UNIVERSITEIT GENT

FACULTEIT GENEESKUNDE EN GEZONDHEIDSWETENSCHAPPEN

Goal Directed Perfusion:
basic concepts and some examples

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Acute risk change for cardiothoracic admissions to intensive care: A new measure of quality in cardiac surgery

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Background: Quality of cardiac surgical care may vary between institutions. Mortality is low and large numbers are required to discriminate between hospitals. Measures other than mortality may provide better comparisons.

Objectives: To develop and assess the Acute Risk Change for Cardiothoracic Admissions to Intensive Care (ARCTIC) index, a new performance measure for cardiothoracic admissions to intensive care units (ICUs).

Methods: The Australian and New Zealand Society of Cardiac and Thoracic Surgeons database and Australian and New Zealand Intensive Care Society Adult Patient Database were linked. Logistic regression was used to generate a predicted risk of death first from preoperative data using the previously validated Allprocscore and second on admission to an ICU using Acute Physiology and Chronic Health Evaluation III score. Change in risk as a percentage (ARCTIC) was calculated for each patient. The validity of ARCTIC as a marker of quality was assessed by comparison with intraoperative variables and postoperative morbidity markers.

Results: Sixteen thousand six hundred eighty-seven patients at 21 hospitals from 2008 to 2011 were matched. An increase in ARCTIC score was associated with prolonged cardiopulmonary bypass time ($P = .001$), intraoperative blood product transfusion ($P < .001$), reoperation ($P < .0001$), postoperative renal failure ($P < .0001$), prolonged ventilation ($P < .0001$), and stroke ($P = .001$).

Conclusions: The ARCTIC index is associated with known markers of perioperative performance and postoperative morbidity. It may be used as an overall marker of quality for cardiac surgery. Further work is required to assess ARCTIC as a method to discriminate between cardiac surgical units. (J Thorac Cardiovasc Surg 2014;■:1-6)

European Journal of Cardio-Thoracic Surgery 44 (2013) e175–e180
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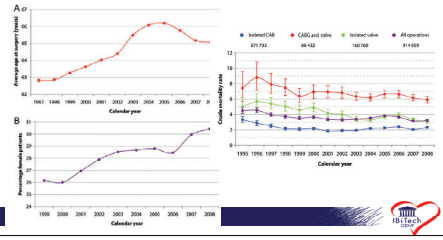
ORIGINAL ARTICLE

The European Association for Cardio-Thoracic Surgery (EACTS) database: an introduction

Stuart J. Head[a], Neil J. Howell[b], Ruben L.J. Osnabrugge[a], Ben Bridgewater[c], Bruce E. Keogh[d], Robin Kinsman[e], Peter Walton[e], Jan F. Gummert[f], Domenico Pagano[g] and A. Pieter Kappetein[a,*]



How do we know that blood flow meet the metabolic needs of a patient?

By retrospective analysis of organ function, blood markers and morbidity

"What we need is a multivariate online analysis of risk during cardiopulmonary bypass" *Charles Wildevuur*

Which parameters?

accp/sccm consensus conference

Definitions for Sepsis and Organ Failure and Guidelines for the Use of Innovative Therapies in Sepsis

THE ACCP/SCCM CONSENSUS CONFERENCE COMMITTEE:

Roger C. Bone, M.D., F.C.C.P., Chairman — *Alan M. Fein, M.D., F.C.C.P.*
Robert A. Balk, M.D., F.C.C.P. — *William A. Knaus, M.D.*
Frank B. Cerra, M.D. — *Roland M. H. Schein, M.D.*
R. Phillip Dellinger, M.D., F.C.C.P. — *William J. Sibbald, M.D., F.C.C.P.*

- Body temperature: >38°C or <36°C
- Heart rate: >90 min^{-1}
- Hyperventilation: RR >20 min^{-1} or $PaCO_2$ <32mmHg
- WBC: >12000 μL^{-1} or <4000 μL^{-1}

PIRO concept

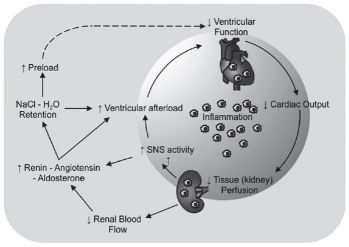
Predisposition: Premorbid illness with reduced probability of short term survival. Cultural or religious beliefs, age, gender.	Age, gender, EF, eGFR, diabetes, REDO
Insult: Culture and sensitivity (infection) or infection pathogens; detection of disease amenable to source control.	Surgery, transfusion, hemodynamics, ischemia, emboli
Response: SIRS, other signs of sepsis, shock, CRP.	↗ Creatinine, ↘ diuresis, delirium, ↗ bilirubin, ↘ PaO2
Organ: Organ dysfunction as number dysfunction of failing organs or composite score (e.g. MODS, SOFA, RIFLE).	AKI, stroke, MCS, RRT, ECMO

Cardiopulmonary bypass related injury

Perioperative:	No AKI	AKI			
CABG	2,080 (70.9)	1,228 (64.7)	Ref		
Valve	488 (16.6)	286 (15.1)	1.18	(0.98–1.41)	0.080
CABG/valve	364 (12.4)	385 (20.4)	2.31	(1.92–2.76)	<0.001
Off-pump surgery	210 (7.2)	76 (4.0)	0.43	(0.32–0.58)	<0.001
Number of valves, mean ± SD	0.32 ± 0.52	0.39 ± 0.56	1.53	(1.36–1.73)	<0.001
Number of anastomoses, mean ± SD	2.74 ± 1.67	2.86 ± 1.66	1.02	(0.98–1.06)	0.433
Pump time (minutes), mean ± SD	110 ± 54	124 ± 55	1.01	(1.01–1.01)	<0.001
Pump time >120 (minutes)	1,093 (37.3)	879 (46.3)	2.07	(1.81–2.36)	<0.001
Cross-clamp time (minutes), mean ± SD	69.7 ± 40.3	77.4 ± 38.6	1.01	(1.01–1.01)	<0.001
Cardioplegia time (minutes), mean ± SD	20.1 ± 7.6	20.7 ± 6.6	1.02	(1.01–1.03)	<0.001
Blood cardioplegia	2,439 (83.2)	1,644 (86.6)	1.22	(1.01–1.46)	0.038
Cold cardioplegia	1,482 (50.6)	802 (42.2)	0.88	(0.77–1.01)	0.068
Cardioplegia hot shot	2,558 (87.2)	1,692 (89.1)	1.11	(0.90–1.36)	0.333
Retrograde autologous priming (RAP)	1,722 (58.7)	1,140 (60.0)	0.85	(0.75–0.98)	0.023
Volume of fluids on bypass (mL), mean ± SD	1,925 ± 2,151	2,213 ± 2,494	1.00	(1.00–1.00)	<0.001
Prime volume (mL), mean ± SD	1,150 ± 535	1,190 ± 559	1.00	(1.00–1.00)	<0.001
Blood prime units, mean ± SD	0.09 ± 0.46	0.20 ± 0.65	1.56	(1.36–1.79)	<0.001
Number of pRBCs units, mean ± SD	0.51 ± 1.24	0.87 ± 1.76	1.33	(1.26–1.40)	<0.001
Highest blood temperature, mean ± SD	37.5 ± 0.41	37.5 ± 0.70	1.00	(0.92–1.09)	0.911
Lowest venous saturation, mean ± SD	69.87 ± 6.27	69.82 ± 6.35	1.00	(0.99–1.01)	0.549
Total volume of heparin > 50,000 units	1,031 (35.2)	700 (36.9)	0.97	(0.84–1.11)	0.619
Last potassium on bypass, mean ± SD	5.58 ± 3.32	5.58 ± 3.54	1.00	(0.98–1.01	0.795
Nadir hematocrit on bypass, mean ± SD	23.24 ± 3.29	22.56 ± 3.39	0.91	(0.90–.93)	<0.001
Nadir hematocrit < 20 on bypass	332 (11.3)	320 (16.9)	1.62	(1.34–1.97)	<0.001
Ultrafiltration (hemoconcentration on bypass)	136 (4.6)	139 (7.3)	1.74	(1.31–2.30)	<0.001
Return to bypass	219 (7.5)	204 (10.7)	1.61	(1.28–2.03)	<0.001
Aprotinin use	1,157 (39.5)	936 (49.4)	2.08	(1.82–2.37)	<0.001

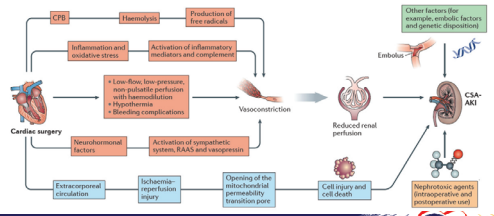
Brown 2012

CardioRenal interrelationship in heart failure



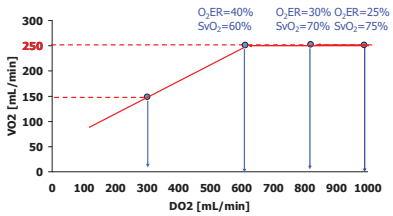
Boudoulas 2017

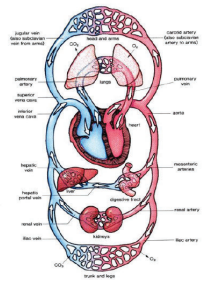
Causes



Wang 2017

DO_2 and VO_2





- Changes based on metabolic needs
- Usually in the range of 2.8 to 3.0 L/min/mq
- May increase up to 15 L/min/m²
- CO with arterial oxygen content, determines the oxygen delivery (DO2)
- Guaranty oxygen need (VO2)
- Pulsatile flow

- Hematocrit: 40 – 50%
- Normal cardiac function
- Normal vascular volume

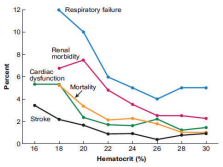
Darling 1999

Intraoperative anemia

TABLE 2. Investigations examining effect of intraoperative anemia on postoperative outcomes

Groups	Design	n	Effect
Habib et al[47]	Observational	3000	Increased mortality and pulmonary, neurologic, renal, and cardiac morbidity
Habib et al[47]	Observational	1760	Increased renal injury
Ranucci et al[7]	Observational	3015	Major morbidity: prolonged ventilation, surgical reoperation, mediastinitis, renal dysfunction, stroke
DeFoe et al[48]	Observational	6980	Mortality, low output heart failure
Jonas et al[49]	Randomized controlled trial	147	Decreased cardiac index and psychomotor development; increased serum lactate and total body water
Swaminathan et al[50]	Observational	1404	Renal insufficiency
Karkouti et al[51]	Observational	113049	Stroke
Bahrainwala et al[46]	Observational	617	Increased risk of stroke
von Heymann et al[52]	Randomized controlled trial	34	Similar oxygen delivery and morbidity
Berger et al[53]	Randomized controlled trial	47	Similar GI permeability and inflammatory response

GI, Gastrointestinal.



Loor 2012

Hematocrit on Cardiopulmonary Bypass and Outcome After Coronary Surgery in Nontransfused Patients

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Background. Preoperative anemia and the lowest registered hematocrit value on cardiopulmonary bypass are recognized risk factors for morbidity and mortality after coronary operations. A low hematocrit often results in blood transfusions with all of the associated possible complications. The relative contribution of these three factors to long-term outcome is still not well established. This study aimed to identify the role of preoperative anemia and hemodilution during cardiopulmonary bypass as determinants of morbidity and mortality after coronary operations.

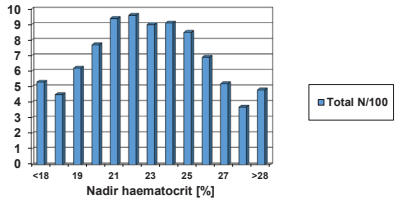
Methods. A consecutive series of 3,003 patients was analyzed. They had all undergone isolated coronary operations without receiving blood transfusions during their hospital stay. The preoperative hematocrit and the lowest hematocrit on cardiopulmonary bypass were analyzed in a multivariable model as predictors of major morbidity and operative mortality.

Results. After adjustment for the other explanatory variables, both the preoperative hematocrit and the lowest hematocrit on cardiopulmonary bypass were found to be independent risk factors for major morbidity, but not for operative mortality. However, low values of preoperative hematocrit were not associated with an increased morbidity, provided that the lowest hematocrit on cardiopulmonary bypass was maintained above 28%. Median values of the lowest hematocrit on cardiopulmonary bypass below 25% were associated with an increased major morbidity rate.

Conclusions. Excessive hemodilution during cardiopulmonary bypass is a risk factor for major morbidity even in the absence of blood transfusions. Techniques that aim to reduce the fall in hematocrit during cardiopulmonary bypass, including blood cardioplegia, may be useful, especially in patients with a low preoperative hematocrit.

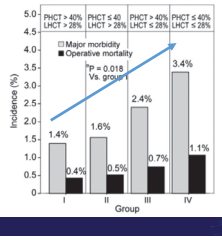
(Ann Thorac Surg 2010;89:11–8)

Haematocrit during CPB

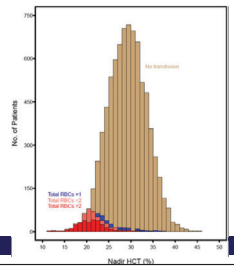


Karkouti 2005

Hemodilution and CPB



Hematocrit during CPB



Loor 2013

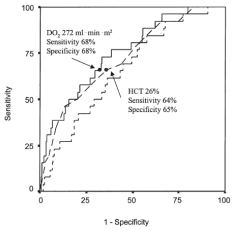
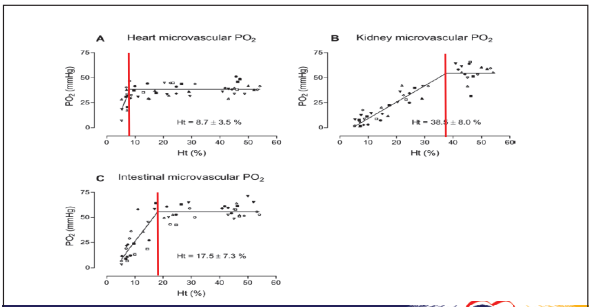
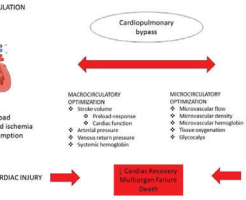


Fig 2. Receiver operating characteristic curve for the three variables being identified as independent risk factors for acute renal failure. — — = lowest hematocrit on CPB; - - - - = pump flow indexed; —— = oxygen delivery indexed. (CPB = cardiopulmonary bypass; DO_2 = two determinants of oxygen delivery; HCT = hematocrit.)

Ranucci 2005

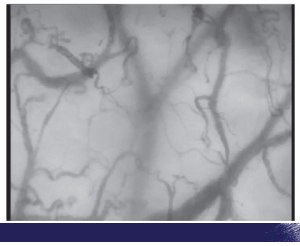


Van Bommel 2008



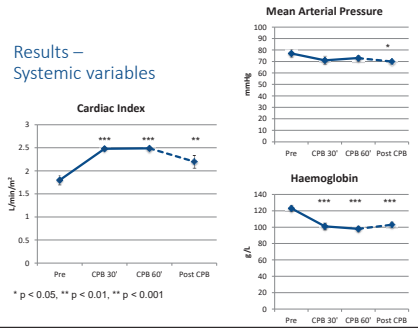
De Cuyper 2024

Microcirculation



De Backer 2007

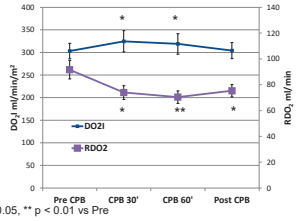
Results – Systemic variables



* p < 0.05, ** p < 0.01, ** p < 0.001

Lannemyr 2017

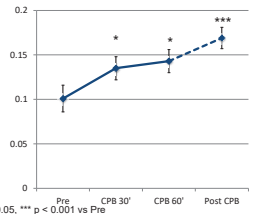
Systemic and renal oxygen delivery



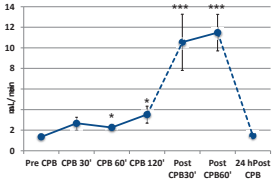
* p < 0.05, ** p < 0.01 vs Pre

Lannemyr 2017

Renal oxygen extraction



NAG - Excretion



* p < 0.05, *** p < 0.001 vs Pre

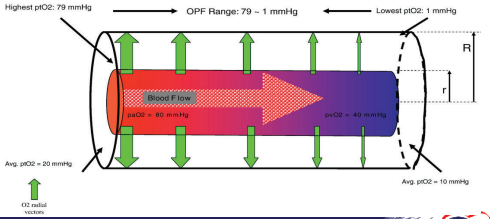
Lannemyr 2017

Oxygen Pressure Field Theory: Krogh Cylinder Model

Capillary radius: r = 5µ
Capillary X-section : A = πr² = 78. 5 µ²

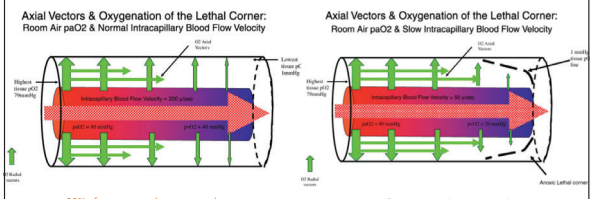
Cylinder radius: R = 10
Cylinder X-section: A = πR² = 314 µ²

Ratio: Capillary X-section / Cylinder X-section = 1/4



Grist 2008

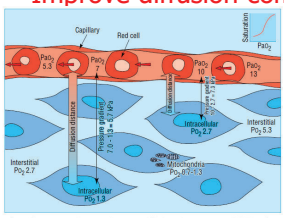
Impact of velocity



20% of oxygen supply venous end

80% of oxygen supply venous end

Improve diffusion component

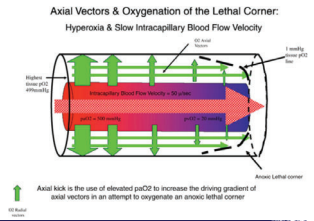


Effect of oxygen tension gradient and diffusion distance on availability of oxygen to cells

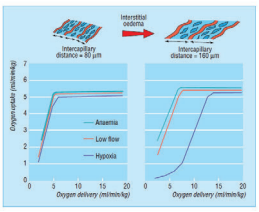
Oxygen-haemoglobin dissociation curve. The curve shifts to the right with increased temperature, acidosis, and 2,3-diphosphoglycerate concentrations

Leach 1998

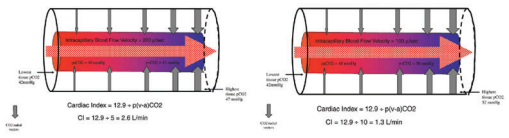
Improve diffusion component



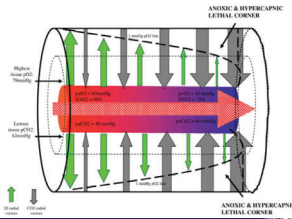
Axial kick is the use of elevated paO2 to increase the driving gradient of axial vectors in an attempt to oxygenate an anoxic lethal corner

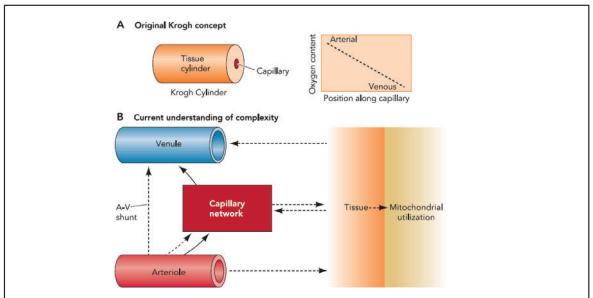


CO_2 removal

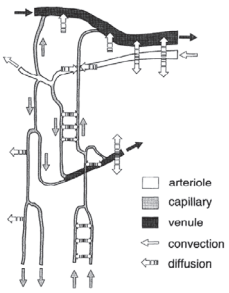


Congestion and microcirculation



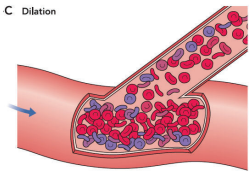


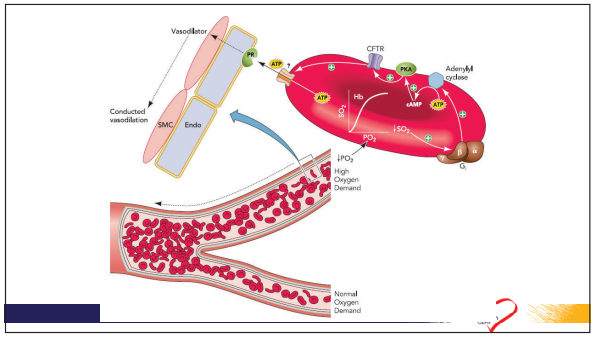
Ellsworth 2009



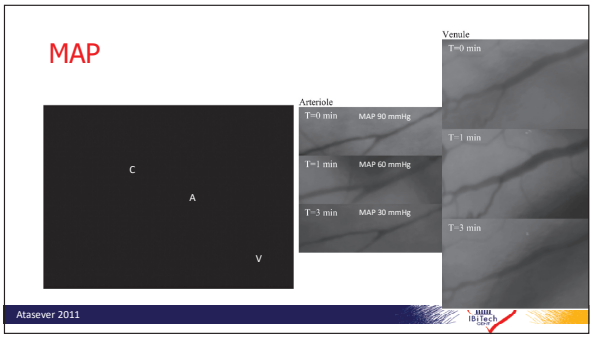
Ellsworth 1994

Regulating mechanisms





MAP



Atasever 2011

Hypoperfusion vs congestion

Mean arterial and pulmonary arterial pressures (MAP and MPAP), pulmonary artery occlusion pressure (PAOP), cardiac output (CO), mixed venous oxygen saturation (SvO_2), and arterial pH and hematocrit (Hct) in SMAO (superior mesenteric artery occlusion, $n = 7$) and SMVO (superior mesenteric vein occlusion, $n = 7$) groups

	Group	BL	I1-45	R30	R60	R120
MAP, mm Hg	SMAO	122.7 ± 7.6	130.9 ± 9	122 ± 8.2	128.8 ± 7.2	128.3 ± 10.3
	SMVO	131 ± 8.1	95.7 ± 9.3[a,b]	102 ± 9.2[a,b]	106 ± 9.8[a,b]	109 ± 7.5[a,b]
MPAP, mm Hg	SMAO	14.5 ± 1.4	14.3 ± 1.8	15.8 ± 2	16.9 ± 1.6	19.1 ± 1.9[a]
	SMVO	15.2 ± 1.9	12.0 ± 2.1	13.4 ± 2.2	13.4 ± 2.3[b]	13.7 ± 2.8[b]
PAOP, mm Hg	SMAO	7.3 ± 1.4	7.7 ± 1.7	7.4 ± 1.6	7.2 ± 1.7	7.5 ± 1.7
	SMVO	7.1 ± 1.2	5.4 ± 0.9[a]	5.9 ± 1.6	4.6 ± 1.3[a,b]	5.1 ± 1.1[a,b]
CO, L/min	SMAO	2.9 ± 0.2	2.6 ± 0.2	2.3 ± 0.1	2.3 ± 0.2	2.3 ± 0.1
	SMVO	3.2 ± 0.2	2.1 ± 0.2[a]	1.9 ± 0.2[a]	1.6 ± 0.2[a,b]	1.6 ± 0.2[a,b]
Arterial lactate, mmol/l	SMAO	0.8 ± 0.1	0.8 ± 0.1	1.0 ± 0.1	0.8 ± 0.1	0.9 ± 0.3
	SMVO	1.2 ± 0.4	2.1 ± 0.4[a,b]	2.2 ± 0.4[a,b]	2.0 ± 0.2[a,b]	1.7 ± 0.1[a,b]
Arterial pH	SMAO	7.4 ± 0.02	7.42 ± 0.02	7.4 ± 0.02	7.39 ± 0.02	7.39 ± 0.01
	SMVO	7.37 ± 0.01	7.33 ± 0.01[a,b]	7.29 ± 0.02[a,b]	7.3 ± 0.01[a,b]	7.29 ± 0.02[a,b]
Arterial Hb_t, %	SMAO	35.3 ± 1.4	34.1 ± 0.6	36.9 ± 1.7	35.8 ± 2.1	35.5 ± 1.9
	SMVO	38.7 ± 1.1	35.8 ± 2.4	37.3 ± 2.1	38 ± 1.8	36.8 ± 2.4

Notes: Baseline (BL), 45 min after intestinal ischemia (I1-45) and 30, 60, and 180 min after reperfusion (R30, R60, and R120, respectively). Data are presented as mean ± standard error of the mean.
[a] $P < 0.05$ versus baseline.
[b] $P < 0.05$ versus SMAO.

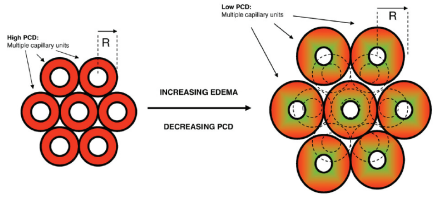
Cruz 2010

Hypoperfusion vs congestion

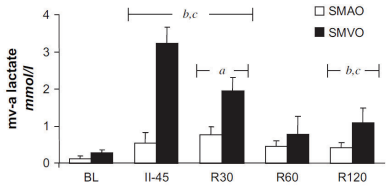
Intestinal oxygen delivery, consumption and extraction ratio (DO_2intest, VO_2intest and O_2ERintest), and mesenteric vein pH and hematocrit (Ht) in SMAO (superior mesenteric artery occlusion, $n = 7$) and SMVO (superior mesenteric vein occlusion, $n = 7$) groups

	Group	BL	II-45	R30	R60	R120
DO_2 intest, mL/min	SMAO	67.7 ± 9.9	-	45.4 ± 6.8[a]	45.5 ± 7.5[a]	38.8 ± 5.3[a]
	SMVO	79.9 ± 10.5	-	15.8 ± 1.9[a,b]	14.6 ± 10.5[a,b]	16.4 ± 2.4[a,b]
VO_2 intest, mL/min	SMAO	4.9 ± 0.2	-	5.8 ± 1.3	5.1 ± 0.3	4.2 ± 1.1
	SMVO	5.8 ± 1.2	-	2.6 ± 0.7[a,b]	3.2 ± 0.6[a,b]	3.3 ± 0.6[a,b]
O_2ER intest, %	SMAO	5.0 ± 1.1	-	10.1 ± 1.9[a]	10.9 ± 2.1[a]	12.4 ± 2.7[a]
	SMVO	5.7 ± 1.6	-	22.7 ± 3.8[a,b]	29.0 ± 4.8[a,b]	22.9 ± 3.6[a,b]
Mesenteric lactate, mmol/l	SMAO	0.9 ± 0.1	1.4 ± 0.3[a]	1.7 ± 0.3[a]	1.2 ± 0.2	1.3 ± 0.3
	SMVO	1.5 ± 0.4	5.3 ± 0.9[a,b]	4.0 ± 0.7[a,b]	3.2 ± 0.6[a,b]	2.6 ± 0.3[a,b]
Mesenteric vein pH	SMAO	7.38 ± 0.02	7.36 ± 0.02	7.35 ± 0.02	7.35 ± 0.02	7.35 ± 0.02
	SMVO	7.35 ± 0.02	7.18 ± 0.03[a,b]	7.21 ± 0.03[a,b]	7.2 ± 0.02[a,b]	7.22 ± 0.01[a,b]
Mesenteric vein	SMAO	37.2 ± 1.7	34.3 ± 1.5	37.7 ± 1.3	36.7 ± 2.3	36.8 ± 1.5
Ht, %	SMVO	39.2 ± 1.2	66.4 ± 0.9[a,b]	40.3 ± 2.6	39.4 ± 1.9	37.1 ± 2.0

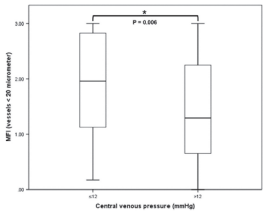
Congestion



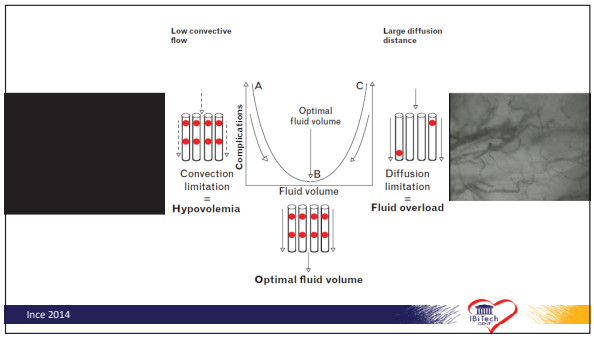
Hypoperfusion vs congestion



Increased RAP

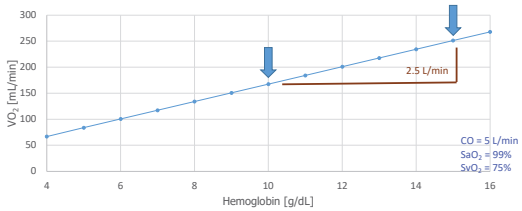


Vellinga 2013

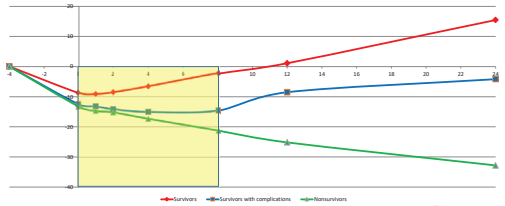


Ince 2014

VO_2 and hemoglobin

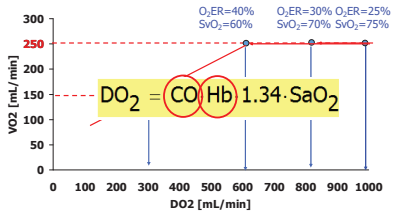


Perioperative oxygen debt



Shoemaker 1991

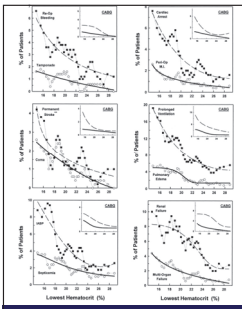
DO_2 and VO_2



Hypothesis

- If DO_2 is a prime variable
- If most perfusionists work with a fixed CI

Must hemoglobin influence quality of Perfusion

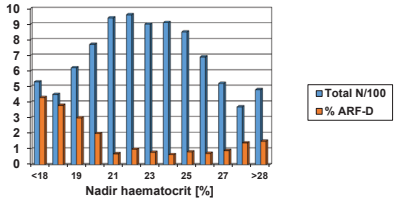


Hematocrit during CPB

Lowest HCT on CPB is associated to:

- Reopening
- Bleeding
- Perioperative MI
- Cardiac arrest
- Stroke
- Coma
- Prolonged ventilation
- IABP
- Renal failure
- MOF

Haematocrit during CPB



Karkouti 2005

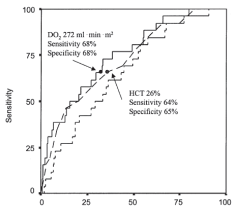
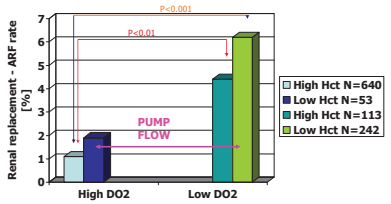


Fig 2. Receiver operating characteristic curve for the three variables being identified as independent risk factors for acute renal failure. — — = lowest hematocrit on CPB; - - - - = pump flow indexed; —— = oxygen delivery indexed. (CPB = cardiopulmonary bypass; DO_2 = two determinants of oxygen delivery; HCT = hematocrit.)

Ranucci 2005

Optimal flow and outcome



Ranucci 2005

Outcome measures in the intensive care unit

Outcome measure	Hematocrit 25%		Hematocrit 20%		*p*
	Median	IQR	Median	IQR	
Number of transfused patients	1		5		0.10
Drainage loss (ml)	382	265–530	400	290–620	0.28
Patients with postoperative stroke (n)	0		0		0.99
Patients with agitated arousal reaction (n)	3		3		0.99
Patients with myocardial infarction (n)	0		0		0.99
CK/CK-MB ratio (%)	6.25	4.8–7.2	5.9	4.4–7.0	0.99
Patients with catecholamines on admission to ICU (n)	10		7		0.57
Patients with catecholamines 6 h after admission to ICU (n)	5		2		0.42
Patients with dopamine 18 h after admission to ICU (n)	2		1		0.53
Patients with respiratory failure (n)	3		3		0.99
Duration of ventilator support (hours)	10	8–12,5	10	10–12	0.36
Patients with renal failure (n)	1		1		0.99
Creatinine 18 h after admission to ICU (mg/dl)	0.92	0.82–1.19	1.06	0.90–1.14	0.30
Urine volume in ICU (ml)	2.810	2.390–3.469	2.815	2.100–3.600	0.82
Combined endpoint of organ failure (n)	8		10		0.57
Duration of ICU stay (hours)	22	21–24	23	21–28	0.24
Mortality (n)	0		1		0.48

CK, creatine kinase; CK-MB, myocardial creatine kinase; ICU, intensive care unit; IQR, interquartile range.

von Heymann 2006

Optimal flow and outcome

Basic patient characteristics

Characteristic	Hematocrit 25%		Hematocrit 20%		*p*
	Median	IQR	Median	IQR	
Age (years)	60	55–67	65	58–71	0.10
Gender (male/female)	28/2		26/0		0.49
Height (m)	1.78	1.73–1.81	1.75	1.72–1.79	0.35
Weight (kg)	93	80–100	87	80–100	0.52
Body mass index (kg/m²)	27.9	26.0–32.2	28.8	26.7–29.9	0.72
Preoperative hematocrit (%)	41.8	40.2–43.0	42.1	39.4–45.4	0.88
Duration of anesthesia (minutes)	300	290–320	310	290–325	0.26
Duration of surgery (minutes)	190	160–220	205	175–250	0.09
CPB time (minutes)	72	55–83	73	63–81	0.50
Aortic cross clamp time (minutes)	45	33–56	45	38–49	0.93
APACHE II score	14	9–19	16	13–27	0.09

APACHE, Acute Physiology and Chronic Health Evaluation; CPB, cardiopulmonary bypass; IQR, interquartile range.

von Heymann 2006

Optimal flow and outcome

Intraoperative outcome measures

Outcome measure	Hematocrit 25%		Hematocrit 20%		*p*
	Median	IQR	Median	IQR	
CI during CPB (l/m²/minute)	3.2	3.0–3.7	3.2	3.0–3.5	0.57
Temperature during CPB (°C)	35.6	35.0–36.0	36.8	35.4–36.0	0.12
Cumulative norepinephrine dosage during CPB (mg)	0.08	0.06–0.10	0.09	0.0–0.08	0.13
Dopamine dosage for weaning from CPB (µg/kg/minute)	1.0	0.0–3.0	1.5	0.0–3.0	0.92
Patients with catecholamines for weaning from CPB (n)	16		16		0.79
Patients with intraaortic balloon pump for weaning from CPB (n)	2		0		0.49
Patients with acute cardiac failure during weaning from CPB (n)	3		2		1.00
Urine volume during CPB (ml)	159	97–354	165	102–440	0.57

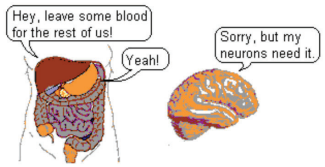
CI, cardiac index; CPB, cardiopulmonary bypass; IQR, interquartile range.

DO2 @ 25% = 356 mL/min/m² DO2 @ 20% = 287 mL/min/m²

> 270 mL/min/m²

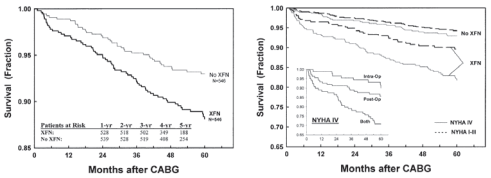
von Heymann 2006

What if flow cannot augmented?



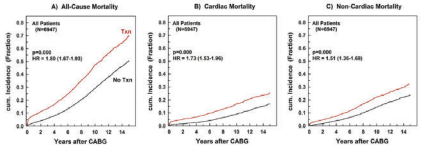
https://faculty.washington.edu/chudler/vessel.html

Blood transfusion: the answer?



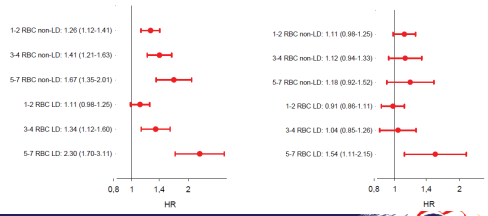
Engoren 2002

Blood transfusion the answer?



Schwann 2016

Blood transfusion: the answer?



Bjursten 2016

Association Between Anemia, Bleeding, and Transfusion with Long-term Mortality Following Noncardiac Surgery

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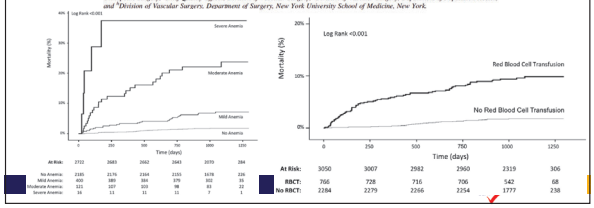
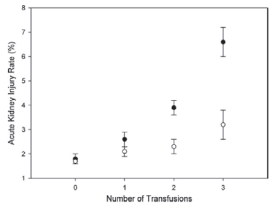
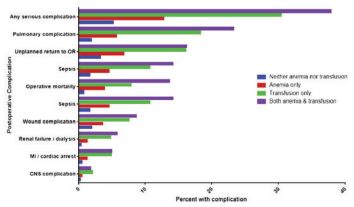


AKI, anemia and transfusion



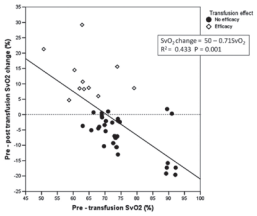
Karkouti 2011

Transfuse or not?



Ferraris 2015

Was transfusion efficacious?



Ranucci 2011

Acute Kidney Injury and Hemodilution During Cardiopulmonary Bypass: A Changing Scenario

Marco Ranucci, MD, FESC, Tommaso Aloisio, MD, Giovanni Carboni, CCP, Andrea Ballotta, MD, FESC, Valeria Pistuddi, Lorenzo Menicanti, MD, and Alessandro Frigiola, MD, for the Surgical and Clinical Outcome REsearch (SCORE) Group

Departments of Cardiothoracic and Vascular Anesthesia and Intensive Care and Department of Cardiac Surgery, IRCCS Policlinico San Donato, Milan, Italy

Background. Severe hemodilution during cardiopulmonary bypass (CPB) is a risk factor for acute kidney injury (AKI) after heart operations. Many improvements to CPB technology have been proposed during the past decade to limit the hemodilution-related AKI risk. The present study is a retrospective analysis of the relationship between hemodilution during CPB and AKI in cardiac operations in the setting of different interventions applied over 14 years.

Methods. We retrospectively analyzed 16,790 consecutive patients undergoing heart operations from 2000 to 2013. Various risk factors for AKI were collected and analyzed, together with a number of interventions as possible modifiers of the relationship between a nadir hematocrit (HCT) value during CPB and AKI.

Results. The relationship between the nadir HCT value during CPB and AKI was confirmed in a multivariable analysis, with the relative risk of AKI increasing by 7% per percentage point of decrease of the nadir HCT value during CPB. The relative risk of AKI decreased by 8% per year of observation ($p = 0.001$) despite a significantly increased risk of AKI ($p = 0.001$). A sensitivity analysis based on differences before and after different interventions demonstrated a beneficial effect of the application of goal-directed perfusion fainted at preserving oxygen delivery during CPB), with a reduction in the AKI rate from 5.8% to 3.1% ($p = 0.001$). A policy restricting angiographic examination on the day of operation was also useful (reduction of AKI rate from 4.8% to 3.7%; $p = 0.029$).

Conclusions. A bundle of interventions mainly aimed at limiting the renal impact of hemodilution during CPB is effective in reducing the AKI rate.

(Ann Thorac Surg 2015;100:95–100)

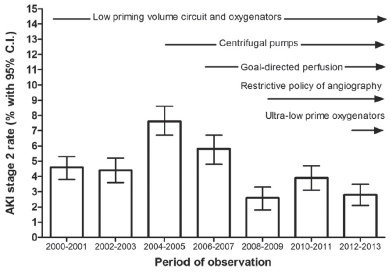


Table 2. Demographics and Renal Risk Factors of the Patient Population in the Different Periods Considered

Period (No. of patients)	Age (y)	eGFR (mL/min)	LVEF (%)	Diabetes (%)	Redo Operations (%)	Nonelective Operations (%)	Noninsulated CABG (%)	IABP Use (%)	CPB time (min)
2000–2001 (2,714)	64.4 (10.7)	56.8 (23)	51.6 (11.8)	12.6	4.0	2.4	42.9	0.3	71.7 (37)
2002–2003 (2,694)	65.6 (11.3)	71.8 (34)	50.4 (11.6)	14.1	5.4	4.0	49.6	0.4	71.8 (36)
2004–2005 (3,006)	66.5 (11.6)	74.3 (36)	51.6 (11.9)	13.8	5.5	6.5	49.3	0.8	75.1 (38)
2006–2007 (2,313)	66.3 (11.8)	77.2 (33)	52.0 (11.1)	12.1	6.2	4.5	49.8	0.8	80.4 (39)
2008–2009 (1,829)	65.9 (12.3)	78.7 (36)	53.9 (11.8)	14.1	6.1	3.1	57.1	0.9	83.1 (37)
2010–2011 (2,157)	65.9 (13.5)	76.9 (40)	53.1 (12.0)	18.5	6.6	3.6	63.7	2.0	87.1 (44)
2012–2013 (2,077)	66.3 (13.0)	75.6 (35)	53.5 (11.5)	18.1	8.1	8.2	68.7	1.3	86.0 (42)
p value (between periods)*	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

* Analysis of variance or Pearson's χ^2 test. Data expressed as mean (standard deviation) or percentage.

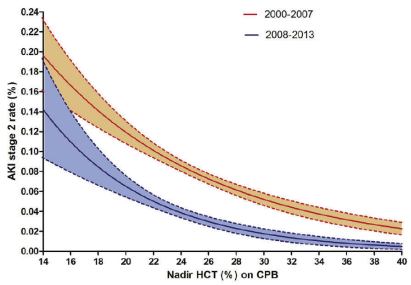
CABG = coronary artery bypass grafting; CPB = cardiopulmonary bypass; eGFR = estimated glomerular filtration rate; IABP = intraaortic balloon pump; LVEF = left ventricular ejection fraction.

Table 3. Renal Risk and Renal Outcome of the Patient Population in the Different Periods Considered

Period	No. of Patients	RRS	AKI Rate	Nadir HCT Value During CPB (%)	AKI Rate at Nadir < 24%	Odds Ratio (95% CI) for AKI As a Function of Nadir HCT Value	*p* Value for Univariate Association
2000–2001	2,714	1.49 (1.1)	124 (4.6)	25.9 (4.1)	48 (6.7)	0.92 (0.88–0.96)	0.001
2002–2003	2,694	1.36 (1.1)	118 (4.4)	27.4 (3.7)	28 (8.0)	0.89 (0.84–0.93)	0.001
2004–2005	3,006	1.36 (1.1)	229 (7.6)	26.6 (3.4)	57 (9.0)	0.95 (0.91–0.98)	0.005
2006–2007	2,313	1.25 (1.1)	133 (5.8)	26.2 (3.4)	45 (8.3)	0.93 (0.89–0.98)	0.010
2008–2009	1,829	1.24 (1.0)	47 (2.6)	26.1 (3.7)	26 (5.5)	0.85 (0.79–0.93)	0.001
2010–2011	2,157	1.51 (1.1)	84 (3.9)	26.1 (3.7)	34 (6.3)	0.85 (0.80–0.91)	0.001
2012–2013	2,077	1.70 (1.2)	58 (2.8)	28.0 (4.1)	14 (4.7)	0.91 (0.86–0.97)	0.006
Total	16,790						
p value (between periods)*		0.001	0.001	0.001	0.001		

* Analysis of variance or Pearson's χ^2 test. Data are expressed as mean (standard deviation) or number (%).

AKI = acute kidney injury; CI = confidence interval; CPB = cardiopulmonary bypass; HCT = hematocrit; RRS = renal risk score.

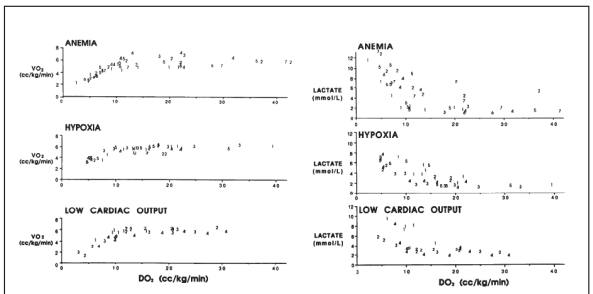


Maintain red blood cell mass

- Low priming volume
- Retrograde autologous priming
- Limit fluid delivery
- Ultrafiltration

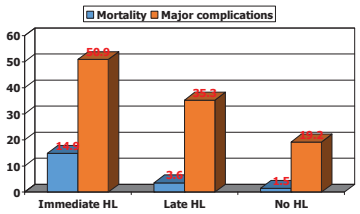
DO_2 as a goal

- Scarce information on DO_2 during CPB
- With a constant pump flow, DO_2 is direct related to Hct
- Most CPB cases are performed at 32 - 34°C
- Pump flow = 2 - 3 L/min/m²
- => Hct = cte => DO_2 varies with 50%

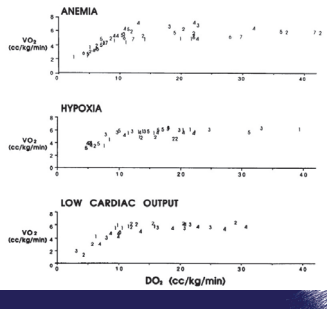


Cilley 1991

Lactate as marker

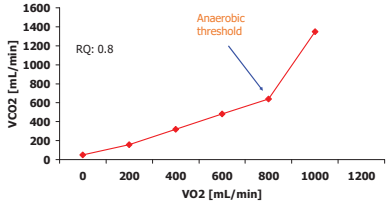


Maillet 2003

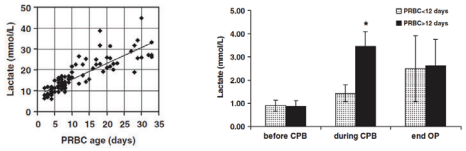


Cilley 1991

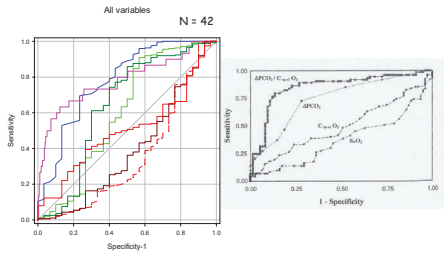
$VCO_2 - VO_2$



Do not measure your therapy



Schroeder 2005



Mekonso-Dessap 2002

How do we know that blood flow meet the metabolic needs of a patient?

By retrospective analysis of organ function, blood markers and morbidity

"What we need is a multivariate online analysis of risk during cardiopulmonary bypass" *Charles Wildevuur*

DO_2i => what we give to the patient

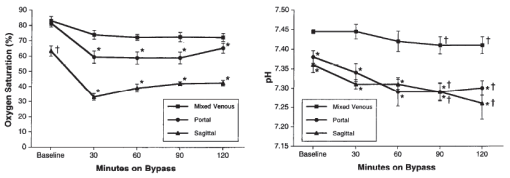
VCO_2i => what we get from the patient

"current guidelines for calculating pump flow during normothermic bypass may be reconciled to better match prebypass systemic oxygen delivery with oxygen delivery during CPB."

McDaniel 1995

Variable	Baseline	Bypass interval (min) 30	60	90	120
pH	7.46 ± 0.02	7.47 ± 0.1	7.45 ± 0.1	7.46 ± 0.2	7.46 ± 0.1
$Paco_2$	37.3 ± 2.4	32.4 ± 1.9	34.3 ± 1.8	33.8 ± 1.8	33.4 ± 1.9
Pao_2	310 ± 20.1	312 ± 34.1	244 ± 32.7	269 ± 42.1	284 ± 42.0
Arterial bicarbonate	27.1 ± 1.2	24.4 ± 0.8*	23.9 ± 0.8*	23.4 ± 0.6*	22.0 ± 0.7*
Hct	26.3 ± 2.2	14.6 ± 1.6*	15.9 ± 1.5*	16.4 ± 1.6*	14.4 ± 1.5*
Temperature (°C)*	37.3 ± 0.4	37.4 ± 0.3	37.6 ± 0.1	37.6 ± 0.2	37.6 ± 1.4

Hct = hematocrit.
* Temperature was measured nasopharyngeally.
* $P < 0.05$ compared with baseline value.



McDaniel 1995

Table 2. Univariate Analysis of Oxygen-Carbon Dioxide Derived Parameters and Other Intraoperative Variables at Arterial Lactate Determinations Below or Above the Threshold Value (3 mmol/L).

Parameter	Arterial Lactates ≤ 3 mmol/L (n = 130)	Arterial Lactates > 3 mmol/L (n = 37)	p
Pao_2 (mmHg)	225 ± 56	228 ± 44	0.7
Svo_2	0.78 ± 0.76	0.76 ± 0.8	0.35
VCO_2i (mL · min^{-1} · m^{-2})	51.4 ± 15.2	82.1 ± 38.4	< 0.001
DO_2i/VCO_2i	6.35 ± 1.7	4.14 ± 1.2	< 0.001
VCO_2i/VO_2i	0.77 ± 0.22	1.35 ± 0.68	< 0.001
Aortic cross-clamp on	72%	46%	0.003
BSA (m^2)	1.85 ± 0.2	1.62 ± 0.45	0.005
CPB time (min)	44.7 ± 36.3	68.9 ± 47.7	0.006

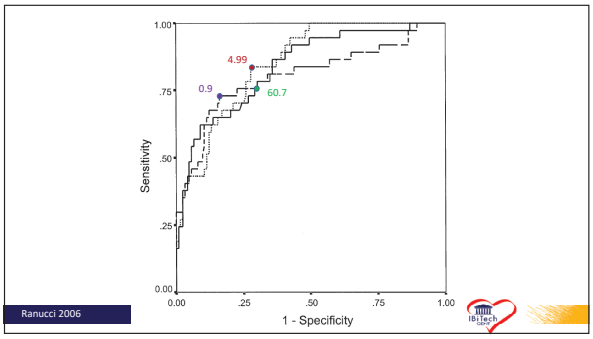
BSA = body surface area; CPB = cardiopulmonary bypass; Do_2i/Vco_2i = oxygen delivery indexed/carbon dioxide elimination indexed; Pao_2 = arterial oxygen tension; Svo_2 = mixed venous oxygen saturation; Vco_2i = carbon dioxide elimination indexed; Vco_2i/Vo_2i = respiratory quotient.

Table 3. Receiver Operating Characteristic Analysis and Relative Cutoff Values

Factor	AUC	p	Cutoff Value	Sensitivity	Specificity
Do_2i/Vco_2i	0.852	< 0.001	4.99	78.4%	74%
Vco_2i	0.838	< 0.001	60.7	75.7%	70.7%
Vco_2i/Vo_2i	0.803	< 0.001	0.90	75.7%	77.2%

AUC = area under the curve; Do_2i/Vco_2i = oxygen delivery indexed/ carbon dioxide elimination indexed; Vco_2i = carbon dioxide elimination indexed; Vco_2i/Vo_2i = respiratory quotient.

Ranucci 2006

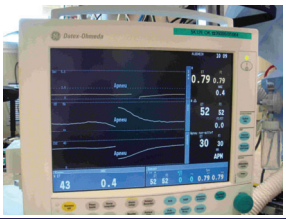


Ranucci 2006

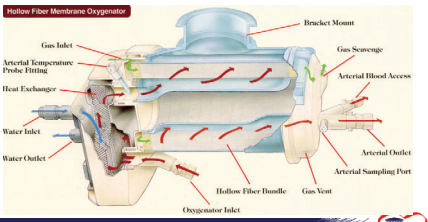
CO_2 production

$$VCO_2 = Q_{gas} \cdot \frac{e_{CO2}}{P_{baro}}$$

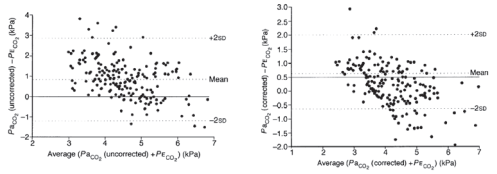
CO_2 can be measured in real time



Capnography: potential problems



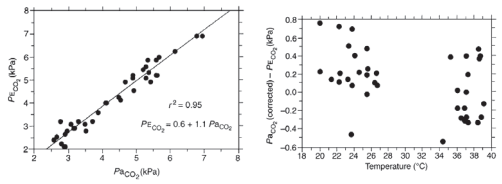
Capnography oxygenator exhaust



O'Leary 1999

- ATP: Ambient Temperature Pressure (room air)
- ATPS: Ambient Temperature Pressure Saturated (H_2O)
- BTPS: Body Temperature Pressure Saturated (H_2O)
- STPD: Standard Temperature (0°C), Pressure (1ATM), Dry

Capnography oxygenator exhaust



Weightman 1999

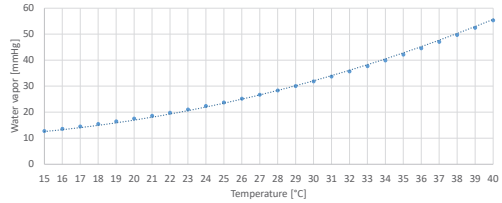
Gas laws

$$P_1 \cdot \frac{V_1}{T_1} = P_2 \cdot \frac{V_2}{T_2} \rightarrow \frac{P_2 \cdot T_1 \cdot V_2}{T_2 \cdot V_1}$$

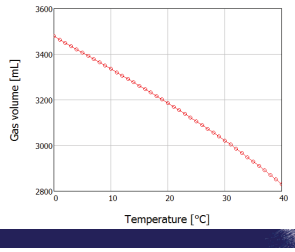
$$V_{STPD} := \frac{(P_{baro} - P_{H2O}) \cdot 273.15K}{P_{baro} \cdot (T_{art})} = 0.826$$

T_{art} in K

Water vapor and temperature



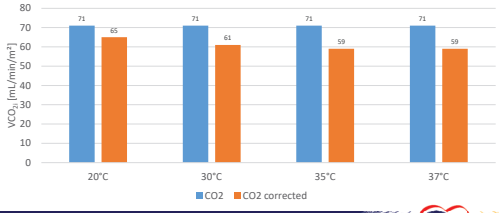
Conversion ATPS to STPD



Example

- eCO_2 = 36 mmHg/760 mmHg = 4.7%
- Q_{gas} = 3000 mL/min
- $P_{barometric}$ = 760 mmHg
- T_{art} = 20°C
- BSA = 2 m²

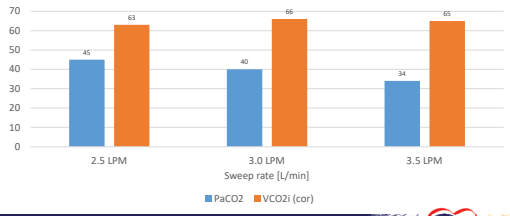
ATPS versus STPD



for venous return. Lowest core body temperature during CPB varied from 27°C to 37°C as requested by the surgeon. Body temperature was measured at the nasopharingeal site and at the rectal site. This last temperature was considered for correcting the values of blood gas analyses. The perfusate temperature was measured at the oxygenator site and used for correcting the values of exhaled carbon dioxide. Antegrade intermittent cold

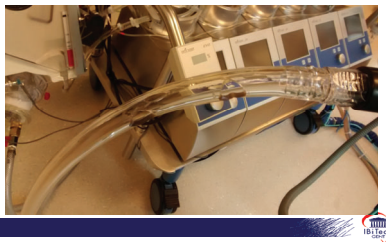
mm Hg. The gas flow was initially settled at 50% oxygen to air ratio and a 1:2 flow ratio with the pump flow indexed, and subsequently arranged in order to maintain an arterial oxygen tension greater than 150 mm Hg and an arterial carbon dioxide tension between 33 and 38 mm Hg.

Do NOT treat $PaCO_2$



Scavenging of volatile anesthetics and capnography

Scavenging of volatile anesthetics and capnography



Scavenging of volatile anesthetics and capnography

$V_{gas} = 2\frac{L}{min}$ Gas flow

$e_{CO2} = 40mmHg$ Oxygenator exhaust CO_2

$P_{baro} = 760mmHg$ Barometric pressure

$V_{CO2} = V_{gas}\frac{e_{CO2}}{P_{baro}} = 105\frac{mL}{min}$ Uncorrected VCO_2

$P_{H2O} = 39.9mmHg$ Water vapor tension @ T_{blood}

$T_{blood} = 34\,°C$ Arterial blood temperature

$V_{STPD} = \frac{(P_{baro} - P_{H2O})\cdot 273.15K}{P_{baro}\,(T_{blood})} = 0.843$ Conversion to STPD, CAVE T_{blood} is converted to K (°C + 273.15)

$V_{CO2c} = V_{CO2}\cdot V_{STPD} = 89\frac{mL}{min}$ Corrected VCO_2

$\frac{DO_2}{V_{CO2c}} = 6.3$

Calculation DO_2 and VCO_2

$Hb = 8\frac{gm}{dL}$ Hemoglobin concentration

$cte = 1.34\frac{mL}{gm}$ Maximum transport capacity hemoglobin

$SaO_2 = 99\%$ Arterial oxygen saturation

$CO = 5\frac{L}{min}$ cardiac output or pump flow

$k_{blood} = 3.666\cdot 10^{-5}\frac{mL}{mmHg\cdot mL}$ oxygen solubility in blood

$PaO_2 = 150mmHg$ Partial oxygen tension

$DO_2 = \left[(Hb\cdot cte\cdot SaO_2) + (PaO_2\cdot k_{blood})\right]\cdot CO = 558\frac{mL}{min}$

Oxygenation

$Hb = 80\frac{gm}{L}$ $Q_{Blood} = 4.5\frac{L}{min}$ $BSA = 1.8m^2$

$SaO_2 = 99\%$ $PaO_2 = 150mmHg$ $k_{Blood} = 3.666\cdot 10^{-5}\frac{mL}{mmHg\cdot mL}$

CO_2

$Q_{gas} = 2\frac{L}{min}$ $e_{CO2} = 40mmHg$ $P_{Baro} = 760mmHg$

$T_{Blood} = 34\,°C$ $P_{H2O} = 39.9mmHg$

Spectrum

$DO2_{M4} = \frac{\left(Hb\cdot 1.34\cdot\frac{mL}{gm}\cdot SaO_2\right)\cdot Q_{Blood}}{BSA} = 265\frac{\frac{mL}{min}}{m^2}$

$V_{CO2\_M4} = \frac{Q_{gas}\cdot\frac{e_{CO2}}{P_{Baro}}}{BSA} = 58\frac{\frac{mL}{min}}{m^2}$

$\frac{DO2_{M4}}{V_{CO2\_M4}} = 4.537$

Connect

$DO2_{Connect} = \frac{\left[\left(Hb\cdot 1.36\cdot\frac{mL}{gm}\cdot SaO_2\right) + (PaO_2\cdot k_{Blood})\right]\cdot Q_{Blood}}{BSA} = 283\frac{\frac{mL}{min}}{m^2}$

$V_{CO2\_Connect} = \frac{\frac{(P_{Baro} - P_{H2O})\cdot 273.15K}{P_{Baro}\cdot T_{Blood}}\cdot Q_{gas}\cdot\frac{e_{CO2}}{P_{Baro}}}{BSA} = 49.276\frac{\frac{mL}{min}}{m^2}$

$\frac{DO2_{Connect}}{V_{CO2\_Connect}} = 5.744$

Develop an algorithm

DO_2/VCO_2 ratio <5

↓

Augment pump flow

Increase Hb content

Decrease T, check anesthesia level

Outcome	All cases N=354	DO2 < 280 mL/min/m² N= 181	DO2 ≥ 280 mL/min/m² N= 173	P
Any AKI	75 (21.2%)	54 (29.8%)	21 (12.1%)	**0.001**
AKI stage 1	31 (8.8%)	23 (12.7%)	8 (4.6%)	**0.007**
AKI stage 2-3	44 (12.4%)	31 (17.1%)	13 (7.5%)	**0.006**

de Somer *et al. Critical Care* 2011, **15**:R192
http://ccforum.com/content/15/4/R192

CRITICAL CARE

RESEARCH Open Access

O_2 delivery and CO_2 production during cardiopulmonary bypass as determinants of acute kidney injury: time for a goal-directed perfusion management?

Filip de Somer[1], John W Mulholland[2], Megan R Bryan[2], Tommaso Aloisio[3], Guido J Van Nooten[1] and Marco Ranucci[3*]

Abstract

Introduction: Acute kidney injury (AKI) is common after cardiac operations. There are different risk factors or determinants of AKI, and some are related to cardiopulmonary bypass (CPB). In this study, we explored the association between metabolic parameters (oxygen delivery (DO_2) and carbon dioxide production (VCO_2)) during CPB with postoperative AKI.

Goal Directed Perfusion:
What we know

- Patients who experience a nadir DO2 on CPB < 272 mL/min/m2 have a higher rate of AKI following cardiac surgery
- This information is coming from retrospective trials, and registries
- This is called «an association»

Goal Directed Perfusion:
What we don't know

- If we intentionally avoid low levels of DO2 through a GDP technique, will we be able to reduce the AKI rate?
- This is called «causative effect»
- To demonstrate that a strategy, a drug, a technique, is able to change the outcome, we need a RCT

GIFT

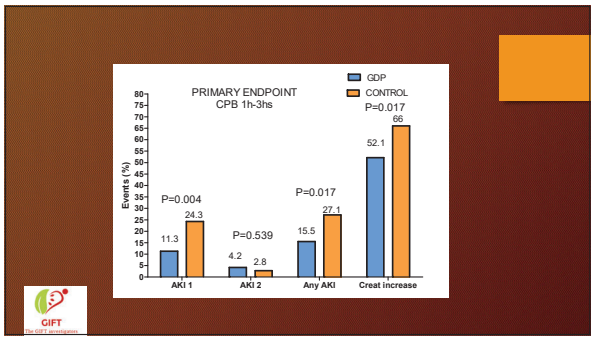
- Prospective, randomized, controlled trial
- Multicenter
- 10 Institutions in Europe, USA, New Zealand
- Co-ordinating Institution: IRCCS PSD
- Ethics Committee Approval at IRCCS PSD
- Registered at clinicaltrials.gov NCT02250131
- Centralized data collection at IRCCS PSD
- Statistical analysis at IRCCS PSD
- Spontaneous study with the external support of Sorin Group.
- Sorin Group shall provide resources for steering committee meetings and GDP monitor

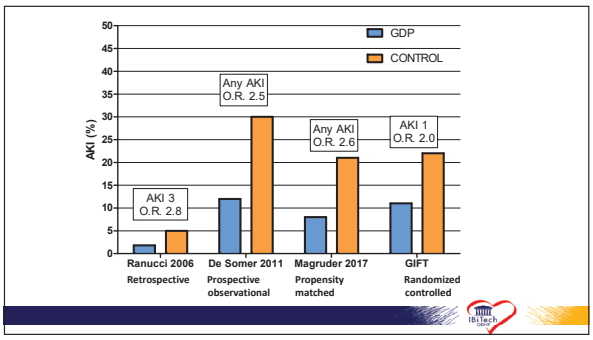
The GDP Trial – protocol

CONTROL (N=350)	TREATMENT (N=350)
GDP monitor	GDP monitor
NO Blood prime (withdrawal)	NO Blood prime (withdrawal)
Priming volume and nature according to local standards	Priming volume and nature according to local standards
Perfusion targeted on BSA and °C	Perfusion targeted on DO2 > 280 mL/min/m2
Perfusion pressure according to local standards	Perfusion pressure according to local standards
Transfusion triggered by HCT according to local standards (<20%)	Transfusion triggered by HCT < 21% and SVO2 < 68% and/or O2ER > 40%
Postoperative care according to local standards	Postoperative care according to local standards

DO2, VCO2, and DO2/VCO2 data adjudication

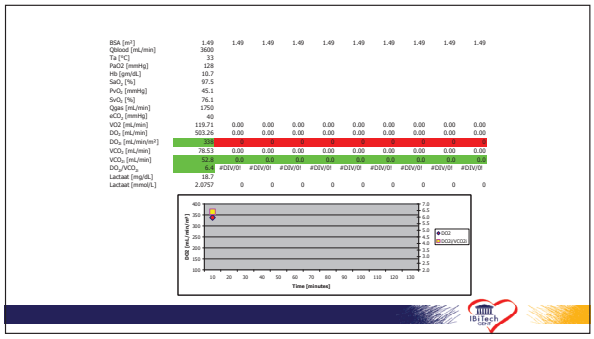
- NADIR DO2: maintained for at least 10 minutes (2 consecutive measures)
- Same for VCO2, and DO2/VCO2



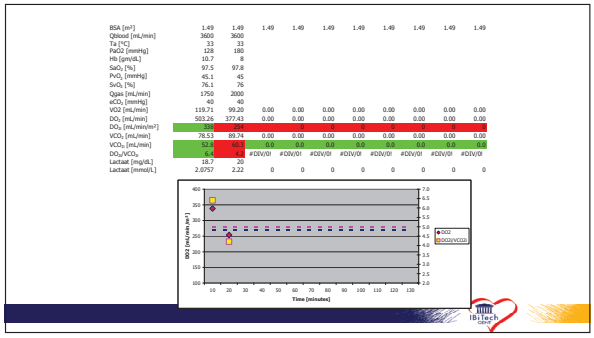


Example

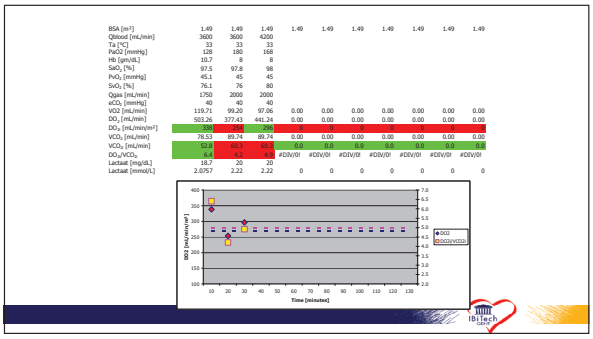
- 45 y female
- 45 kg, 1.49 m²
- CI (2.4 LPM/m²) = 3.6
- Baseline Hb: 10.7 g/dL
- AVR + MVR



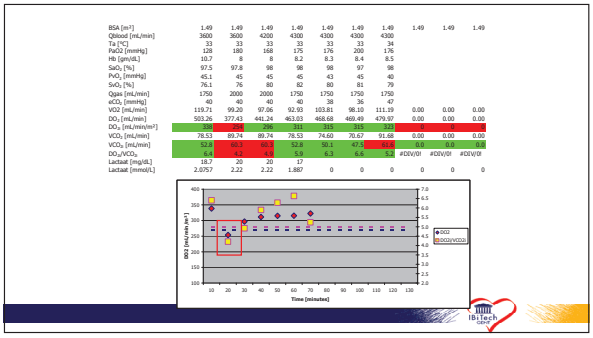
BSA [m²]	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49
Qblood [mL/min]	3600									
Ta [°C]	33									
PaO2 [mmHg]	128									
Hb [gm/dL]	10.7									
SaO_2 [%]	97.5									
PvO2 [mmHg]	45.1									
SvO_2 [%]	76.1									
Qgas [mL/min]	1750									
eCO_2 [mmHg]	40									
VO2 [mL/min]	119.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DO_2 [mL/min]	503.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DO_2 [mL/min/m²]	338	0	0	0	0	0	0	0	0	0
VCO_2 [mL/min]	78.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VCO_2 [mL/min]	52.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DO_2/VCO_2	6.4	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Lactaat [mg/dL]	18.7									
Lactaat [mmol/L]	2.0757	0	0	0	0	0	0	0	0	0



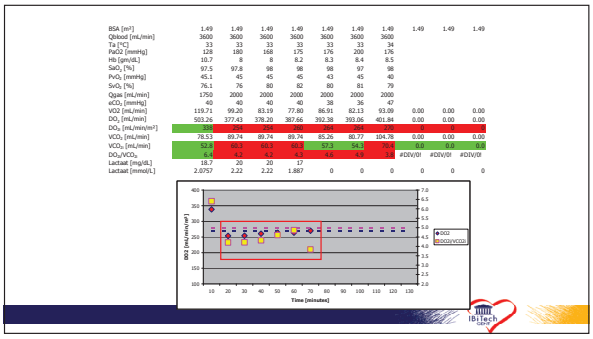
BSA [m²]	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49
Qblood [mL/min]	3600	3600								
Ta [°C]	33	33								
PaO2 [mmHg]	128	180								
Hb [gm/dL]	10.7	8								
SaO_2 [%]	97.5	97.8								
PvO2 [mmHg]	45.1	45								
SvO_2 [%]	76.1	76								
Qgas [mL/min]	1750	2000								
eCO_2 [mmHg]	40	40								
VO2 [mL/min]	119.71	99.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DO_2 [mL/min]	503.26	377.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DO_2 [mL/min/m²]	338	254	0	0	0	0	0	0	0	0
VCO_2 [mL/min]	78.53	89.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VCO_2 [mL/min]	52.4	59.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DO_2/VCO_2	6.4	4.2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Lactaat [mg/dL]	18.7	20								
Lactaat [mmol/L]	2.0757	2.22	0	0	0	0	0	0	0	0



BSA [m²]	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49
Qblood [mL/min]	3600	3600	4200							
Ta [°C]	33	33	33							
PaO2 [mmHg]	128	180	168							
Hb [gm/dL]	10.7	8	8							
SaO_2 [%]	97.5	97.8	98							
PvO2 [mmHg]	45.1	45	45							
SvO_2 [%]	76.1	76	80							
Qgas [mL/min]	1750	2000	2000							
eCO_2 [mmHg]	40	40	40							
VO2 [mL/min]	119.71	99.20	97.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DO_2 [mL/min]	503.26	377.43	441.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DO_2 [mL/min/m²]	338	254	296	0	0	0	0	0	0	0
VCO_2 [mL/min]	78.53	89.74	89.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VCO_2 [mL/min]	52.4	59.8	59.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DO_2/VCO_2	6.4	4.2	4.9	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Lactaat [mg/dL]	18.7	20	20							
Lactaat [mmol/L]	2.0757	2.22	2.22	0	0	0	0	0	0	0



BSA [m²]	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49
Qblood [mL/min]	3600	3600	4200	4300	4300	4300	4300			
Ta [°C]	33	33	33	33	33	33	34			
PaO2 [mmHg]	128	180	168	176	176	200	176			
Hb [gm/dL]	10.7	8	8	8.2	8.3	8.4	8.5			
SaO_2 [%]	97.5	97.8	98	98	98	97	98			
PvO2 [mmHg]	45.1	45	45	45	43	45	40			
SvO_2 [%]	76.1	76	80	82	80	81	79			
Qgas [mL/min]	1750	2000	2000	1750	1750	1750	1750			
eCO_2 [mmHg]	40	40	40	40	38	36	47			
VO2 [mL/min]	119.71	99.20	97.06	92.93	103.81	98.10	111.19	0.00	0.00	0.00
DO_2 [mL/min]	503.26	377.43	441.24	463.03	468.68	468.49	479.97	0.00	0.00	0.00
DO_2 [mL/min/m²]	338	254	296	311	315	315	323	0	0	0
VCO_2 [mL/min]	78.53	89.74	89.74	78.53	74.60	70.67	91.58	0.00	0.00	0.00
VCO_2 [mL/min]	52.4	59.8	59.8	52.4	50.1	47.1	61.6	0.0	0.0	0.0
DO_2/VCO_2	6.4	4.2	4.9	5.9	6.3	6.6	5.2	#DIV/0!	#DIV/0!	#DIV/0!
Lactaat [mg/dL]	18.7	20	20	17						
Lactaat [mmol/L]	2.0757	2.22	2.22	1.887	0	0	0	0	0	0



BSA [m²]	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49
Qbiood [mL/min]	3600	3600	3600	3600	3600	3600	3600			
Ta [°C]	33	33	33	33	33	33	34			
PaO2 [mmHg]	128	180	168	175	176	200	176			
Hb [gm/dL]	10.7	8	8	8.2	8.3	8.4	8.5			
SaO2 [%]	97.5	97.8	98	98	98	97	98			
PvO2 [mmHg]	45.1	45	45	45	43	45	40			
SvO2 [%]	76.1	76	80	82	80	81	79			
Qgas [mL/min]	1750	2000	2000	2000	2000	2000	2000			
eCO2 [mmHg]	40	40	40	40	38	36	47			
VO2 [mL/min]	119.71	99.20	83.19	77.80	86.91	82.13	93.09	0.00	0.00	0.00
DO2 [mL/min]	503.26	377.43	378.20	367.66	392.38	393.06	451.84	0.00	0.00	0.00
DO2 [mL/min/m²]	338	254	254	247	264	264	303	0	0	0
VCO2 [mL/min]	78.53	89.74	89.74	89.74	85.26	80.77	104.78	0.00	0.00	0.00
VCO2 [mL/min]	52.8	60.3	60.3	60.3	57.3	54.3	70.4	0.0	0.0	0.0
DO2/VCO2	6.4	4.2	6.3	4.3	4.6	4.9	3.1	#DIV/0!	#DIV/0!	#DIV/0!
Lactaat [mg/dL]	18.7	20	20	17						
Lactaat [mmol/L]	2.0757	2.22	2.22	1.887	0	0	0	0	0	0

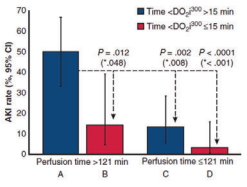
45 y.o. female, 45 Kg., 1.49 m²
2.4 CI = 3.58 LPM, AVR MVR, Sorin Inspire™ 6
Baseline Hgb = 10.7

Time	BQ	RQ	Temp	SvO_2	HCT	DO_2i	VO_2	VO_2i/DO_2i	DO_2/VCO_2	VCO_2i
5	3.64	99	35.2	88	24	299	79.4	18.3	4.8	61.9
25	3.51	98	3				75.5	19	4.8	57.5
40	3.69	103					73.4	16.8	6.6	46
45	3.59	100					79.8	19	6.5	44.4
70	3.6	100					72.5	18	5.8	47.6
100 *	3.9	109					103	25.5	4.6	60.3
120	3.9	109	3				126.2	27	4.8	64.2
140	4	112	36.5	78	24	328	94.3	19.3	7.5	43.5

AKI Score
Pre-op creatinine = 1.07 mmol/l
Peak post creatinine = 0.77 mmol/l

* 1 unit PRBC at 110 minutes, low volume , absolute Hgb trigger reached

Importance of time



Mukaida 2019

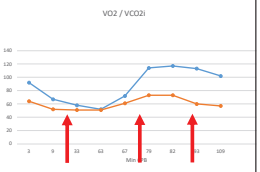
35 y.o. male, 136 Kg., 2.55 m². BMI = 45
2.4 CI = 6.1 LPM, IBW = 75 Kg, IBSA = 1.9, Ideal 2.4 CI = 4.56 LPM
Redo PVR RVOT repair, Baseline Hgb = 12 g/dL

Time	BQ	RQ						VO_2i/DO_2i	DO_2/VCO_2	VCO_2i
5	4.6	0.75					5	17	6.1	43
30	5.0	0.82					1	15.4	6.9	41
60	5.0	0.82					8	13.2	6.8	44
90	5.2	0.85					2	16.3	6.4	46
125	5.0	0.82					2	18.4	5.4	52

AKI Score
Pre-op creatinine = 0.97 mmol/l
Peak post creatinine = 1.12 mmol/l

73 y.o female, 61 Kg. critical AS, baseline HCT 27%, CBF Risk
Q_b 100% = 3.72 LPM , BSA = 1.55 M^2
MAP goal > 70 mmHg

Time	Q_b	T	Hct	DO_{2i}	VO_{2i}	VCO_{2i}	DO_{2i} / VCO_{2i}	VCO_{2i} / VO_{2i}	SVR
3	4.4	36						1.08	1572
9	4.4	34	AKI Score					1.20	1290
33	4.2	32	Pre-op creatinine = 0.86 mmol/l					1.36	1314
63	3.77	32						1.52	1633
67	4.12	34	Peak post creatinine = 1.11 mmol/l					1.31	1430
79	4.3	35						0.99	1302
82	4.4	36	23	308	117	73	4.2	0.97	1204
93	4.62	36	24	324	113	60	5.4	0.83	1043
109	4.42	36.5	26	340	102	57	5.9	0.87	1170



Why does it not always work?

What we need is a multivariate online analysis of risk during cardiopulmonary bypass *Charles Wildevuur*

Which parameters?

Effect of mean arterial pressure, haemoglobin and blood transfusion during cardiopulmonary bypass on post-operative acute kidney injury

Michael Haase[1,2], Rinaldo Bellomo[3], David Story[4], Angela Letis[4], Katja Klemz[1], George Matalanis[5], Siven Seevanayagam[5], Duska Dragun[1], Erdmann Seeliger[6], Peter R. Mertens[2] and Anja Haase-Fielitz[2]

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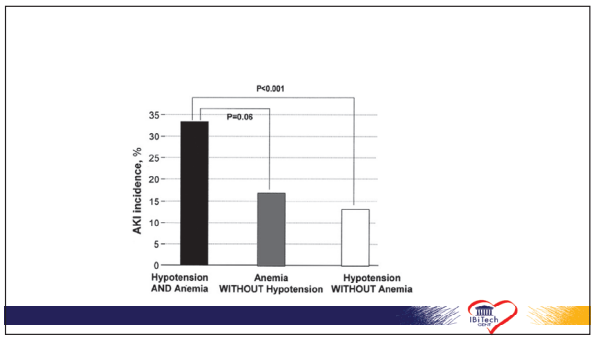
Variable	AKI ($N = 179$)	No AKI ($N = 741$)	P univariate	Adjusted OR (95% CI)	P multivariate
Model 0					
AKICS Score, points [3][b]	5.8 (3.9–8.1)	4.3 (2.6–6.3)	<0.001	1.09 per point increase (1.04–1.15)	<0.001
Emergency[c]	25 (13.8%)	22 (3.1%)	<0.001	4.36 (2.31–8.22)	<0.001
Return to operating room, *n*	34 (19.0%)	52 (7.0%)	<0.001	2.74 (1.68–4.49)	<0.001
Atrial fibrillation, *n*	47 (26.3%)	69 (9.3%)	<0.001	2.66 (1.69–4.17)	<0.001
Intra-aortic balloon pump, *n*	19 (10.6%)	25 (3.4%)	<0.001	1.27 (0.61–2.66)	0.521
Intraoperative variables added to Model 0					
Haemoglobin concentration, g/dL[d]					
Median[e]	8.1 (7.4–9.3)	8.7 (7.7–9.7)	<0.001	1.18 per g/dL decrease (1.02–1.34)	0.028
Lowest[e]	7.4 (6.4–8.6)	8.2 (7.0–9.3)	<0.001	1.16 per g/dL decrease (1.03–1.31)	0.018
Variability, %[e]	1.2 (0.6–2.2)	0.9 (0.5–1.5)	<0.001	1.10 per % increase (0.94–1.28)	0.239
Arterial O_2 content, mL/dL[d]					
Median[e]	12.2 (11.2–13.9)	13.0 (11.6–14.4)	<0.001	1.13 per mL/dL decrease (1.02–1.26)	0.027
Lowest[e]	10.9 (9.6–12.5)	12.0 (10.4–13.5)	<0.001	1.11 per mL/dL decrease (1.02–1.22)	0.018
Variability, %[e]	1.7 (0.8–3.0)	1.2 (0.7–2.1)	<0.001	1.07 per % increase (0.96–1.20)	0.241
SaO_2, %	99.7 (99.6–99.8)	99.7 (99.6–99.8)	0.949	N/A	N/A
PaO_2, mmHg	324 (274–385)	319 (272–375)	0.543	N/A	N/A
Red blood cell transfusion, mL[d]	750 (500–1000)	500 (250–750)	<0.001	1.001 per mL (1.000–1.002)	0.013
Vasopressors					
Metaraminol, mg	3.5 (1.9–6.5)	3.5 (1.5–6.0)	0.852	N/A	N/A
Phenylephrine, mg	4.9 (2.2–8.5)	2.3 (1.3–4.5)	0.007	1.05 (0.95–1.16)	0.334
MAP, mmHg					
Median[e]	68.5 (64.0–73.0)	68.0 (64.0–73.0)	0.841	N/A	N/A
Lowest[e]	31.0 (25.0–36.0)	32.0 (25.5–36.5)	0.554	N/A	N/A
Variability, %[e]	16.7 (14.1–19.7)	17.0 (14.3–19.6)	0.390	N/A	N/A
AUC MAP, min × mmHg					
<50 mmHg[c]	0.32 (0.13–0.66)	0.37 (0.17–0.69)	0.304	N/A	N/A
<60 mmHg[c]	1.49 (0.86–2.68)	1.51 (0.93–2.58)	0.673	N/A	N/A
<70 mmHg[c]	5.27 (3.55–7.46)	5.17 (3.51–7.38)	0.986	N/A	N/A



	Low-Target Group (n=93)	High-Target Group (n=98)
Age, y	65.0±10.7	69.4±8.9
Male sex, n (%)	93 (93.9)	84 (85.7)
Nonwhite race, n (%)	2 (2.0)	0 (0)
Previous myocardial infarction, n (%)*	37 (37.4)	37 (37.8)
Recent myocardial infarction (past 2 wk), n (%)	30 (30.3)	25 (25.5)
Aortic valvular disease, n (%)	34 (34.3)	34 (34.7)
Angina, CCS score >1, n (%)†	64 (64.6)	47 (48.0)
Current or previous atrial fibrillation, n (%)	14 (14.1)	13 (13.3)
Hypertension, n (%)	83 (84.8)	87 (88.8)
Diabetes mellitus, type 1 or 2 (insulin treated), n (%)	10 (10.1)	10 (10.2)
Diabetes mellitus, type 2 (non–insulin treated), n (%)	14 (14.1)	14 (14.3)
Chronic lung disease, n (%)	9 (9.1)	12 (12.2)
Current smoker, n (%)	18 (18.2)	15 (15.3)
Current alcohol abuse, n (%)	7 (7.1)	7 (7.1)
BMI, kg/m²	27.0 (3.8)	27.6 (4.0)
Left ventricular ejection fraction, n (%)		
>50%	54 (54.5)	50 (51.5)
35%–50%	32 (32.3)	40 (41.2)
20%–34%	12 (12.1)	7 (7.2)
<20%	1 (1.0)	0 (0)

	Low-Target Group (n=98)	High-Target Group (n=97)
Hematocrit, before start of surgery, %	40.3±5.9	40.6±4.7
MAP before anesthesia induction, mm Hg	92.3±15.7	96.9±13.4
MAP during bypass, mm Hg	44.7±4.7	66.8±4.9
MAP below target during bypass, n (%)*	2 (2.0)	18 (18.5)
MAP above target during bypass, n (%)†	5 (5.1)	0 (0)
Blood flow rate during bypass, L·min⁻¹·m⁻²	2.69±0.1	2.69±0.1
Hematocrit, mean level during bypass, %	31.5±3.8	33.1±4.2
Nadir hematocrit sampling value during bypass, %	28.7±3.7	29.2±4.0
Surgery time, min	184.9±50.8	194.3±66.6
Bypass time, min	94.0±32.0	105.6±77.4
Cross-clamp time, min‡	63.3±26.9	64.8±32.6
Peak lactate level during surgery, mmol	2.25±0.83	2.16±0.82
Norepinephrine infused in the OR, µg/kg	2.65±6.01	17.43±20.14
Patients receiving norepinephrine in the OR, n (%)	35 (35.7)	90 (92.7)

Circulation

ORIGINAL RESEARCH ARTICLE

High-Target Versus Low-Target Blood Pressure Management During Cardiopulmonary Bypass to Prevent Cerebral Injury in Cardiac Surgery Patients

A Randomized Controlled Trial

Editorial, see p 1781

BACKGROUND: Cerebral injury is an important complication after cardiac surgery with the use of cardiopulmonary bypass. The rate of overt stroke after cardiac surgery is 1% to 2%, whereas silent strokes, detected by diffusion-weighted magnetic resonance imaging, are found in up to 50% of patients. It is unclear whether a higher versus a lower blood pressure during cardiopulmonary bypass reduces cerebral infarction in these patients.

METHODS: In a patient- and assessor-blinded randomized trial, we allocated patients to a higher (70–80 mm Hg) or lower (40–50 mm Hg) target for mean arterial pressure by the titration of norepinephrine during cardiopulmonary bypass. Pump flow was fixed at 2.4 L·min⁻¹·m⁻². The primary outcome was the total volume of new ischemic cerebral lesions (summed in millimeters cubed), expressed as the difference between diffusion-weighted imaging conducted preoperatively and again postoperatively between days 3 and 6. Secondary outcomes included diffusion-weighted imaging–evaluated total number of new ischemic lesions.

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MAP: high vs low

	Low-Target Group, n		High-Target Group, n		Difference (95% CI)	OR (95% CI)	P Value
Primary outcome							
Total volume of new cerebral lesions, mm³							
Complete cases, median (IQR)	89	25 (0 to 118)	80	29 (0 to 143)	0 (−25 to 0.028)*		0.41
Excluding 3 outliers, median (IQR)	88	24 (0 to 118)	78	28 (0 to 134)			
Complete cases, mean (SD)	89	415 (2682)	80	488 (2539)	81 (−978 to 956)†		0.994
Excluding 3 outliers, mean (SD)	88	133 (313)	78	144 (265)			
Secondary outcome							
Total number of new cerebral lesions							
Complete cases, median (IQR)	89	1 (0 to 2)	80	1 (0 to 2)	0 (0 to 0)*		0.54
Complete caset, mean (SD)	99	1.82 (3.62)	98	2.25 (4.41)	0.23 (−0.99 to 1.46)†		0.71†
Patients with new infarcts in watershed border zones, n (%)‡	89	32 (36.0)	80	33 (41.3)			0.49
Stroke, n (%)		1 (1.1)		6 (7.0)		6.64 (0.78 to 310.75)	0.06
Symptoms on awakening	97	0	92	4			
Symptom onset between days 2 and 30	97	1	92	2			
POCD, n (%)							
At 7 d	91	21 (23.1)	78	27 (34.6)		1.76 (0.90 to 3.47)	0.12
At 90 d	89	8 (9.0)	75	5 (6.7)		0.72 (0.23 to 2.31)	0.77

MAP: high vs low

	Low-Target Group	High-Target Group	OR (95% CI)	*P* Value
Length of stay in ICU, h, median (IQR)	21 (20–26)	21 (19–22)		0.82
ICU stays >36 h, n (%)	11 (11.5)	12 (12.6)	1.12 (0.42–2.97)	0.82
Lactate, peak value at POD 1, mmol	2.61±1.17	2.90±1.70		0.16
Inotropes >24 h, n (%)	4 (4.1)	10 (10.4)	2.72 (0.75–12.32)	0.10
Vasopressors >24 h, n (%)	3 (3.1)	10 (10.4)	3.66 (0.90–21.37)	0.05
Time to extubation, h, median (IQR)	4.6 (2.9–6.7)	4.6 (3.2–7.9)		0.43
Atrial fibrillation, n (%)	49 (49.5)	52(53.1)	1.18 (0.65–2.16)	0.57
Creatinine, peak value, mmol/L	118.0±47.4	121.9±48.6		0.57
Creatinine, doubling of baseline value, n (%)	2 (2.0)	9 (9.4)	4.93 (1.02–48.12)	0.03
Hallucinations or delirium, n (%)*	7 (7.1)	10 (10.5)	1.53 (0.50–4.95)	0.45
Length of stay in cardiac surgery ward, d	6 (5–8)	6 (5–7.75)		0.92

MAP as an absolute goal

After initiation of CPB without haemodynamic

during pressure increase with phenylephrine 20 mm Hg

after discontinuation of phenylephrine

Maier 2009

Kanji *et al. Journal of Cardiothoracic Surgery* 2010, **5**:71
http://www.cardiothoracicsurgery.org/content/5/1/71

JOURNAL OF CARDIOTHORACIC SURGERY

RESEARCH ARTICLE Open Access

Difference between pre-operative and cardiopulmonary bypass mean arterial pressure is independently associated with early cardiac surgery-associated acute kidney injury

Hussein D Kanji[1], Costas J Schulze[1,2], Marilou Hervas-Malo[3], Peter Wang[1], David B Ross[1,2], Mohamad Zibdawi[1,2,4], Sean M Bagshaw[2,3,4*]

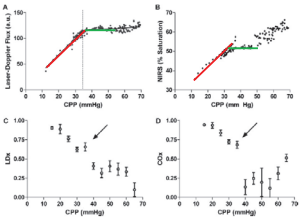
Table 2 Summary of intra-operative variables stratified by post-operative CSA-AKI

Variable	No AKI (n = 92)	AKI (n = 65)	p-value
Valve only surgery (%)	26 (28.3)	12 (18.5)	0.16
Combined (valve + CABG) (%)	43 (46.7)	21 (32.3)	0.07
Re-operation (%)	8 (8.7)	6 (9.2)	0.91
# Grafts (mean [± SD])	3.4 ± 1.1	3.5 ± 1.1	0.77
Duration of CPB (min, mean [± SD])	126.6 ± 52	127.2 ± 63.2	0.69
Duration of cross clamp (min, mean [± SD])	90.9 ± 46.9	88.7 ± 57.1	0.42
Average CPB MAP (mmHg, mean [± SD])	57.8 ± 5.1	56.9 ± 4.9	0.25
Minutes <MAP 60 mmHg (median [± IQR])	5.9 ± 6.5	5.6 ± 4.5	0.49
Minutes <MAP 50 mmHg (median [± IQR])	2.5 ± 10	5.0 ± 15	0.35
Delta MAP (mmHg, mean [± SD])	28.0 ± 13.2	31.3 ± 13.8	0.10
PRBC transfusions (units, mean [± SD])	1.8 ± 1.5	2.4 ± 2.3	0.27
Patients transfused with PRBC (%)	23 (25)	19 (29.2)	0.56
Insulin dose (Units, mean [± SD])	3.3 ± 1.3	3.6 ± 3.1	0.72
Furosemide dose (mg, n = 9, n = 7, mean [± SD])	22.8 ± 10.3	27.1 ± 12.5	0.50
Ultrafiltration (mL, n = 34, n = 25, mean [± SD])	1440 ± 1049	1470 ± 1344	0.98
Received tranexamic acid (%)	83 (90.2)	58 (89.2)	0.84
Received aprotinin (%)	0 (0)	0 (0)	NS
Use of side-biting clamp (%)	16 (17.4)	21 (32.2)	0.03
Average flow (mL/kg/min, mean[± SD])	60.9 ± 7.1	55.5 ± 8.4	0.001
Average temperature (°C, mean [± SD])	35.3 ± 1.4	35.5 ± 1.1	0.75

Table 3 Univariate Factors associated with early CSA-AKI

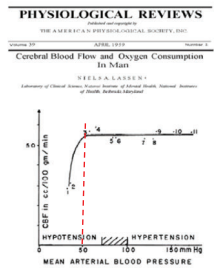
Predictor	Odds Ratio	95% CI	P-value
Male Sex	1.06	0.5-2.1	0.87
Age (per year)	1.01	0.99-1.04	0.25
Age ≥ 75 years (present)	1.7	0.8-3.5	0.15
BMI (kg/m^2)(per 1 point)	1.2	0.8-3.5	< 0.0001
BMI ≥25 kg/m^2 (present)	4.4	1.9-10.2	0.0007
Valve disease (present)	0.55	0.3-1.0	0.06
DM (present)	2.2	1.1-4.2	0.025
PVD (present)	1.9	0.9-3.3	0.19
HTN (present)	1.7	0.9-3.3	0.12
Delta MAP (per 1 mmHg)	1.02	0.99-1.04	0.14
Delta MAP ≥26 mmHg (present)	2.1	1.1-4.2	0.024
Flow ≥54 per mL/kg/min (present)	0.2	0.1-0.5	0.0002
pH	1.4	0.8-2.7	0.26
Pre-operative ACE inhibitor (present)	0.6	0.3-1.1	0.1
Valve Surgery (present)	0.5	0.3-1	0.07
Peak CPB MAP	0.5	0.2-0.97	0.04
Pre-operative Systolic BP (≥111 mmHg)	2.1	0.99-4.6	0.05
Duration of CPB MAP ≤60 (per 1 min)	1.99	0.9-4.4	0.89

Quantification of autoregulation



- When Cox approaches 1, autoregulation is disturbed.
  - COx > 0.30 -> no autoregulation
- When COx approaches 0, blood pressure is in the autoregulation range.
  - COx < 0.30 -> cerebral autoregulation

Brady 2007

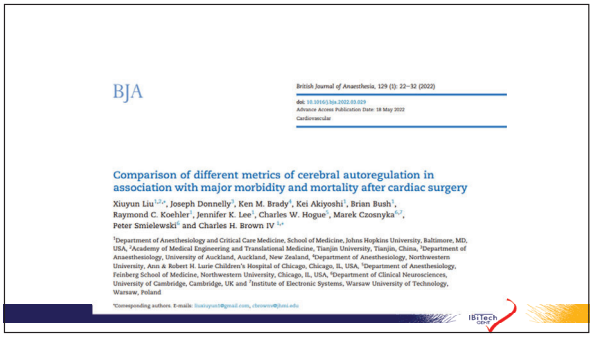

PHYSIOLOGICAL REVIEWS

Cerebral Blood Flow and Oxygen Consumption In Man

NIELS A. LASSEN

Cerebral Autoregulation

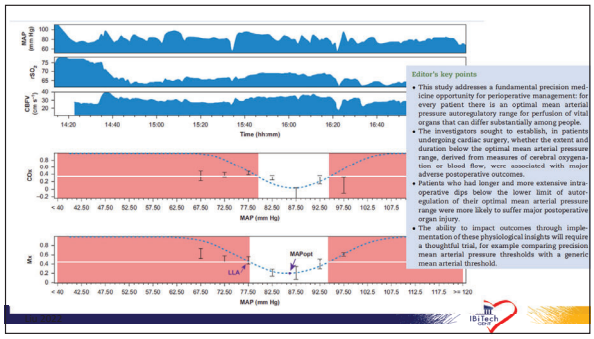
- Summarized results of 11 studies
- Plotted CBF versus MAP
- Manually drew line at 50 mmHg, lower limit of autoregulation


BJA

British Journal of Anaesthesia, 129 (1): 22–32 (2022)

Comparison of different metrics of cerebral autoregulation in association with major morbidity and mortality after cardiac surgery

Xiuyun Liu, Joseph Donnelly, Ken M. Brady, Kei Akiyoshi, Brian Bush, Raymond C. Koehler, Jennifer K. Lee, Charles W. Hogue, Marek Czosnyka, Peter Smielewski and Charles H. Brown IV



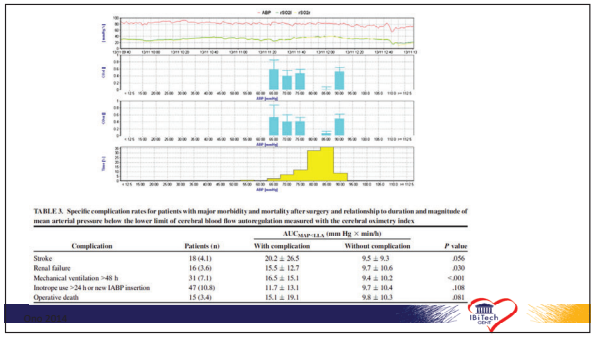
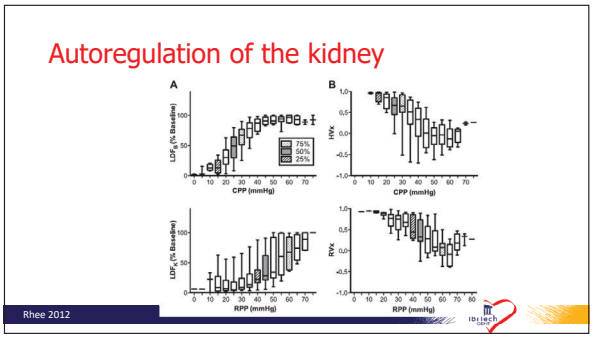


TABLE 3. Specific complication rates for patients with major morbidity and mortality after surgery and relationship to duration and magnitude of mean arterial pressure below the lower limit of cerebral blood flow autoregulation measured with the cerebral oximetry index

		$AUC_{MAP<LLA}$ (mm Hg × min/h)		
Complication	Patients (n)	With complication	Without complication	*P* value
Stroke	18 (4.1)	20.2 ± 26.5	9.5 ± 9.3	.056
Renal failure	16 (3.6)	15.5 ± 12.7	9.7 ± 10.6	.030
Mechanical ventilation >48 h	31 (7.1)	16.5 ± 15.1	9.4 ± 10.2	<.001
Inotrope use >24 h or new IABP insertion	47 (10.8)	11.7 ± 13.1	9.7 ± 10.4	.108
Operative death	15 (3.4)	15.1 ± 19.1	9.8 ± 10.3	.081



Influence of variations in systemic blood flow and pressure on cerebral and systemic oxygen saturation in cardiopulmonary bypass patients

A. Moerman[1]*, W. Denys[1], F. De Somer[2], P. F. Wouters[1] and S. G. De Hert[1]

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Editor's key points

- Maintenance of adequate tissue perfusion and oxygenation is important during anaesthesia.
- In patients undergoing cardiopulmonary bypass, the authors independently manipulated blood flow and systemic arterial pressure.
- Cerebral and systemic oxygenation were positively correlated with flow but not with pressure.

Background. Although both pressure and flow are considered important determinants of regional organ perfusion, the relative importance of each is less established. The aim of the present study was to evaluate the impact of variations in flow, pressure, or both on cerebral and whole body oxygen saturation.

Methods. Thirty-four consenting patients undergoing elective cardiac surgery on cardiopulmonary bypass were included. Using a randomized cross-over design, four different haemodynamic states were simulated: (i) 20% flow decrease, (ii) 20% flow decrease with phenylephrine to restore baseline pressure, (iii) 20% pressure decrease with sodium nitroprusside (SNP) under baseline flow, and (iv) increased flow with baseline pressure. The effect of these changes was evaluated on cerebral (Sc_{O_2}) and systemic (Ss_{O_2}) oxygen saturation, and on systemic oxygen extraction ratio (OER). Data were assessed by within- and between-group comparisons.

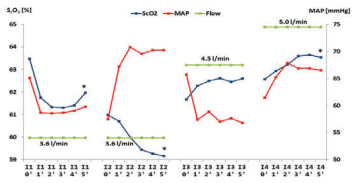
Results. Decrease in flow was associated with a decrease in Sc_{O_2} [from 63.5 (7.4) to 62.0 (8.5) %, $P<0.001$]. When arterial pressure was restored with phenylephrine during low flow, Sc_{O_2} further decreased from 61.0 (9.7) to 59.2 (10.2)%, $P<0.001$. Increase in flow was associated with an increase in Sc_{O_2} from 62.6 (7.7) to 63.6 (8.9) %, $P<0.03$, while decreases in pressure with the use of SNP did not affect Sc_{O_2}. Ss_{O_2} was significantly lower ($P<0.001$) and OER was significantly higher ($P<0.001$) in the low flow arms.

Conclusions. In the present elective cardiac surgery population, Sc_{O_2} and Ss_{O_2} were significantly lower with lower flow, regardless of systemic arterial pressure. Moreover, phenylephrine administration was associated with a reduced cerebral and systemic oxygen saturation.

Keywords: cardiopulmonary bypass; oximetry; phenylephrine; spectroscopy, near-infrared

Accepted for publication: 28 March 2013

Results

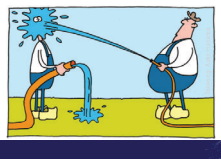


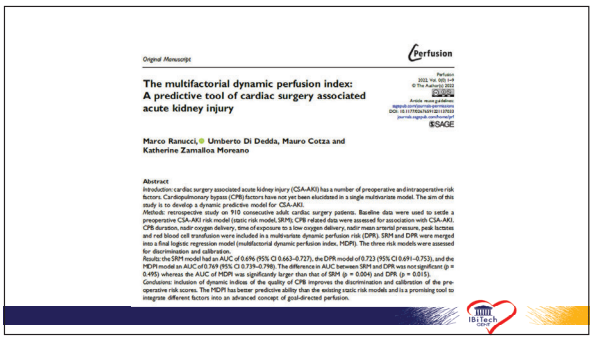
Analysis

Q_{blood} L/min	DO_{2i} mL/min/m²	VO_{2i} mL/min/m²	VO_{2i}/DO_{2i}
3.6 BL -20%	256	46	0.18
3.6 BL -20% + PE	256	46	0.18
4.5 BL+NSP=> -20%P	320	49	0.15
5.0 BL+20%=>MAP	356	47	0.13

Conclusion pressure vs flow

- Cerebral and venous oxygen saturations are more dependent on flow than on pressure
- Change in paradigm "pressure vs flow"





Original Manuscript

Perfusion

The multifactorial dynamic perfusion index: A predictive tool of cardiac surgery associated acute kidney injury

Marco Ranucci, Umberto Di Dedda, Mauro Cotza and Katherine Zamalloa Moreano

Abstract

$$\text{SRM of AKI risk} = \frac{\exp(-1.079 + 0.079*\text{CRS} + 0.035*\text{Age} - 0.095*\text{HCT})}{(1 + \exp[-1.079 + 0.079*\text{CRS} + 0.035*\text{Age} - 0.095*\text{HCT}])}$$

Table 1. Logistic model parameter estimates, score points, and AUC for each risk factor included in the scoring model[a]

Risk Factor	Estimate (CI)	*P* Value	Points	AUC for Single Variable
Female gender	0.48 (0.21–0.75)	<0.001	1	55.3
Congestive heart failure	0.48 (0.20–0.76)	<0.001	1	63.9
Left ventricular ejection fraction <35%	0.39 (0.07–0.71)	0.016	1	56.4
Preoperative use of IABP	1.08 (0.49–1.67)	<0.001	2	52.6
COPD	0.70 (0.37–1.04)	<0.001	1	54.9
Insulin-requiring diabetes	0.40 (0.05–0.76)	0.026	1	54.4
Previous cardiac surgery	0.54 (0.28–0.81)	<0.001	1	57.5
Emergency surgery	1.33 (0.65–1.64)	<0.001	2	54.3
Surgery type				
valve only	0.45 (0.10–0.80)	0.013	1	63.3
CABG + Valve	0.86 (0.53–1.19)	<0.001	2	
other cardiac surgeries	1.02 (0.56–1.49)	<0.001	2	
Preoperative creatinine 1.2 to <2.1 mg/dl	0.92 (0.64–1.21)	<0.001	2	68.6
Preoperative creatinine ≥2.1 mg/dl	2.66 (2.28–3.04)	<0.001	5	

[a]CI, confidence interval; AUC, area under the receiver operating characteristic curve; IABP, intra-aortic balloon pump; COPD, chronic obstructive pulmonary disease.

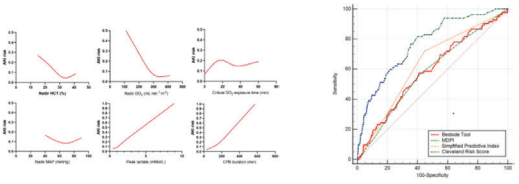
Table 2. Cardiopulmonary bypass-related factors in AKI and non-AKI patients.

Item	AKI (N = 84)	Non-AKI (N = 746)	*p*
Nadir hematocrit (%)	26 (4.2)	28.6 (4.2)	0.001
Nadir oxygen delivery (ml·min^{-1}·m^{-2})	263 (52)	297 (46)	0.001
Time of exposure to critical oxygen delivery (min)	15.8 (12)	5.8 (10.8)	0.001
Pump flow (L/min/m^2)	2.31 (2.9)	2.39 (1.9)	0.014
Cardiopulmonary bypass duration (min)	132 (76)	95 (45)	0.001
Nadir mean arterial pressure (mmHg)	59.9 (9.5)	61.1 (8.9)	0.271
Use of norepinephrine	17 (20.2)	117 (15.7)	0.276
Peak lactates (mMol/L)	1.48 (1.45)	1.01 (0.4)	0.001
Red blood cell transfusion	33 (39.3)	53 (7.1)	0.001

Data are mean (standard deviation) or number (%). AKI: Acute kidney injury.

Thakar 2005

$$\text{MDPI CSA} - \text{AKI risk} = \frac{\exp(-3.35 + 4.17*\text{SRM} + 5.37*\text{DPR})}{1 + \exp[-3.3 + 4.17*\text{SRM} + 5.37*\text{DPR}]}$$



Ranucci 2022

GDP and PIRO: static risk

- Male
- 60 years
- Hematocrit: 43%
- CABG

4.7%

- Female
- 60 years
- Hematocrit: 36%
- COPD
- Diabetes
- Isolate valve

11.6%

- Male
- 70 years
- Hematocrit: 40%
- EF: < 35%
- CABG + VR

10%

GDP and PIRO: perfusion related risk

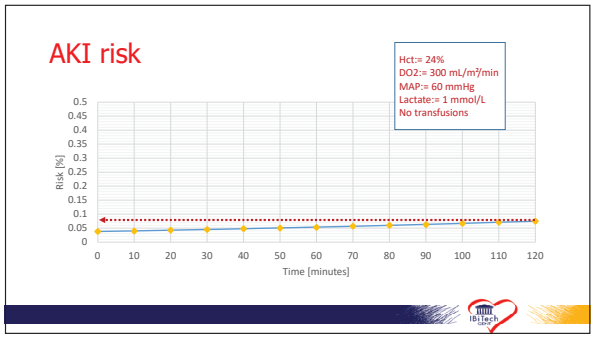
- Nadir Hct:= 28%
- Nadir DO2i:= 300 mL/min
- Time below:= 0 min
- Transfusion:= 0
- CPB:= 95 min
- Peak lactate:= 1 mmol/L
- Nadir MAP:= 60 mmHg

6.1%

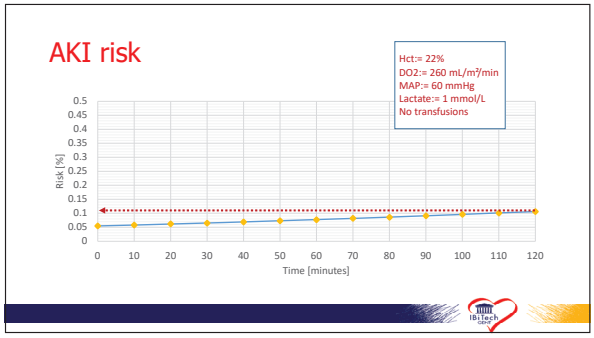
- Nadir Hct:= 20%
- Nadir DO2i:= 220 mL/min
- Time below:= 15 min
- Transfusion:= 2
- CPB:= 95 min
- Peak lactate:= 4 mmol/L
- Nadir MAP:= 60 mmHg

77%

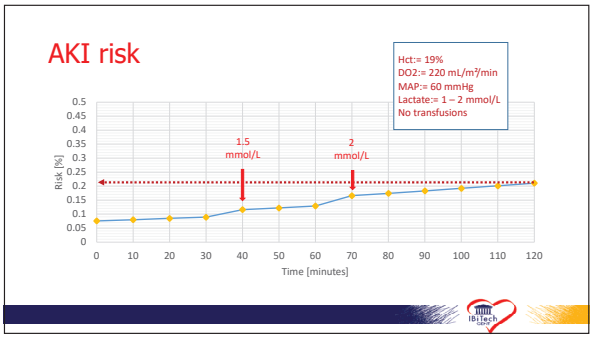
AKI risk



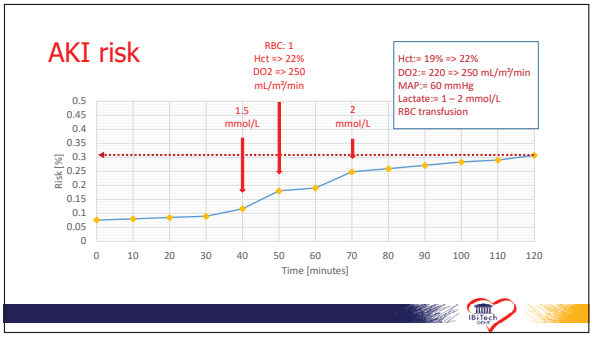
AKI risk



AKI risk



AKI risk



Conclusions

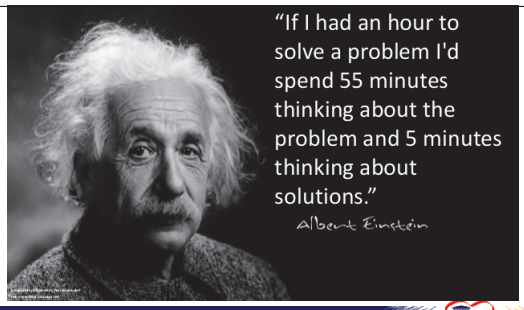
- GDP should be based upon oxygen delivery and CO2 production
- Increased RQ is indicative for a disturbed microcirculation
- MAP should stay in the autologous regulation
- Flow is more important than pressure

Conclusions

- GDP reduces postoperative morbidity
- GDP is a multivariate online analysis of risk
- More variables are needed

Goal Directed Perfusion

Wants to preserve organ function
by influencing host response
but this asks for
continuous markers



Correct communication helps!