STRATEGIES VENTILATOIRES EN CHIRURGIE CARDIAQUE SOUS CEC

David Lagier, MD, PhD
Service d'Anesthésie Réanimation - CHU La Timone - Assistance Publique des Hôpitaux de Marseille

APHM
Assistance Publique
Hôpitaux de Marseille

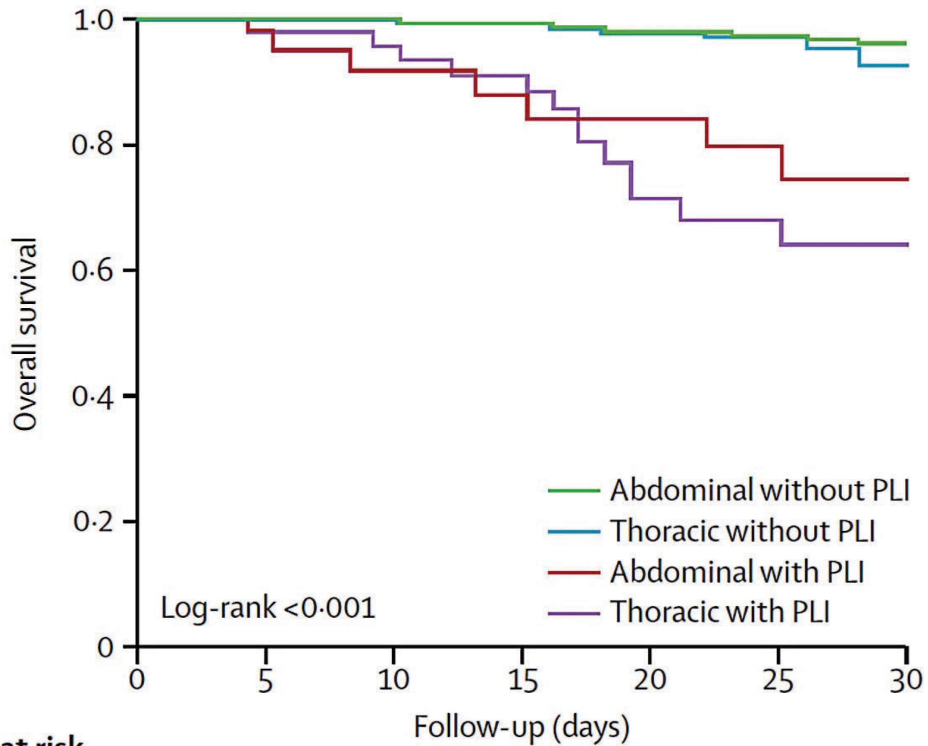
POST-OPERATIVE PULMONARY COMPLICATIONS (PPCs)

- ARDS about **1%**.
- Hypoxemia (*i.e.* SpO2 < 90% in room air) **> 30 %** after elective cardiac surgery.
- Impact:
  - ICU and hospital length of stay.
  - Impact on health-care system.
  - Patient satisfaction.

Ng *et al*, Chest, 2002
Ranucci *et al*, PlosOne, 2014

PERI-OPERATIVE LUNG INJURY

Increased 30-day postoperative mortality and ICU length of stays



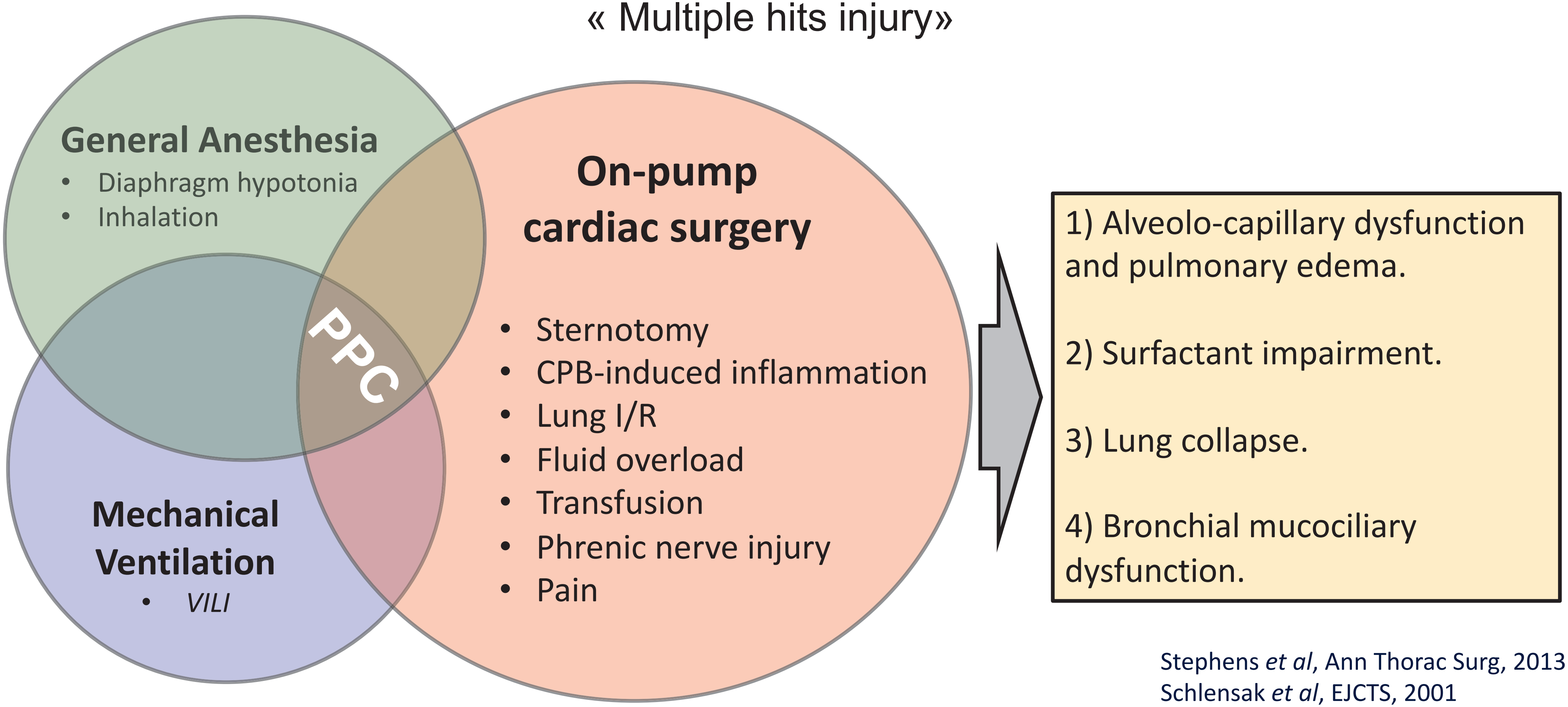
Number at risk

Abd without PLI	1591	1120	655	401	277	211	96
Abd with PLI	38	31	25	22	17	15	8
Tho without PLI	1191	980	586	236	92	44	11
Tho with PLI	51	43	40	33	21	13	5

Serpa Neto *et al*, Lancet Respir Med, 2014

PATHOPHYSIOLOGY OF PPC IN CARDIAC SURGERY

« Multiple hits injury»



Stephens *et al*, Ann Thorac Surg, 2013
Schlensak *et al*, EJCTS, 2001
Govender *at al*, Heart and Lung, 2019
Carney *et al*, Circulation, 1999
Sanchez-Veliz *et al*, Plos One, 2015

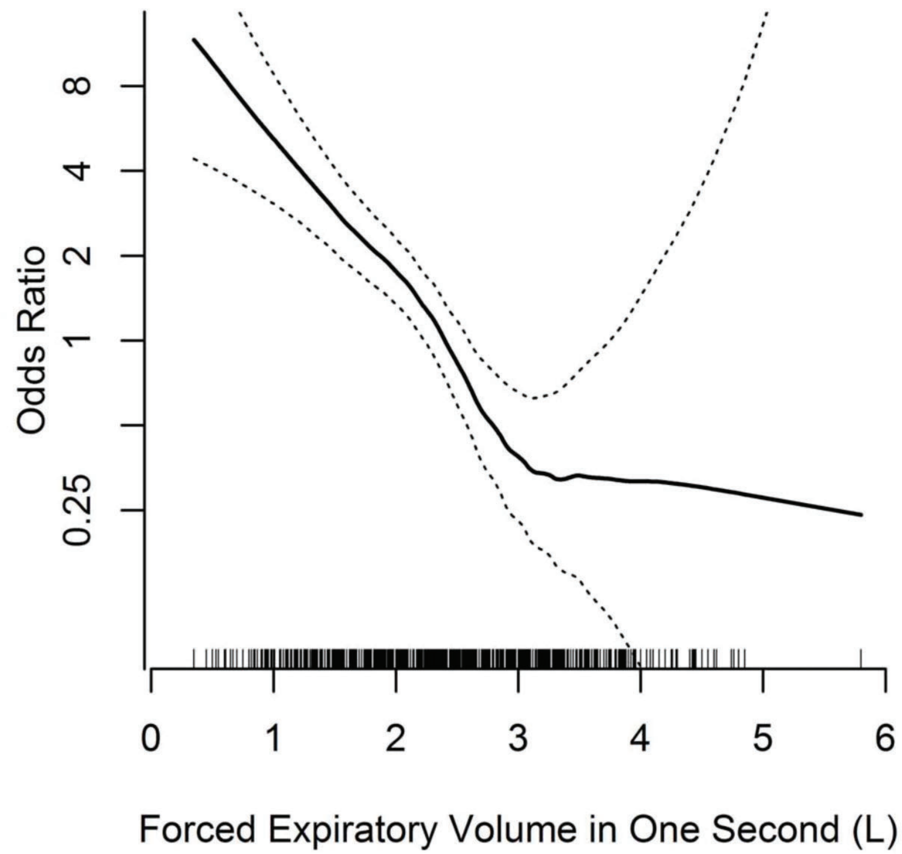
RISK FACTORS / CARDIAC SURGERY

PREOPERATIVE	*INTRAOPERATIVE*	*POSTOPERATIVE*
• Age > 65 yo	• Urgent surgery	• Resternotomy for bleeding
• LVEF < 40%	• Redo surgery	• LCOS.
• Diabetes mellitus	• Aorta surgery	• Mediastinitis / Sepsis
• Hypertension	• Combined surgery	• AKI
• NYHA > III	• Transfusion	• MV > 24h
• Current smoking	• CPB duration	• Neurological complication (stroke, phrenic nerve injury)
• Underweight		
• Morbid obesity		

Ranucci *et al*, Plosone, 2014
Mathis *et al*, Anesthesiology, 2019
Milot *et al*, Chest, 2001

Asimakopoulos *et al*, JTCVS, 1999
Christenson *et al*, Cardiovascular surgery, 1996

Forced Expiratory Volume in One Second Predicts Length of Stay and In-Hospital Mortality in Patients Undergoing Cardiac Surgery: A Retrospective Cohort Study



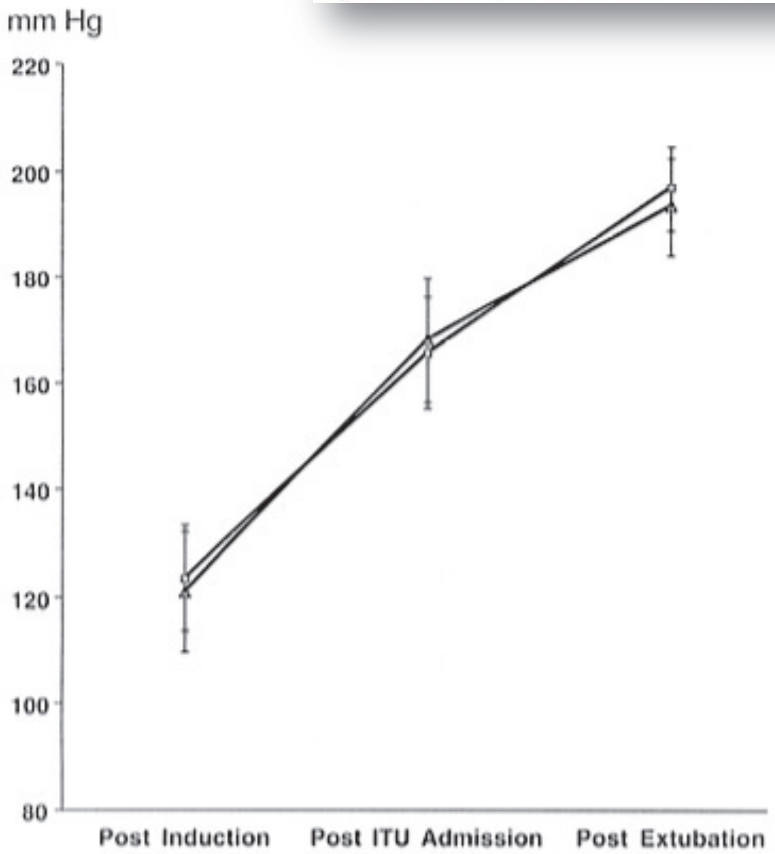
McAllister *et al*, Plos One, 2013

IMPACT DE LA CEC

Effect of Cardiopulmonary Bypass on Pulmonary Gas Exchange: A Prospective Randomized Study

Craig M. Cox, FRCA, Raimondo Ascione, MD, Alan M. Cohen, FRCA, Ian M. Davies, FRCA, Ian G. Ryder, FRCA, and Gianni D. Angelini, FRCS
Department of Anaesthesia and Bristol Heart Institute, University of Bristol, Bristol, United Kingdom

On pump *versus* off pump CABG



Variable	CPB Group (n = 26)	Non-CPB Group (n = 26)
Net fluid balance at 24 h (mL)	+1,527 ± 473	+960 ± 330[a]
Total chest tube drainage (mL)	1,268 ± 777	646 ± 298[a]
Intubation time (h)	9.3 ± 6.1	7.1 ± 3.8
Number patients suffering respiratory complications	10	3
Total respiratory complications	13	4[a]
Chest infection	5	2
Pneumothorax	4	1
Lung collapse	4	1
ARDS	0	0
POMI	0	0
Length of stay in ITU (days)	1.2 ± 0.5	1.0 ± 0.0
Length of stay in hospital (days)	6.8 ± 2.3	5.8 ± 1.5

Results are shown as frequencies, except where stated.
[a] $p < 0.05$.

Ann Thorac Surg, 2000

IMPACT DE LA CEC
Inflammation pulmonaire et systémique

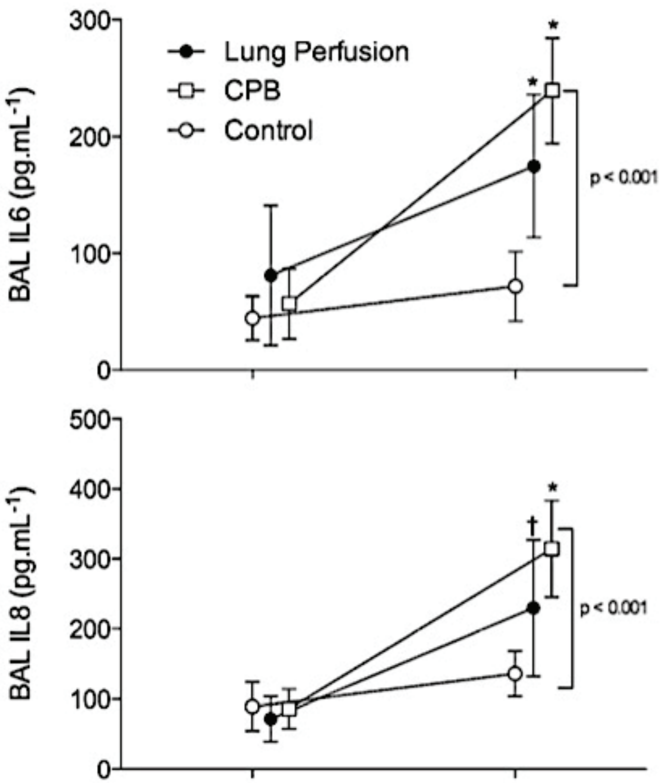
Table 2. Key Proinflammatory Cytokines in the Immune Response to Cardiac Surgery

Cytokine	Source	Functions	In Cardiac Surgery
TNF-α	Macrophages Monocytes Natural killer cells T cells and B cells Mast cells Endothelial cells	Primary mediator in inflammatory response Provokes pathophysiologic effects of SIRS Proinflammatory cytokine release Neutrophil release (from bone marrow) and activation Macrophage/monocyte differentiation and activation Activates coagulation/complement cascades Endothelial adhesion molecule synthesis Acute phase protein production Endogenous pyrogen	Elevated early following cardiac surgery[52,53]
IL-1β	Macrophages Monocytes Endothelial cells	Primary mediator in inflammatory response Initiation of cell mediated immune response Activation of T cells and macrophages iNOS expression; prostaglandin production Inhibition of lipoprotein lipase Procoagulant activity Release of proinflammatory cytokines Endothelial adhesion molecule synthesis Acute phase protein production Endogenous pyrogen	Elevated early following cardiac surgery[52,53] May predict outcome in certain critically ill patient subgroups[51]
IL-6	Macrophages Type 2 helper cells	Key later role in inflammatory cascade Activation of lymphocytes Differentiation of B cells and antibody production T-cell activation and differentiation Acute phase protein production Endogenous pyrogen	Elevated later following cardiac surgery[52,53] Myocardial depressant[64] Serum concentrations may correlate with mortality following pediatric cardiac surgery[55] May predict outcome in from critically illness[51]
IL-8	Macrophages T cells Endothelial cells	Key later role in inflammatory cascade Chemotaxis of neutrophils, basophils, and T cells Regulates neutrophil activity, including neutrophil chemotaxis, the neutrophil respiratory burst, transendothelial neutrophil migration, and neutrophil dependent plasma leak	Elevated later following cardiac surgery[52,53,402] Important role suggested in regulating neutrophil inflammatory response to cardiac surgery.[427] Negative correlation between IL-8 and postoperative cardiac index.[402]

Laffey *et al*, Anesthesiology, 2002

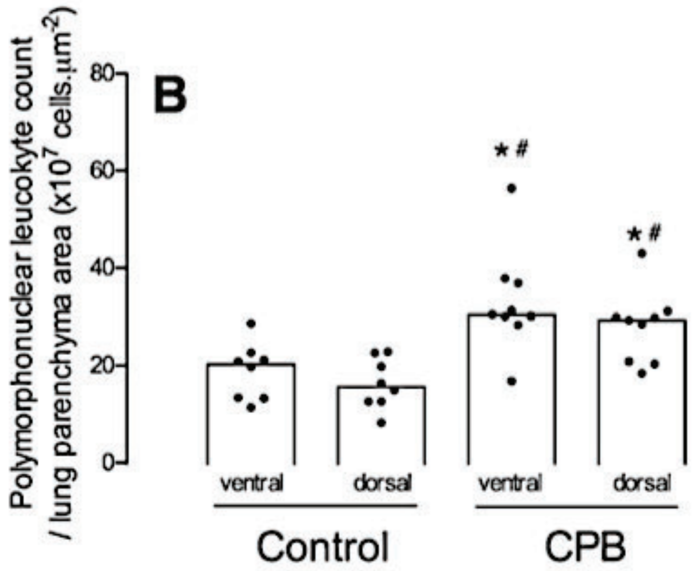
IMPACT DE LA CEC
Inflammation pulmonaire et systémique

LBA : cytokines

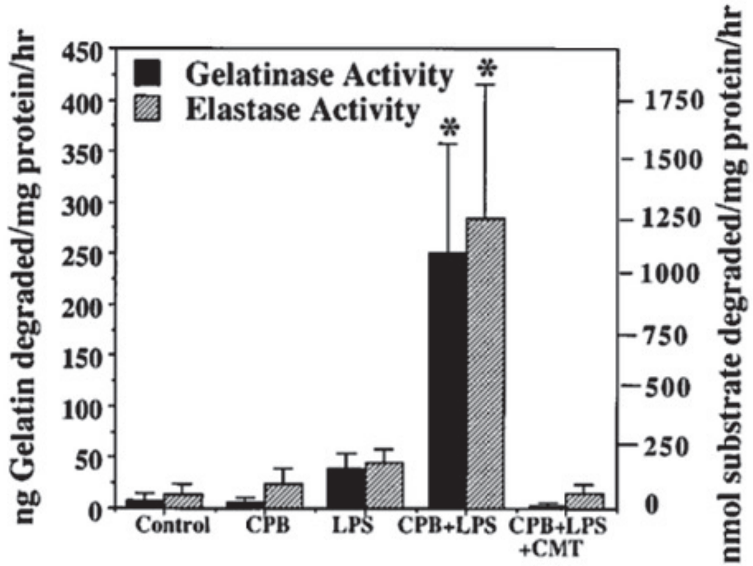


Baseline **90' postCPB**

Recrutement et activation leucocytaire



Elastase / MMP



Da Costa Freitas *et al*, Anesth Analg, 2016
Carney *et al*, Circulation, 1999

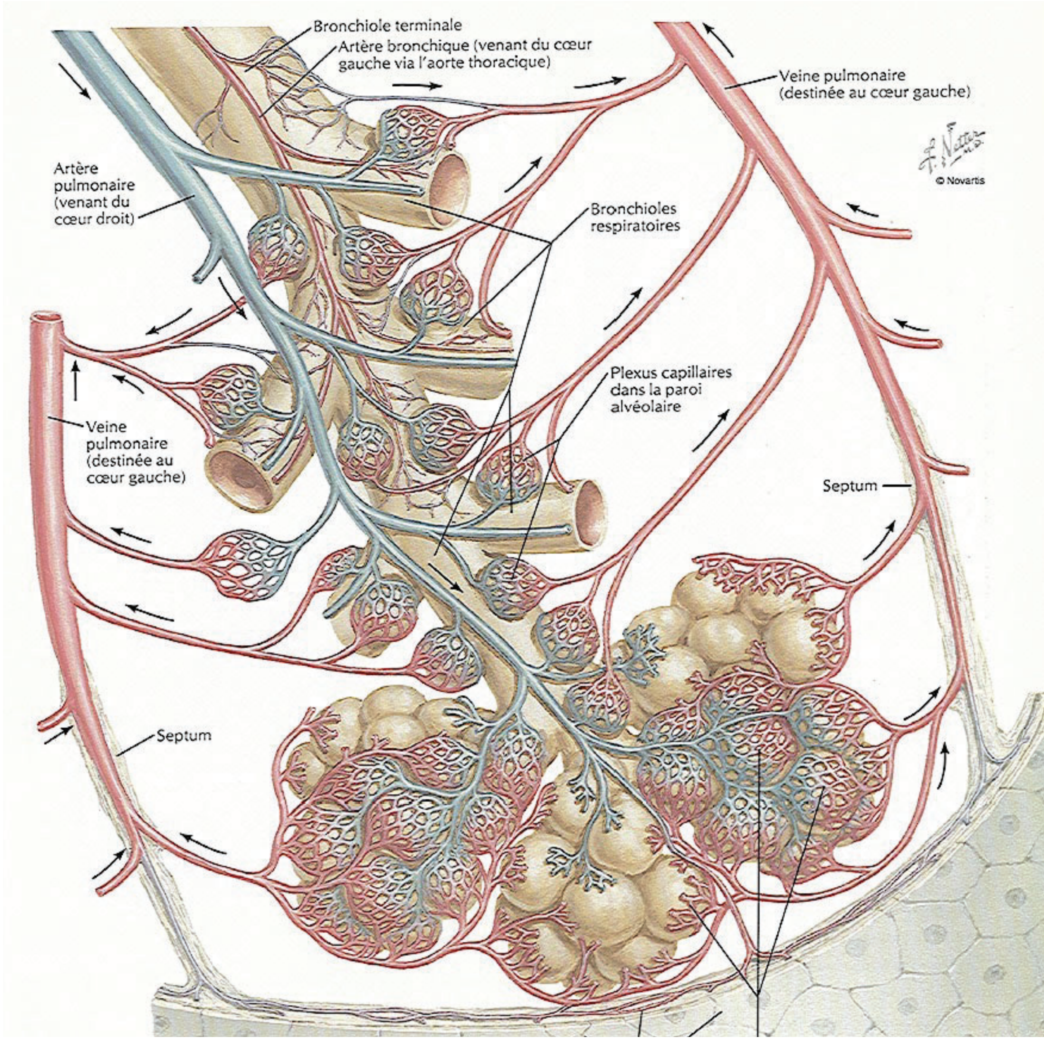
IMPACT DE LA CEC / CLAMPAGE
Ischémie - Reperfusion Pulmonaire

Oxygénation pulmonaire : triple apport

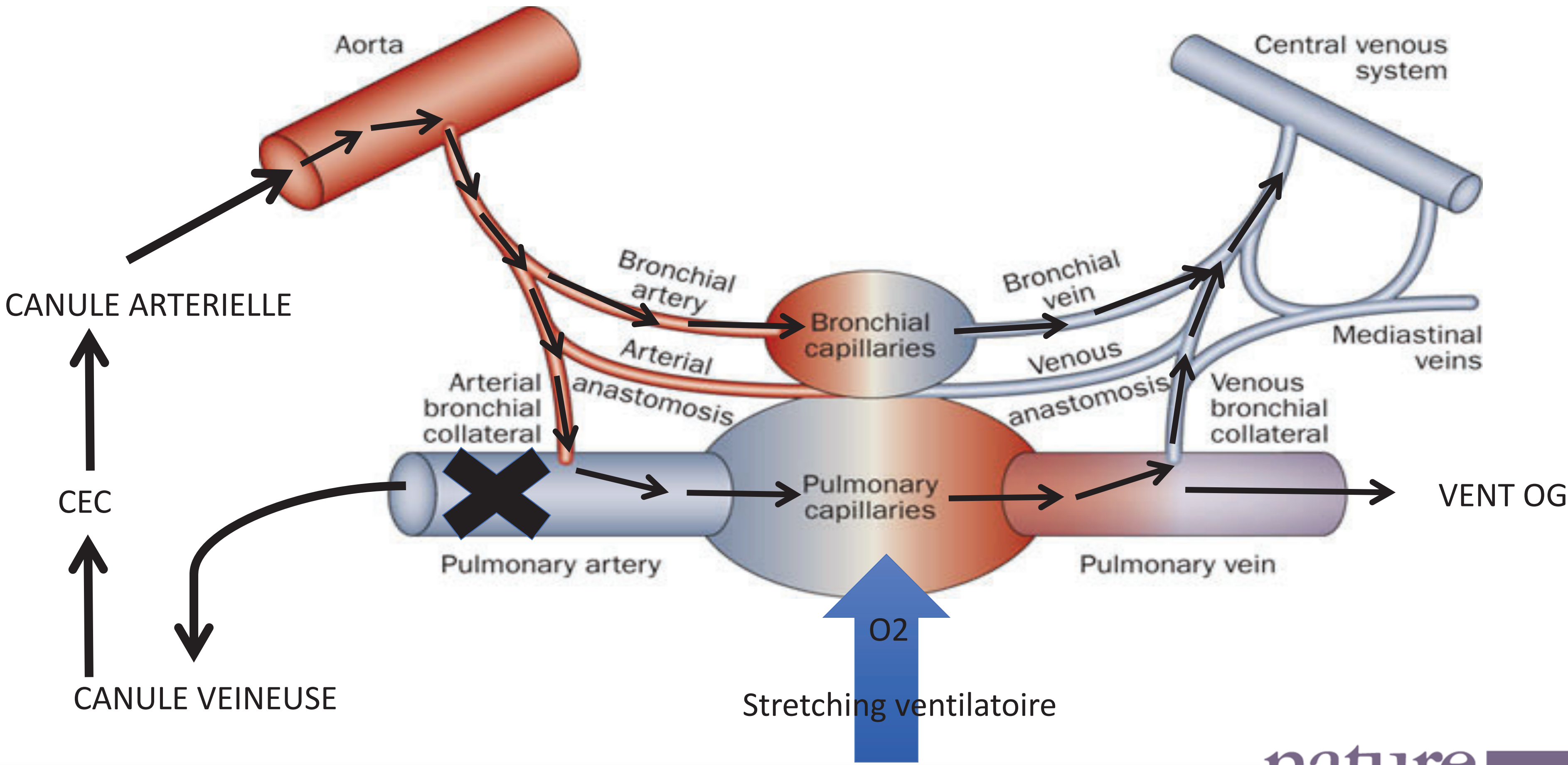
- Circulation trophique bronchique:
- 5% DC.
- Aorte thoracique descendante.

- Circulation fonctionnelle pulmonaire:
- Anastomoses avec la circulation bronchique.
- Exclu lors du clampage aortique et du drainage veineux.

- Diffusion direct de l'oxygène alvéolaire:
- Exclu si arrêt de la ventilation.



IMPACT DE LA CEC
Ischémie - Reperfusion Pulmonaire

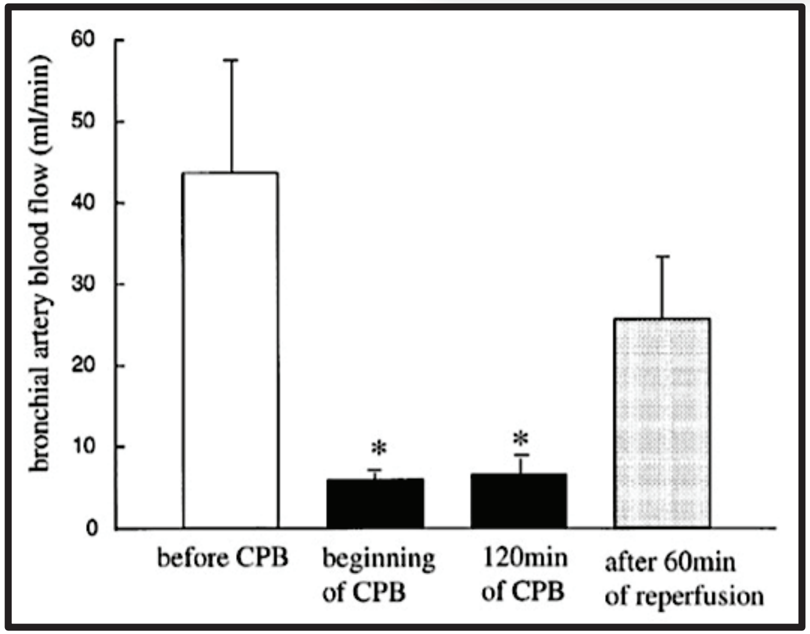


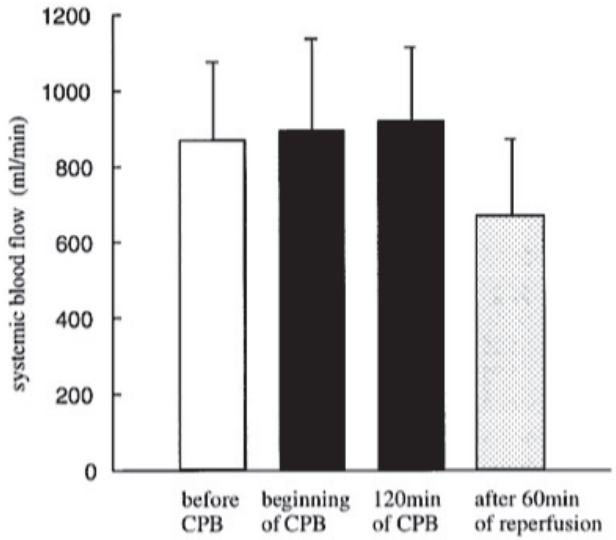
de Leval, M. R. & Deanfield, J. E. (2010) Four decades of Fontan palliation
Nat. Rev. Cardiol. doi:10.1038/nrcardio.2010.99

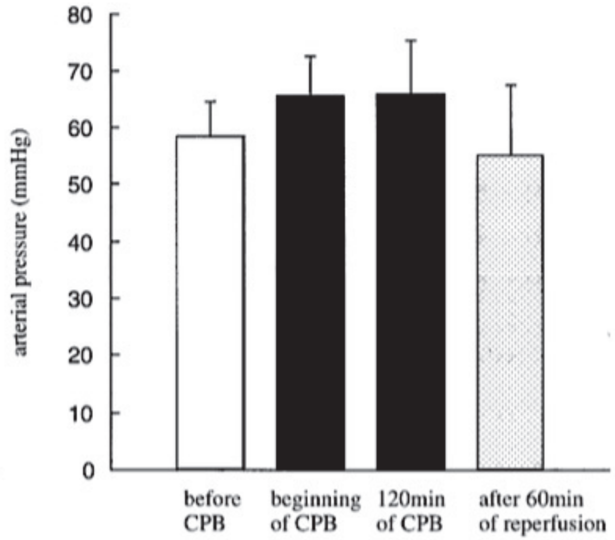
nature REVIEWS CARDIOLOGY

IMPACT DE LA CEC
Ischémie - Reperfusion Pulmonaire

Bronchial artery perfusion during cardiopulmonary bypass does not prevent ischemia of the lung in piglets: assessment of bronchial artery blood flow with fluorescent microspheres☆



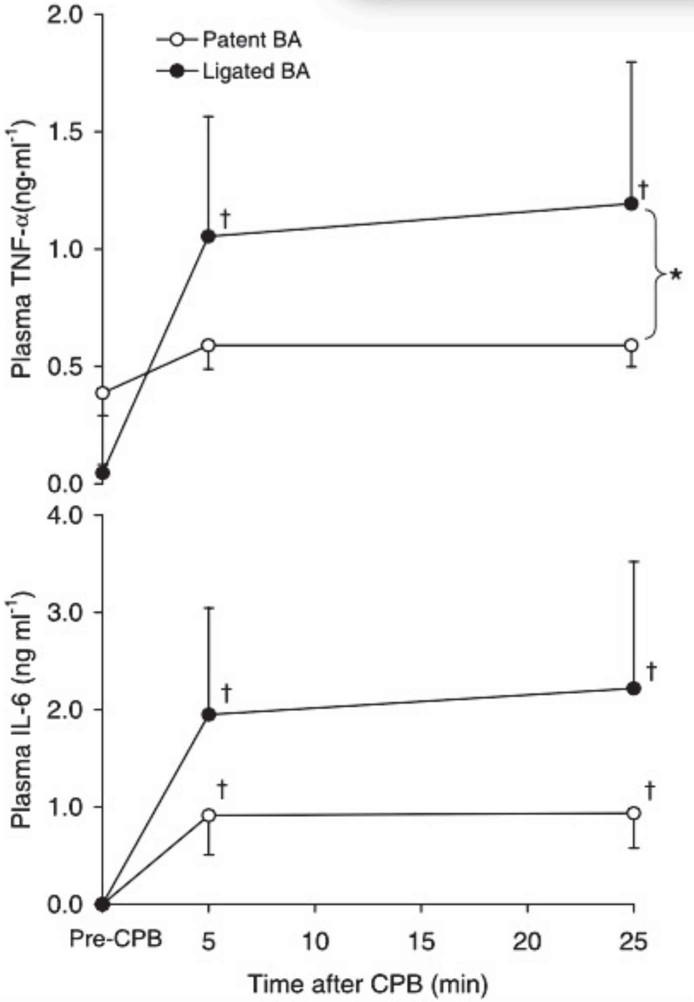


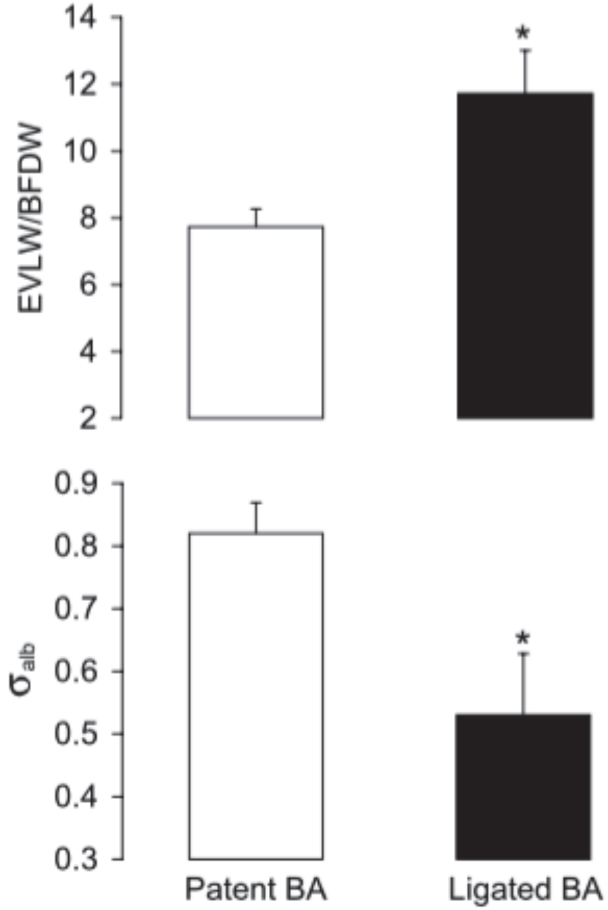


- Perte pulsatilité ?
- Rapport circulation pulmonaire / circulation bronchique (shunt) ?
- Affaissement pulmonaire ?

Schlensak *et al*, EJCTS, 2001

Effect of bronchial artery blood flow on cardiopulmonary bypass-induced lung injury





Dodd-o *et al*, Am J Physiol Heart Circ Physiol, 2004

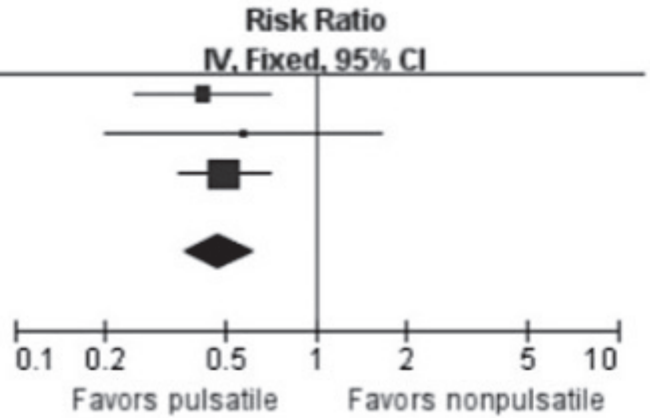
IMPACT DE LA CEC
Ischémie - Reperfusion Pulmonaire

A Meta-Analysis of Pulmonary Function With Pulsatile Perfusion in Cardiac Surgery

Need for NIV

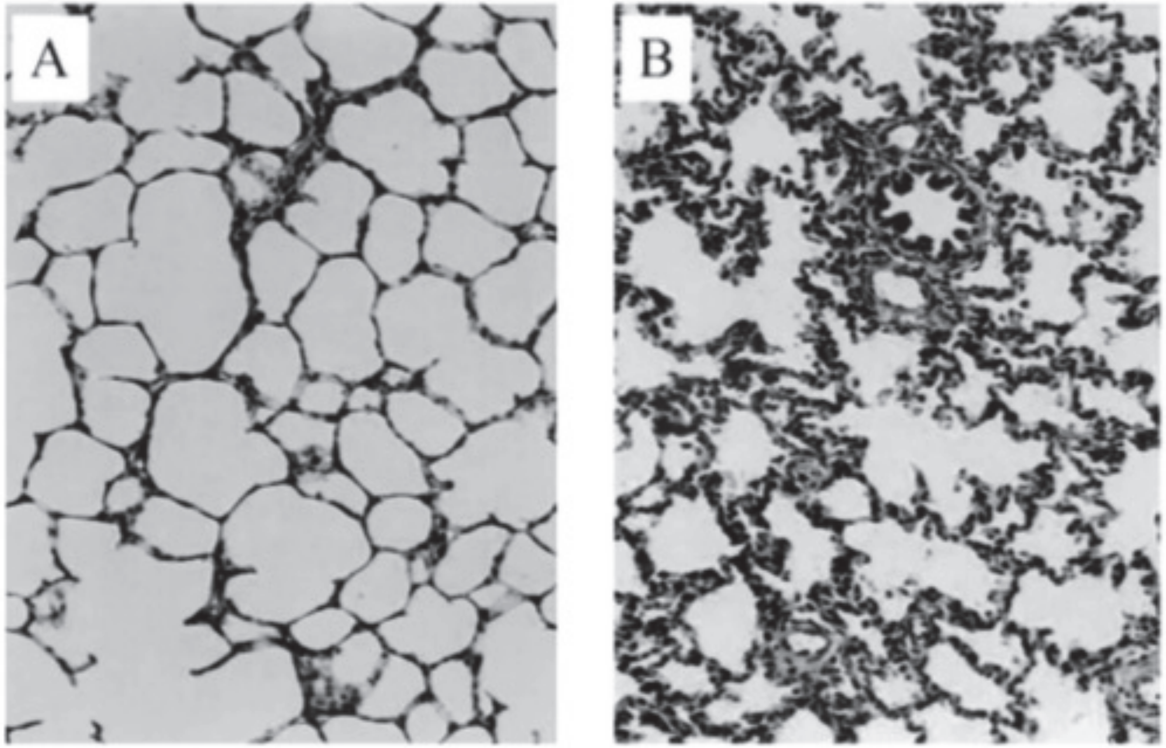
Study or Subgroup	Pulsatile Flow Events	Pulsatile Flow Total	Nonpulsatile Flow Events	Nonpulsatile Flow Total	Weight	Risk Ratio IV, Fixed, 95% CI
Onorati 2009	16	87	31	71	29.1%	0.42 [0.25, 0.71]
Onorati 2010	4	20	7	20	6.9%	0.57 [0.20, 1.65]
Serraino 2012	36	231	85	270	64.0%	0.50 [0.35, 0.70]
Total (95% CI)		**338**		**361**	**100.0%**	**0.48 [0.36, 0.63]**
Total events	56		123			

Heterogeneity: $\chi^2 = 0.38$, df = 2 ($P = 0.83$); $I^2 = 0\%$
Test for overall effect: $Z = 5.21$ ($P < 0.00001$)



Lim *et al*, Artif Organs, 2014

IMPACT DE LA CEC
Sur le plan lésionnel: alvéoles



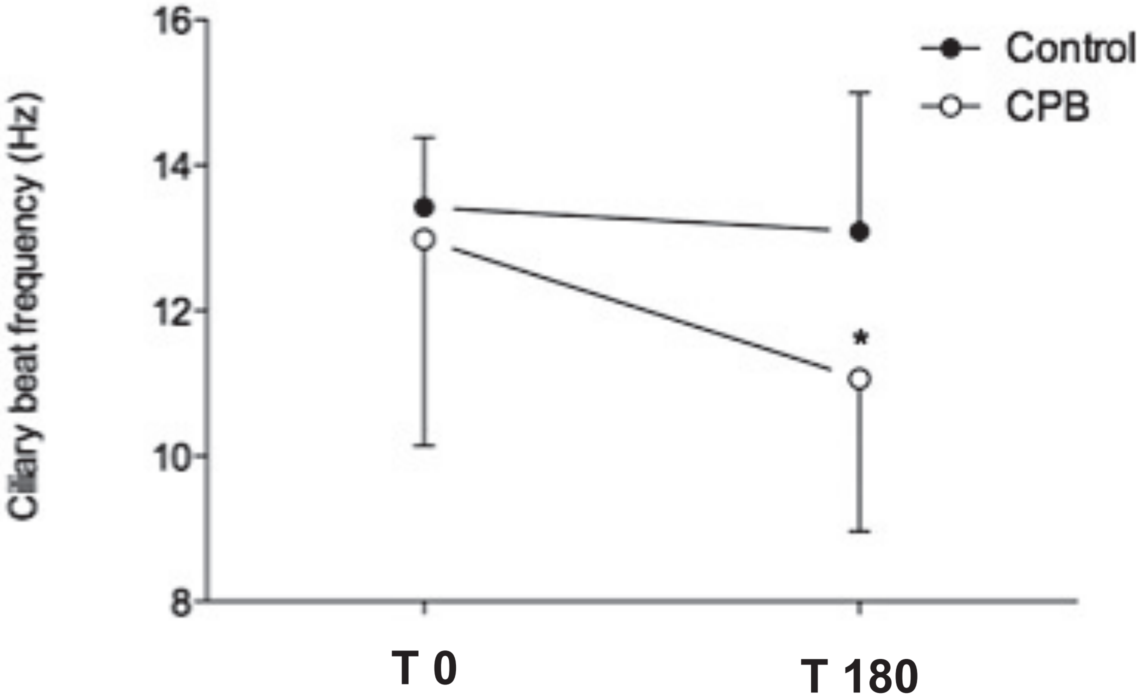
PRE CPB **POST 120' CPB AND 60' REPERF**

- Atteinte de la membrane alvéolo-capillaire.
- Augmentation de la perméabilité alvéolaire.
- Œdème pulmonaire lésionnel et/ou cardiogénique.

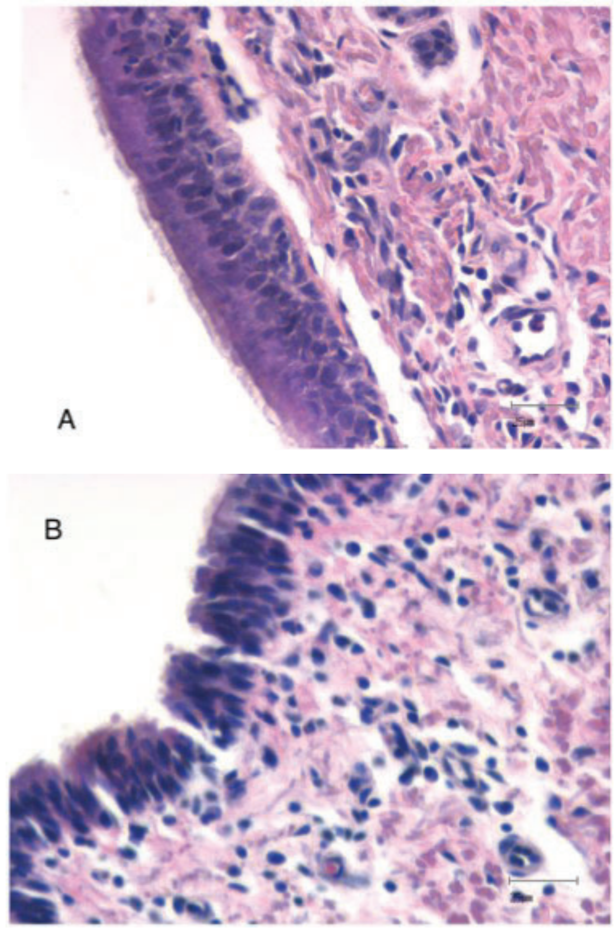
Schlensak *et al*, EJCTS, 2001

IMPACT DE LA CEC
Sur le plan lésionnel: bronches

Impact of Cardiopulmonary Bypass on Respiratory Mucociliary Function in an Experimental Porcine Model



T 0

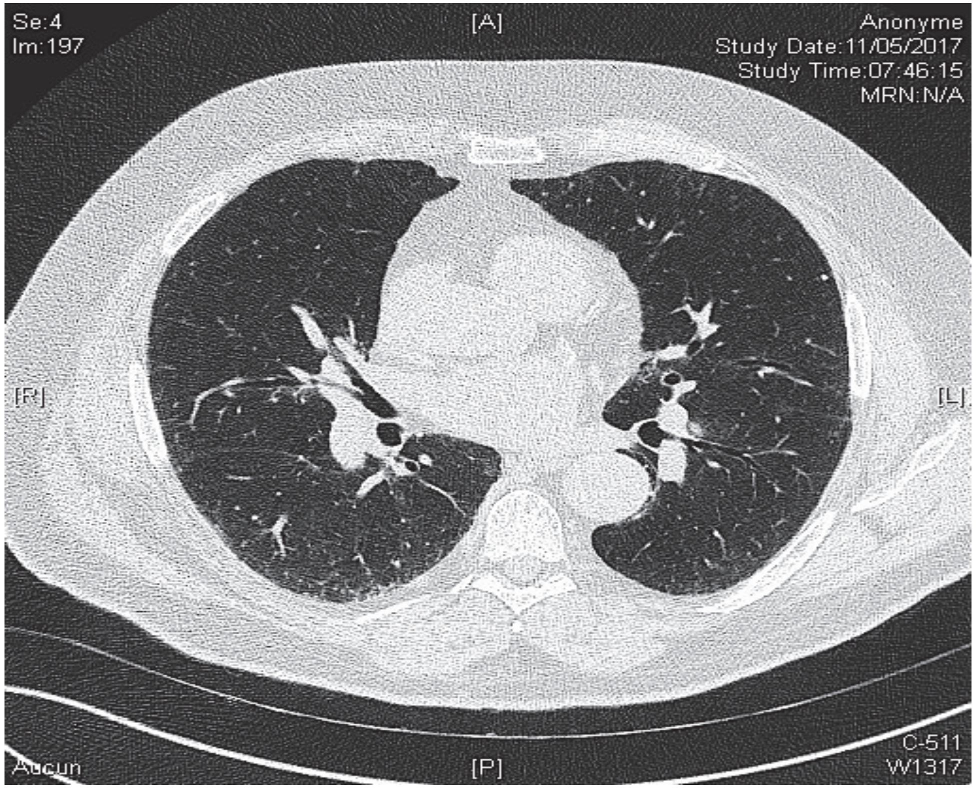


T 180

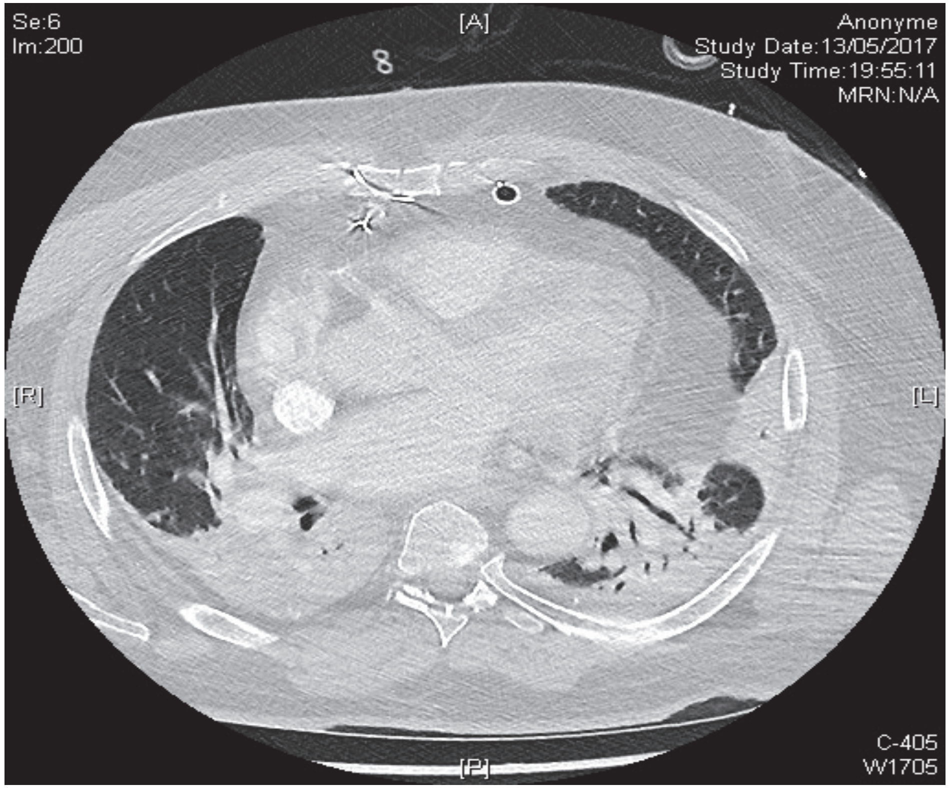
Sanchez-Veliz *et al*, Plos One, 2015

CT PHENOTYPE = PULMONARY ATELECTASIS

PREOP: 05/11/17



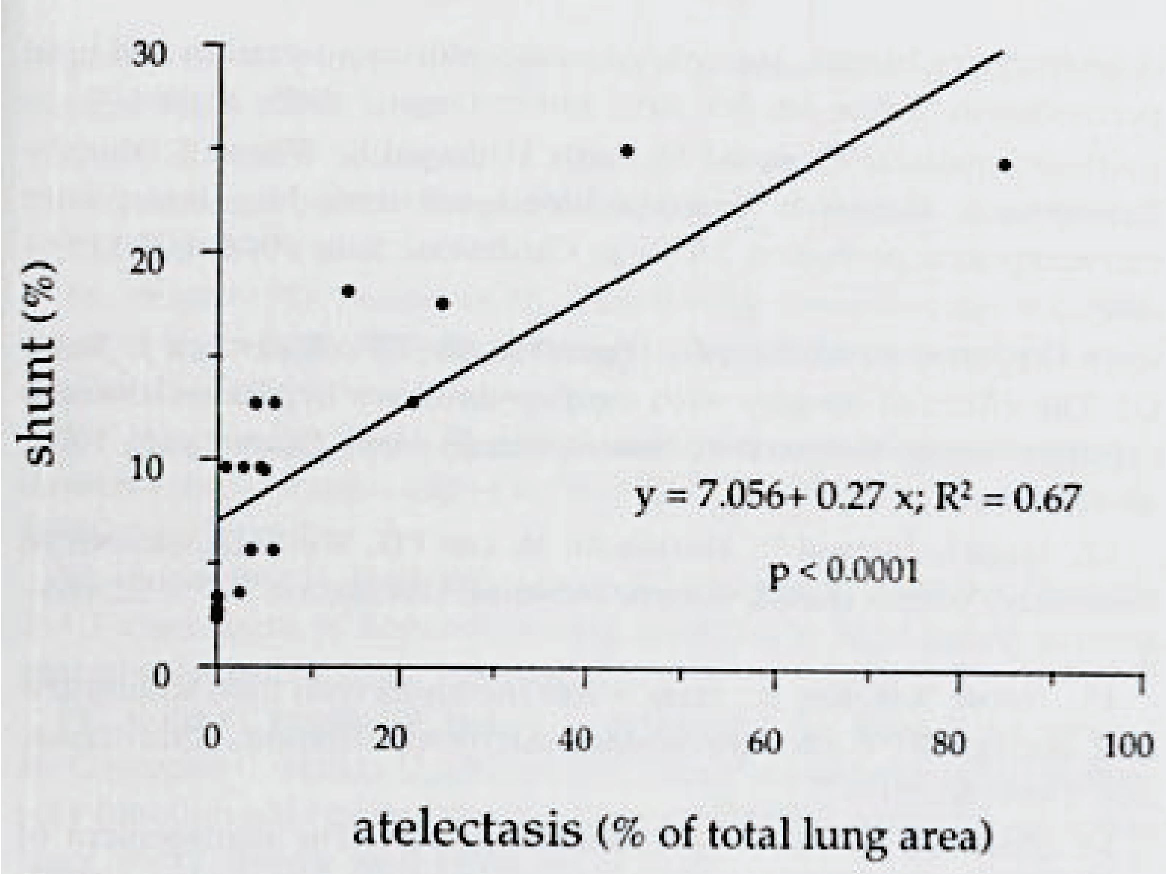
POSTOP: 05/13/17



70 yo male, emergent CABG, active smoking, obesity, hypertension, diabetes

Atelectasis Is a Major Cause of Hypoxemia and Shunt after Cardiopulmonary Bypass

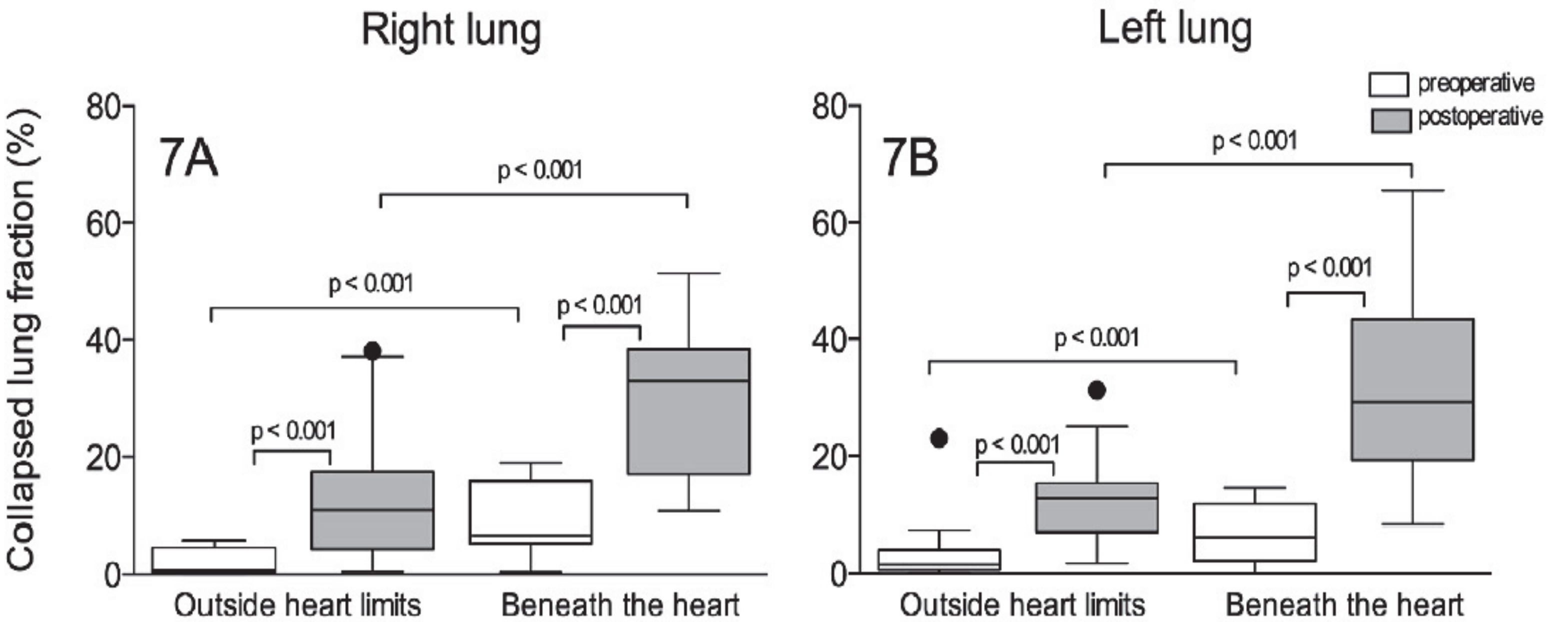
An Experimental Study



Magnusson *et al*, Anesthesiology, 1997

OPEN ACCESS Freely available online PLOS | ONE

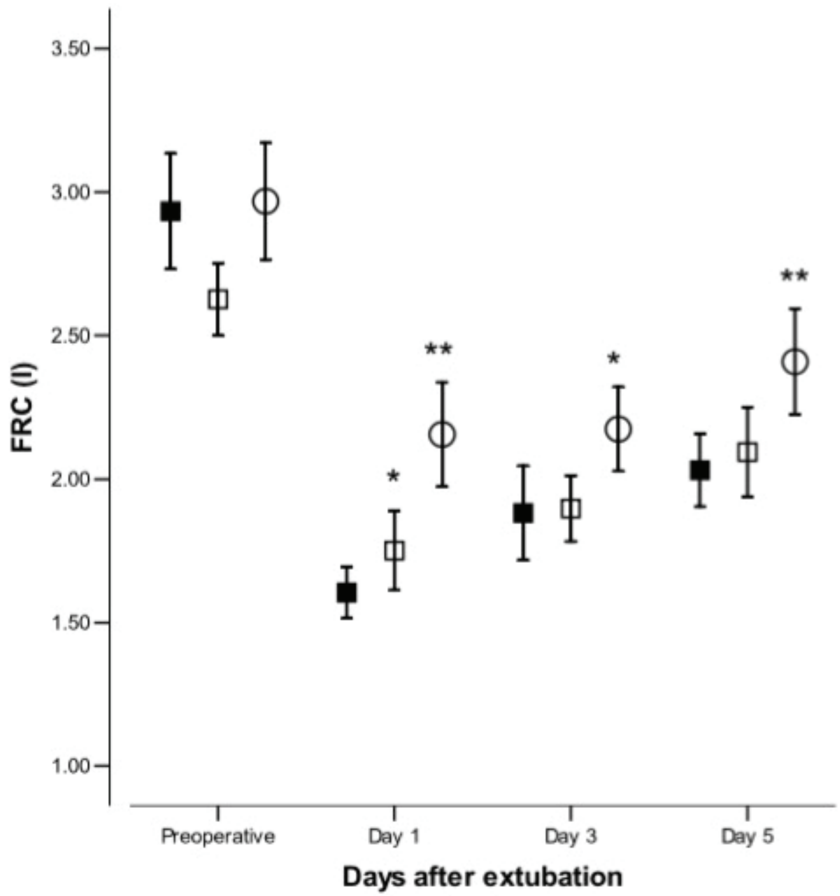
Cardiac Compression of Lung Lower Lobes after Coronary Artery Bypass Graft with Cardiopulmonary Bypass



n = 17 CABG
VT 8 ml/kg, PEEP 5 cmH_2O
No ventilation during CEC

Neves *et al*, Plos One, 2013

IMPACT DE LA CHIRURGIE CARDIAQUE SOUS CEC
Sur le plan physiologique : baisse CRF et effet shunt



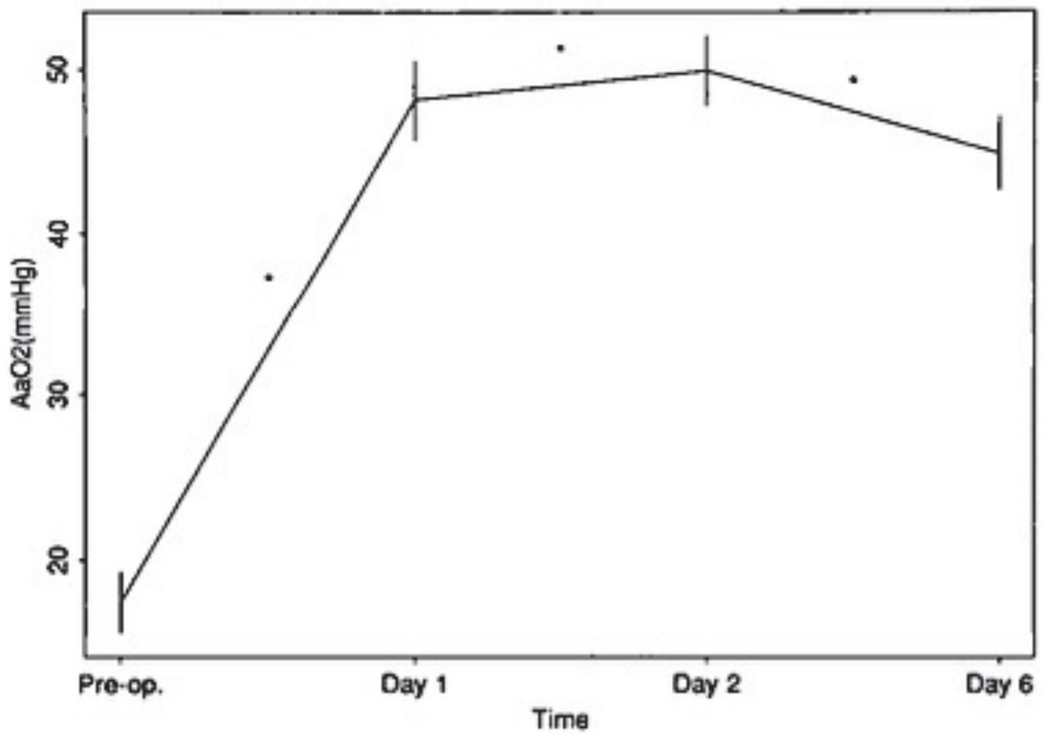
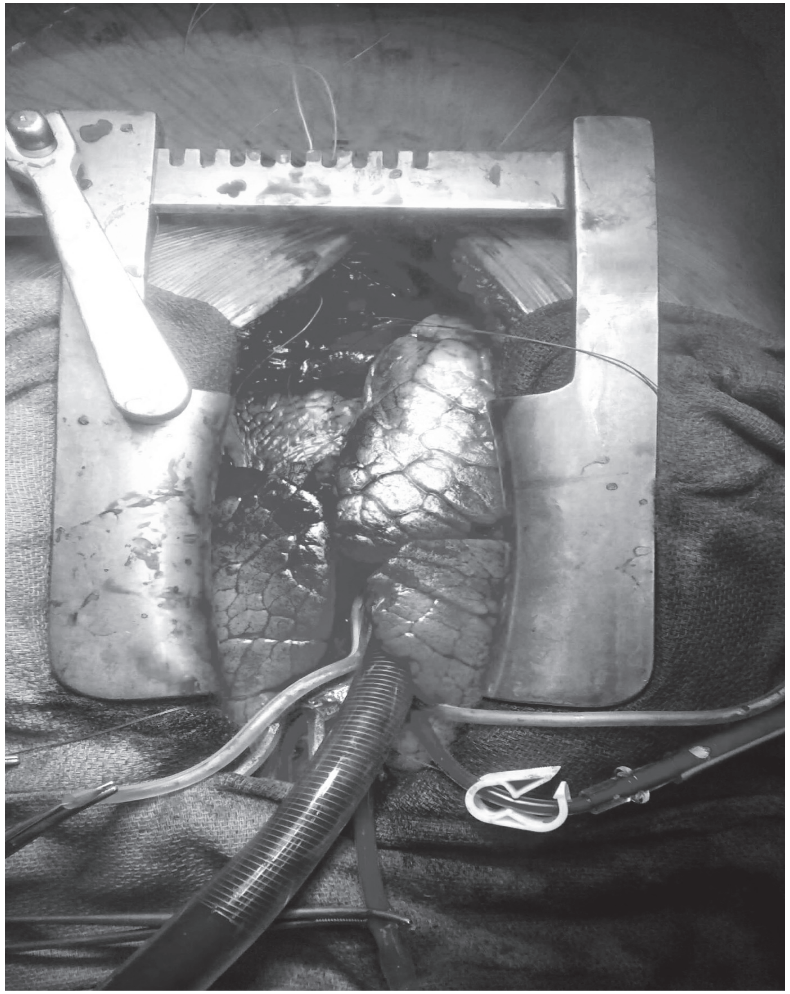


Fig 2. Serial changes in alveolar-arterial oxygen gradient (AaO2) (mean ± standard error) at various time points. (p < 0.001 versus preoperative value.)*

Reis Miranda *et al*, Crit Care Med, 2005
Taggart *et al*, Ann Thorac Surg, 1993

STRATEGIE VENTILATOIRE PER CEC
Considérations chirurgicales

« Traditionnellement » la ventilation est interrompue lors de la CEC.



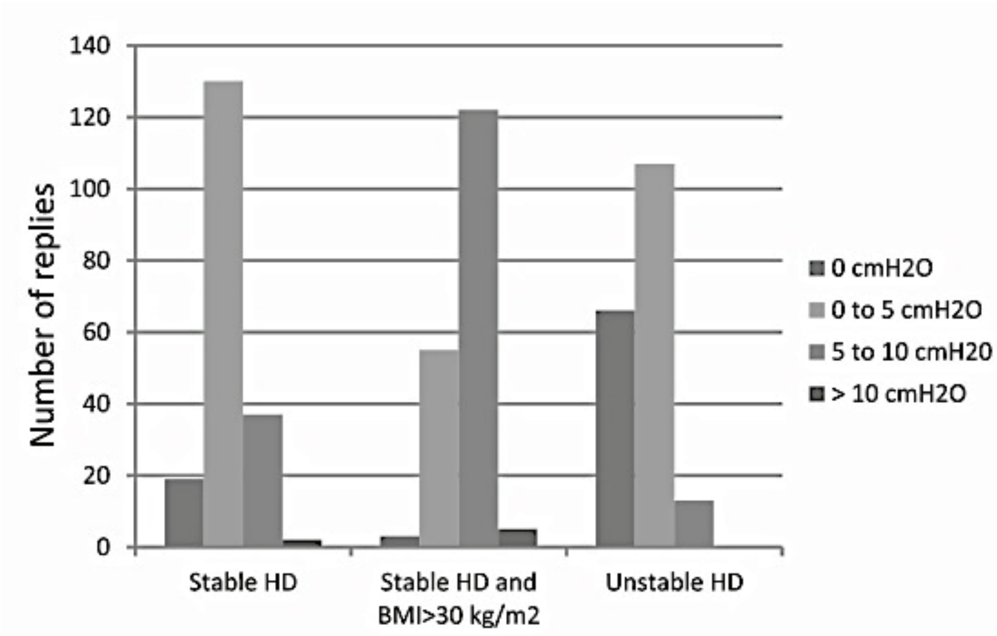
- Hématose assurée par l'oxygénateur extra corporel.
- Visibilité et réalisation technique du geste chirurgical gênées par:
- Mouvements pulmonaires.
- PEEP.
- Retour veineux pulmonaire dans le champ opératoire.
- Chirurgie mitrale, anastomose coronaire.
- Relative bonne tolérance respiratoire dans les CEC courtes.

Perioperative Ventilatory Management in Cardiac Surgery

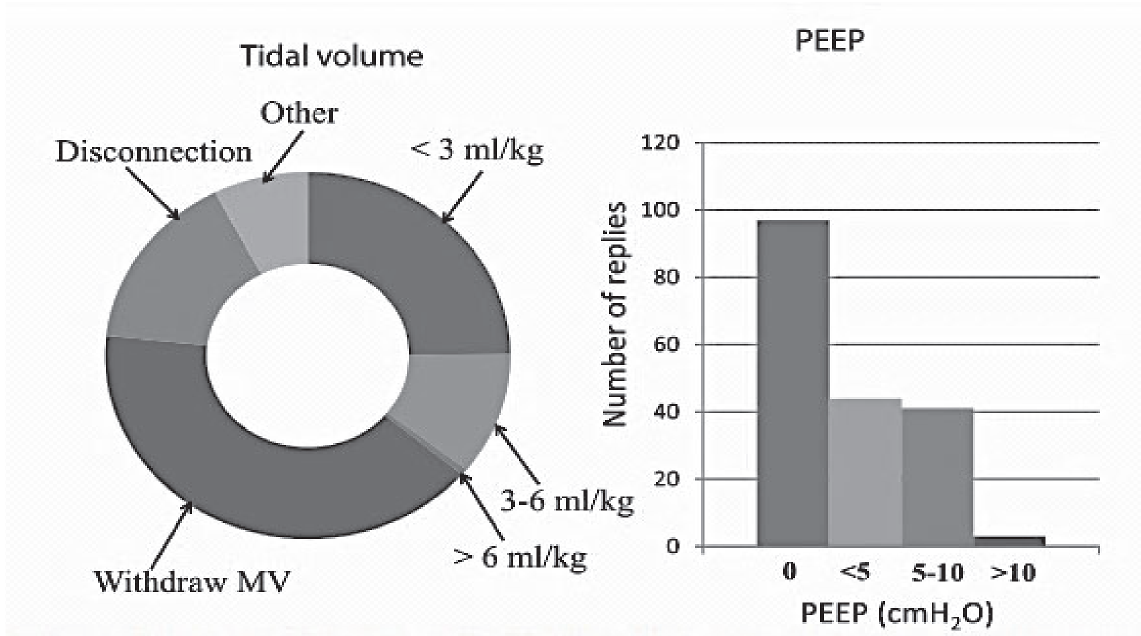
A French Nationwide Survey

n = 186 MAR

PRE AND POST CPB



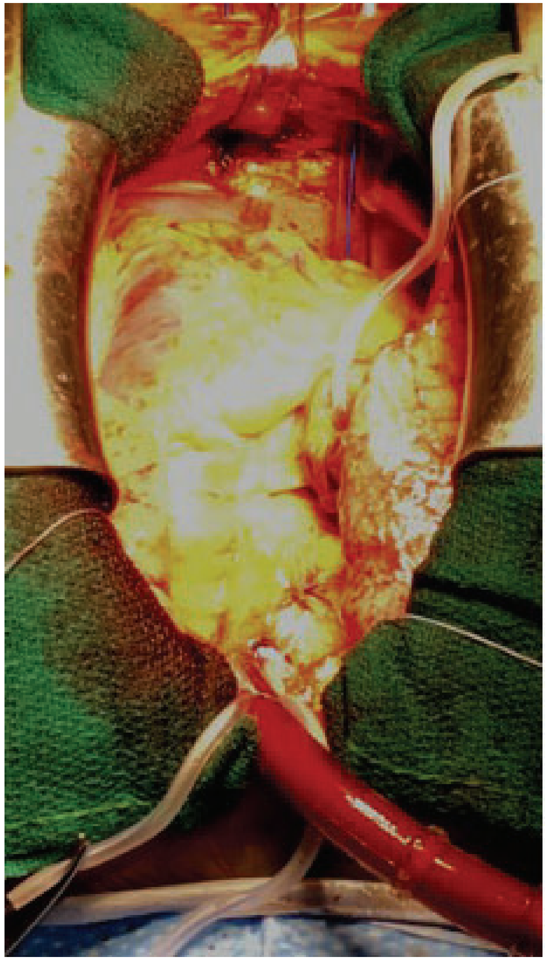
DURING CPB



Fischer *et al*, Medicine, 2016

A SURGICAL ISSUE ?

PEEP 2 cmH_2O



PEEP 8 cmH_2O

QUESTION N°1

Bénéfice du maintien d'une ventilation per CEC ?

CPAP ou Ventilation Ultra-Protectrice ?

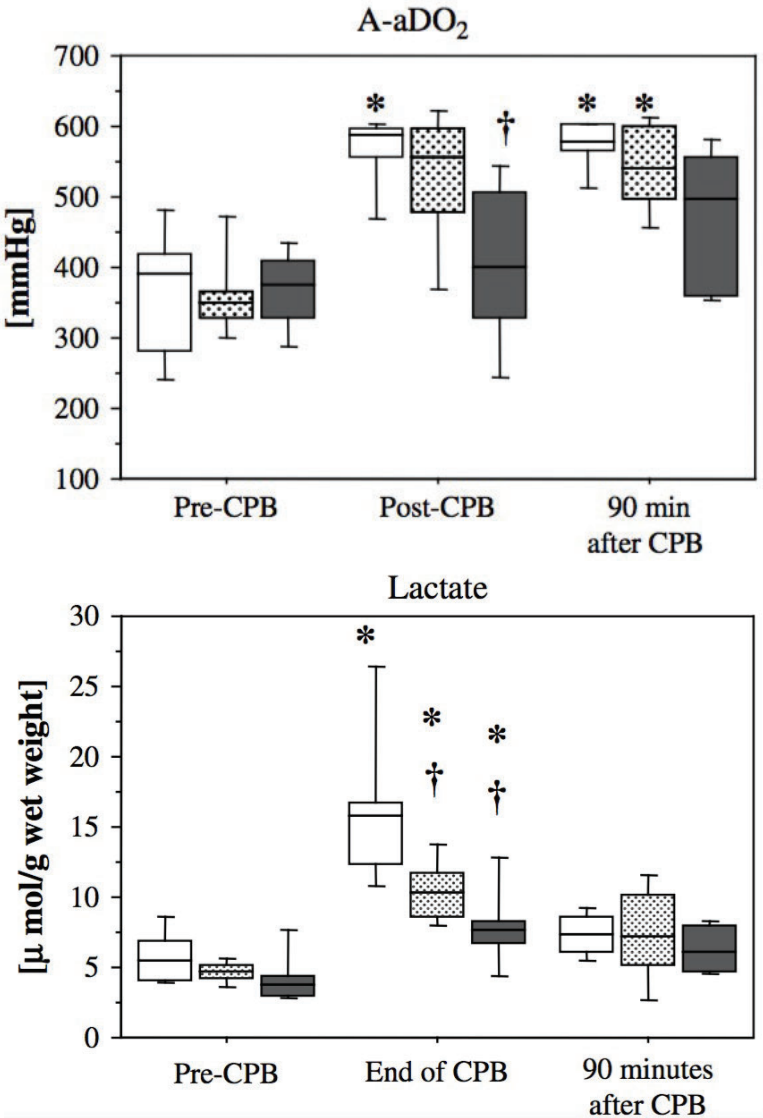
- *n* = 18 cochons.
- 3 groupes per CEC :

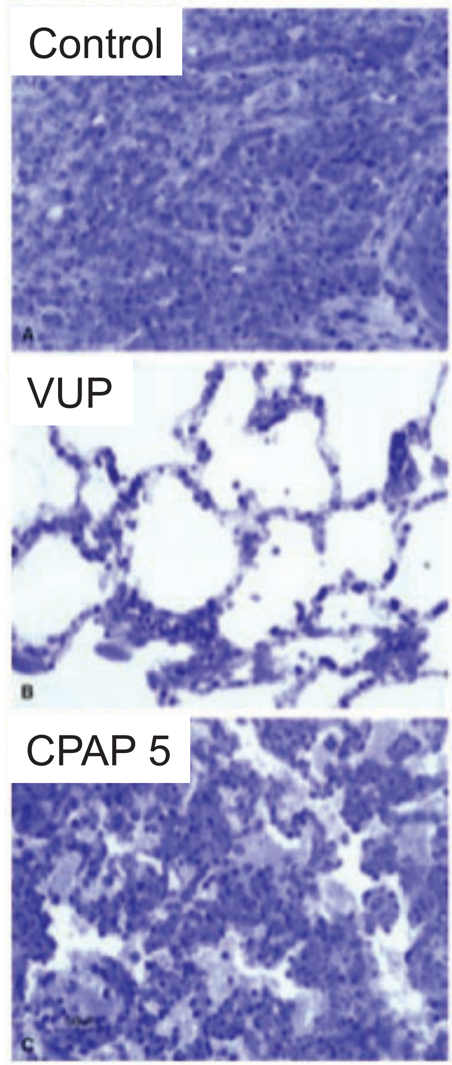
Control : no ventilation.

CPAP : 5cmH2O, FiO2 21%.

VUP : VT ?, FR 5 cpm, FiO2 21%. (PEP ?)

- GDS.
- LBA.
- Biopsies pulmonaires.



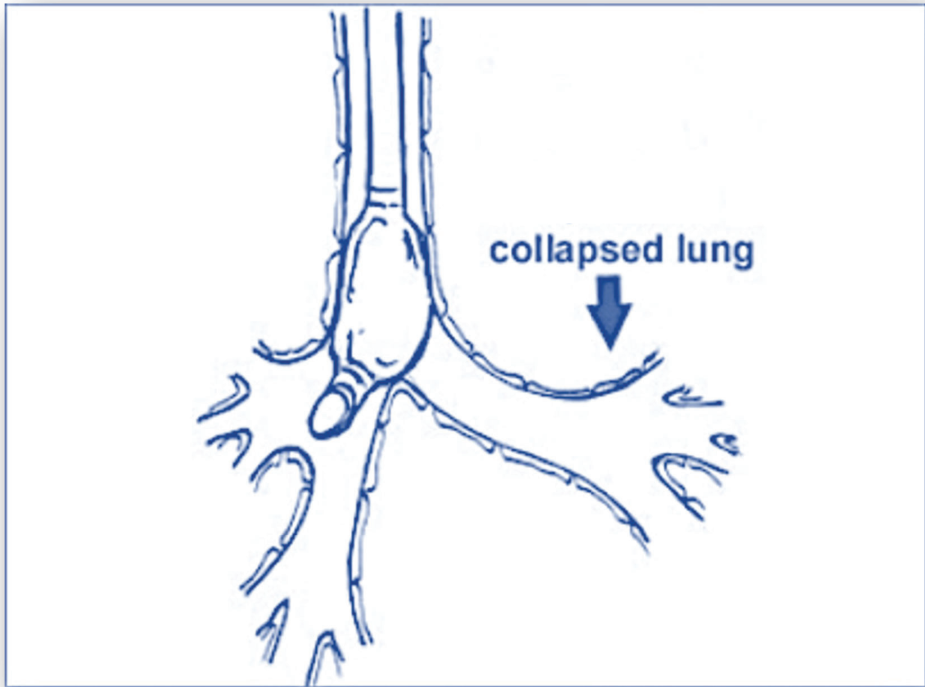


Imura *et al*, JTCVS, 2009

Effects of ventilation and nonventilation on pulmonary venous blood gases and markers of lung hypoxia in humans undergoing total cardiopulmonary bypass

Loer, Stephan A. MD; Kalweit, Gerhard MD; Tarnow, Jörg MD, FRCA

- *n* = 12 CABG.
- Durée de CEC : environ 60 min.
- Ventilation uni-pulmonaire per CEC : 150 mL x 6 avec FiO2 60%.
- Comparaison des prélèvements veineux pulmonaires droite et gauche.
- **Poumon ventilé : PaO2 augmentée, TXB2 diminuée.**
- **Pas de différence sur lactates et LDH.**



Critical Care Med, 2000

Ventilation During Cardiopulmonary Bypass: Impact on Cytokine Response and Cardiopulmonary Function

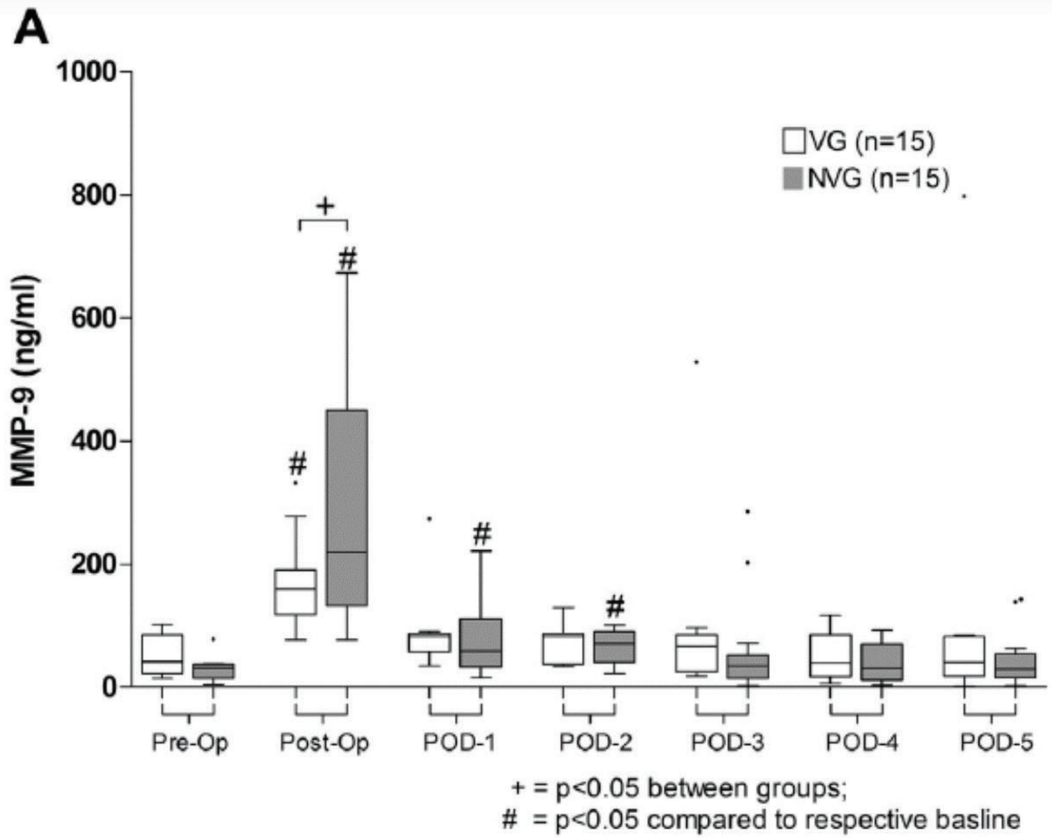
- *n* = 50 patients.
- Pré et post CEC : Vt 5 – 7 ml/kg, FiO2 50%, PEP ?
- Per CEC : Vt 5 ml / kg x 5, FiO2 50%, PEP ?
- LBA : pas de différence significative.

Table 3. Blood Levels of Proinflammatory Mediators in Continuous Ventilation (V) and Nonventilation (NV) Patients During Cardiopulmonary Bypass

Blood	Preoperative[a]	1 Hour Postdeclamping[a]	*p* Value 1 Hour Compared With Preoperative	4 Hours Postdeclamping[a]	*p* Value 4 Hours Compared With Preoperative	6 Hours Postdeclamping[a]	*p* Value 6 Hours Compared With Preoperative
IL-8 (pg/mL)							
NV	34 ± 15	71 ± 99	0.02	137 ± 219	0.0001	75 ± 77	0.01
V	26 ± 20	44 ± 50	0.2	69 ± 58	0.003	59 ± 45	0.005
p value between groups (intergroup differences)	0.4	0.2	/	0.04	/	0.2	/
IL-10 (pg/mL)							
NV	4 ± 1	128 ± 67	0.0001	56 ± 29	0.0001	32 ± 24	0.0001
V	4 ± 2	161 ± 118	0.0001	68 ± 52	0.0001	52 ± 26	0.0001
p value between groups (intergroup differences)	0.9	0.6	/	0.6	/	0.04	/
Dynamic compliance (mL/cm H_2O)							
NV	77 ± 12	79 ± 12	0.5	62 ± 19	0.003	54 ± 24	0.003
V	74 ± 14	77 ± 13	0.4	65 ± 24	0.2	77 ± 29	0.6
p value between groups (intergroup differences)	0.7	0.8	/	0.3	/	0.0008	/

Ng *et al*, Ann Thorac Surg, 2008

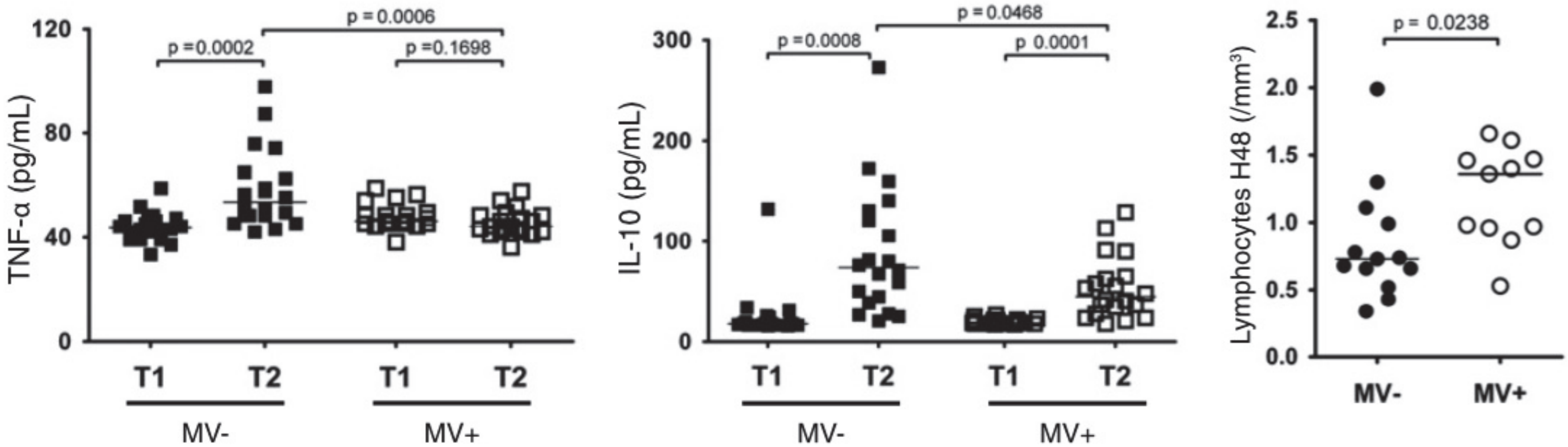
Intraoperative ventilation strategy during cardiopulmonary bypass attenuates the release of matrix metalloproteinases and improves oxygenation



Beer *et al*, J Surg Res, 2015

IMMUNE DYSFUNCTION AFTER CARDIAC SURGERY WITH CARDIOPULMONARY BYPASS: BENEFICIAL EFFECTS OF MAINTAINING MECHANICAL VENTILATION

- *n* = 50 patients.
- Pré et post CEC : Vt 8 ml/kg, PEP 5 cmH2O.
- Per CEC : Vt 2,5 ml / kg x 5, PEP 5 cmH2O, FiO2 50%.

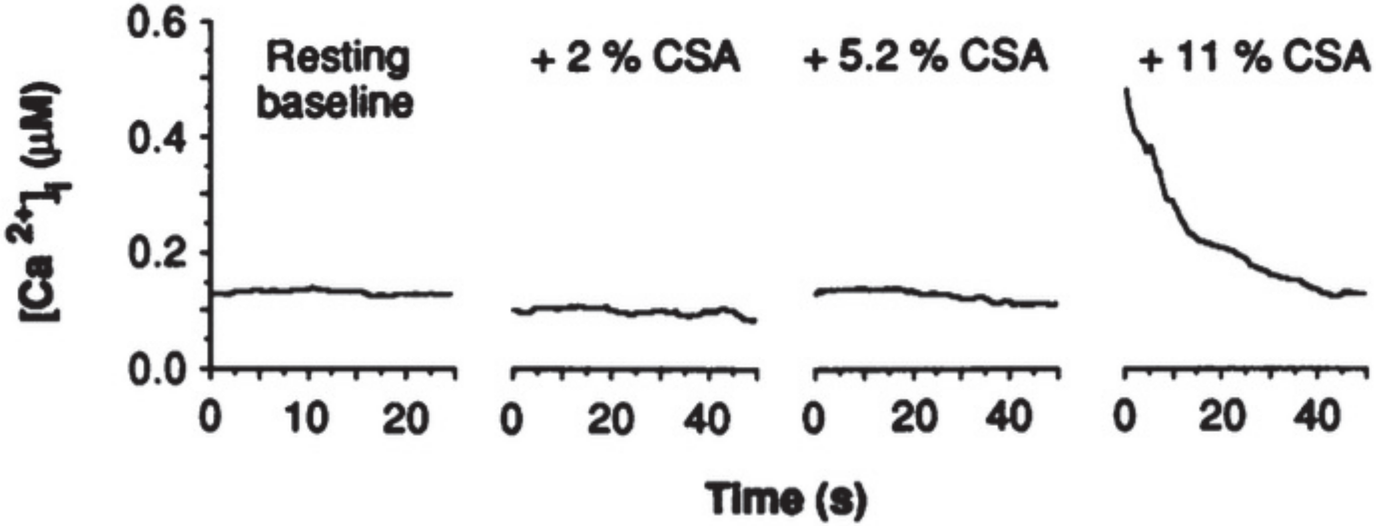


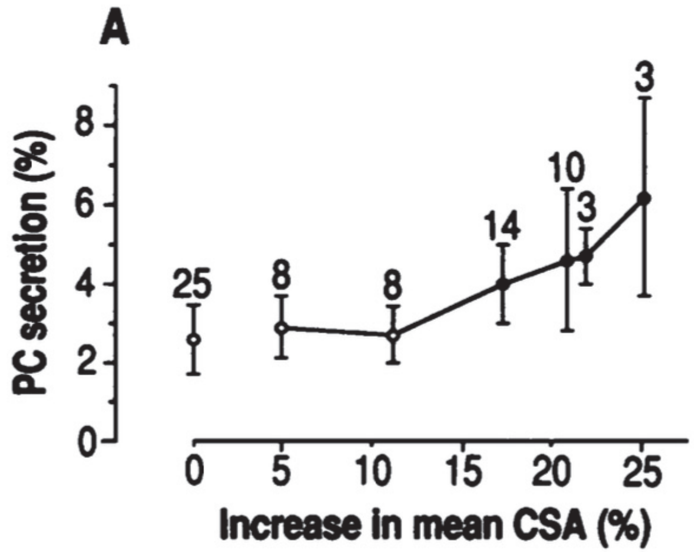
Gaudriot *et al*, Shock, 2015

Calcium Mobilization and Exocytosis After One Mechanical Stretch of Lung Epithelial Cells

HUBERT R. W. WIRTZ* AND LELAND G. DOBBS†

- Stretch stimuli de cellules pulmonaires de type II *in vitro*.
- CSA: 2D *Cell Surface Adhesion*.

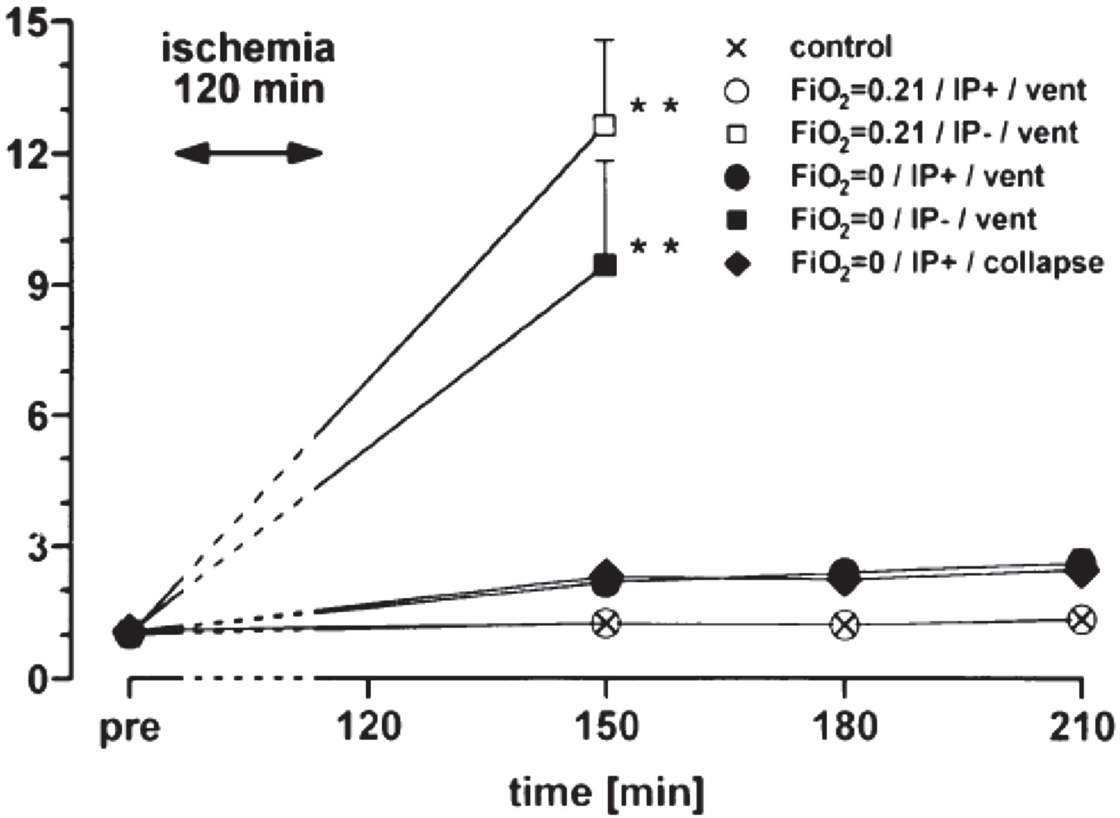




Stretch du pneumocyte de type 2: libération Ca2+ et sécrétion de surfactant

Science, 1990

EFFET PNEUMOPROTECTEUR DE LA VENTILATION ?



Poumon de lapin isolé = modèle d'ischémie pulmonaire.

- Rôle bénéfique du triple maintien :

- d'une distension vasculaire pulmonaire.
- d'une ventilation pulmonaire (vs CPAP).
- d'une oxygénation alvéolaire.

- **Bénéfice du maintien d'une ventilation en l'absence de perfusion ?**

- IP: Intravascular Pressure.
- Kfc : Coefficient de filtration capillaire.

Schütte *et al*, AJRCCM, 1998

Tumor necrosis factor-α in ischemia and reperfusion injury in rat lungs

PAVEL L. KHIMENKO,[1] G. J. BAGBY,[2] J. FUSELER,[3] AND AUBREY E. TAYLOR[1]

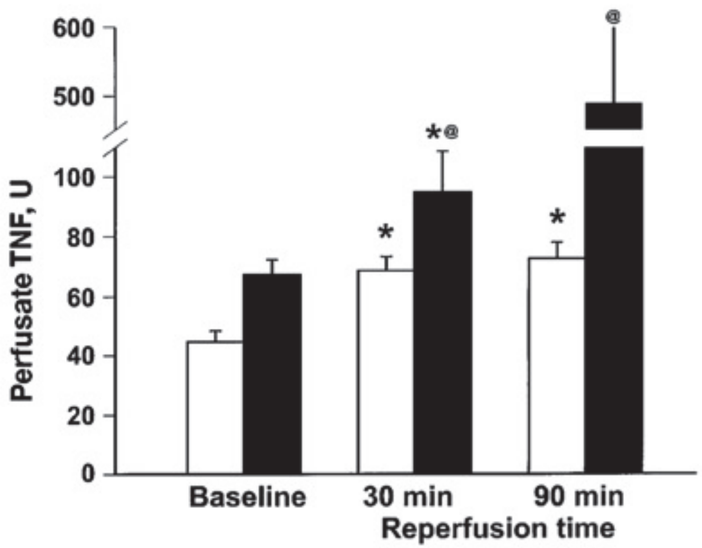


Fig. 2. Measurement of perfusate tumor necrosis factor-α (TNF) levels in I/R (open bars) and V̇/R (solid bars). Note that TNF-α significantly increased after 30 min of reperfusion in both groups compared with controls (* $P < 0.05$), and TNF-α levels were higher in the V̇/R group compared with I/R group (@ $P < 0.05$). TNF-α levels were greater in V̇/R than in I/R ischemic model after both 30 and 90 min (@ $P < 0.05$); however, in the I/R group, amount of TNF-α after 60 min of reperfusion did not increase above 30-min values.

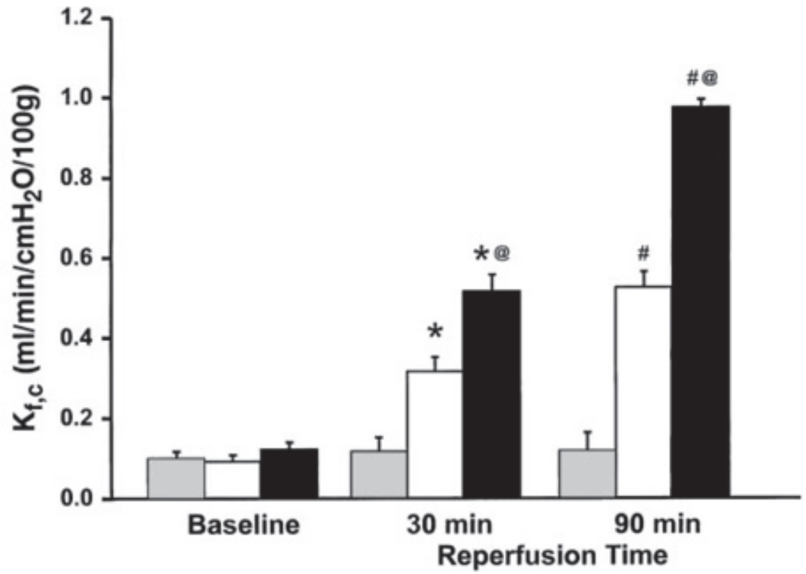


Fig. 1. Effect of nonventilated ischemia followed by reperfusion (I/R) and ventilation (open bars) and of ventilation with 21% O_2-5% CO_2-74% N_2 mixture during ischemia followed by reperfusion and continued ventilation (V̇/R; solid bars) on endothelial damage, as measured by filtration coefficient (K_{fc}). Note that after 30 min of reperfusion permeability was increased significantly in both types of ischemic injury (* $P < 0.05$) and damage in both ischemic models was exacerbated after an additional 60 min compared with 30 min of reperfusion (# $P < 0.05$). Also, V̇/R model produced more endothelial damage than I/R at 30 and 90 min after reperfusion (@ $P < 0.05$). Gray histograms represent time-matched control lungs not subjected to I/R or V̇/R.

JAP, 1998

Evaluation of effect of continuous positive airway pressure during cardiopulmonary bypass on cardiac de-airing after open heart surgery in randomized clinical trial

- RCT, *n* = 40 CEC.
- 2 groupes per CEC :
- CPAP 20 cmH2O.
- ZEEP.
- ETO en aveugle : temps de purge des cavités cardiaque.

Durations of LA air bubble occupation and de-airing process	CPAP group minute (mean±SD)	Control group minute (mean±SD)	*P* value
Duration of severe grade of LA air bubble occupation	1.4±2.25	5.4±4.87	0.003
Duration of moderate grade of LA air bubble occupation	1.8±1.53	5.2±4.18	0.002
Duration of mild grade of LA air bubble occupation	5.3±4.0	9.5±5.25	0.008
De-airing time after the start of mechanical ventilation	10.8±4.5	21.1±10.01	<0/0001
De-airing time after the start of cardiac ejection	4.6±3.3	12.6±8.0	<0/0001

- **Meilleure perfusion pulmonaire ?**
- **Diminution des complications micro-emboliques (delirium) ?**

Mansour *et al*, Adv Biomed Res, 2014

Low-tidal volume mechanical ventilation against no ventilation during cardiopulmonary bypass in heart surgery (MECANO): a randomized controlled trial

Authors : Lee S. Nguyen[1,2], MD, PhD; Philippe Estagnasie[1,2], MD; Messaouda Merzoug[2], PhD; Alain Brusset[1,2], MD; Jean-Dominique Law Koune[2,3], MD; Stephane Aubert[2,4], MD; Thierry Waldmann[2,4], MD; Cecile Naudin[2], PhD; Jean-Michel Grinda[2,4], MD; Hadrien Gibert[2,3], MD; and Pierre Squara[1,2], MD.

- RCT monocentrique.
- *n* = 1501
- Per CEC: V_T=3ml/kg x 5 , PEEP 5 vs. no ventilation
- Pre post CPB: V_T=6 mL/kg, PEEP of 5 cmH2O and RM in both groups.
- Primary outcome: composite of death, early respiratory failure (PaO2/FiO2 ratio <200 during the first day of ICU care), advanced respiratory support (non-invasive ventilation, mechanical ventilation, or high flow oxygen) at 2 days after arrival in the ICU, and/or hospital- or ventilator-acquired pneumonias.

Chest, 2020

Low-tidal volume mechanical ventilation against no ventilation during cardiopulmonary bypass in heart surgery (MECANO): a randomized controlled trial

Authors : Lee S. Nguyen[1,2], MD, PhD; Philippe Estagnasie[1,2], MD; Messaouda Merzoug[2], PhD; Alain Brusset[1,2], MD; Jean-Dominique Law Koune[2,3], MD; Stephane Aubert[2,4], MD; Thierry Waldmann[2,4], MD; Cecile Naudin[2], PhD; Jean-Michel Grinda[2,4], MD; Hadrien Gibert[2,3], MD; and Pierre Squara[1,2], MD.

	VENT group (n=756)	noV group (n=745)	OR or mean absolute differences (95% CI lower & upper bound)	p-value
Primary outcome				
Primary composite	112 (14.8%)	133 (17.9%)	0.80 (0.61 - 1.05)	0.11
Death	9 (1.2%)	13 (1.7%)	0.68 (0.29 - 1.60)	0.37
Early respiratory dysfunction	16 (2.1%)	23 (3.1%)	0.68 (0.36 - 1.30)	0.24
Respiratory support after day 2	44 (5.8%)	49 (6.6%)	0.88 (0.58 - 1.33)	0.54
Reintubation	32 (4.2%)	23 (3.1%)	1.39 (0.80 - 2.39)	0.24
Pneumonia	81 (10.7%)	83 (11.1%)	0.96 (0.69 - 1.32)	0.79
Secondary outcomes				
Surgical revision	28 (3.7%)	23 (3.1%)	1.21 (0.69 - 2.12)	0.51
Pneumothorax	18 (2.4%)	15 (2.0%)	1.19 (0.59 - 2.37)	0.63
Heart failure	28 (3.7%)	29 (3.9%)	0.95 (0.56 - 1.61)	0.85
Sepsis (other than pneumonia)	12 (1.6%)	12 (1.6%)	0.98 (0.44 - 2.20)	0.97
Ischemic event	27 (3.6%)	25 (3.4%)	1.07 (0.61 - 1.86)	0.82
Major hemorrhage	19 (2.5%)	14 (1.9%)	1.35 (0.67 - 2.71)	0.40
Cardiopulmonary bypass duration, mean (SD), min	80.0 ±31.8	77.8 ±26.3	2.17 (-0.79; 5.13)	0.15
Other outcomes				
Bleeding in the first 3 days, mean (SD), mL	940.9 ±615.0	968.0 ±605.1	-27.10 (-88.99; 34.79)	0.39
Red blood cells transfused, mean (SD), units	0.89 ±1.43	0.85 ±1.32	0.045 (-0.09; 0.18)	0.53
Average temperature in the first 3 days, mean (SD), °C	37.00 ±0.38	37.04 ±0.37	0.036 (-0.003; 0.756)	0.07
Fever in the first 3 days	17.0 (2.2%)	19 (2.6%)	0.88 (0.45 - 1.71)	0.70
Average leucocytes' count in the first 3 days, mean (SD), G/L	12839.0 ±3745.1	13057.6 ±3919.3	-218.60 (-610.65; 173.45)	0.27
Average P/F ratio in the first 3 days, mean (SD), mmHg	350.39 ±93.61	339.24 ±95.32	11.15 (-3.98; 26.29)	0.15

Abbreviations: SD : standard deviation ; P/F ratio : ratio of arterial oxygen partial pressure to fractional inspired oxygen.

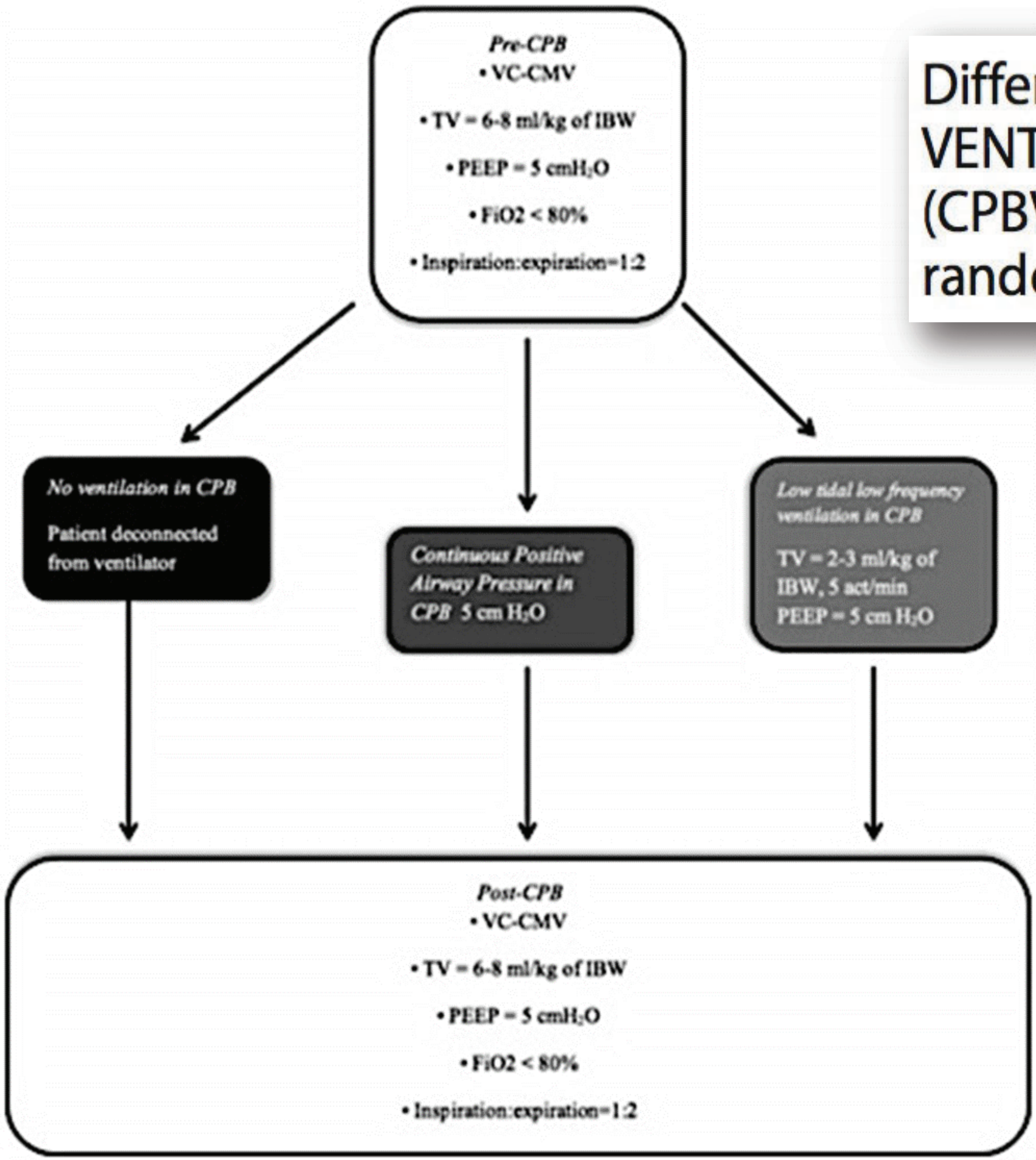
Chest, 2020

Low-tidal volume mechanical ventilation against no ventilation during cardiopulmonary bypass in heart surgery (MECANO): a randomized controlled trial

Authors : Lee S. Nguyen[1,2], MD, PhD; Philippe Estagnasie[1,2], MD; Messaouda Merzoug[2], PhD; Alain Brusset[1,2], MD; Jean-Dominique Law Koune[2,3], MD; Stephane Aubert[2,4], MD; Thierry Waldmann[2,4], MD; Cecile Naudin[2], PhD; Jean-Michel Grinda[2,4], MD; Hadrien Gibert[2,3], MD; and Pierre Squara[1,2], MD.

	OR	lower CI	upper CI	p-value	p for interaction
Overall population	0.80	0.61	1.05	0.11	-
Isolated CABG procedures	0.56	0.37	0.84	0.005	0.015
Combined CABG procedures	1.12	0.76	1.64	0.57	

Chest, 2020



Different strategies for mechanical VENTilation during CardioPulmonary Bypass (CPBVENT 2014): study protocol for a randomized controlled trial

- Primary endpoint : PaO2 / FiO2 < 200 jusqu'à la sortie de réanimation.
- Single-blind.
- 1 MR en fin de CEC.
- Pas de déviation de protocole ?
- NSN : 870 patients.
- NCT02090205.

Bignami *et al*, Trials, 2017

Maintaining Mechanical Ventilation During Cardiopulmonary Bypass for Cardiac Surgery (VECAR)

Sponsor:
Rennes University Hospital
Information provided by (Responsible Party):
Rennes University Hospital

ClinicalTrials.gov Identifier: NCT03372174

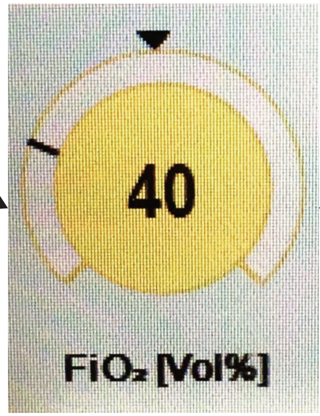
Recruitment Status : Recruiting
First Posted : December 13, 2017
Last Update Posted : March 20, 2018
See **Contacts and Locations**

QUELLE FiO2 EN PER CEC ?
Approche théorique

Oxygénation pulmonaire par diffusion directe de l’oxygène intra-alvéolaire.

Toxicité de l’O_2 : stress oxydatif, atélectasie par dénitrogénation, effet délétère de l’hyperoxie.

?



O_2 radicals mediate reperfusion lung injury in ischemic O_2-ventilated canine pulmonary lobe

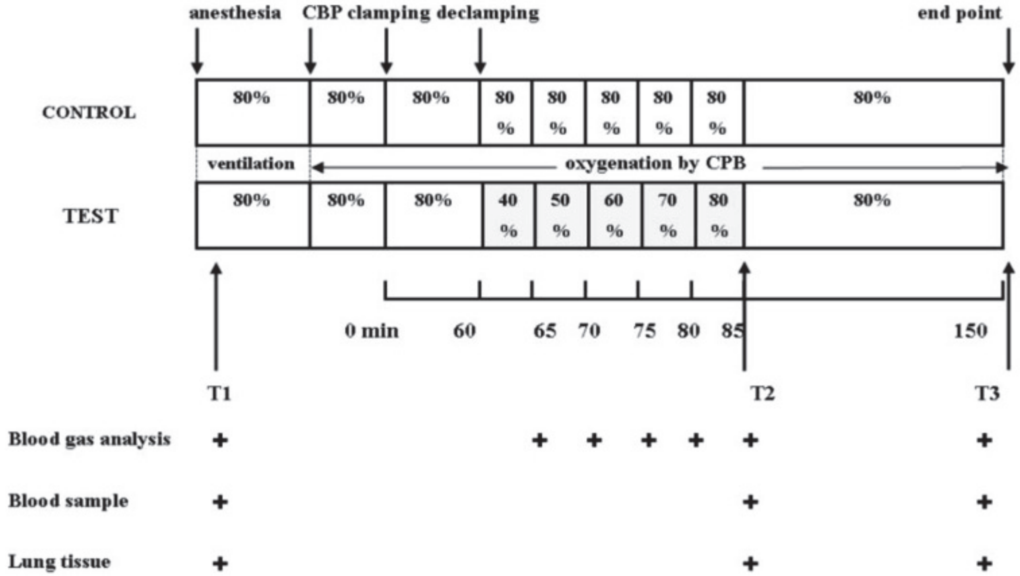
ISAMU KOYAMA, THOMAS J. K. TOUNG, MARK C. ROGERS,
GAIL H. GURTNER, AND RICHARD J. TRAYSTMAN

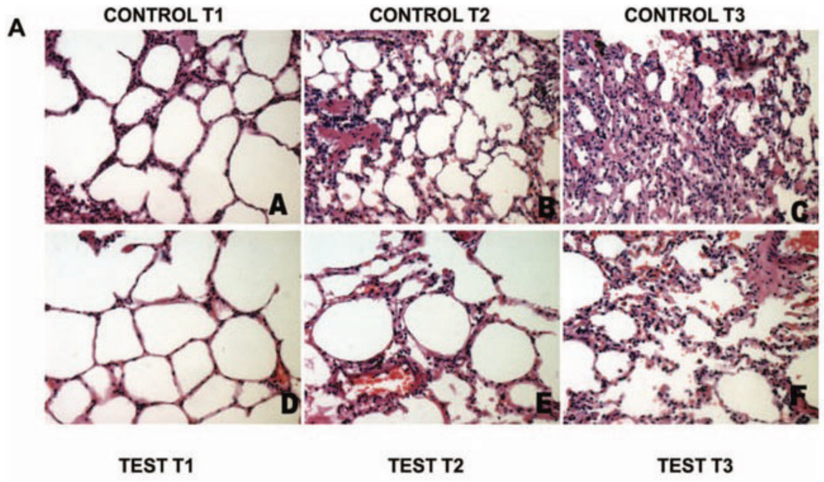
	Time after Reperfusion, h	*Group 1* 100% O_2	*Group 2* Room Air (20% O_2)	*Group 3* 100% N_2	*Group 4* SOD + 100% O_2	*Group 5* SOD + Room Air (20% O_2)
Pulmonary lobe wt, % change	0	0	0	0	0	0
	1	47±17	45±24	14±9*	18±7	18±10
	2	84±23	79±23	25±17*	27±8*	25±11*
	3	129±36	139±77	39±21*	37±9†	35±15†
	4	228±125	215±120	48±23*	52±8†	48±24†

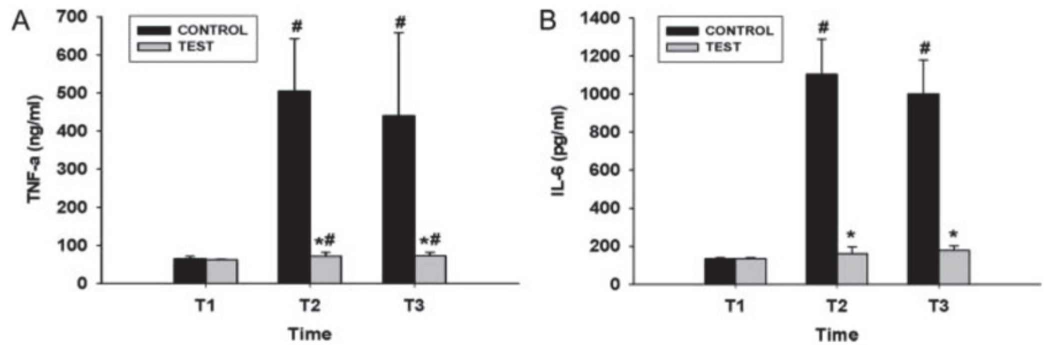
JAP, 1987

Controlled oxygen reperfusion protects the lung against early ischemia-reperfusion injury in cardiopulmonary bypasses by downregulating high mobility group box 1

Jian Rong,[1,§] Sheng Ye,[2] Zhong-Kai Wu,[3] Guang-Xian Chen,[3,§] Meng-Ya Liang,[3] Hai Liu,[3]
Jin-Xin Zhang,[4] and Wei-Ming Huang[1]



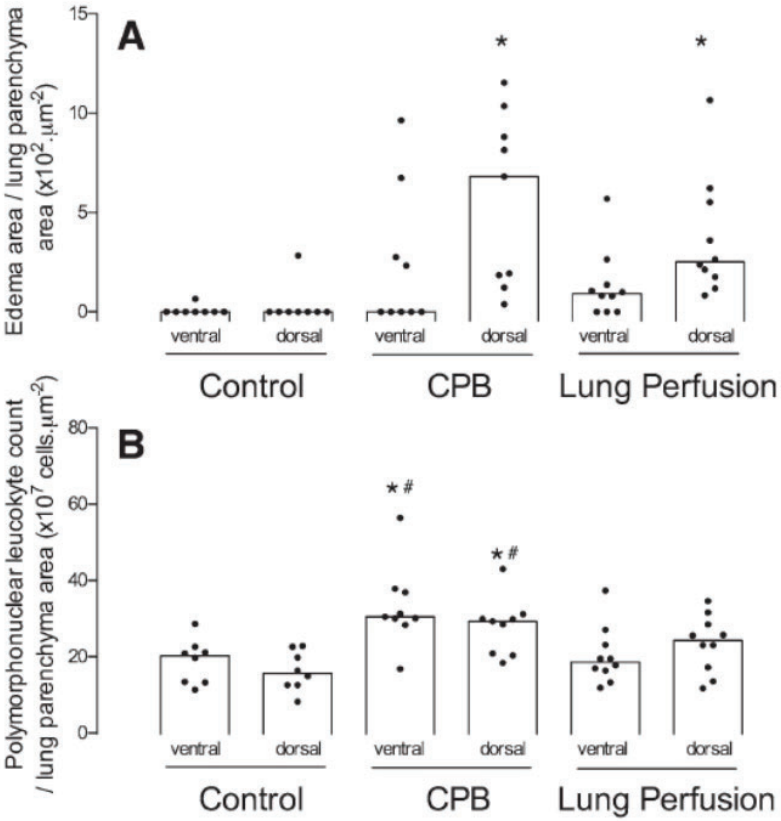


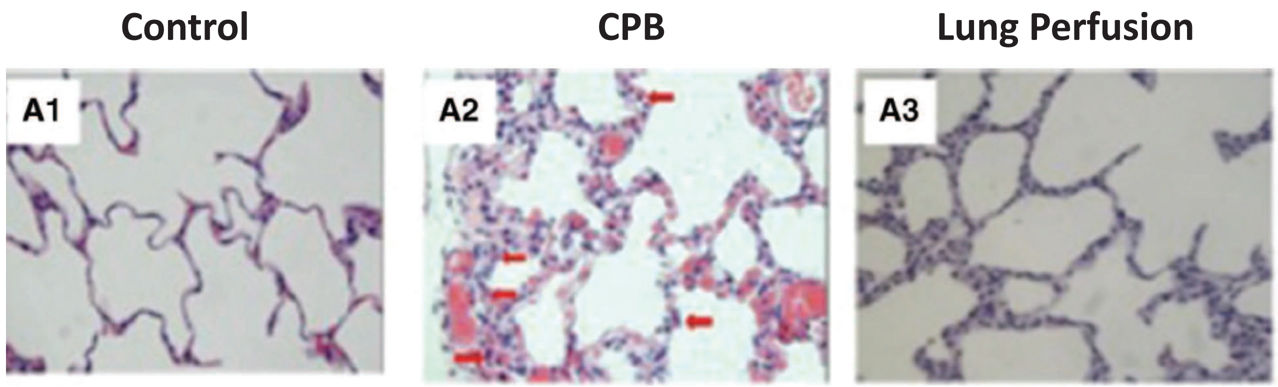


Exp Lung Res, 2012

Lung Perfusion and Ventilation During Cardiopulmonary Bypass Reduces Early Structural Damage to Pulmonary Parenchyma

Claudia Regina da Costa Freitas, MD, PhD,* Luiz Marcelo Sa Malbouisson, MD, PhD,*
Anderson Benicio, MD, PhD,† Elnara Marcia Negri, MD, PhD,‡ Filipe Minussi Bini, MD,*
Cristina Oliveira Massoco, DVM, PhD,§ Denise Aya Otsuki, PhD,* Marcos Francisco Vidal Melo, MD, PhD,||
and Maria Jose Carvalho Carmona, MD, PhD*





Anesth Analg, 2016

BJA

British Journal of Anaesthesia, xxx (xxx): xxx (xxxx)

doi: 10.1016/j.bja.2025.01.015
Advance Access Publication Date: xxx
Special Article

SPECIAL ARTICLE

2024 EACTS/EACTAIC/EBCP Guidelines on cardiopulmonary bypass in adult cardiac surgery

Recommendation Table 31 Recommendation for lung ventilation techniques during cardiopulmonary bypass

Recommendation	Class [a]	Level [b]	Ref [c]
The continuation of ventilation or CPAP during aortic cross-clamp is not recommended.	III	A	399,401,406

QUESTION N°2

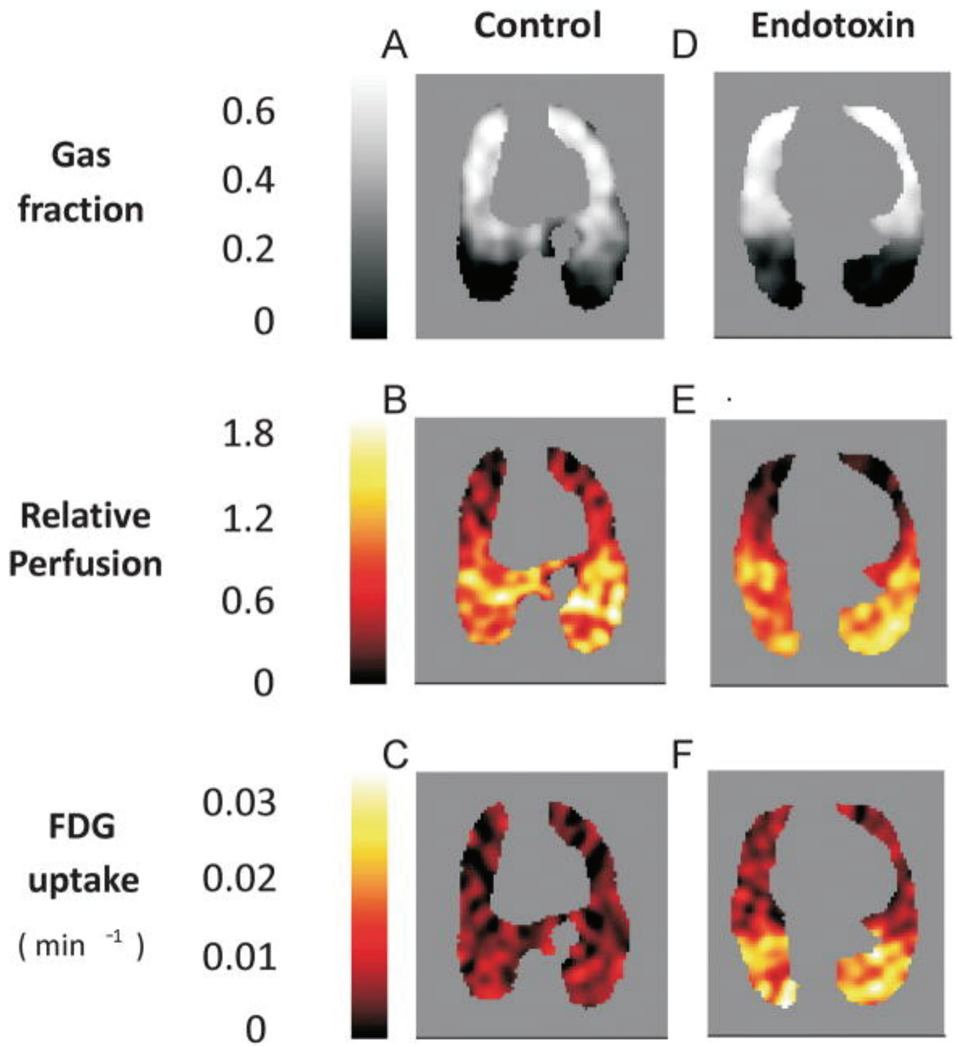
Quelle ventilation avant et après la CEC ?

Déterminants de la lésion induite par la ventilation mécanique

Rôle du stress chirurgical : *2-hit lung injury*

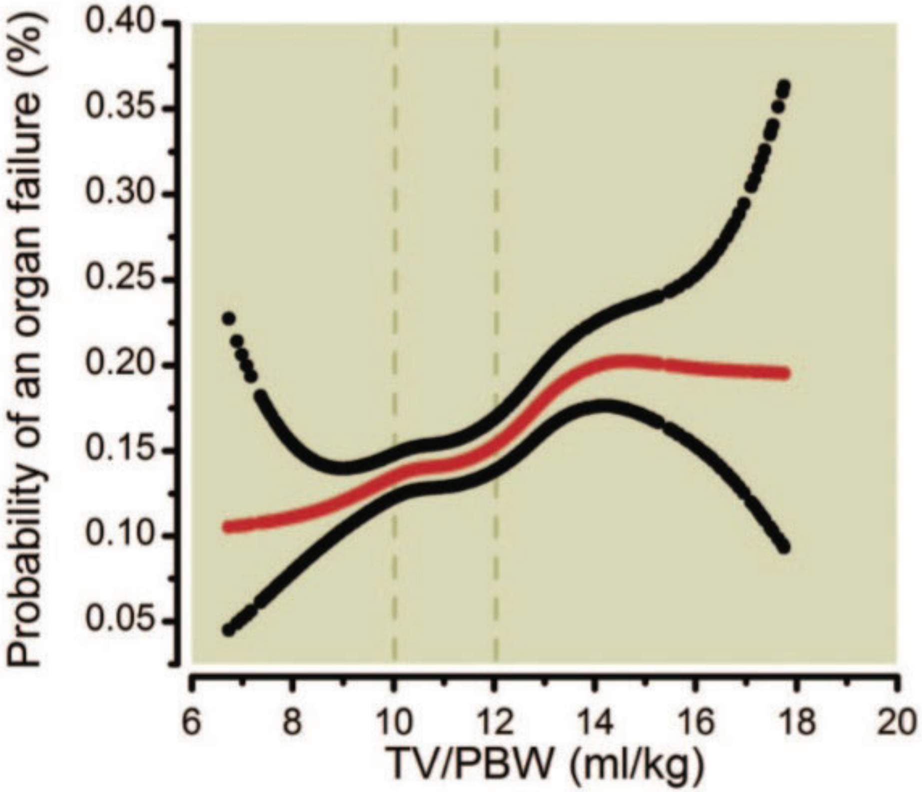
Sheep model of lung injury

- PEEP = 0cmH_2O
- Driving pressure = 30cmH_2O
- For 2 hours
- +/- endotoxemia



Costa *et al*, Anesthesiology, 2010

High Tidal Volumes in Mechanically Ventilated Patients Increase Organ Dysfunction after Cardiac Surgery



Avoid TV > 10 mL / kg

n = 3434

Lellouche *et al*, Anesthesiology, 2012

The New England Journal of Medicine

Volume 269 NOVEMBER 7, 1963 Number 19

IMPAIRED OXYGENATION IN SURGICAL PATIENTS DURING GENERAL ANESTHESIA WITH CONTROLLED VENTILATION*

A Concept of Atelectasis

H. H. Bendixen, M.D.,† J. Hedley-Whyte, M.B., B.Chir.,‡ and M. B. Laver, M.D.§

BOSTON

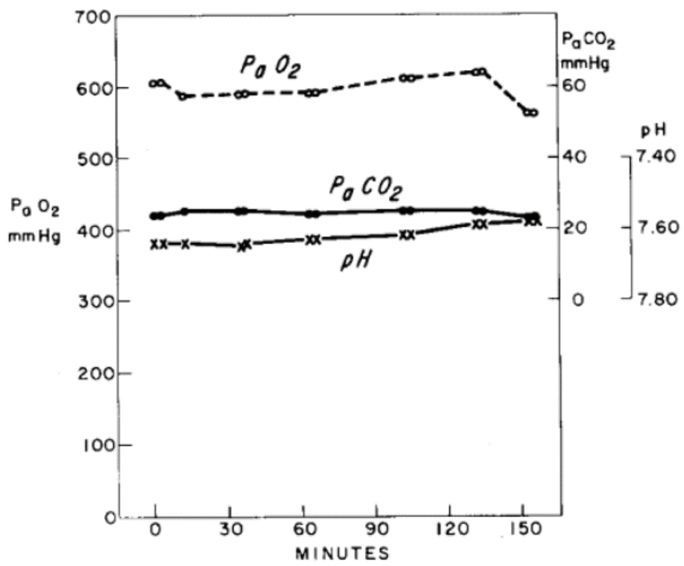


Figure 4. *Unchanged Oxygen Tension during Constant Ventilation with Large Tidal Volumes (Resulting in a Carbon Dioxide Tension of Only 23 Mm. of Mercury).*

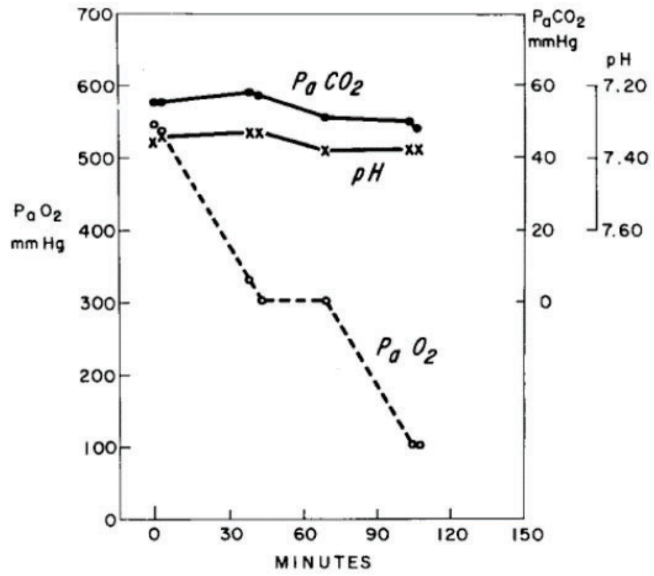


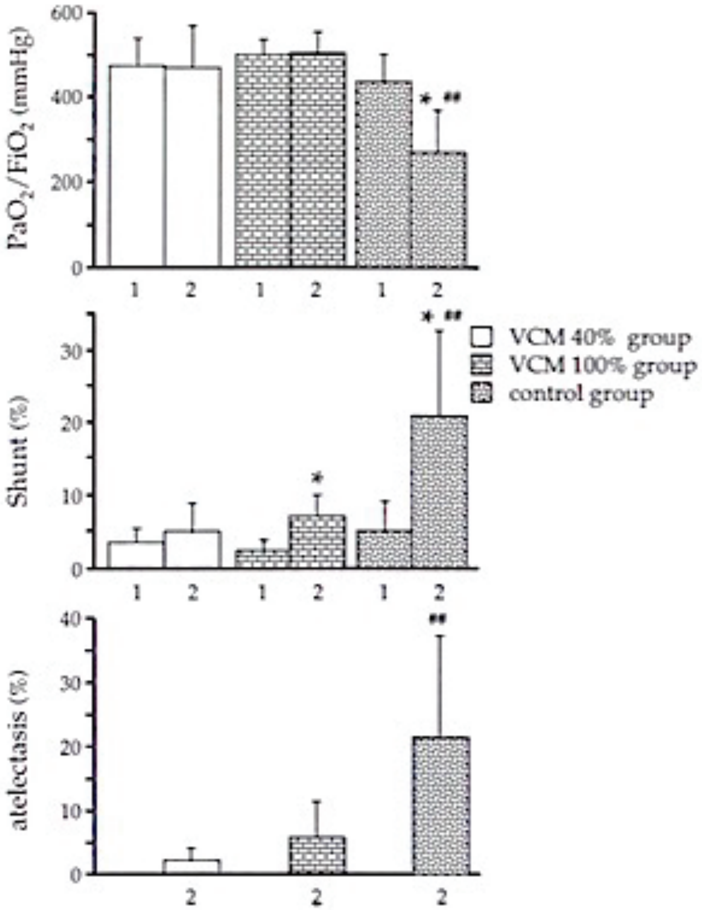
Figure 5. *Dramatic Fall in Oxygen Tension during Ventilation with Shallow Tidal Volumes (Maintaining Carbon Dioxide at Greater than Normal Tension).*

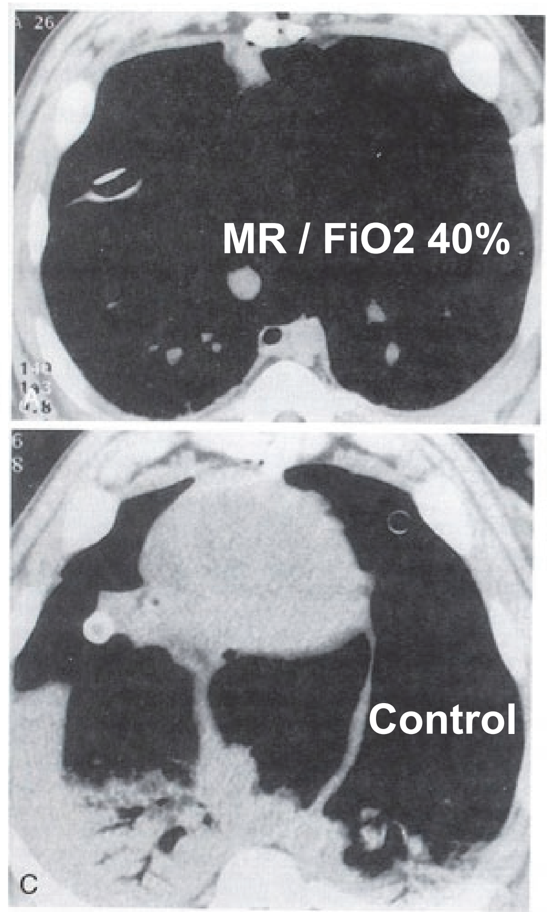
PREVENTION DU COLLAPSUS ALVEOLAIRE

Use of a Vital Capacity Maneuver to Prevent Atelectasis after Cardiopulmonary Bypass

An Experimental Study

- *n* = 18 cochons.
- Fin de CEC : 15 sec à 40 cmH2O.
- FiO2 40 % ou FiO2 100%.
- Mesure du shunt.
- Quantification TDM des atélectasies sous ventilation mécanique en fin de procédure.

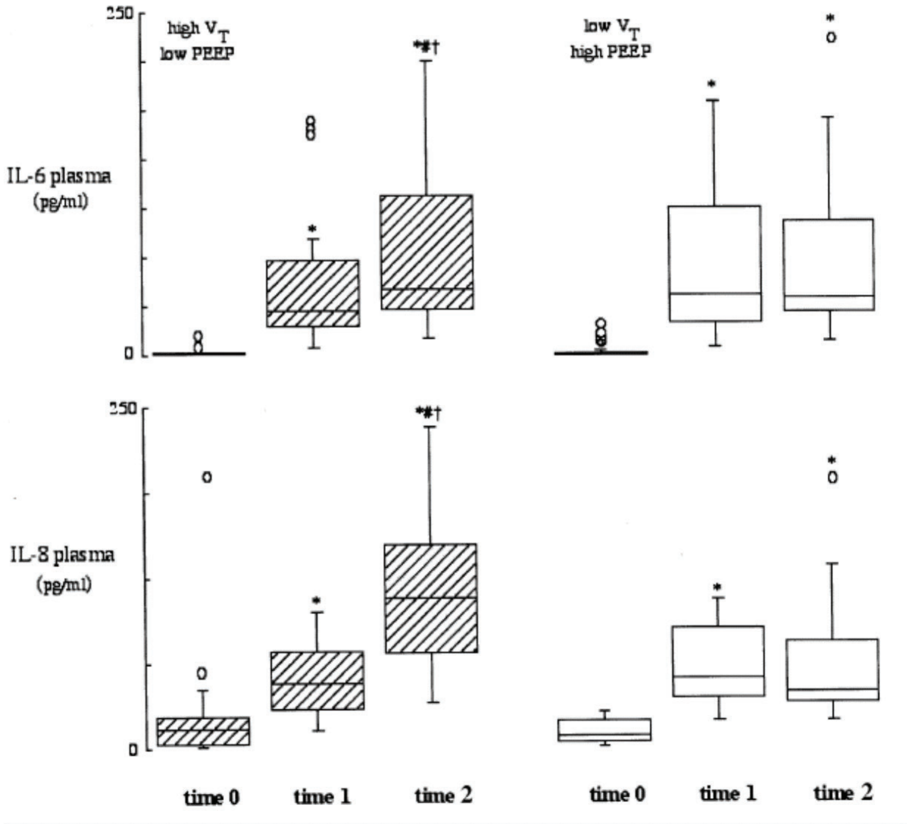




Magnusson *et al*, Anesthesiology, 1998

Mechanical ventilation affects inflammatory mediators in patients undergoing cardiopulmonary bypass for cardiac surgery: A randomized clinical trial

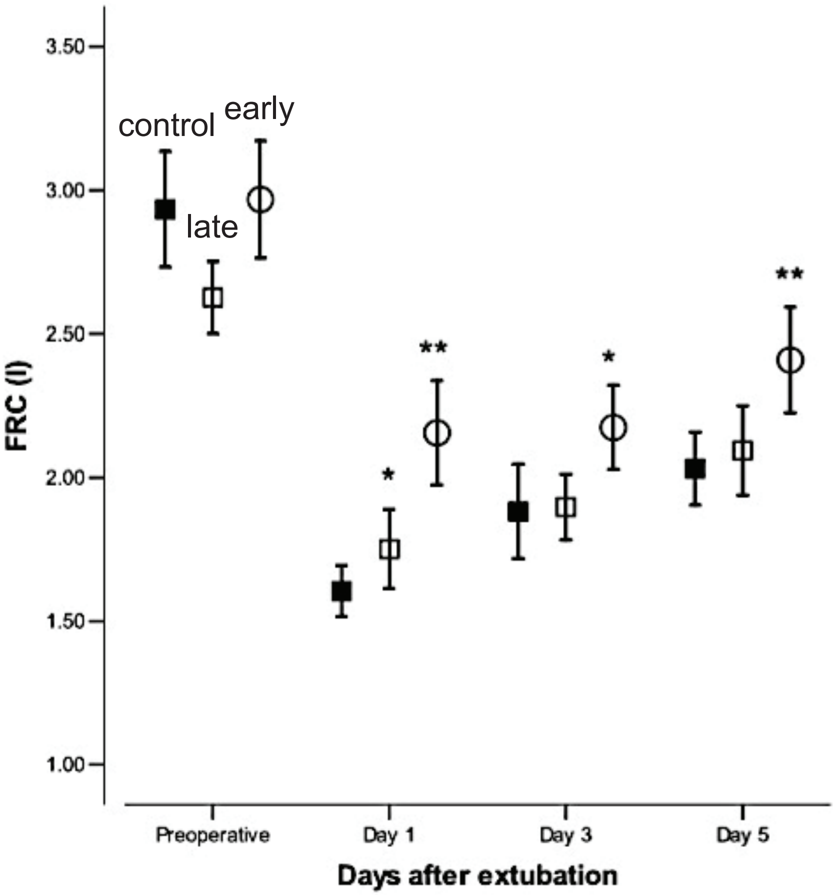
Enrico Zupancich, MD,[a]†‡ Domenico Paparella, MD,[b]*‡ Franco Turani, MD,[a,c] Christopher Munch, MD,[a] Alessandra Rossi, MD,[a] Simone Massaccesi, MD,[a] and V. Marco Ranieri, MD[b]

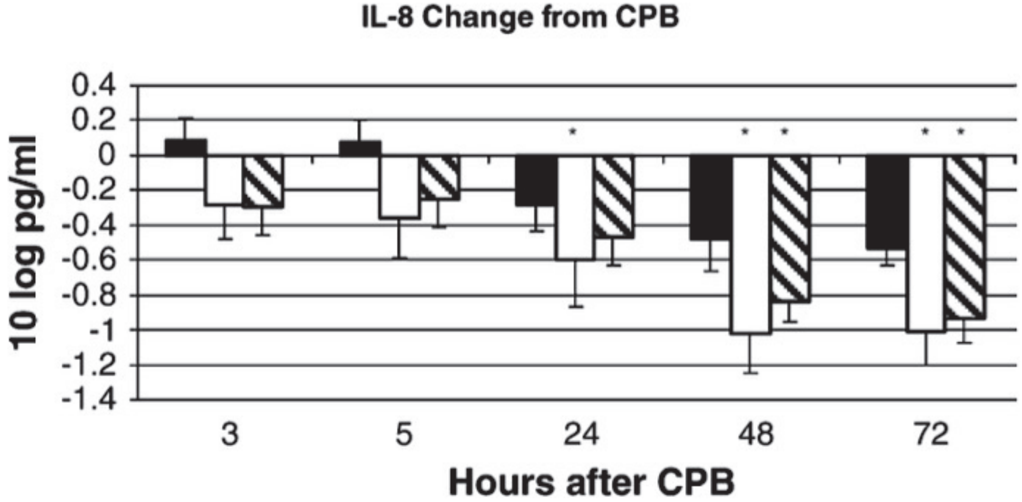


JTCVS, 2005

EARLY MULTIMODAL *OPEN-LUNG* VENTILATION

RECRUITMENT MANEUVERS + HIGHER PEEP + VENTILATION DURING CPB





Control: no RM, PEEP 5, CPAP during CPB 3 cmH2O.

Late open-lung: Control + RM and PEEP 10cmH2O started in the ICU.

Early open-lung: RM + PEEP 10 + UPV during CPB.

Reis Miranda *et al,* Crit Care Med, 2005

Reis Miranda *et al*, EJCTS, 2005

SEVEN-DAY PROFILE PUBLICATION

Effect of open-lung vs conventional perioperative ventilation strategies on postoperative pulmonary complications after on-pump cardiac surgery: the PROVECS randomized clinical trial

Lagier *et al*, Intensive Care Med, 2019

PROVECS
TRIAL

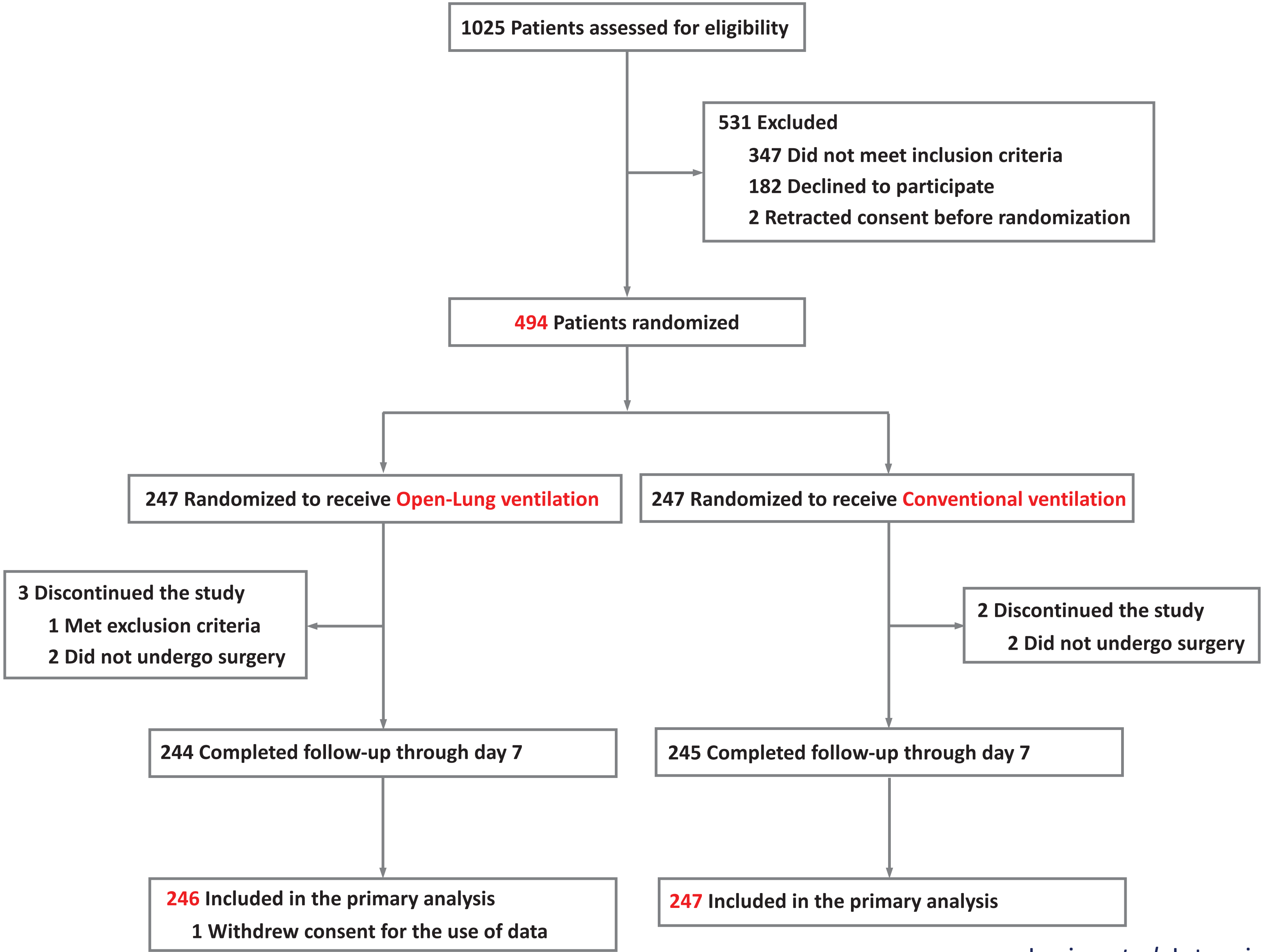
NCT 02866578
PHRCI-2015

PROVECS: PROtective VEntilation in Cardiac Surgery

Design: Pragmatic, multicenter, randomized, controlled clinical trial
Participants: Elective on-pump cardiac surgery with median sternotomy
Primary endpoint: Postoperative Pulmonary Complications at Day 7

	Open-Lung Strategy	Conventional Strategy
TV (ml/kg IBW)	6-8	6-8
PEEP (cmH_2O)	8	2
Recruitment Maneuvers	YES 30 cmH_2O / 30 sec x 4	NO
Per CPB	PEEP 8 cmH_2O, TV 3 ml/kg, RR 12, FiO2 40%	CPAP 2 cmH_2O FiO2 40%
ICU until H4-6	RM at arrival + PEEP 8 cmH_2O	No RM + PEEP 2 cmH_2O

Lagier *et al*, Intensive Care Med, 2019



Lagier *et al*, Intensive Care Med, 2019

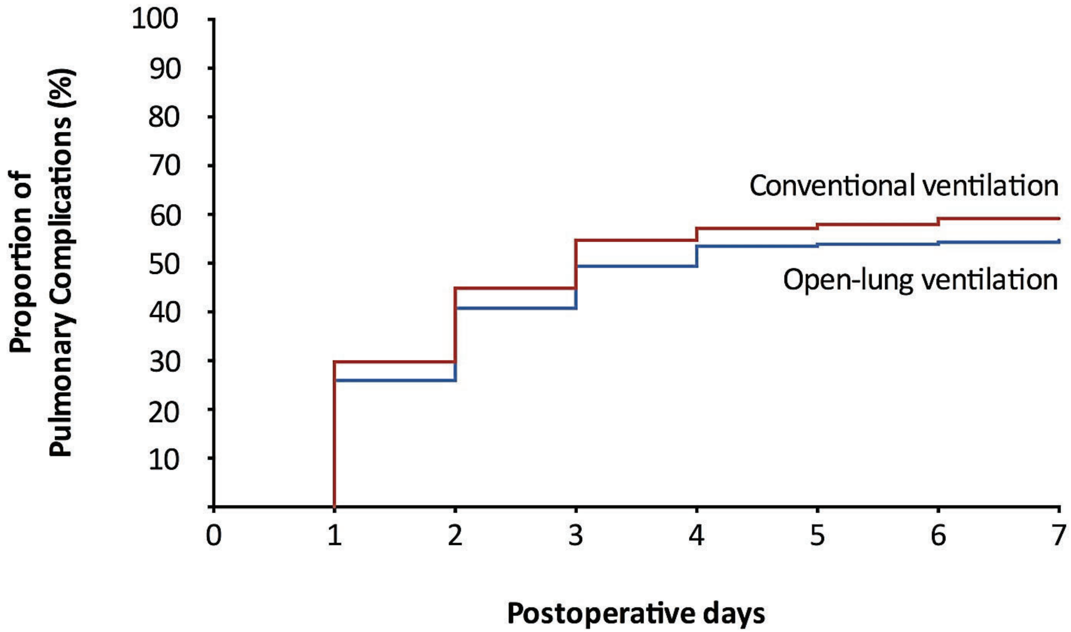
RESULTS: *Intraoperative*

	Conventional Ventilation (N=247)	Open-Lung Ventilation (N=246)	P value
Tidal volume – ml	460 (420 to 500)	450 (400 to 490)	-
Tidal volume – ml of PBW	7.0 (6.7 to 7.8)	6.9 (6.3 to 7.3)	-
Median level of PEEP (IQR) – cm of water			
Lowest	2 (2 to 2)	5 (2 to 8)	<0.001
Highest	2 (2 to 2)	8 (8 to 8)	<0.001
Mode	2 (2 to 2)	8 (5 to 8)	<0.001
Recruitment maneuver done – no./total no. (%)			<0.001
At least 1	19/245 (7.7)	236/243 (97.1)	
At least 2	0/245 (0)	235/243 (96.7)	
At least 3	0/245 (0)	221/243 (90.9)	
At least 4	0/245 (0)	210/243 (86.4)	
More than 4	1/245 (0.4)	166/243 (68.3)	
Intervention adjustment for arterial hypotension	0/245 (0)	43/243 (17.7)	<0.001
Intervention adjustment for surgical requirements	10/245 (4.1)	153/243 (63.0)	<0.001
Rescue for critical hypoxemia*	35/245 (14.3)	4/243 (1.6)	<0.001
CPB duration, median (IQR), min	84 (67 - 108)	90 (74 - 119)	0.05
Aortic cross clamp duration, median (IQR), min	64 (48 - 83)	68 (52 - 91)	0.12

* $SpO_2 < 92\%$ under FiO_2 0,8

RESULTS: *Primary End Point*

Absolute Difference (95% CI): –4.5% [–13.1% to 4.3%]; *P* = 0.32



No. at Risk

Conventional	245	172	135	111	105	103	100
Open-lung	243	180	144	123	113	112	111

log-rank (Mantel-Cox): P= 0.29

Lagier *et al*, Intensive Care Med, 2019

RESULTS

Postoperative Pulmonary Complications

End-point– no./total no. (%)	Conventional Ventilation (N=247)	Open-Lung Ventilation (N=246)	Absolute Difference (95%CI), %	P Value
PPC within 7 days				
Mild respiratory failure*	97/245 (39.6)	91/243 (37.4)	−2.2 [−10.7 to 6.4]	0.63
Moderate respiratory failure	26/245 (10.6)	18/243 (7.4)	−3.2 [−8.4 to 2.0]	0.22
Severe respiratory failure	13/245 (5.3)	16/243 (6.6)	1.2 [−3.2 to 5.6]	0.55
Fast-track extubation failure with hypoxemia	7/245 (2.9)	5/243 (2.1)	−0.8 [−4.0 to 2.2]	0.57
New invasive ventilation with hypoxemia	6/245 (2.4)	2/243 (0.8)	−1.6 [−4.5 to 0.9]	0.28
Bronchospasm	5/245 (2.0)	4/243 (1.6)	−0.4 [−3.2 to 2.4]	1.0
Severe tracheo-bronchial congestion	21/245 (8.6)	17/243 (7.0)	−1.6 [−6.5 to 3.3]	0.52
Respiratory acidosis	20/245 (8.2)	18/243 (7.4)	−0.8 [−5.7 to 4.1]	0.75
Pneumonia				
Suspected	12/245 (4.9)	15/243 (6.2)	1.3 [− 3.0 to 5.5]	0.54
Confirmed	2/245 (0.8)	1/243 (0.4)	−0.4 [2.5 to 1.6]	1.0
Pleural effusion with need for pleural drainage	2/245 (0.8)	1/243 (0.4)	− 0.4 [− 2.5 to 1.6]	1.0
Radiological atelectasis	30/245 (12.2)	20/243 (8.2)	− 4.0 [− 9.5 to 1.4]	0.14

* SpO2 < 90% or PaO2 < 60 mmHg after a 10-minute room air trial

Lagier *et al*, Intensive Care Med, 2019

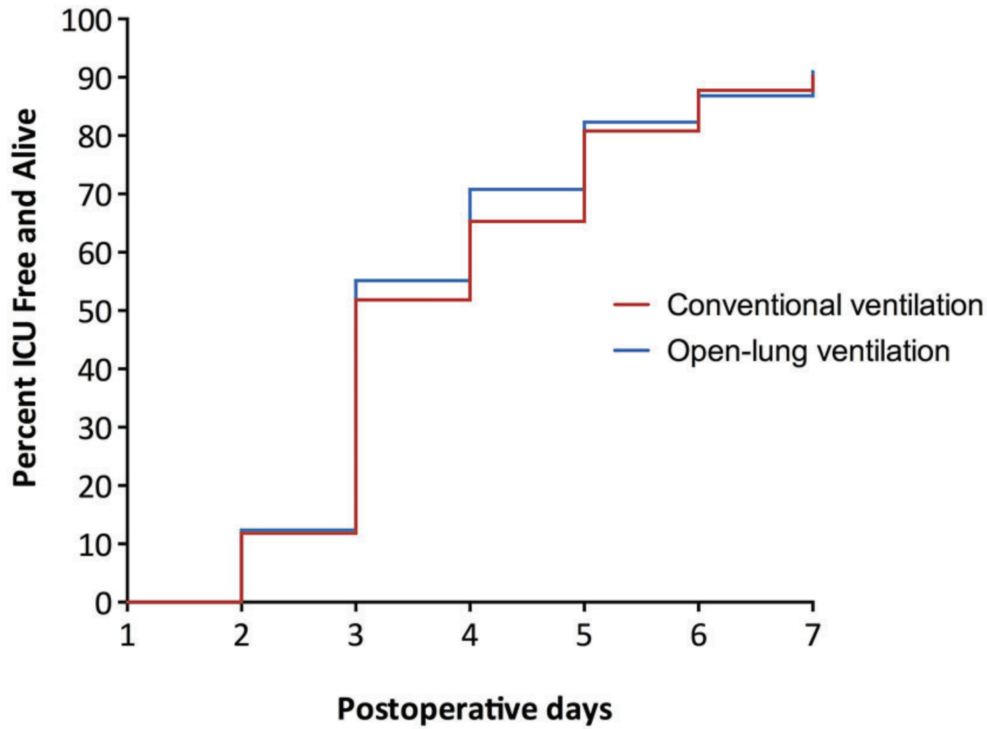
RESULTS
Ventilatory Support

End-point - no./total no. (%)	Conventional Ventilation (N=247)	Open-Lung Ventilation (N=246)	Absolute Difference (95%CI), %	P Value
Need for high-flow nasal oxygen therapy	23/245 (9.4)	21/243 (8.6)	−0.8 [−6.0 to 4.5]	0.77
Need for non-invasive ventilation	38/245 (15.5)	32/243 (13.2)	− 2.3 [− 8.6 to 3.9]	0.46
Need for new invasive mechanical ventilation	6/245 (0.8)	2/243 (2.4)	− 1.6 [− 4.5 to 0.8]	0.28

Lagier *et al*, Intensive Care Med, 2019

RESULTS: *ICU-free days at Day 7*

Median number of alive ICU-free days did not differ between groups (5 d *vs* 5 d, *P* = 0.51)



No. at Risk							
Conventional	245	245	216	118	85	47	30
Open-lung	243	243	213	109	71	43	32

Log-rank *P* =0.45

Lagier *et al*, Intensive Care Med, 2019

DISCUSSION PROVECS trial

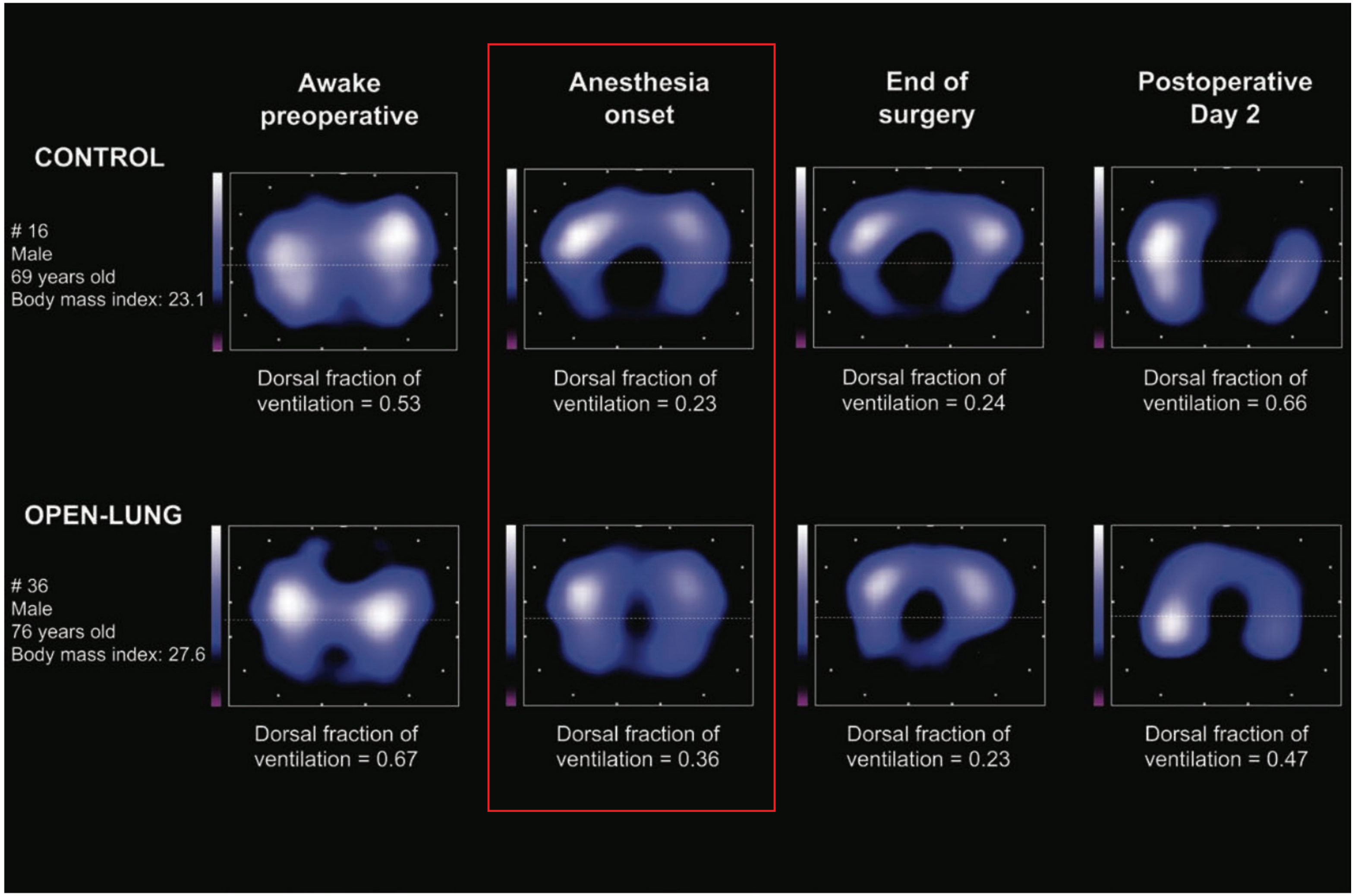
- **Elective** cardiac surgery.
- **Non-individualized** approach.
- **Sustainability** of alveolar recruitment after extubation ?
- Role of **atelectasis** in PPC.
- **Other etiologies** of PPC: pain, diaphragmatic dysfunction, fluid overload…
- Effect of **anterior chest opening** on recruitment performance and alveolar overdistension.

ANESTHESIOLOGY

Perioperative Open-lung Approach, Regional Ventilation, and Lung Injury in Cardiac Surgery

A PROVECS Trial Substudy

David Lagier, M.D., Ph.D., Lionel J. Velly, M.D., Ph.D., Benoit Guinard, M.D., Nicolas Bruder, M.D., Ph.D., Catherine Guidon, M.D., Marcos F. Vidal Melo, M.D., Ph.D., Marie-Christine Alessi, M.D., Ph.D.



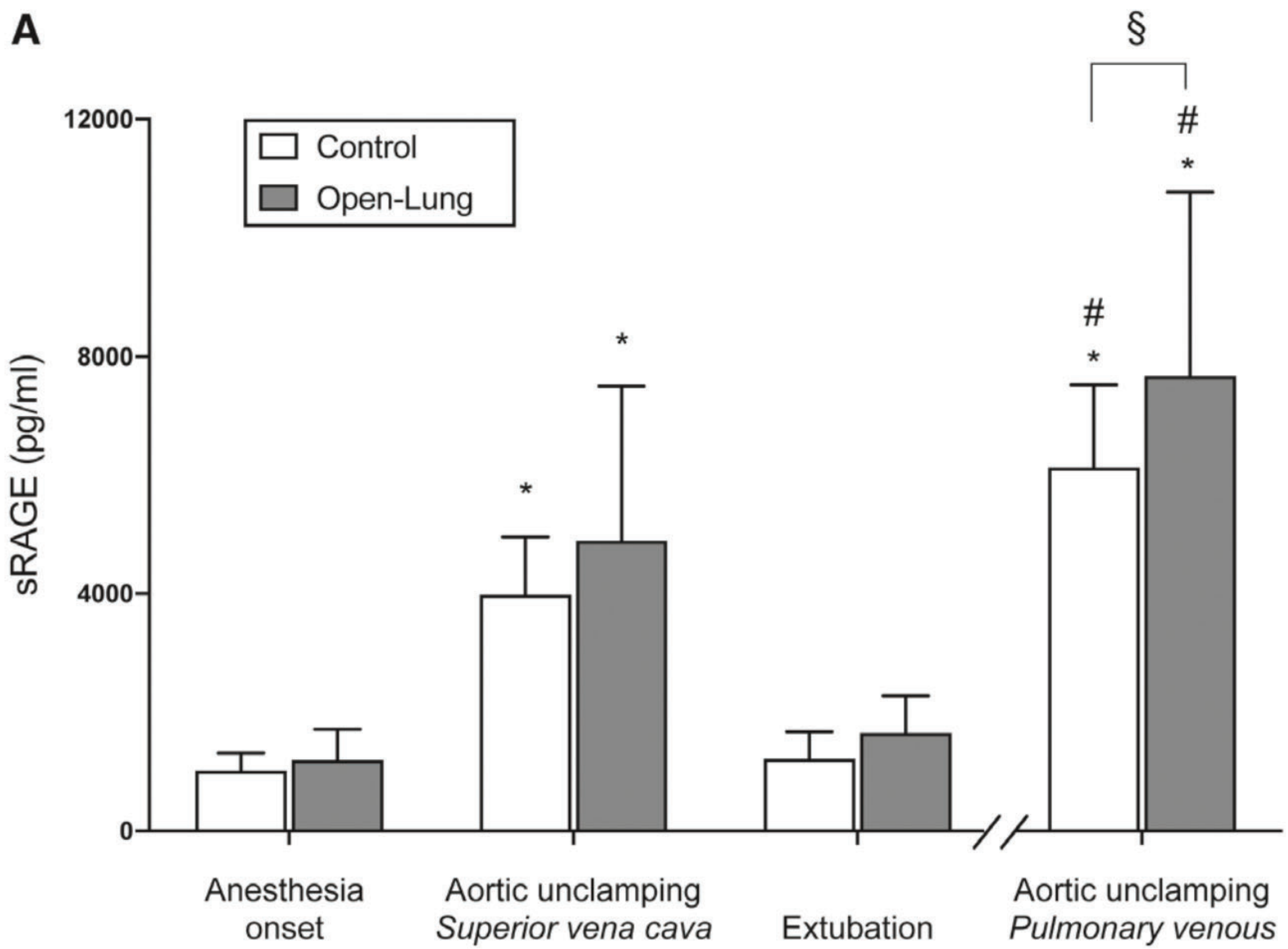
Lagier *et al*, Anesthesiology, 2020

ANESTHESIOLOGY

Perioperative Open-lung Approach, Regional Ventilation, and Lung Injury in Cardiac Surgery

A PROVECS Trial Substudy

David Lagier, M.D., Ph.D., Lionel J. Velly, M.D., Ph.D., Benoit Guinard, M.D., Nicolas Bruder, M.D., Ph.D., Catherine Guidon, M.D., Marcos F. Vidal Melo, M.D., Ph.D., Marie-Christine Alessi, M.D., Ph.D.



Lagier *et al*, Anesthesiology, 2020

EFFECT OF STERNOTOMY ON RESPIRATORY MECHANICS

Lung Expansion, Airway Pressure Transmission, and Positive End-Expiratory Pressure

James C. Chapin, MD; John B. Downs, MD; Michal E. Douglas, MD; Edmund J. Murphy, MD†; Bruce C. Ruiz

Values (Mean ± SD) for Subgroups Based on Alterations of Lung (C_L), Thoracic (C_T), and Total (C_{LT}) Compliances*

Treatment	No. of Swine	Direction of Compliance		Value of Compliance		
		C_L	C_T	C_L	C_T	C_{LT}
Control	10	N	N	57 ± 14	45 ± 6	29 ± 5
Abdominal and thoracic binders	10	N	↓	54 ± 27	31 ± 8†	20 ± 4
Sternotomy	5	N	↑	33 ± 9†	467 ± 361†	32 ± 9
Acid aspiration	5	↓	N	14 ± 10†	57 ± 20	9 ± 5†
Acid aspiration and binders	5	↓	↓	8 ± 2†	48 ± 17	7 ± 2†
Acid aspiration and sternotomy	4	↓	↑	12 ± 4†‡	421 ± 398†	12 ± 3†‡

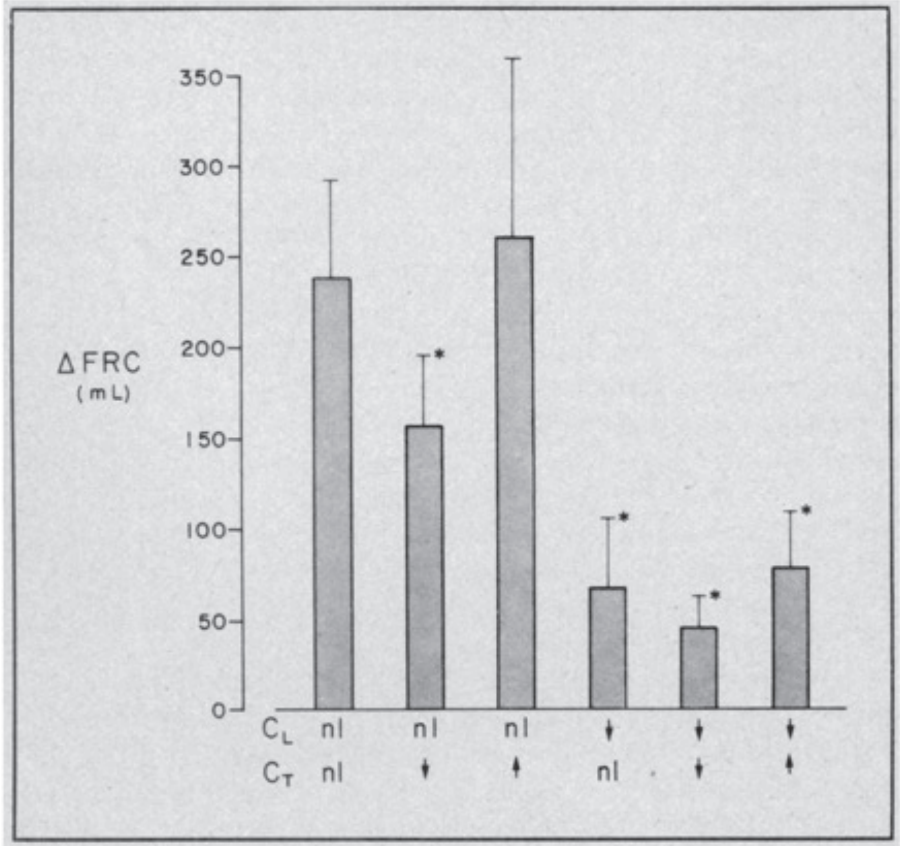
Arch Surg, 1979

In cardiosurgical patients we observed a significant (P=0.037) increase in C_{RS} with an upward and leftward shift of the PV-curve after median sternotomy. Armaganidis *et al*, ICVTS, 2009

Lung Expansion, Airway Pressure Transmission, and Positive End-Expiratory Pressure

James C. Chapin, MD; John B. Downs, MD; Michal E. Douglas, MD; Edmund J. Murphy, MD†; Bruce C. Ruiz

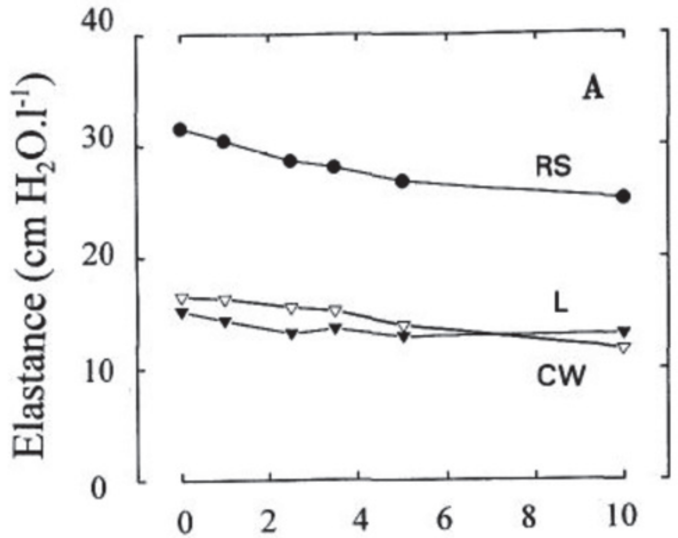
Fig 2.—Lung volume expansion (mean ± SD) assessed by calculated change in functional residual capacity (FRC) induced by 10 cm H_2O PEEP under conditions of varying lung compliance (C_L) and thoracic compliance (C_T). Asterisk indicates that differences between observed C_L and C_T and normal C_L and C_T are significant at $P < .05$. Arrows indicate greater than or less than normal (nl) compliance.



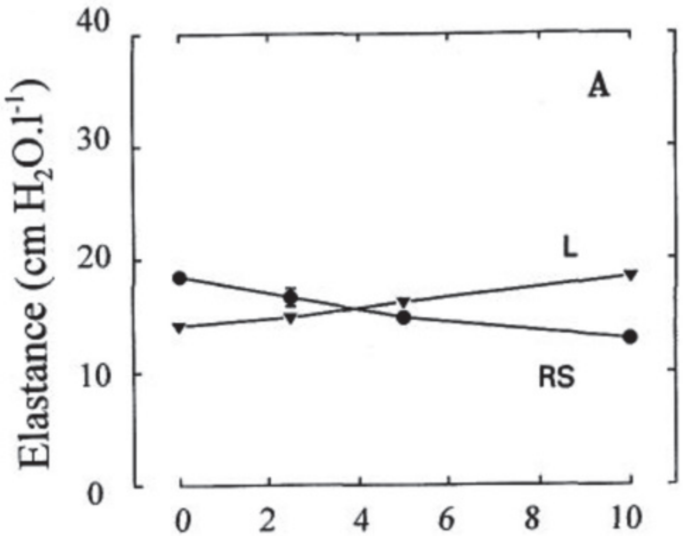
Arch Surg, 1979

The Effect of Changing End-Expiratory Pressure on Respiratory System Mechanics in Open- and Closed-Chest Anesthetized, Paralyzed Patients

Gail S. Dechman, PhD*, Daniel A. Chartrand, MD, PhD†‡, Pedro P. Ruiz-Neto, MD, PhD*†, and Jason H. T. Bates, PhD‡§



Closed chest



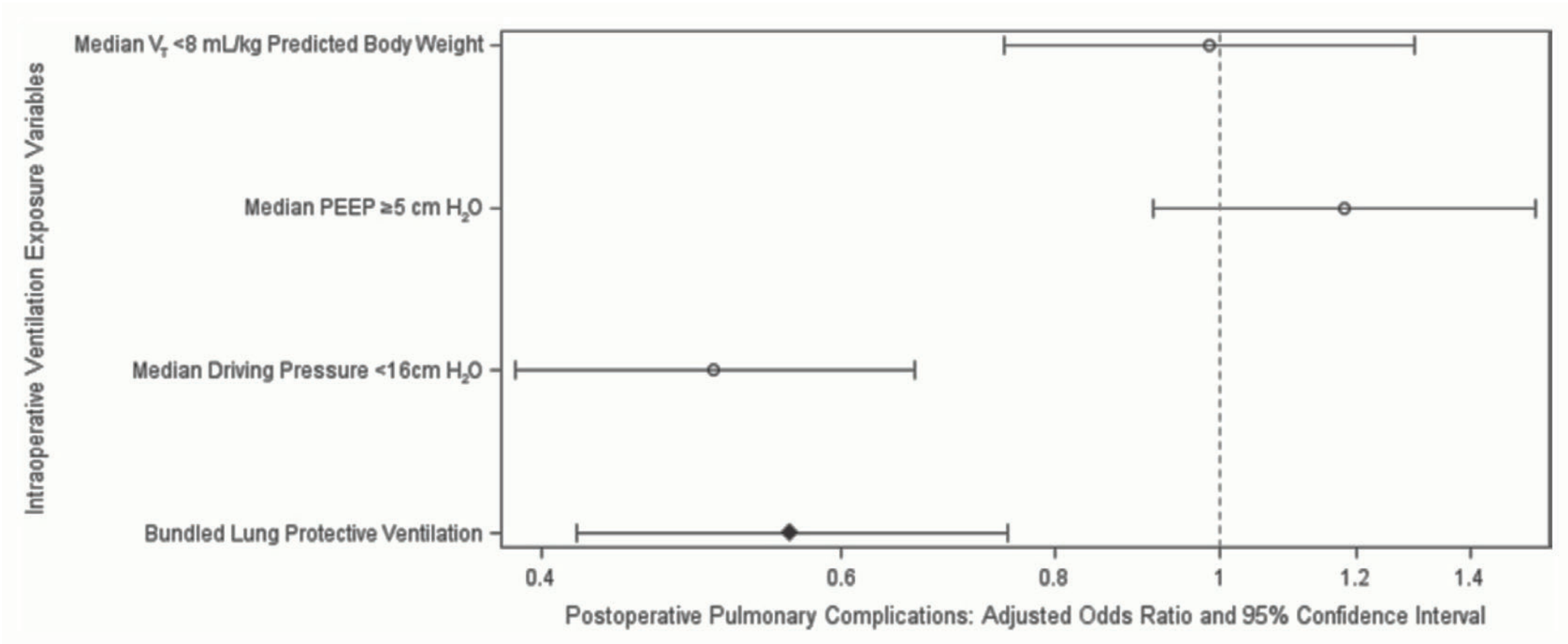
Open chest

Anesth Analg, 1995

ANESTHESIOLOGY

Intraoperative Mechanical Ventilation and Postoperative Pulmonary Complications after Cardiac Surgery

n = 4694

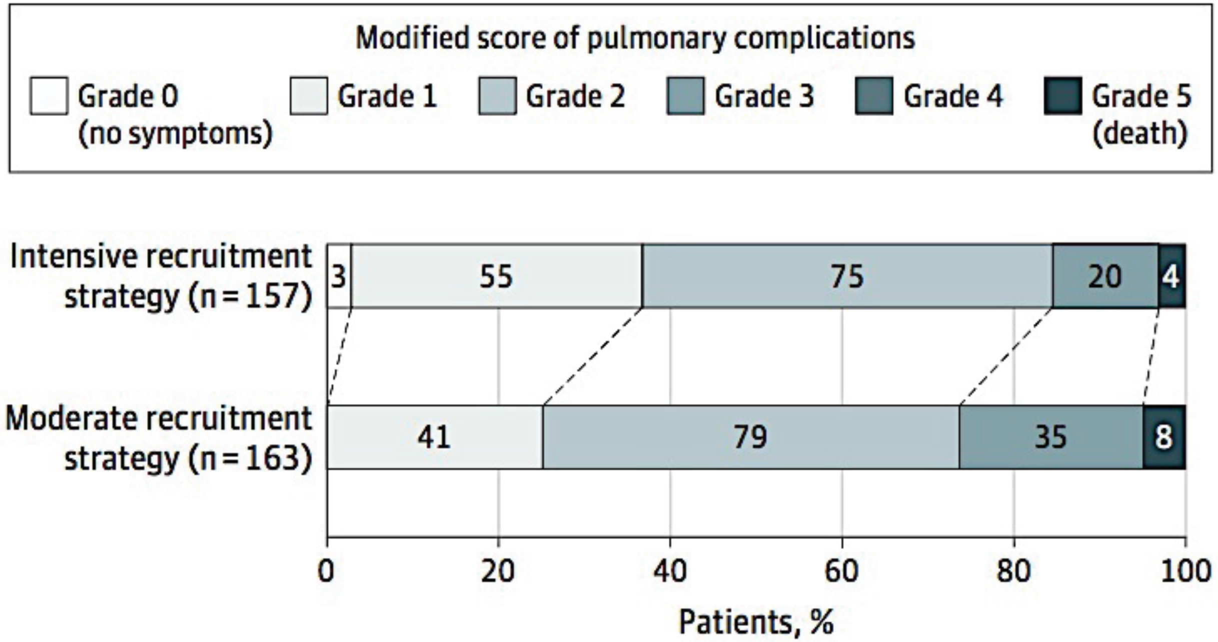


Mathis *et al*, Anesthesiology, 2019

JAMA | Preliminary Communication | CARING FOR THE CRITICALLY ILL PATIENT

Effect of Intensive vs Moderate Alveolar Recruitment Strategies Added to Lung-Protective Ventilation on Postoperative Pulmonary Complications
A Randomized Clinical Trial

- *<u>Postoperative</u>* use when chest is closed.
- Recruitment maneuvers + PEEP 13 cmH2O
- *<u>If PaO2 / FiO2 < 250</u>*



Leme *et al*, JAMA, 2017

PREVENTING PULMONARY COMPLICATIONS: *TO-DO LIST*

PREOPERATIVE

- Identify risk factors.
- Nutritional support.
- Preoperative physiotherapy in at-risk patients.

INTRAOPERATIVE

- Tidal volume = 8 mL/kg of IBW.
- PEEP 2 - 4 cmH_20 (unless P/F < 250 or DP > 15 cmH_2O).
- CPAP 2 - 4 cmH_2O during CPB.
- Recruit. maneuvers if P/F < 250 or DP > 15 cmH_2O.
- Limit intraoperative FiO_2 (PaO_2 80-100mmHg): lung reperfusion+++
- Use of volatile anesthetics.
- Goal-directed fluid therapy.
- Restrictive transfusion (PBM).

POSTOPERATIVE

- Recruit. maneuvers + PEEP titration if P/F < 250.
- Head of bed elevation (≥ 30°).
- NMBs reversal.
- Fast-track extubation.
- Pain control (multimodal, epidural).
- Curative NIV or HFNO in hypoxemic pts.
- Early mobilization / ERAS.
- Incentive spirometry or deep breathing (hourly).
- Preventive CPAP/NIV in at risk pts (obese, COPD).

Level of evidence:
High
Moderate

Low LOE: preoperative IV iron, dexamethasone, off-pump or minimally invasive surgery, lung perfusion/CPB, pulsatile CPB, remote ischemic preconditioning, mild hypothermia/CPB.