czosnyka M, Piechnik S, Richards HK, Kirkpatrick P, Smielewski P, Pickard JD.
Contribution of mathematical modelling to the interpretation of bedside tests of cerebrovascular autoregulation.
J Neurol Neurosurg Psychiatry. 1997, 63(6):721-31

task 4: Cerebral arterial time constant (τ)

- ✓ **time to fill cerebral arterial bed with blood volume after a sudden change in ABP during one cardiac cycle**

$$\tau = C_a \cdot CVR \quad [s]$$

$$\frac{\times \cdot \mathrm{Amp}_{C_aBV}}{\mathrm{Amp}_{ABP}}$$

$$\frac{\mathrm{mean}CPP}{\mathrm{mean}CBFV \cdot \times}$$

Kim DJ, Kasprowicz M, Carrera E, Castellani G, Zweifel C, Lavinio A, Smielewski P, Sutcliffe MP, Pickard JD, Czosnyka M.
The monitoring of relative changes in compartmental compliances of brain.
Physiol Meas. 2009 Jul;30(7):647-59

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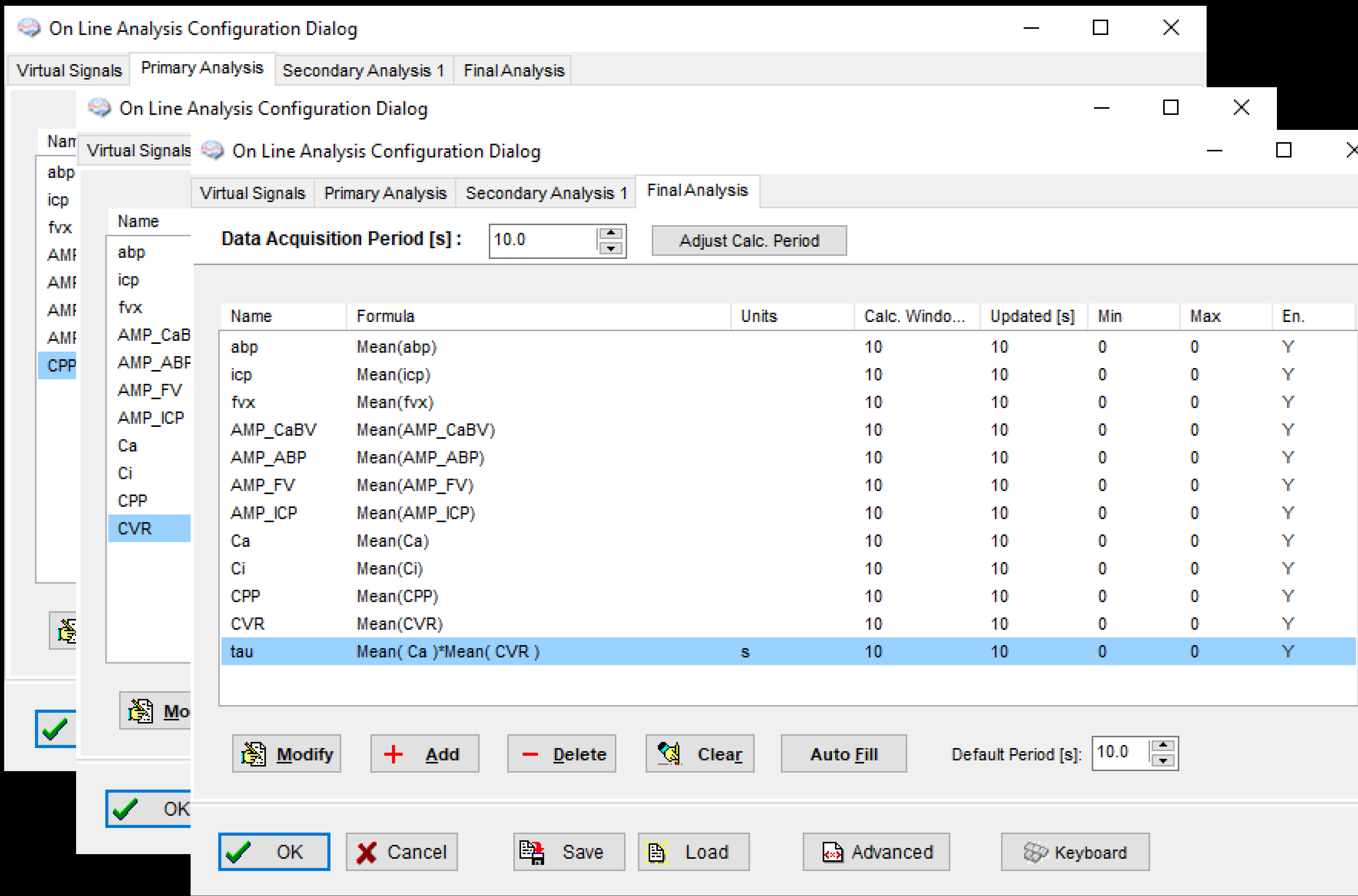
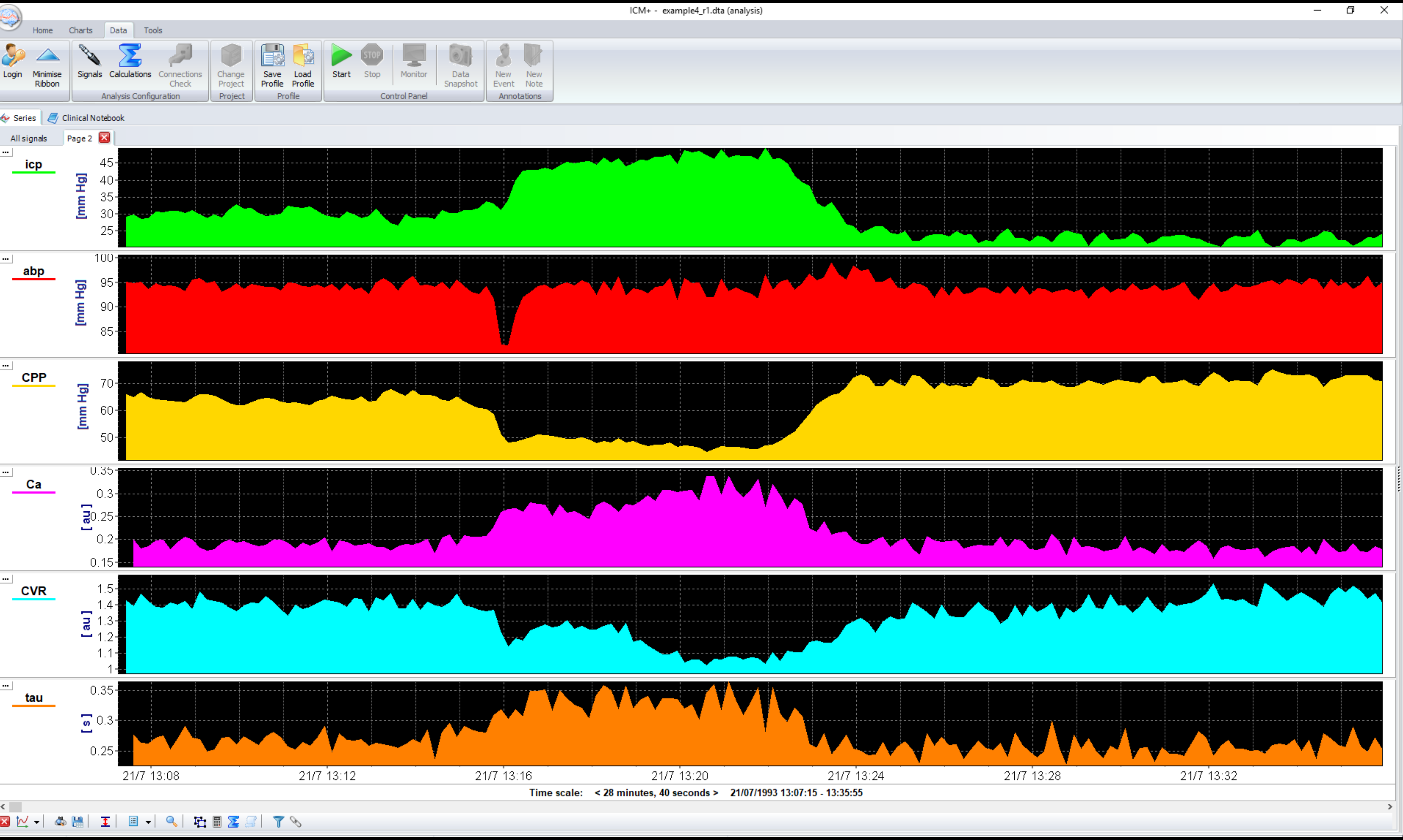
task 4: τ estimation using ICM+ configuration profile



task 4: τ estimation using ICM+ configuration profile



Cerebral arterial time constant in experimental studies

Neurol Res. 2012 Jan;34(1):17-24.

Cerebrovascular time constant: dependence on cerebral perfusion pressure and end-tidal carbon dioxide concentration

Marek Czosnyka[1], Hugh K Richards[1], Matthias Reinhard[2], Luzius A Steiner[3], Karol Budohoski[1], Piotr Smielewski[1], John D Pickard[1], Magdalena Kasprowicz[1,4]

[1]Academic Neurosurgical Unit, Addenbrooke's Hospital, Cambridge, UK, [2]Department of Neurology, University of Freiburg, Freiburg, Germany, [3]Department of Anaesthesiology, Lausanne University Hospital Center and University of Lausanne, Lausanne, Switzerland, [4]Institute of Biomedical Engineering and Instrumentation, Wroclaw University of Technology, Wroclaw, Poland

Objective: The cerebrovascular time constant (τ) describes the time to establish a change in cerebral blood volume after a step transient in arterial blood pressure (ABP). We studied the relationship between τ, ABP, intracranial pressure (ICP), and end-tidal carbon dioxide concentration ($EtCO_2$).

Method: Recordings from 46 anaesthetized, paralysed and ventilated New Zealand rabbits were analysed retrospectively. ABP was directly monitored in the femoral artery, transcranial Doppler (TCD) cerebral blood flow velocity (CBFV) from the basilar artery, and ICP using an intraparenchymal sensor. In nine animals end-tidal CO_2 ($EtCO_2$) was monitored continuously. ABP was decreased with injection of trimetophan (n=11) or haemorrhage (n=6) and increased by boluses of dopamine (n=11). ICP was increased by infusion of normal saline into the lumbar cerebrospinal fluid space (n=9). Changes in cerebral compliance (C_a) were estimated as a ratio of the pulse amplitude of the cerebral arterial blood volume (CBV) and the pulse amplitude of ABP. Changes in cerebrovascular resistance (CVR) were expressed as mean ABP or cerebral perfusion pressure (CPP) divided by mean CBFV. Time constant τ was calculated as the product of CVR and C_a.

Results: The time constant changed inversely to the direction of the change in ABP (during arterial hypo- and hypertension) and CPP (during intracranial hypertension). C_a increased with decreasing CPP, while CVR decreased. During a decrease in CPP, changes in C_a exceeded changes in CVR. In contrast, during hypercapnia, the decrease in CVR was more pronounced than the increase in C_a, resulting in a decrease in τ.

Conclusion: Cerebrovascular time constant τ is modulated by ABP, ICP, and $EtCO_2$.

Keywords: Cerebral blood flow, Cerebral blood volume, Transcranial Doppler, Experiment

Short summary

- τ conceptually shows how fast brain arterial blood volume settles after step change in ABP
- τ has units [s] therefore comparison between patients is possible
- τ changes inversely to direction of change in CPP

Thank you