Wavelet Based Algorithm for Autoregulation Monitoring with ICM+

Xiuyun Liu, PhD
Department of Anesthesiology and Critical Care Medicine
School of Medicine
Johns Hopkins University

Email: liuxiuyun1@gmail.com

CA Assessment

JOHNS HOPKINS
SCHOOL of MEDICINE

Static Way

Shows how much CVR reacts to changes in CPP measured with long-term changes in CPP (or ABP) Pharmacological increase or decrease in ABP

Dynamic Way

Characterizes what the time delay of changes in CVR relative to step change in CPP measured with short-term changes in CPP (or ABP)

- **Thigh-cuff test**
- **Time correlation**
- **Transfer-function analysis**
- **Valsalva manoeuvre**
- **Transient hyperaemic response test**

[1]F. P. Tiecks, A. M. Lam, R. Aaslid, and D. W. Newell, *Stroke*, 1995
[2] M. Czosnyka, P. Smielewski, P. Kirkpatrick, D. K. Menon, and J. D. Pickard, “Monitoring of cerebral autoregulation in head-injured patients,” Stroke, vol. 27, no. 10, pp. 1829–1834, 1996.
[3] RB. Panerai. Grading of Cerebral Dynamic Autoregulation From Spontaneous Fluctuations in Arterial Blood Pressure. Stroke. 1998

CA Assessment

JOHNS HOPKINS
SCHOOL of MEDICINE

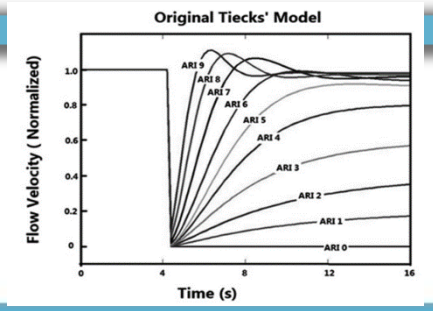
Static Way

Shows how much CVR reacts to changes in CPP measured with long-term changes in CPP (or ABP) Pharmacological increase or decrease in ABP

Dynamic Way

Characterizes what the time delay of changes in CVR relative to step change in CPP measured with short-term changes in CPP (or ABP)

- **Thigh-cuff test**
- **Time correlation**
- **Transfer-function analysis**
- **Valsalva manoeuvre**
- **Transient hyperaemic response test**



[1]F. P. Tiecks, A. M. Lam, R. Aaslid, and D. W. Newell, *Stroke*, 1995
[2] M. Czosnyka, P. Smielewski, P. Kirkpatrick, D. K. Menon, and J. D. Pickard, “Monitoring of cerebral autoregulation in head-injured patients,” Stroke, vol. 27, no. 10, pp. 1829–1834, 1996.
[3] RB. Panerai. Grading of Cerebral Dynamic Autoregulation From Spontaneous Fluctuations in Arterial Blood Pressure. Stroke. 1998

CA Assessment

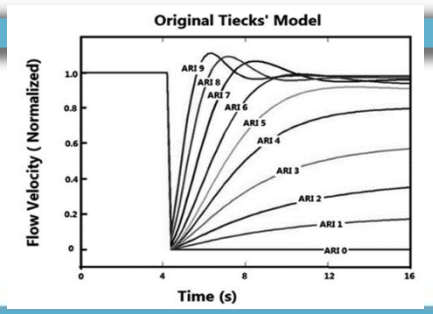
Static Way

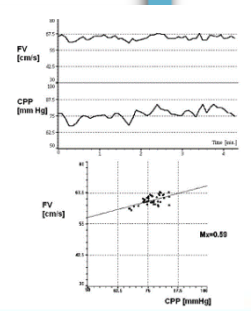
Shows how much CVR reacts to changes in CPP measured with long-term changes in CPP (or ABP) Pharmacological increase or decrease in ABP

Dynamic Way

Characterizes what the time delay of changes in CVR relative to step change in CPP measured with short-term changes in CPP (or ABP)

- **Thigh-cuff test**
- **Time correlation**
- **Transfer-function analysis**
- **Valsalva manoeuvre**
- **Transient hyperaemic response test**

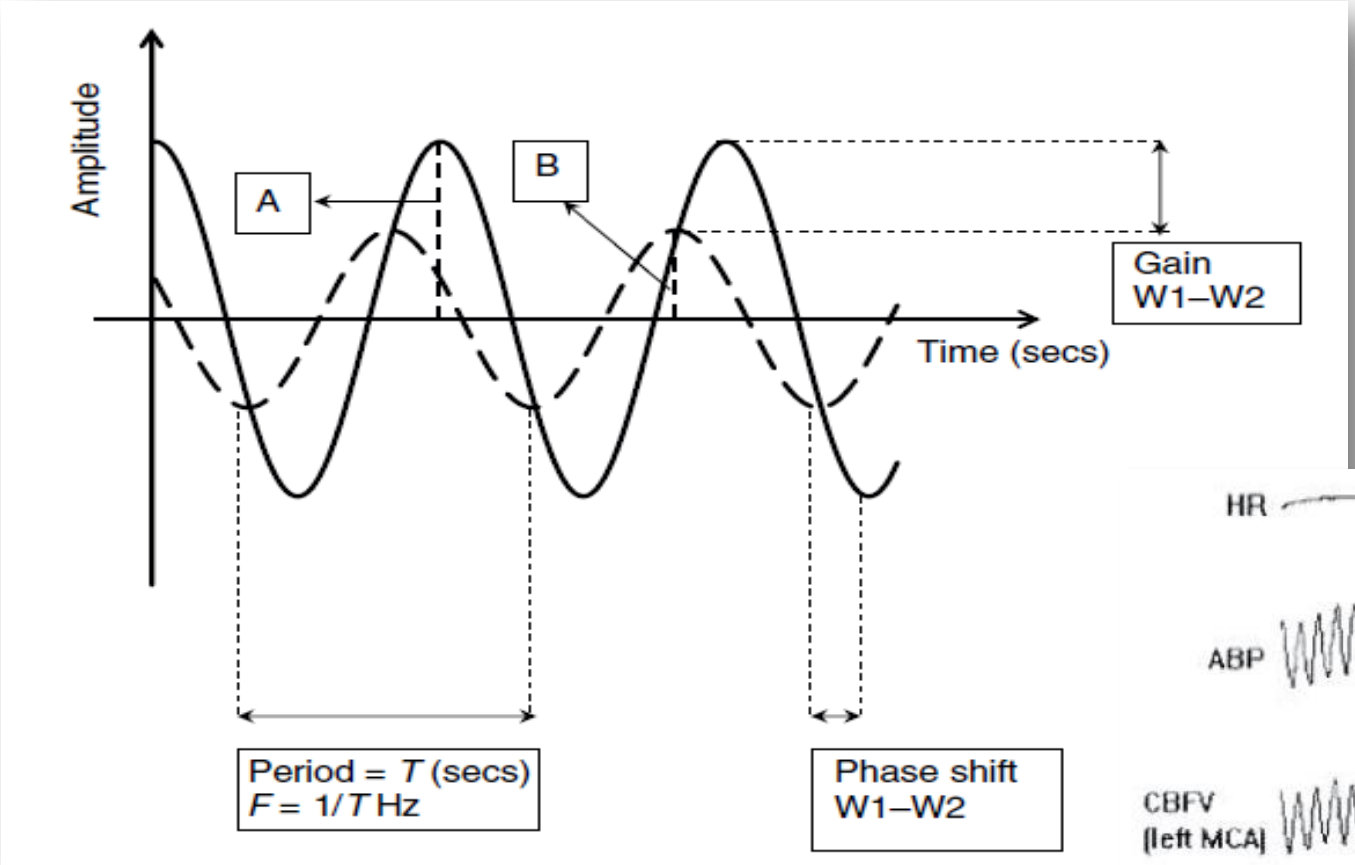


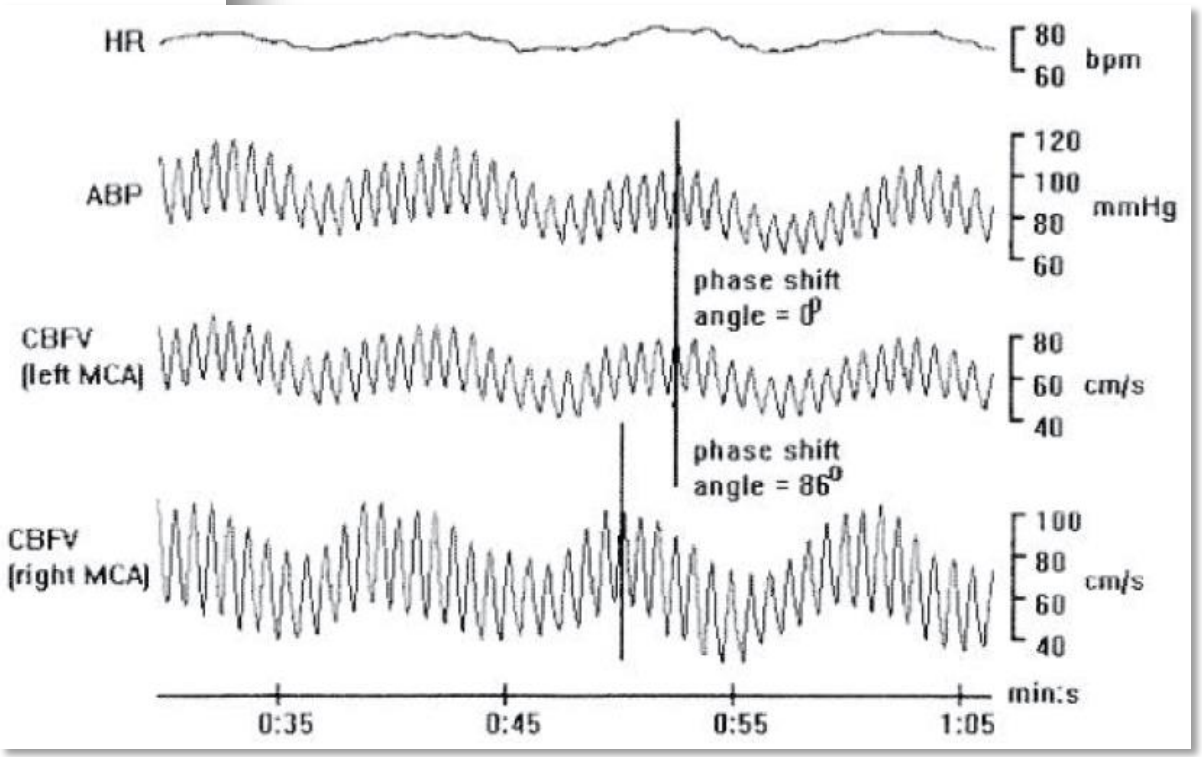


[1]F. P. Tiecks, A. M. Lam, R. Aaslid, and D. W. Newell, *Stroke*, 1995

[2] M. Czosnyka, P. Smielewski, P. Kirkpatrick, D. K. Menon, and J. D. Pickard, “Monitoring of cerebral autoregulation in head-injured patients,” Stroke, vol. 27, no. 10, pp. 1829–1834, 1996.

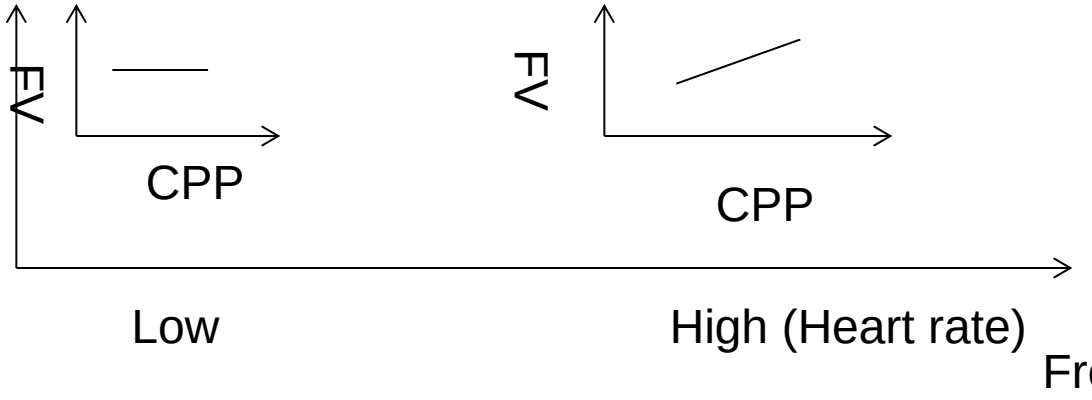
[3] RB. Panerai. Grading of Cerebral Dynamic Autoregulation From Spontaneous Fluctuations in Arterial Blood Pressure. Stroke. 1998

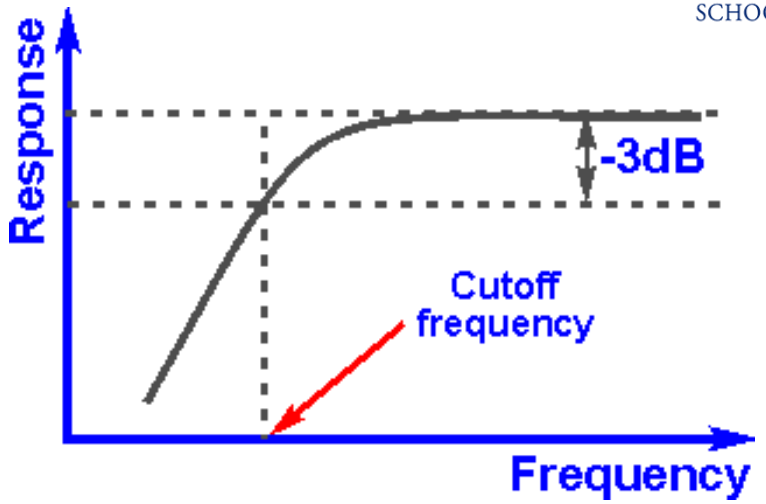


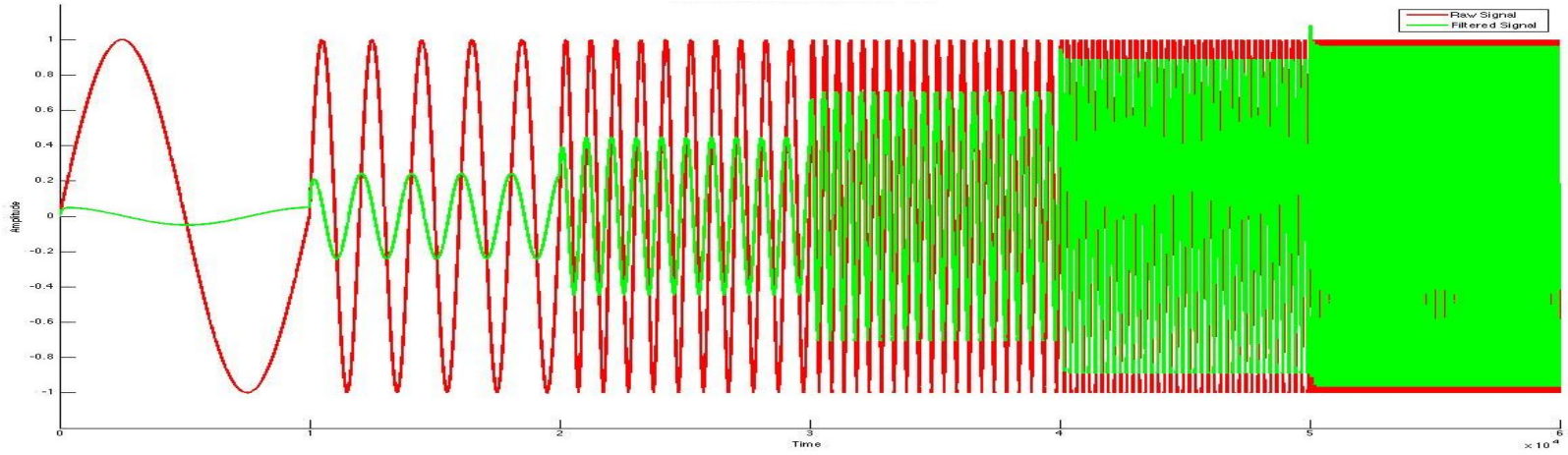


[1]Van Beek A, et al J Cerebr Blood Flow & Metab (2008) 28, 1071–1085

Frequency Domain

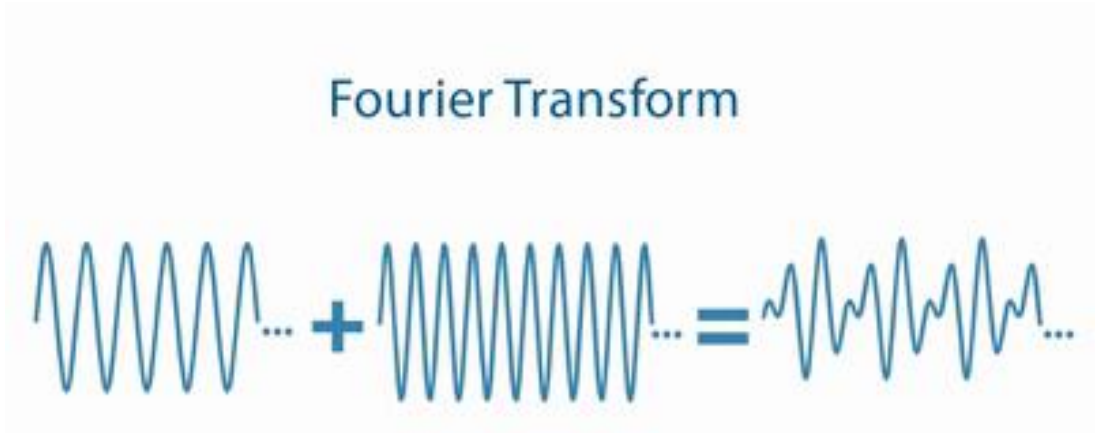




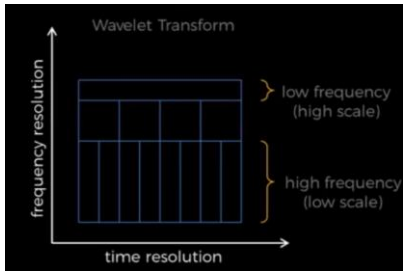


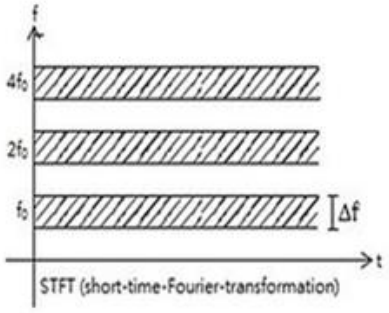
Input
Output

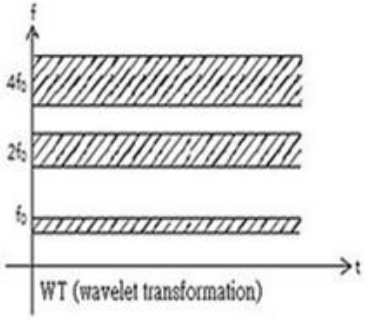
FFT vs Wavelet Transform



For Linear and Stationary system: statistical moments remain constant over time.

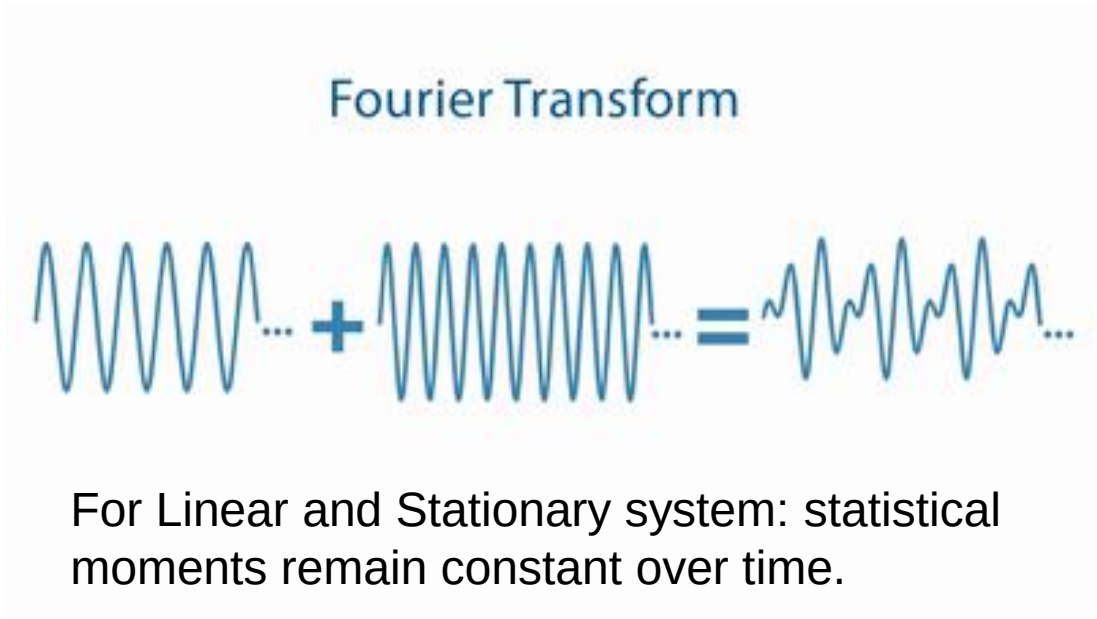




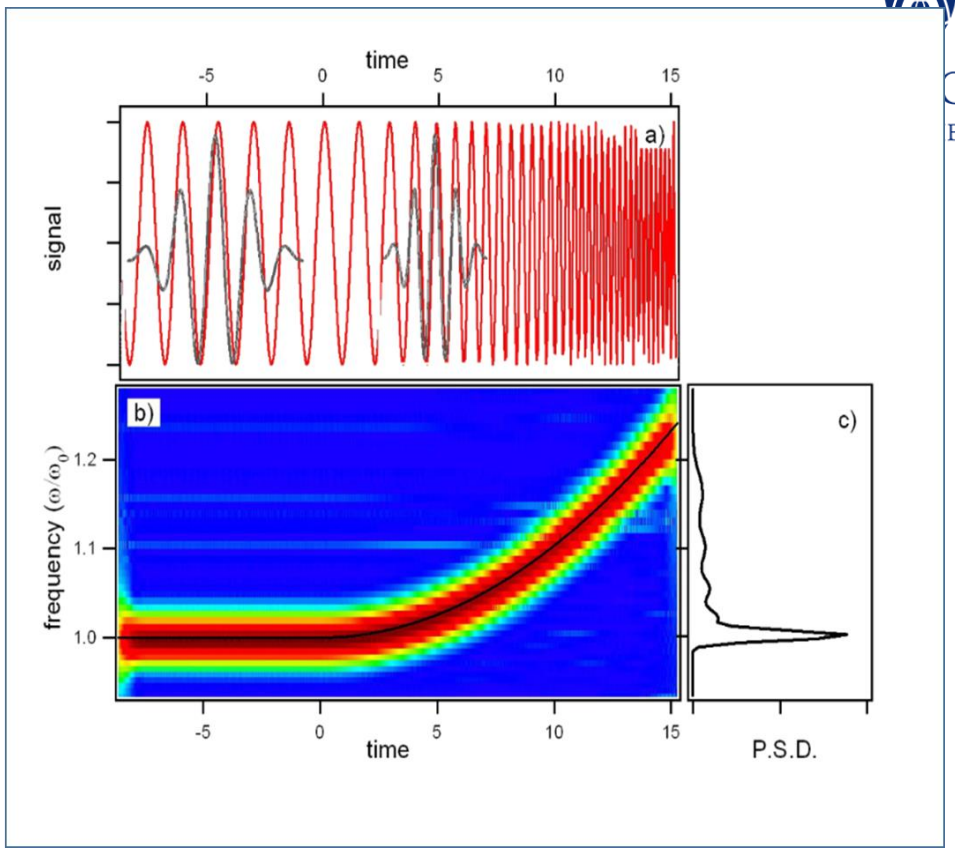


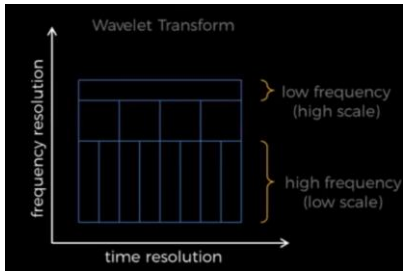
For non-stationary, noisy signal analysis. It is able to perform local analysis and reveal signal features with desired temporal–frequency resolution

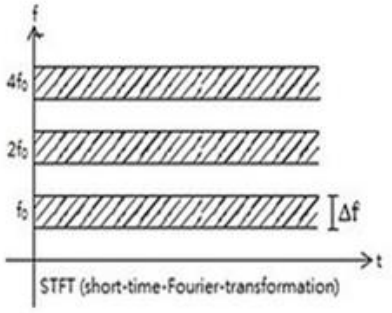
FFT vs Wavelet Transform

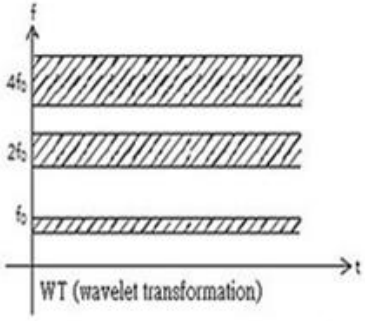


For Linear and Stationary system: statistical moments remain constant over time.





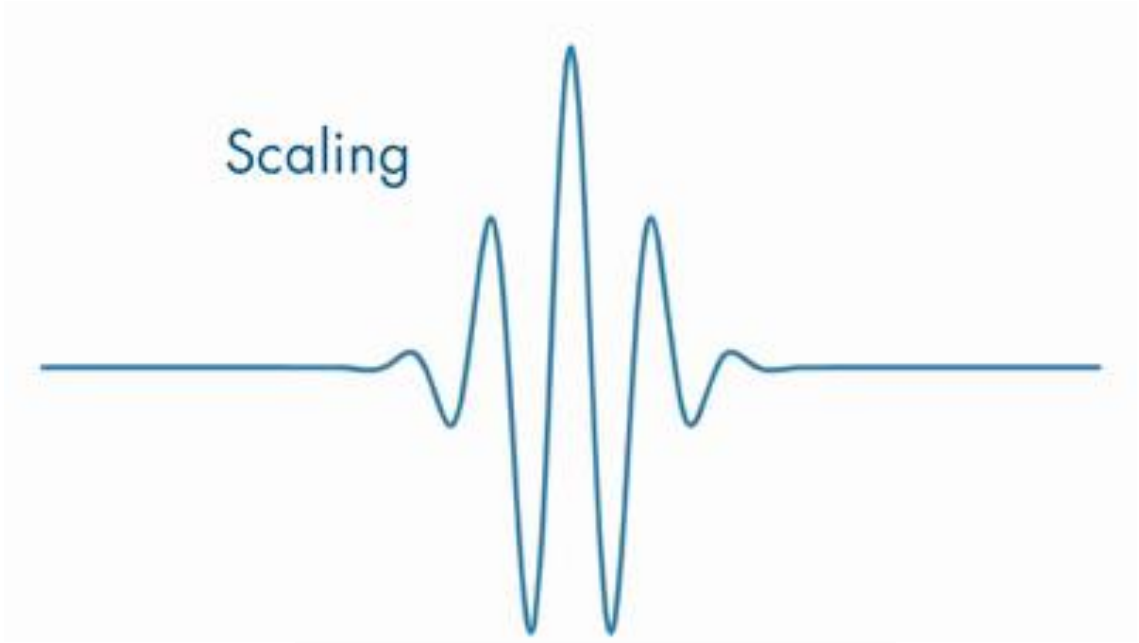


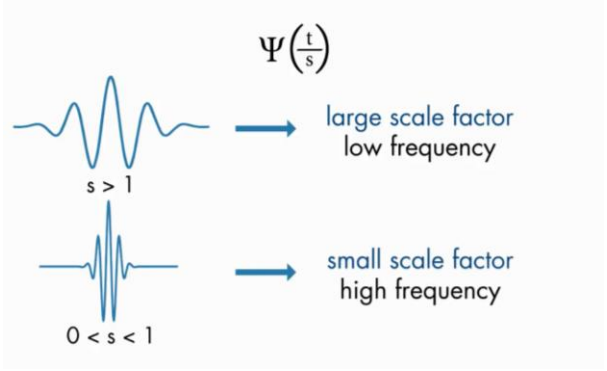


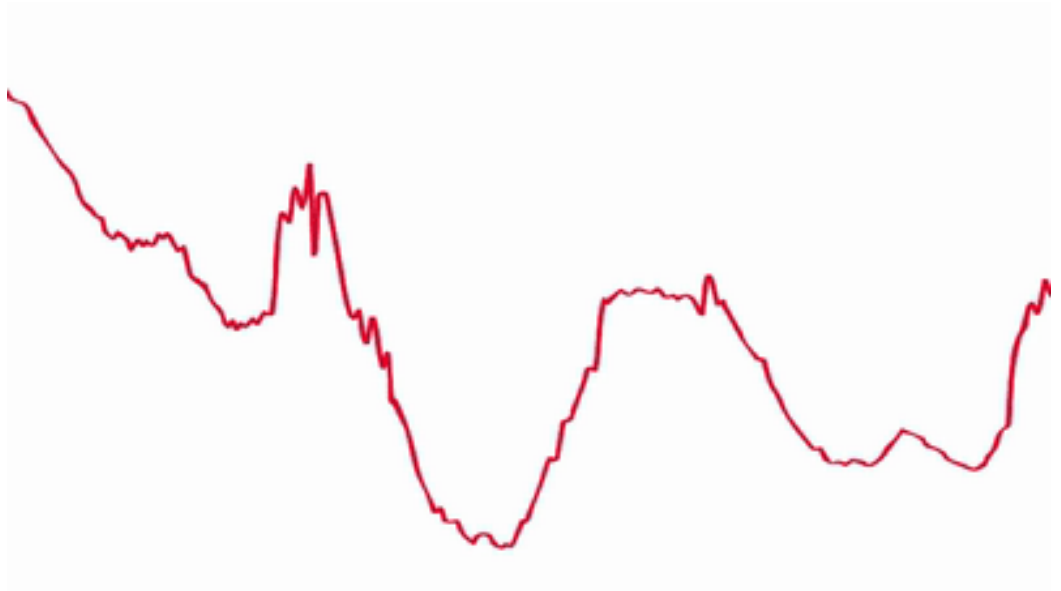
For non-stationary, noisy signal analysis. It is able to perform local analysis and reveal signal features with desired temporal–frequency resolution

Key Wavelet Concepts: Scaling & Shifting

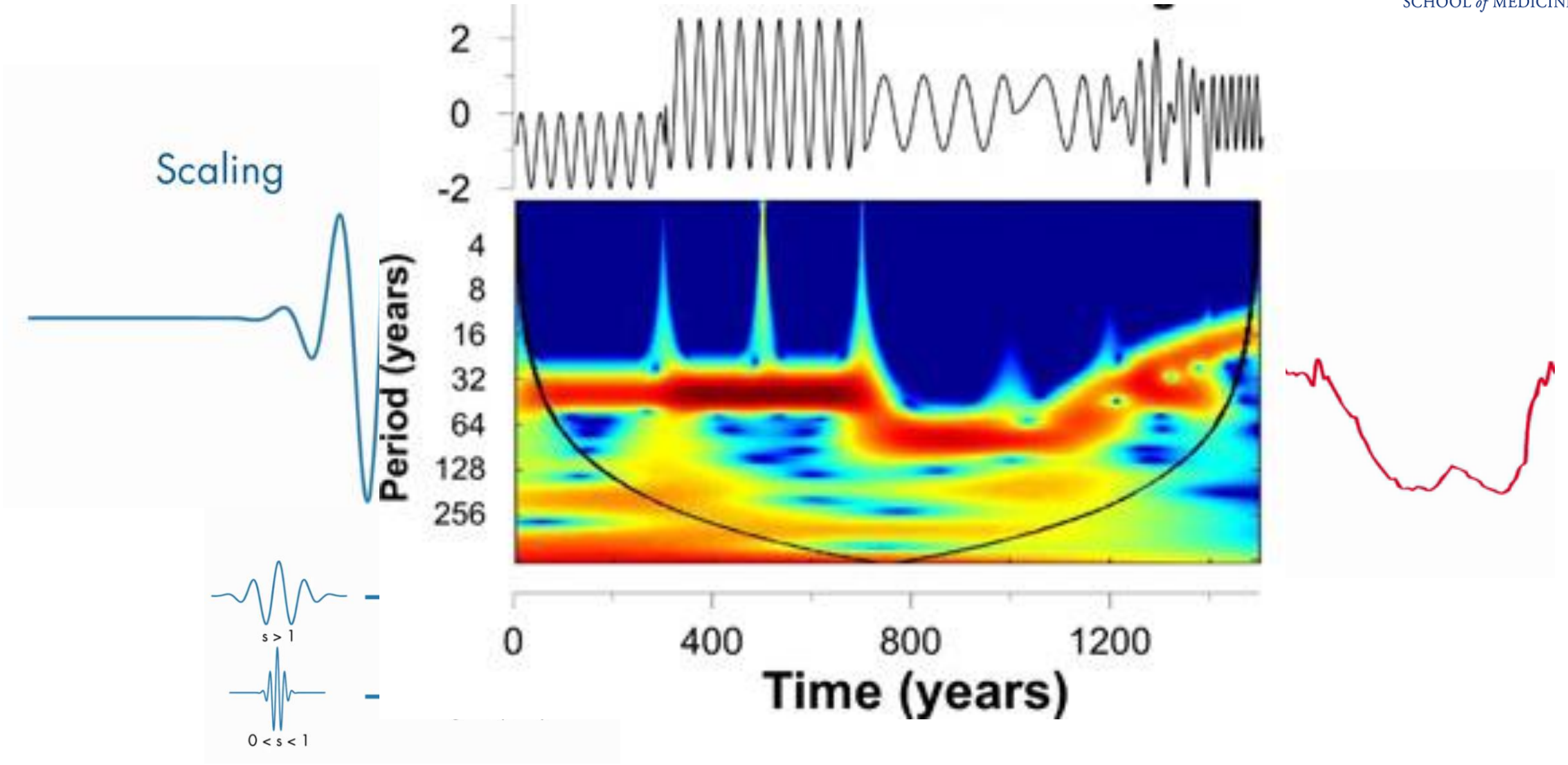
JOHNS HOPKINS
SCHOOL of MEDICINE







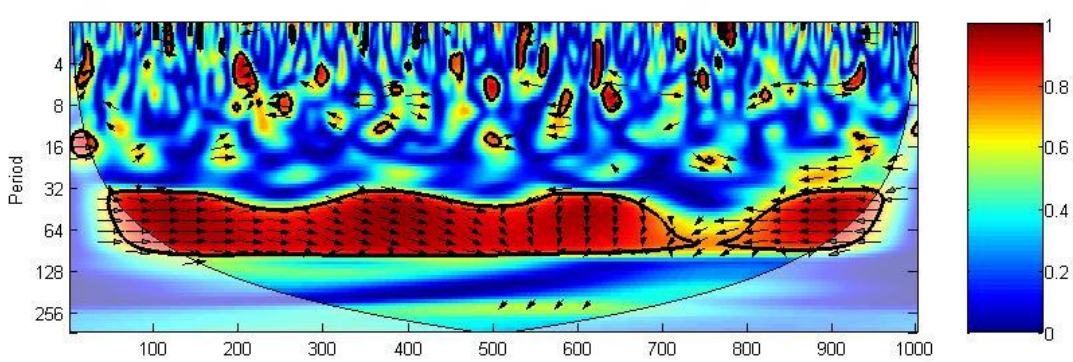
Key Wavelet Concepts: Scaling & Shifting

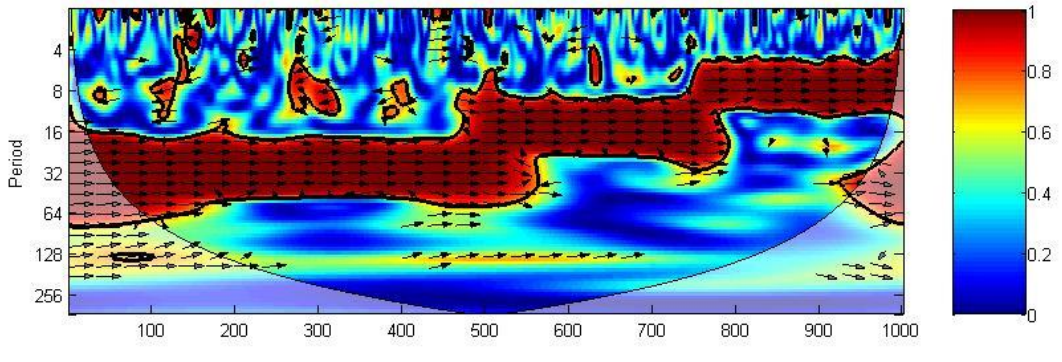


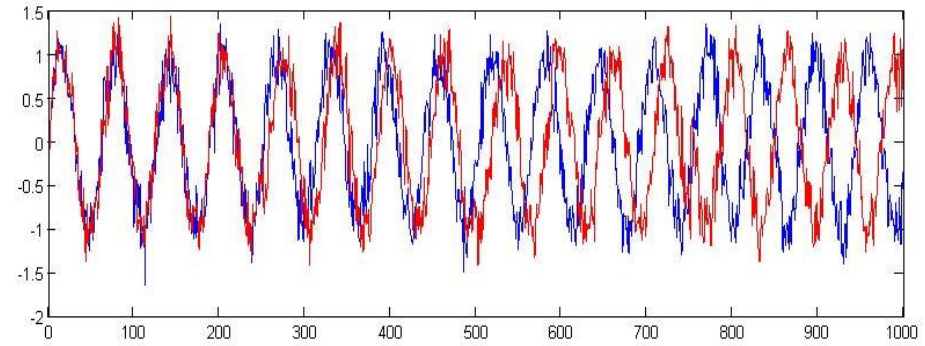
Key Wavelet Concepts: Scaling & Shifting

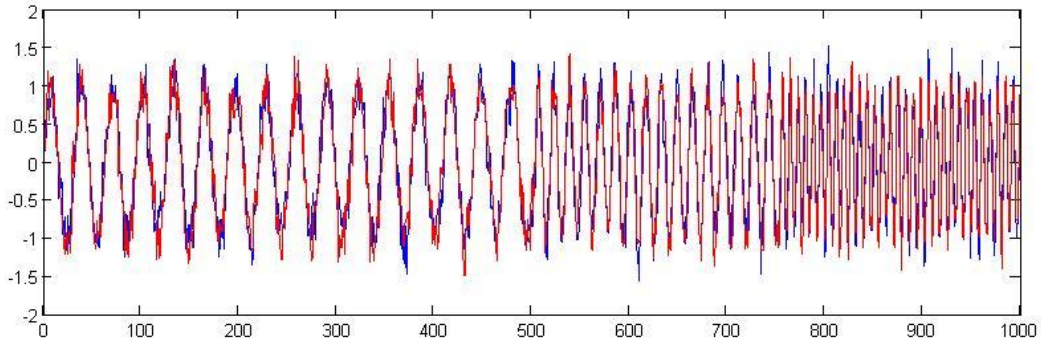
JOHNS HOPKINS
SCHOOL of MEDICINE

- Phase shift: produces a local measure of the delay between the two time series.
- Phase coherence: can be used to find correlated areas in time-frequency space of two signals

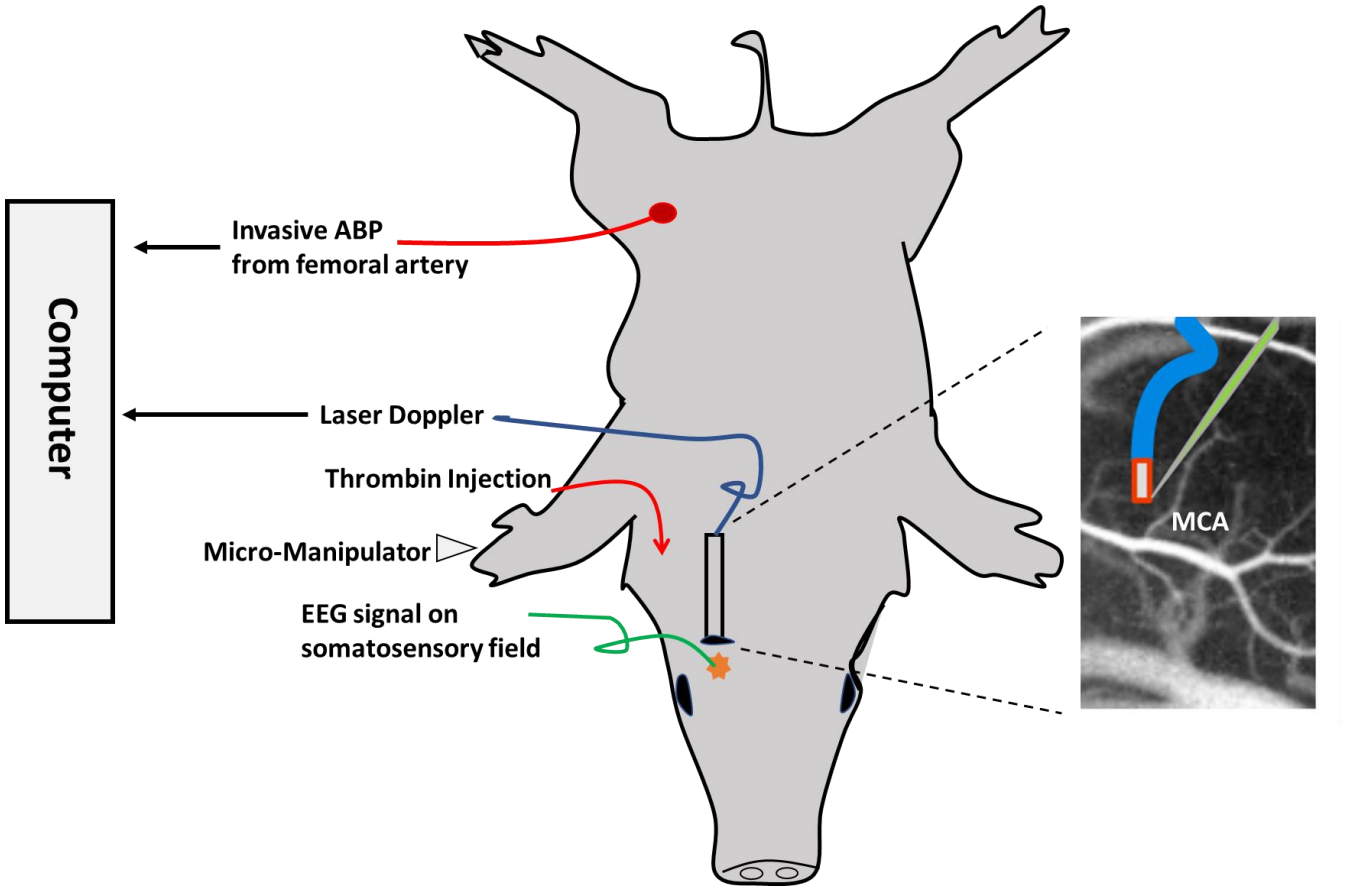






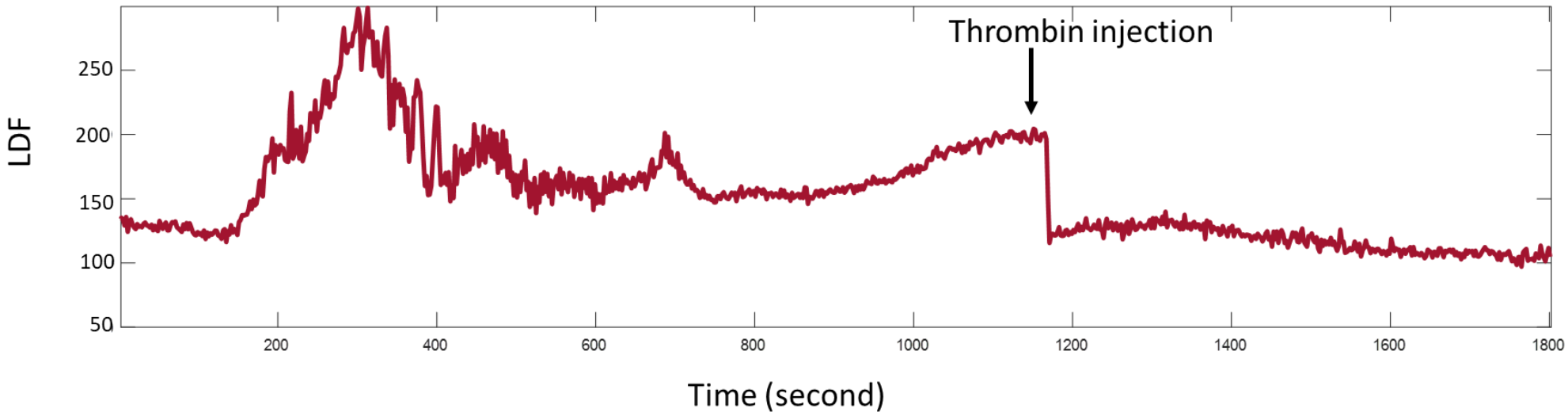


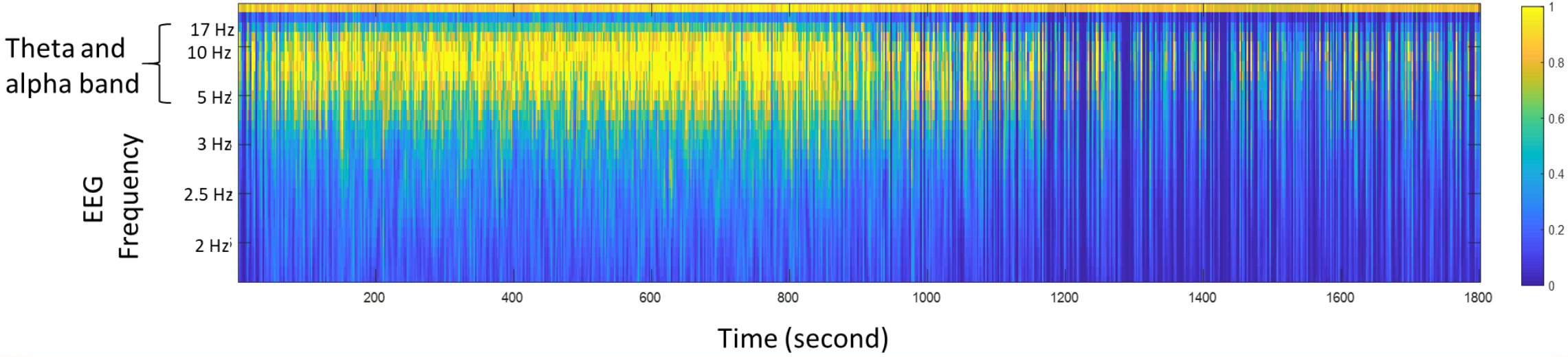
Piglet stroke model



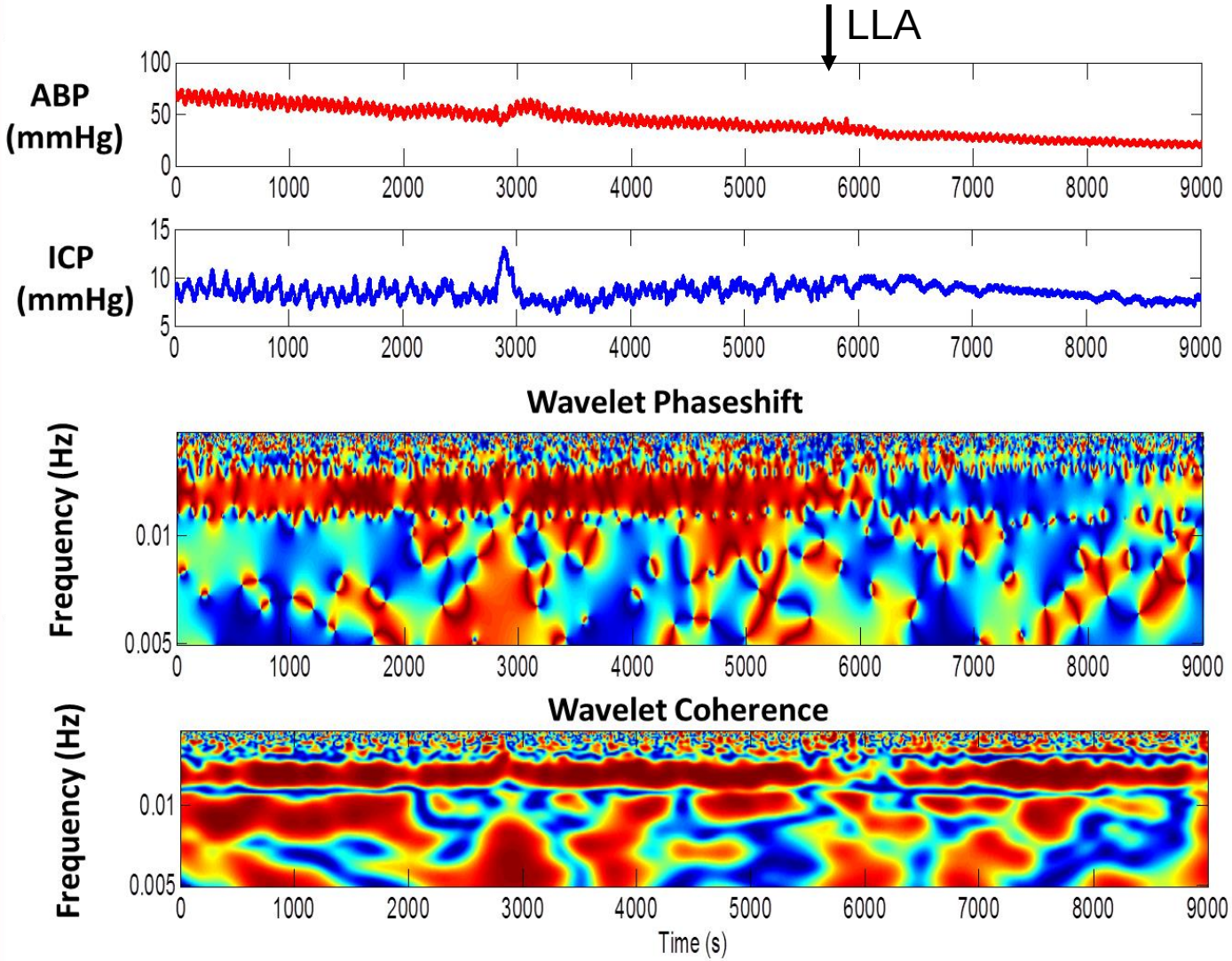
Thrombin is the principal enzyme of **hemostasis**. It catalyzes the conversion of fibrinogen to fibrin and activates procoagulant factors V, VIII, XI, and XIII.

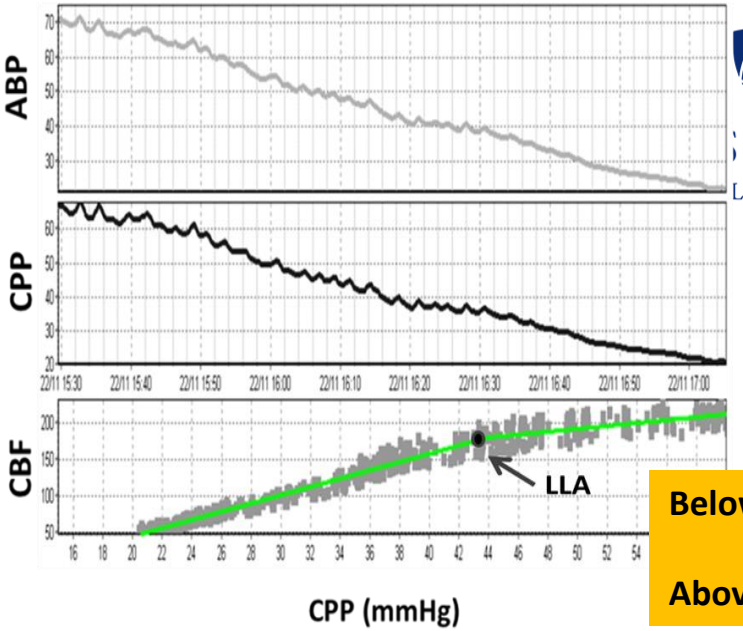
Wavelet for stroke model





Piglet Lower Limit of Autoregulation Model





Below LLA: bad CA

Above LLA: good CA

Wavelet phase shift between ABP and ICP: 0.0067 – 0.05 HZ

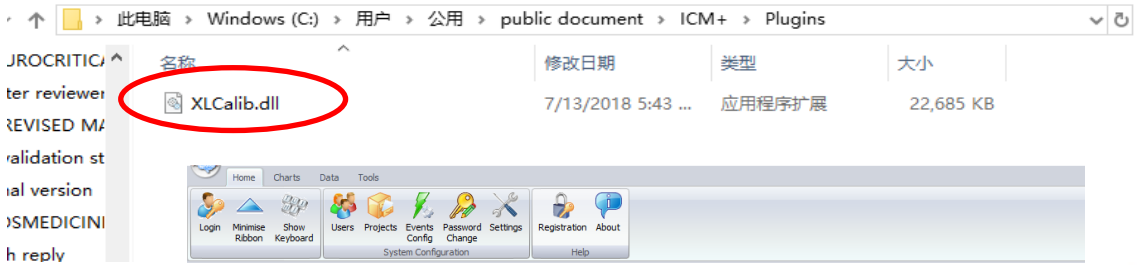
wPRx: cosine of phase shift

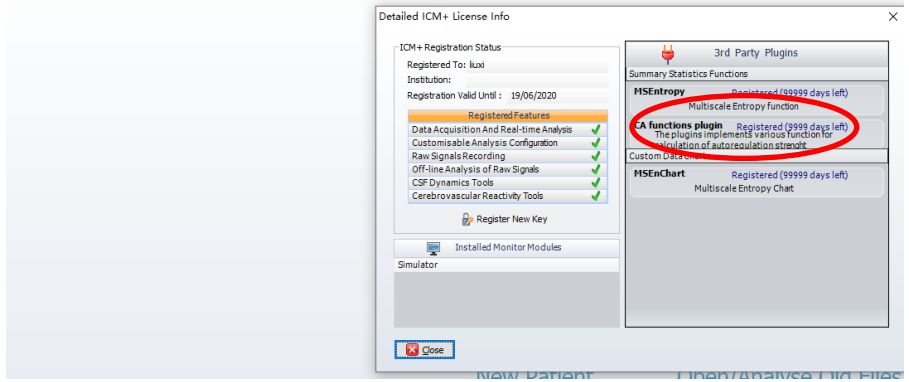
Coherence: was used to reject the Corresponding unreliable phase values through Monte Carol Simulations

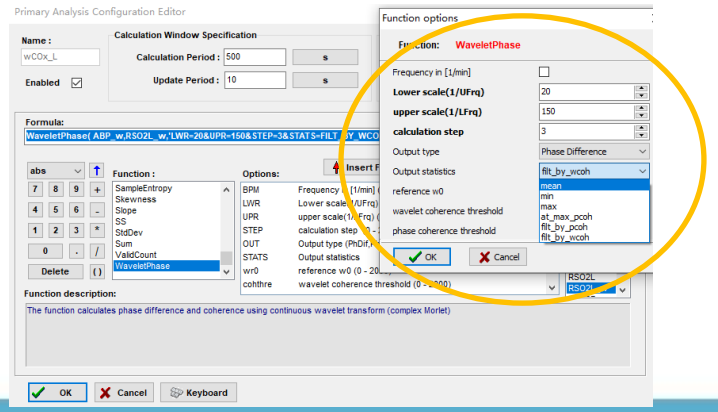
Thanks to Dr. Ken Brady and Dr. Jennifer Lee

Plugin in ICM+

Matlab → **Delphi** → **ICM+**



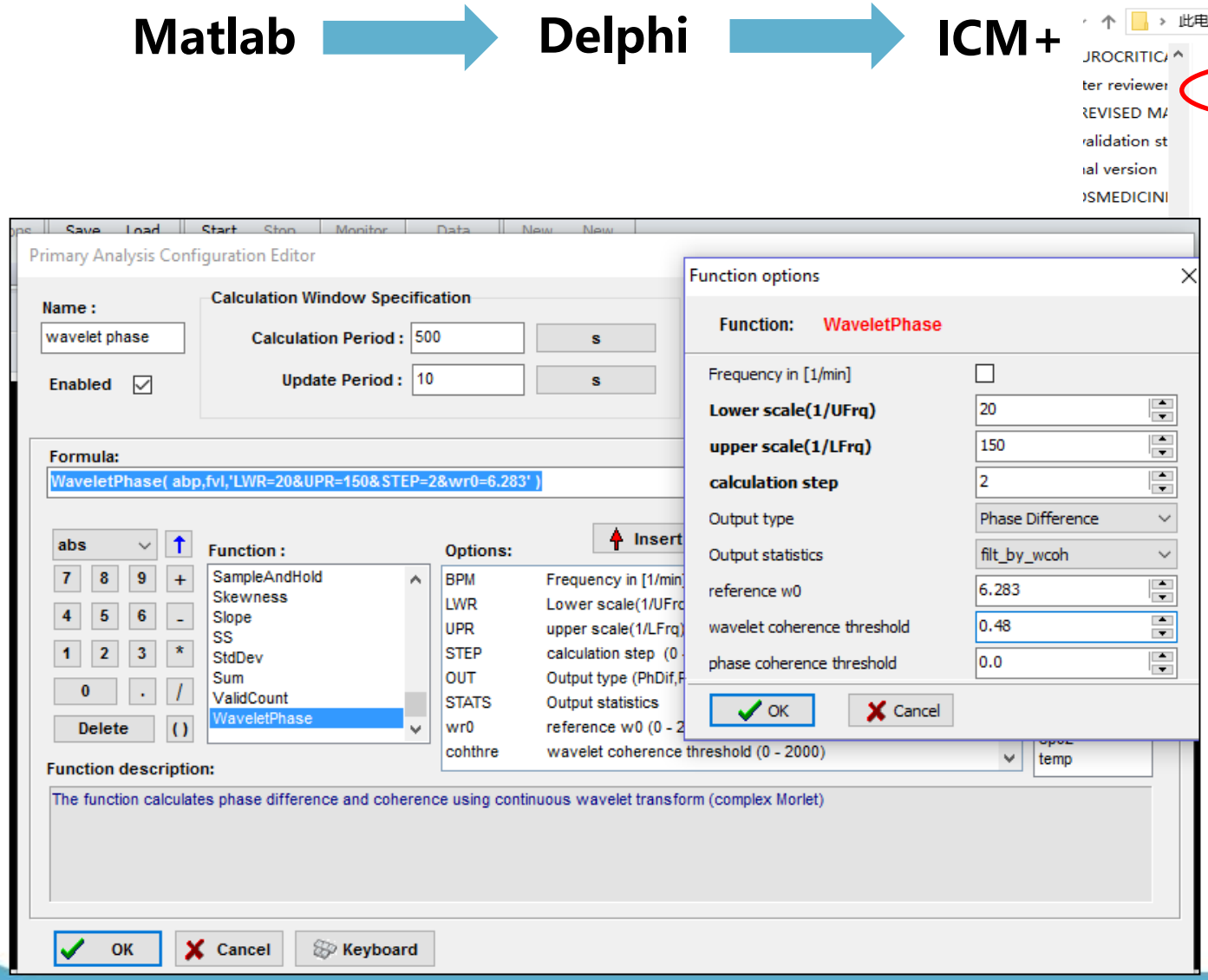


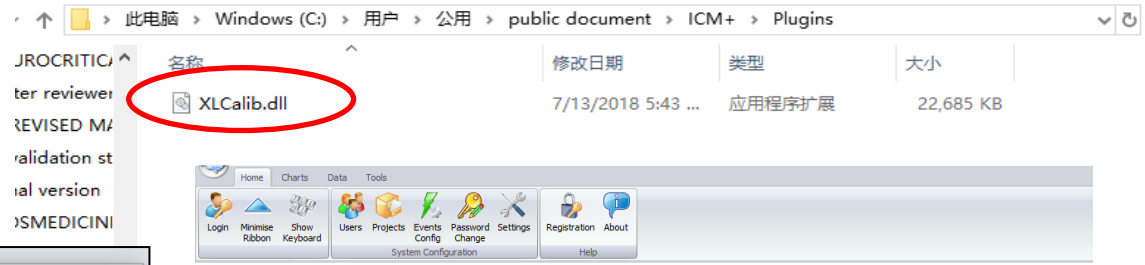


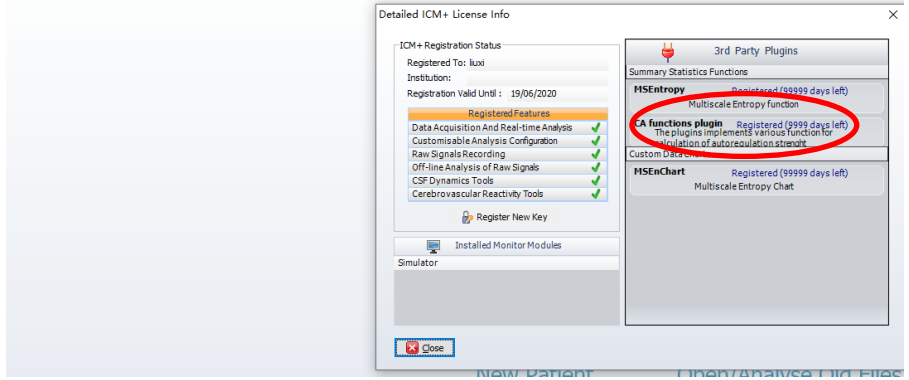
Plugin in ICM+

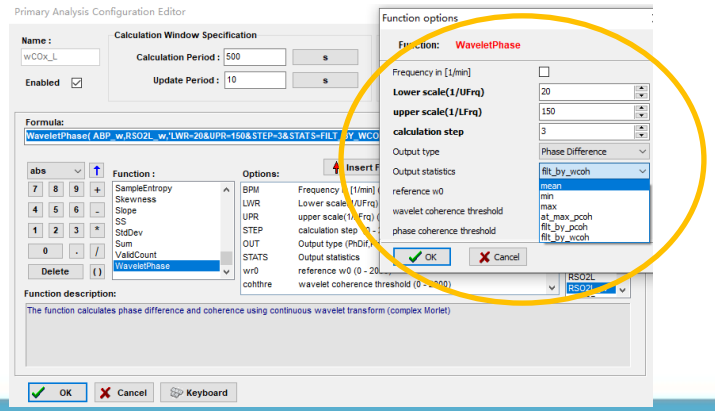
JOHNS HOPKINS
SCHOOL of MEDICINE

Matlab → **Delphi** → **ICM+**



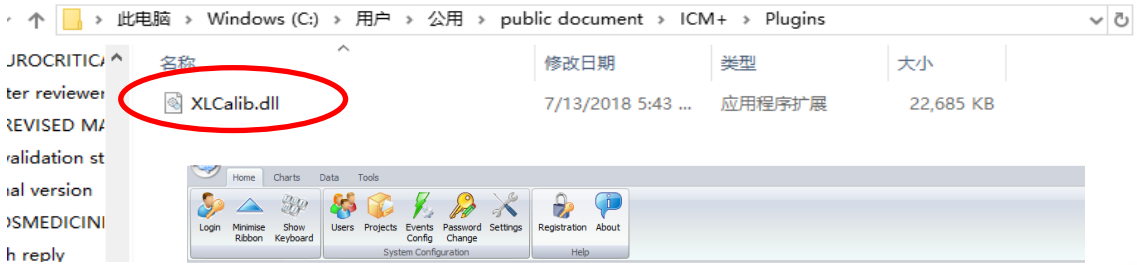


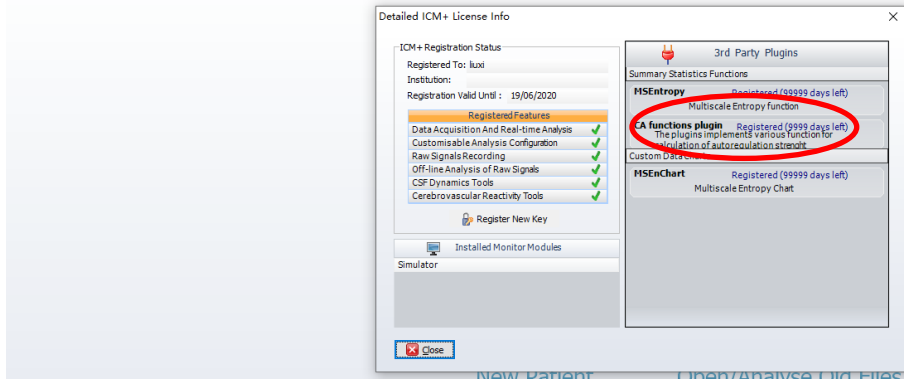


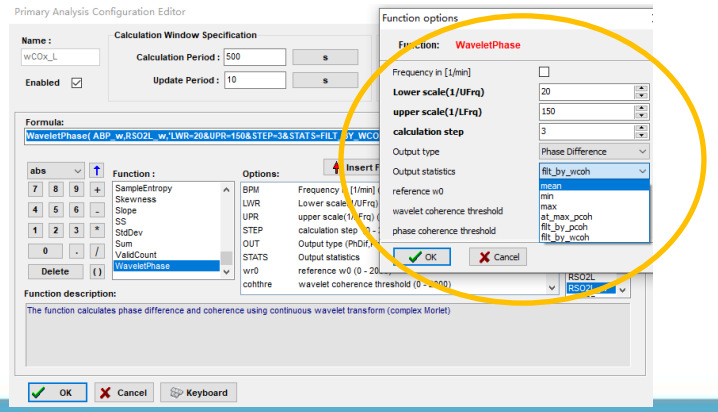


Plugin in ICM+

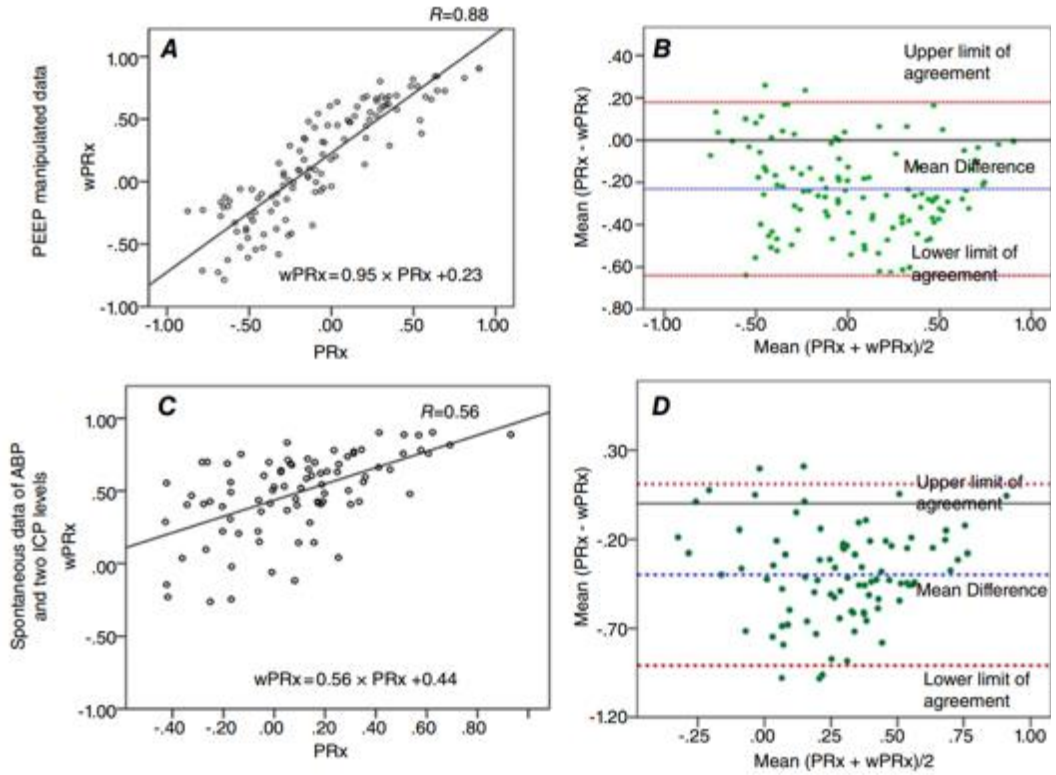
Matlab → **Delphi** → **ICM+**

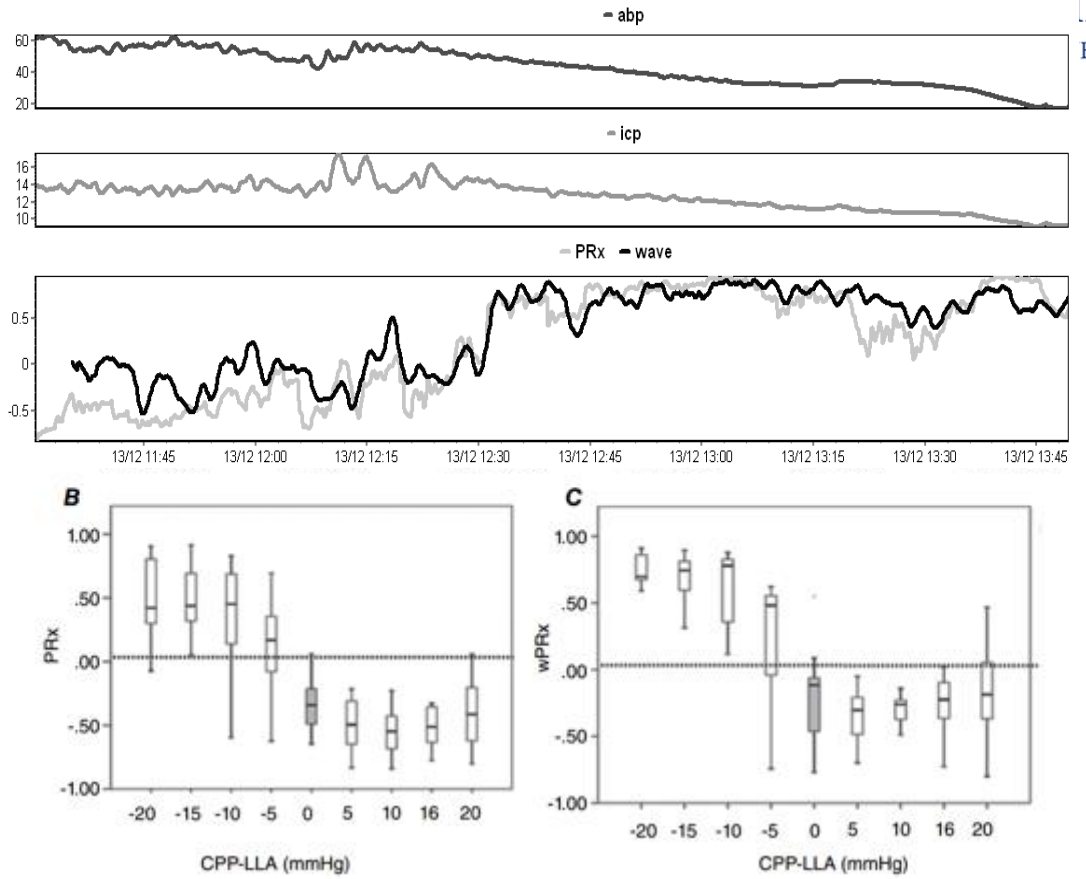






wPRx (wavelet PRx in piglet)





Thanks to Dr. Ken Brady

Wavelet for stroke model

The Journal of Physiology

Wavelet pressure reactivity index: a validation study

Xiuyun Liu[1,2], Marek Czosnyka[1,3], Joseph Donnelly[1,4], Danilo Cardim[1], Manuel Cabeleira[1], Peter J. Hutchinson[1], Xiao Hu[5], Peter Smielewski[1,*] and Ken Brady[6,*]

[1]Brain Physics Laboratory, Division of Neurosurgery, Department of Clinical Neurosciences, Addenbrooke's Hospital, University of Cambridge, Cambridge, UK
[2]Department of Physiological Nursing, UCSF, San Francisco, CA, USA
[3]Institute of Electronic Systems, Warsaw University of Technology, Poland
[4]Department of Anaesthesiology, University of Auckland, Auckland, New Zealand
[5]Faculty of Medicine, Department of Anesthesiology, Pharmacology & Therapeutics, The University of British Columbia, Vancouver, Canada
[6]Baylor College of Medicine, Houston, TX, USA

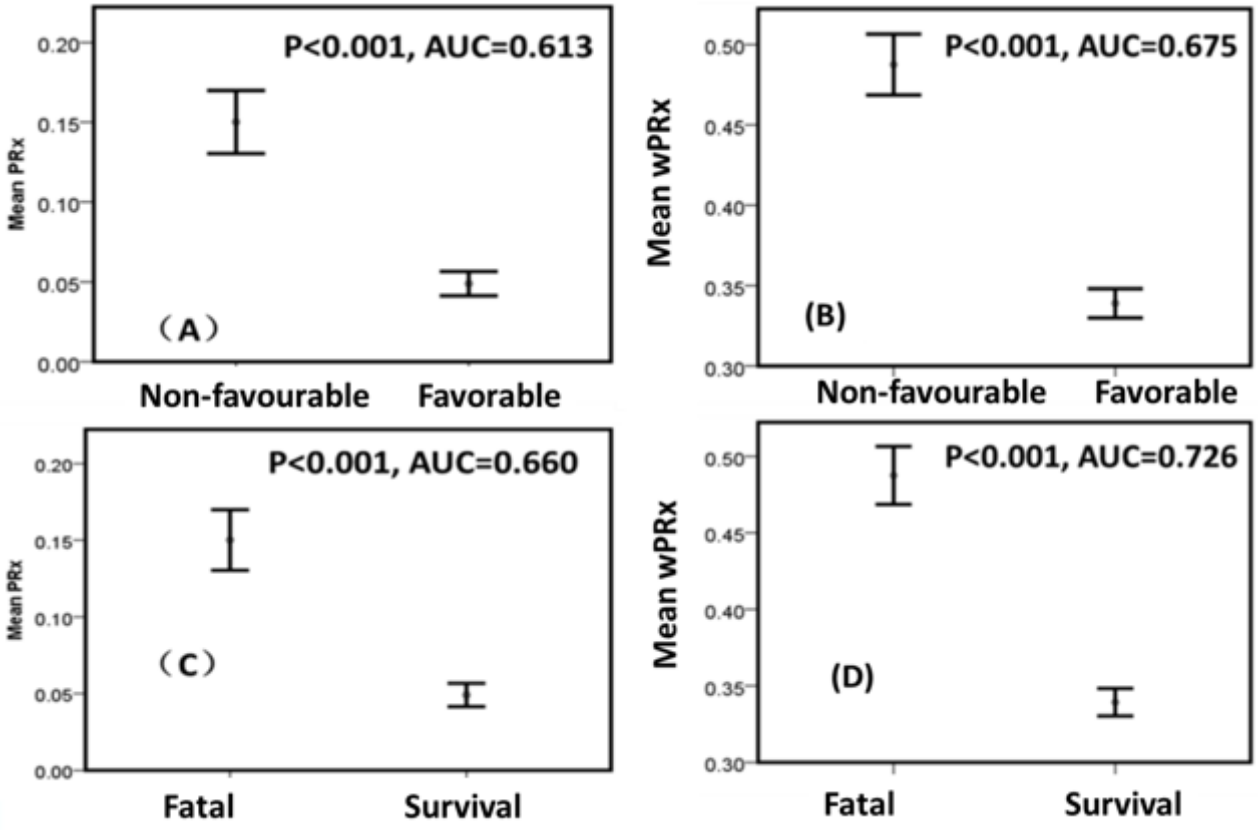
Edited by: Harold Schultz & Laura Bennet

Key points

- The brain is vulnerable to damage from too little or too much blood flow. A physiological mechanism termed cerebral autoregulation (CA) exists to maintain stable blood flow even if cerebral perfusion pressure (CPP) is changing.
- A robust method for assessing CA is not yet available. There are still some problems with the traditional measure, the pressure reactivity index (PRx).
- We introduce a new method, the wavelet transform method (wPRx), to assess CA using data from two sets of controlled hypotension experiments in piglets: one set had artificially manipulated arterial blood pressure (ABP) oscillations; the other group were spontaneous ABP waves.
- A significant linear relationship was found between wPRx and PRx in both groups, with wPRx providing a more stable result for the spontaneous waves.
- Although both methods showed similar accuracy in distinguishing intact and impaired CA, it seems that wPRx tends to perform better than PRx, although not significantly so.

Abstract We present a novel method to monitor cerebral autoregulation (CA) using the wavelet transform (WT). The new method is validated against the pressure reactivity index (PRx) in two piglet experiments with controlled hypotension. The first experiment (*n* = 17) had controlled

wPRx in TBI patients



PLOS MEDICINE

RESEARCH ARTICLE

Cerebrovascular pressure reactivity monitoring using wavelet analysis in traumatic brain injury patients: A retrospective study

Xiuyun Liu[1]*, Joseph Donnelly[1], Marek Czosnyka[1,2], Marcel J. H. Aries[1,3], Ken Brady[4], Danilo Cardim[1], Chiara Robba[1,5], Manuel Cabeleira[1], Dong-Joo Kim[6], Christina Haubrich[7], Peter J. Hutchinson[1], Peter Smielewski[1]

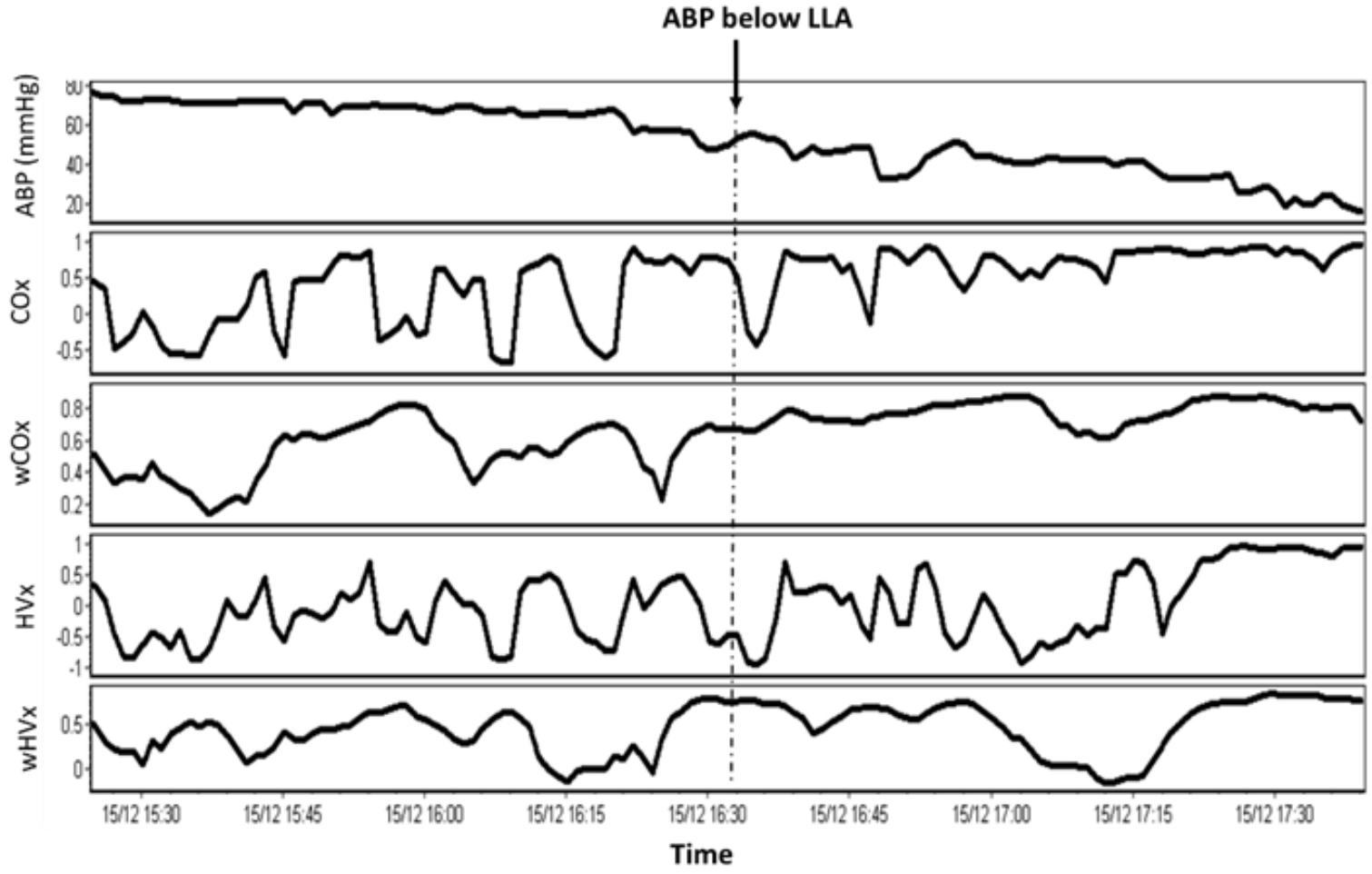
1 Division of Neurosurgery, Department of Clinical Neurosciences, Addenbrooke's Hospital, University of Cambridge, Cambridge, United Kingdom, **2** Institute of Electronic Systems, Warsaw University of Technology, Poland, **3** Department of Intensive Care, University of Maastricht, Maastricht University Medical Center, Maastricht, The Netherlands, **4** Baylor College of Medicine, Houston, Texas, United States of America, **5** Department of Neuroscience, University of Genova, Genova, Italy, **6** Department of Brain & Cognitive Engineering, Korea University, Seoul, South Korea, **7** Faculty of Medicine, University of Aachen, Germany

* xl334@cam.ac.uk

wCOx, wHVx in piglets

JOHNS HOPKINS
SCHOOL of MEDICINE

68 pediatric piglets after cardiac arrest

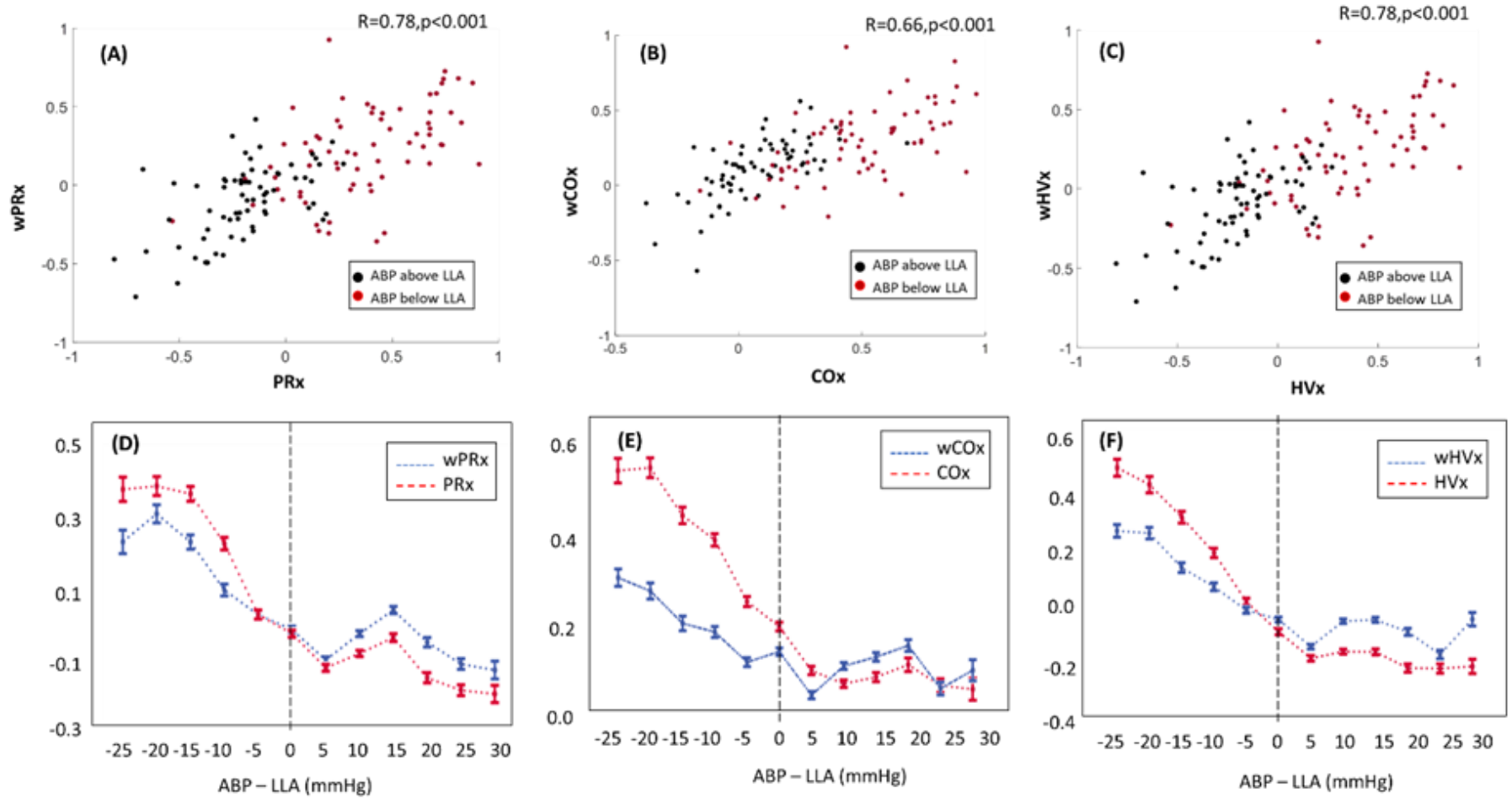


Thanks to Dr. Jennifer Lee

wCOx, wHVx in piglets

JOHNS HOPKINS
SCHOOL of MEDICINE

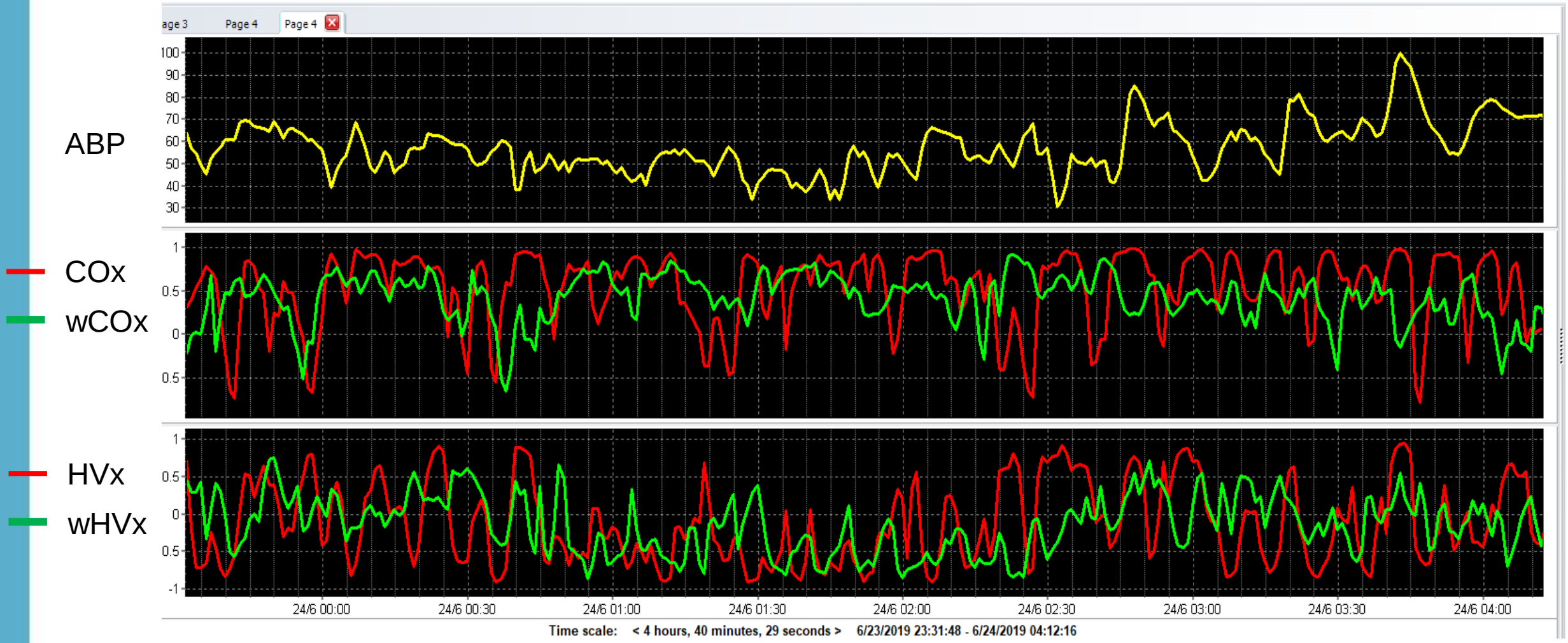
68 pediatric piglets after cardiac arrest



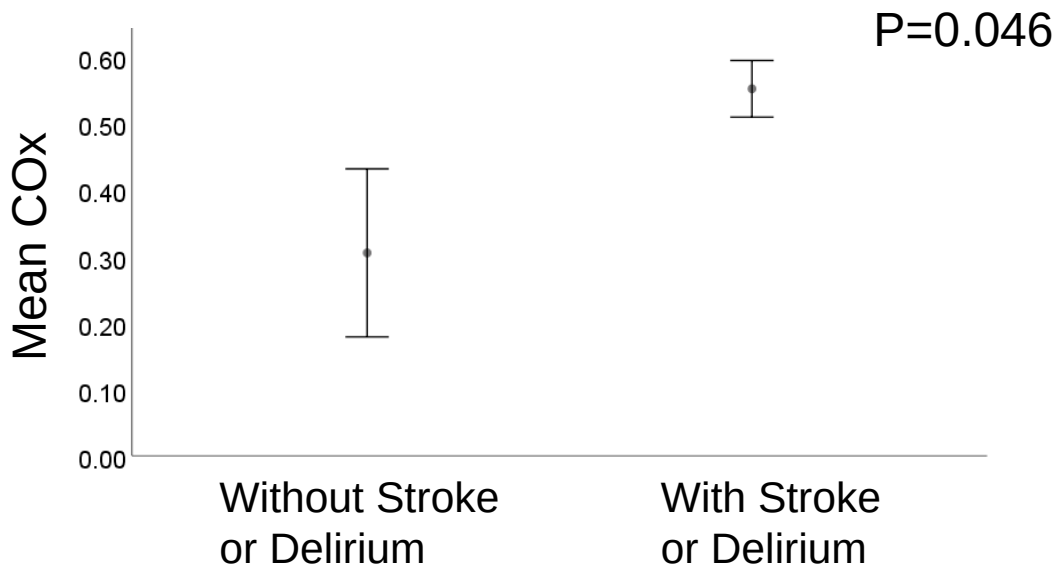
Thanks to Dr. Jennifer Lee

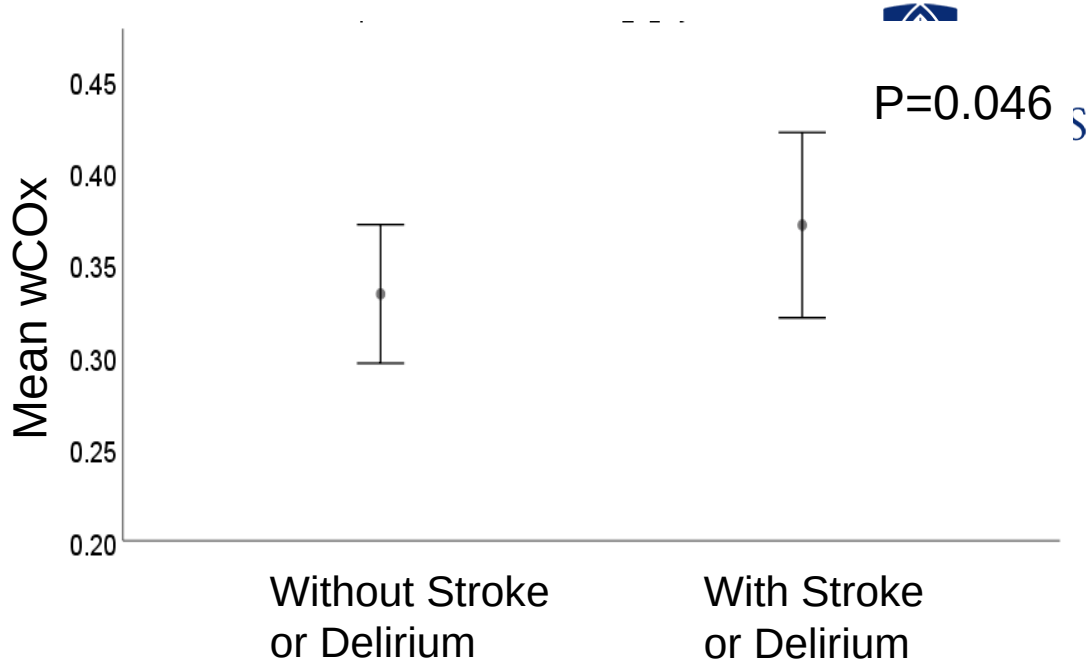
wCOx in lung transplant patients

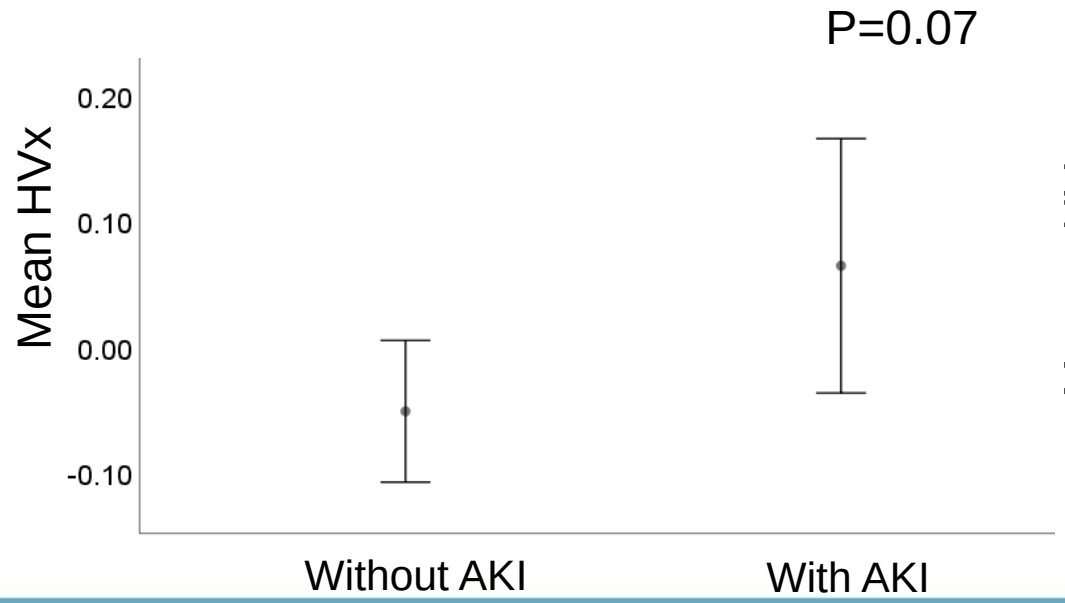
JOHNS HOPKINS
SCHOOL of MEDICINE

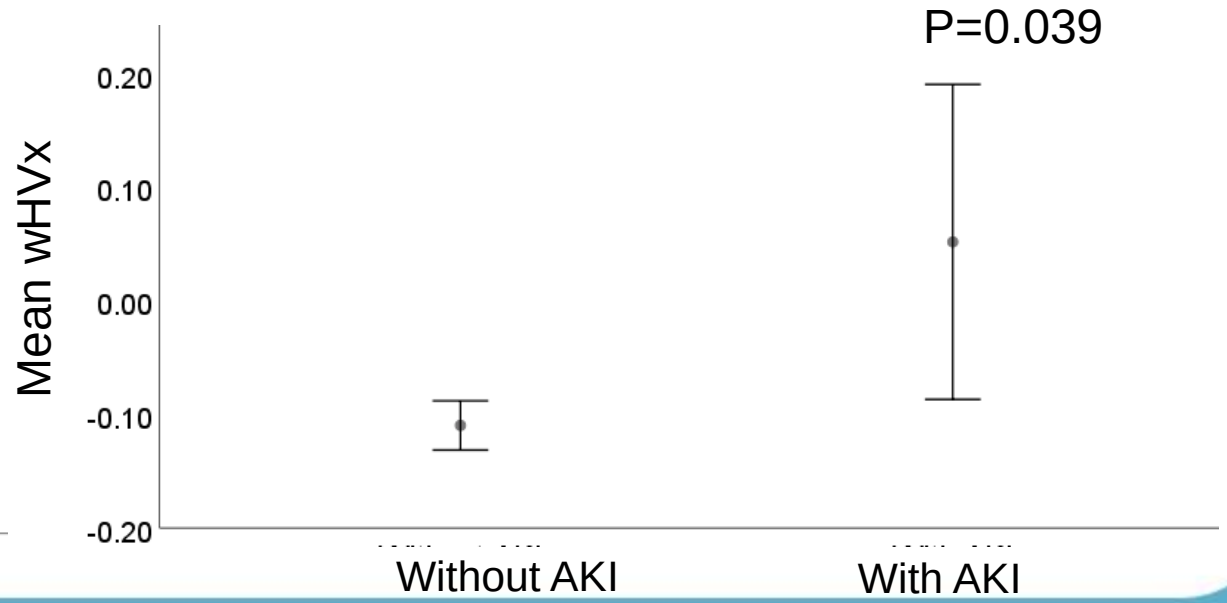


wCOx in lung transplant patients



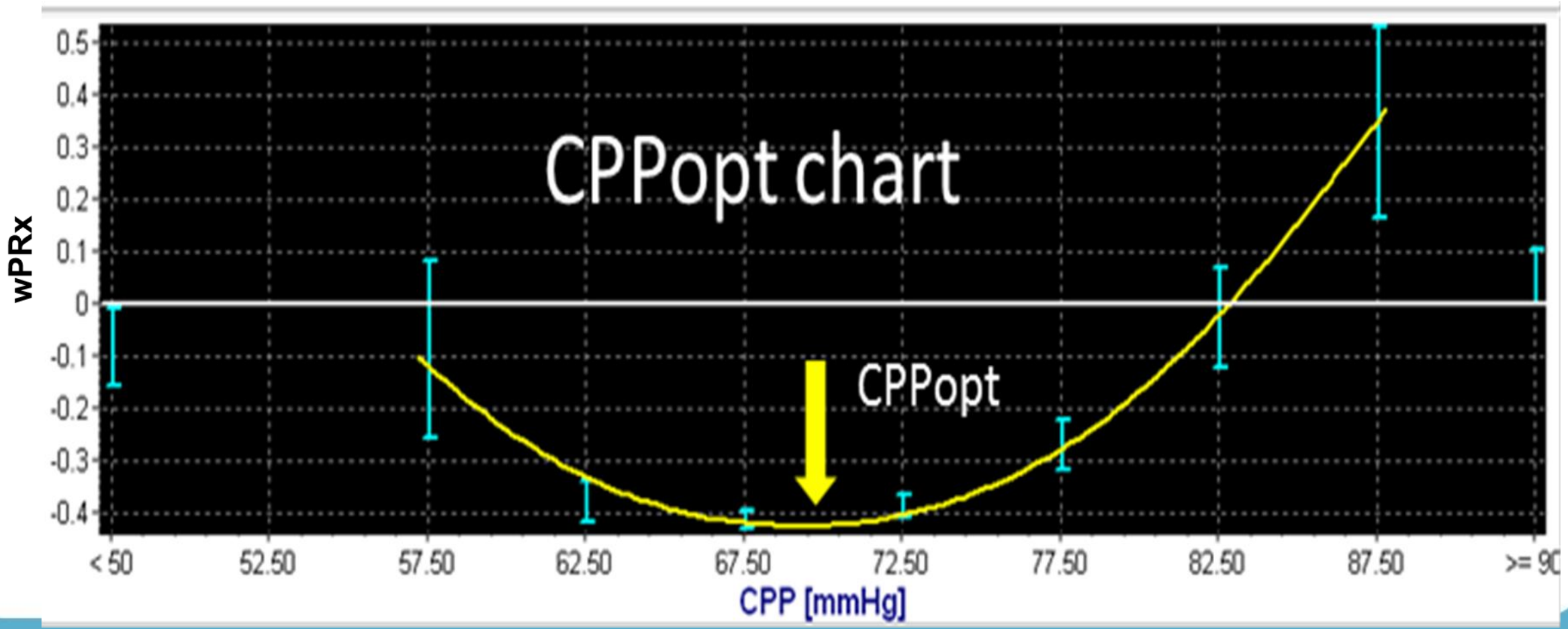




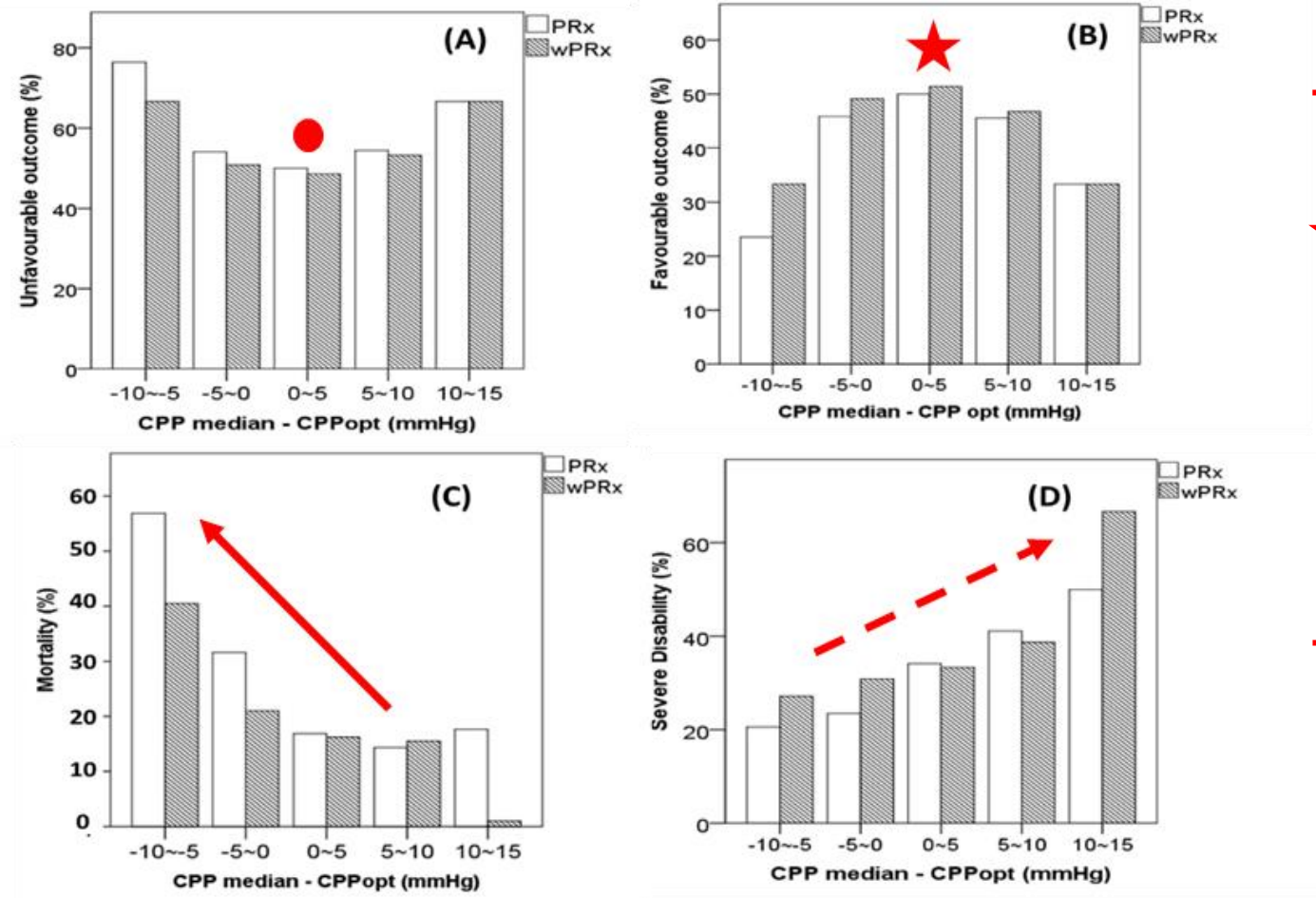


wPRx for CPPopt

Over the years, a dynamic patient-targeted CPP protocol based on the CA ability of cerebral vasculature has been proposed. In 2002, Steiner et al, introduced this concept of looking at CPPopt by plotting PRx against CPP to generate a U shape curve from the whole monitoring period.



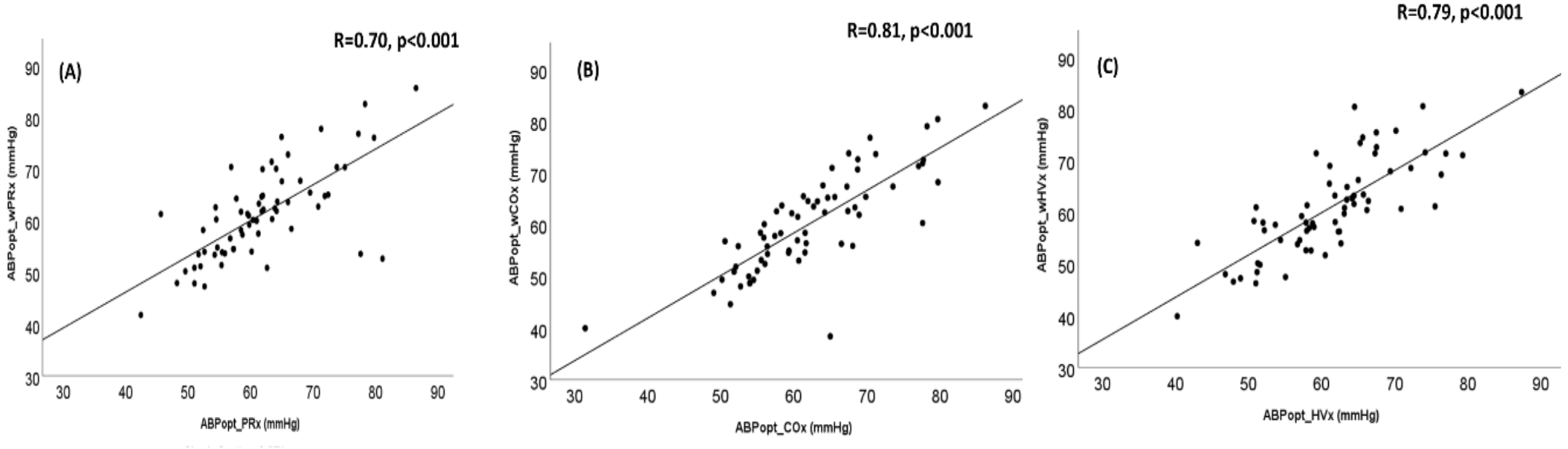
wPRx for CPPopt

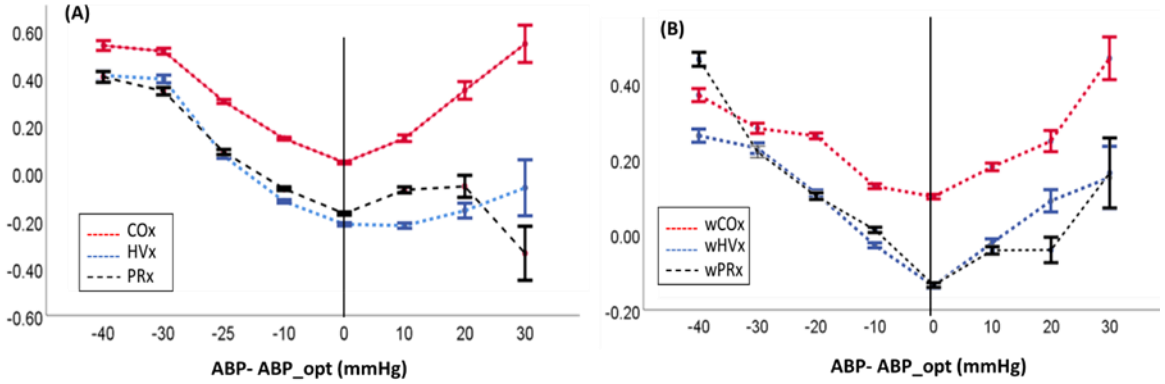


- The mortality increased steadily with the median CPP shifting below CPPopt.
- An inverse 'U'-shape curve with the highest favourable outcome rate appeared at the smallest difference between CPP and CPPopt.
- In contrast, the unfavourable outcome showed a rate increasing below or above CPPopt.
- The disability rate was increased while median CPP is above CPPopt .

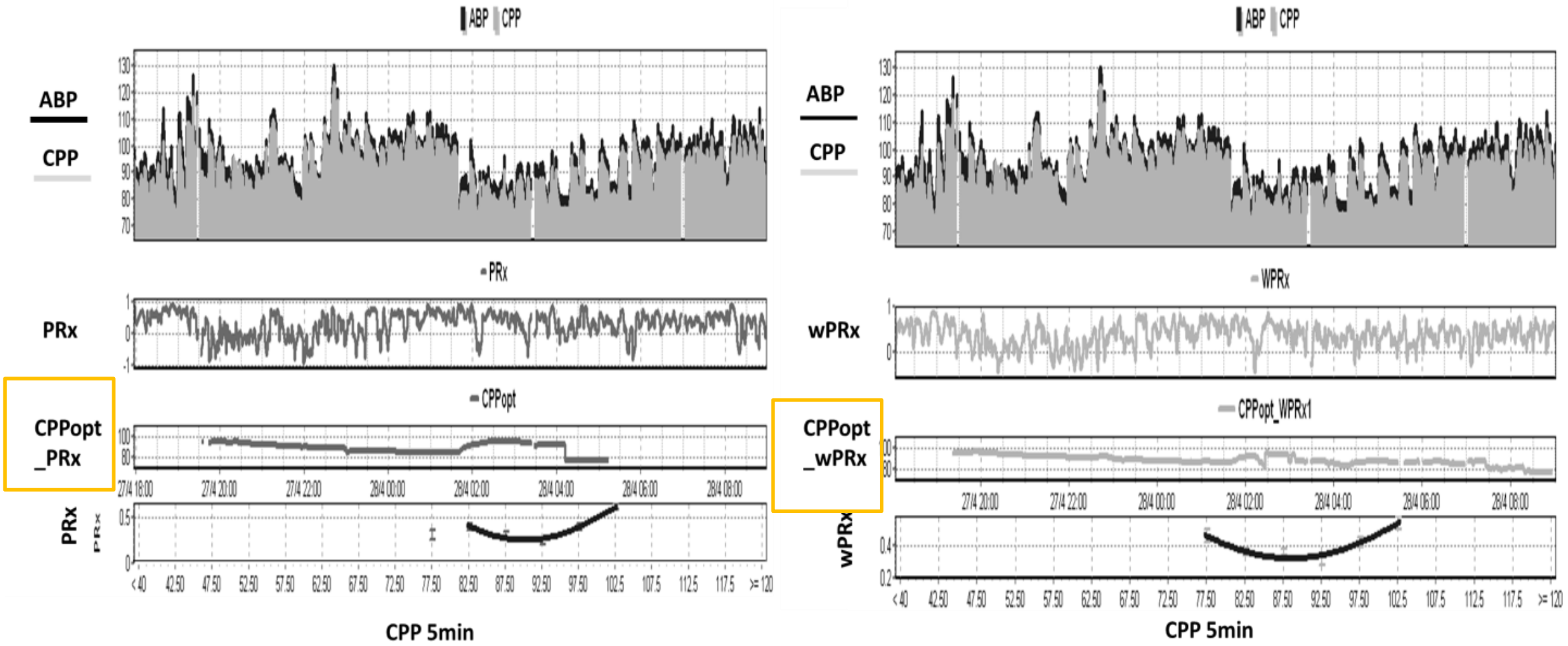
Cerebrovascular pressure reactivity monitoring using wavelet analysis in traumatic brain injury patients: A retrospective study. Xiuyun Liu ,Joseph Donnelly, et al. Plos Medicine, 2017

wPRx for ABPopt





wPRx for ABPopt




Thank you for your listening.
liuxiuyun1@gmail.com