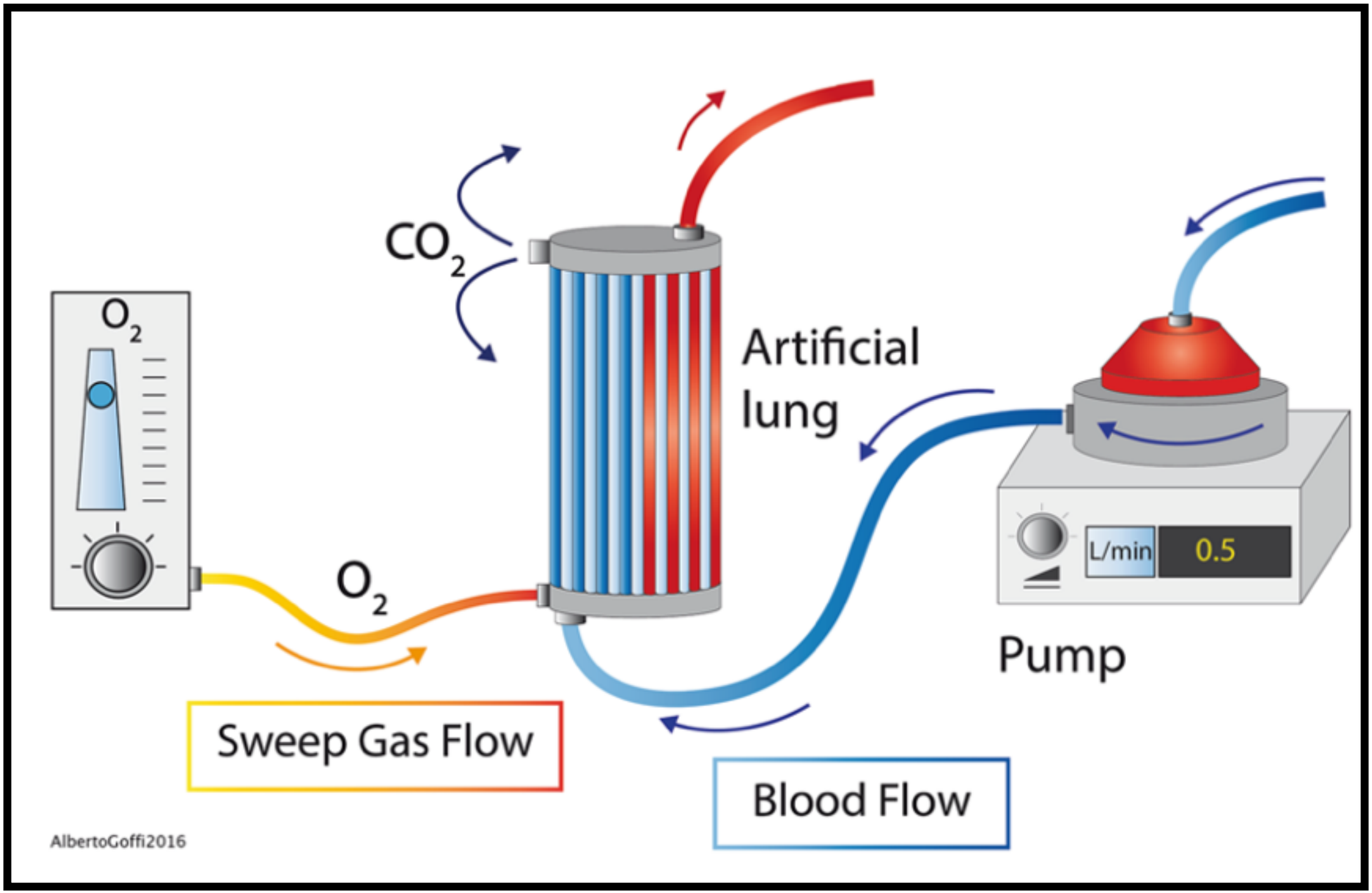
# L'ECCO$_2$R fin 2017

Dr Yves Bouckaert
Soins Intensifs C.H.U. Tivoli

# Table des matières

# ExtraCorporeal $CO_2$ Removal

# Table des matières

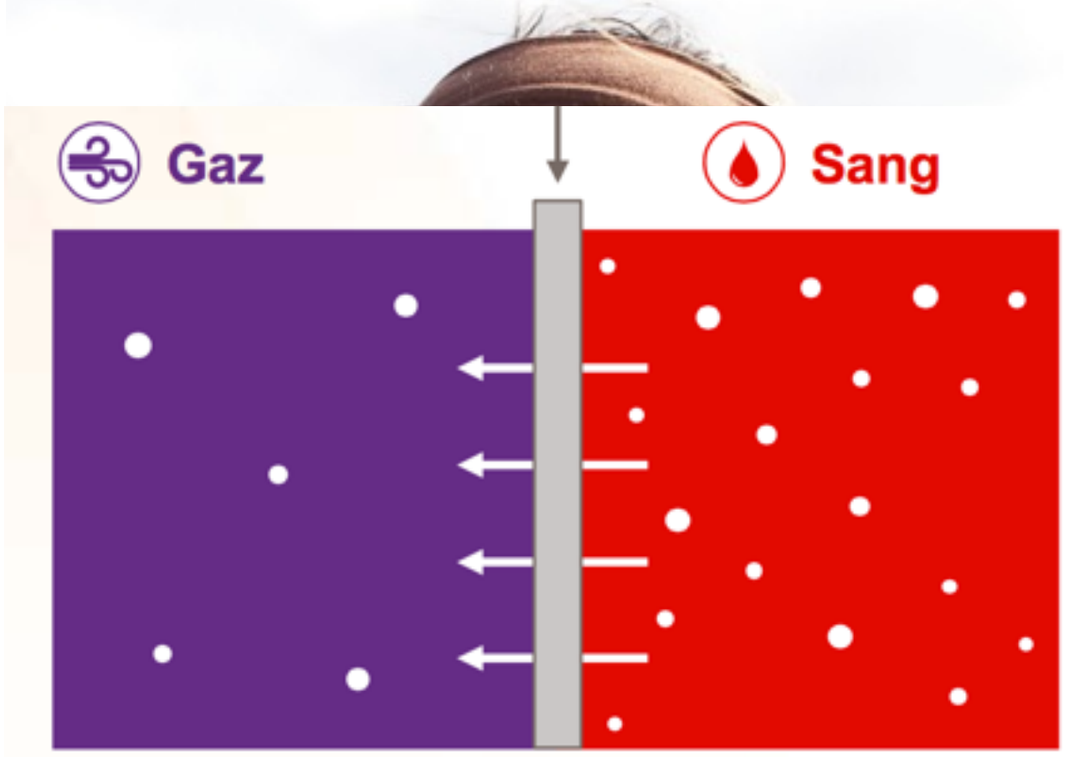

$CO_2$
$O_2$
Artificial lung
L/min
0.5
Pump
$O_2$
Sweep Gas Flow
Blood Flow
AlbertoGoffi2016

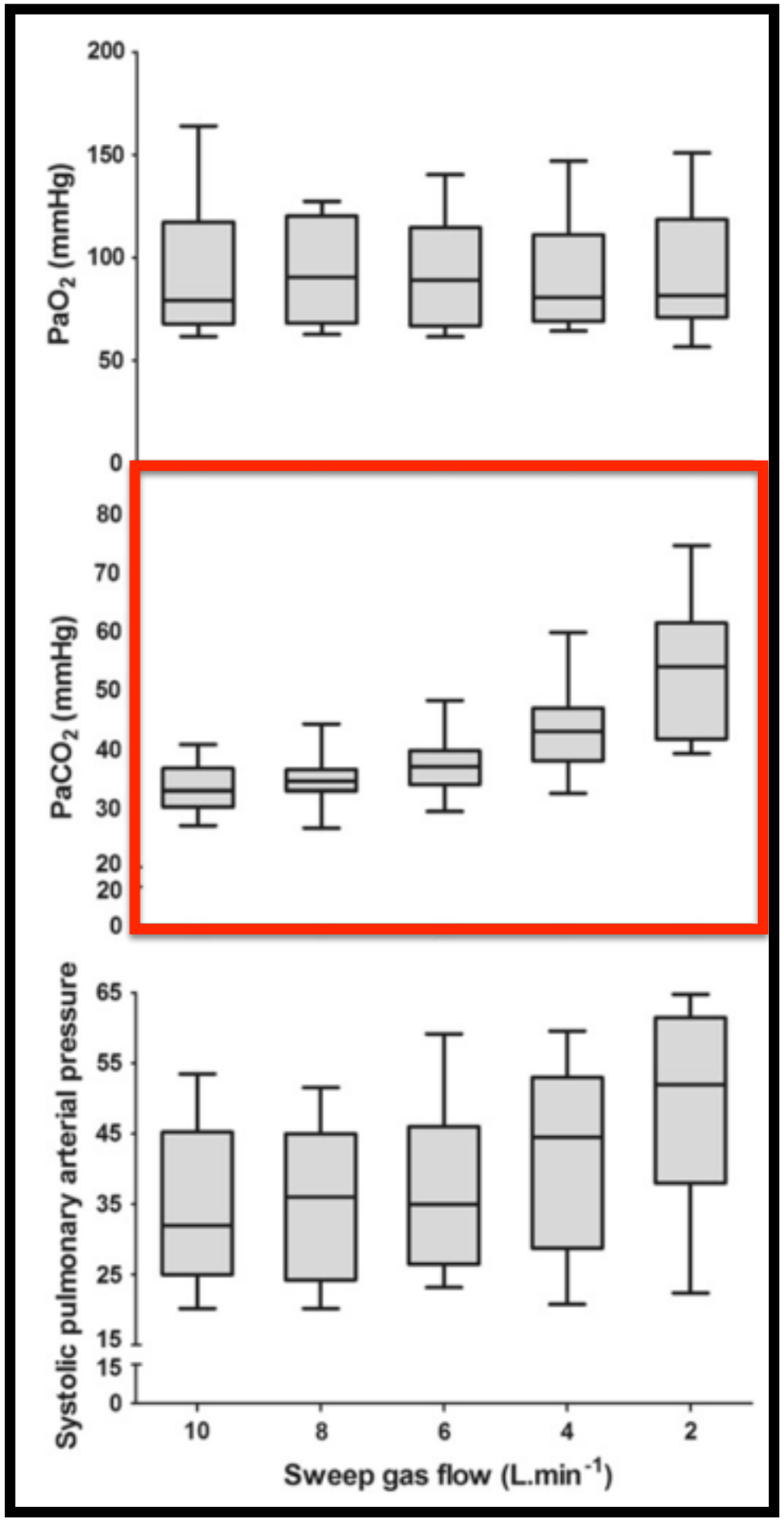
# Membrane

- CO2 20 fois plus soluble que l'O2

- Meilleure diffusion CO2 au travers d'une membrane

- Plus facile d'épurer le CO2 que d 'oxygéner le sang




Intensive Care Med (2013) 39:838–846
DOI 10.1007/s00134-012-2785-8

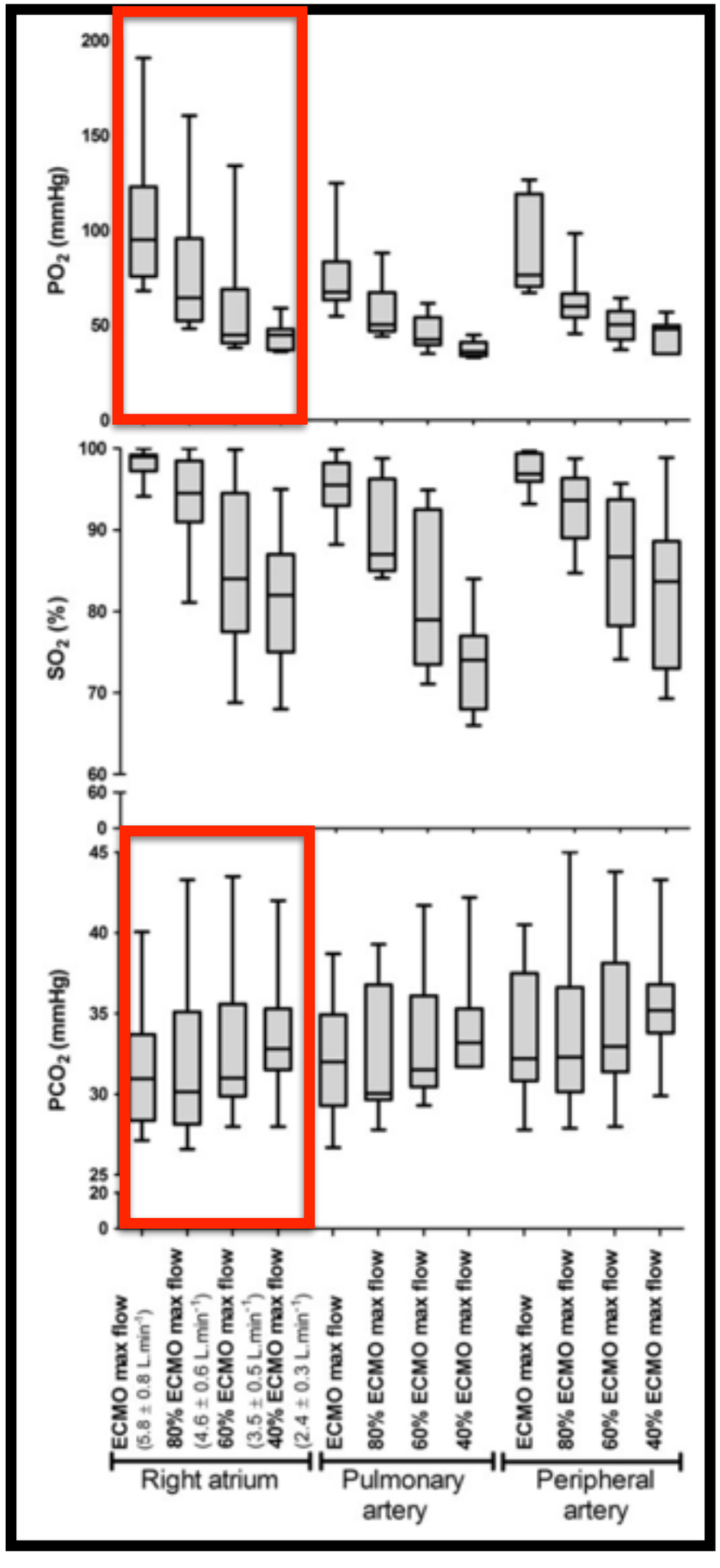
ORIGINAL

Matthieu Schmidt
Guillaume Tachon
Christine Devilliers
Grégoire Muller
Guillaume Hekimian
Nicolas Bréchot
Sybille Merceron
Charles Edouard Luyt
Jean-Louis Trouillet
Jean Chastre
Pascal Leprince
Alain Combes

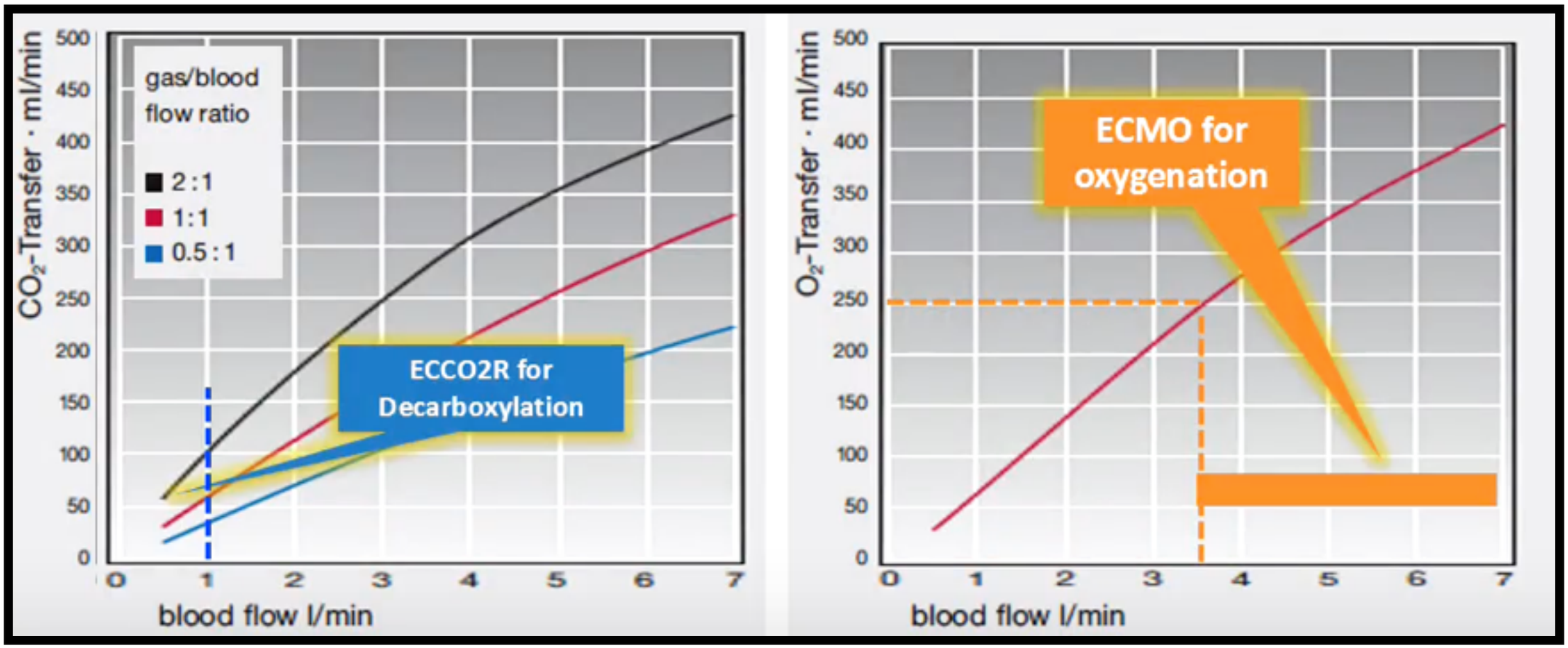
**Blood oxygenation and decarboxylation determinants during venovenous ECMO for respiratory failure in adults**

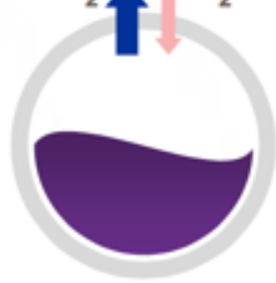
Balayage

Débit sang



# Transfert d'$O_2$ et de $CO_2$



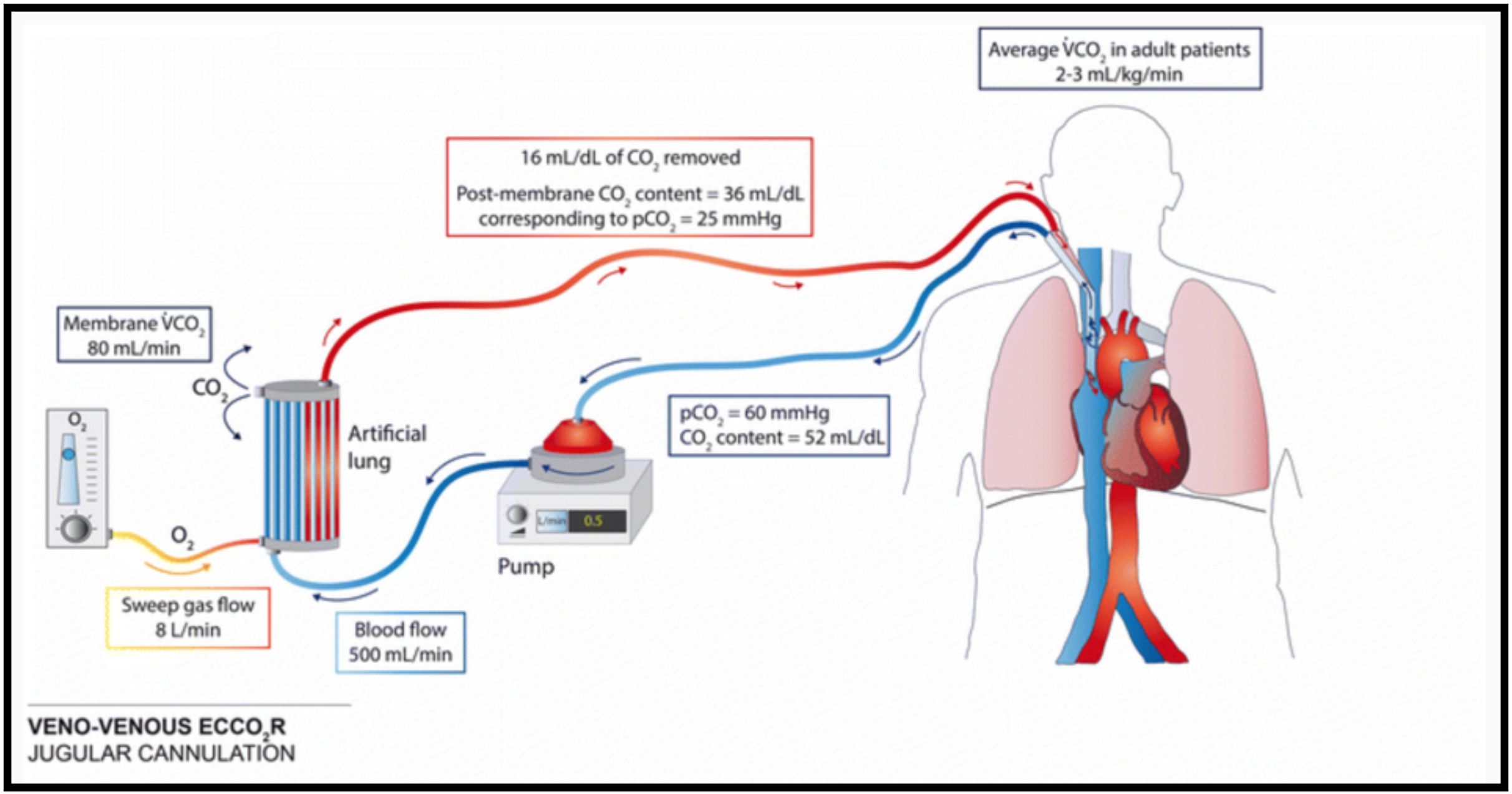
| | ECCO$_2$R bas débit | ECCO$_2$R débit moyen | ECCO$_2$R débit élevé/ECMO |
|---|---|---|---|
| ÉCHANGE GAZEUX | CO$_2$ ↑ | CO$_2$ ↑ O$_2$ ↓ | CO$_2$ ↑ O$_2$ ↓ |
| |  |  |  |
| | **Élimination partielle du CO$_2$** | **Élimination du CO$_2$ et oxygénation partielle** | **Élimination du CO$_2$ et oxygénation** |
| **DÉBIT SANGUIN** | ≤ 500 ml/minute[1] | ≤ 2 400 ml/minute[2] | ≤ 7 000 ml/minute[2] |
| **ACCÈS VASCULAIRE VV** | Petit cathéter à double lumière (14 FR maximum)[1] | Cathéter moyen à double lumière[1] | 2 grands cathéters à lumière unique (24 FR maximum)[1] |
| **CARACTÈRE INVASIF** | Faible[1] | Moyen[1] | Élevé[1] |

*Intensive Care Med (2017) 43:519–530*
DOI 10.1007/s00134-016-4673-0

REVIEW

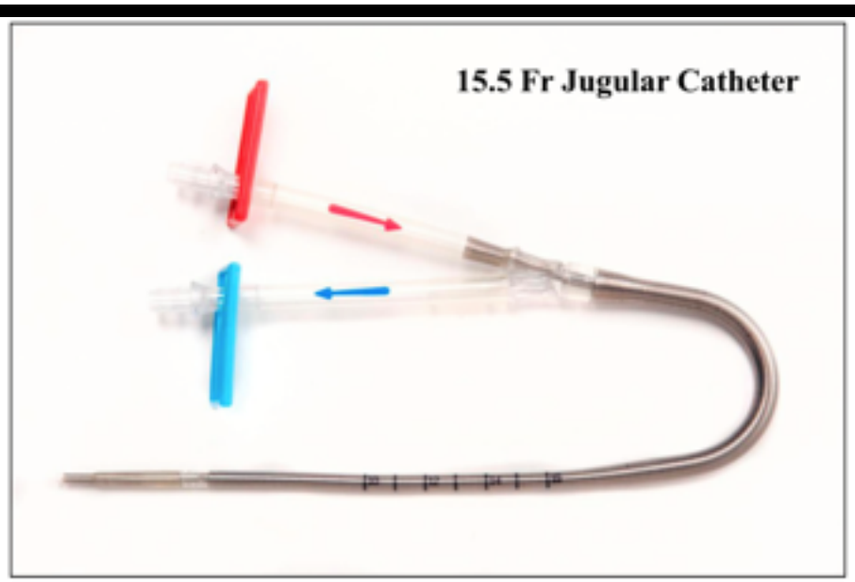
# Extracorporeal carbon dioxide removal ($ECCO_2R$) in patients with acute respiratory failure

Andrea Morelli[1], Lorenzo Del Sorbo[2,3], Antonio Pesenti[4], V. Marco Ranieri[1] and Eddy Fan[2,3*]




**VENO-VENOUS $ECCO_2R$**
JUGULAR CANNULATION

Canul double




*Intensive Care Med (2017) 43:519–530*
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REVIEW

# Extracorporeal carbon dioxide removal ($ECCO_2R$) in patients with acute respiratory failure

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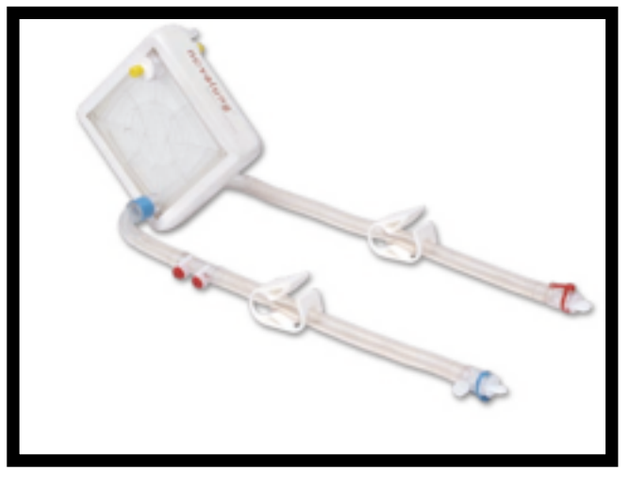
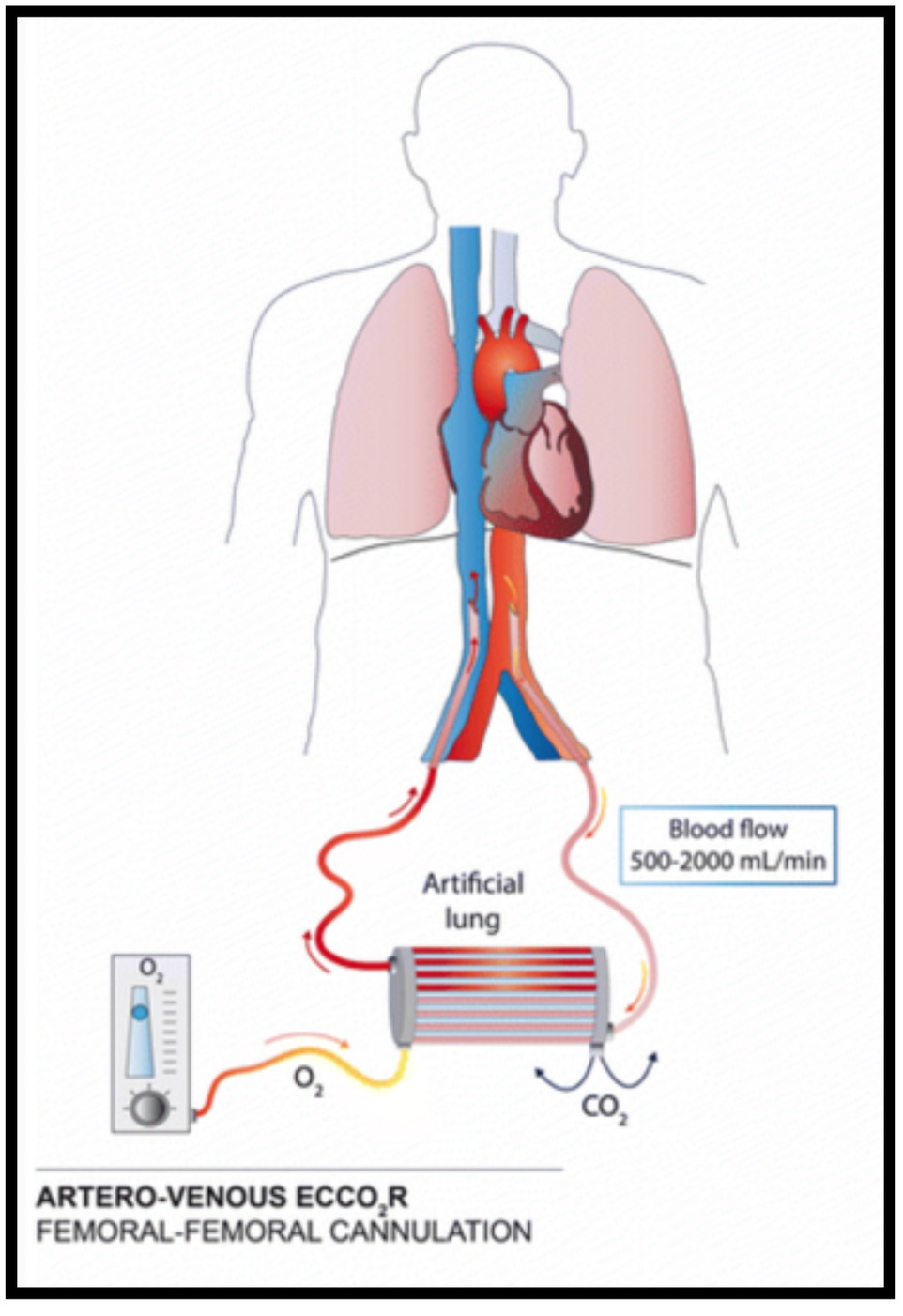





**ARTERO-VENOUS $ECCO_2R$**
FEMORAL-FEMORAL CANNULATION

# ECCO2 combinée à l'épuration extra-rénale


Crit Care Med. 2015 Dec; 43(12): 2570–2581. PMCID: PMC4648187
Published online 2015 Nov 17. doi: 10.1097/CCM.0000000000001296

**Safety and Efficacy of Combined Extracorporeal $Co_2$ Removal and Renal Replacement Therapy in Patients With Acute Respiratory Distress Syndrome and Acute Kidney Injury: The Pulmonary and Renal Support in Acute Respiratory Distress Syndrome Study***

Jérôme Allardet-Servent, MD, MSc,[1] Matthias Castanier, MD, Thomas Signouret, MD, Rattinavelou Soundaravelou, MD, Anne Lepidi, MD, and Jean-Marie Seghboyan, MD

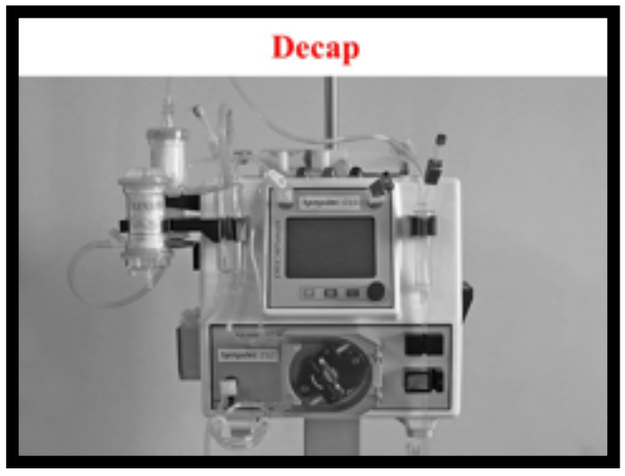
# Table des matières

# Les machines disponibles

iLA Novalung Membrane

Hemolung - Alung


ProLung-Decap -




Prismal ung - Baxter


iLA ActiVVE de Novalung

ABYLCAP

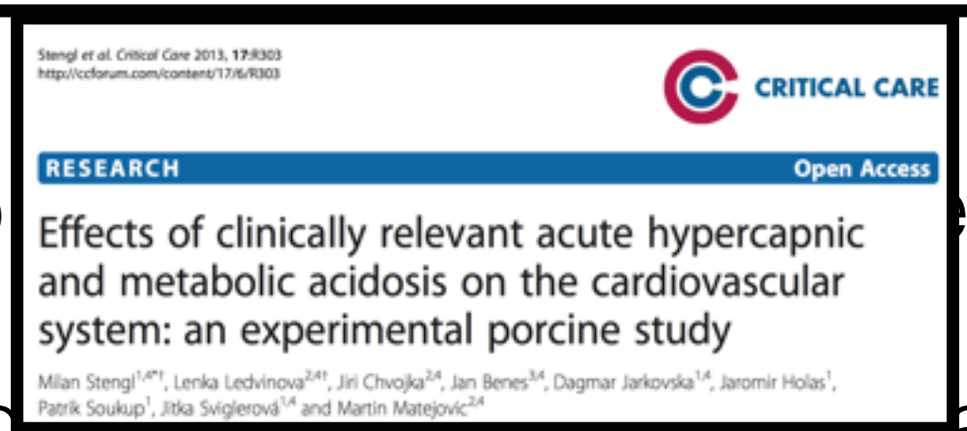

PALP - Maquet

# Table des matières

# L’acidose respiratoire
# et
# L’hypercapnie

# Effets négatifs de l'hypercapnie

- Augmentatio ébral
  - Aggravation de l'hypertension intracrânienne
- Vasoconstriction pulmonaire
  - HTAP et insuffisance ventriculaire droite
- Diminution de la contractilité myocardique



Stengl et al. Critical Care 2013, 17:R303
http://ccforum.com/content/17/6/R303

CRITICAL CARE

RESEARCH Open Access

Effects of clinically relevant acute hypercapnic and metabolic acidosis on the cardiovascular system: an experimental porcine study

Milan Stengl[1,4*†], Lenka Ledvinova[2,4†], Jiri Chvojka[2,4], Jan Benes[3,4], Dagmar Jarkovska[1,4], Jaromir Holas[1], Patrik Soukup[1], Jitka Sviglerová[1,4] and Martin Matejovic[2,4]

# Indications potentielles de l'$ECCO_2R$

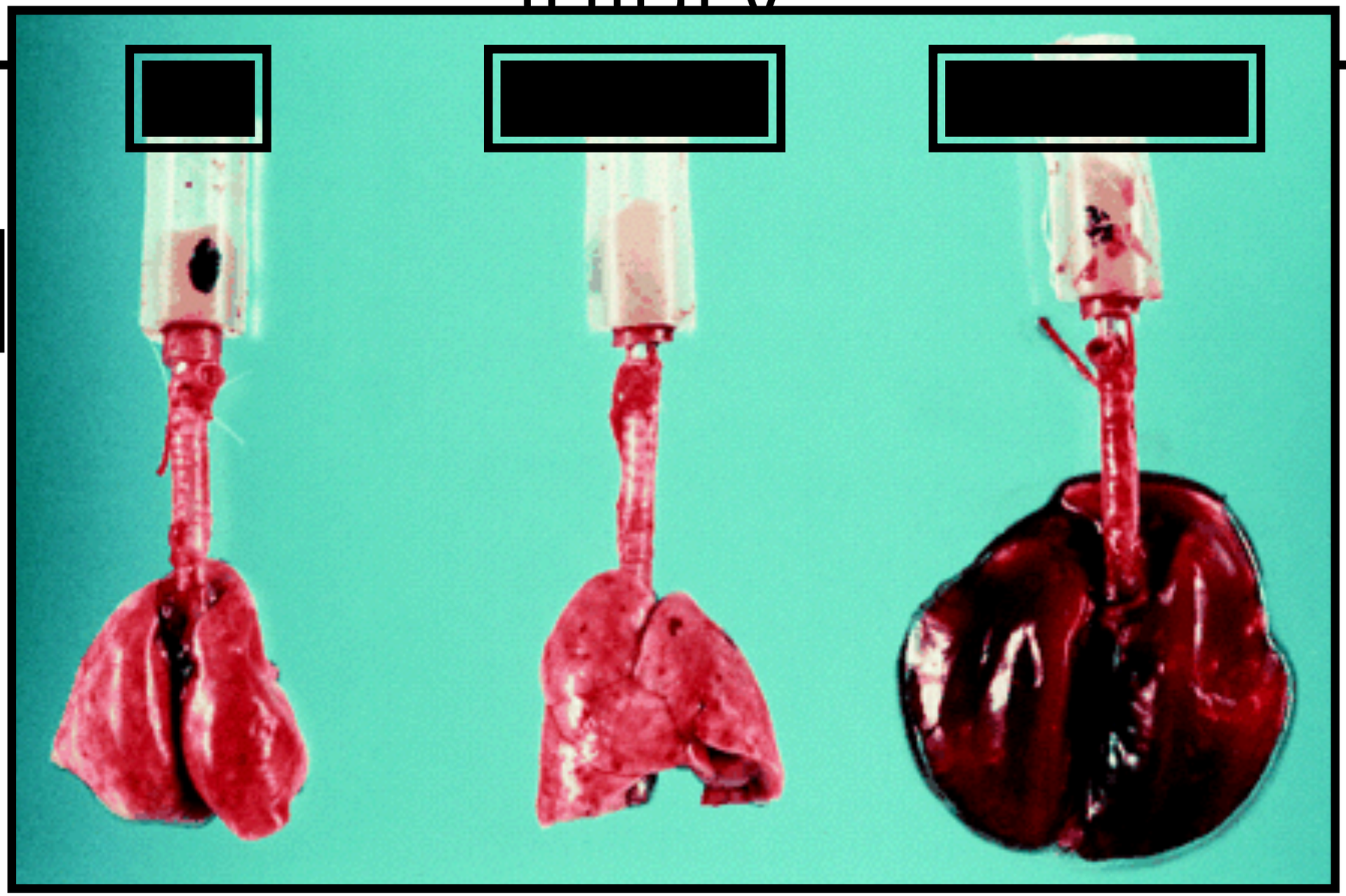
- ARDS
  - Ventilation Protectrice
  - Ventilation « Ultra » Protectrice
- BPCO
  - Pour éviter l'intubation et la ventilation invasive
  - Pour accélérer le sevrage de la ventilation invasive
- Insuffisance cardiaque droite induite ou favorisée par la ventilation invasive
- Mal asthmatique
- Bridge vers la transplantation (Mucoviscidose)
- Hypercpanie et HTIC

# Table des matières

# VILI-Ventilator induced lung injury

Rats

P 45 cm
H20

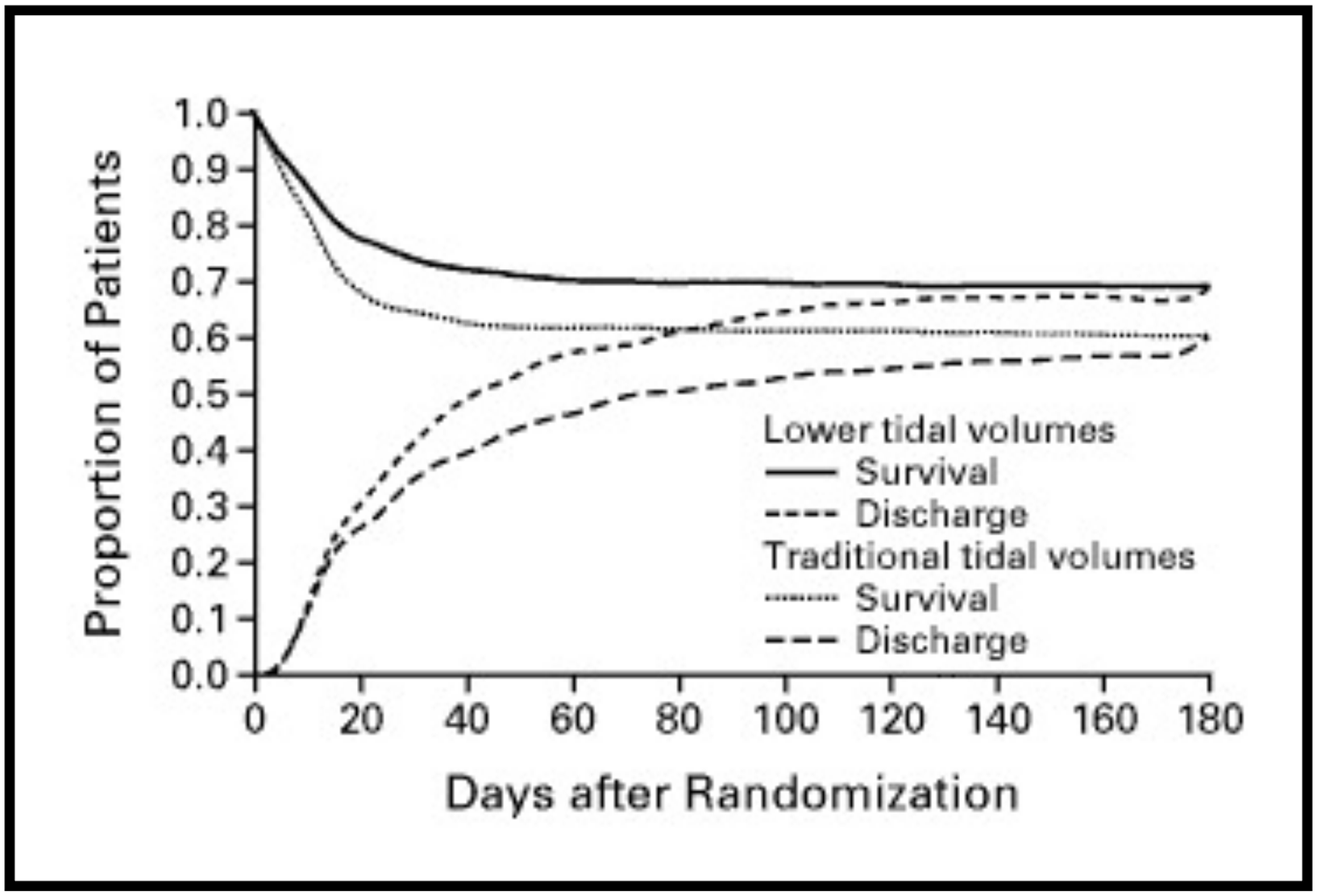


ORIGINAL ARTICLE

# Ventilation with Lower Tidal Volumes as Compared with Traditional Tidal Volumes for Acute Lung Injury and the Acute Respiratory Distress Syndrome

The Acute Respiratory Distress Syndrome Network*

N Engl J Med 2000; 342:1301-1308 | May 4, 2000 | DOI: 10.1056/NEJM200005043421801



# Ventilation protectrice

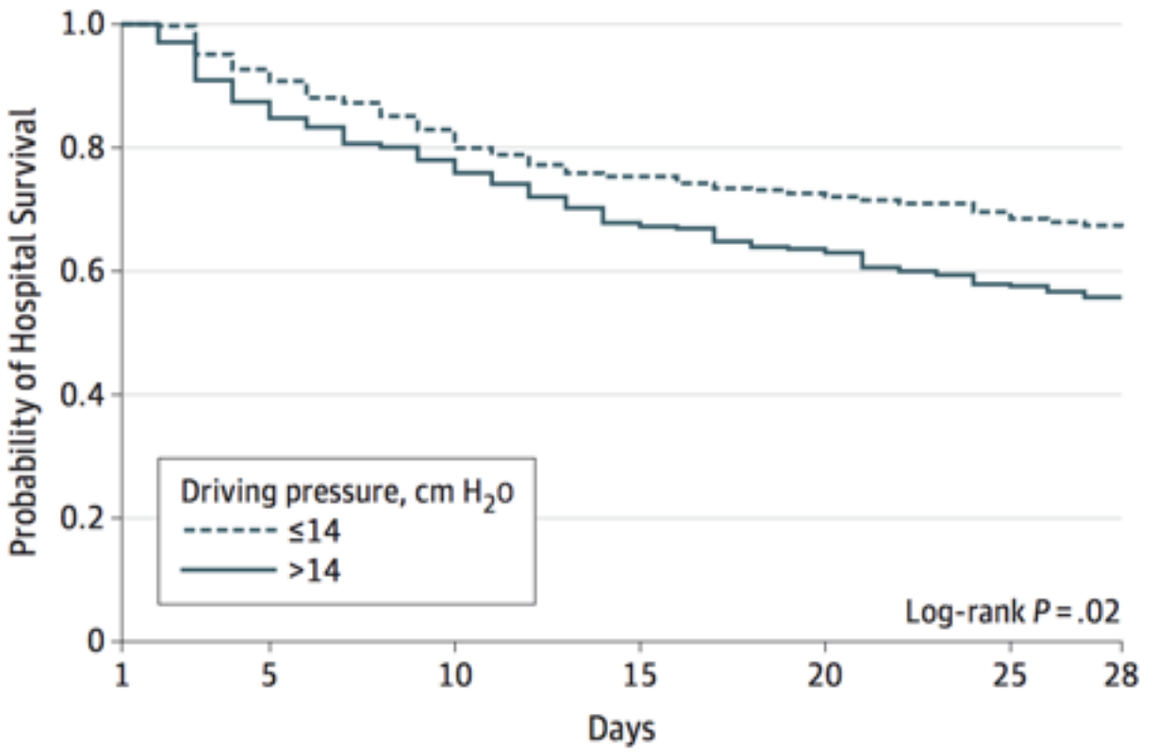
- Vt  6 ml/kg de poids idéal
- Pression Plateau < 30 cm $H_2O$
- Peep suffisante
- $FIO_2$ suffisante

JAMA | Original Investigation | CARING FOR THE CRITICALLY ILL PATIENT

# Epidemiology, Patterns of Care, and Mortality for Patients With Acute Respiratory Distress Syndrome in Intensive Care Units in 50 Countries

Giacomo Bellani, MD, PhD; John G. Laffey, MD, MA; Tài Pham, MD; Eddy Fan, MD, PhD; Laurent Brochard, MD, HDR; Andres Esteban, MD, PhD; Luciano Gattinoni, MD, FRCP; Frank van Haren, MD, PhD; Anders Larsson, MD, PhD; Daniel F. McAuley, MD, PhD; Marco Ranieri, MD; Gordon Rubenfeld, MD, MSc; B. Taylor Thompson, MD, PhD; Hermann Wrigge, MD, PhD; Arthur S. Slutsky, MD, MASc; Antonio Pesenti, MD; for the LUNG SAFE Investigators and the ESICM Trials Group

C Probability of hospital survival by driving pressure




No. at risk

| Driving pressure, cm $H_2O$ | | | | | | | |
|---|---|---|---|---|---|---|---|
| ≤14 | 370 | 342 | 306 | 277 | 266 | 254 | 245 |
| >14 | 342 | 298 | 262 | 225 | 211 | 192 | 185 |

JAMA. 2016;315(8): 788-800. doi:10.1001/jama.2016.0291

# Evolution du paradigme Ventilation « ultra-protectrice »

- Diminution du Vt au delà de 6 ml/kg de poids idéal
  - Vt 2 à 4 ml/kg?
- Diminution de la Pression plateau en dessous de 30 cmH2O (ARDSnet)
  - P Plat < 25 cmH2O?
- Diminution de la Driving Pressure < 12 - 14 cmH2O
- Peep suffisante

Alain Combes

Intensive Care Med (2017) 43:519–530
DOI 10.1007/s00134-016-4673-0

REVIEW

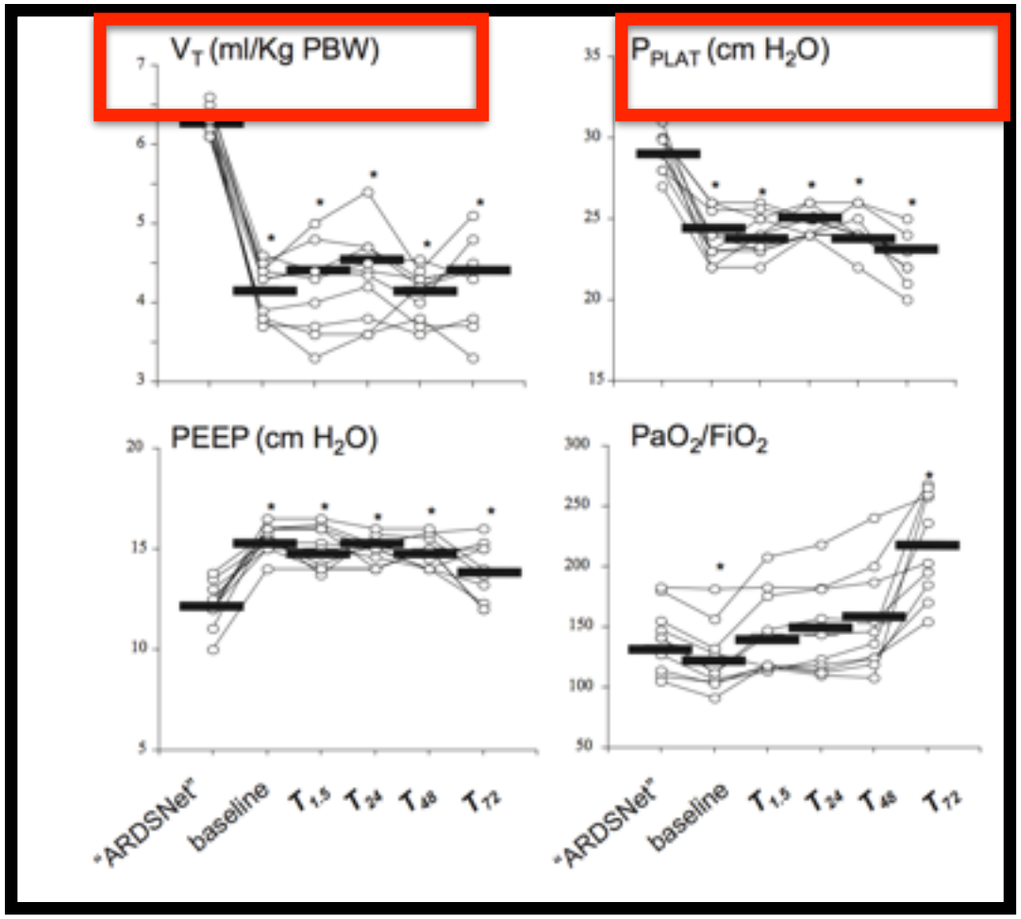
# Extracorporeal carbon dioxide removal ($ECCO_2R$) in patients with acute respiratory failure

Andrea Morelli[1], Lorenzo Del Sorbo[2,3], Antonio Pesenti[4], V. Marco Ranieri[1] and Eddy Fan[2,3*]

**Table 1 Relevant clinical studies of $ECCO_2R$ in ARDS patients**

| Study | $ECCO_2R$ technique | Notes |
|---|---|---|
| Terragni et al. [34] | Modified continuous VV hemofiltration system with membrane lung via a 14-Fr single dual lumen catheter (femoral) with an extracorporeal blood flow of 191–422 mL/min | Prospective study<br>Ten ARDS patients with 28 ≤ Pplat ≤ 30 after 72 h of ARDSNet ventilation were placed on $ECCO_2R$ and had progressive reduction in $V_T$<br>$V_T$ was reduced from 6.3 ± 0.2 to 4.2 ± 0.3 mL/kg PBW and Pplat decreased from 29.1 ± 1.2 to 25.0 ± 1.2 $cmH_2O$ ($p < 0.001$)<br>Consequent respiratory acidosis was managed by $ECCO_2R$<br>Improvement of morphological markers of lung protection and reduction in pulmonary cytokines ($p < 0.01$) after 72 h of ventilation with $V_T$ <6 mL/kg PBW<br>No patient-related complications<br>Membrane clotting in three patients |
| Bein et al. [35] | Femoral *AV* pumpless extracorporeal lung assist (PECLA) via a 15-Fr arterial cannula and 17-Fr venous cannula with a mean extracorporeal blood flow of 1.3 L/min | Randomized controlled trial<br>Moderate/severe ARDS after 24-h stabilization period with higher PEEP<br>Randomized to $ECCO_2R$ group with ~3 mL/kg PBW ventilation or control group with ~6 mL/kg PBW ventilation<br>There were no significant differences in VFDs at day 28 (10 vs. 9 days, $p = 0.78$) or day 60 (33 vs. 29, $p = 0.47$)<br>Post hoc analysis showed that patients with P/F ≤150 at randomization in $ECCO_2R$ group had significantly shorter duration of ventilation (VFDs at day 60, 41 vs. 28, $p = 0.033$)<br>Significantly higher red blood cell transfusion in the PECLA group up to day 10 (3.7 vs. 1.5 units; $p < 0.05$) |
| Fanelli et al. [6] | VV configuration via a 15.5-Fr single dual lumen catheter (femoral or jugular) with a mean extracorporeal blood flow of 435 mL/min | Prospective study<br>Moderate/severe ARDS<br>$V_T$ was reduced from baseline to 4 mL/kg PBW<br>Low-flow $ECCO_2R$ was initiated when pH <7.25 and PaCO2 >60 mmHg<br>$ECCO_2R$ was effective in correcting pH and $PaCO_2$<br>Life-threatening hypoxemia such as prone position and ECMO were necessary in four and two patients, respectively |

| Etude | Année | Machine | N | Taille du cathéter | Débit sanguin | Débit de gaz | anticoag. | durée |
|---|---|---|---|---|---|---|---|---|
| **Terragni et Al.** | 2009 | Hémodec-Décap | 10 | 14Fr | 280-350ml/min | 8l/min | HNF APTT 1,3 à 1,5 | 84 à 168 heures |
| **Bein et Al.** | 2013 | iLA Novalung | 40 vs 39 | Art 15 Fr V 17Fr | 1000 à 2000 ml/min | ? | HNF` APTT 40-50 sec | ? |
| **Fanelli et AL.** | 2016 | Hemolung | 15 | 15,5 Fr | 420-435ml/min | 10l/min | HNF APP 1,77 | 48 à 96 heures |
| **SUPERNOVA** | 2018 | | 95 | | | | | |
| **REST** | 2021 | | | | | | | |

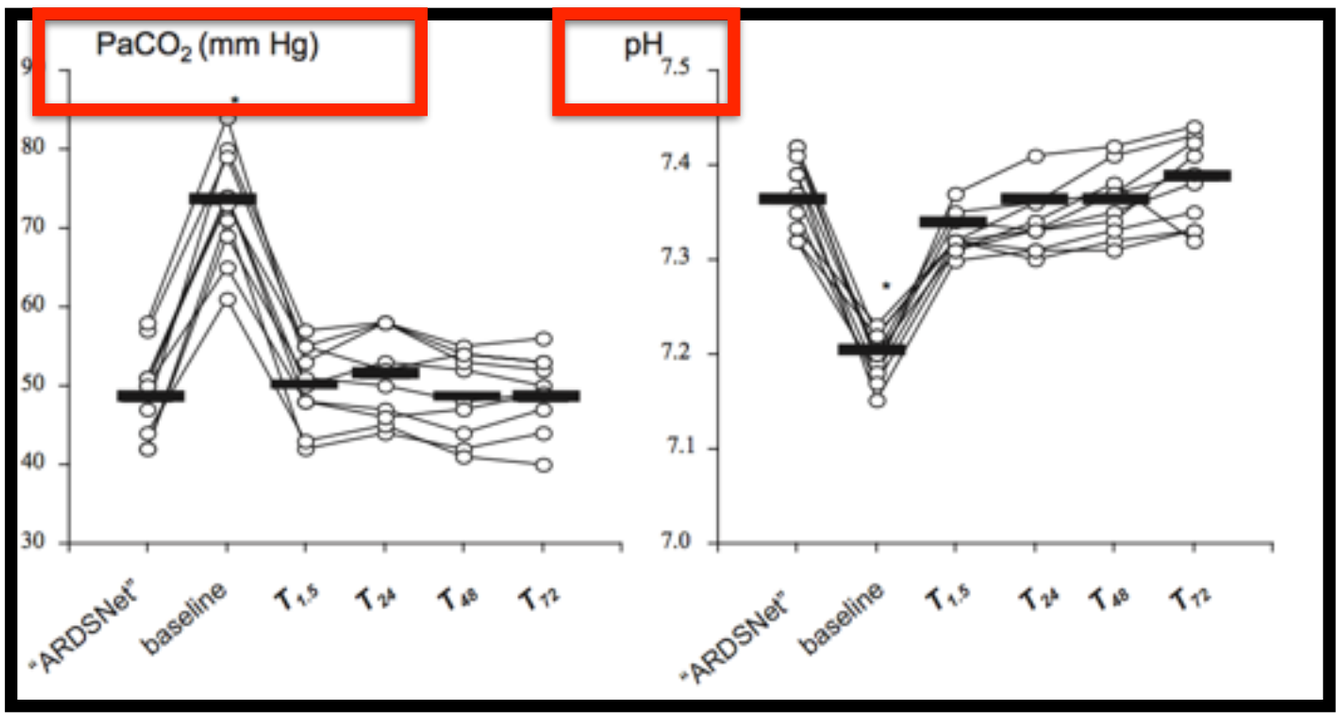



Anesthesiology 2009; 111:826–35 

# *Tidal Volume Lower than 6 ml/kg Enhances Lung Protection*

## *Role of Extracorporeal Carbon Dioxide Removal*

*Pier Paolo Terragni, M.D.,* Lorenzo Del Sorbo, M.D.,* Luciana Mascia, M.D., Ph.D.,* Rosario Urbino, M.D.,* Erica L. Martin, Ph.D.,* Alberto Birocco, M.D.,† Chiara Faggiano, M.D.,† Michael Quintel, M.D.,‡ Luciano Gattinoni, M.D.,§ V. Marco Ranieri, M.D.‖*



Safe
Moins de sédation
Il-6 réduite
Bénéfice dans analyse posthoc P/F < 150

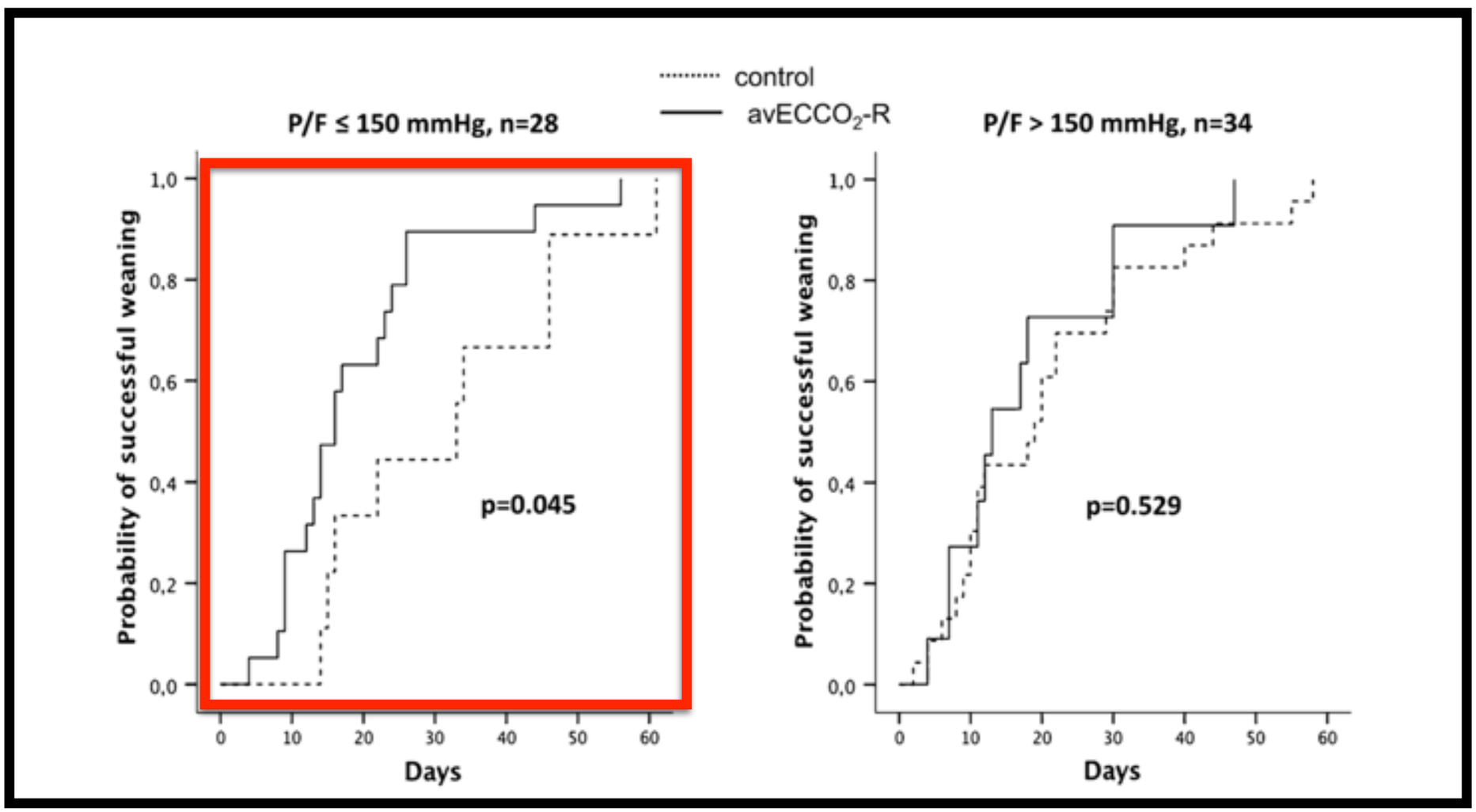
Intensive Care Med (2013) 39:847–856
DOI 10.1007/s00134-012-2787-6

ORIGINAL

Thomas Bein
Steffen Weber-Carstens
Anton Goldmann
Thomas Müller
Thomas Staudinger
Jörg Brederlau
Ralf Muellenbach
Rolf Dembinski
Bernhard M. Graf
Marlene Wewalka
Alois Philipp
Klaus-Dieter Wernecke
Matthias Lubnow
Arthur S. Slutsky

# Lower tidal volume strategy (≈3 ml/kg) combined with extracorporeal $CO_2$ removal versus 'conventional' protective ventilation (6 ml/kg) in severe ARDS

## The prospective randomized Xtravent-study



# Strategy of UltraProtective Lung Ventilation With Extracorporeal CO3 Removal for New-Onset Moderate to Severe ARDS (SUPERNOVA)

- n = 95
- Vt 4 ml/kg
- ECCO2R
- Diminution Pplateau et Driving pressure
- SAFE: Pas d'EI sévère
- Mortalité de 27%, inférieure à la mortalité prédite

# Dans l'ARDS, l'ECCO$_2$R:

- Permet:
  - une réduction du volume courant, Vt (3 à 4 ml/kg)
  - une réduction de la Pplateau < 25 à 28 cm $H_2O$ et de la ΔP
  - une élimination de $CO_2$ et une diminution de la PaCO2
  - une augmentation du pH
- Diminue les taux de cytokines pro-inflammatoires pulmonaires
- Diminue peut-être la durée de la ventilation mécanique (P/F < 150)

# Table des matières

# BPCO

- VNI à tout prix (échec dans 25 à 50% des cas)
- Mortalité Ventilation Invasive (25 à 70%)
- VAP
- Sédation
- Immobilisation-Amyotrophie
- Hyperinflation - $Peep_i$

Intensive Care Med (2017) 43:519–530
DOI 10.1007/s00134-016-4673-0

REVIEW

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**Table 2 Relevant clinical studies of $ECCO_2R$ in COPD patients**

| Study | $ECCO_2R$ technique | Notes |
|---|---|---|
| Kluge et al. [42] | Femoral AV pumpless extracorporeal lung assist (PECLA); 13- to 15-Fr arterial cannula and 13- to 17-Fr venous cannula with a mean extracorporeal blood flow of 1.1 L/min | Retrospective study<br>Chronic pulmonary disease with acute hypercapnic respiratory failure not responding to NIV<br>21 PECLA patients matched to historical controls with conventional IMV<br>19 (90%) PECLA patients did not require intubation<br>Two major and seven minor bleeding complications during PECLA<br>No significant difference in 28-day (24 vs. 19%, $p = 0.85$), 6-month mortality (33 vs. 33%), or hospital length of stay (23 vs. 42 days, $p = 0.06$)<br>Significantly fewer trachesotomies in PECLA group (10 vs. 67%, $p = 0.004$) |
| Burki et al. [43] | VV configuration via a 15.5-Fr single dual lumen catheter (femoral or jugular) with a mean extracorporeal blood flow of 430 mL/min | Pilot study<br>20 hypercapnic COPD patients received $ECCO_2R$ in three distinct groups: group 1 ($n = 7$) NIV patients with high risk of IMV; group 2 ($n = 2$) could not be weaned from NIV; and group 3 ($n = 11$) on IMV and failed to wean<br>IMV avoided in all patient in group 1<br>Both patients in group 2 weaned from NIV<br>In group 3, three patients weaned, and IMV was reduced in two patients<br>One patient died due to a retroperitoneal hemorrhage (during cannulation) |
| Abrams et al. [48] | VV configuration via a 20- to 24-Fr single dual lumen jugular catheter using lower flow on ECMO system with an extracorporeal blood flow of 1–1.7 L/min | Prospective pilot study<br>Five patients with acute COPD exacerbations requiring IMV<br>All subjects met primary endpoint of extubation within 72 h [median (IQR) 4 (1.5–21.5) h]<br>Mean (SD) time to ambulation after $ECCO_2R$ initiation was 29.4 ± 12.6 h<br>Four patients were discharged home and one underwent planned lung transplantation<br>Only two minor bleeding complications |
| Del Sorbo et al. [45] | Modified continuous VV hemofiltration system with membrane lung via 14-Fr single dual lumen catheter (femoral) with an extracorporeal blood flow of 177–333 mL/min | Retrospective study<br>Patients requiring NIV for acute hypercapnic COPD exacerbations<br>21 $ECCO_2R$-NIV patients matched to historical NIV-only controls<br>Significantly higher risk of intubation in NIV-only group (HR 0.27; 95% CI 0.07–0.98)<br>13 patients experienced adverse events: three had bleeding, one had vein perforation, and nine had device malfunction |
| Braune et al. [44] | VV configuration via a 22 or 24-Fr single dual lumen catheter (femoral or jugular)<br>with a mean extracorporeal blood flow of 1.3 L/min | Case–control study<br>25 patients with acute hypercapnic respiratory failure refractory to NIV and treated with $ECCO_2R$ were compared to controls<br>Seven $ECCO_2R$ patients were intubated because of progressive hypoxaemia and four due to ventilatory failure despite $ECCO_2R$ and NIV<br>Nine $ECCO_2R$ patients (36%) suffered from major bleeding complications<br>90-day mortality rates were 28 vs. 28% |

| Etude | Année | Machine | N | Taille du cathéter | Débit sanguin | Débit de gaz | anticoag. | durée |
|---|---|---|---|---|---|---|---|---|
| **kluge et al** | 2012 | iLa Novalung | 21 | 13 à 17 Fr X2 | 1 à 1,5l/min | | HNF APTT 45 à 55 sec | 216 heures |
| **Burki et al** | 2013 | Hemolung | 20 | 15,5Fr | 120 à 580 ml/min | | HNF APTT 1,5 à 2,3 | 3 à 192 heures |
| **Abrams et AL** | 2013 | Palp | 5 | 20 Fr | 1000 à 1700 ml/min | 1 à 7 l/min | HNF APTT 40 à 60 sec | 193 heures |
| **del sorbo et Al** | 2015 | Decap | 25 | 14Fr | 255ml/min | 8l/min 100% | HNF APTT 1,5 | 29 heures |
| **braune et al** | 2016 | iLA Active | 25 | 22Fr | 1400ml/min | | | 204 heures |

# Eviter intubation?

Intensive Care Med (2012) 38:1632–1639
DOI 10.1007/s00134-012-2649-2

ORIGINAL

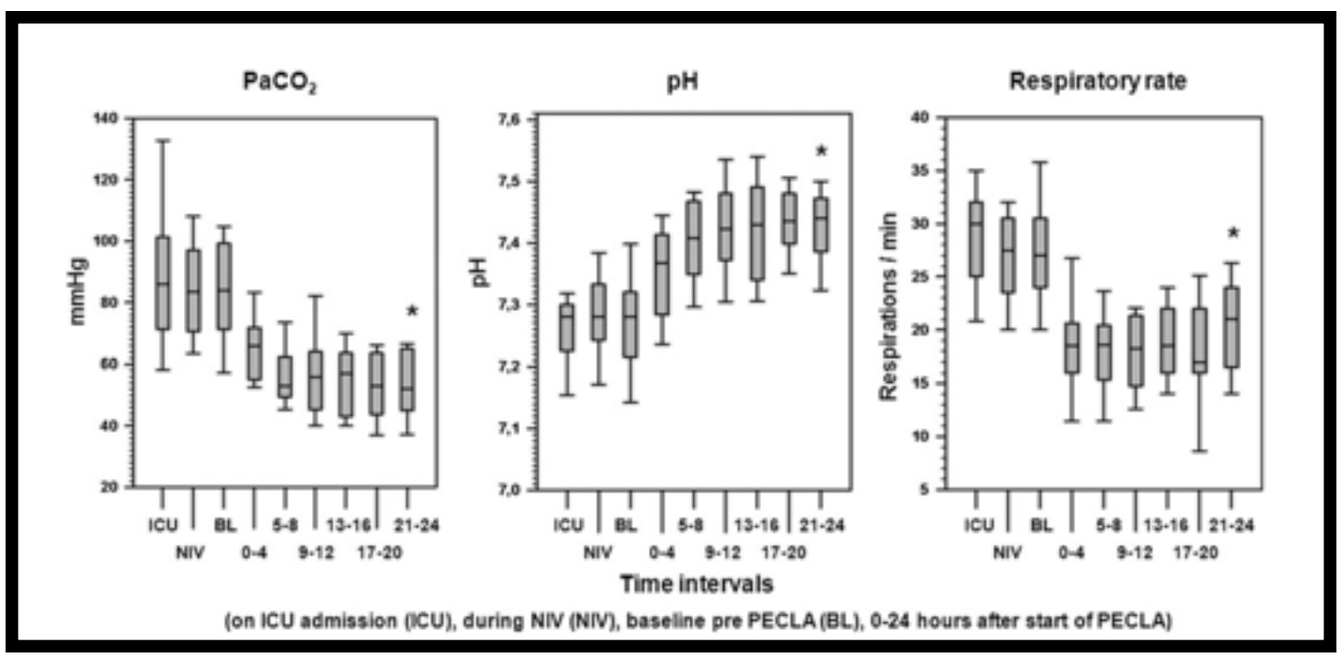
Stefan Kluge
Stephan A. Braune
Markus Engel
Axel Nierhaus
Daniel Frings
Henning Ebelt
Alexander Uhrig
Maria Metschke
Karl Wegscheider
Norbert Suttorp
Simone Rousseau

# Avoiding invasive mechanical ventilation by extracorporeal carbon dioxide removal in patients failing noninvasive ventilation

**Table 2** Comparison of outcomes between the PECLA group and the mechanical ventilation group

| | PECLA group ($n = 21$) | MV group ($n = 21$) | $p$ value | $p$ value* |
|---|---|---|---|---|
| Outcome | | | | |
| Intubation, $n$ (%) | 2 (10) | 21 (100) | <0.001 | <0.001 |
| 28-day mortality, $n$ (%) | 5 (24) | 4 (19) | 1 | 0.845 |
| 6-month mortality, $n$ (%) | 7 (33) | 7 (33) | 1 | 0.897 |
| Time on PECLA/MV (days) | 9 (1–116) | 21 (1–47) | 0.944 | 0.944 |
| Length of ICU stay (days) | 15 (4–137) | 30 (4–66) | 0.577 | 0.263 |
| Length of hospital stay (days) | 23 (4–137) | 42 (4–248) | 0.342 | 0.056 |
| Tracheostomy, $n$ (%) | 2 (10) | 14 (67) | 0.004 | 0.004 |

Values given as median (range) or no (%). *PECLA* pumpless extracorporeal lung assist, *MV* mechanical ventilation
* Adjusted for baseline characteristics of patients (Table 1)



# Faciliter sevrage du respirateur?

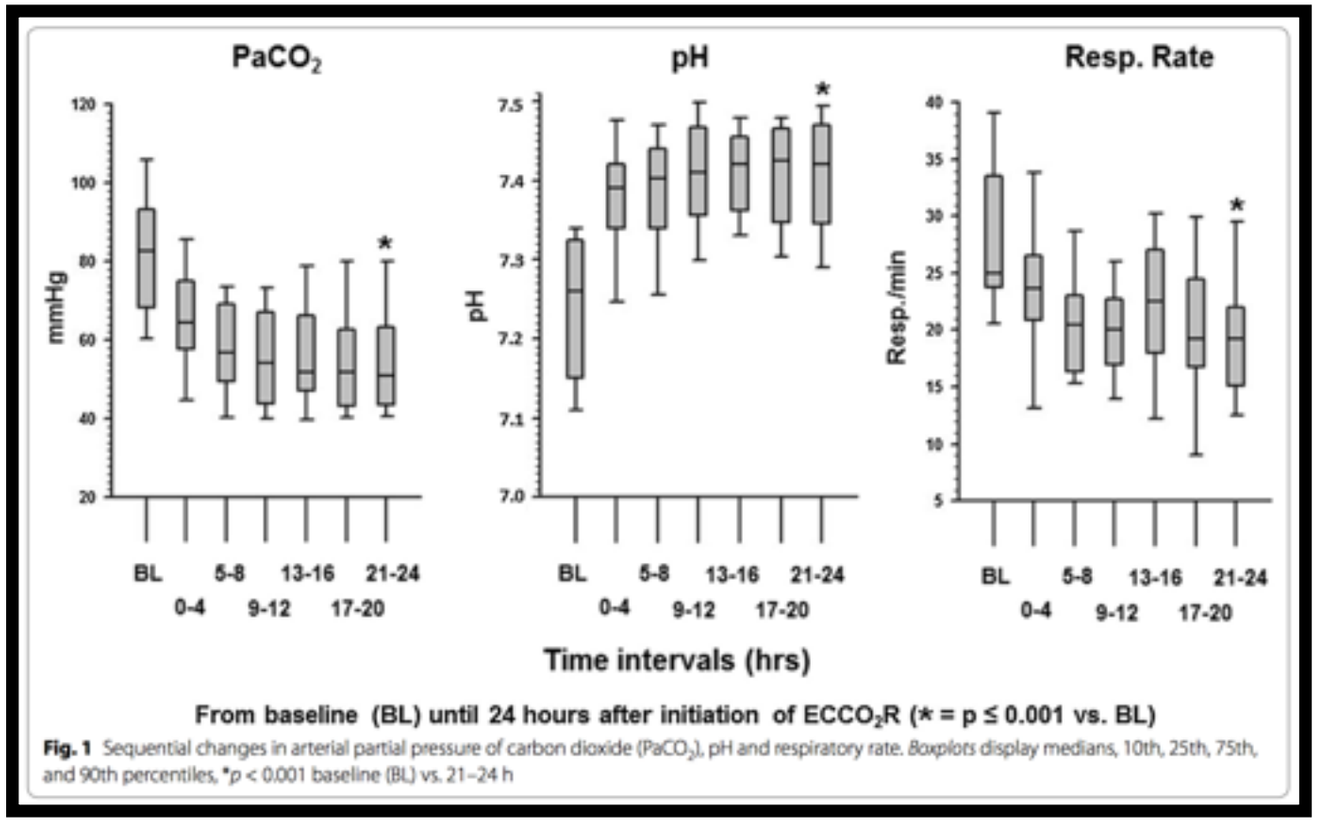
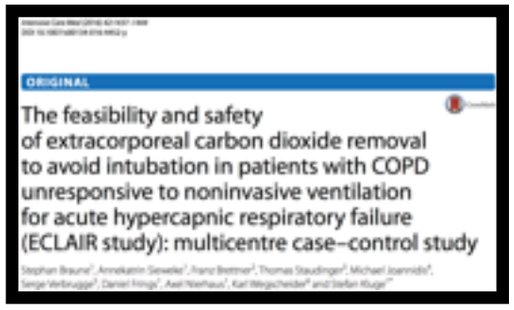



**Fig. 1** Sequential changes in arterial partial pressure of carbon dioxide ($PaCO_2$), pH and respiratory rate. *Boxplots* display medians, 10th, 25th, 75th, and 90th percentiles, *$p < 0.001$ baseline (BL) vs. 21–24 h


ORIGINAL

The feasibility and safety of extracorporeal carbon dioxide removal to avoid intubation in patients with COPD unresponsive to noninvasive ventilation for acute hypercapnic respiratory failure (ECLAIR study): multicentre case–control study

**Table 2 Clinical course and outcomes**

| Clinical course | $ECCO_2R$ group ($n = 25$) | Control group ($n = 25$) | $p$ value |
|---|---|---|---|
| Days on $ECCO_2R$ | 8.5 (1.0–27.0) | N/A | N/A |
| Days on IMV | 8.3 (0–60.0) | 13.7 (1.0–52.0) | 0.02* |
| Tracheotomy | 9.0 (36.0) | 15.0 (60.0) | 0.09* |
| Days on NIV during $ECCO_2R$ | 4.6 (0–22.0) | N/A | N/A |
| Mode of NIV used during $ECCO_2R$ | A-NIV 12.0 %<br>C-NIV 8.0 %<br>Mix-NIV 44.0 % | N/A | N/A |
| Length of stay | | | |
| Days in ICU | 28.9 (8.0–100.0) | 24.0 (2.0–66.0) | 0.09* |
| Days in hospital | 36.9 (9.0–100.0) | 37.0 (12.0–248.0) | 0.49* |
| Mortality *n* (%) | | | |
| 28-day mortality | 4.0 (16.0) | 3.0 (12.0) | 0.68 |
| Hospital mortality | 6.0 (24.0) | 3.0 (12.0) | 0.28 |
| 90-day mortality | 7.0 (28.0) | 7.0 (28.0) | 1.0 |

Values presented as mean (range) or number (%)

*$ECCO_2R$* extracorporeal carbon dioxide removal, *ICU* intensive care unit, *IMV* invasive mechanical ventilation, *N/A* not applicable, *NIV* noninvasive ventilation, *A-NIV* pressure-assisted NIV, *C-NIV* pressure-controlled NIV, *Mix-NIV* pressure-controlled and pressure-assisted NIV

* Adjusted *p* value

# Dans la BPCO, l'ECCO$_2$R:

- Permet de diminuer la $PaCO_2$ et d'améliorer le pH
- Permet de diminuer la fréquence respiratoire dyspnée
- Permet peut-être de diminuer le nombre d'intubations
- Permet peut-être un sevrage plus rapide du ventilateur

# Table des matières

# Complications

- Dépendent de:
  - taille des canules
  - site d’insertion des canules
  - type de pompe et de membrane
  - débit de sang
  - anticoagulation

# Complicatio

- Hémorragiques
- Thromboemboliques
- Aggravation hypoxémie
- Hémolyse
- Liées aux machines et aux canules
- Liée à l'héparine - HIT
- Liée à la VNI ou à la non intubation

**Table 3 $ECCO_2R$-associated adverse events and bleeding/thromboembolic complications**

| Adverse events (*n*) | $ECCO_2R$ group | Control group |
|---|---|---|
| Major $ECCO_2R$-associated adverse events | 14 | N/A |
| Major bleeding | 11 | 2* |
| Pulmonary haemorrhage | 2 | – |
| Bleeding from tracheostomy | 2 | 1 |
| Haematothorax | 2 | – |
| Bleeding from gastric ulcer | 1 | – |
| Bleeding from rectal ulcer | 1 | – |
| Bleeding from oesophageal varices | – | 1 |
| Retroperitoneal haematoma | 1 | – |
| Dislodged sealing cap of DLC | 1 | – |
| Cannula insertion site | 1 | – |
| Device-related | 3 | N/A |
| Air detection in the circuit | 1 | – |
| Extracorporeal clotting | 2 | – |
| Minor $ECCO_2R$-associated adverse events | 11 | N/A |
| Minor bleeding/thrombosis | 10 | 10 |
| Haematuria | 3 | 1 |
| Cannula insertion site | 2 | – |
| Intracerebral bleeding (small) | – | 1 |
| Epistaxis | 2 | – |
| Haemorrhagic pleural effusion | 1 | – |
| Tracheobronchial haemorrhage | 1 | 3 |
| Bleeding from ileostomy | 1 | – |
| Inguinal haematoma | – | 1 |
| Intramuscular bleeding lower limb | – | 1 |
| Postoperative wound bleeding | – | 1 |
| Bleeding from tracheostomy | – | 1 |
| Thrombosis inferior vena cava and renal vein | | 1 |
| Device-related | 1 | N/A |
| Disconnection of sweep gas tubing | 1 | – |

Of 11 patients suffering major $ECCO_2R$-related adverse events, 2 patients each suffered two major bleeding episodes and 1 patient suffered a major bleeding episode and a device-related adverse event

*DLC* double-lumen catheter, *$ECCO_2R$* extracorporeal carbon dioxide removal, *N/A* not applicable

* $p < 0.001$

# Anticoagulation

- Héparine non fractionnée
- APTT entre 1,3 et 2,3 x la normale
- ou entre 40 et 60 secondes

# Anticoagulation régionale au Citrate?

ASAIO J. 2006 Jul-Aug;52(4):467-70.

**Percutaneous venovenous CO2 removal with regional anticoagulation in an ovine model.**

Cardenas VJ Jr[1], Miller L, Lynch JE, Anderson MJ, Zwischenberger JB.

**Author information**

**Abstract**

Extracorporeal CO2 removal may reduce minute ventilation requirements and allow for better tolerance of low tidal volume ventilating strategies in patients with severe respiratory insufficiency. Conventional extracorporeal gas exchange is labor-intensive, expensive, and usually requires systemic anticoagulation. In this study, a simplified venovenous circuit was developed by using regional citrate anticoagulation to avoid potential complications associated with systemic heparin. Five healthy adult sheep underwent percutaneous placement of a double-lumen 18F catheter into the internal jugular vein. The extracorporeal circuit consisted of a hollow fiber oxygenator and a variable speed roller pump. Regional anticoagulation consisted of a continuous citrate infusion to the inflow limb of the circuit. Systemic calcium levels were maintained by calcium chloride infusion through a central line. CO2 transfer was measured at varying levels of blood and gas flow. CO2 transfer ranged from 31 ml/min (500 ml/min blood flow; 2 l/min gas flow) to 150 ml/min (1000 ml/min blood flow; 15 l/min gas flow) and was directly proportional to blood flow and gas flow ($p < 0.05$). Normocapnia was maintained despite a 75% reduction in minute ventilation. At 24 hours, there was no significant clot formation in the circuit.

# Aggravation de l'hypoxémie en $ECCO_2R$

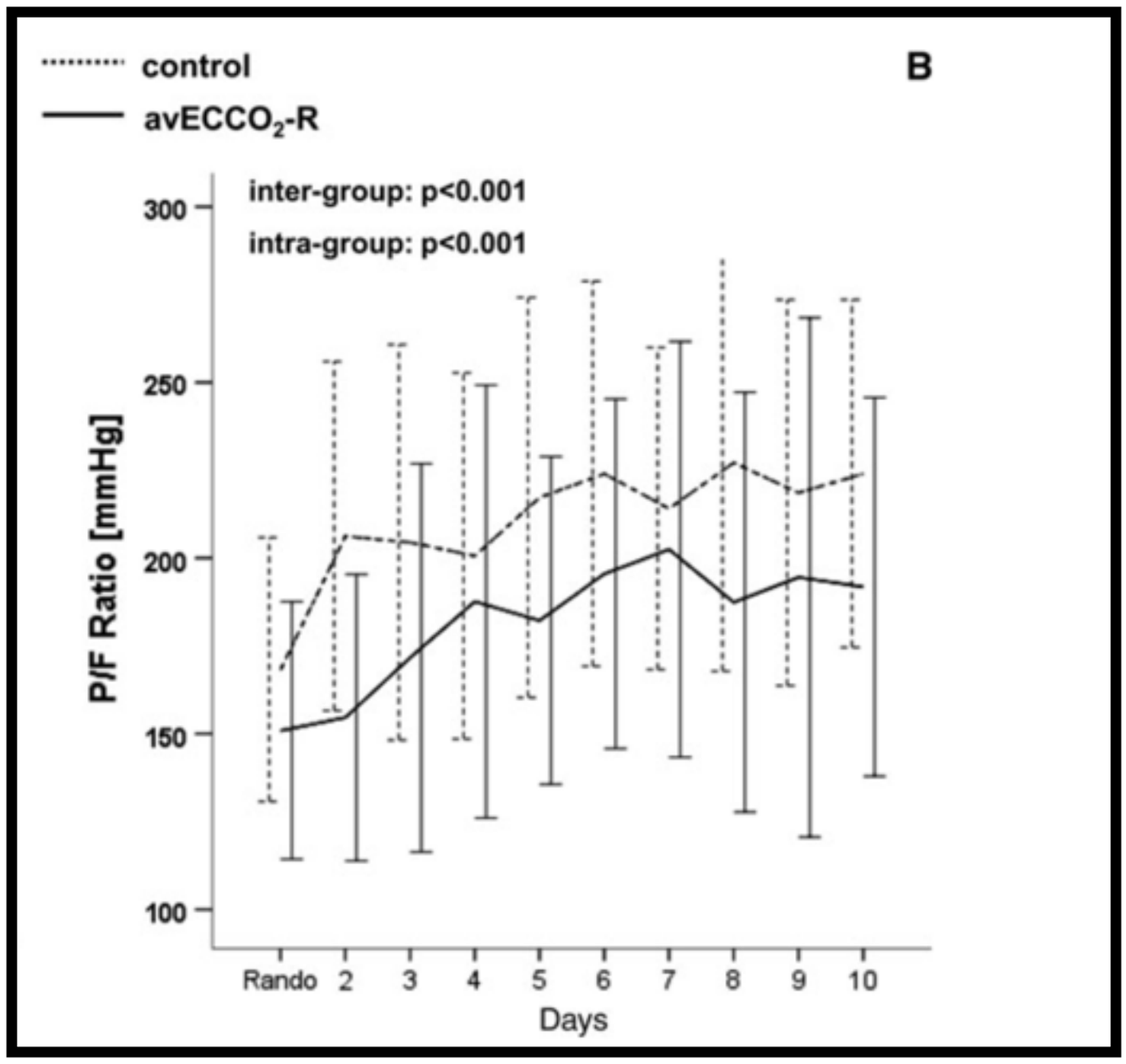
Intensive Care Med (2013) 39:847–856
DOI 10.1007/s00134-012-2787-6

ORIGINAL

Thomas Bein
Steffen Weber-Carstens
Anton Goldmann
Thomas Müller
Thomas Staudinger
Jörg Brederlau
Ralf Muellenbach
Rolf Dembinski
Bernhard M. Graf
Marlene Wewalka
Alois Philipp
Klaus-Dieter Wernecke
Matthias Lubnow
Arthur S. Slutsky

**Lower tidal volume strategy (≈3 ml/kg) combined with extracorporeal $CO_2$ removal versus 'conventional' protective ventilation (6 ml/kg) in severe ARDS**

**The prospective randomized Xtravent-study**



# Aggravation de l'hypoxémie en $ECCO_2R$

- Atélectasies gravitationnelles (Pmoyenne)
  - augmenter Peep
- Pression < Pression d'ouverture = dérecrutement
- Atélectasies de réabsorption (Sweep FIO2 > FIO2)
- Diminution du quotient respiratoire
  - $P_AO_2 = FIO_2 (P_{atm}-P_{H2O}) - PaCO_2/Q$

Crit Care. 2016; 20: 130. PMCID: PMC4865006
Published online 2016 May 12. doi: 10.1186/s13054-016-1310-9

**Ultra-protective ventilation and hypoxemia**

Luciano Gattinoni

# Table des matières


Débit 0 - 450 ml/min
KT 13 Fr
Associée ou non à l'EER

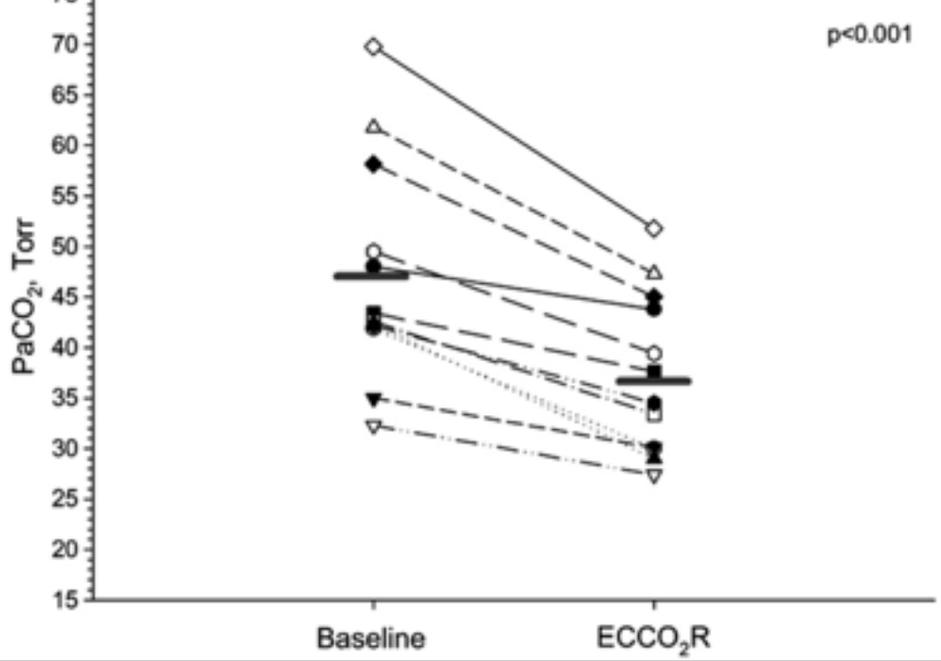
Crit Care Med. 2015 Dec; 43(12): 2570–2581.
Published online 2015 Nov 17. doi: 10.1097/CCM.0000000000001296
PMCID: PMC4648187

# Safety and Efficacy of Combined Extracorporeal $Co_2$ Removal and Renal Replacement Therapy in Patients With Acute Respiratory Distress Syndrome and Acute Kidney Injury: The Pulmonary and Renal Support in Acute Respiratory Distress Syndrome Study*

Jérôme Allardet-Servent, MD, MSc,[✉] Matthias Castanier, MD, Thomas Signouret, MD, Rettinavelou Soundaravelou, MD, Anne Lepidi, MD, and Jean-Marie Seghboyan, MD


ARDS + Acute kidney injury
n = 11

**Figure 1.**



Crit Care Med. 2015 Dec; 43(12): 2570–2581. PMCID: PMC4648187
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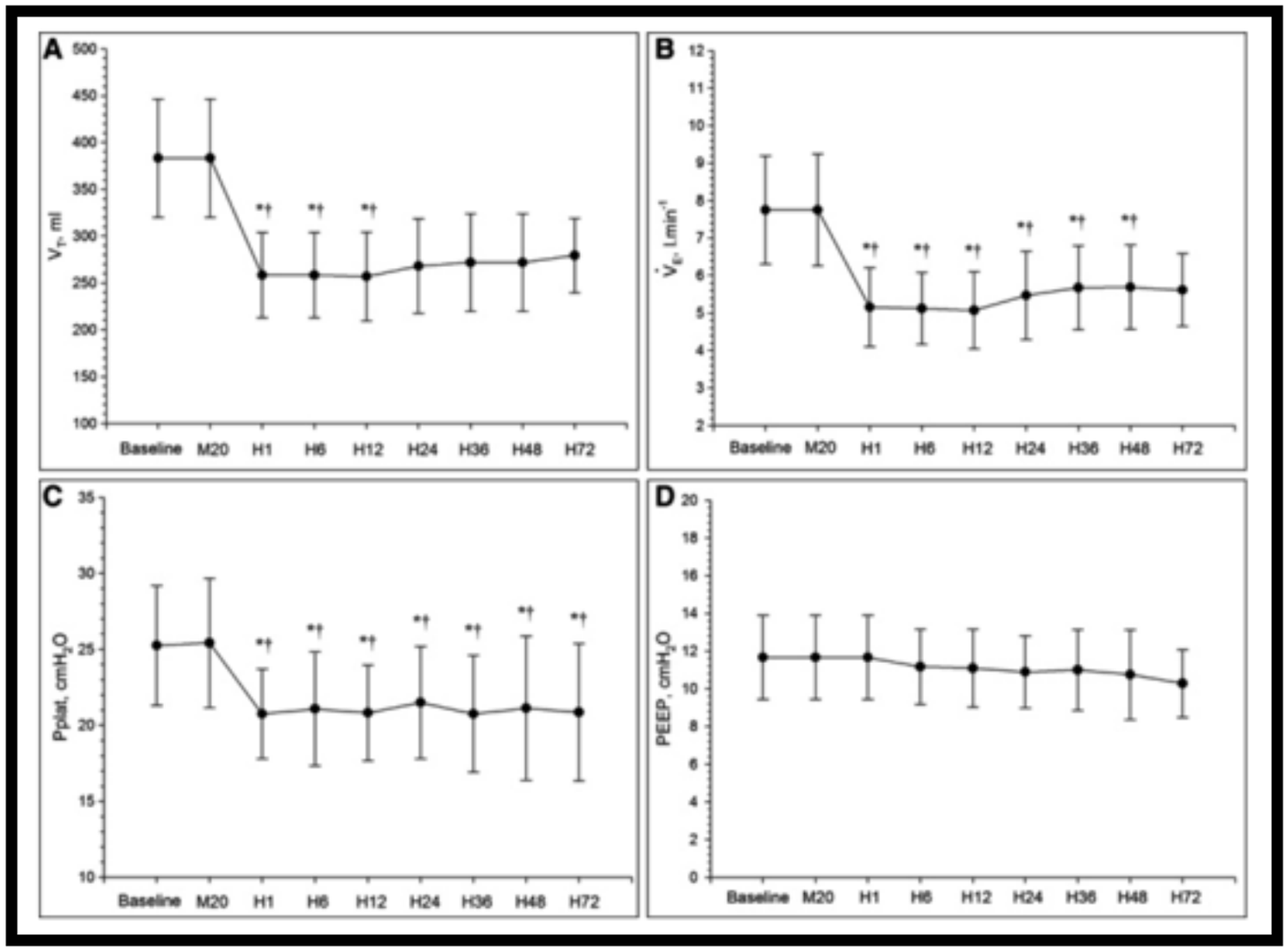
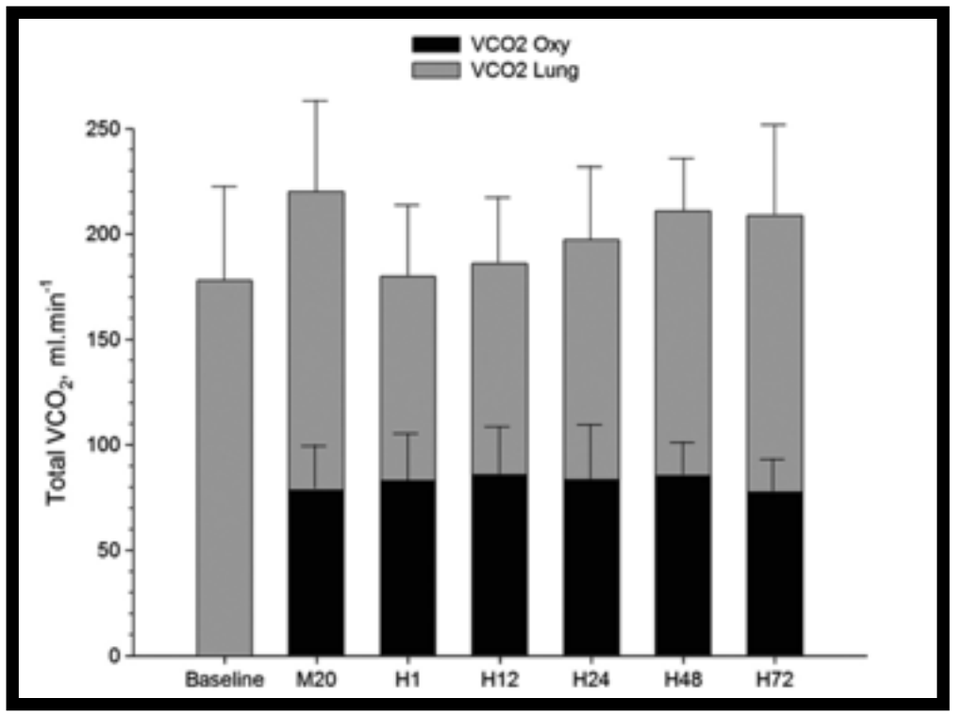
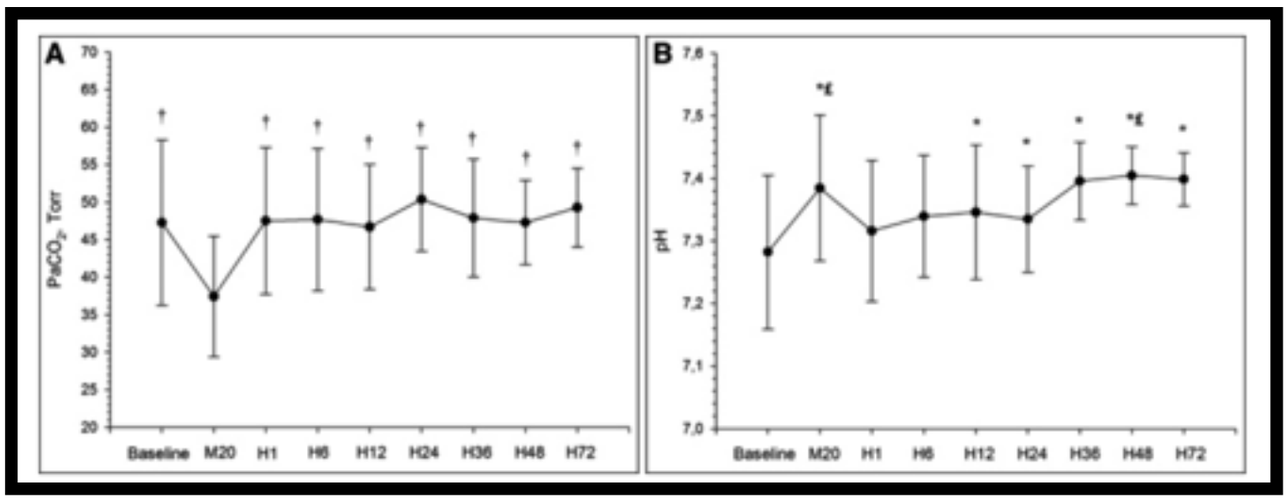


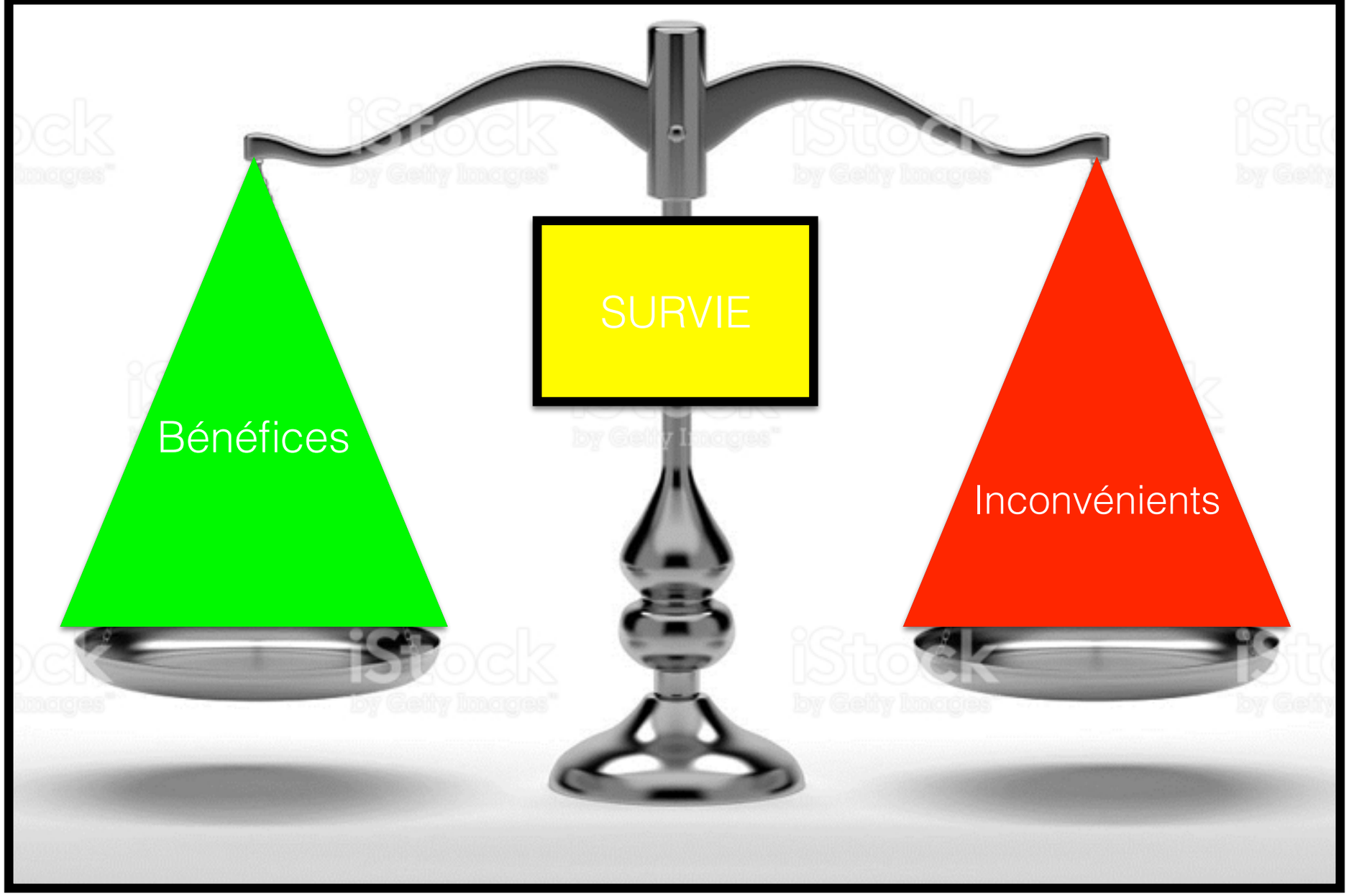

Durée 72 heures
1 hemofilter clotting
Pas de saignement
KT 15,5 Fr; 410 ml/min
Sweep gas 8l/min FIO2 1



# Table des matières

1500 à 2500 euros par filtre
Maximum 72 heures

# Table des matières




Durée et complications de la ventilation

Complications de l'ECCO2R
Coût

Pas d'EBM

Effets secondaires Ventilation mécanique
versus
Effets secondaires ECCO2R

= Etudes de survie/mortalité

# Table des matières

# The Berlin Definition

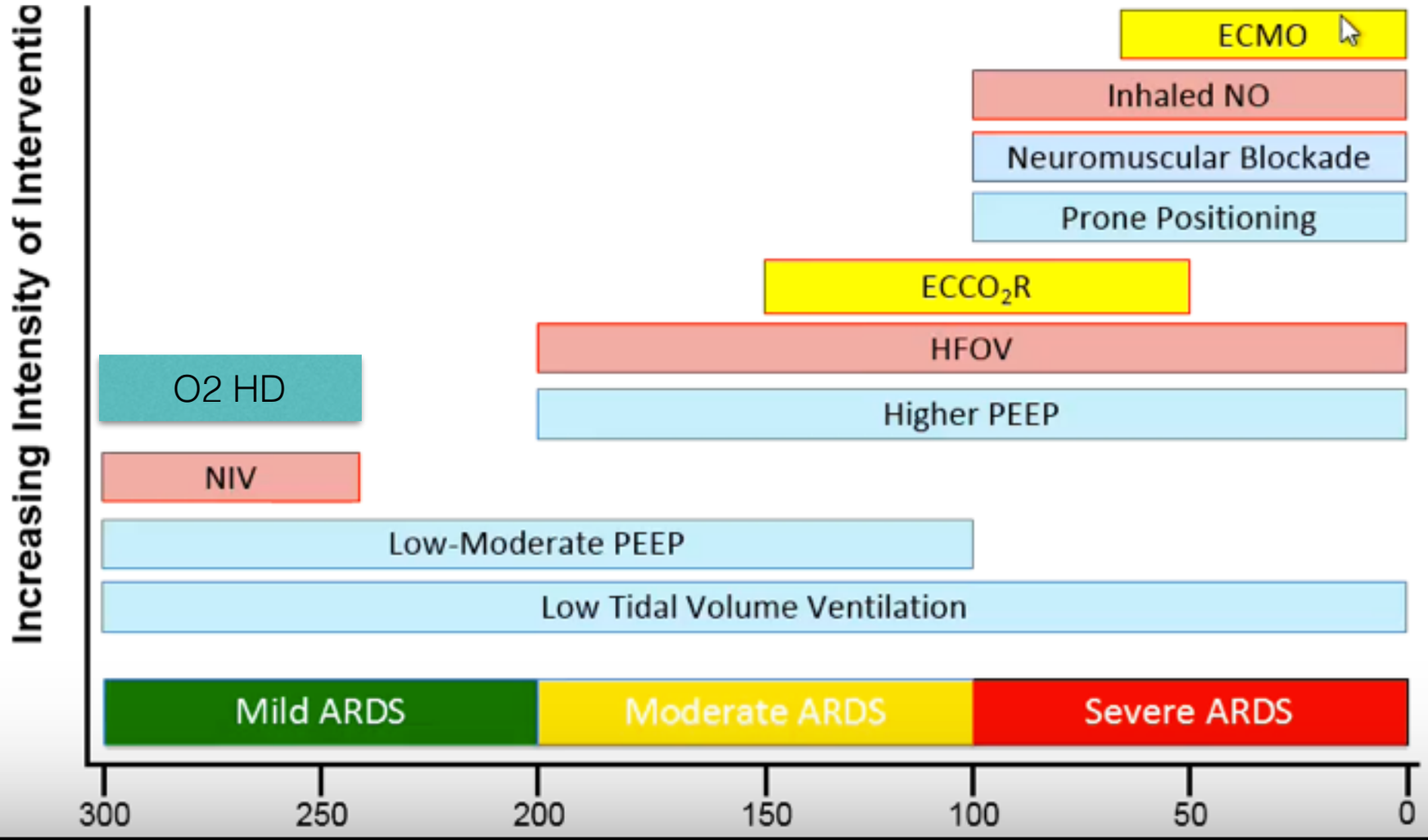



**Table 3.** The Berlin Definition of Acute Respiratory Distress Syndrome

| | Acute Respiratory Distress Syndrome |
|---|---|
| Timing | Within 1 week of a known clinical insult or new or worsening respiratory symptoms |
| Chest imaging[a] | Bilateral opacities—not fully explained by effusions, lobar/lung collapse, or nodules |
| Origin of edema | Respiratory failure not fully explained by cardiac failure or fluid overload<br>Need objective assessment (eg, echocardiography) to exclude hydrostatic edema if no risk factor present |
| Oxygenation[b] | |
| Mild | 200 mm Hg < $Pa_{O_2}/F_{IO_2}$ ≤ 300 mm Hg with PEEP or CPAP ≥5 cm $H_2O$[c] |
| Moderate | 100 mm Hg < $Pa_{O_2}/F_{IO_2}$ ≤ 200 mm Hg with PEEP ≥5 cm $H_2O$ |
| Severe | $Pa_{O_2}/F_{IO_2}$ ≤ 100 mm Hg with PEEP ≥5 cm $H_2O$ |

Abbreviations: CPAP, continuous positive airway pressure; $F_{IO_2}$, fraction of inspired oxygen; $Pa_{O_2}$, partial pressure of arterial oxygen; PEEP, positive end-expiratory pressure.
[a] Chest radiograph or computed tomography scan.
[b] If altitude is higher than 1000 m, the correction factor should be calculated as follows: [$Pa_{O_2}/F_{IO_2}$ × (barometric pressure/760)].
[c] This may be delivered noninvasively in the mild acute respiratory distress syndrome group.

# ARDS

## Pour permettre la ventilation protectrice

Options?

Accepter la Pplat > 30
Accepter l'acidémie
L'ECMO
L'ECCO$_2$R

++ si CVVH

## Pour permettre une ventilation ultra-protectrice

Pas d'EBM

Etudes en cours

Pas d’EBM

Envisager si CVVH
mais
Coût +

# Asthme

Medicine (Baltimore). 2017 Oct;96(41):e8248. doi: 10.1097/MD.0000000000008248.

**Rescue therapeutic strategy combining ultra-protective mechanical ventilation with extracorporeal CO2 removal membrane in near-fatal asthma with severe pulmonary barotraumas: A case report.**

Pavot A[1], Mallat J, Vangrunderbeeck N, Thevenin D, Lemyze M.

# ECCO2R et Insuffisance cardiaque droite

Perfusion. 2016 Sep;31(6):525-9. doi: 10.1177/0267659115621783. Epub 2015 Dec 6.

## Effect of extracorporeal CO2 removal on right ventricular and hemodynamic parameters in a patient with acute respiratory distress syndrome.

Cherpanath TG[1], Landburg PP[2], Lagrand WK[3], Schultz MJ[4], Juffermans NP[3].

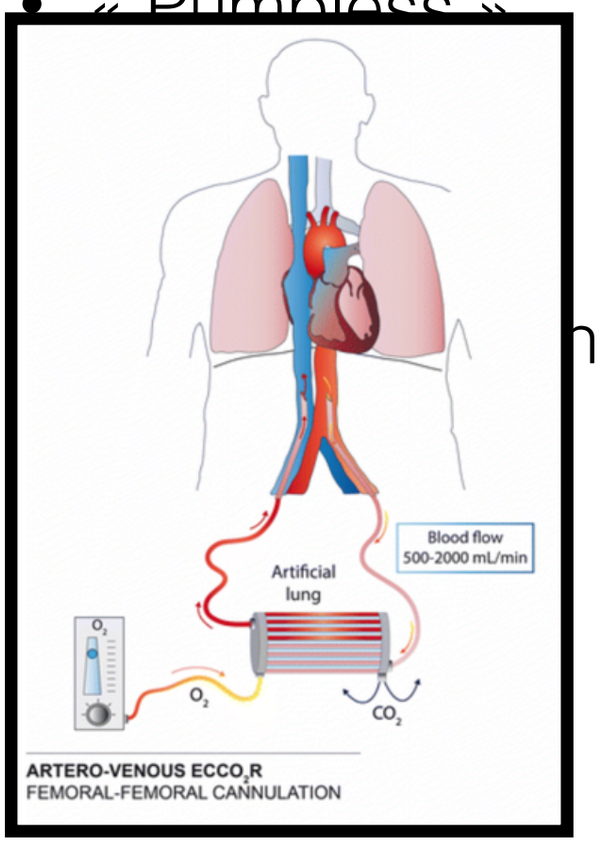
Author information

**Abstract**

We present a female patient with severe acute respiratory distress syndrome (ARDS) necessitating intubation and mechanical ventilation on the intensive care unit (ICU). High ventilatory pressures were needed because of hypoxia and severe hypercapnia with respiratory acidosis, resulting in right ventricular dysfunction with impaired haemodynamic stability. A veno-venous extracorporeal CO2 removal (ECCO2R) circuit was initiated, effectively eliminating carbon dioxide while improving oxygenation and enabling a reduction in applied ventilatory pressures. We noted a marked improvement of right ventricular function with restoration of haemodynamic stability. Within one week, the patient was weaned from both ECCO2R and mechanical ventilation. Besides providing adequate gas exchange, extracorporeal assist devices may be helpful in ameliorating right ventricular dysfunction during ARDS.

# Table des matières

# iLA Novalung Membrane Ventilator

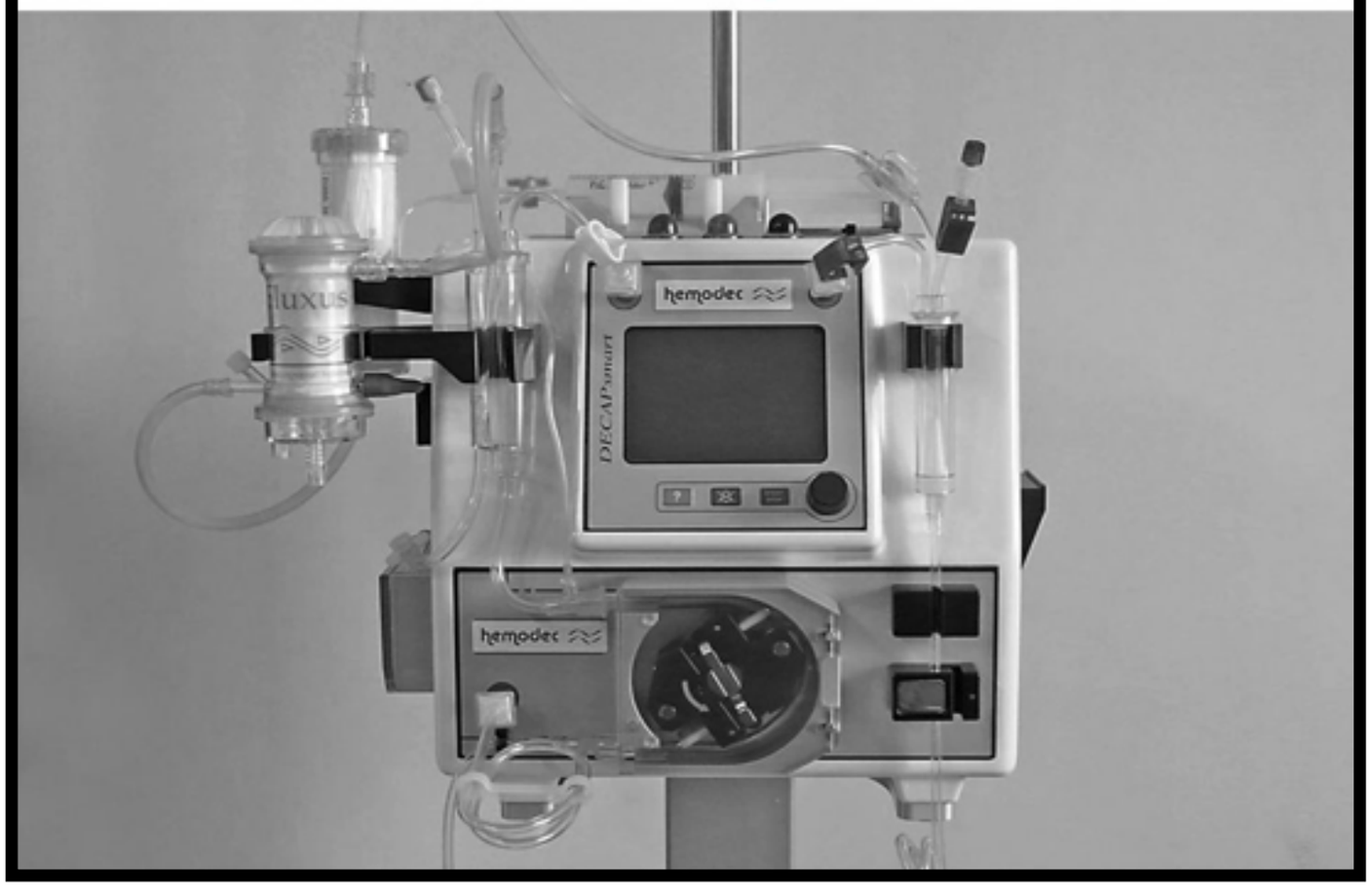



# Hemolung - Alung

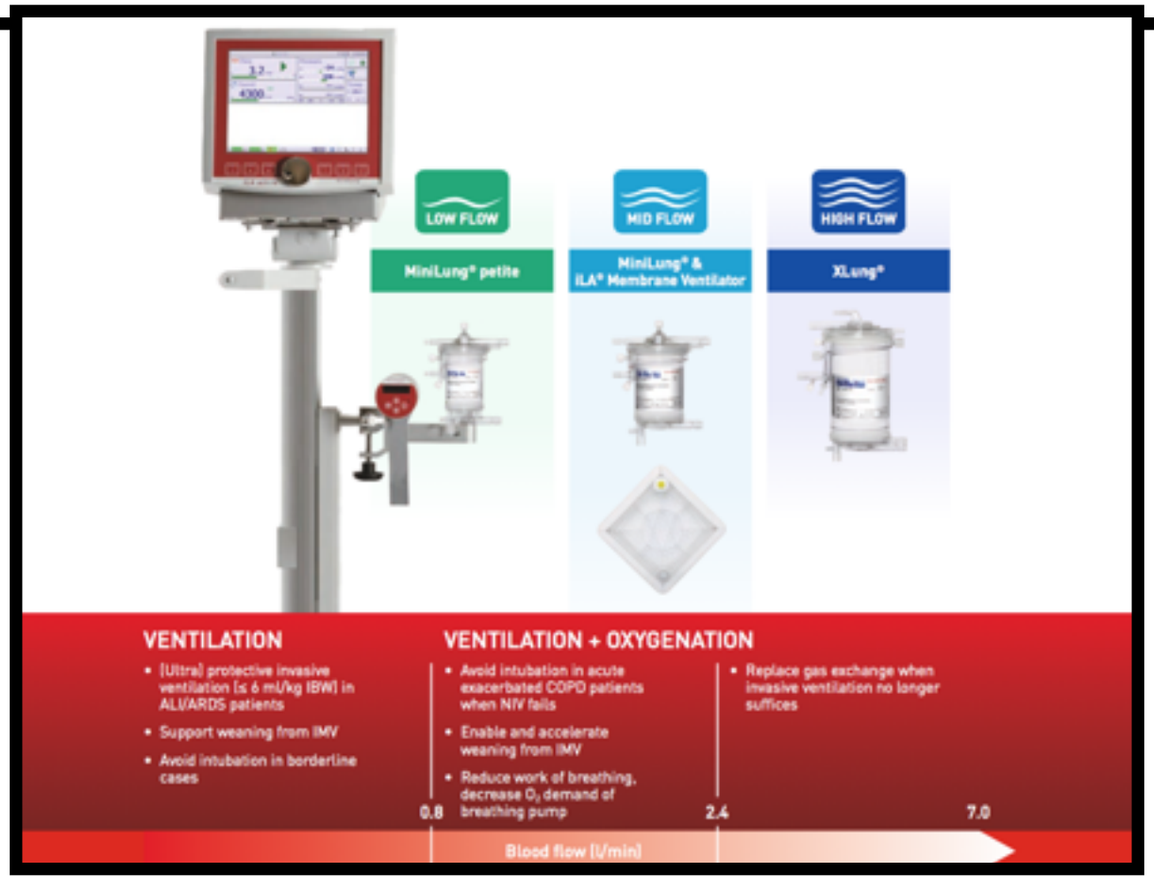
- Débit 350 - 550 ml/mi,
- KT 15,5 Fr
- Membrane héparin-coated
    - APTT x 1,5

Débit 0 - 500 ml/min
KT 13 Fr

**Decap**



# iLA ActiVVE de Novalung




Intensive Care Med. 2015 Oct;41(10):1773-80. doi: 10.1007/s00134-015-3957-0. Epub 2015 Jul 14.

**A novel pump-driven veno-venous gas exchange system during extracorporeal CO2-removal.**

Hermann A[1], Riss K[1], Schellongowski P[1], Bojic A[1], Wohlfarth P[1], Robak O[1], Sperr WR[1], Staudinger T[2].

n = 10

22 Fr

Sweep gas 1 to 14 l/min

Q 0,5 to 2,0 l/min

| Technical Data | PALP Set |
|---|---|
| Blood flow | 0.2 – 2.8 l/min |
| Surface area gas exchange membrane | 0.98 m² |
| Priming volume PALP Module | 80 ml |
| Priming vol. PALP Set with 2 x 2.2 m tubing length | 247 ml |
| Membrane | Diffusion membrane (PMP) |
| Coating | BIOLINE Coating (SOFTLINE Coating available) |
| Integrated measuring cell | – venous oxygen saturation $S_vO_2$<br>– hemoglobin<br>– hematocrit<br>– venous temperature |
| Integrated sensors | 3 pressures<br>– venous<br>– arterial<br>– internal |
| Duration of use | PALP Set with BIOLINE coating max. 30 days<br>PALP HIT Set with SOFTLINE coating max. 5 days |

Anaesth Crit Care Pain Med. 2015 Jun;34(3):135-40. doi: 10.1016/j.accpm.2014.08.006. Epub 2015 May 23.

# Novel CO2 removal device driven by a renal-replacement system without hemofilter. A first step experimental validation.

Godet T[1], Combes A[2], Zogheib E[3], Jabaudon M[4], Futier E[5], Slutsky AS[6], Constantin JM[7].

n = 5 cochons
Sweep Gas 2, 5,10 ,50 l/min
Q 200, 300, 400 l/min
Clearance CO2 35 à 75 ml/min
FIO2 21% = 100%

Minerva Anestesiol. 2017 Aug;83(8):812-823. doi: 10.23736/S0375-9393.17.11524-5. Epub 2017 Mar 8.

# Low flow veno-venous extracorporeal CO2 removal for acute hypercapnic respiratory failure.

Hilty MP[1], Riva T[2,3], Cottini SR[4], Kleinert EM[2], Maggiorini A[2], Maggiorini M[2].

Author information

## Abstract

**BACKGROUND:** Ventilation with low tidal volume and airway pressure results in a survival benefit in ARDS patients. Previous research suggests that avoiding mechanical ventilation altogether may be beneficial in some cases of respiratory failure. Our hypothesis was that low flow veno-venous extracorporeal CO2 removal (ECCO2R) enables maintenance of a lung protective ventilation strategy or awake spontaneous ventilation despite severe hypercapnic respiratory failure (HRF).

**METHODS:** Twenty patients with HRF were investigated while mechanically ventilated (N.=14) or breathing spontaneously close to respiratory exhaustion (N.=6). Low flow ECCO2R was performed using a hemoperfusion device with a polypropylene gas-exchanger.

**RESULTS:** Causes of HRF were severe ARDS (N.=11), COPD (N.=4), chronic lung transplant rejection (N.=3) and cystic fibrosis (N.=2). During the first 8h of ECCO2R, PaCO2 decreased from 10.6 (9.3-12.9) to 7.9 (7.3-9.3) kPa (P<0.001) and pH increased from 7.23 (7.09-7.40) to 7.36 (7.27-7.41) (P<0.05). Thereafter, steady state was achieved while maintaining lung protective tidal volume (4.7 (3.8-6.5) mL/kg) and peak ventilator pressure (28 (27-30) mbar at 24 h). During the first 48 h, thrombocyte count decreased by 52% (P<0.01), Fibrinogen by 38% (P<0.05). Intubation could be avoided in all spontaneously breathing patients. In 4/6 high blood flow extracorporeal circulation was required due to increased oxygen demand. 6/14 mechanically ventilated patients recovered from respiratory support.

**CONCLUSIONS:** Our results suggest that in mechanically ventilated patients with HRF, low flow ECCO2R supports the maintenance of lung protective tidal volume and peak ventilator pressure. In selected awake patients with acute HRF, it may be a novel treatment approach to avoid mechanical ventilation, hence preventing ventilator- and sedation-associated morbidity and mortality.

ABYLCAP

$CO_2$ REMOVAL

Bellco

BMC Anesthesiol. 2017 Nov 28;17(1):155. doi: 10.1186/s12871-017-0445-9.

**Low flow extracorporeal CO2 removal in ARDS patients: a prospective short-term crossover pilot study.**

Peperstraete H[1], Eloot S[2,3], Depuydt P[4,3], De Somer F[3,5], Roosens C[4], Hoste E[4,3,6].

n = 10 ARDS

PaCO2 de 58 à 49 mmHg

50 % hémorragies mineures

30 % thrombose du circuit

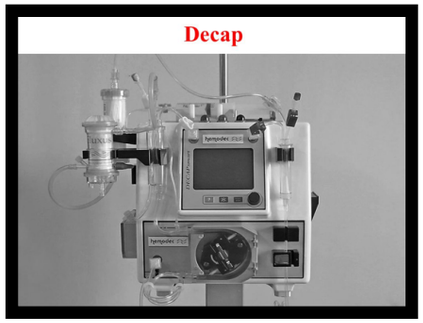
| Etude | N | Taille du cathéter | Débit sanguin | anticoag. | complications | Pompe | thrombose circuit | locoregional | hypoxémie | hémorragie | HIT Thrombopénie |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Terragni et Al.** | 10 | 14Fr | 280-350 ml/min | HNF APTT 1,3 à 1,5 | | 1/22 | 3/22 | 4/22 | | | |
| **Bein et Al.** | 40 vs 39 | Art 15 Fr V 17Fr | 1000 à 2000 ml/ min | HNF` APTT 40-50 sec | - Plus de GRC | | | 7,5 % 1 ischémie | + | | |
| **Fanelli et AL.** | 15 | 15,5 Fr | 420-435 ml/min | HNF APP 1,77 | transfusion 1 hémolyse | 2/15 | | 2/15 | 33% aggravation hypoxémie | | |
| **SUPERNOVA** | 95 | | | | | | | | | | |

Anesthesiology 2009; 111:826–35 

# *Tidal Volume Lower than 6 ml/kg Enhances Lung Protection*

## *Role of Extracorporeal Carbon Dioxide Removal*

*Pier Paolo Terragni, M.D.,* Lorenzo Del Sorbo, M.D.,* Luciana Mascia, M.D., Ph.D.,* Rosario Urbino, M.D.,* Erica L. Martin, Ph.D.,* Alberto Birocco, M.D.,† Chiara Faggiano, M.D.,† Michael Quintel, M.D.,‡ Luciano Gattinoni, M.D.,§ V. Marco Ranieri, M.D.‖*




Etude prospective

Machine d'hémofiltration modifiée

Membrane ECMO néonatologie

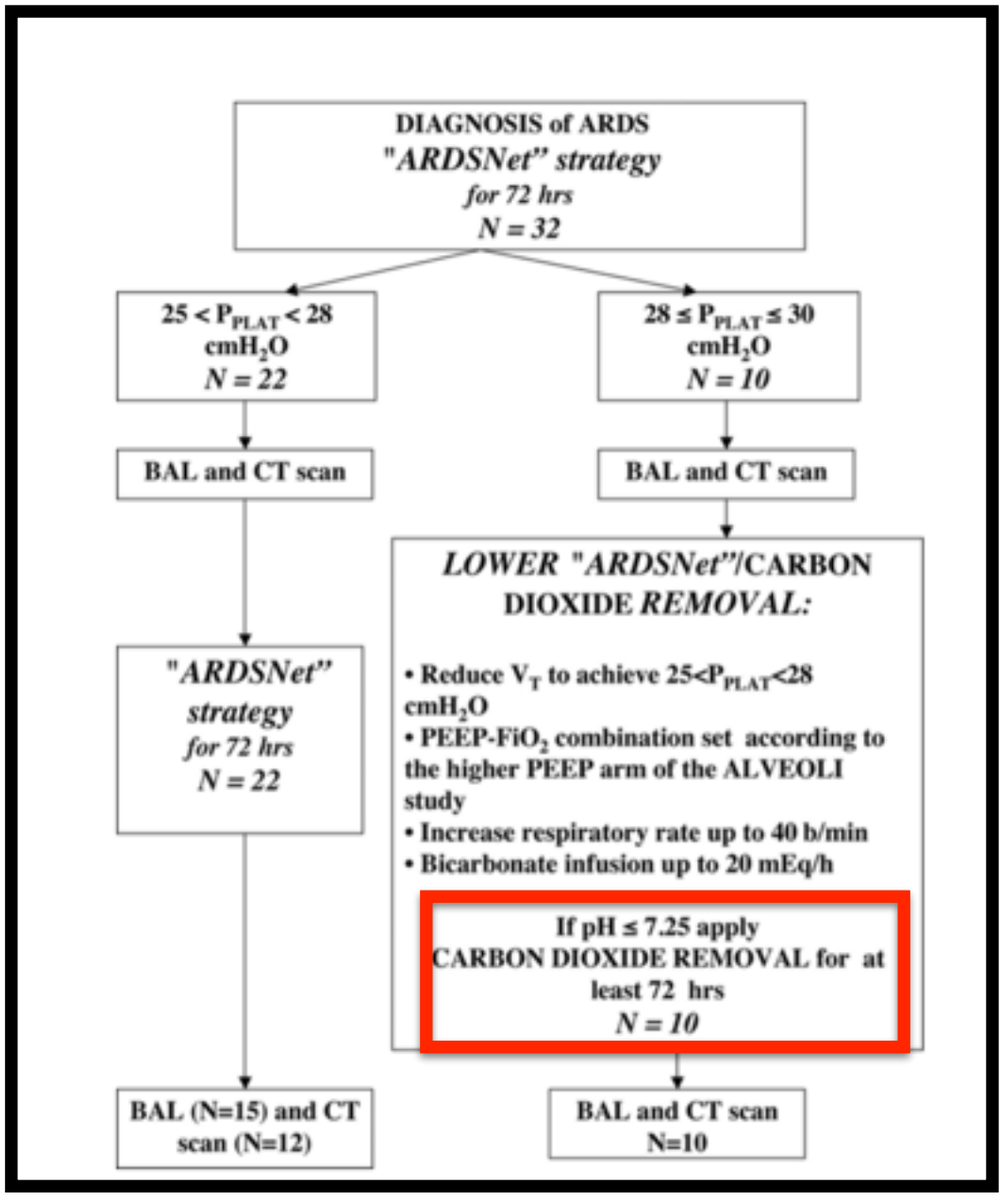
Vt < 6 ml/kg (step de 1/4h)

augmentation peep

14Fr fémoral

Débit 0-500 ml/min

O2 pure 8l/min

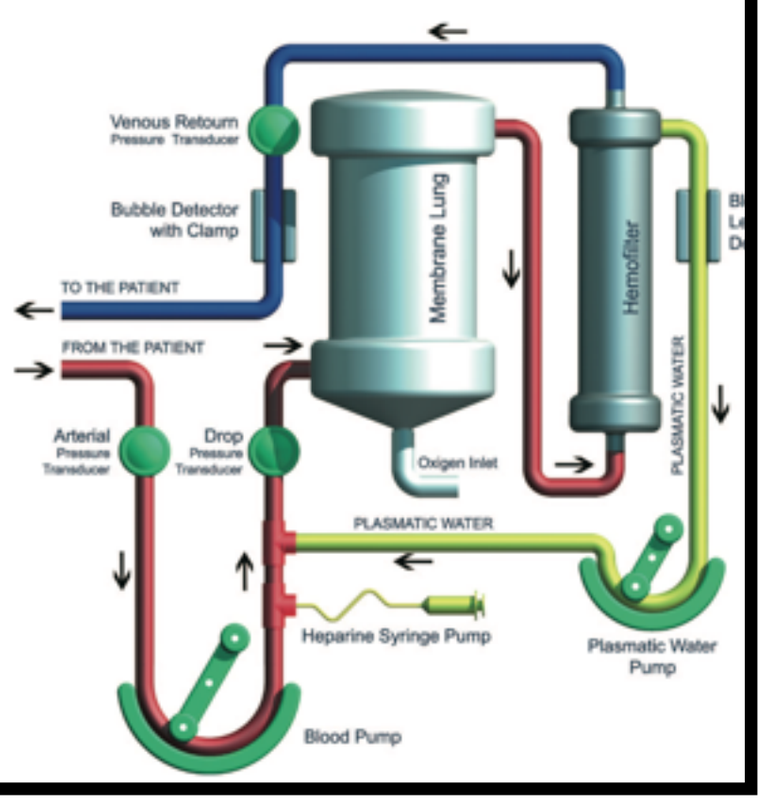


Anesthesiology 2009; 111:826–35 

# *Tidal Volume Lower than 6 ml/kg Enhances Lung Protection*

## *Role of Extracorporeal Carbon Dioxide Removal*

*Pier Paolo Terragni, M.D.,* Lorenzo Del Sorbo, M.D.,* Luciana Mascia, M.D., Ph.D.,* Rosario Urbino, M.D.,* Erica L. Martin, Ph.D.,* Alberto Birocco, M.D.,† Chiara Faggiano, M.D.,† Michael Quintel, M.D.,‡ Luciano Gattinoni, M.D.,§ V. Marco Ranieri, M.D.‖*




Héparine
APTT x 1,5
80 UI/kg et 18UI/kg/h

**Table 2. Quantitative CT Scan of the Study Population**

| | | *ARDSNet* 25 < $P_{PLAT}$ < 28 | | *ARDSNet* 28 ≤ $P_{PLAT}$ ≤ 30 | |
|---|---|---|---|---|---|
| | Overall Population (n = 32) | Study Entry (n = 22) | After 72 h of Conventional *ARDSNet* (n = 12) | Study Entry (n = 10) | After 72 h of Lower *ARDSNet*/Carbon Dioxide Removal (n = 10) |
| Lung weight, g | 1.661 ± 466 | 1.488 ± 513 | 1.143 ± 234§ | 1.919 ± 402* | 1.519 ± 106# |
| End inspiratory CT lung compartments, % total lung volume | | | | | |
| Non-aerated (+100 and –100 HU) | 16.2 ± 7.8 | 12.6 ± 8.7 | 3.1 ± 1.1§ | 23.2 ± 7.0* | 12.3 ± 2.6# |
| Poorly aerated (–101 and –500 HU) | 14.3 ± 6.1 | 11.2 ± 6.5 | 1.1 ± 0.3§ | 16.3 ± 2.8* | 11.4 ± 6.7# |
| Normally aerated (–501 and –900 HU) | 58.7 ± 10.5 | 72.3 ± 10.1 | 94.5 ± 3.8§ | 40.1 ± 9.5* | 75.5 ± 8.8# |
| Hyperinflated (–901 and –1,000 HU) | 10.8 ± 8.5 | 3.9 ± 3.4 | 1.3 ± 0.2§ | 20.4 ± 4.4* | 0.8 ± 0.7# |

Anesthesiology 2009; 111:826–35 

# *Tidal Volume Lower than 6 ml/kg Enhances Lung Protection*

## *Role of Extracorporeal Carbon Dioxide Removal*

*Pier Paolo Terragni, M.D.,* Lorenzo Del Sorbo, M.D.,* Luciana Mascia, M.D., Ph.D.,* Rosario Urbino, M.D.,* Erica L. Martin, Ph.D.,* Alberto Birocco, M.D.,† Chiara Faggiano, M.D.,† Michael Quintel, M.D.,‡ Luciano Gattinoni, M.D.,§ V. Marco Ranieri, M.D.‖*

**Table 3. Coagulation Parameters and Blood Flow**

| | $T_{1.5}$ | $T_{24}$ | $T_{48}$ | $T_{72}$ |
|---|---|---|---|---|
| aPTT ratio* | 1.3 ± 0.2 | 1.4 ± 0.1 | 1.5 ± 0.2 | 1.4 ± 0.2 |
| Heparin, IU/kg* | 8 ± 5 | 11 ± 7 | 11 ± 8 | 11 ± 7 |
| Blood flow through $CO_2$ removal device, ml/min* | 348 ± 74 | 357 ± 75 | 329 ± 78 | 282 ± 91 |
| Cardiac output, ml/min* | 5.8 ± 1.3 | 5.6 ± 1.2 | 5.7 ± 1.1 | 6.4 ± 2.3 |
| Fluid balance, ml† | 530 (–420, 1,545) | –215 (–2,944, 2,041) | 648 (–220, 1,100) | 119 (–1,062, 625) |

**Table 4. Total Number of Mechanical Complications Occurring during the 144 (84, 168)* Hours of Treatment**

| | Frequency (n) |
|---|---|
| Pump malfunction | 1 |
| Membrane lung/hemofilter clotting | 3 |
| Catheter displacement | 1 |
| Cannula problems, *i.e.* need for two cannulas instead of a single double-lumen | 3 |

"ARDSNet" strategy: $25<P_{PLAT}<28$

◇ *Entry (N = 22)*

◆ *after 72 hrs (N = 15)*

"ARDSNet" strategy: $28\leq P_{PLAT}\leq 30$

○ *Entry (N = 10)*

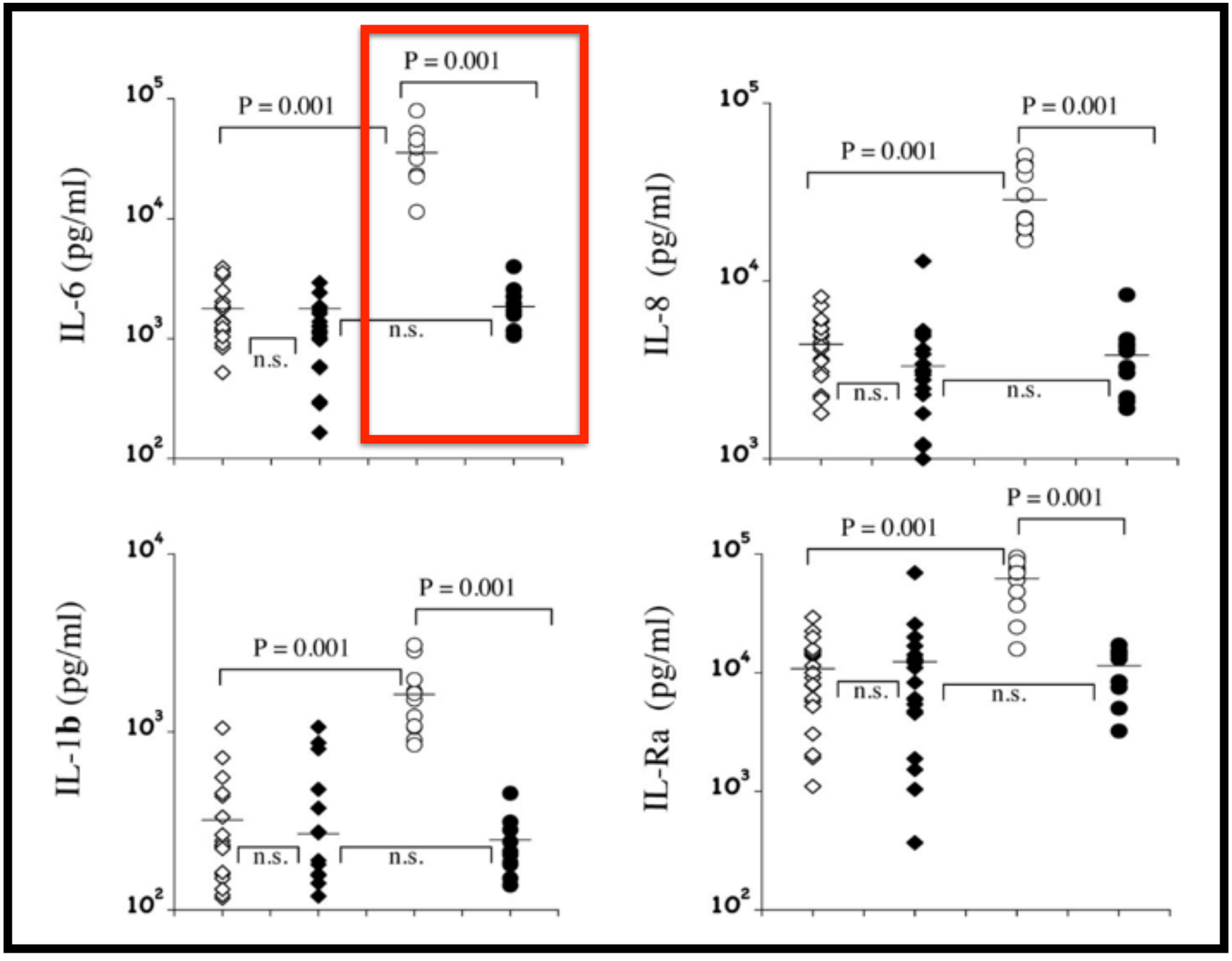
● *after 72 hrs* of *LOWER*"ARDSNet"/CARBON DIOXIDE REMOVAL *(N = 10)*

Anesthesiology 2009; 111:826–35

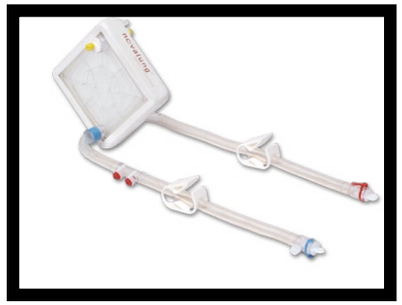

# *Tidal Volume Lower than 6 ml/kg Enhances Lung Protection*

## *Role of Extracorporeal Carbon Dioxide Removal*

*Pier Paolo Terragni, M.D.,* Lorenzo Del Sorbo, M.D.,* Luciana Mascia, M.D., Ph.D.,* Rosario Urbino, M.D.,* Erica L. Martin, Ph.D.,* Alberto Birocco, M.D.,† Chiara Faggiano, M.D.,† Michael Quintel, M.D.,‡ Luciano Gattinoni, M.D.,§ V. Marco Ranieri, M.D.‖*



# Xtravent Study



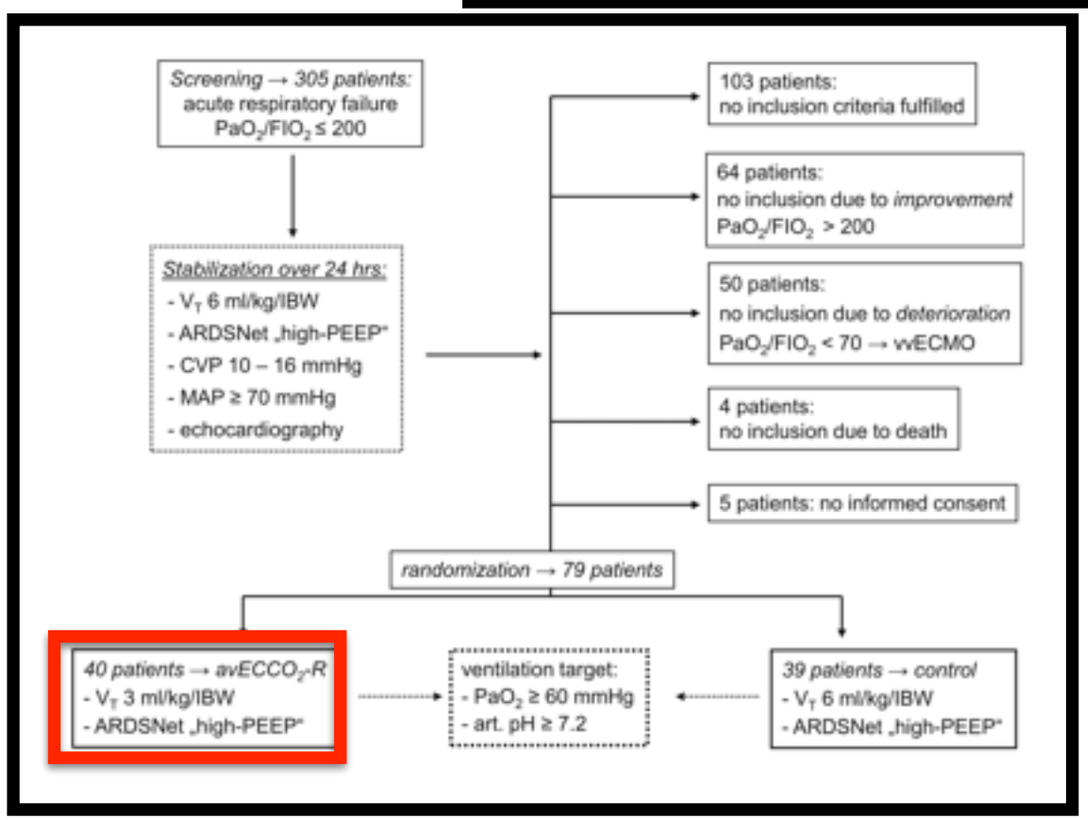
Intensive Care Med (2013) 39:847–856
DOI 10.1007/s00134-012-2787-6

ORIGINAL

Thomas Bein
Steffen Weber-Carstens
Anton Goldmann
Thomas Müller
Thomas Staudinger
Jörg Brederlau
Ralf Muellenbach
Rolf Dembinski
Bernhard M. Graf
Marlene Wewalka
Alois Philipp
Klaus-Dieter Wernecke
Matthias Lubnow
Arthur S. Slutsky

## Lower tidal volume strategy (≈3 ml/kg) combined with extracorporeal $CO_2$ removal versus 'conventional' protective ventilation (6 ml/kg) in severe ARDS

### The prospective randomized Xtravent-study




Etude randomisée contrôlée

P/F < 200

Pplat > 25 cmH2O avec Vt 6ml/kg

ECCO2R + Vt 3 ml/kg

**Table 2** Ventilation parameters and gas exchange after 24-h stabilization period at randomization

| | avECCO$_2$-R ($n$ = 40) | Control ($n$ = 39) | $p$ |
|---|---|---|---|
| $PaO_2/FIO_2$ | 152 ± 37 | 168 ± 37 | 0.044 |
| $PaCO_2$ (mmHg) | 57.3 ± 12 | 54.3 ± 9 | 0.352 |
| Arterial pH | 7.34 ± 0.07 | 7.36 ± 0.07 | 0.317 |
| $V_T$ (ml/kg, PBW) | 5.9 ± 1.2 | 6.0 ± 0.6 | 0.495 |
| Minute ventilation (l/min) | 9.9 ± 1.6 | 9.8 ± 2.4 | 0.745 |
| Frequency/min | 22.4 ± 3 | 22.7 ± 3.5 | 0.854 |
| PEEP ($cmH_2O$) | 16.1 ± 3 | 16.0 ± 3 | 0.898 |
| Plateau pressure ($cmH_2O$) | 29.0 ± 5 | 28.0 ± 7 | 0.384 |
| Delta (PEEP-Plateau) ($cmH_2O$) | 12.9 ± 4 | 12.4 ± 4 | 0.475 |
| $FIO_2$ | 0.62 ± 0.2 | 0.53 ± 0.1 | 0.028 |

The data are presented as mean ± standard deviation


Fanelli *et al. Critical Care* (2016) 20:36
DOI 10.1186/s13054-016-1211-y

Critical Care

RESEARCH Open Access

# Feasibility and safety of low-flow extracorporeal carbon dioxide removal to facilitate ultra-protective ventilation in patients with moderate acute respiratory distress syndrome

Vito Fanelli[1*], Marco V. Ranieri[2], Jordi Mancebo[3], Onnen Moerer[4], Michael Quintel[4], Scott Morley[5], Indalecio Moran[3], Francisco Parrilla[3], Andrea Costamagna[1], Marco Gaudiosi[1] and Alain Combes[6]

Etude prospective

ARDS modéré

Vt de 6 à 4 ml/kg

Pplat entre 23 et 25 cmH2O

n=15

ECCO2R si pH < 7,25 et PaCO2 > 60 mmHg

**Table 3** Time course of ventilation variables, blood gases, $ECCO_2R$ operational characteristics and hemodynamics at $V_T$ 4 mL/kg plus $ECCO_2R$

| Variables | Baseline | $V_T$ 4 mL/kg plus $ECCO_2R$ | | | | |
|---|---|---|---|---|---|---|
| | | Day 1 | Day 2 | | Day 3 | |
| Time (h) | 8.00 | 8.00 | 8.00 | 20.00 | 8.00 | 20.00 |
| Patients (number) | 15 | 15 | 10 | 10 | 8 | 6 |
| $V_T$ (mL/kg) | 6.2 ± 0.7 | 4.29 ± 0.5* | 4.58 ± 0.7* | 4.59 ± 0.8* | 4.8 ± 0.7* | 4.8 ± 0.7* |
| Respiratory rate (beats/minute) | 28 ± 7 | 31.6 ± 4.6* | 29.6 ± 6.8 | 29.6 ± 6.8 | 28 ± 7 | 27.4 ± 8.6 |
| Positive end-expiratory pressure ($cmH_2O$) | 12 ± 3 | 14 ± 2 | 13 ± 3 | 12 ± 4 | 13 ± 5 | 13 ± 3 |
| Arterial partial pressure of oxygen/inspired oxygen fraction | 159 ± 34 | 175 ± 45 | 185 ± 91 | 190 57 | 176 ± 59 | 176 ± 80 |
| Plateau pressure ($cmH_2O$) | 27.7 ± 1.6 | 23.9 ± 1* | 24 ± 4* | 24 ± 3* | 24 ± 3* | 23 ± 3* |
| Blood flow (ml/min) | | 435 ± 60 | 424 ± 63 | 423 ± 35 | 424 ± 29 | 436 ± 39 |
| Rotations per minute (RPM) | | 1407 ± 26 | 1408 ± 30 | 1409 ± 32 | 1411 ± 36 | 1414 ± 41 |
| Sweep gas (L/min) | | 8.6 ± 3.5 | 9.2 ± 2.9 | 9 ± 3 | 9.9 ± 0.3 | 8.7 ± 3.2 |
| $CO_2$ removal (ml/min) | | 81 ± 9 | 70 ± 29 | 70 ± 31 | 81 ± 22 | 71 ± 11 |
| PH | | | | | | |
| PaO2 (mmHg) | 95 ± 29 | 90 ± 22 | 91 ± 26 | 84 ± 10 | 81 ± 15 | 99 ± 29 |
| PaCO2 (mmHg) | 51 ± 15 | 53 ± 15 | 51 ± 18 | 52 ± 17 | 55 ± 20 | 49 ± 11 |
| HCO3 (mmol/L) | 28 ± 5 | 27.6 ± 6.1 | 28.7 ± 6.2 | 28. ± 6.9 | 28.1 ± 7.4 | 28.3 ± 6.03 |
| Lactate (mmol/L) | 2 ± 1 | 2.9 ± 4.8 | 1.9 ± 1.7 | 1.8 ± 1.8 | 1.9 ± 2.0 | 1.3 ± 0.4 |
| Heart rate (beats/minute) | 76 ± 9 | 90 ± 17 | 86 ± 15 | 95 ± 21 | 94 ± 19 | 94 ± 17 |
| Mean arterial pressure (mmHg) | 98 ± 20 | 74 ± 14 | 80 ± 10 | 76 ± 12 | 76 ± 19 | 85 ± 14 |
| Norepinephrine dose (mcg/kg/min) | 0.51 ± 0.6 | 0.45 ± 0.4 | 0.34 ± 0.3 | 0.29 ± 0.27 | 0.57 ± 0.4 | 0.5 ± 0.6 |

*$P$ <0.05 vs baseline. $V_T$ tidal volume, $ECCO_2R$ extracorporeal carbon dioxide removal

Fanelli *et al. Critical Care* (2016) 20:36
DOI 10.1186/s13054-016-1211-y

Critical Care

RESEARCH Open Access

# Feasibility and safety of low-flow extracorporeal carbon dioxide removal to facilitate ultra-protective ventilation in patients with moderate acute respiratory distress syndrome

Vito Fanelli[1*], Marco V. Ranieri[2], Jordi Mancebo[3], Onnen Moerer[4], Michael Quintel[4], Scott Morley[5], Indalecio Moran[3], Francisco Parrilla[3], Andrea Costamagna[1], Marco Gaudiosi[1] and Alain Combes[6]

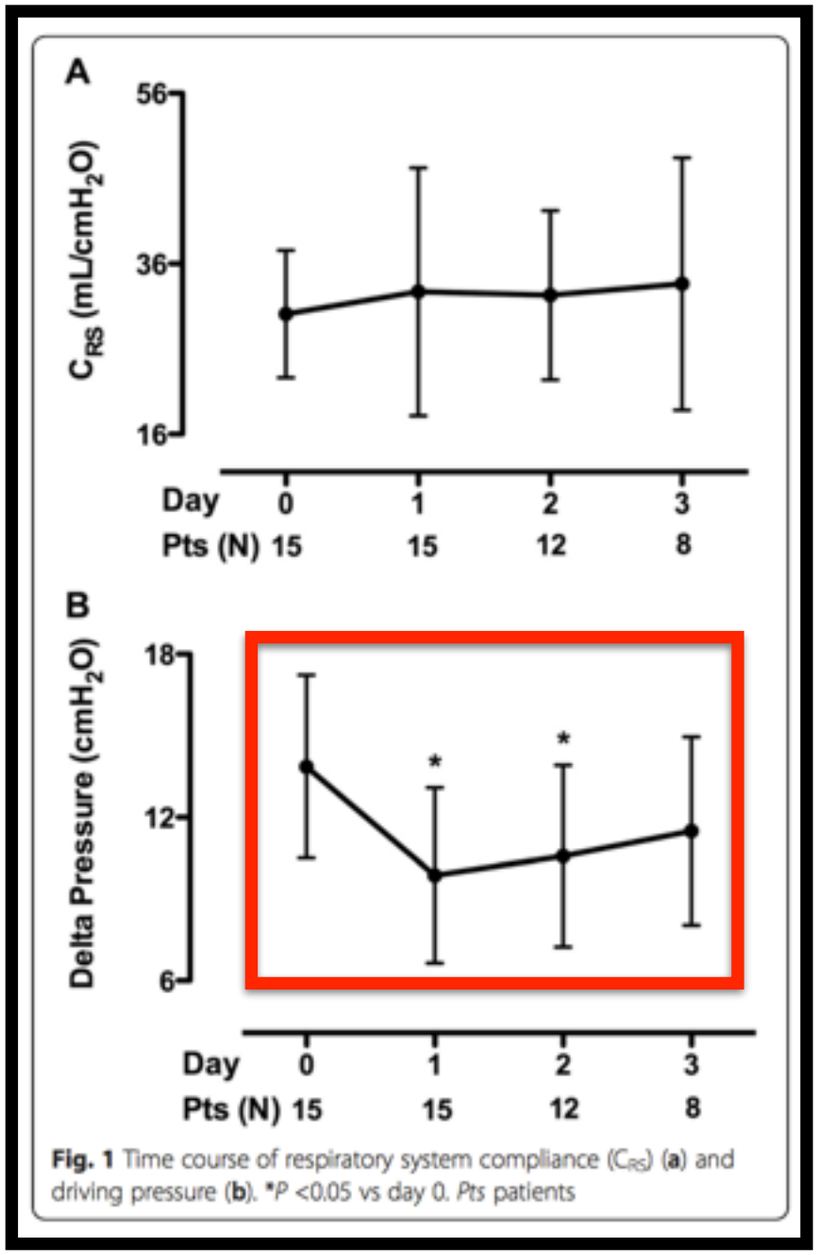



**Fig. 1** Time course of respiratory system compliance ($C_{RS}$) (**a**) and driving pressure (**b**). *$P$ <0.05 vs day 0. *Pts* patients

# pRotective vEntilation With Vv Lung assisT in Respiratory Failure (REST)

- ARDS
- Mulitcentrique
- Vt < 3ml/kg
- Pplat < 25cmH2O
- ECCO2R < 1l/min
- Fin étude 2021

Intensive Care Med (2012) 38:1632–1639
DOI 10.1007/s00134-012-2649-2

ORIGINAL

Stefan Kluge
Stephan A. Braune
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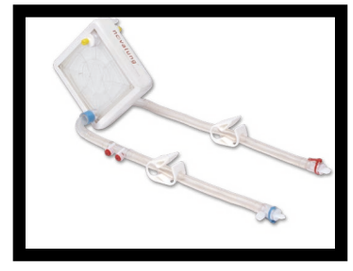
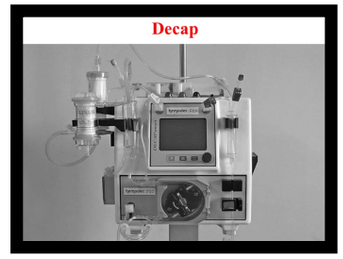
Maria Metschke
Karl Wegscheider
Norbert Suttorp
Simone Rousseau

# Avoiding invasive mechanical ventilation by extracorporeal carbon dioxide removal in patients failing noninvasive ventilation



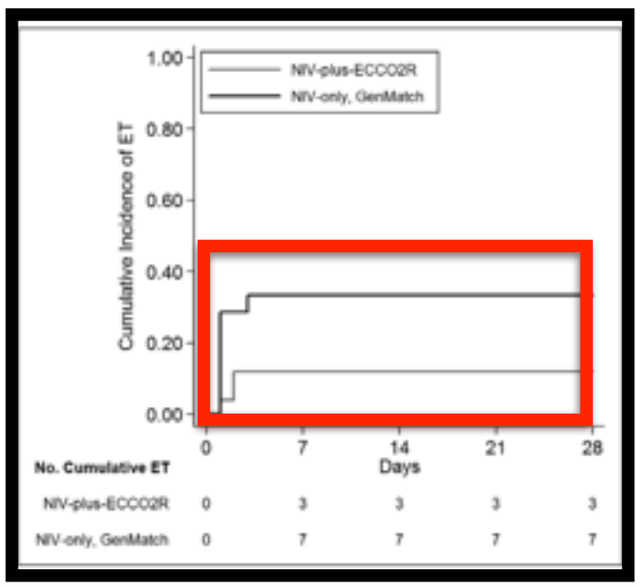
Etude rétrospective
n = 21 échecs VNI
(BPCO 14; Bridge 9)
contrôle = patient matché 1:1




# Extracorporeal $Co_2$ Removal in Hypercapnic Patients At Risk of Noninvasive Ventilation Failure: A Matched Cohort Study With Historical Control*

Lorenzo Del Sorbo, MD[1]; Lara Pisani, MD[2]; Claudia Filippini, PhD[1]; Vito Fanelli, MD[1]; Luca Fasano, MD[2]; Pierpaolo Terragni, MD[1]; Andrea Dell'Amore, MD[3]; Rosario Urbino, MD[1]; Luciana Mascia, MD, PhD[1]; Andrea Evangelista, MD[4]; Camillo Antro, MD[5]; Raffaele D'Amato, MD[1]; Maria José Sucre, MD[1]; Umberto Simonetti, MD[1]; Pietro Persico, MD[1]; Stefano Nava, MD[2]; V. Marco Ranieri, MD[1]

Etude prospective
versus patients matchés
25 BPCO sous VNI
Diminution intubation
52% effets secondaires




| Study Variables | NIV-Plus-Extracorporeal $Co_2$ Removal ($n = 25$) | NIV-Only After Genetic Matching ($n = 21$) | $p$ |
|---|---|---|---|
| Hospital mortality, $n$ (%) | 2 (8) | 8 (35) | 0.0347 |
| ICU length of stay (d) | 8 (7, 10) | 12 (6, 15) | 0.1943 |
| Hospital length of stay (d) | 24 (21, 28) | 22 (13, 36) | 0.8007 |

NIV = noninvasive ventilation.
Data are expressed as number (percentage) or median (interquartile range).
Comparisons between groups are made using Fisher exact test.

Crit Care Med 2015; 43:120–127


CHEST

Original Research

COPD

# A Novel Extracorporeal $CO_2$ Removal System

## Results of a Pilot Study of Hypercapnic Respiratory Failure in Patients With COPD

*Nausherwan K. Burki, MD, PhD, FCCP; Raj Kumar Mani, MD, FCCP; Felix J. F. Herth, MD, FCCP; Werner Schmidt, MD; Helmut Teschler, MD; Frank Bonin, MD; Heinrich Becker, MD; Winfried J. Randerath, MD, FCCP; Sven Stieglitz, MD; Lars Hagmeyer, MD; Christina Priegnitz, MD; Michael Pfeifer, MD; Stefan H. Blaas, MD; Christian Putensen, MD, PhD; Nils Theuerkauf, MD; Michael Quintel, MD, PhD; and Onnen Moerer, MD*

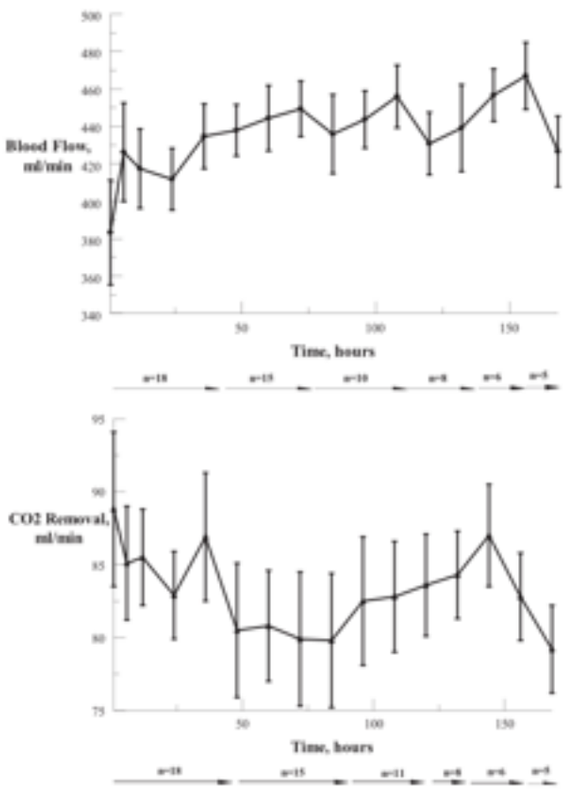



FIGURE 2. Blood flow (mean ± SEM) and $CO_2$ removal (mean ± SEM) through the catheter over time, where n = number of subjects at various time points.

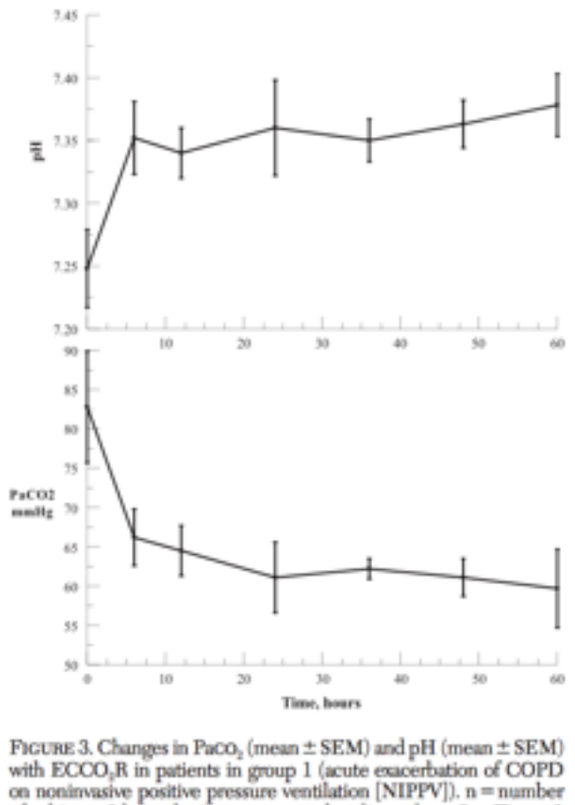



FIGURE 3. Changes in $PaCO_2$ (mean ± SEM) and pH (mean ± SEM) with $ECCO_2R$ in patients in group 1 (acute exacerbation of COPD on noninvasive positive pressure ventilation [NIPPV]). n = number of subjects; 0 h on abscissa represents baseline values. See Figure 1 legend for expansion of other abbreviations.

Etude pilote descriptive

n = 20 BPCO

éviter intubation 7

refus intubation 2

échec sevrage vent inv 11

CHEST 2013; 143(3):678–686

ORIGINAL RESEARCH

# Pilot Study of Extracorporeal Carbon Dioxide Removal to Facilitate Extubation and Ambulation in Exacerbations of Chronic Obstructive Pulmonary Disease

Darryl C. Abrams[1], Keith Brenner[1], Kristin M. Burkart[1], Cara L. Agerstrand[1], Byron M. Thomashow[1], Matthew Bacchetta[2*], and Daniel Brodie[1*]

Etude prospective

n = 5 BPCO intubés

100% extubés à 72 heures (6,8hr)

**Table 3.** Extracorporeal carbon dioxide removal settings, pH ranges, and supplemental oxygen requirements

| Subject | Cannula Size (Fr) | Blood Flow Rate (*L/min*) | Sweep Gas Flow Rate (*L/min*) | pH on $ECCO_2R$ | $PaCO_2$ on $ECCO_2R$ | Supplemental Oxygen |
|---|---|---|---|---|---|---|
| 1 | 23 | 1.0–1.5 | 1.0–1.5 | 7.36–7.47 | 48–54 | None |
| 2 | 20 | 1.0–1.6 | 2.0–4.5 | 7.34–7.48 | 50–59 | NC 1–5 L/min |
| 3 | 20 | 1.5–1.7 | 1.5–2.0 | 7.42–7.48 | 39–63 | HFNC 35–50% |
| 4 | 20 | 1.0–1.3 | 1.3–7.0 | 7.36–7.46 | 43–68 | HFNC 40–100% |
| 5 | 20 | 1.5–1.6 | 0.5–2.0 | 7.38–7.41 | 54–69 | NC 3–6 L/min |

*Definition of abbreviations*: $ECCO_2R$ = extracorporeal $CO_2$ removal; Fr = French; HFNC = high-flow nasal cannula; NC = nasal cannula.

**Table 4.** Outcomes after extracorporeal carbon dioxide removal initiation

| Subject | Duration of $ECCO_2R$ (*h*) | Time from $ECCO_2R$ Initiation to Extubation (*h*) | Time from $ECCO_2R$ Initiation to Mobilization (*h*) | Maximal Ambulation on $ECCO_2R$ (*ft*) | ICU LOS (*d*) | Hospital LOS (*d*) |
|---|---|---|---|---|---|---|
| 1 | 91 | 2 | 18.5 | 150 | 7 | 8 |
| 2 | 140 | 21.5 | 26.5 | 450 | 8 | 10 |
| 3 | 280 | 1.5 | 45 | 70 | 12* | 30† |
| 4 | 240 | 5 | 40 | 240 | 12 | 15 |
| 5 | 214 | 4 | 17 | 600 | 12 | 15 |

Ann Am Thorac Soc Vol 10, No 4, pp 307–314, Aug 2013

*Intensive Care Med (2016) 42:1437–1444*
DOI 10.1007/s00134-016-4452-y

**ORIGINAL**

# The feasibility and safety of extracorporeal carbon dioxide removal to avoid intubation in patients with COPD unresponsive to noninvasive ventilation for acute hypercapnic respiratory failure (ECLAIR study): multicentre case–control study

Stephan Braune[1], Annekatrin Sieweke[1], Franz Brettner[2], Thomas Staudinger[3], Michael Joannidis[4], Serge Verbrugge[5], Daniel Frings[1], Axel Nierhaus[1], Karl Wegscheider[6] and Stefan Kluge[1*]

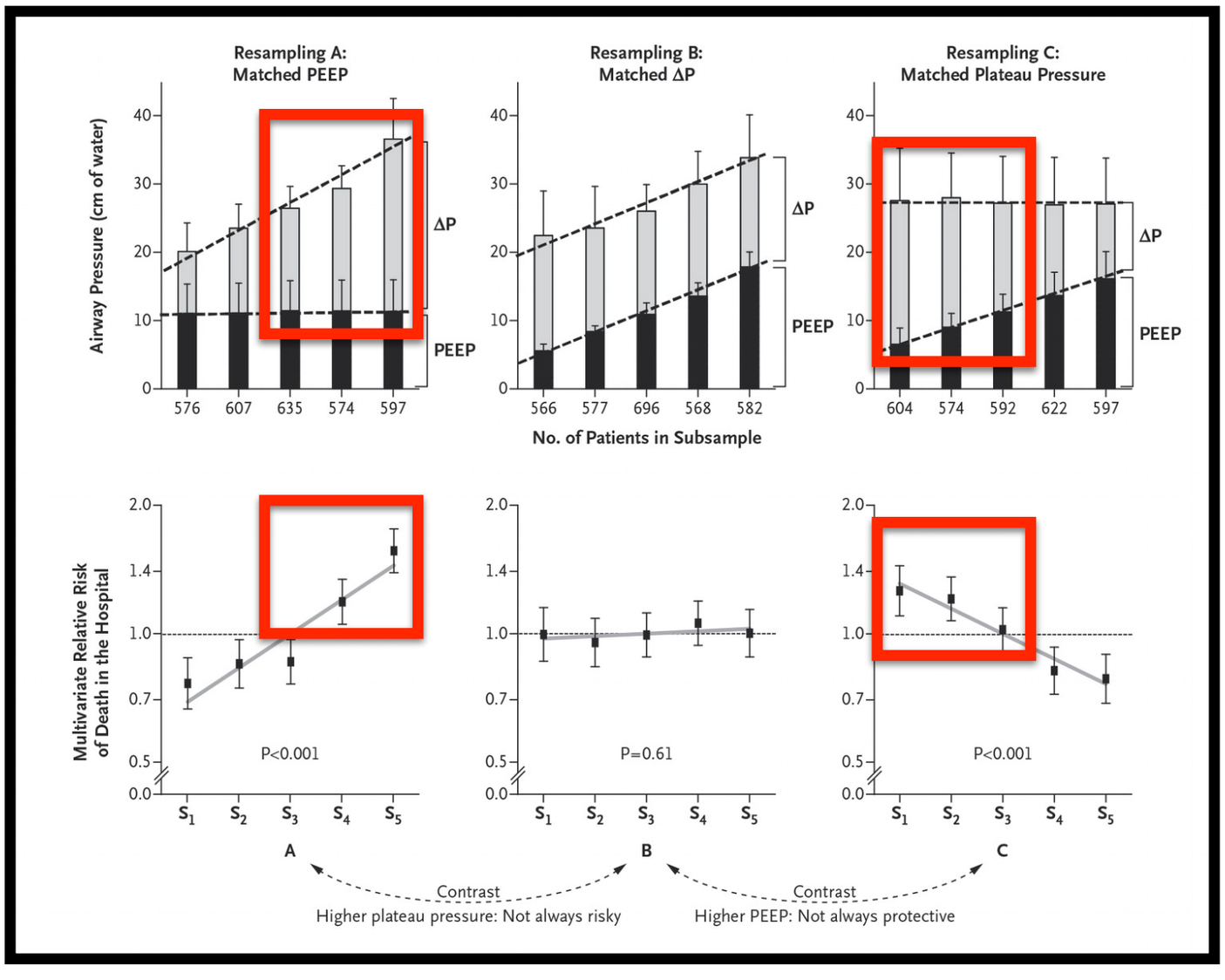
Etude prospective cas-contrôle
match = patient historique
n = 25 BPCO échec VNI

SPECIAL ARTICLE

# Driving Pressure and Survival in the Acute Respiratory Distress Syndrome

Marcelo B.P. Amato, M.D., Maureen O. Meade, M.D., Arthur S. Slutsky, M.D., Laurent Brochard, M.D., Eduardo L.V. Costa, M.D., David A. Schoenfeld, Ph.D., Thomas E. Stewart, M.D., Matthias Briel, M.D., Daniel Talmor, M.D., M.P.H., Alain Mercat, M.D., Jean-Christophe M. Richard, M.D., Carlos R.R. Carvalho, M.D., and Roy G. Brower, M.D.

N Engl J Med 2015; 372:747-755 | February 19, 2015 | DOI: 10.1056/NEJMsa1410639



# Effet sur la dyspnée

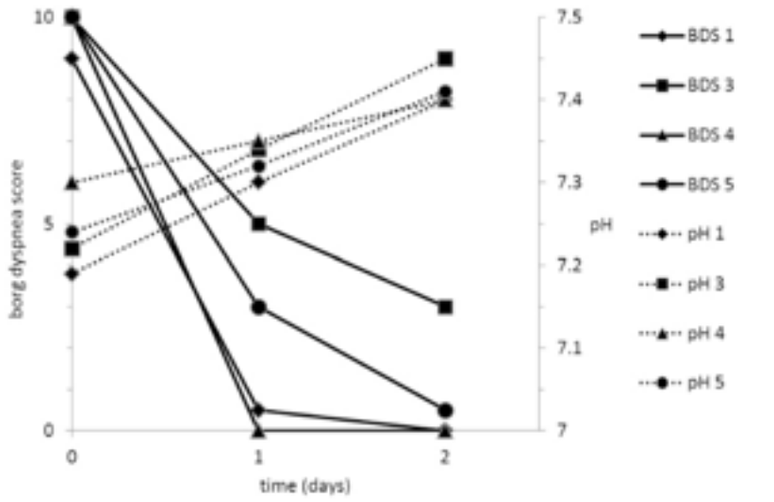



**Figure 2.** Borg dyspnea scores (BDS) correlate inversely with pH over time.

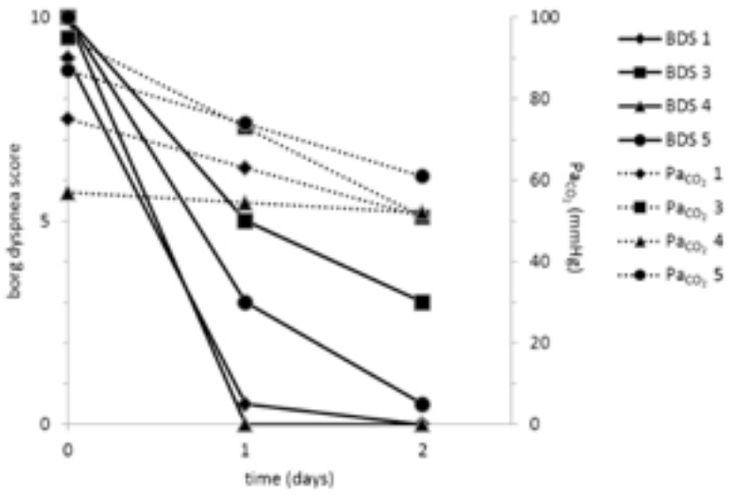



**Figure 3.** Borg dyspnea scores (BDS) correlate with $Pa_{CO_2}$ over time.

ORIGINAL RESEARCH

**Pilot Study of Extracorporeal Carbon Dioxide Removal to Facilitate Extubation and Ambulation in Exacerbations of Chronic Obstructive Pulmonary Disease**

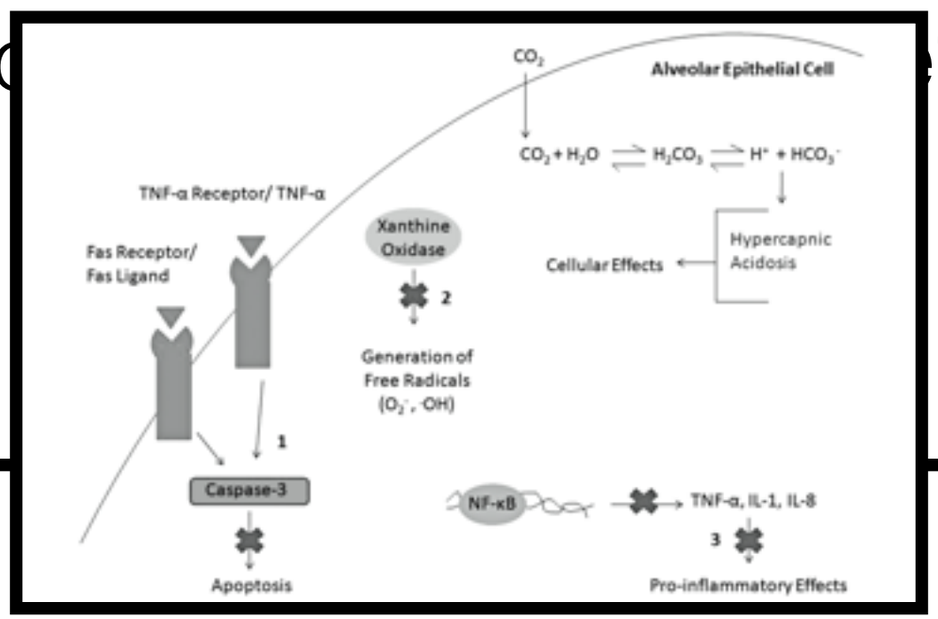
Darryl C. Abrams[1], Keith Brenner[1], Kristin M. Burkart[1], Cara L. Agerstrand[1], Byron M. Thomashow[1], Matthew Bacchetta[2]*, and Daniel Brodie[1]*

# Effets de l'hypercapnie

Effects of hypercapnia and hypercapnic acidosis on attenuation of ventilator-associated lung injury

N. M. ISMAIEL [1, 2], D. HENZLER [1, 2]

- Modulation de l'inflammation pulmonaire (?)
- Immunosuppression
  - exacerbatio[illegible]?




Minerva Anestesiol 2011;77:723-33

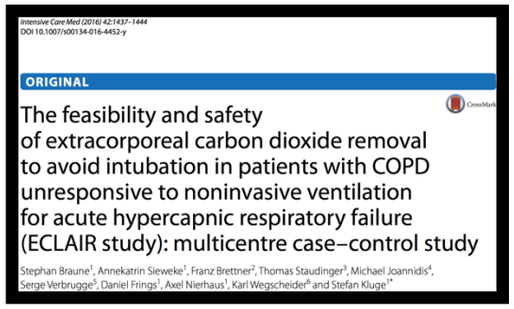
**Table 3 $ECCO_2R$-associated adverse events and bleeding/thromboembolic complications**

| Adverse events (*n*) | $ECCO_2R$ group | Control group |
|---|---|---|
| Major $ECCO_2R$-associated adverse events | 14 | N/A |
| Major bleeding | 11 | 2* |
| Pulmonary haemorrhage | 2 | – |
| Bleeding from tracheostomy | 2 | 1 |
| Haematothorax | 2 | – |
| Bleeding from gastric ulcer | 1 | – |
| Bleeding from rectal ulcer | 1 | – |
| Bleeding from oesophageal varices | – | 1 |
| Retroperitoneal haematoma | 1 | – |
| Dislodged sealing cap of DLC | 1 | – |
| Cannula insertion site | 1 | – |
| Device-related | 3 | N/A |
| Air detection in the circuit | 1 | – |
| Extracorporeal clotting | 2 | – |
| Minor $ECCO_2R$-associated adverse events | 11 | N/A |
| Minor bleeding/thrombosis | 10 | 10 |
| Haematuria | 3 | 1 |
| Cannula insertion site | 2 | – |
| Intracerebral bleeding (small) | – | 1 |
| Epistaxis | 2 | – |
| Haemorrhagic pleural effusion | 1 | – |
| Tracheobronchial haemorrhage | 1 | 3 |
| Bleeding from ileostomy | 1 | – |
| Inguinal haematoma | – | 1 |
| Intramuscular bleeding lower limb | – | 1 |
| Postoperative wound bleeding | – | 1 |
| Bleeding from tracheostomy | – | 1 |
| Thrombosis inferior vena cava and renal vein | | 1 |
| Device-related | 1 | N/A |
| Disconnection of sweep gas tubing | 1 | – |

Of 11 patients suffering major $ECCO_2R$-related adverse events, 2 patients each suffered two major bleeding episodes and 1 patient suffered a major bleeding episode and a device-related adverse event

*DLC* double-lumen catheter, *$ECCO_2R$* extracorporeal carbon dioxide removal, *N/A* not applicable

* $p < 0.001$


Intensive Care Med (2016) 42:1437–1444
DOI 10.1007/s00134-016-4452-y

ORIGINAL

The feasibility and safety of extracorporeal carbon dioxide removal to avoid intubation in patients with COPD unresponsive to noninvasive ventilation for acute hypercapnic respiratory failure (ECLAIR study): multicentre case–control study

Stephan Braune[1], Annekatrin Sieweke[1], Franz Brettner[2], Thomas Staudinger[3], Michael Joannidis[4], Serge Verbrugge[5], Daniel Frings[1], Axel Nierhaus[1], Karl Wegscheider[6] and Stefan Kluge[1*]

| Etude | N | Taille du cathéter | Débit sanguin | anticoag. | complications | Pompe | thrombose circuit | Locorégional | hypoxémie | hémorragie | HIT Thrombopénie |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **kluge et al** | 21 | 13 à 17 Fr X2 | 1 à 1,5l/ min | HNF APTT 45 à 55 sec | | ? | ? | 1 pseudoanévrisme 2 Kt's | - | | 1HIT |
| **Burki et al** | 20 | 15,5Fr | 120 à 580 ml/min | HNF APTT 1,5 à 2,3 | | | | | | 1 | % |
| **Abrams et AL** | 5 | 20 Fr | 1000 à 1700 ml/ min | HNF APTT 40 à 60 sec | | - | - | - | - | - | - |
| **del sorbo et Al** | 25 | 14Fr | 255ml/min | HNF APTT 1,5 | 52 % | 2 | 7 | | | 4 | |
| **braune et al** | 25 | 22Fr | 1400ml/ min | | 44% des patients 36% sévères | | | | 28 % | | |