Neuromonitoring au cours de la chirurgie cardiaque pédiatrique sous CEC

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Actualisation 12/2022: DIU Anesthésie Réanimation des Cardiopathies Congénitales

Plan

- Introduction: conséquences neurologiques de la CEC
- Débit Sanguin cérébral, estimation par la NIRS
- Autorégulation cérébrale pendant la CEC
  - Théorie
  - Mesure non invasive, Cox
  - Preuve de concept chez l'adulte
  - Résultats préliminaires en pédiatrie
- Autres éléments du neuromonitoring per CEC
- Conclusion

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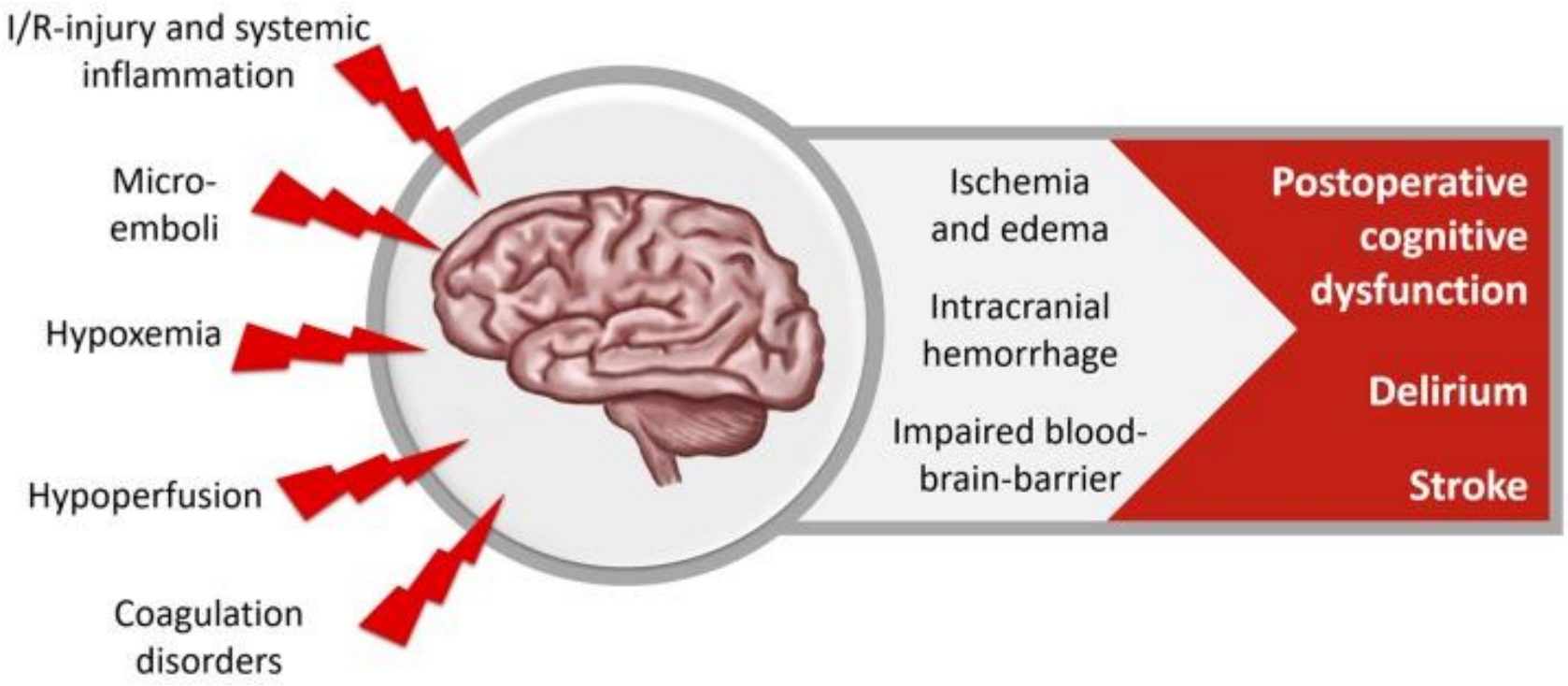
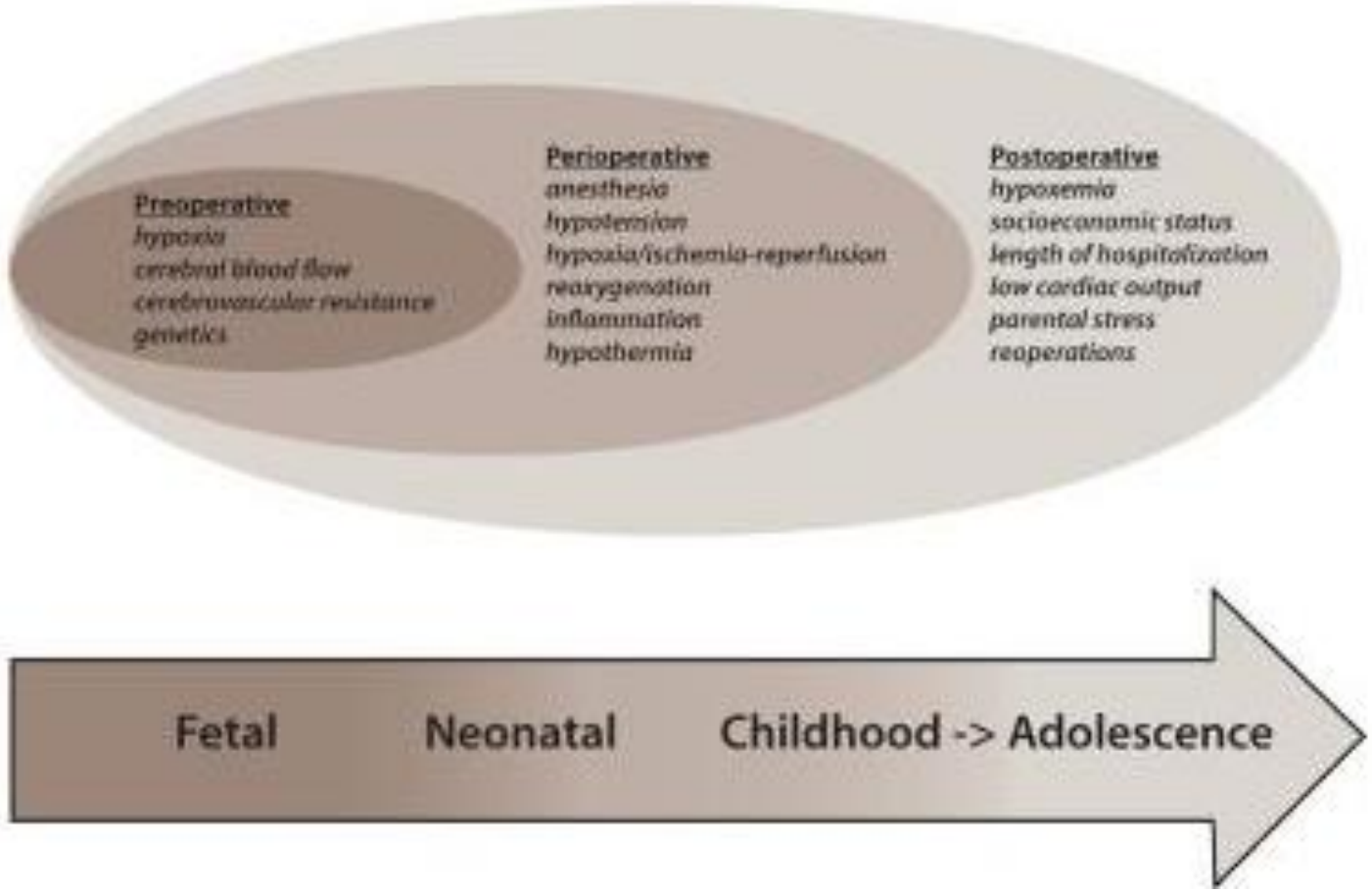
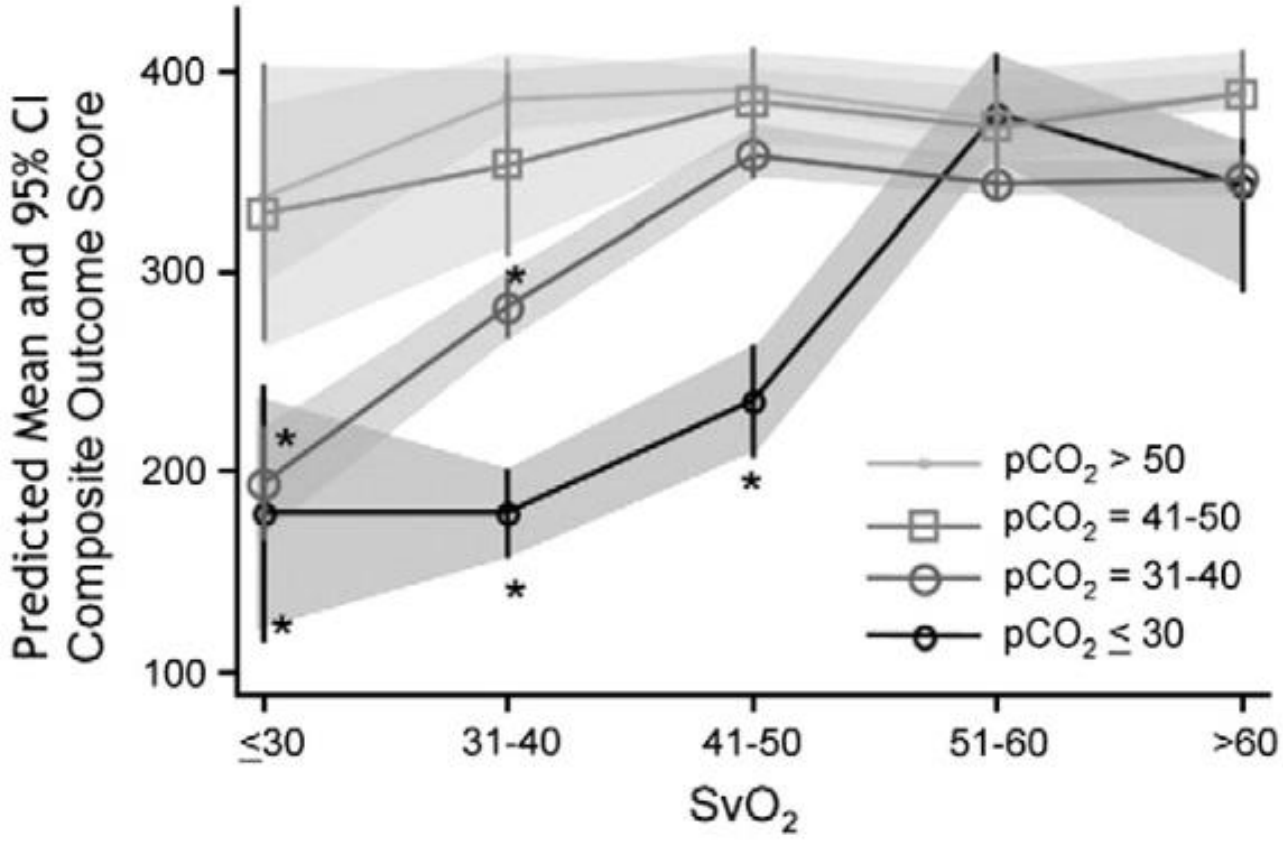
Cardiac Surgery related brain injuries



Neurodevelopmental outcomes in children w/ CHD

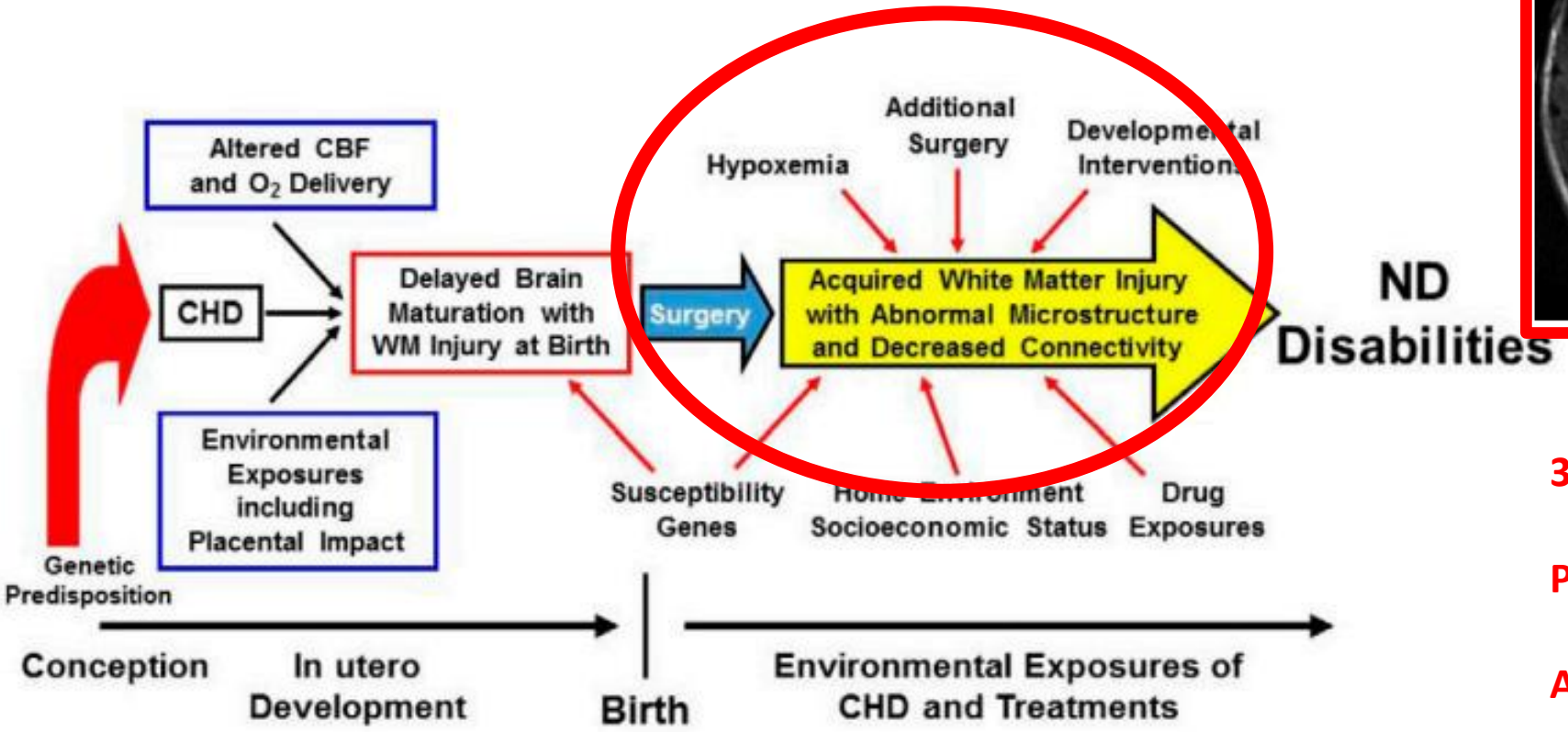


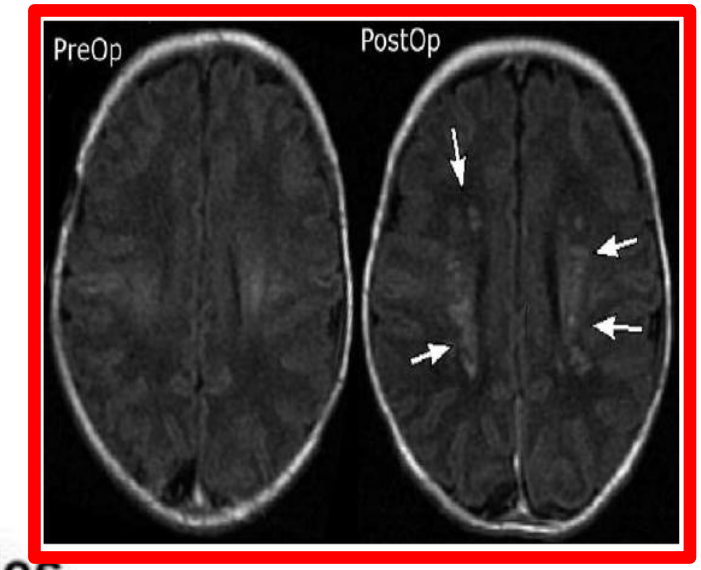
Does the anesthesiologist play any role?



Hoffman GM *Anesthesiology* 1997

Optimizing Neurodevelopmental Outcomes in neonates and children with Congenital heart diseases





30-50% New diagnosed WMI

Perioperative Hypoxia

Abrupt changes in CBF

Ortineau C Peds 2022

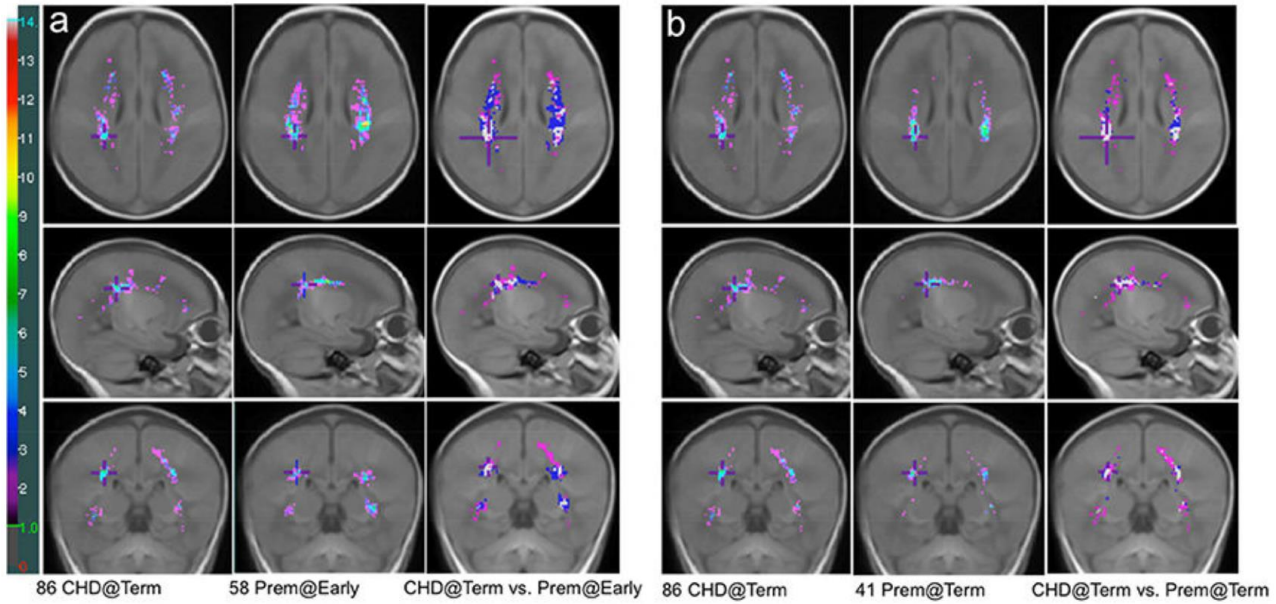
MRI assessment of Neurologic injury after CHD Surgery

Microembols, Bleeds:

→ Fréquents,
→ Quantifiables (MRI injury Score)
→ Association pronostique?

Lésions périventriculaires:

→ Nouveau-né,
→ Analogie preterm
→ Liés aux modifications de CBF
→ Immaturité BBB
→ WMInjury
→ Association pronostique possible



Guo et Al, Neuroimage 2019

Stroke:

→ Rares,
→ Embols, hémorragies
→ Non dépistables en per op sauf massifs
→ Association pronostique?

Watersheed infarcts:

→ Liés à modification CBF prolongée
→ Dépistables

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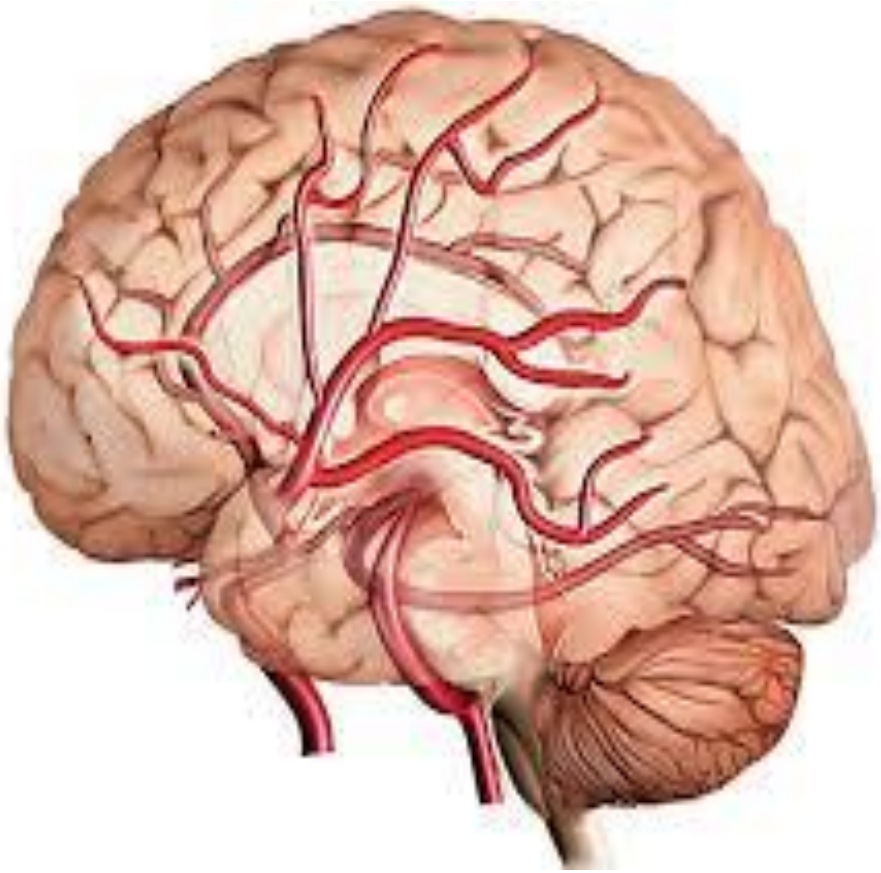
Débit Sanguin Cérébral

Débit Sanguin Cérébral (DSC)

→ Seule source d'O2
→ 15 à 30% de Qc (50 ml/100g/min)

→ DSC = PPC / RVC

→ PPC = PAM – (PVC + PIC)



Pediatric Anesthesia

Pediatric Anesthesia ISSN 1155-5645

REVIEW ARTICLE

Cerebral blood flow in the neonate

Laszlo Vutskits[1,2]

1 Department of Anesthesiology, Pharmacology and Intensive Care, University Hospital of Geneva, Geneva, Switzerland
2 Department of Fundamental Neuroscience, Geneva University Medical School, Geneva, Switzerland

Normal values of CBF in healthy volunteers: 40-50 ml/ 100g.min-1

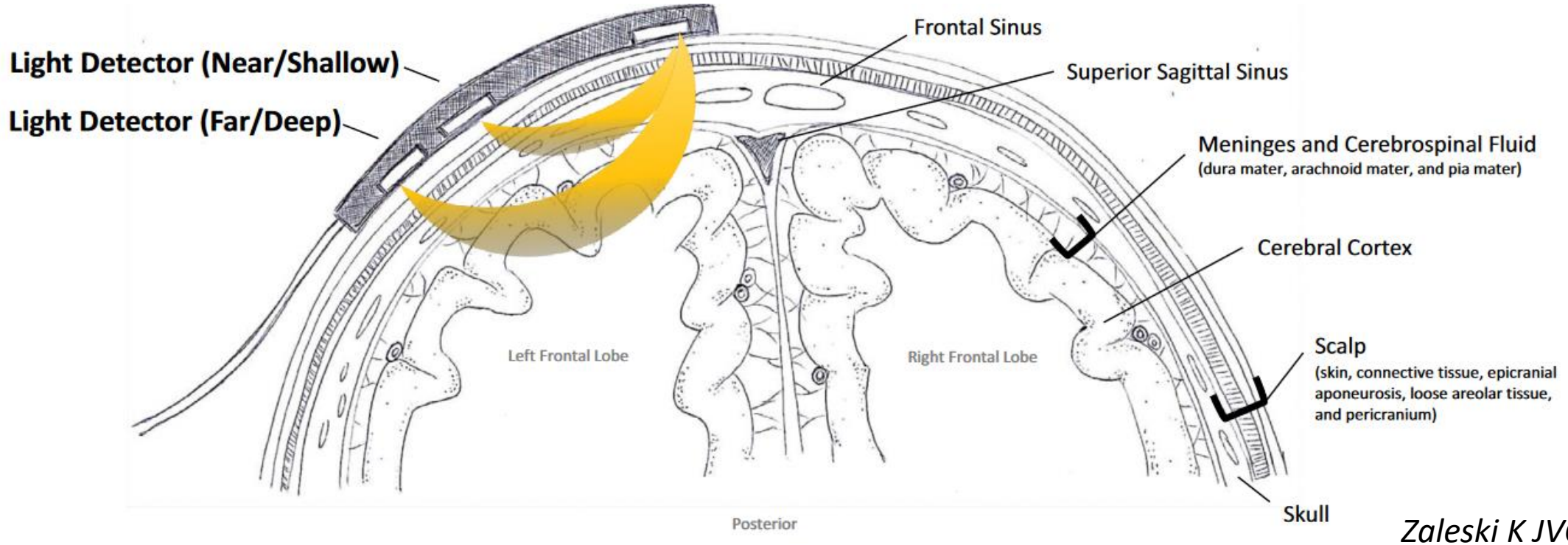
Irreversible brain damage < 10 ml/100g.min-1

How to monitor CBF in the Bedside?

→ TCD
→ NIRS

How to ensure adequat CBF during CPB?

→ Optimal MAP? Optimal Blood flow?



Zaleski K JVCA 2019

Near Infra Red Light : 700-1000 nm

Atténuation de la lumière au travers de
(1): oxygen (O 2)-dependent chromophores (oxyhemoglobin [HbO2], deoxyhemoglobin [HbR], cytochrome c oxidase [CytOx], myoglobin) of variable concentrations;
(2): chromophores of fixed concentrations (melanin, water, collagen, lipids);
et (3) light scattering (« diffusion dynamique »)

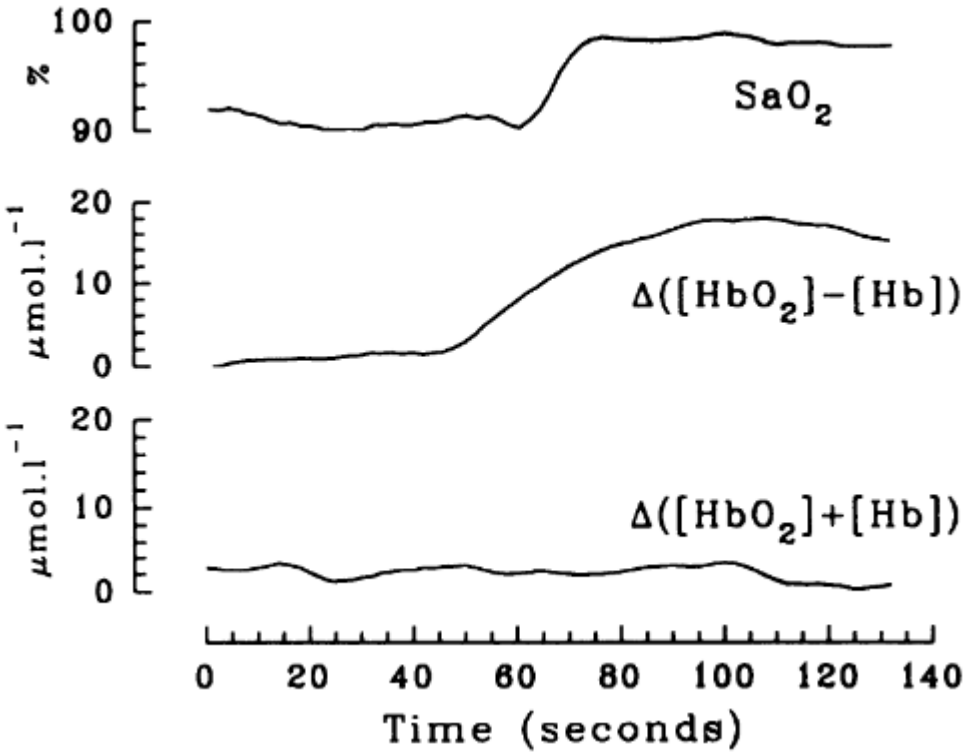
Profondeur de détection: ½ distance Emetteur-Détecteur

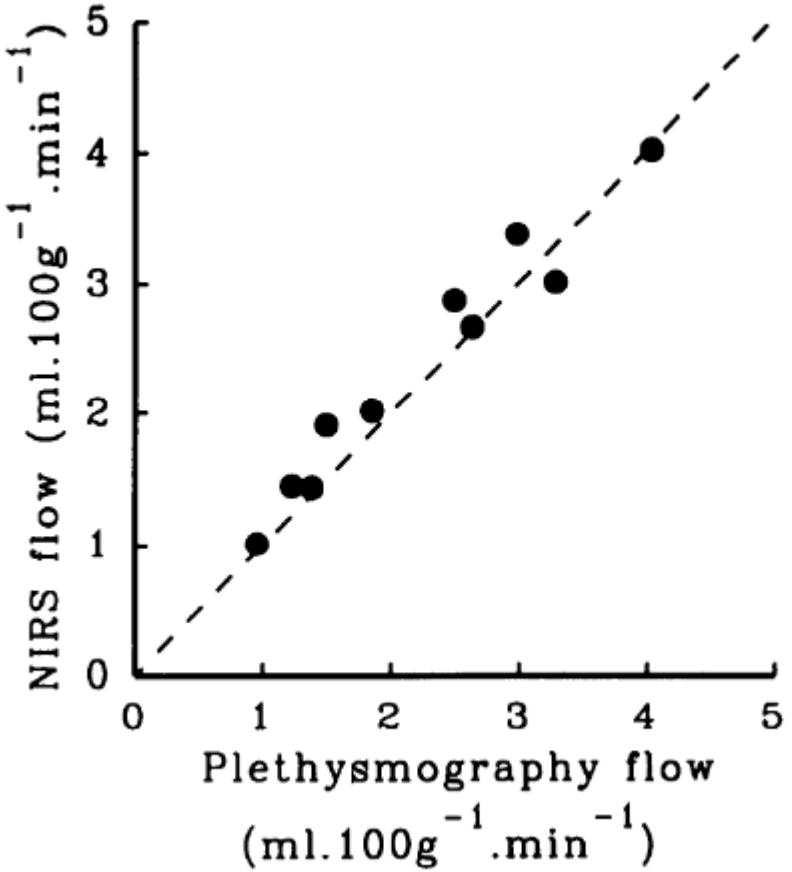
Measurement of hemoglobin flow and blood flow by near-infrared spectroscopy

A. D. EDWARDS, C. RICHARDSON, P. VAN DER ZEE, C. ELWELL, J. S. WYATT, M. COPE, D. T. DELPY, AND E. O. R. REYNOLDS
Department of Paediatrics and Department of Medical Physics and Bioengineering, University College and Middlesex School of Medicine, London W12 ONN, United Kingdom

J Appl Physiol 1993

$$HF = (\Delta[HbO_2] - \Delta[Hb])/ [2 \cdot \int_0^t (\Delta Sa_{O_2})dt] \ (\mu mol \cdot l^{-1} \cdot min^{-1})$$


100
%
90
20
μmol.l⁻¹
10
0
SaO2
Δ([HbO2]−[Hb])
20
μmol.l⁻¹
10
0
Δ([HbO2]+[Hb])
0 20 40 60 80 100 120 140
Time (seconds)

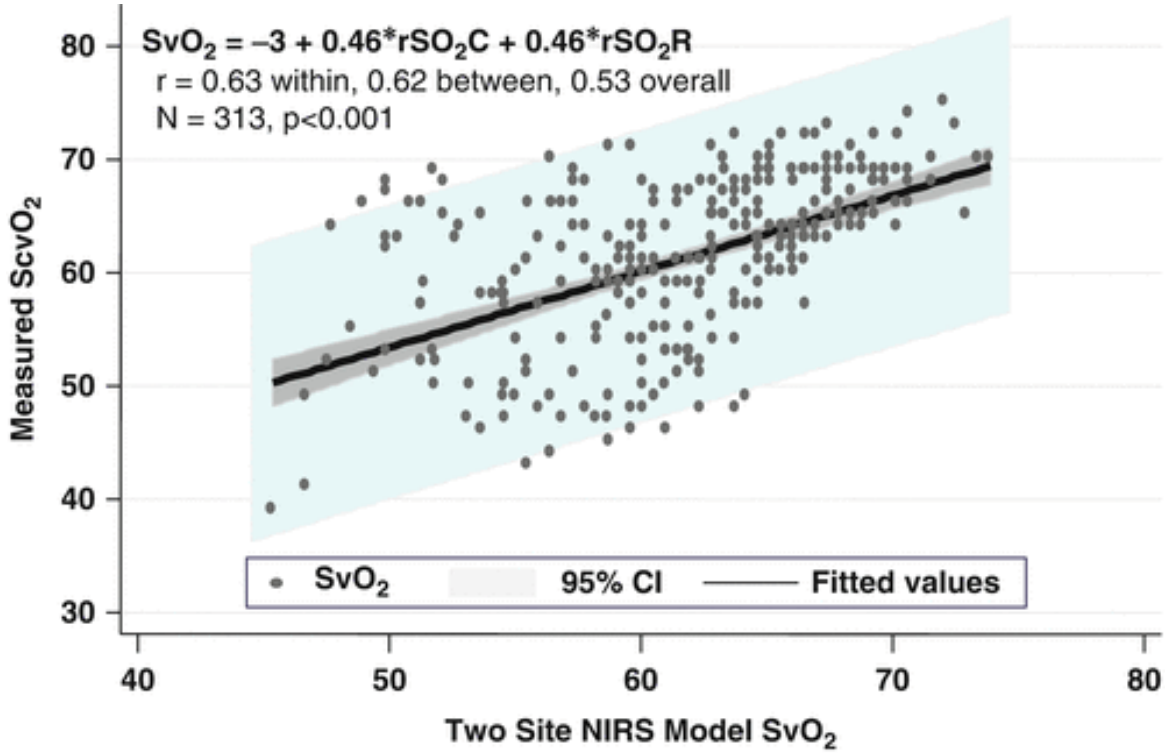

NIRS flow (ml.100g⁻¹.min⁻¹)
0 1 2 3 4 5
Plethysmography flow
(ml.100g⁻¹.min⁻¹)

NIRS et estimation de la SVO2

Fick:

SvO2 = SaO2 - VO2/DO2

rSO2 = SaO2 - rVO2/rDO2



Hoffman GM, *Anesthesiology* 2003

NIRS & Tissue injury

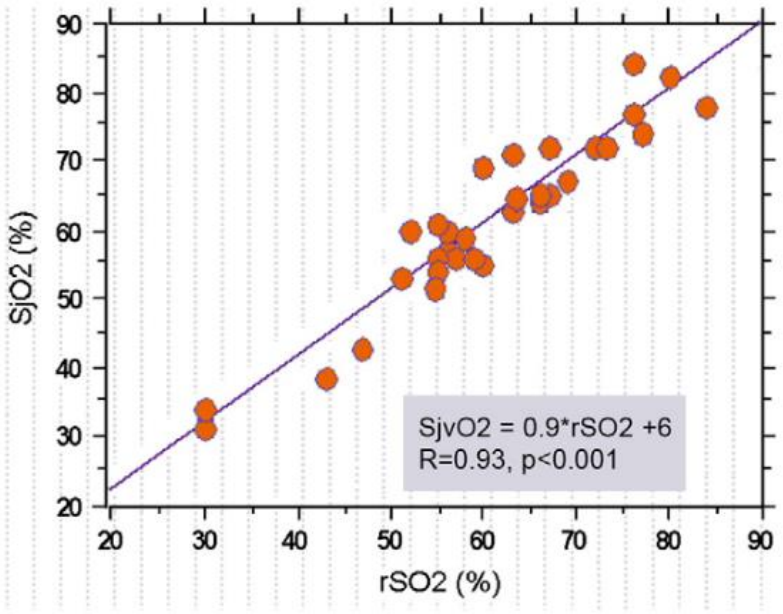


Fig. 2. The relationship between cerebral oxygen saturation by NIRS (rSO2) and jugular bulb saturation (SjO2) in human neonates, showing excellent agreement over a wide range of saturations. From Abdul-Khaliq [50] with permission.

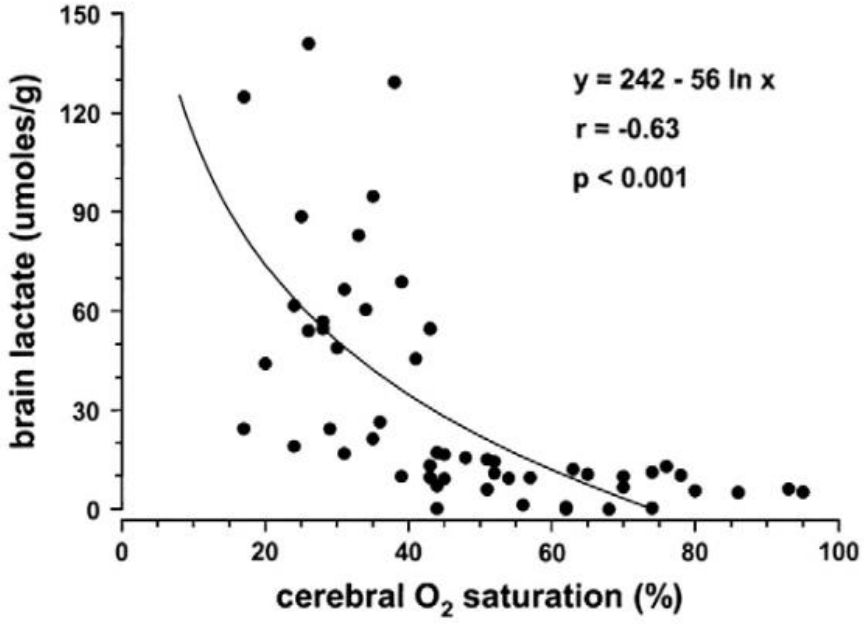


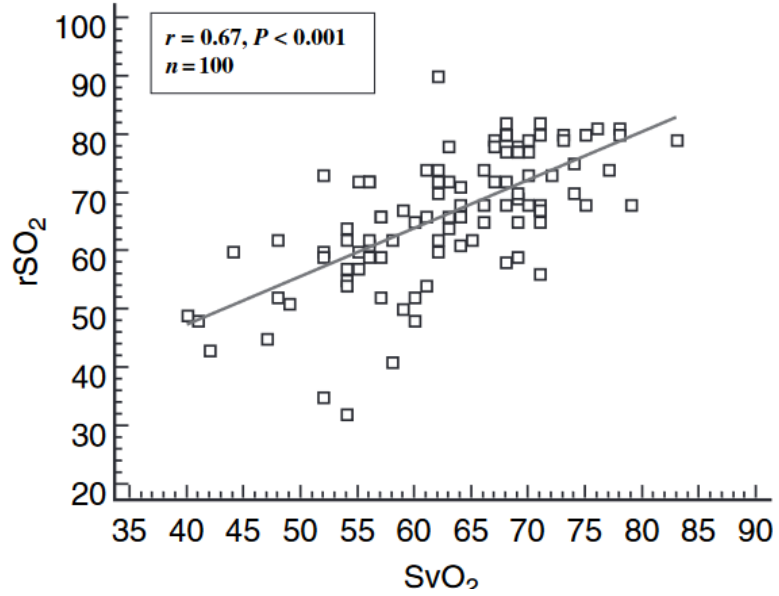
Fig. 3. The relationship between cerebral oxygen saturation and brain lactate concentration in piglets undergoing graded hypoxia–ischemia. From Kurth [104] with permission.

Pediatric Anesthesia 2005 **15**: 495–503 doi:10.1111/j.1460-9592.2005.0

A noninvasive estimation of mixed venous oxygen saturation using near-infrared spectroscopy by cerebral oximetry in pediatric cardiac surgery patients

TIA A. TORTORIELLO MD FAAP*, STEPHEN A. STAYER MD†, ANTONIO R. MOTT MD FAAP*, E. DEAN McKENZIE MD‡, CHARLES D. FRASER MD‡, DEAN B. ANDROPOULOS MD† AND ANTHONY C. CHANG MD FAAP*

**The Lillie Frank Abercrombie Section of Paediatric Cardiology, †Paediatric Cardiovascular Anaesthesia and ‡Congenital Heart Surgery, The Heart Center, Texas Children's Hospital, Baylor College of Medicine, Houston, TX, USA*



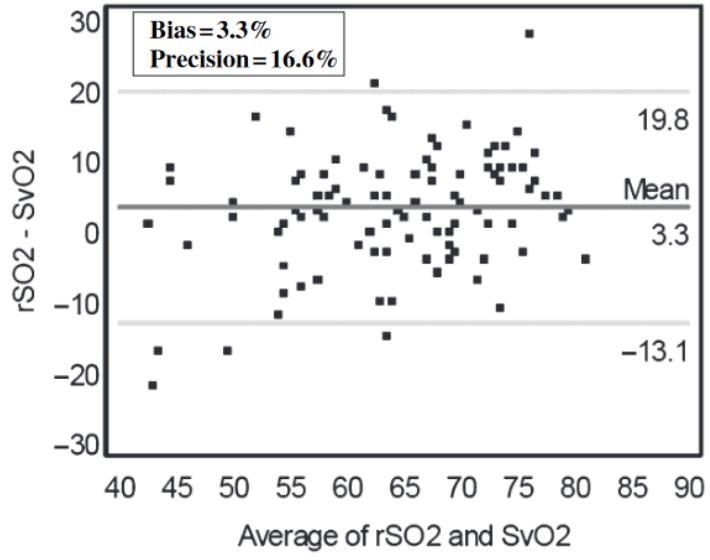
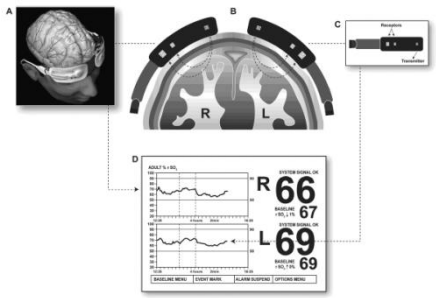


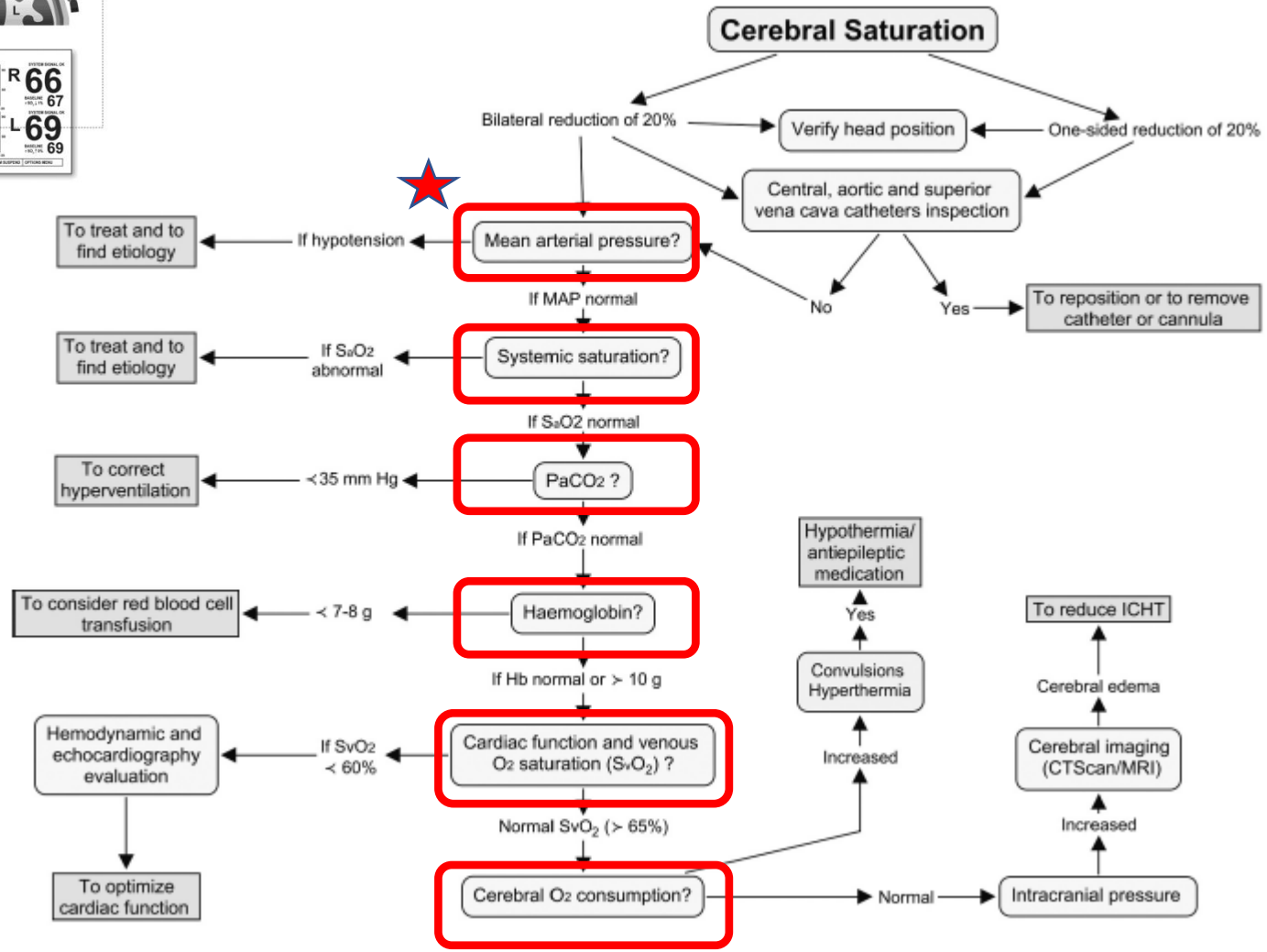
Table 3
Correlation and agreement between NIRS measurement of rSO_2 and co-oximetry measurement of SVO_2

	r-value	*P-value*	*Bias*	*Precision*
All patients	0.67	<0.0001	+3.3%	16.6%
Biventricular repair patients	0.71	<0.0001	−0.3%	11.8%
BDG patients	0.60	<0.0001	+3.6	18.4%
Fontan patients	0.45	0.04	+7.1%	14.0%

BDG, bidirectional Glenn; NIRS, near-infrared spectroscopy; *r*, correlation coefficient; rSO_2, regional cerebral oxygen saturation; SVO_2, mixed venous oxygen saturation.

Murkin Protocole 2008. NIRS-based Algorithm





Cerebral Blood Flow Is Determined by Arterial Pressure and Not Cardiopulmonary Bypass Flow Rate

Arthur E. Schwartz, MD, Aqeel A. Sandhu, MD, Richard J. Kaplon, MD, William L. Young, MD, Amy E. Jonassen, MD, David C. Adams, MD, Niloo M. Edwards, MD, Joseph J. Sistino, CCP, Pawel Kwiatkowski, MD, and Robert E. Michler, MD

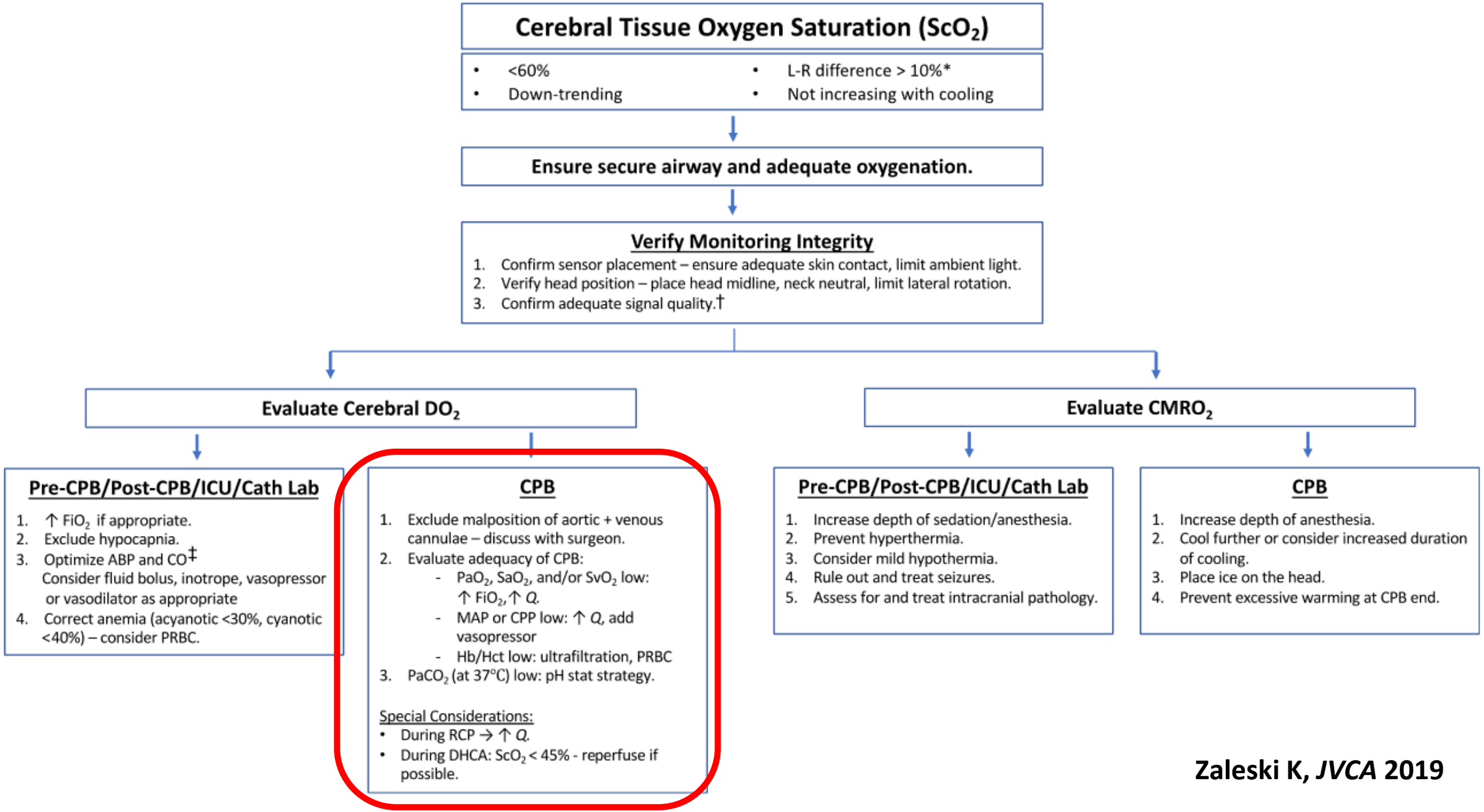
Departments of Anesthesiology and Surgery, College of Physicians and Surgeons, Columbia University, and Anesthesiology and Surgery Services, Presbyterian Hospital in the City of New York, New York, New York

Table 1. Physiologic Variables Before and During Cardiopulmonary Bypass[a]

Variable	Before Bypass	Full-Flow CPB		Low-Flow CPB	
		High BP	Low BP	High BP	Low BP
CBF ($mL \cdot min^{-1} \cdot 100\ g^{-1}$)	26.0 ± 3.1	27.6 ± 9.9	16.8 ± 3.7[b]	34.0 ± 8.3	14.1 ± 3.7[b]
A-VO_2 (mL/100 mL)	5.1 ± 1.7[b]	2.5 ± 1.3	3.0 ± 1.8	2.2 ± 0.9	3.3 ± 0.5
$CMRO_2$ ($mL \cdot min^{-1} \cdot 100\ g^{-1}$)	1.2 ± 0.4[b]	0.68 ± 0.40	0.49 ± 0.25	0.70 ± 0.20	0.44 ± 0.20
MABP (mm Hg)	69 ± 13	61 ± 2	24 ± 3	62 ± 2	23 ± 3
Pump flow ($L \cdot min^{-1} \cdot m^{-2}$)	. . .	2.23 ± 0.06	2.23 ± 0.06	0.75	0.75
Temp (°C)	35 ± 0.8	27.7 ± 0.4	27.7 ± 0.5	27.7 ± 0.5	27.8 ± 0.4
pCO_2 (mm Hg)	33 ± 4	34 ± 2	33 ± 2	36 ± 4	36 ± 3
pH	7.48 ± 0.03[c]	7.42 ± 0.04	7.43 ± 0.07	7.41 ± 0.05	7.41 ± 0.04
pO_2 (mm Hg)	499 ± 31[d]	377 ± 128	382 ± 115	431 ± 95	425 ± 112
Hematocrit (%)	30 ± 3[b]	16 ± 4	16 ± 4	16 ± 3	16 ± 4

[a] Values are mean ± standard deviation (n = 7); arterial blood gas analyses were performed at 37°C. [b] $p < 0.01$ compared with others. [c] $p < 0.05$ compared with others. [d] $p < 0.05$ compared with full-flow high BP, full-flow low BP, low-flow low BP.

A-VO_2 = cerebral arteriovenous oxygen content difference; BP = arterial blood pressure; CPB = cardiopulmonary bypass; CBF = cerebral blood flow; $CMRO_2$ = cerebral oxygen metabolic rate; MABP = mean arterial blood pressure; pCO_2 = carbon dioxide tension; pO_2 = oxygen tension.



Zaleski K, *JVCA* 2019

Figure 2
Aortic cannula position.

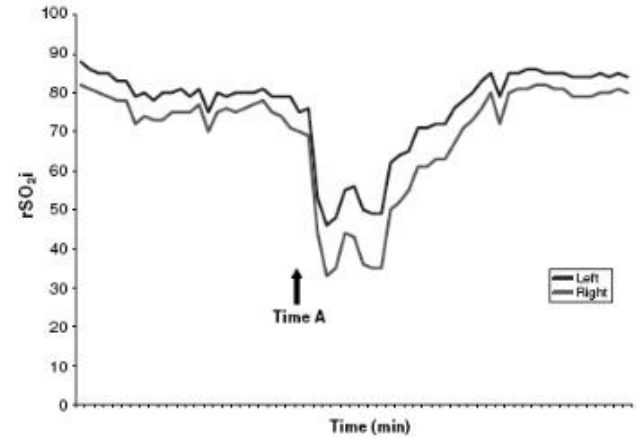


Figure 1
Cerebral oxygen saturation. An abrupt decrease in regional cerebral saturation index (rSO_2i) occurred at the onset of CPB (Time A). After repositioning of the aortic cannula, rSO_2i recovered to baseline levels.

Rappel: Evaluation d'un dispositif de monitoring/ Outil diagnostic

1

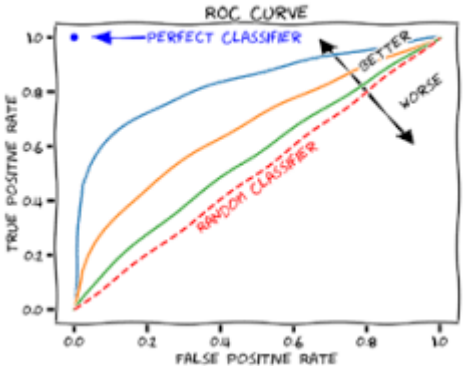
- Déterminer une **valeur pronostique**
- Etude observationnelle prospective. Preuve de concept. En aveugle. Critère de jugement sensibles (marqueurs biologiques, imagerie).

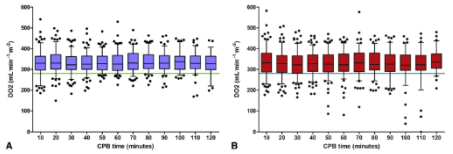
2

- Déterminer un **impact dans la prise en charge**: l'outil modifie t il la pratique et de quelle manière?
- Etude observationnelle randomisée avec choix du critère de jugement principal sensible (exemple: modification de pratique, marqueurs biologiques)

3

- Prouver un **bénéfice clinique**
- Etude interventionnelle randomisée dont le bras interventionnel utilise l'outil (algorithme de prise en charge) et le groupe témoin est une pratique standard. Evaluation en aveugle du groupe de randomisation.





Cochrane Library

Cochrane Database of Systematic Reviews

Cerebral near-infrared spectroscopy (NIRS) for perioperative monitoring of brain oxygenation in children and adults (Review)

Yu Y, Zhang K, Zhang L, Zong H, Meng L, Han R

Open Access Research

BMJ Open

Effects of cerebral near-infrared spectroscopy on the outcome of patients undergoing cardiac surgery: a systematic review of randomised trials

Giuseppe Filiberto Serraino, Gavin J Murphy

Table 3 Summary of main findings of systematic review and GRADE assessment of trial results

Near-infrared spectroscopy algorithm compared with control (standard care) in cardiac surgery

Patient population: adult cardiac surgery; setting: tertiary cardiac centres

Intervention: near-infrared spectroscopy algorithms for personalised optimisation of cerebral oxygenation

Control: standard care

Outcomes	Anticipated absolute effects* (95% CI)		Relative effect (95% CI)	Participants (n) (studies)	Quality of the evidence (GRADE)
	Risk with control	Risk with NIRS			
Mortality	32 per 1000	25 per 1000 (10 to 63)	RR 0.76 (0.30 to 1.96)	608 (4 RCTs)	⊕⊕◯◯ Low
Red cell transfusion	504 per 1000	469 per 1000 (388 to 564)	RR 0.93 (0.77 to 1.12)	744 (4RCTs)	⊕⊕◯◯ Low
Stroke	16 per 1000	17 per 1000 (6 to 46)	RR 1.08 (0.40 to 2.91)	1138 (7 RCTs)	⊕◯◯◯ Very low
Myocardial infarction	29 per 1000	26 per 1000 (12 to 54)	RR 0.90 (0.43 to 1.89)	1038 (6 RCTs)	⊕◯◯◯ Very low
Renal failure	71 per 1000	62 per 1000 (41 to 95)	RR 0.88 (0.58 to 1.34)	1043 (6 RCTs)	⊕◯◯◯ Very low
Reoperation for bleeding	19 per 1000	21 per 1000 (8 to 56)	RR 1.11 (0.41 to 3.04)	744 (4 RCTs)	⊕◯◯◯ Very low
ICU length of stay (ICU LOS)		The mean ICU LOS in the intervention group was 0 (0.44 lower to 0.44 higher).			⊕◯◯◯ Very low
Hospital length of stay (H LOS)		The mean H LOS was 0.45 lower (0.9 lower to 0.01 higher).			⊕⊕◯◯ Low

*The risk in the intervention group (and its 95% CIs) is based on the assumed risk in the comparison group and the relative effect of the intervention (and its 95% CI).

2016

Cerebral oxygen saturation and tissue hemoglobin concentration as predictive markers of early postoperative outcomes after pediatric cardiac surgery

Tomohiko Suemori[1,2], Justin Skowno[3,4], Steve Horton[5,6], Stephen Bottrell[5], Warwick Butt[7,8] & Andrew J. Davidson[1,9,10]

Table 5 Cut-off values for postoperative TOI and Δ[HHb]

	Major morbidity				Mortality			
	Sensitivity	Specificity	PPV	NPV	Sensitivity	Specificity	PPV	NPV
TOI postop <40%	21	95	27	93	25	94	12	98
TOI postop <45%	27	91	22	93	33	90	10	98
TOI postop <50%	42	83	18	94	75	83	12	99
Δ[HHb] >10	27	91	21	93	41	86	8	98
Δ[HHb] >8	33	87	18	94	50	77	6	98
Δ[HHb] >6	52	78	18	95	50	71	5	98

TOI, tissue oxygenation index; Δ[HHb], amount change in deoxygenated hemoglobin; PPV, positive predictive value; NPV, negative predictive value.

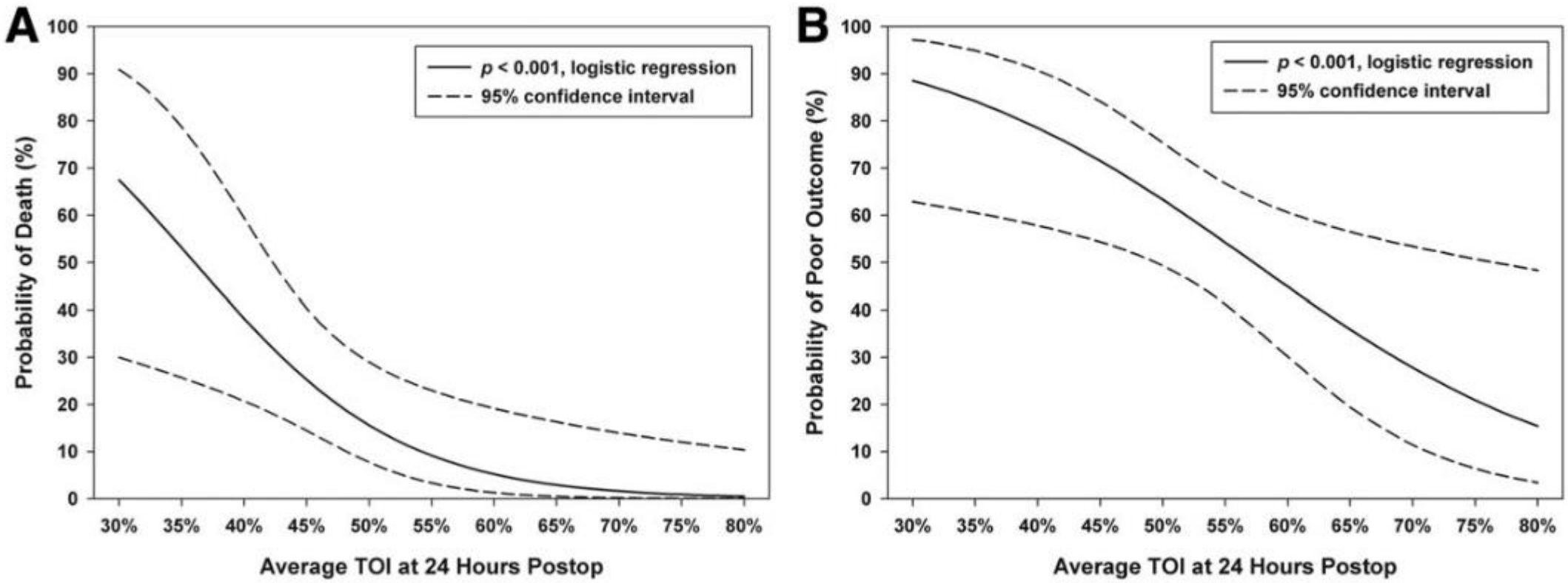
ORIGINAL ARTICLE

WILEY Congenital Heart Disease

2017

Cerebral tissue oxygenation index and lactate at 24 hours postoperative predict survival and neurodevelopmental outcome after neonatal cardiac surgery

Safwat A. Aly, MD, MSc[1] | David Zurakowski, PhD[2] | Penny Glass, PhD[3] | Kami Skurow-Todd, MSN[4] | Richard A. Jonas, MD[5] | Mary T. Donofrio, MD[4]



Perioperative Near-Infrared Spectroscopy Monitoring in Neonates With Congenital Heart Disease: Relationship of Cerebral Tissue Oxygenation Index Variability With Neurodevelopmental Outcome PCCM 2016

Michael C. Spaeder, MD[1]; Darren Klugman, MD[2]; Kami Skurow-Todd, MSN[3]; Penny Glass, PhD[4]; Richard A. Jonas, MD[5]; Mary T. Donofrio, MD[3]

TABLE 2. Patient and Clinical Characteristics Stratified by Neurodevelopmental Outcome

Characteristic	Normal Neurodevelopmental Outcome ($n = 24$) *n* (%)	Poor Neurodevelopmental Outcome ($n = 20$) *n* (%)	*p*
Age (d)	6 (IQR, 3–7)	6 (IQR, 4–9)	0.27
Weight (g)	3,482 (SD, 475)	3,320 (SD, 495)	0.14
Cardiopulmonary bypass time (min)	123 (IQR, 109–143)	116 (IQR, 106–125)	0.36
Underwent DHCA	24 (100%)	18 (90%)	0.20
DHCA time (min)	25 (IQR, 8–42)	45 (IQR, 39–50)	**0.01**
CHD classification			0.06
Class 1	12 (50%)	4 (20%)	
Class 2	2 (8%)	1 (5%)	
Class 3	0	0	
Class 4	10 (42%)	15 (75%)	
Single ventricle defects (class 3 and 4)	10 (42%)	15 (80%)	**0.03**
CHD with aortic obstruction (class 2 and 4)	12 (50%)	16 (80%)	**0.04**
Mean intraoperative cTOI	63 (SD, 7)	63 (SD, 9)	0.41
Nadir intraoperative cTOI	35 (SD, 14)	33 (SD, 16)	0.31
Intraoperative cTOI variability	2.7 (IQR, 2.2–3.5)	2.7 (IQR, 2.1–3.9)	0.99
Mean postoperative cTOI	56 (SD, 12)	55 (SD, 11)	0.32
Nadir postoperative cTOI	34 (SD, 16)	38 (SD, 11)	0.71
Postoperative cTOI variability	1.6 (IQR, 1.2–3)	1 (IQR, 0.8–1.7)	**0.01**

cTOI = cerebral tissue oxygenation index, CHD = congenital heart disease, DHCA = deep hypothermic circulatory arrest, IQR = interquartile range.
Boldface values reflect significant results.

Review Article

Near-Infrared Spectroscopy in Pediatric Congenital Heart Disease

Katherine L. Zaleski, MD[1], Barry D. Kussman, MBBCh, FFA(SA)

Department of Anesthesiology, Perioperative, and Critical Care Medicine, Division of Cardiac Anesthesia, Boston Children's Hospital, Boston, MA

NIRS en chirurgie cardiaque pédiatrique:

- Un outil devenu incontournale
- Algorithme interventionnel « de bon sens »
- Association pronostique modeste
- Aucune étude rapportant la faisabilité d'intervention basées sur l'utilisation du NIRS
- Prédiction d'évènements neurologiques: bas débit (et non: stroke!)

Plan

- Introduction: conséquences neurologiques de la CEC
- Débit Sanguin cérébral
- Autorégulation cérébrale pendant la CEC
  - Théorie
  - Mesure non invasive, Cox
  - Preuve de concept chez l’adulte
  - Résultats préliminaires en pédiatrie
- Autres éléments du neuromonitoring per CEC
- Conclusion

Débit Sanguin Cérébral

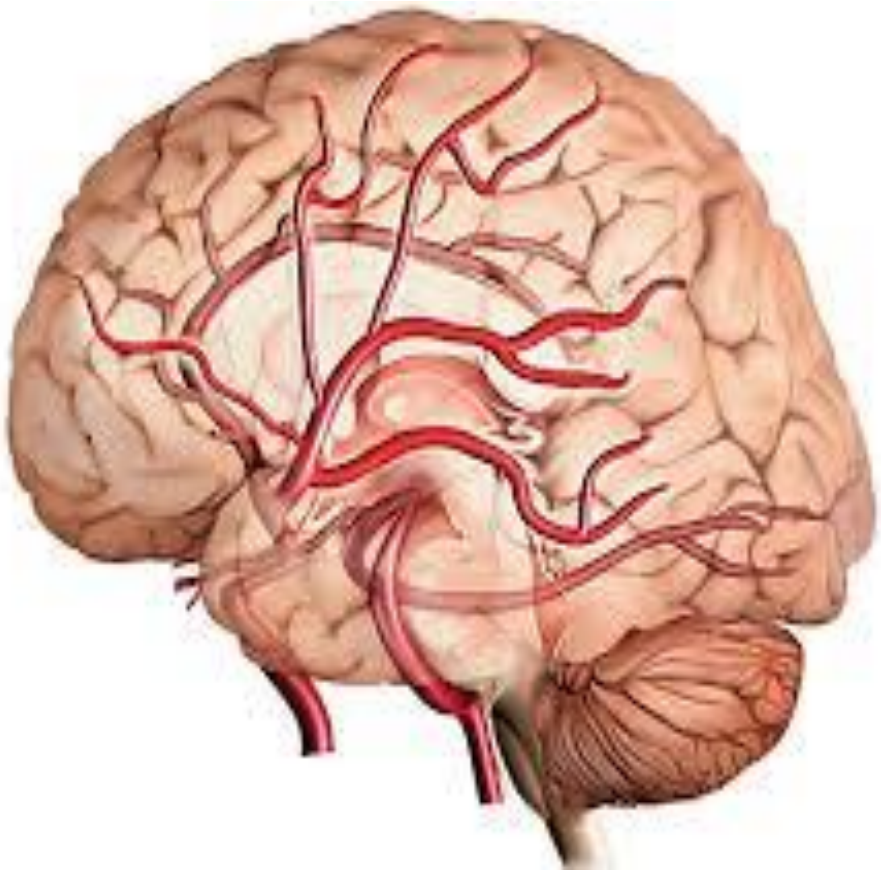
Débit Sanguin Cérébral (DSC)

→ Seule source d'O2
→ 15 à 30% de Qc (50 ml/100g/min)

→ DSC = PPC / RVC

→ PPC = PAM – (PVC + PIC)

→ Sujet à une AUTOREGULATION

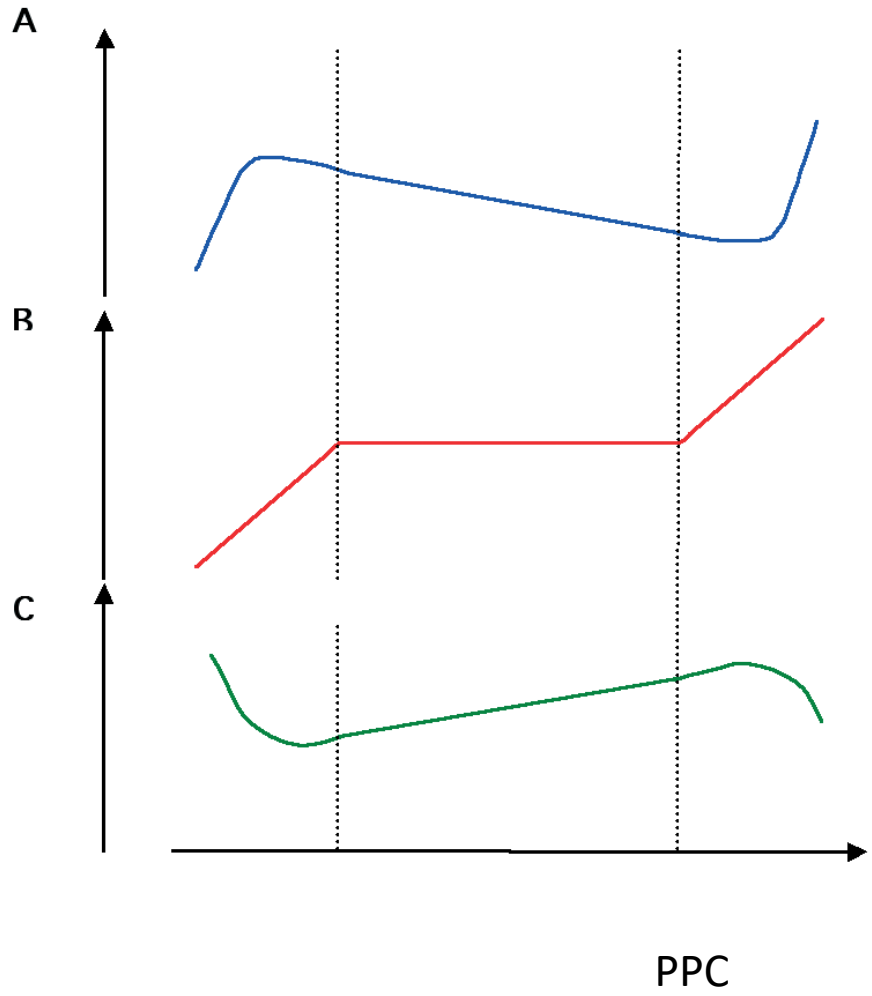


Variations des RVC

Diamètre des artères
Pie mériennes

DSC

RVC



Variations intrinsèques des RVC: autorégulation cérébrale

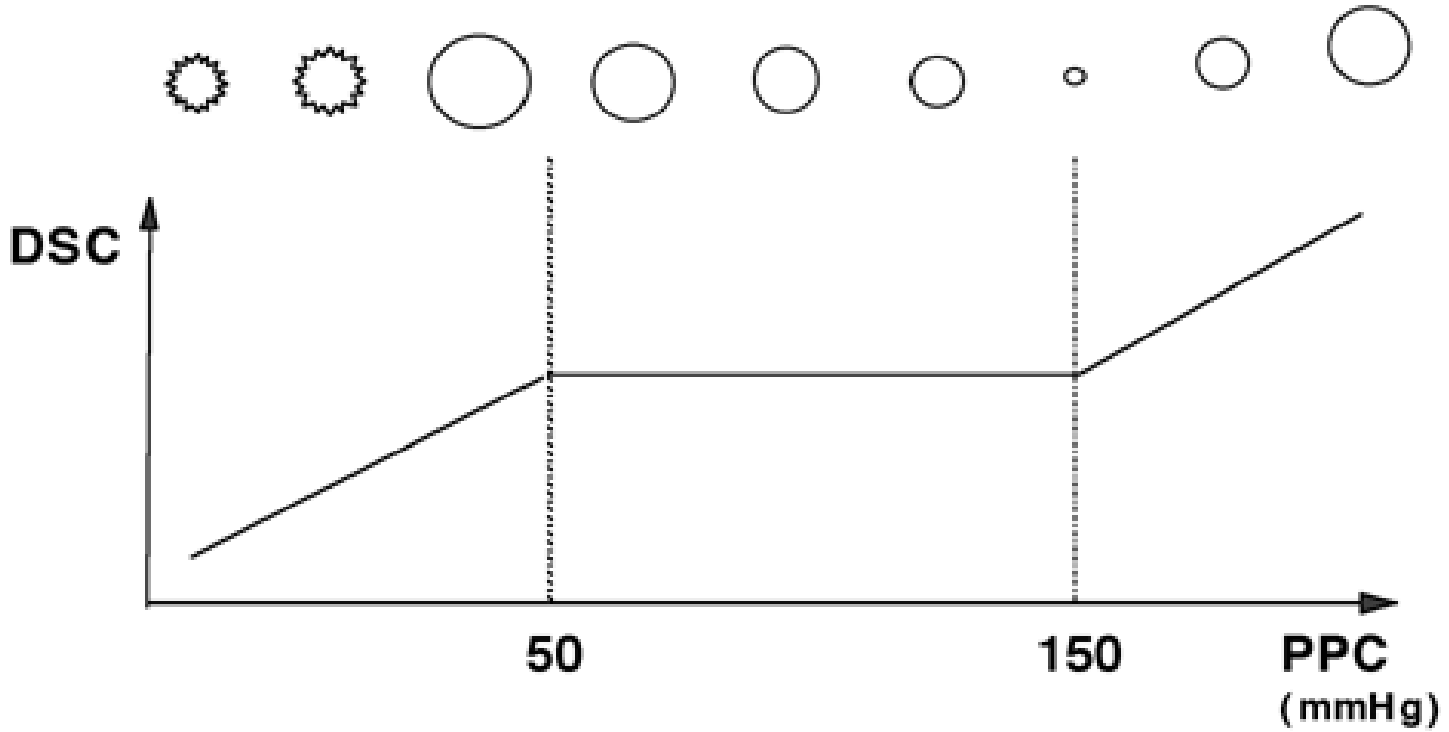
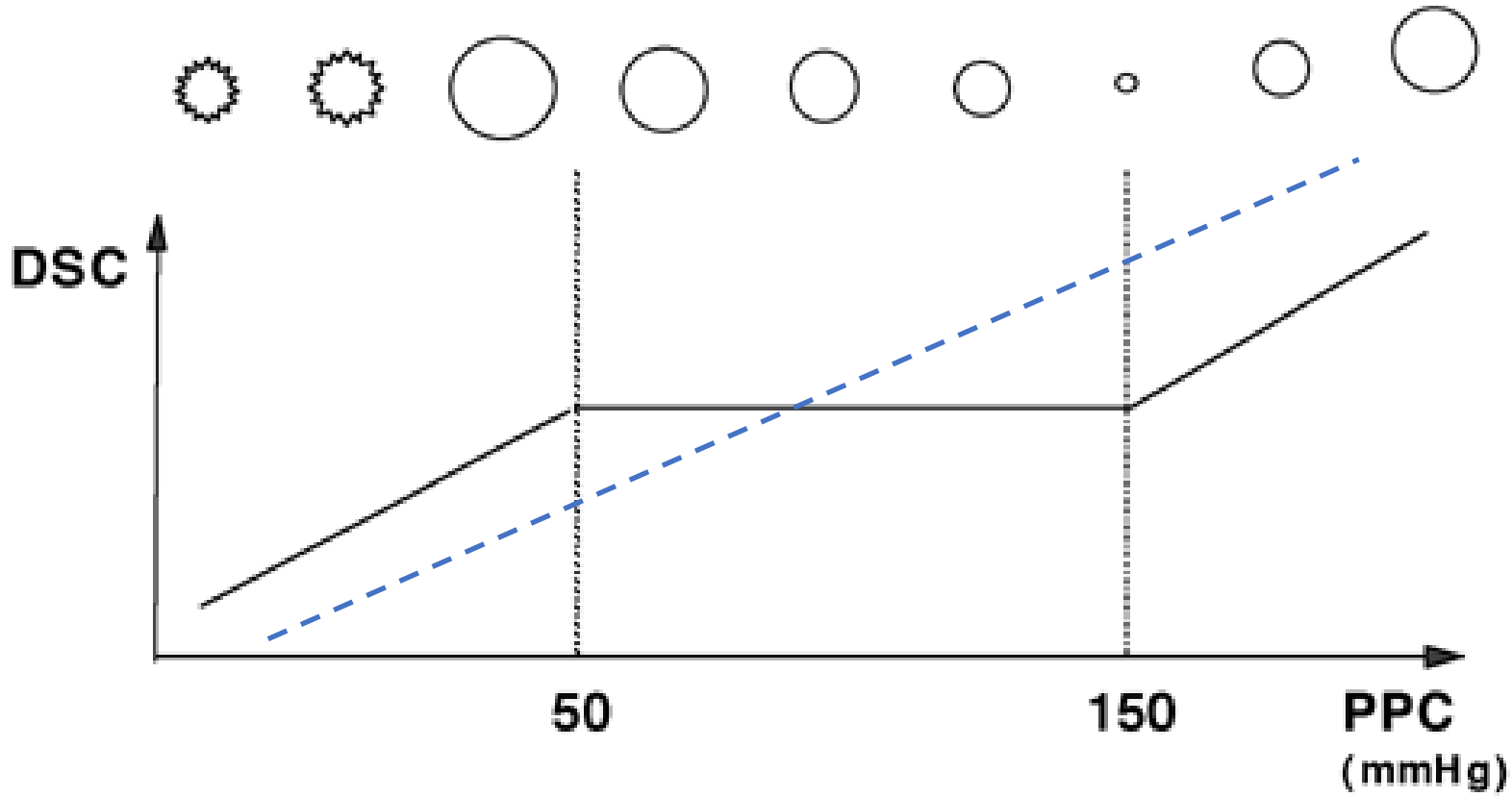


Diagramme de Lassen

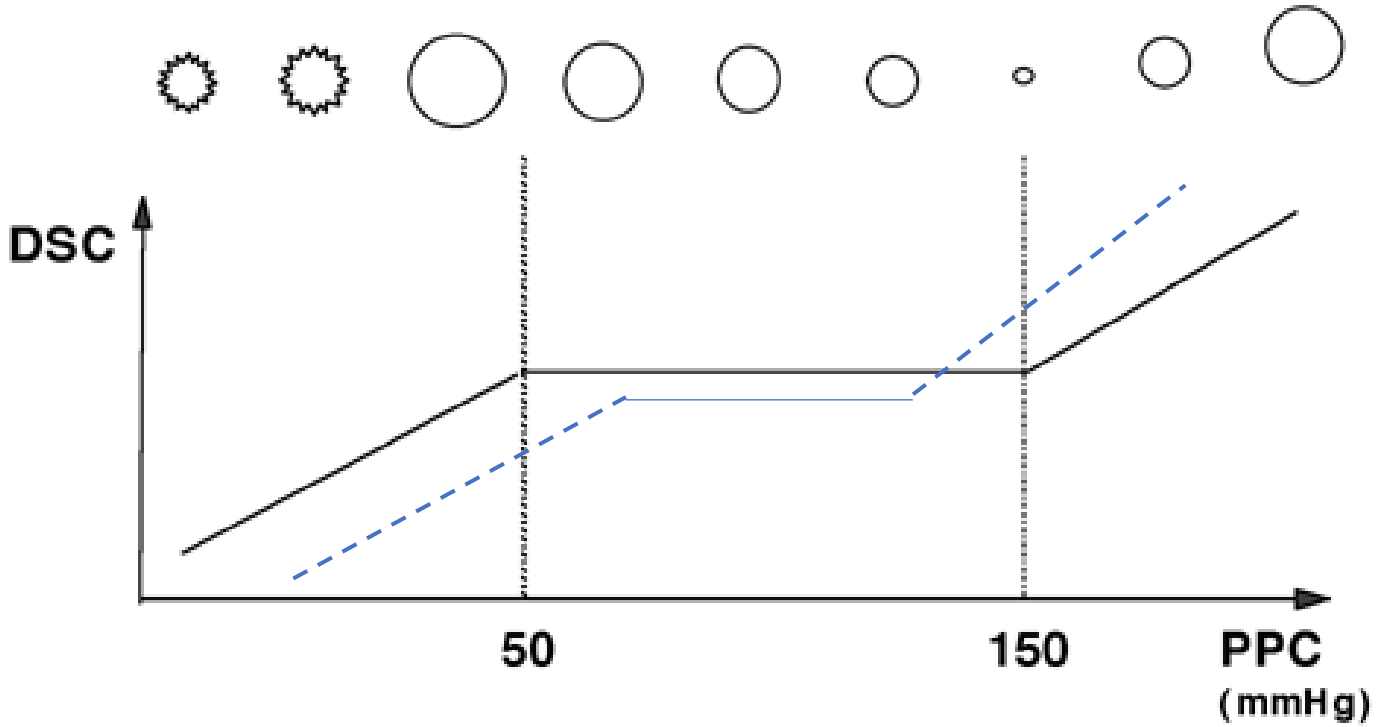
4 théories classiques, non exclusives les unes des autres

- **Myogène**: CML de l'intima sensibles aux variations de PPC/ PTMurales
- **Métabolique**: indépendante des variations de PaCO2 (car PCO2 tissulaire et du LCR restent constantes) : accumulation de métabolites en cas de baisse de PPC: Pg, adénosine, K+, CO2, baisse de PO2 tissulaire
- **Neurogène**: extrinsèque (Sympathique, Baroréflexe) intrinsèque (Noyau du faisceau solitiaire)
- **Endothéliale**: NO, Pg, Thromboxane A2, l'Endothelium, Derived Hyperpolarizing Factor (EDHF) et l'adrénomédulline

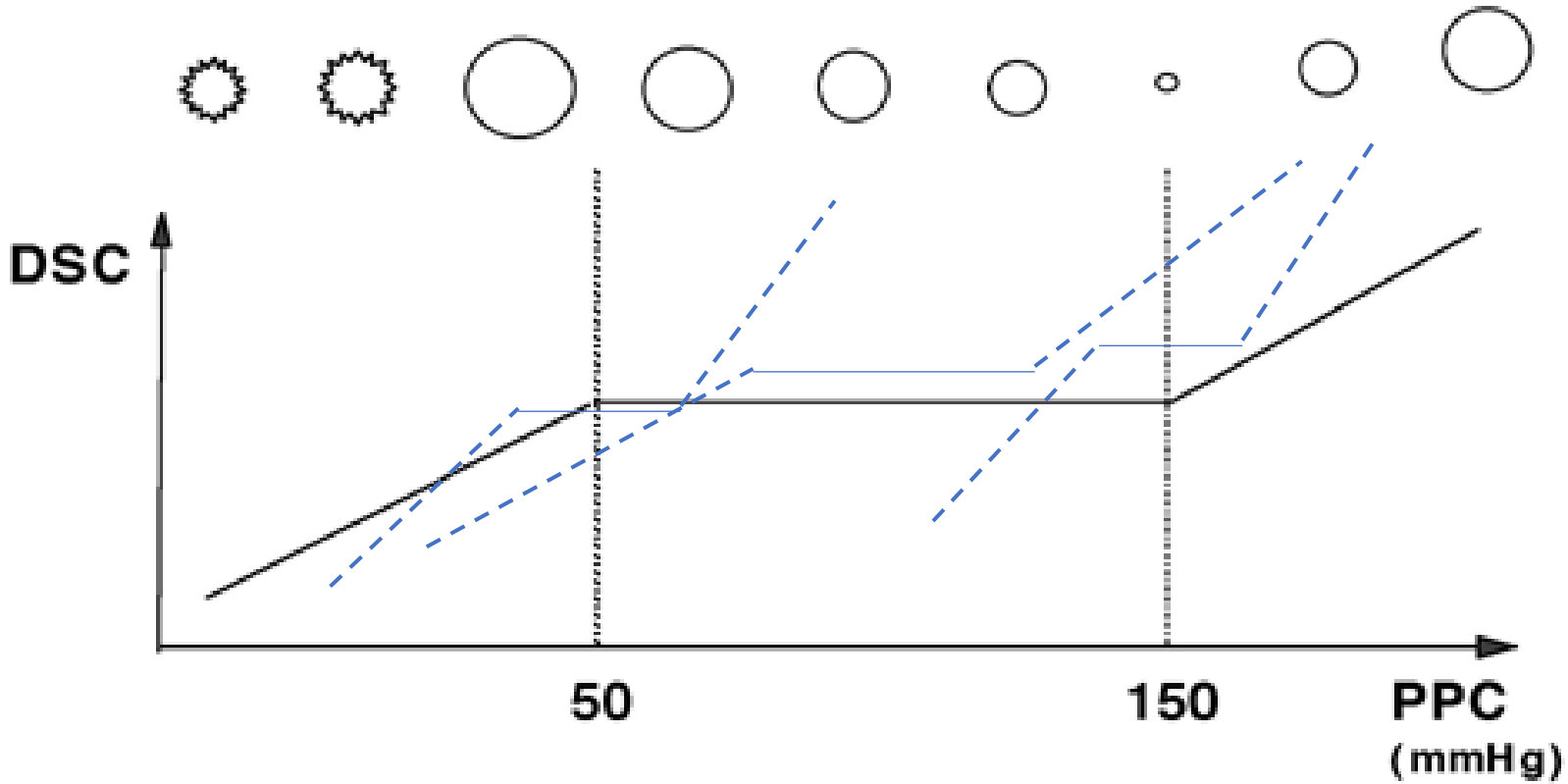
Vision Classique: Perte de l'AR au cours d'un TBI sévère



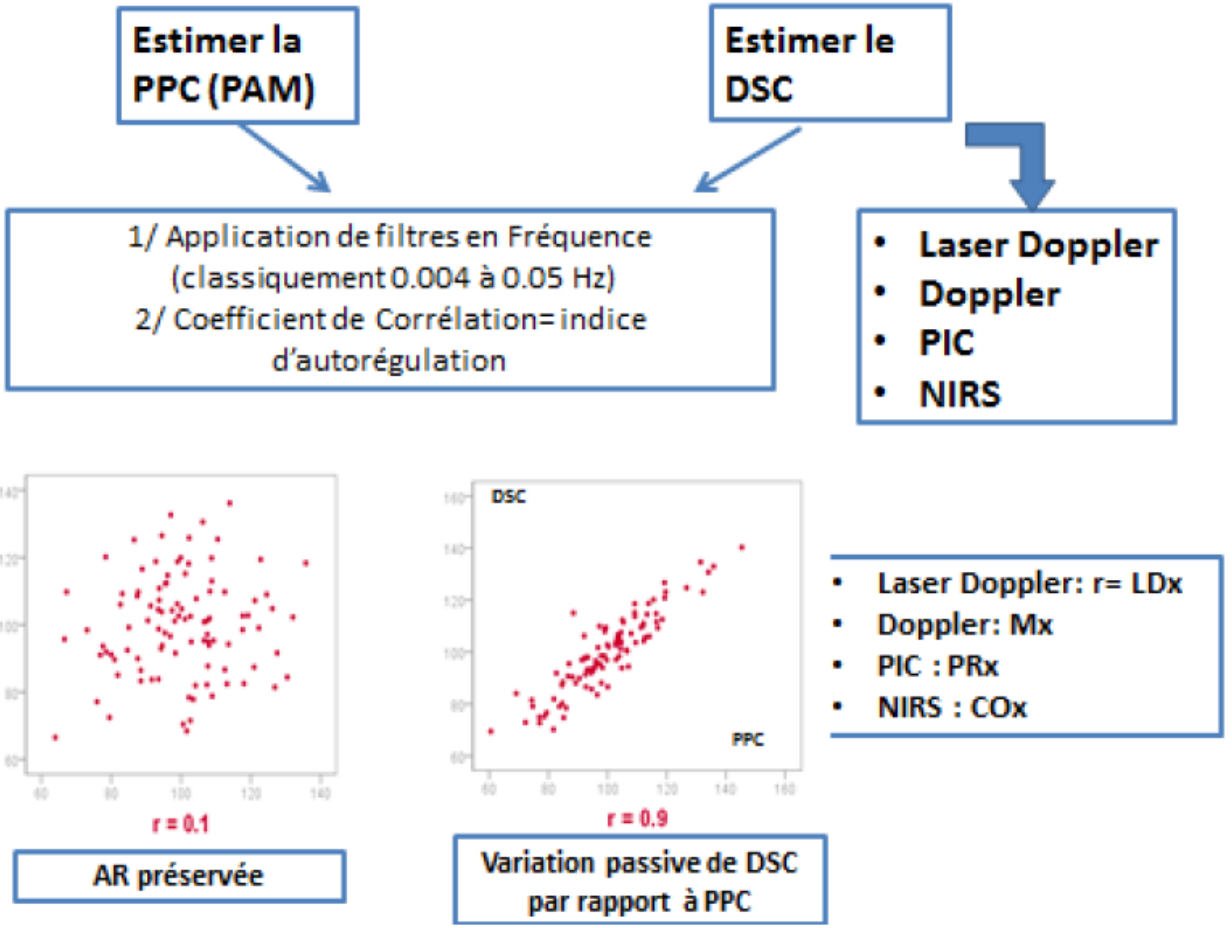
Vision moins classique



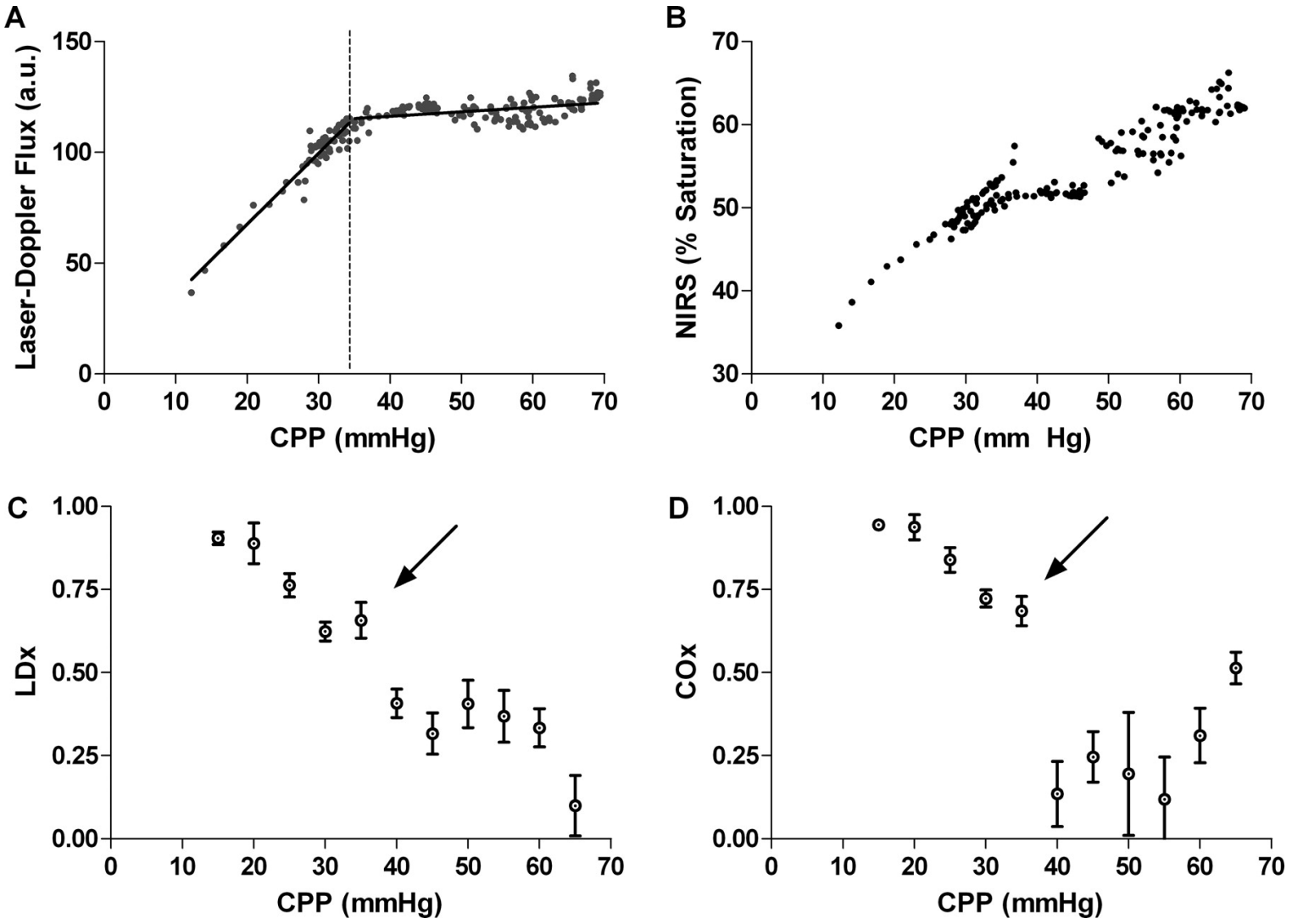
Vision Dynamique: PPC influe Qualité de l’autorégulation, évolution dans le temps



How to estimate Cerebral AR's quality over time?

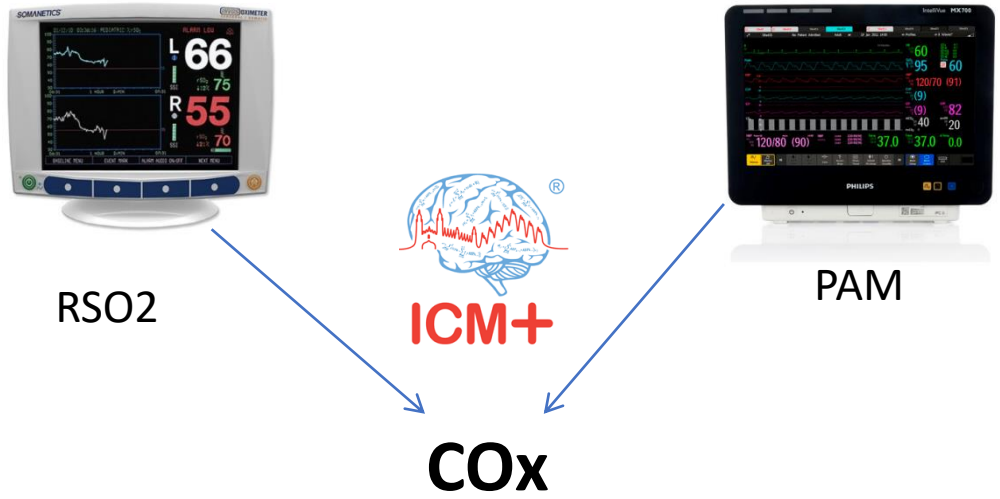


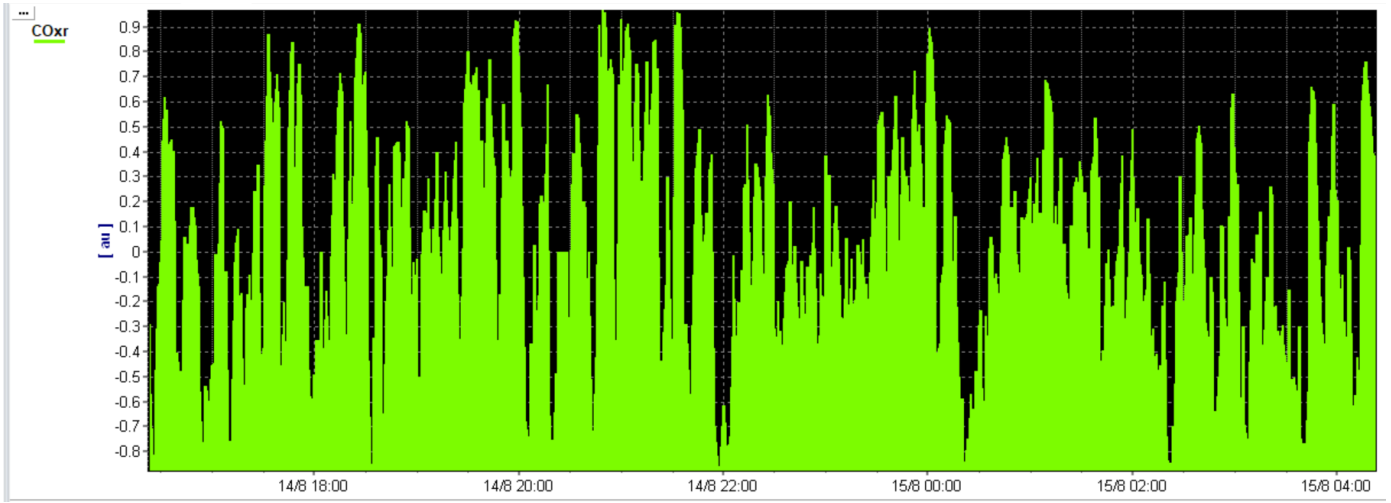
Investigating lower limit of CAR using NIRS

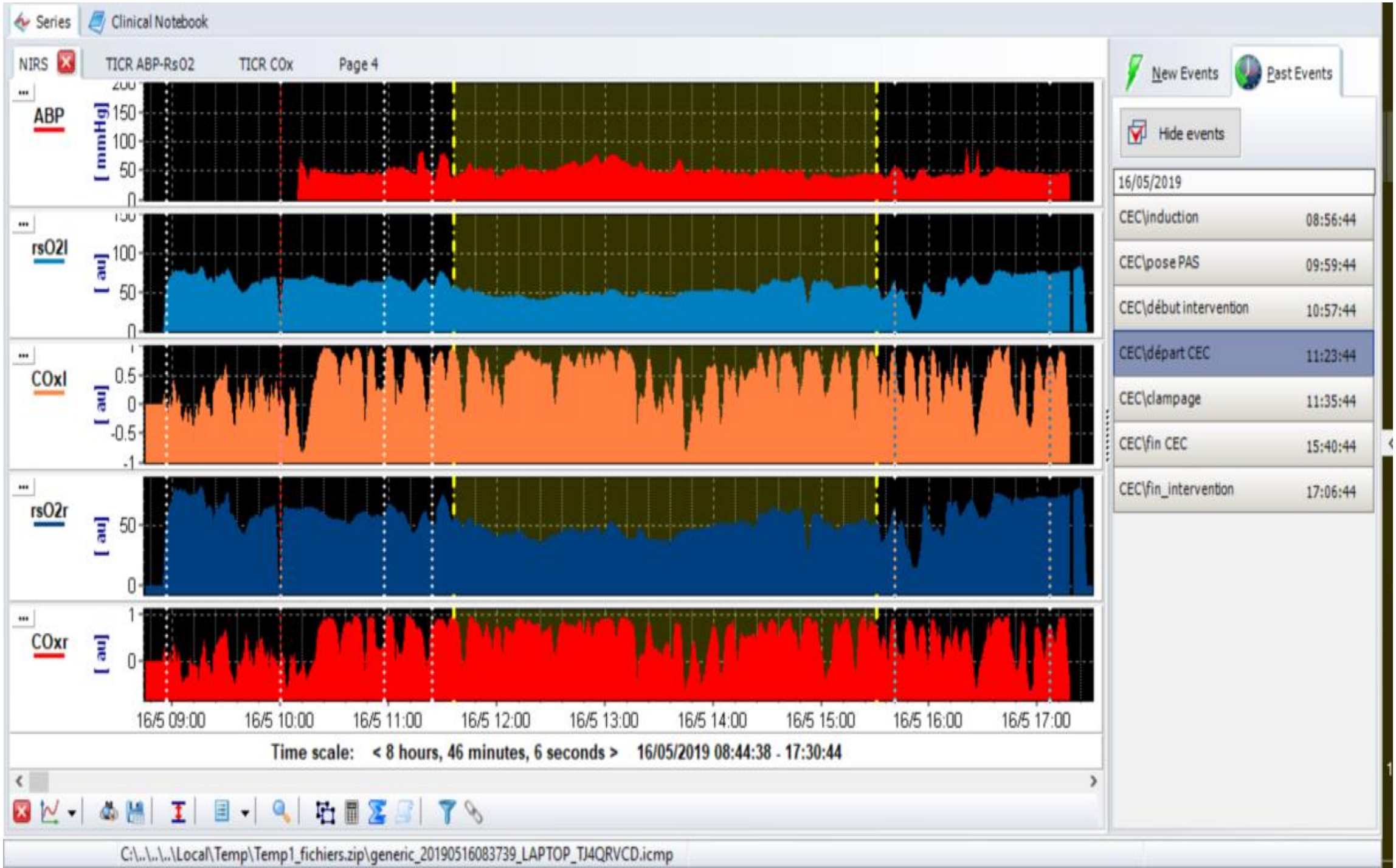


Brady K Stroke 2007

1/ Collect DATA over Time






Series
Clinical Notebook
NIRS
TICR ABP-RsO2
TICR COx
Page 4
ABP
[mmHg]
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100
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0
rsO2l
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100
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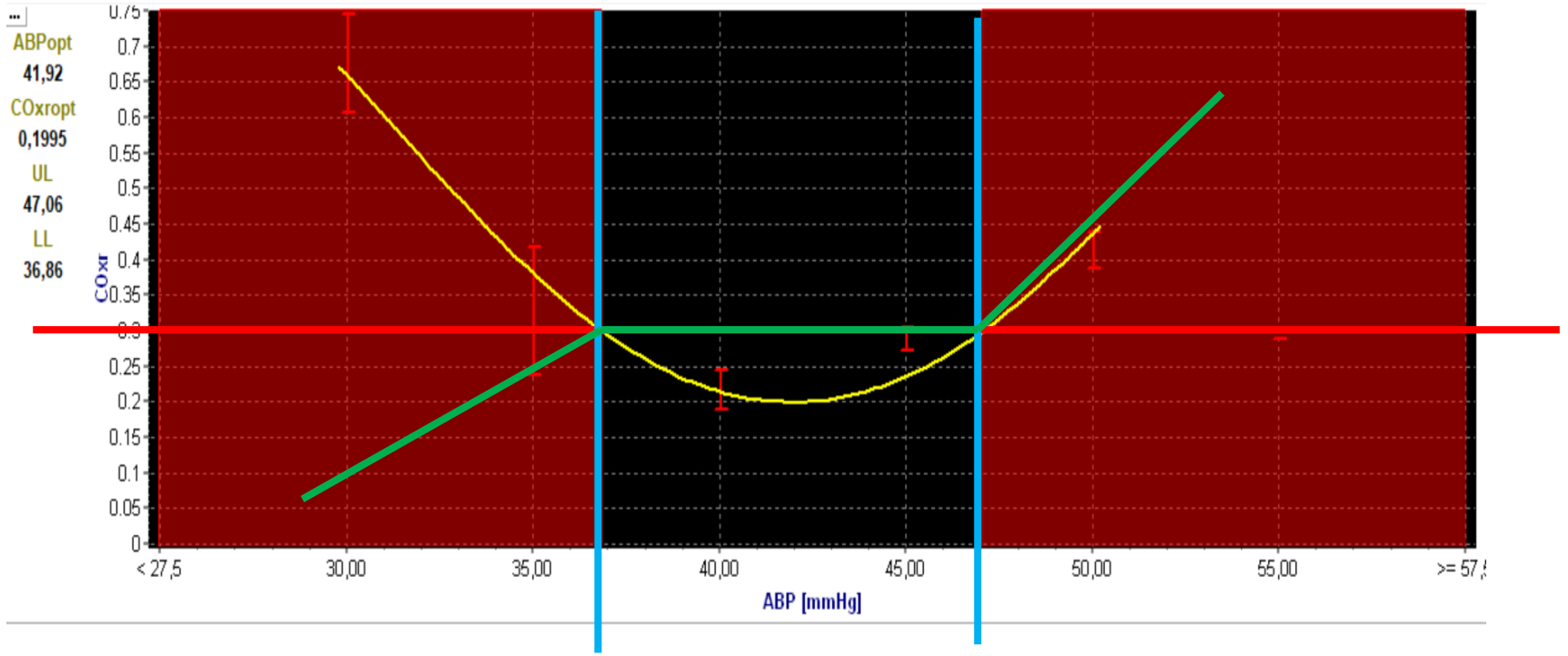
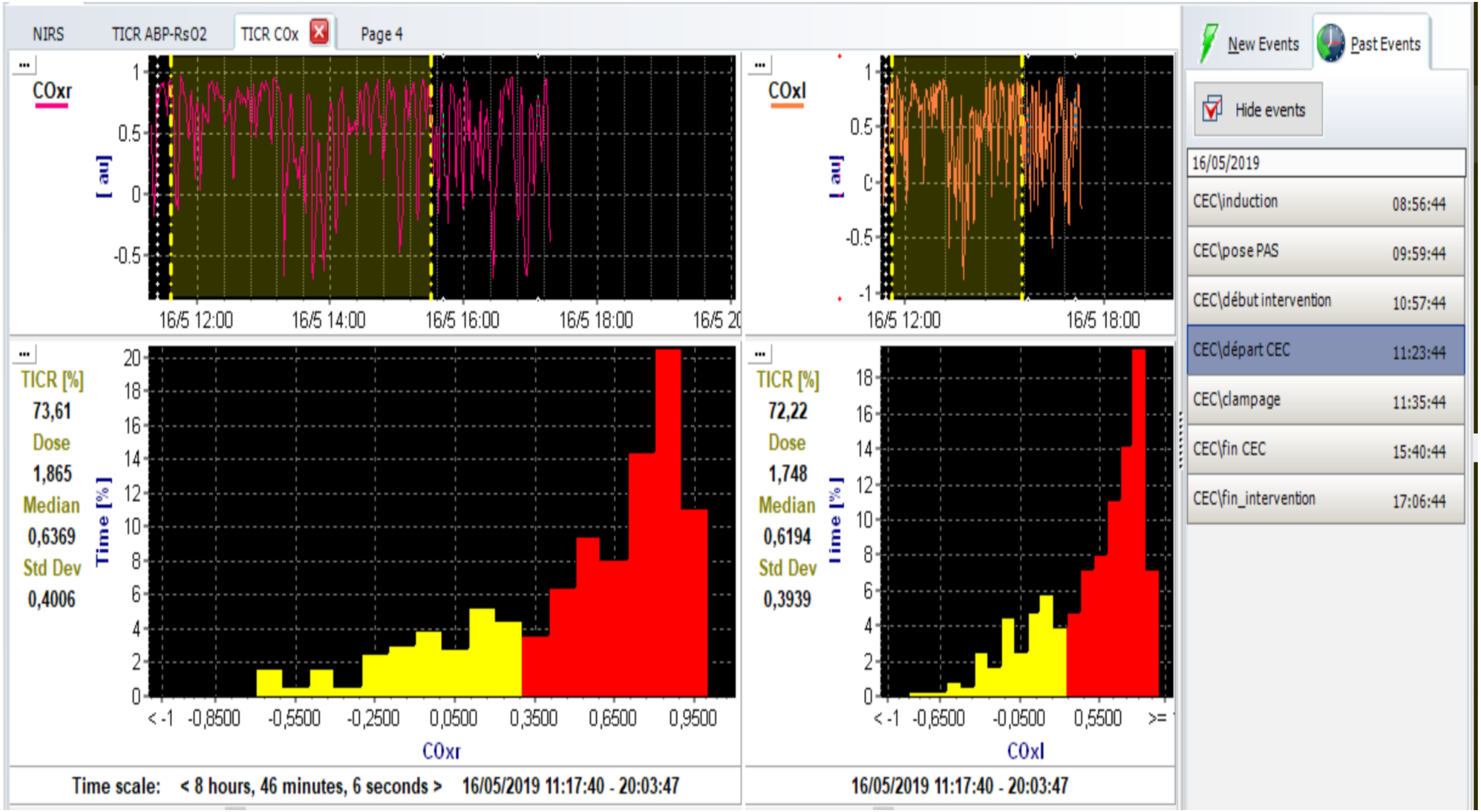
CEC\fin_intervention 17:06:44
C:\..\..\..\Local\Temp\Temp1_fichiers.zip\generic_20190516083739_LAPTOP_TJ4QRVCD.icmp

2/ Pool data over Ranges of Mean Arterial pressure, Then Reproduce Lassen's Curve

COx = 0.3



LLA ULA


NIRS
TICR ABP-RsO2
TICR COx
Page 4
COxr
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COxl
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Dose
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Median
0,6369
Std Dev
0,4006
Time [%]
< -1
-0,8500
-0,5500
-0,2500
0,0500
0,3500
0,6500
0,9500
COxr
TICR [%]
72,22
Dose
1,748
Median
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Std Dev
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CEC\début intervention 10:57:44
CEC\départ CEC 11:23:44
CEC\clampage 11:35:44
CEC\fin CEC 15:40:44
CEC\fin_intervention 17:06:44

Plan

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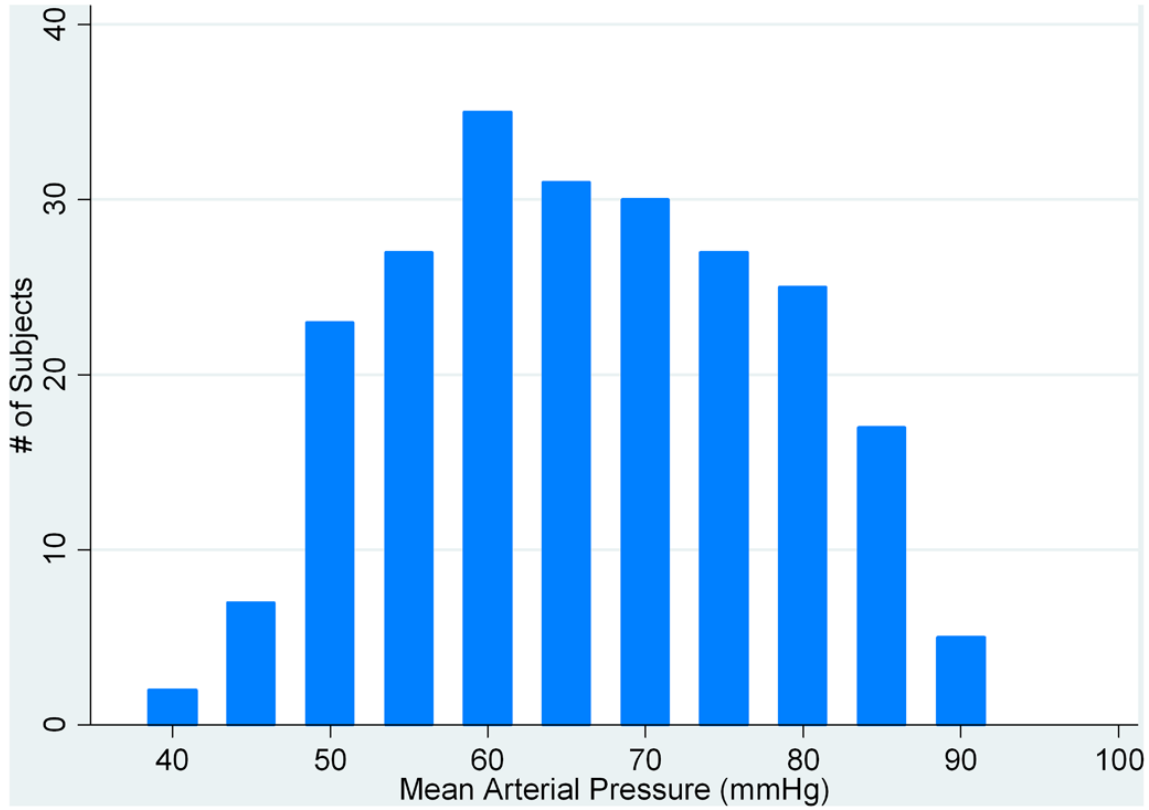
- Conclusion

Predicting the Limits of Cerebral Autoregulation During Cardiopulmonary Bypass

Joshi B, Anest Analg 2013



Lower limit of CA

Predicting the Limits of Cerebral Autoregulation During Cardiopulmonary Bypass

Joshi B, Anest Analg 2013

Optimal blood pressure during cardiopulmonary bypass defined by cerebral autoregulation monitoring

Daijiro Hori, MD,[a] Yohei Nomura, MD,[a] Masahiro Ono, MD,[b] Brijen Joshi, MD,[c] Kaushik Mandal, MD,[a] Duke Cameron, MD,[a] Masha Kocherginsky, PhD,[d] and Charles W. Hogue, MD[e]

Hori, JTCS 2017

TABLE 2. Optimal mean arterial blood pressure and mean arterial blood pressure at the lower limit of autoregulation and upper limit of autoregulation for the entire cohort and by study

	Entire cohort N = 617	Study 1[17] N = 183	Study 2[34] N = 105	Study 3 N = 326	*P* value
Optimal MAP (mean ± SD, mm Hg)	78 ± 11	74 ± 12	75 ± 10	80 ± 11	<.001
LLA (mm Hg)	65 ± 12	63 ± 11	66 ± 13	66 ± 12	.024
ULA (mm Hg)	84 ± 11	81 ± 10	82 ± 9	86 ± 12	.002
Patients who crossed LLA	434 (71%)	141 (77%)	70 (67%)	223 (68%)	.074
Patients who crossed ULA	323 (52%)	102 (56%)	58 (55%)	163 (50%)	.387

The optimal MAP was defined as the MAP with the lowest Mx (see text). Data are listed as mean ± SD or number (%) of patients. *MAP*, Mean arterial pressure; *SD*, standard deviation; *LLA*, lower limit of autoregulation; *ULA*, upper limit of autoregulation.

Duration and magnitude of blood pressure below cerebral autoregulation threshold during cardiopulmonary bypass is associated with major morbidity and operative mortality

Masahiro Ono, MD, PhD,[a] Kenneth Brady, MD,[b] R. Blaine Easley, MD,[b] Charles Brown, MD,[c] Michael Kraut, MD, PhD,[d] Rebecca F. Gottesman, MD, PhD,[e] and Charles W. Hogue, Jr, MD[c]

JTCS 2014

TABLE 2. Blood pressure, regional cerebral oxygen saturation, and cerebral oximetry index autoregulation data stratified by major morbidity or mortality

Variable	No MMOM (n = 354)	MMOM (n = 83)	*P* value
Average MAP during CPB (mm Hg)	74 ± 8 (73-75)	75 ± 9 (72-76)	.203
Average $rScO_2$	54 ± 11 (52-55)	55 ± 7 (53-56)	.388
Average COx	0.27 ± 0.18 (0.25-0.29)	0.26 ± 0.17 (0.21-0.29)	.749
LLA (mm Hg)	69 ± 14 (67-70)	71 ± 12 (67-72)	.136
$AUC_{MAP<LLA}$ (mm Hg × min/h)	2.4 (1.1-5.7)	6.5 (2.1-15.4)	.017

Data reported as mean ± SD (95% confidence intervals), except for $AUC_{MAP<LLA}$, which is reported as the median (25%-75% interquartile range). *MMOM*, Major morbidity and operative mortality; *MAP*, mean arterial pressure; *CPB*, cardiopulmonary bypass; $rScO_2$, regional cerebral oxygen saturation; *COx*, cerebral oximetry index; *LLA*, lower limit of autoregulation; $AUC_{MAP<LLA}$, area under the curve of MAP less than the LLA during CPB.

Duration and magnitude of blood pressure below cerebral autoregulation threshold during cardiopulmonary bypass is associated with major morbidity and operative mortality

Masahiro Ono, MD, PhD,[a] Kenneth Brady, MD,[b] R. Blaine Easley, MD,[b] Charles Brown, MD,[c] Michael Kraut, MD, PhD,[d] Rebecca F. Gottesman, MD, PhD,[e] and Charles W. Hogue, Jr, MD[c]

JTCS 2014

TABLE 4. Variables independently associated with major organ morbidity and mortality on multivariate logistic regression analysis*

Variable	OR	*P* value	95% CI
Baseline eGFR	0.98	<.001	0.97-0.99
Previous stroke	2.42	.035	1.07-5.51
Diabetes	1.64	.087	0.93-2.89
Preoperative LV ejection fraction	0.96	<.001	0.95-0.98
β Blockers	2.31	.006	1.27-4.21
Type of surgery	1.63	.001	1.22-2.19
$AUC_{MAP<LLA}$ (mmHg × min/h)	1.36	0.008	1.08-1.71

OR, Odds ratio; *CI*, confidence interval; *eGFR*, estimated glomerular filtration rate; *LV*, left ventricular; $AUC_{MAP<LLA}$, area under the curve of mean arterial pressure less than the lower limit of autoregulation during cardiopulmonary bypass. *The area under receiver operating characteristic curve, 0.7601.

TABLE 3. Specific complicat
mean arterial pressure belov

Complication	
Stroke	
Renal failure	
Mechanical ventilation >48 h	
Inotrope use >24 h or new IAB	
Operative death	

Data presented as n (%) or mean
cardiopulmonary bypass; *IABP*, int

o to duration and magnitude of
metry index

mplication	*P* value
9.3	.056
10.6	.030
10.2	<.001
10.4	.108
10.3	.081

ower limit of autoregulation during

British Journal of Anaesthesia **113** (6): 1009–17 (2014)
Advance Access publication 25 September 2014 · doi:10.1093/bja/aeu319

BJA

Arterial pressure above the upper cerebral autoregulation limit during cardiopulmonary bypass is associated with postoperative delirium

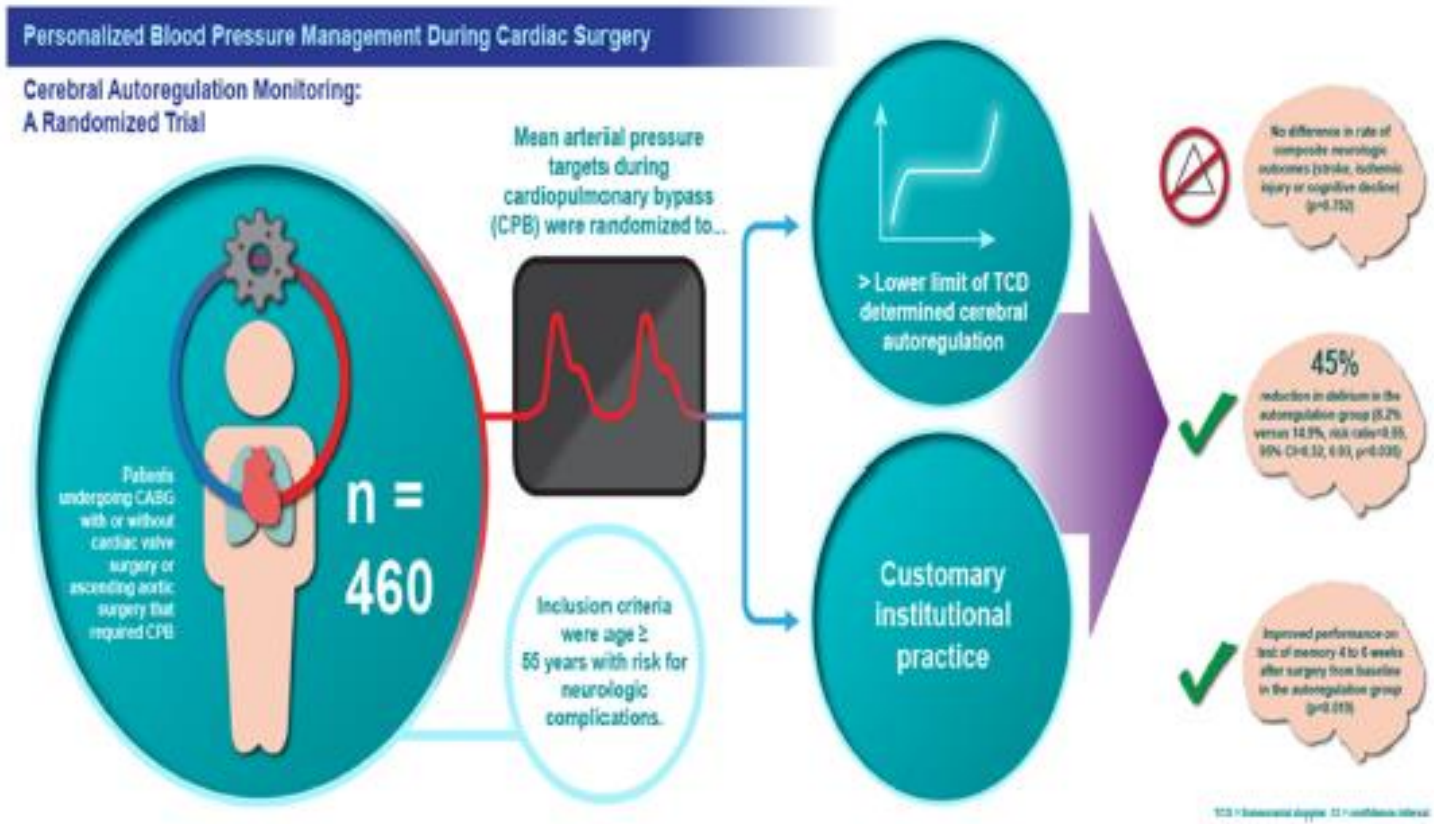
D. Hori[1], C. Brown[2], M. Ono[1], T. Rappold[2], F. Sieber[2], A. Gottschalk[2], K. J. Neufeld[3], R. Gottesman[4], H. Adachi[5] and C. W. Hogue[2*]

Table 4 Variables that had statistically independent association with postoperative delirium based on logistic regression model. MAP, mean arterial pressure; ULA, upper limit of cerebral autoregulation; OR, odds ratio. *For each additional year of age

Variables	OR	95% CI	*P*-value
Mechanical ventilation >48 h	3.94	1.72–9.03	0.001
Antidepressant drug	3.00	1.29–6.96	0.011
Prior stroke	2.79	1.12–6.96	0.027
CHF	2.68	1.28–5.62	0.009
Magnitude of MAP above ULA (mm Hg h)	1.09	1.03–1.15	0.001
Age*	1.04	1.01–1.072	0.030

Personalized Blood Pressure Management During Cardiac Surgery With Cerebral Autoregulation Monitoring: A Randomized Trial

Charles W. Hogue, MD,[*] Charles H. Brown IV, MD, MPH,[†] Daijiro Hori, MD,[‡] Masa Ono, MD,[§] Yohei Nomura, MD,[‡] Lauren C. Balmert, PhD,[¶] Nina Srdanovic, MS,[¶] Jordan Grafman, PhD,[‖] and Kenneth Brady, MD[**] The Cerebral Autoregulation Study Group [#]



Personalized Blood Pressure Management During Cardiac Surgery With Cerebral Autoregulation Monitoring: A Randomized Trial

Charles W. Hogue, MD,[*] Charles H. Brown IV, MD, MPH,[†] Daijiro Hori, MD,[‡] Masa Ono, MD,[§] Yohei Nomura, MD,[‡] Lauren C. Balmert, PhD,[¶] Nina Srdanovic, MS,[¶] Jordan Grafman, PhD,[‖] and Kenneth Brady, MD[**] The Cerebral Autoregulation Study Group [#]

Table 2. Composite and individual neurological end-points for patients randomized to the Autoregulation versus Usual Care Groups. In the former, mean arterial pressure targets were set to be above the lower limit of cerebral blood flow autoregulation measured during cardiopulmonary bypass. In the Usual Care Group, these targets were based on standard institutional practice. The composite neurological outcome was composed of clinical stroke, or new ischemic lesions detected on postoperative brain diffusion-weighted magnetic resonance imaging (DWI), or cognitive decline from baseline to 4 to 6 weeks after surgery. The data are listed as the number of patients with the outcome amongst those in whom the outcome was fully assessed. The number of patients with available data is listed as a denominator for each end-point category

End-Point	Autoregulation Group	Usual Care Group	*P* Value	Risk Ratio (95% Confidence Intervals)
Composite neurological outcome	70 of 93 (75.3%)	79 of 101 (78.2%)	0.752	0.96 (0.82, 1.12)
Clinical stroke	13 of 232 (5.6%)	9 of 228 (3.9%)	0.539	1.42 (0.62, 3.26)
Delayed neurocognitive recovery	27 of 172 (15.7%)	35 of 164 (21.3%)	0.233	0.74 (0.47, 1.16)
Brain DWI lesions	48 of 79 (60.8%)	47 of 85 (55.3%)	0.582	1.10 (0.85, 1.43)
Clinically detected delirium	19 of 232 (8.2%)	34 of 228 (14.9%)	0.035	0.55 (0.32, 0.93)

Plan

- Introduction: conséquences neurologiques de la CEC
- Débit Sanguin cérébral
- Autorégulation cérébrale pendant la CEC
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  - Mesure non invasive, Cox
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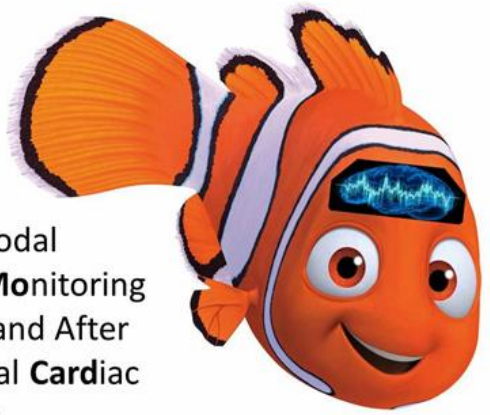
  - Résultats préliminaires en pédiatrie
- Autres éléments du neuromonitoring per CEC
- Conclusion

NEMOCARD Study (NCT04295239) Timeline



Multimodal **Ne**uro**Mo**nitoring during and After Neonatal **Card**iac Surgery

2019 | 2021 | 2022 | 2023

CAR monitoring during ped. ECMO
Preliminary ECMOx Study

ECMOx2 Study: exploring CAR patterns during ECMO and outcomes

2020- 2022 Monitoring in the OR: n=442 pediatric patients

Preliminary Results:
-Feasability
-Describing CAR during CPB
-Describing opt. MAP during CPB

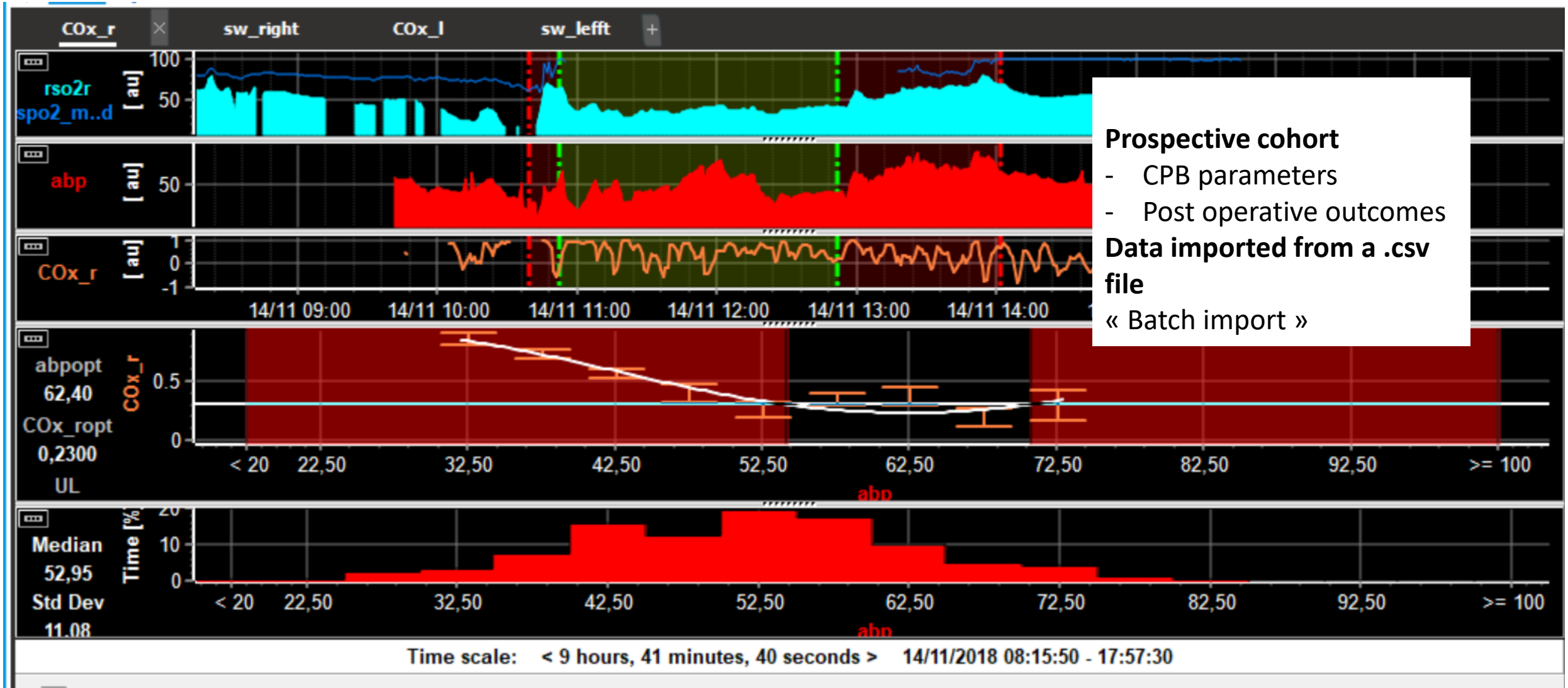
Discovering ICM+
Starting recordings

ICM+®

NEMOCARD Study. Inclusion March 2020- March 2022
N= 45 neonates with post operative MRI & continuous EEG

IMMUNOPED2 Study. Inclusions are almost Completed
N= 45 infants < 3mo. NEUROBIOMARKERS & INFLAMMATiON

442 consecutive patients « plugged » 2020-2022



Prospective cohort

- CPB parameters
- Post operative outcomes

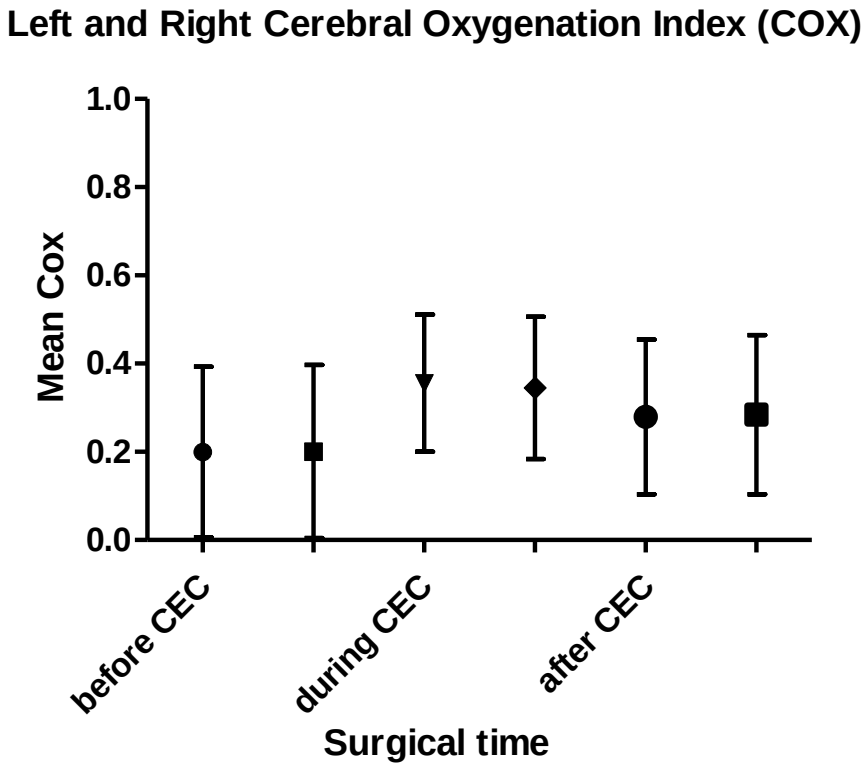
Data imported from a .csv file

« Batch import »

Feasability and description of CAR during CPB

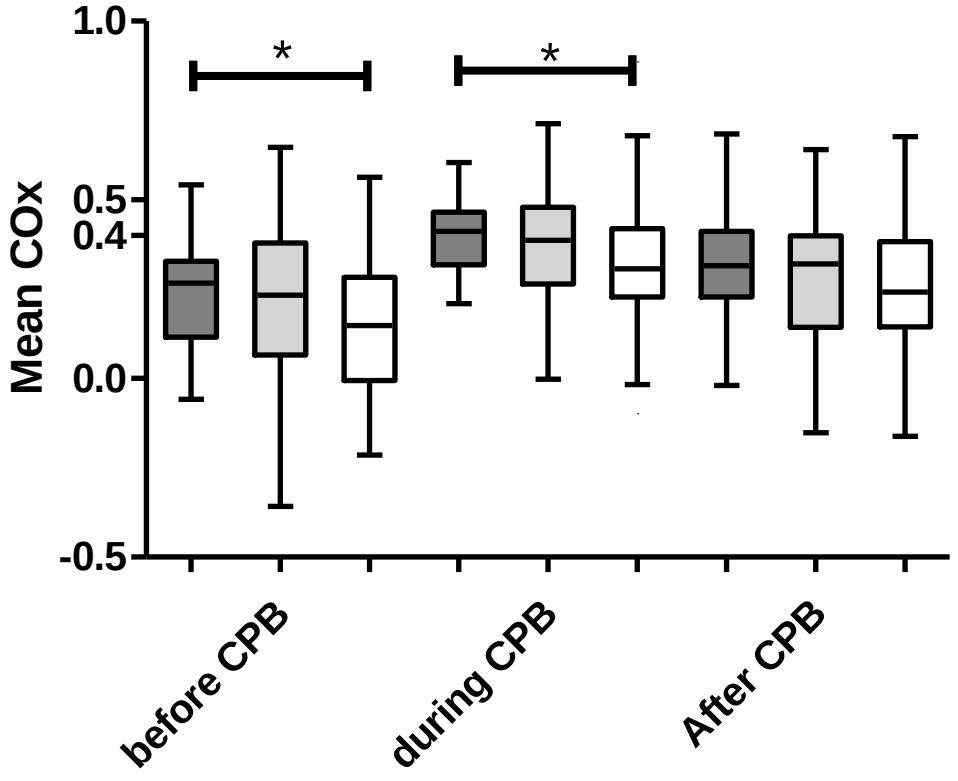
Table 1 Patients characteristics (N = 244)

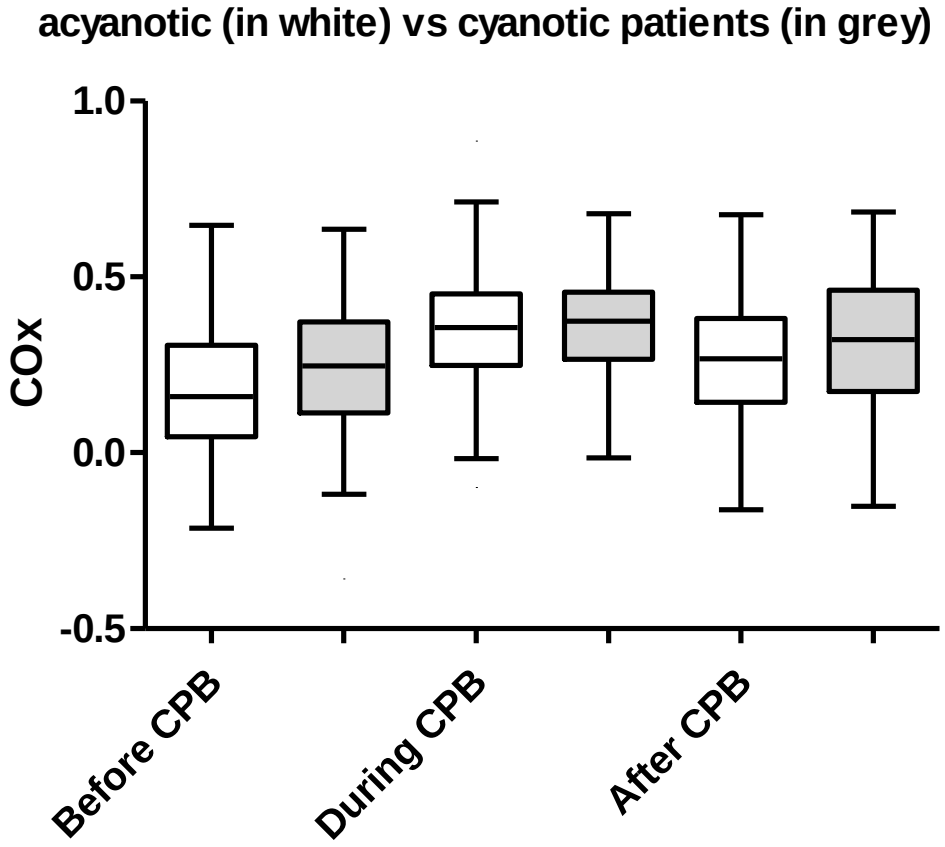
Patient characteristics	Values
Age, day (median [IQR])	406 [88-1723]
Weight, kg (median [IQR])	7.4 [4.4-15.6]
ECHSA Diagnostic Category (N, %)	
Septal defects	81 (33%)
Right heart lesions	52 (21%)
Left heart lesions	31 (13%)
Transposition of the great arteries	21 (9%)
Thoracic Arteries and veins	17 (7%)
Palliative procedures, Uni Ventricule Heart	15 (6%)
Pulmonary Venous Anomalies	12 (5%)
Others (Double Outlet Right Ventricule Cardiomyopathy, Conduit operations, Cor Triatrium, Double Outlet Left Ventricule, Electrophysiological procedures, heart transplant)	15 (6%)
Neonatal Cardiac Surgery (N, %)	44 (18%)
Cyanotic heart disease	85 (34%)



-CAR disruption during CPB
-No difference LEFT/ RIGHT side

Feasability and description of CAR during CPB

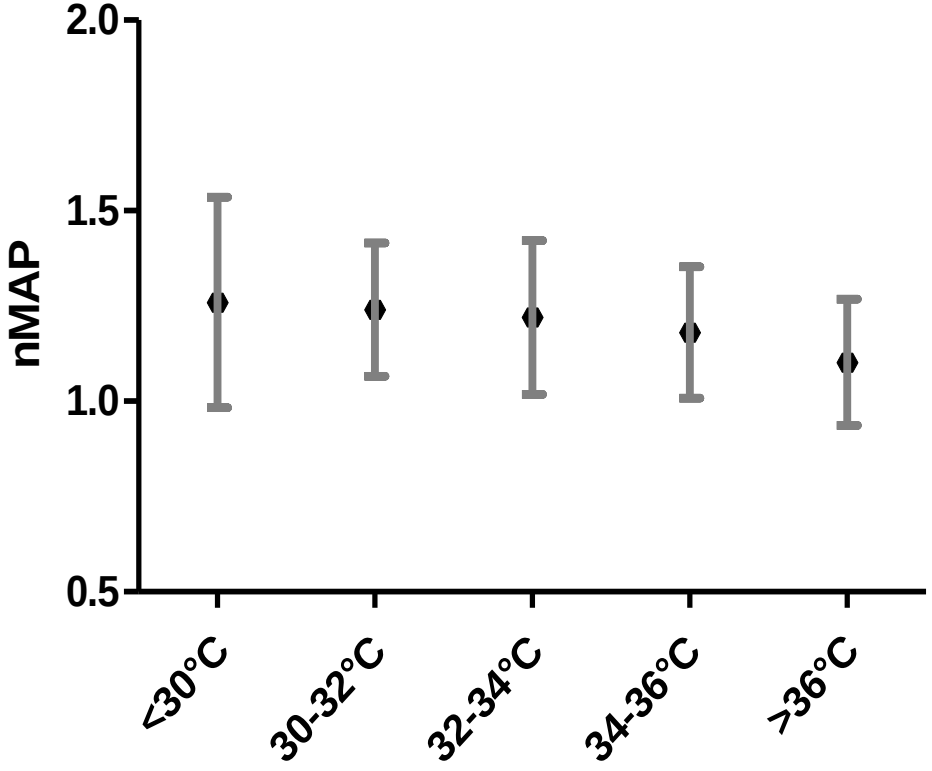




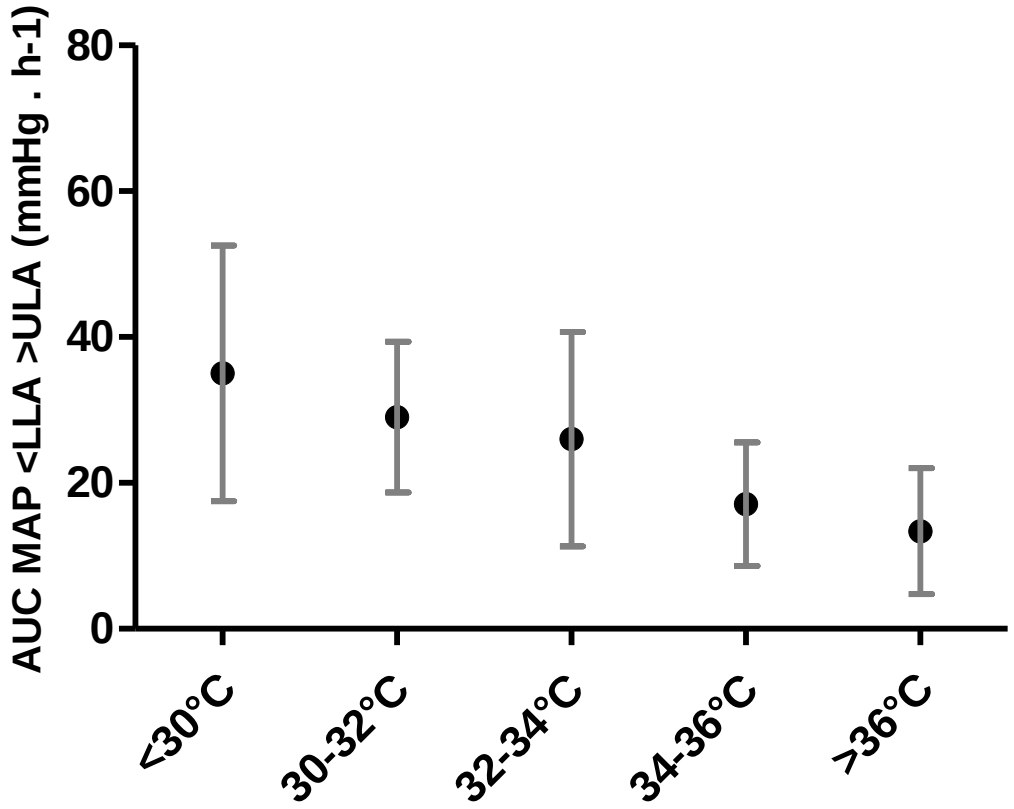
Age groups: CPB mostly affects CAR in Neonates (Dark grey)

Cyanotic or non cyanotic CHD: same patterns

Feasability and description of CAR during CPB

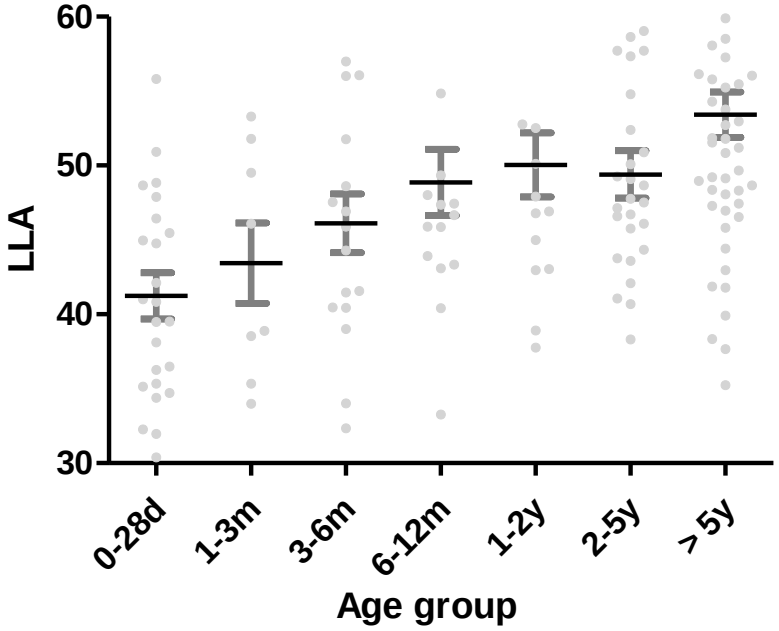


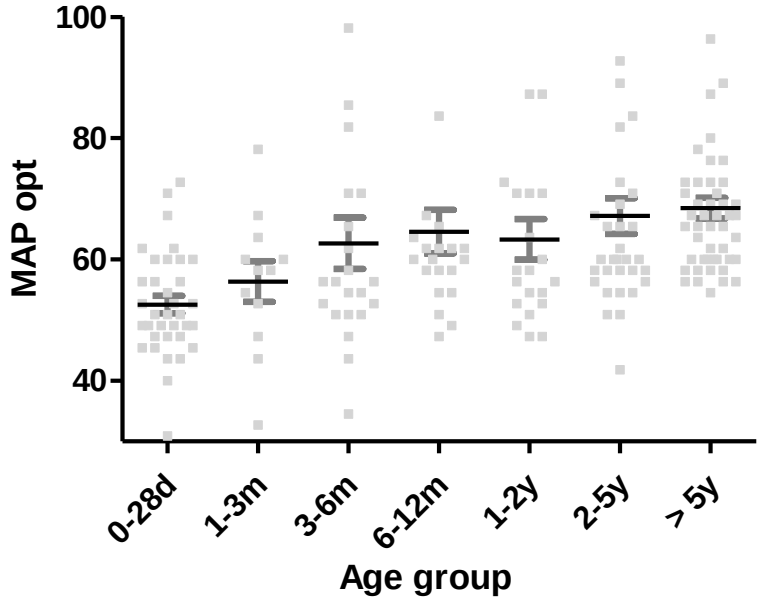
Mean Arterial pressure normalized for age. Lower Core temperature during CPB

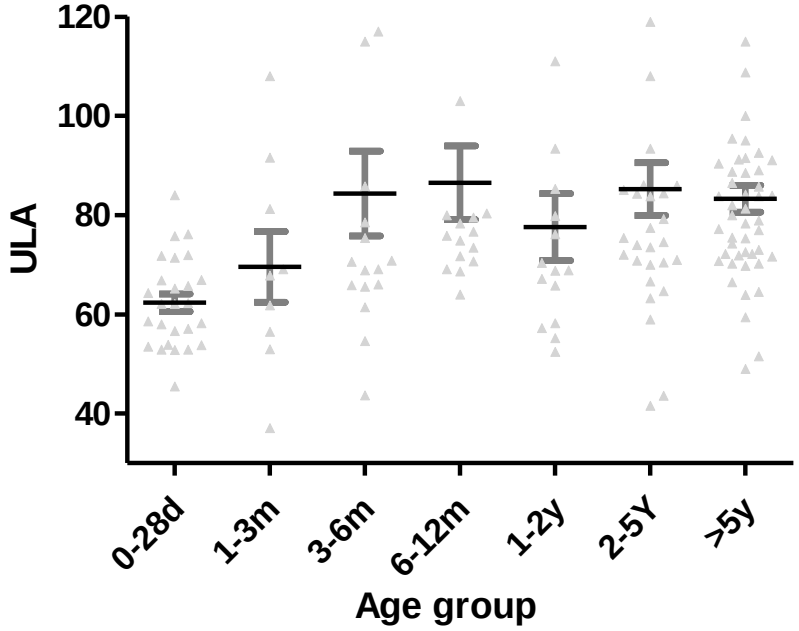


CPB under deep hypothermia probably confers a high risk of CAR disruption. Manual determination of AUC of MAP outside ranges of MAPopt in a selected sample of neonates

Optimal MAP during neonatal or pediatric surgery. Whole Surgery time. Available Up to 80% of cases

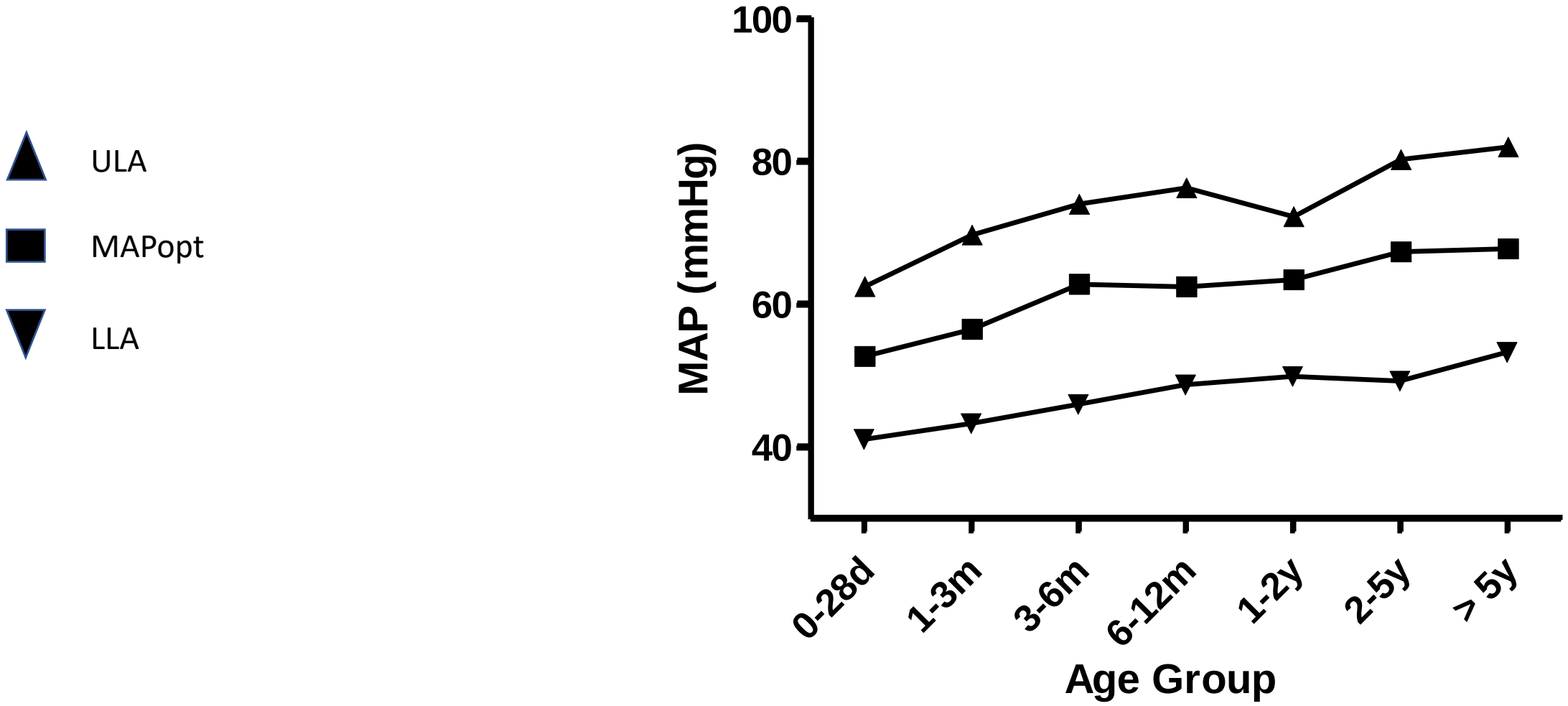






-→ Data calculated manually…..hard job! -→ it is expected to automatized batch analysis!

Optimal MAP during neonatal or pediatric surgery. Whole Surgery time. Available Up to 80% of cases

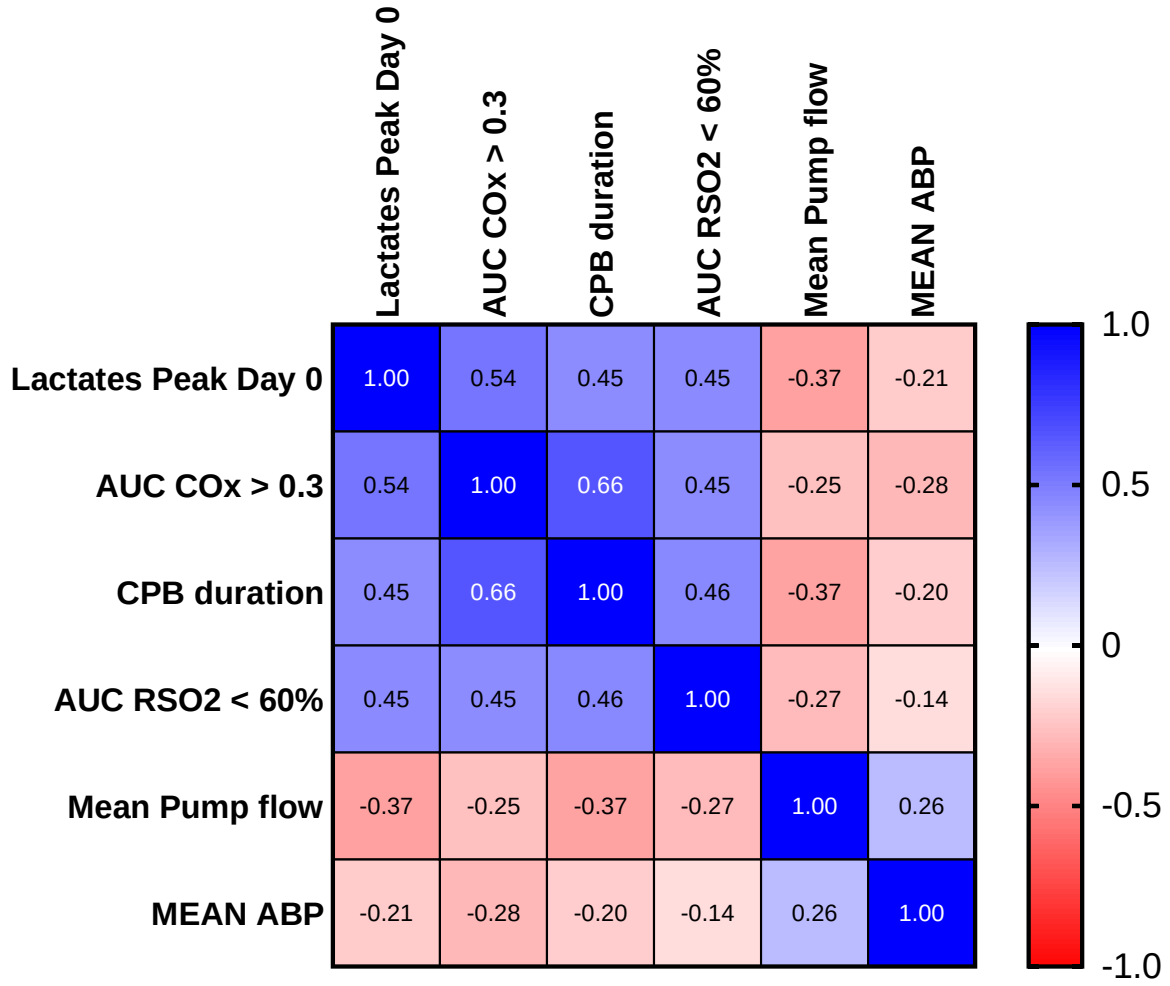


Association of intraoperative CAR disruption and early postoperative outcomes

Multiple Correlation Matrix

N=121 Neonates and infants 0-12 Mo

Post operative Lactates Peak†



†PO lactates Peak within the day of surgery until 7 am the next day

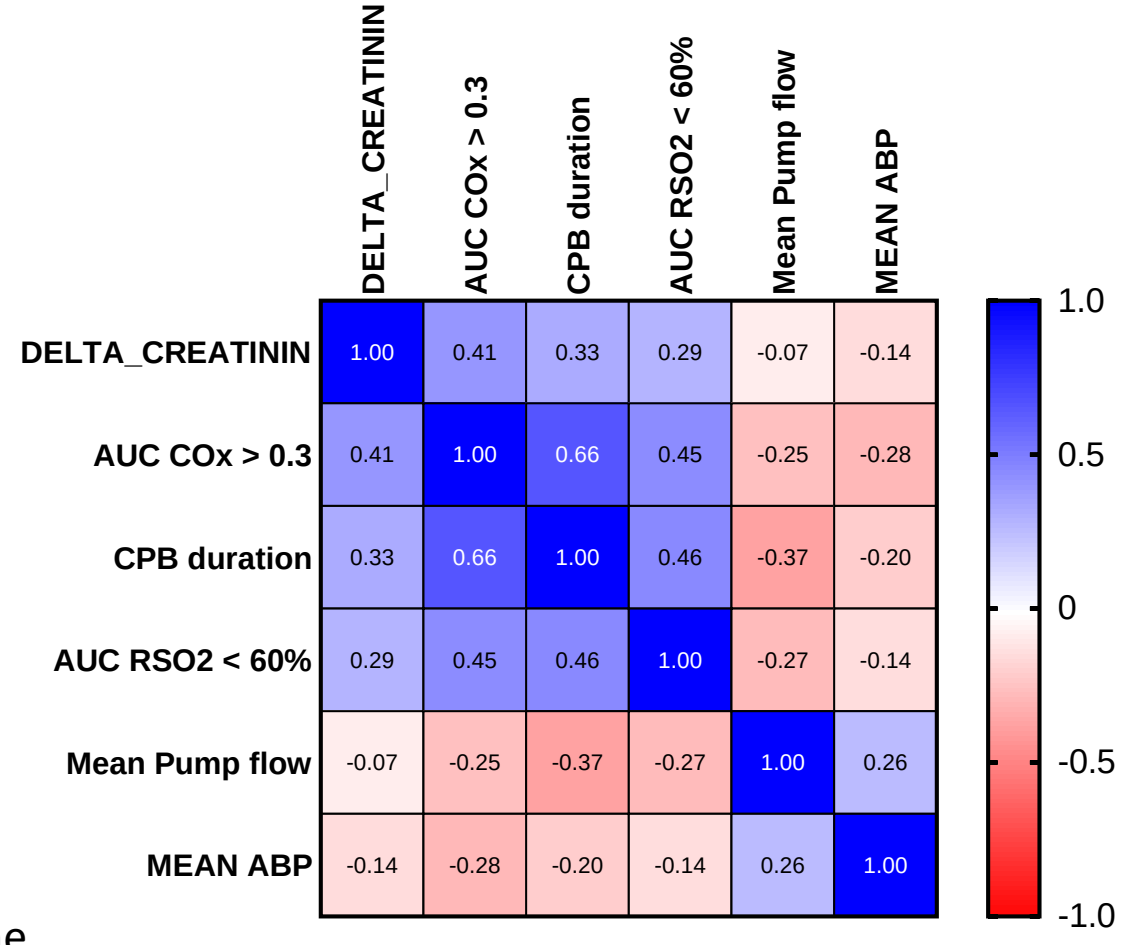
Résultats préliminaires non publiés

Association of intraoperative CAR disruption and postoperative outcomes

Multiple Correlation Matrix

N=114 Neonates and infants 0-12 Mo

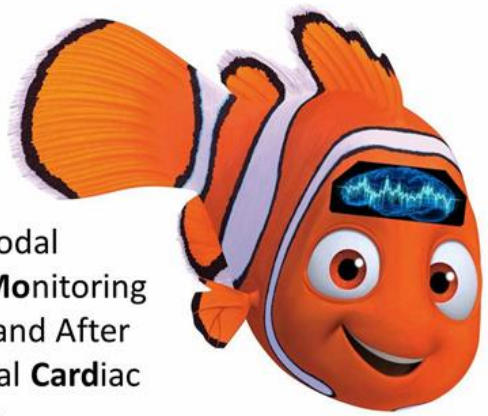
Post operative ΔCreatinine‡



‡Delta Creatinine is the ratio between maximal Serum Creatine within 3 PO days and Preoperative value

Monitoring CAR during CPB: Short term perspectives

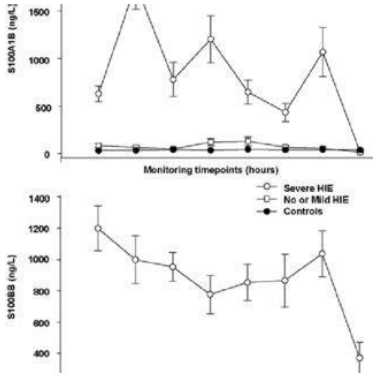
ICM+®



Multimodal **Ne**uro**Mo**nitoring during and After Neonatal **Card**iac Surgery

-Association between Intraoperative hemodynamics AND post operative MRI

→ MRI scoring available in DEC 2022 in 60 neonates following cardiac surgery

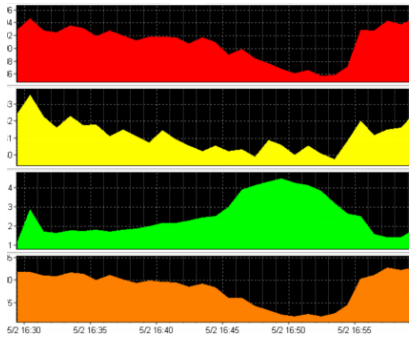


-Association between Intraoperative hemodynamics AND post operative BIOMARKERS plasma levels

→ Available early in 2023

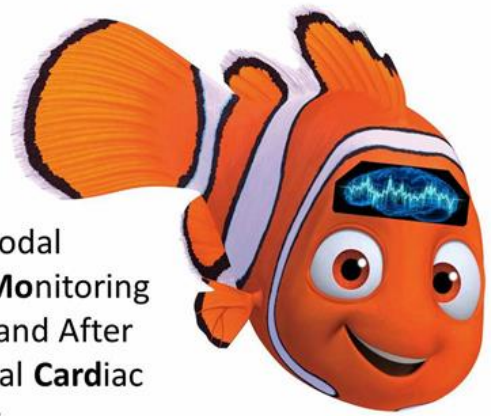
Monitoring CAR during CPB: Short term perspectives depending on preliminary results

ICM+®



Bedside monitoring: are we ready to guide bedside interventions during CPB?

→ Application of PRE-CPB findings during surgery and intensive care following surgery



Multimodal **Ne**uro**Mo**nitoring during and After Neonatal **Card**iac Surgery

→ Preliminary anlysis (20 neonates)
→ Due to a too short period of time before CPB onset, Defining optimal MAP values is only available in 50% of the patients. But appears to be well correlated with optimal values under CPB.

Plan

- Introduction: conséquences neurologiques de la CEC
- Débit Sanguin cérébral
- Autorégulation cérébrale pendant la CEC
  - Théorie
  - Mesure non invasive, Cox
  - Preuve de concept chez l'adulte
  - Résultats préliminaires en pédiatrie
- Autres éléments du neuromonitoring per CEC
- Conclusion

Review Article

Neuromonitoring Modalities in Pediatric Cardiac Anesthesia: A Review of the Literature

Elizabeth Finucane, DO[1], Edmund Jooste, MBChB, Kelly A. Machovec, MD, MPH

Duke University Medical Center, Durham, NC

Table 1
Summary of Advantages and Disadvantages of Each Neuromonitoring Modality, Including Recommendations for Use

Modality	Advantages	Disadvantages	Uses	Recommendations
TCD	• Noninvasive • Inexpensive	• Variable anatomic window • Anterior fontanelle closes by 9-18 mo • Subjective results • User dependent • Does not indicate flow through smaller cerebral vessels • Dependent on adequate blood flow	• Cerebral blood flow measurement during low-flow CPB • CPB pump flow titration and pulsatility index • Cerebral emboli detection	Use of >1 neuromonitoring modality simultaneously
EEG	• Noninvasive	• Cumbersome equipment • Expensive • Time consuming • Need trained technician	• Obtain preoperative neurologic status • Monitoring during DHCA • Prediction of postoperative seizures and monitor for seizures	
NIRS	• Noninvasive • Able to use throughout perioperative period • Real-time monitoring • More effective than TCD in low-flow states and DHCA	• Limited by location on forehead • Need baseline measurement • Interference by other substances (conjugated bilirubin, methylene blue) • Unreliable if hematocrit >60%	• Monitoring of perfusion during low-flow states (eg, innominate artery cannulation, DHCA) • Adjustment of vasoactive medications, ventilator settings, and CPB indices in response to cerebral saturation changes	

Novel cerebral physiologic monitoring to guide low-flow cerebral perfusion during neonatal aortic arch reconstruction

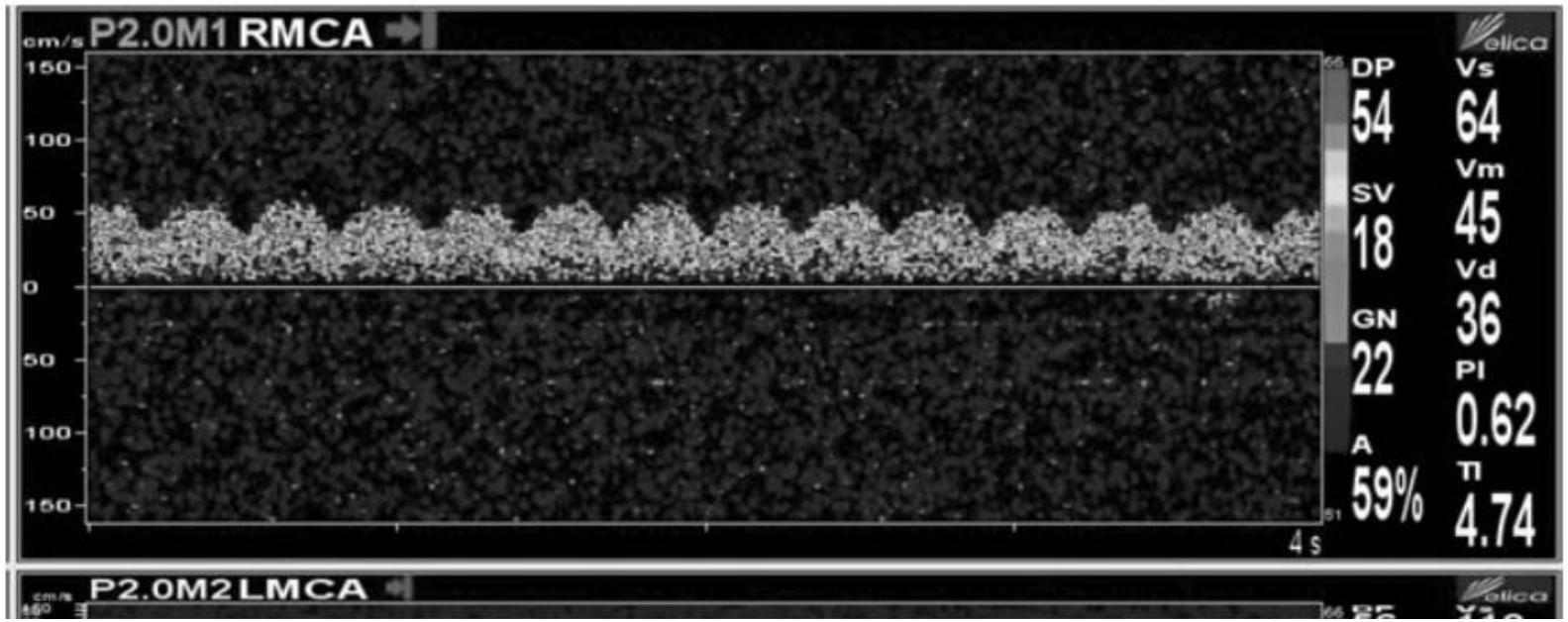
Dean B. Andropoulos, MD[a]
Stephen A. Stayer, MD[a]
E. Dean McKenzie, MD[b]
Charles D. Fraser, Jr, MD, FACS[b]

JCTVS 2003

Real-Time Continuous Neuromonitoring Combines Transcranial Cerebral Doppler with Near-Infrared Spectroscopy Cerebral Oxygen Saturation During Total Aortic Arch Replacement Procedure: A Pilot Study

ASAIO 2012

Xiaohua Wang,* Bingyang Ji,† Baohui Yang,‡ Gang Liu,† Na Miao,§ Jing Yang,§ Jinping Liu,† and Cun Long†



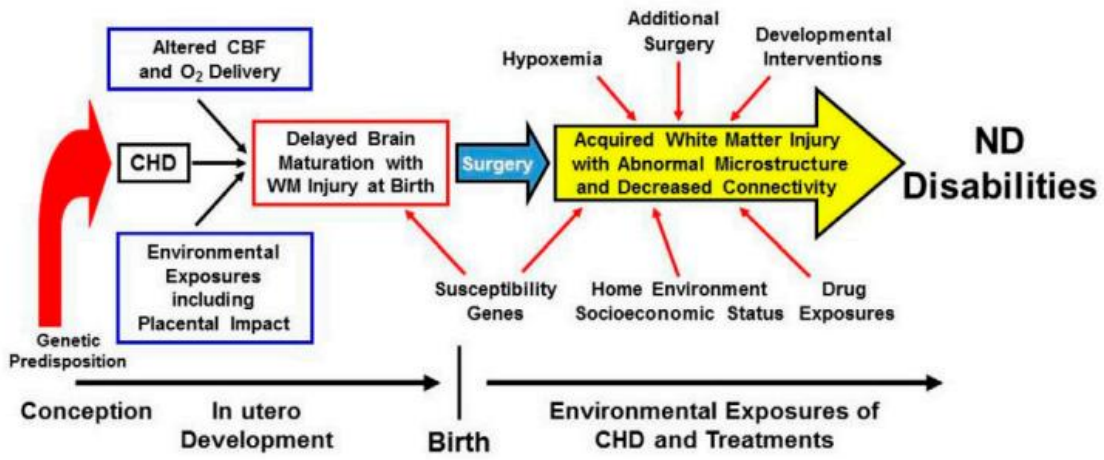
« Bonne » corrélation rSO2 VmMCA (r2= 0.22 Andropoulos et al.)

Table 2. Perioperative Monitoring Parameters

Variable	Pump Flow (ml/min)	Temperature (°C)	MAP (mm Hg)	VmMCA (cm/s)	rSO_2 (%)	SVO_2 (%)
Before incision		36.4 ± 0.7	80 ± 9.2	34.7 ± 14.2	68.8 ± 9.4	
10 min post-CPB	4240 ± 450	30.4 ± 2.4	55.4 ± 9.7	32.7 ± 11.6	63.4 ± 11.6	84.2 ± 5.4
10 min post–cross-clamp	4290 ± 440	26.3 ± 3.6	57.8 ± 11.2	28.9 ± 10.1	57.9 ± 9.8	89.7 ± 6.6
5 min post-ASCP	832 ± 189	21.8 ± 2.8	22 ± 7	15.3 ± 7.2*†	51.4 ± 7.8*	67.4 ± 7.9
10 min post-ASCP	807 ± 214	22.4 ± 2.3	24 ± 6	14.7 ± 6.4*†	52.7 ± 8.9*	61.5 ± 5.8
5 min after full flow	4350 ± 520	21.2 ± 3.1	61.7 ± 13.1	29.4 ± 9.8	55.3 ± 4.5	80.1 ± 9.3
10 min postrewarming	4340 ± 480	28.7 ± 3.9	59.4 ± 9.7	31.3 ± 12.7	54.1 ± 5.8	78.4 ± 7.9
10 min postresuscitation	4370 ± 540	29.7 ± 3.4	58.2 ± 10.2	32.3 ± 12.0	55.4 ± 8.6	77.2 ± 6.5
Postoff pump		36.8 ± 2.4	77.8 ± 14.1	32.7 ± 11.9	53.7 ± 9.1	

*Compared with the induced, $p < 0.05$.
†Compared with post-off pump, $p < 0.05$.
ASCP, antegrade selective cerebral perfusion; CPB, cardiopulmonary bypass; rSO_2, regional cerebral oxygen saturation; VmMCA, middle cerebral artery mean velocity; SVO_2, venous oxygen saturation; MAP, mean arterial pressure.

Conclusion



NIRS 1ère modalité d'estimation du DSC

En comprendre les limites:

Association pronostique modeste
Algorithmes non évalués

DSC optimal = perfusion tissulaire optimale

Des stratégies de détermination de MAP opt sont à l'étude

TCD: difficile, à associer au NIRS (cf présentation suivante)

aEEG: plutôt en post opératoire

PH-STAT

vs

α-STAT

PCO2 corrigée à la température

Principe: ↓du DGF pendant l'hyporthermie: PaCO2 corrigée stable, PaCO2 non corrigée↑

CBF stable, Améliore DO2 (shift de la courne de dissociation de l'Hb vers la droite)

Améliore le cooling

« Perte d'autorégulation »

PCO2 NON corrigée à la température

Principe: PaCO2 non corrigée stable (PaCO2 corrigée baisse)

CBF abaissé

« Autorégulation maintenue » (pas d'ajout de CO2)

Fonctions cellulaires préservées à pH alcalin.