Diplôme d'Université
CEC en chirurgie cardiaque et en suppléance d'organes

université de BORDEAUX

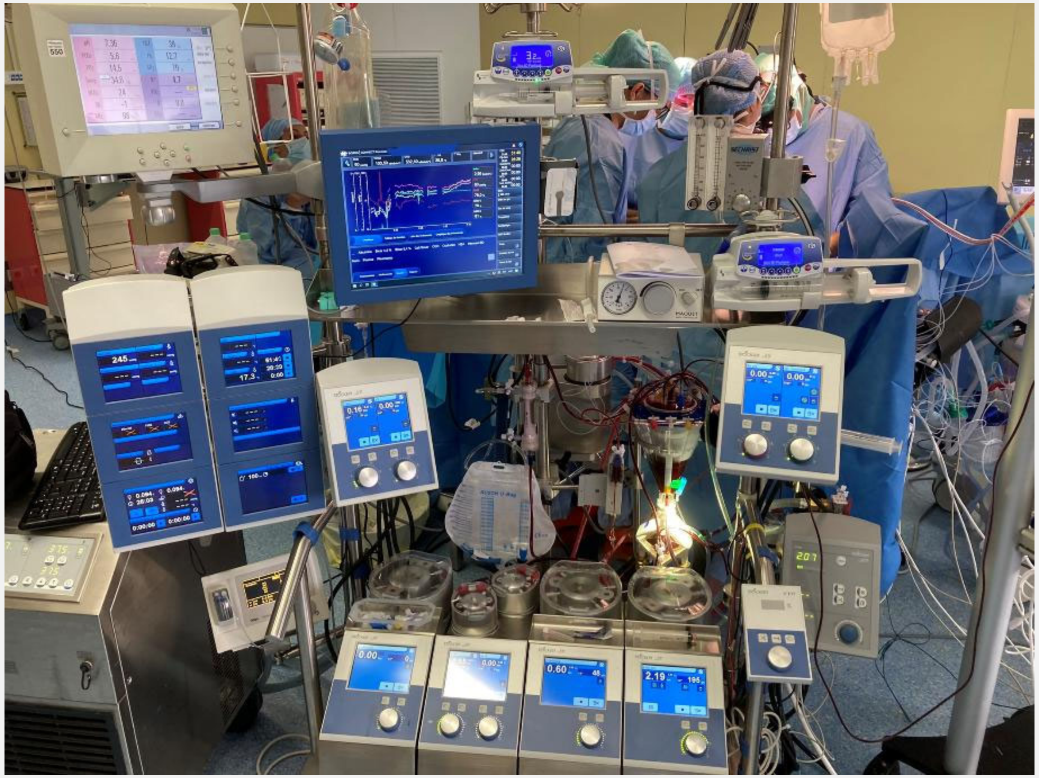
Circulation Extra Corporelle et cardiopathies congénitales

CHU BDX CENTRE HOSPITALIER UNIVERSITAIRE BORDEAUX
MATHIEU Laurent
CHU Bordeaux
mathieu.laurent@chu-bordeaux.fr

21 mai 2024

Quelques chiffres

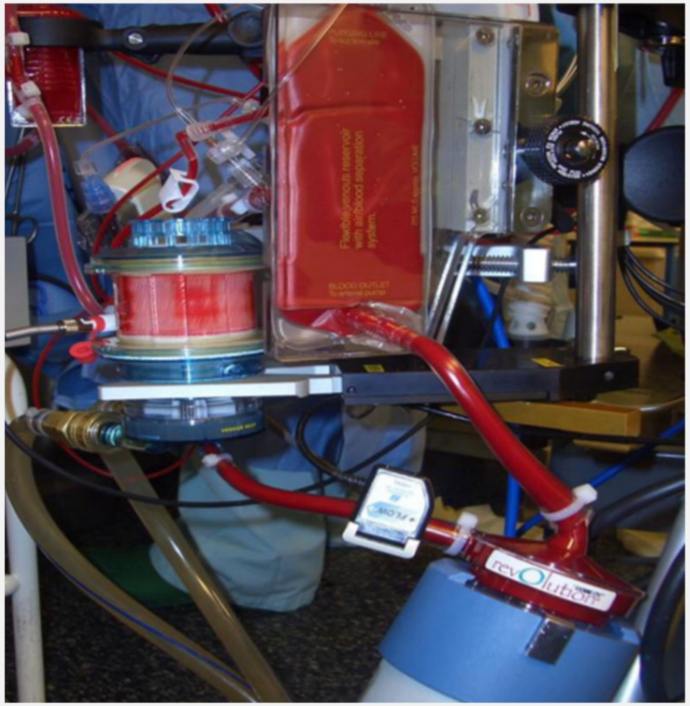
- Malformations cardiaques : 1 % des naissances
- 3 500 CEC pédiatriques en France / an
- 10 centres de chirurgie cardiaque congénitale



Particularités des enfants

- Volémie et Poids réduits
- Immaturité des organes
- Besoins métaboliques élevés
- Cœur néonatal peu compliant
- Cardiopathies complexes avec réparations intracardiaques

Les pompes



Centrifuge – circuit clos

Occlusive – circuit ouvert

Les pompes

Revue de la littérature (2019)

Type de pompe	Avantages	Limites
Pompe occlusive	• Contrôle précis du débit • Réutilisable • Pas de flux rétrograde	• Risque de surpression • Mauvaise occlusion (sur ou sous-occlusion) • Hémolyse
Pompe centrifuge	• Moins d'activation des facteurs de coagulation et de la fibrinolyse • Moins d'hémolyse	• Priming plus important • Plus cher • Flux rétrograde possible • Peut augmenter la durée d’hospitalisation

Medikonda R et al. J Cardiothorac Vasc Anesth. 2019

Le tubing

Le PVC :

- Problème des additifs : DEHP (Di Ethyl Hexyl Phtalate)
- PVC sans phtalate obligatoire depuis 2015 en pédiatrie et néonatologie

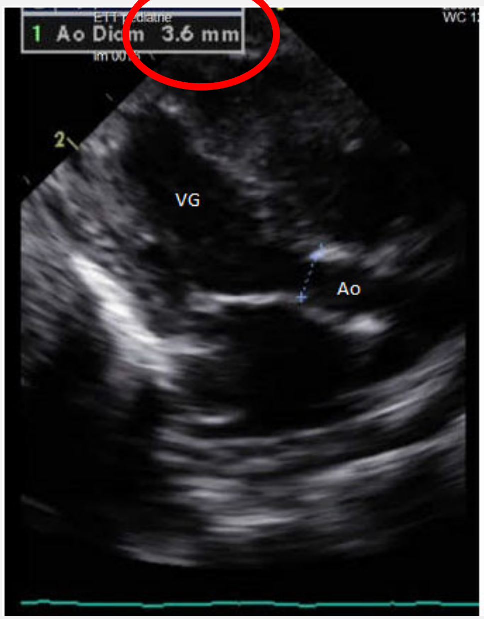
Le silicone :

- Diminue l'agrégation plaquettaire et l'activation leucocytaire
- Rejet de particules (de l'ordre de 5µm)
- Risque de plicature

Les canules

<u>Canule aortique :</u> débit élevé autour de $3 l.min^{-1}.m^{-2}$

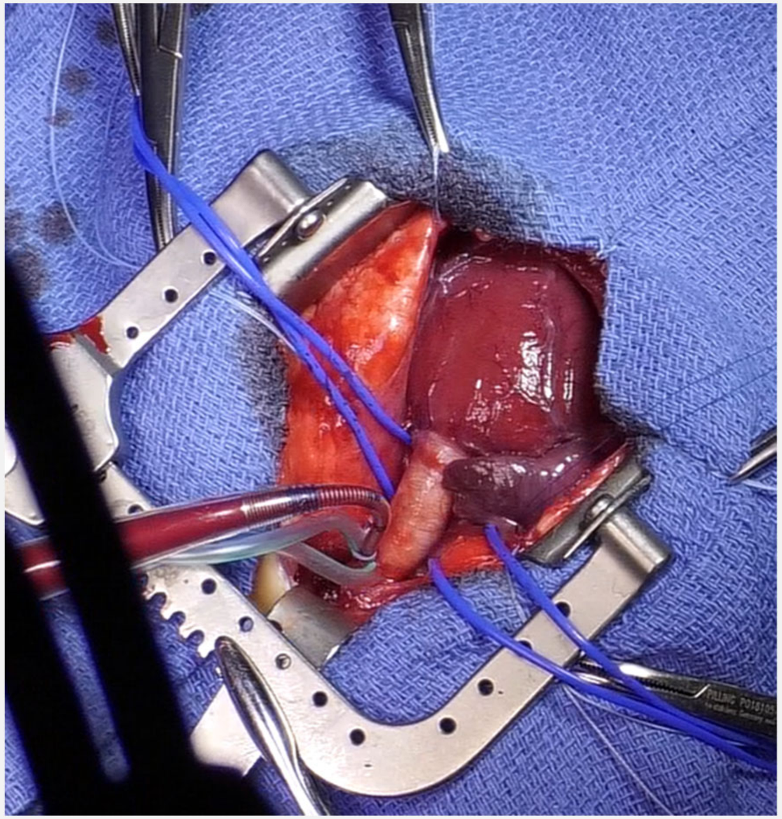
- Pour un nouveau né de $0,20 m^2$: $600 ml.min^{-1}$



6 Fr → 2.0 mm ✗

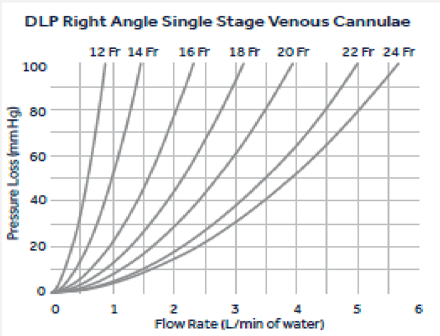
8 Fr → 2.5 mm ✓

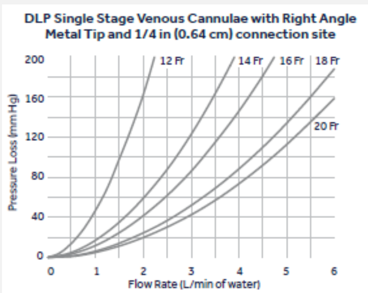
10 Fr → 3.3 mm ✗

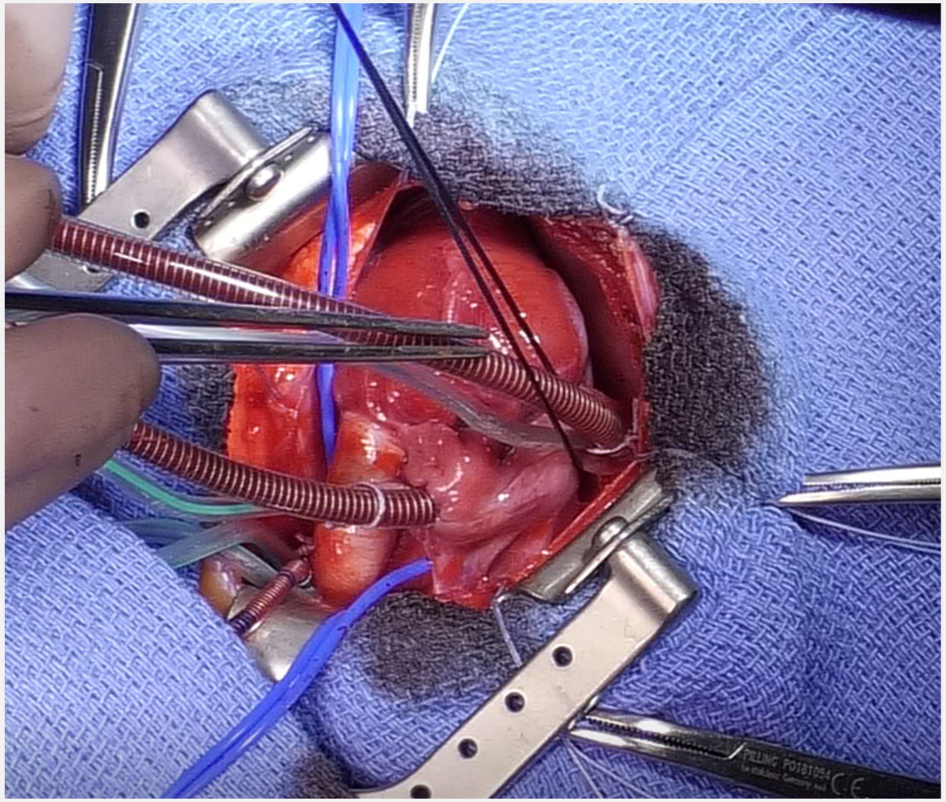


Les canules

Canules veineuses : double canulation







L'hémodilution

<u>Conséquences</u>

- Diminue la pression oncotique
- Diminue l'hématocrite
- Augmente l'œdème tissulaire
- Baisse les résistances artérielles périphériques
- Diminue la concentration des plaquettes et des facteurs de coagulation

Nécessaire à basse température pour limiter la viscosité mais pas < 30%

Priming

Cristalloïde

Compliqué en dessous de 15 kg

Volémie de la naissance à 1 an ≈ 85ml.kg^{-1}

$$Ht\ cec = \frac{Ht\ patient \times volémie}{volémie + volume\ priming}$$

Sang

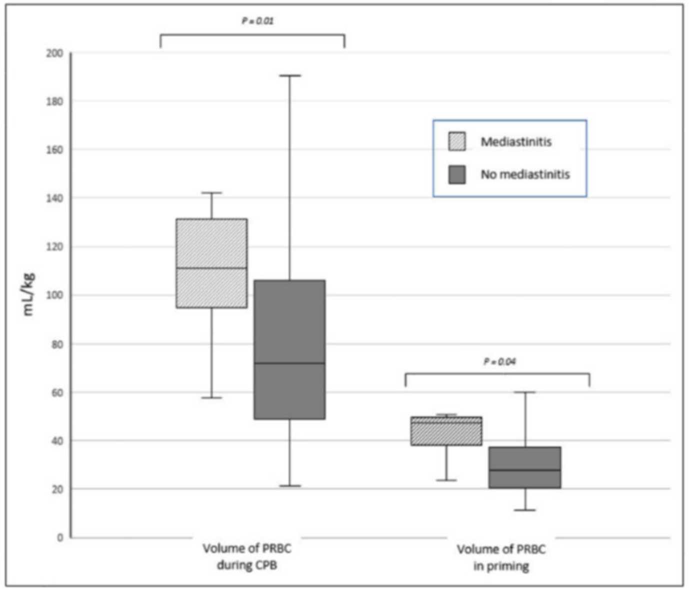
- Hb : quantité de CGR en fonction de l'Hb du patient et de la pathologie
- pH : correction bicar 8,4%
- K^+ : CGR déplasmatisés pour la néo-nat (+/- dialyse du priming)
- Attention au Ca^{2+} (citrate)
- Héparine

Pourquoi réduire le priming sanguin ?

<u>Étude rétrospective 2024</u>

208 patients inclus (de 3,8 à 10 kg)

- Groupe priming inf volume médian
- Groupe priming sup volume médian



astinitis cases by the priming PRBC volume and the volume of PRBCs transfused during CPB. PRBC, packed red blood ive care unit. The median PRBC volume during CPB was higher in patients who developed mediastinitis (111 [95–131] nL/kg; $p = .04$). The median priming PRBC volume was also higher in patients with mediastinitis (47 [44–49] vs. 28 [20– 01).

Table 3. Postoperative data.

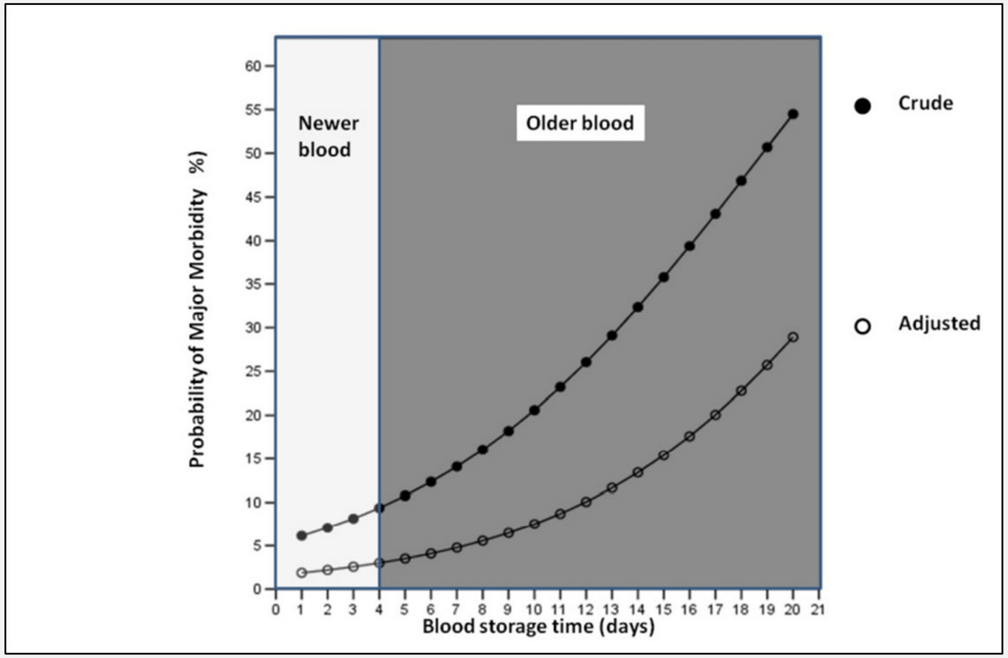
	High priming volume (n = 104)	Low priming volume (n = 104)	*p*-value
Creatinine peak, mg/dL	59.1 ± 27.8	49.9 ± 30.9	**0.02**
CRP peak, mg/L	134 ± 67	110 ± 68	**0.01**
Procalcitonin peak, ng/mL	19.4 ± 75.7	13.0 ± 48.8	0.47
Mechanical ventilation, h	68 [20–110]	5 [2–26]	**0.01**
ECMO-VA, *n*	8 (7.7%)	5 (4.8%)	0.39
Extrarenal replacement therapy, n	8 (7.7%)	7 (6.7%)	0.79
Reintubation, *n*	6 (5.8%)	3 (2.9%)	0.50
ICU stay, days	6 [4–9]	4 [3–6]	**$<10^{-3}$**

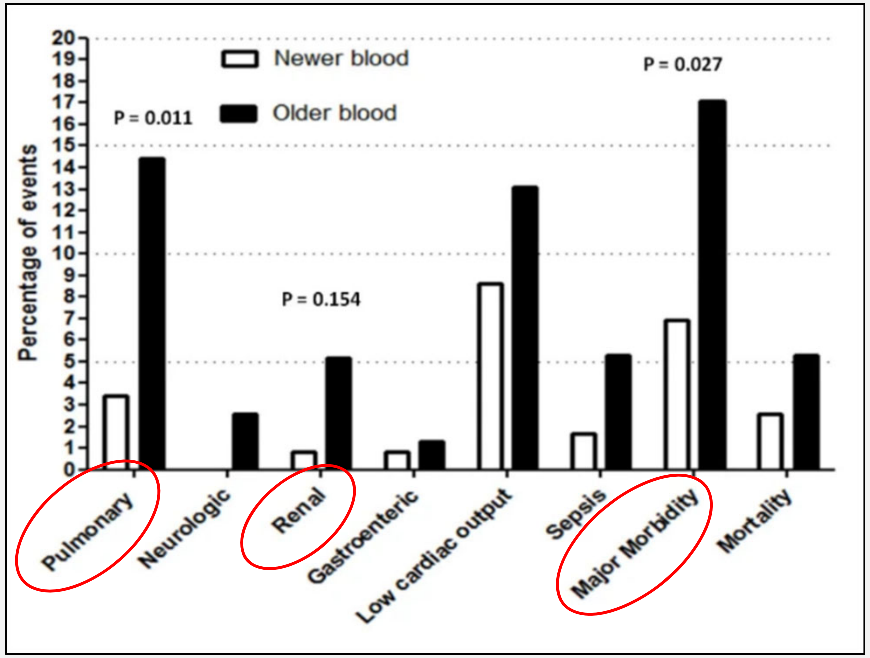
CRP, C-reactive protein; ECMO-VA, extracorporeal membrane oxygenation veno-arterial; ICU, intensive care unit. Data are expressed as the mean ± SD, median [1st – 3rd quartile], or n (%). The values in bold are associated with *p*-values less than 0.05 and are statistically significant.

Mathieu et al. Perfusion 2024

Transfusion

Complications associées à l'augmentation du temps de stockage des CGR

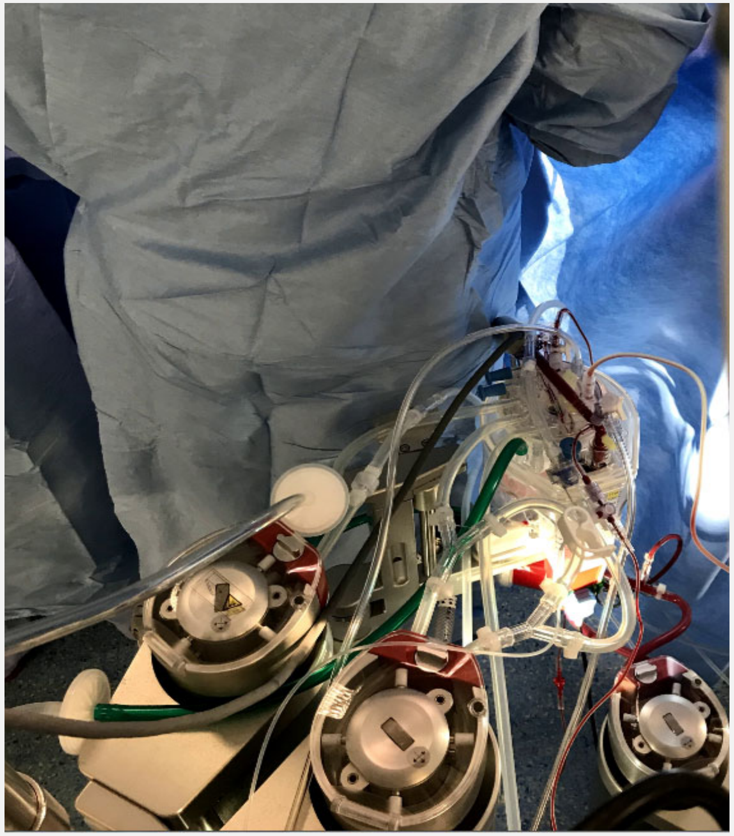




Marco Ranucci et al. Crit Care. 2009

Comment réduire le priming ?

- Taille tubing
- Taille oxygénateur
- Positionnement de la pompe
- Pompes déportées
- VAVD (Pas sans conséquence)



Les limites du VAVD

Perfusion 2000; **15**: 485–494

Investigation and quantification of the blood trauma caused by the combined dynamic forces experienced during cardiopulmonary bypass

JW Mulholland Medical Engineering Division, Department of Engineering, Queen Mary and Westfield College, London and Department of Clinical Perfusion, Cardiac Surgery, St Bartholomew's Hospital and the Royal London Trust, London, **W Massey** Department of Clinical Perfusion, Cardiac Surgery, St Bartholomew's Hospital and the Royal London Trust, London and **JC Shelton** Medical Engineering Division, Department of Engineering, Queen Mary and Westfield College, London

Blood is exposed to various dynamic forces during cardiopulmonary bypass (CPB). Understanding the damaging nature of these forces is paramount for research and development of the CPB circuit. The object of this study was to identify the most damaging dynamic non-physiological forces and then quantify this damage.

A series of *in vitro* experiments simulated the different combinations of dynamic forces experienced during CPB while damage to the blood was closely monitored.

A combination of air interface (*a*) and negative pressure (*P*) caused the greatest rate of change in plasma Hb (Δp Hb) (4.94×10^{-3} mg/dl/s) followed by negative pressure and then an air interface. Shear stresses, positive pressures, wall impact forces and a blood–nonendothelial surface caused the least damage (0.26×10^{-3} mg/dl/s). An air interface showed no threshold value for blood damage, with the relationship between the size of the interface and the blood damage modelled by a second-order polynomial. However, negative pressure did exhibit a threshold value at –120 mmHg, beyond which point there was a linear relationship.

Investigating the reasons for the increased blood trauma caused by the low-pressure suction (LPS) system makes it clear how research into minimizing or completely avoiding certain forces must be the next step to advancing extracorporeal technology.

Address for correspondence: JW Mulholland, Perfusion Room, Cardiac Theatres, 5th Floor QEII Building, St Bartholomew's Hospital, West Smithfield, London EC1A 7BE, UK.

0267-6591(00)PF421OA

Une dépression trop importante

entraine une hémolyse

Passage possible d'air

des fibres de l'oxygénateur

vers la ligne artérielle

JECT. 2003;35:207–211
The Journal of The American Society of Extra-Corporeal Technology

Limitations Using the Vacuum-Assist Venous Drainage Technique During Cardiopulmonary Bypass Procedures

David Jegger, ECCP; Hendrik T. Tevaearai, MD; Xavier M. Mueller, MD; Judith Horisberger, ECCP; Ludwig K. von Segesser, MD

Department of Cardiovascular Surgery, Centre Hospitalier Universitaire Vaudois (CHUV), Rue du Bugnon 46, 1011- Lausanne, Switzerland

Abstract: Vacuum-assist venous drainage (VAVD) can increase venous blood return during cardiopulmonary bypass (CPB) procedures. However, the negative pressure created in the closed cardiotomy reservoir can be transmitted to the oxygenator if a nonocclusive or centrifugal arterial pump is used, resulting in bubble transgression (BT) from the gas to blood compartment of the oxygenator. We analyzed the vacuum pressure required to produce BT using an *in vitro* circuit including successively a closed reservoir, a pump (centrifugal or roller), and an oxygenator. A constant hydrostatic pressure was maintained onto the oxygenator. Vacuum was applied on the cardiotomy reservoir, progressively increasing negative pressure from 0 to −80 mmHg and monitoring BT with a bubble detector. Six different oxygenators were compared. A partially occlusive roller pump and a centrifugal pump were compared to a control, which was without any pump. A mean negative pressure of −53 ± 7 mmHg was necessary to produce BT in all the oxygenators in the absence of a pump. The presence of a centrifugal pump between the reservoir and the oxygenator significantly increased the negative pressure required to produce BT compared to the control (−67 ± 7 mmHg, $p < .05$). No bubbles were detected using the roller pump (>−80 mmHg needed for BT), thus statistically significant when compared to the centrifugal pump ($p < .05$). The centrifugal pump offers significant resistance to BT but not as much compared to the roller pump, though BT cannot be prevented if the pump is turned off while the vacuum remains on the reservoir. Therefore, VAVD is a safe technique as long as the perfusionist stops the vacuum when the arterial pump is no longer in use. **Keywords:** cardiopulmonary bypass, centrifugal, hollow fiber membrane oxygenator. *JECT. 2003;35:207–211*

Standard cardiac surgery procedures with cardiopulmonary bypass (CPB) necessitates a median sternotomy and has gained confidence due to its simplicity, safety, and success over many years. In several situations such as minimally invasive surgery and emergency cardiac resuscitation peripheral venous cannulae are needed. These cannulae are longer and have smaller diameters compared to classic cannulae, thus blood drainage is limited. Gravity siphon or passive venous drainage (PVD) may thus provide insufficient blood return for adequate tissue perfusion.

This drawback has lead to the development of active venous drainage (AVD), which can increase venous return to more acceptable levels of perfusion. AVD is generally divided into kinetic-assist venous drainage (KAVD) and vacuum-assist venous drainage (VAVD). KAVD uses a centrifugal pump (CP) placed in the venous line to generate negative pressure and consequently increase venous return. This technique has been shown to guarantee adequate global tissue perfusion for use in minimally invasive CPB procedures (1–3). VAVD involves a constant vacuum pressure, onto an airtight venous reservoir, allowing more blood to be drained from the patient via the venous line. However, it was recently shown that AVD techniques might introduce gaseous microemboli (GME) into the patient undergoing CPB (4). Although many potential causes for gaseous emboli during CPB have been identified (5), the creation of a negative pressure in the venous line facilitates entrapment of air around the venous cannula, possibly increasing GME. However, when a CP is used in the arterial pump position in combination with VAVD it apparently aids in clearing the GME (6).

If the arterial pump is stopped for various reasons and the vacuum source is left on the venous reservoir, microbubble transgression (BT) can occur from the gas compartment to the liquid compartment of the oxygenator, creating another source of GME as soon as the arterial pump is turned on again. We analyzed the nega-

Address correspondence to: D. Jegger, ECCP, Department of Cardiovascular Surgery, Centre Hospitalier Universitaire Vaudois (CHUV), Rue du Bugnon, 46 1011- Lausanne, Switzerland. Tel: +41.21.3142314; Fax: +41.21.3142121; E-mail: David.Jegger@chuv.hospvd.ch
Received June 18, 2002; accepted July 12, 2003.

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Les limites du VAVD

JECT. 2008;40:249–256
The Journal of ExtraCorporeal Technology

Review Articles

Vacuum-assisted Venous Drainage and Gaseous Microemboli in Cardiopulmonary Bypass

Shigang Wang, MD;* Akif Ündar, PhD*†

*Pediatric Cardiac Research Laboratories, Department of Pediatrics; and †Department of Surgery and Department of Bioengineering, Penn State Milton S. Hershey Medical Center, Penn State College Medicine, Penn State Children's Hospital, Hershey, Pennsylvania

Abstract: When conventional gravity siphon venous drainage cannot achieve satisfactory venous drainage during minimally invasive cardiac and neonatal surgeries, assisted venous drainage techniques are needed to ensure adequate flow. One assisted venous drainage technique, vacuum-assisted venous drainage (VAVD), the aid of a vacuum in the venous reservoir, is now widely used to augment venous drainage during cardiopulmonary bypass (CPB) procedures. VAVD permits the use of smaller venous cannulae, shorter circuit tubing, and lower priming and blood transfusion volumes, but increases risk of arterial gaseous microemboli and blood trauma. The vacuum should be set as low as possible to facilitate full venous return, and real-time monitoring of gaseous microemboli in the arterial and venous line should be used to achieve the safest conditions. With current ultrasound technology, it is possible to simultaneously detect and classify gaseous microemboli in the CPB circuit. In this article, we summarize the components, setup, operation, advantages, and disadvantages of VAVD techniques and clinical applications and describe the basic principles of microemboli detectors, such as the Emboli Detection and Classification (EDAC) Quantifier (Luna Innovations, Roanoke, VA) and Bubble Counter Clinical 200 (GAMPT, Zappendorf, Germany). These novel gaseous microemboli detection devices could help perfusionists locate the sources of entrained air, eliminate hidden troubles, and minimize the postoperative neurologic impairments attributed to gaseous microemboli in clinical practice.
Keywords: cardiopulmonary bypass, equipment, embolism, perfusion. *JECT. 2008;40:249–256*

Most cardiac operations require cardiopulmonary bypass (CPB) with cannulae directly inserted into the right atrium and ascending aorta. This conventional method relies on gravity and height differences between the venous cannula tip and the venous reservoir blood level to facilitate venous drainage. Thus, drainage is limited by the internal diameter and length of the drainage catheter, the central venous pressure, the tubing internal diameter and length, the venous reservoir air pressure, the height difference, etc. (1). As advances in cardiac surgery permit correction of congenital heart defects in small infants, smaller venous cannulae are required to prevent obstruction of the visual field and lower the priming volumes (2). Additionally, the use of a sanguinous priming solution may further benefit neonates during CPB (3). In minimally invasive surgery, using peripheral cannulation and smaller diameter venous cannulae is also advantageous to the patient (4). These modifications, although beneficial to the patient and surgeon, are also limiting because they further restrict venous return. If resistance to venous return cannot be overcome, assisted venous return techniques are necessary to ensure adequate flow.

Vacuum-assisted venous drainage (VAVD), a vacuum in the venous reservoir, augments the venous drainage and is now widely used during CPB procedures. VAVD is not a simple perfusion technique and has both advantages and disadvantages, so correct, safe use of VAVD is essential.

VACUUM-ASSISTED VENOUS DRAINAGE

Two types of assisted venous drainage are currently available: VAVD and kinetic-assisted venous drainage (KAKD). VAVD, also known as vacuum-assisted venous

Address correspondence to: Akif Ündar, PhD, Penn State College of Medicine, Department of Pediatrics, H085, 500 University Drive, PO Box 850, Hershey, PA 17033-0850. E-mail: aundar@psu.edu
The senior author has stated that authors have reported no material, financial, or other relationship with any healthcare-related business or other entity whose products or services are discussed in this paper.

Augmente les micro emboles artériels gazeux

Les micro emboles sont responsables de troubles neurocognitifs

Perfusion 2004; **19**: S49–S55

Bubbles and bypass: an update

Mark Kurusz[1] and Bruce D Butler[2]

[1]University of Texas Medical Branch, Galveston, TX, USA;
[2]University of Texas Health Science Center, Houston, TX, USA

Bubbles in the bloodstream are not a normal condition – yet they remain a fact of cardiopulmonary bypass (CPB), having been extensively studied and documented since its inception some 50 years ago. While detectable levels of gaseous microemboli (GME) have decreased significantly in recent years and gross air embolism has been nearly eliminated due to increased awareness of etiologies and technological advances, methods of use of current perfusion systems continue to elicit concerns over how best to totally eliminate GME during open-heart procedures. A few studies have correlated adverse neurocognitive manifestations associated with excessive quantities of GME.

Newer techniques currently in vogue, such as vacuum-assisted venous drainage, low-prime perfusion circuits, and carbon dioxide flooding of the operative field, have, in some instances, exacerbated the problem of gas embolism or engendered secondary complications in the safe conduct of CPB. Doppler monitoring (circuit or transcranial) primarily remains a research tool to detect GME emanating from the circuit or passing into the patients' cerebral vasculature. Newer developments not yet widely available, such as multiple-frequency harmonics, may finally provide a tool to distinguish particulate microemboli from GME and further delineate the clinical significance of GME. *Perfusion* (2004) **19**, S49–S55.

Introduction

The purpose of this paper is to update previous reviews[1–3] on the subject of air embolism associated with cardiopulmonary bypass (CPB) and outline recent technique or device interventions that have been shown to minimize production of bubbles. Both gross air bubbles and gaseous microemboli (GME) have been the subject of numerous studies, and efforts have been directed at elimination of both types. In the case of gross air embolism, these efforts have been highly successful, but occasional case reports continue to appear.[4] However, elimination of GME from conventional CPB has proved more difficult.

When viewed from the perspective of several decades, the presence of gas bubbles during CPB has decreased for a variety of reasons, the most important being the transition from bubble oxygenators in the mid-1980s to membrane types that are universally used today. Thirty years ago, the conventional CPB circuit consisted of a bubble oxygenator with a roller pump for systemic flow. Venous drainage was by gravity siphon, and screen arterial filters were only used in approximately half of all clinical cases. An external cardiotomy reservoir (filtered or not) was used to collect suctioned and vent blood, which was then allowed to drain into the arterial reservoir where it was returned with the arterial perfusate. Hypothermia to 28°C or lower was routinely practiced and pH-stat blood gas management was used to regulate blood gases. Crystalloid cardioplegia dominated myocardial protection, but, in some settings, simple ischemic arrest with aortic cross-clamping or elective fibrillation was used when the heart had to be stopped. Gross air embolism when employing such a circuit was a relatively frequent risk, and several mechanisms were described by retrospective surveys.[5–7] The most predominant etiology was simply inattention by the perfusionist to the arterial reservoir level, which, when depleted of perfusate, allowed the roller pump to rapidly transmit large volumes of air into the systemic flow tubing and patient's aorta. In 1986, a new mechanism for gross air was reported, which was described as aortic root air during cardioplegia administration.[7] Less frequent were unexpected heart beats before adequate cardiac de-airing, reversed left ventricular vent, pressurized cardiotomy, ruptured arterial pump-head tubing, or unnoticed rotation of the arterial pump-head. Virtually all of these etiologies were caused by operator error – on the part of the surgeon or perfusionist.

Perhaps, in response to this sobering and well publicized information, safeguards in the form of improved technique or devices specifically designed to prevent gross air embolism were developed, implemented, and presumably have led to dramatic reductions in reported cases of fatal gross

Address for correspondence: M. Kurusz, UTMB, 301 University Blvd., Galveston, Texas, TX 77555-0528, USA
E-mail: mkurusz@utmb.edu

10.1191/0267659104pf720oa

VAVD recommandations

Recommandations de l'Association Européenne de Chirurgie Cardio-Thoracique :

- Réservoir veineux rigide
- Monitorage de la dépression sur la ligne veineuse
- Pression négative excessive -> hémolyse

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

Authors/Task Force Members: Alexander Wahba [a,b,*,†] (Co-Chairperson) (Norway), Gudrun Kunst [c,d,*,†] (Co-Chairperson) (United Kingdom), Filip De Somer [e,†,*] (Co-Chairperson) (Belgium), Henrik Agerup Kildahl [a,b,†] (Norway), Benjamin Milne [f,†] (United Kingdom), Gunilla Kjellberg [g,†] (Sweden), Adrian Bauer [h] (Germany), Friedhelm Beyersdorf [i,j] (Germany), Hanne Berg Ravn [k] (Denmark), Gerdy Debeuckelaere [l] (Belgium), Gabor Erdoes [m] (Switzerland), Renard Gerhardus Haumann [n,o] (The Netherlands), Tomas Gudbjartsson [p] (Iceland), Frank Merkle [q] (Germany), Davide Pacini [r,s] (Italy), Gianluca Paternoster [t,u] (Italy), Francesco Onorati [v] (Italy), Marco Ranucci [w] (Italy), Nemanja Ristic [x] (Serbia), Marc Vives [y,z] (Spain), Milan Milojevic [aa] (Serbia) EACTS/EACTAIC/EBCP Scientific Document Group

Recommendations for use of assisted venous drainage

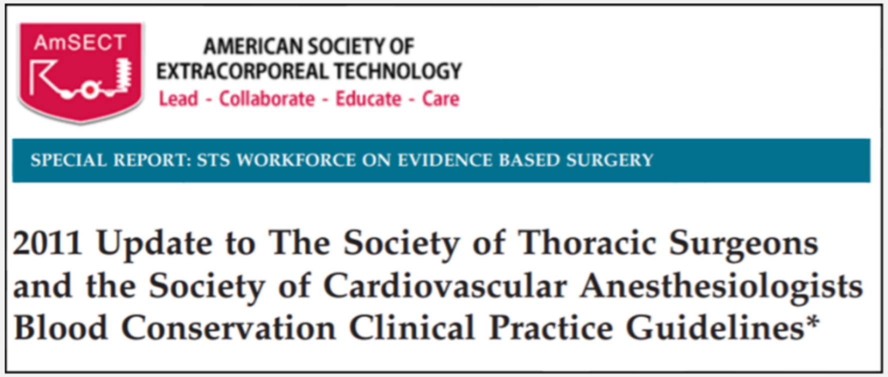
Recommendations	Class[a]	Level[b]	Ref[c]
It is recommended that an approved venous reservoir be used for assisted venous drainage.	I	C	
It is recommended that the venous line pressure be monitored when using assisted venous drainage.	I	C	
Excessive negative venous pressures are not recommended due to the deleterious haemolytic effects.	III	B	[236]

VAVD recommandations

Recommandations société américaine de CEC :

- Pression négative nette maximale d'environ

  -80 à -90 mmHg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AMERICAN SOCIETY OF EXTRACORPOREAL TECHNOLOGY

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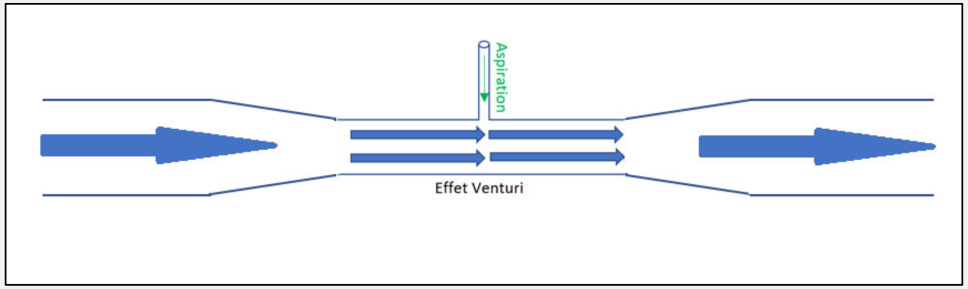
SPECIAL REPORT: STS WORKFORCE ON EVIDENCE BASED SURGERY

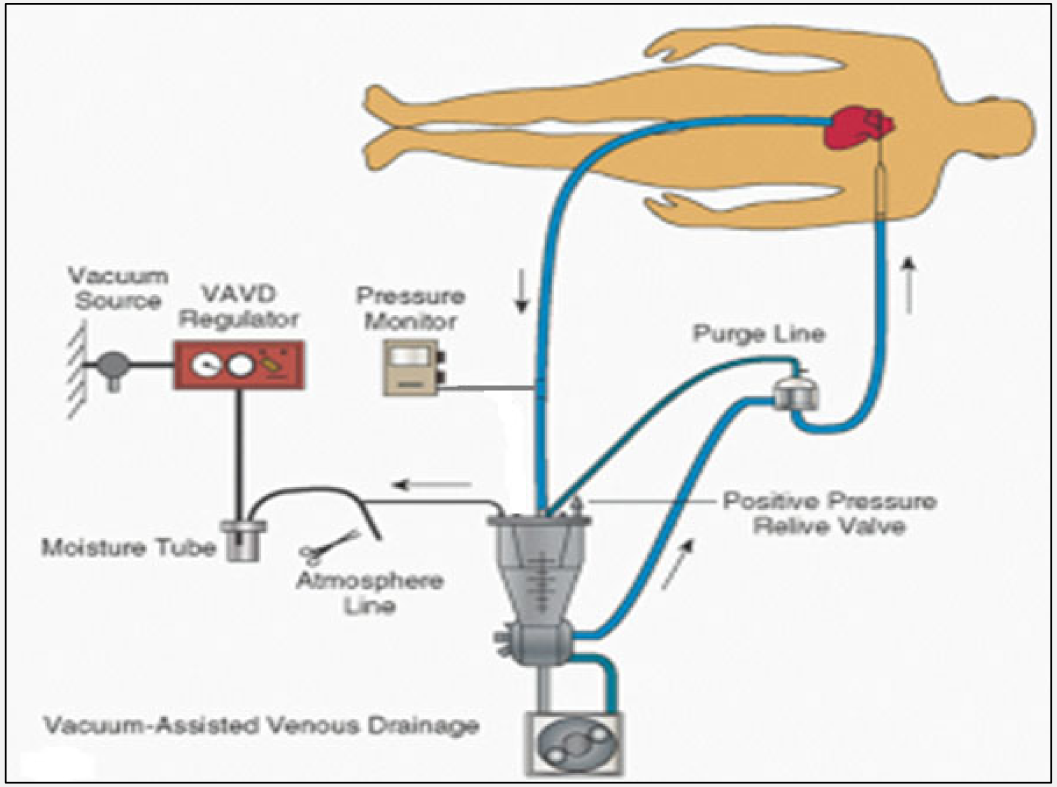
2011 Update to The Society of Thoracic Surgeons and the Society of Cardiovascular Anesthesiologists Blood Conservation Clinical Practice Guidelines*

(Pression négative nette = VAVD + effet Venturi)



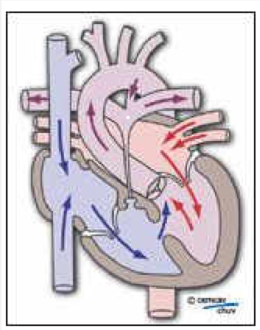
VAVD recommandations

- Pression négative minimale pour obtenir un retour veineux optimal
- Système d'ouverture rapide à la pression atm.
- Monitorage de la dépression veineuse
- Arrêt du vide avant l'arrêt de la pompe artérielle



Départ de la CEC

- <u>Canal artériel perméable</u>



(atrésie pulmonaire, blalock …)

Laisser le cœur éjecter

déséquilibre RAS / RAP

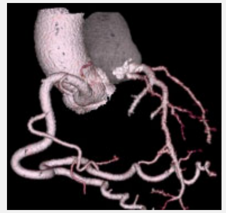
-> Inondation pulmonaire - vol systémique

- <u>Cardiopathies cyanogènes</u>

Démarrage en douceur

FiO2 ↓ Balayage faible

- <u>Naissance anormale du tronc coronaire gauche</u>



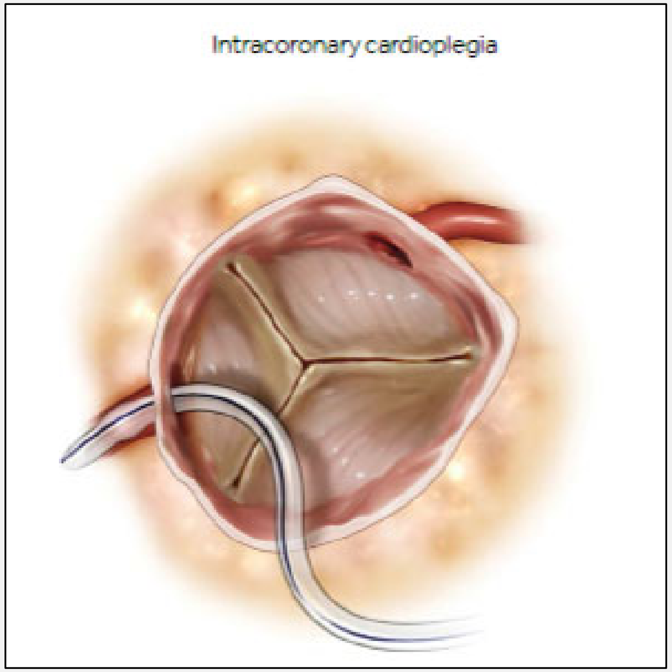
- <u>Veine cave supérieure gauche</u>

- <u>MAPCA</u> (Major Aorto Pulmonary Collateral Artery)
  et collatérales aorto-pulmonaires

Protection myocardique

Différents types de cardioplégies

- Froide aux cristalloïdes
- Sanguine froide
- Sanguine chaude
- Antérograde / rétrograde



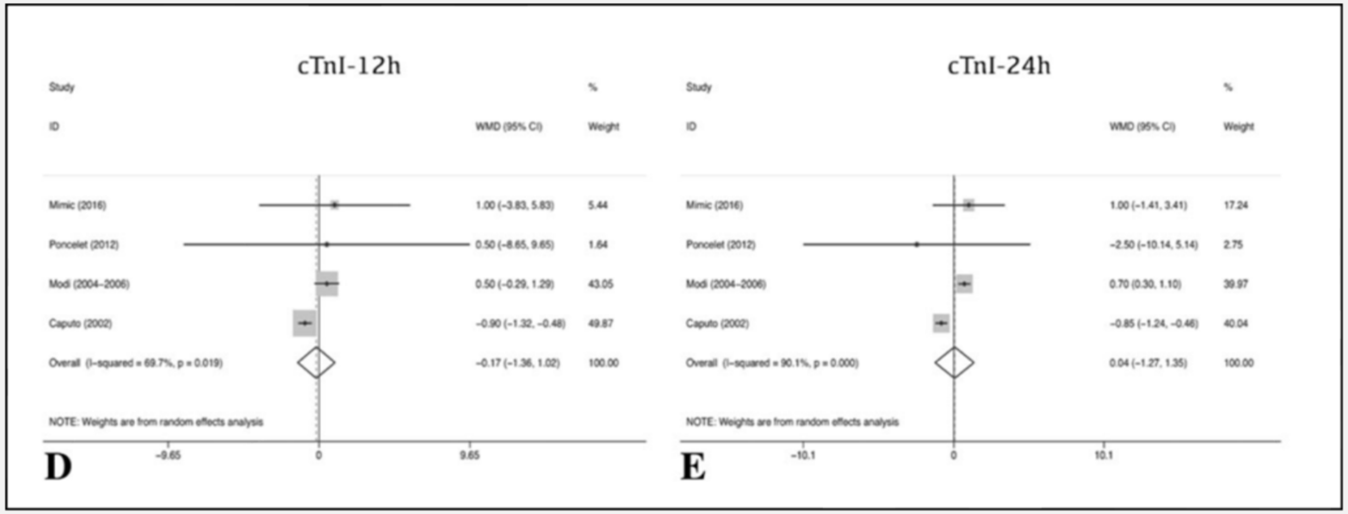
Protection myocardique

Méta-analyse (2017)

10 études :
- sanguine (n = 416)

  VS
- cristalloïde (n = 281)

Troponine

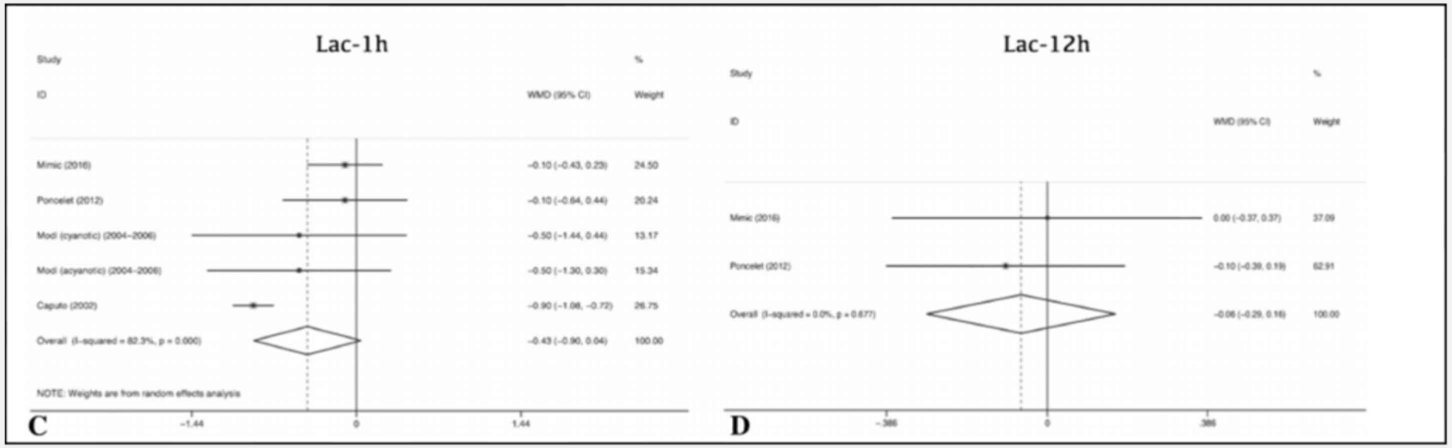


En faveur cpg sang ⟷ En faveur cpg cristalloïde

Mylonas KS et al. Pediatr Cardiol. 2017

Protection myocardique

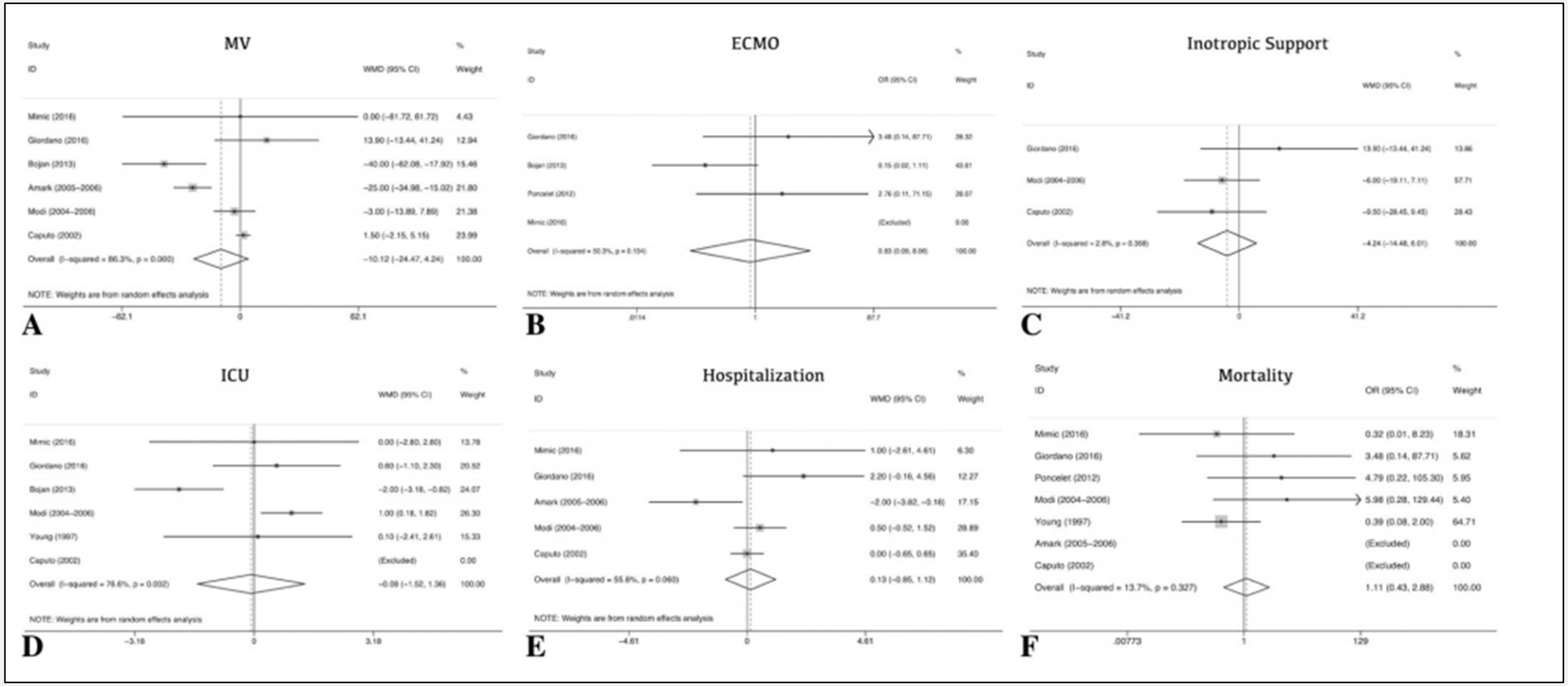
Lactatémie



En faveur cpg sang ↔ En faveur cpg cristalloïde

Mylonas KS et al. Pediatr Cardiol. 2017

Protection myocardique



Mylonas KS et al. Pediatr Cardiol. 2017

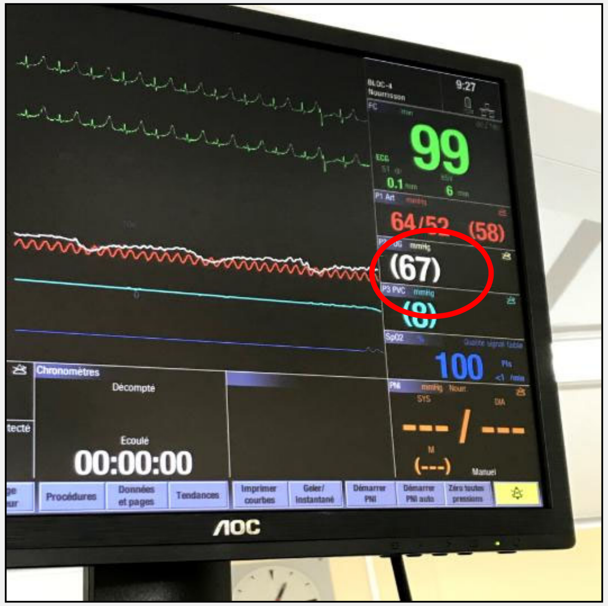
Protection myocardique

Mesure des pressions d'injection obligatoire

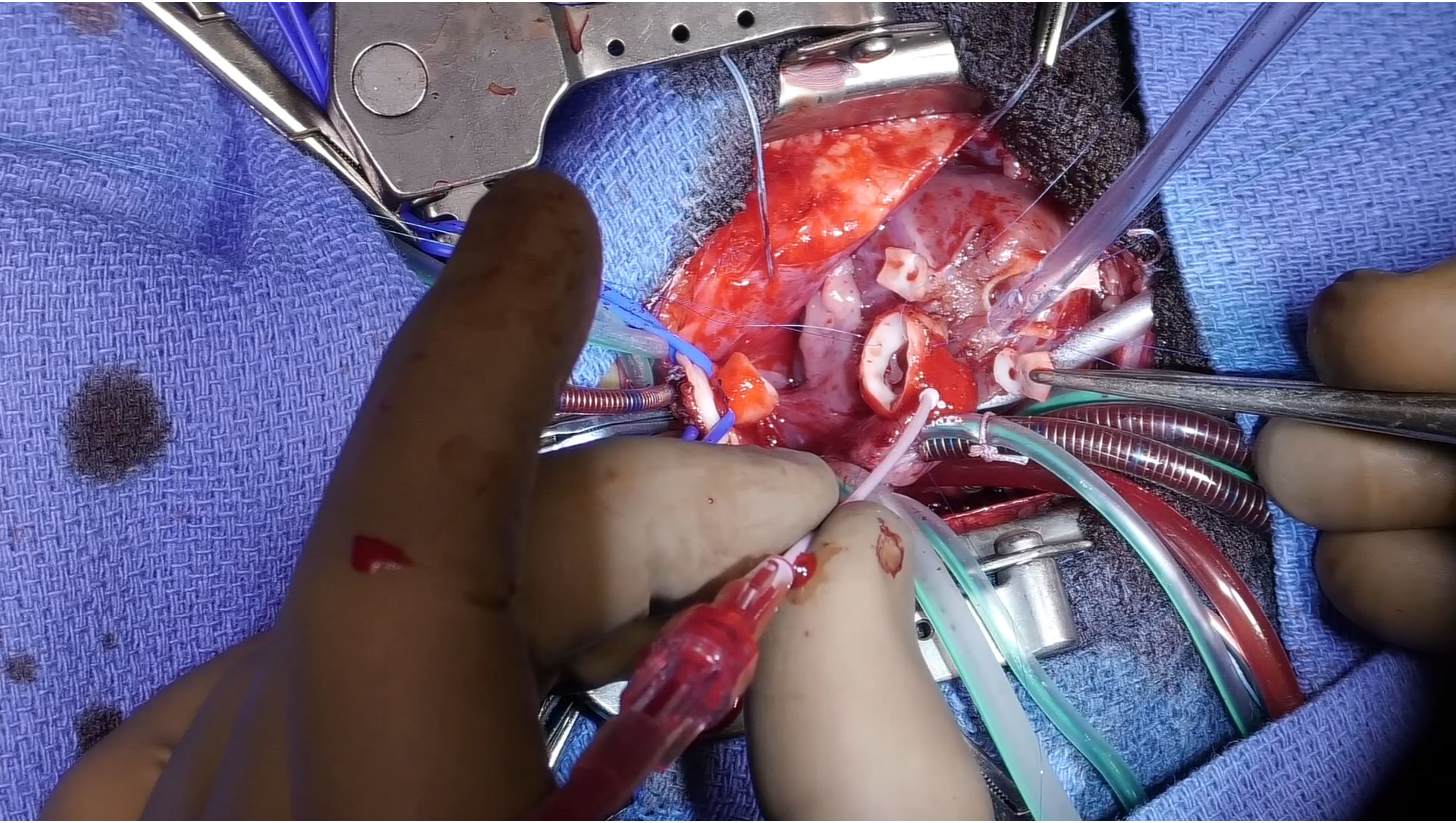
Protection myocardique

Pression d'injection max = perte de charge + ≈ 50 mmHg

Perte de charge : 23 mmHg



Perfusion cardioplégie
23 + 50 = 73 mmHg max.



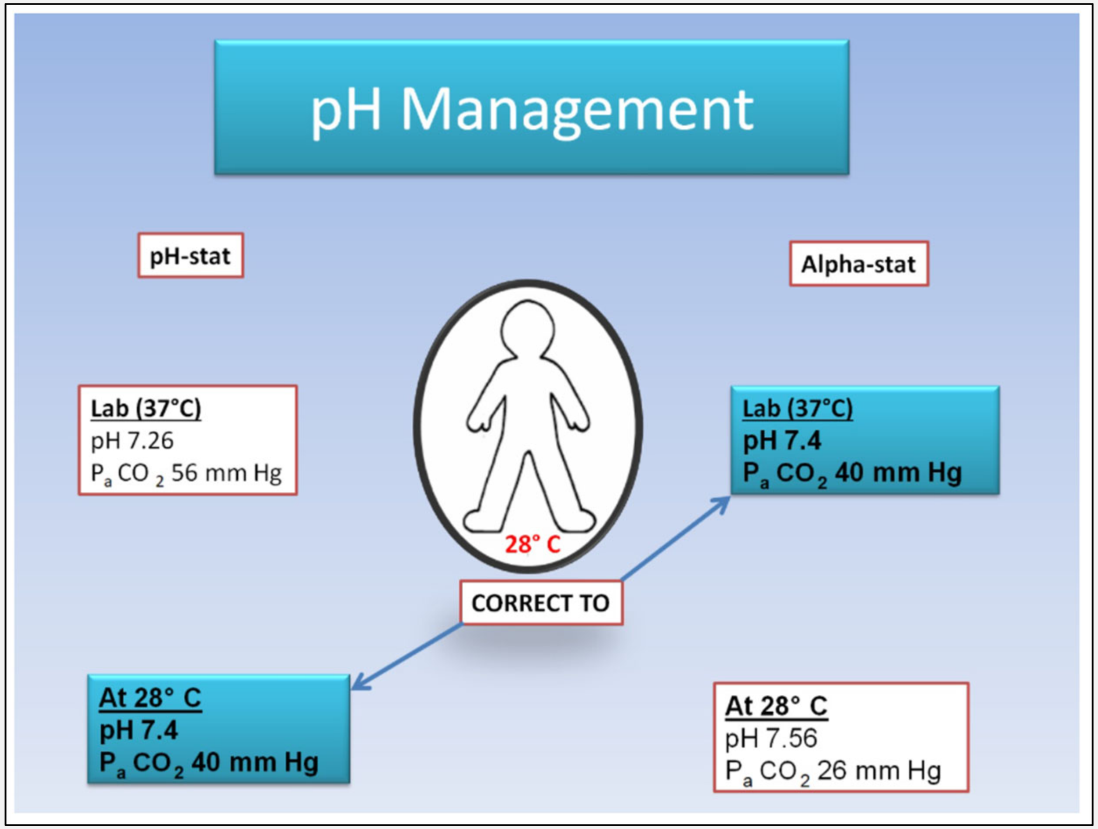
Hypothermie et gaz du sang

Alpha-stat :

- Interprétation des gaz du sang à 37°C
- Pas de correction à la température corporelle du patient

pH-stat :

- Interprétation des gaz du sang à la température du patient
- Apports en CO2 dans les gaz de CEC



Hypothermie

40 patients (âge > 1 an) CEC pour cardiopathies cyanogènes (1998)

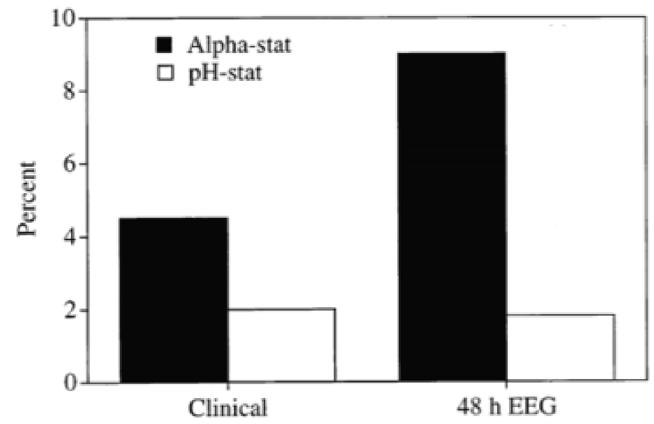


Fig 6. Incidence of postoperative seizures with use of alpha-stat and pH-stat strategies in infants undergoing reparative heart operations. (EEG = electroencephalogram.)

La stratégie pH-stat :

- Améliore l'oxygénation cérébrale
- Taux de lactate plus bas
- Moins de troubles neurologiques

Hickey PR et al. Ann Thorac Surg. 1998

Hypothermie


Cardiopulmonary Support and Physiology

The influence of pH strategy on cerebral and collateral circulation during hypothermic cardiopulmonary bypass in cyanotic patients with heart disease: Results of a randomized trial and real-time monitoring

Étude prospective randomisée (2004) n = 40

Groupe 1 : alpha-stat *vs* groupe 2 : pH-stat

La stratégie pH-stat chez les patients cyanosés

- ↑ l'oxygénation cérébrale
- ↓ le taux de lactate
- ↓ la circulation collatérale pulmonaire systémique

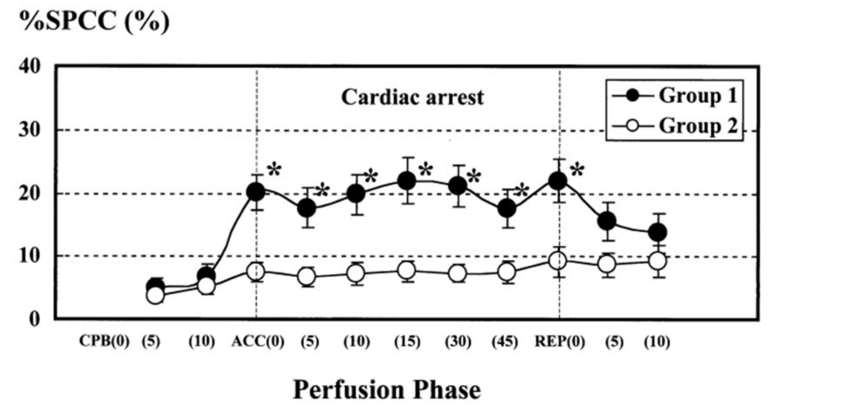


Figure 2. Change in %SPCC. The SPCC was calculated according to the following equation using the pump flow rates, and recorded every 5 minutes. ANOVA, $P < .0001$, $^*P < .01$. %SPCC = (perfusion flow − drainage flow)/perfusion flow × 100.

Sakamoto T et al. J Thorac Cardiovasc Surg. 2004

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Hypothermie

Revue de la littérature 2010

16 articles analysés :

- 1 article non concluant
- 4 en faveur de pH-stat (3 pédiatriques)
- 7 en faveur de alpha-stat
- 4 aucune différence

pH-stat : pédiatrique

Alpha-stat : adulte

Comparing the 16 studies based on the age of the patients studied, three out of the four papers which demonstrated that the pH-stat method is a better strategy to improve intraoperative and postoperative outcome were based on a sample of paediatric patients. Conversely, all seven papers that suggested alpha-stat method is associated with better intraoperative and postoperative outcome were based on studies done on adult patients. The remaining four papers suggested no significant difference between the pH-stat group and alpha-stat group.

In conclusion, there is evidence to suggest that the best technique to follow in the management of acid-base in patients undergoing deep hypothermic circulatory arrest during cardiac surgery is dependent upon the age of the patient with better results using pH-stat in the paediatric patient and alpha-stat in the adult patient.

Abdul Aziz KA et al. Interact Cardiovasc Thorac Surg. 2010

Anticoagulation

Nouveau né : tendance à l'hypercoagulabilité

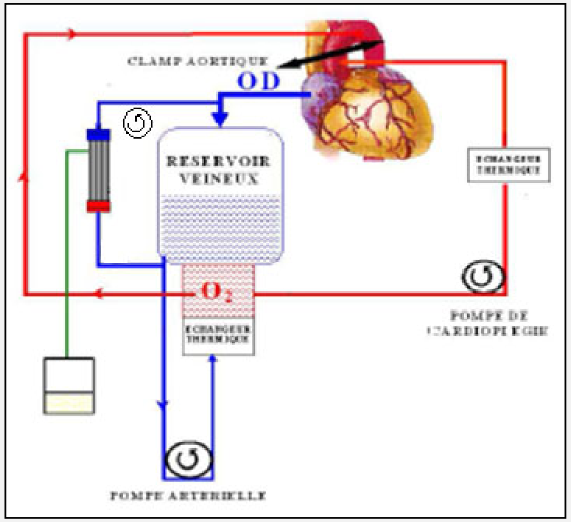
- Système de la coagulation immature
- Augmentation de l'hématocrite
- Sensibilité plus faible à l'héparine : taux AT III variable, hémodilution

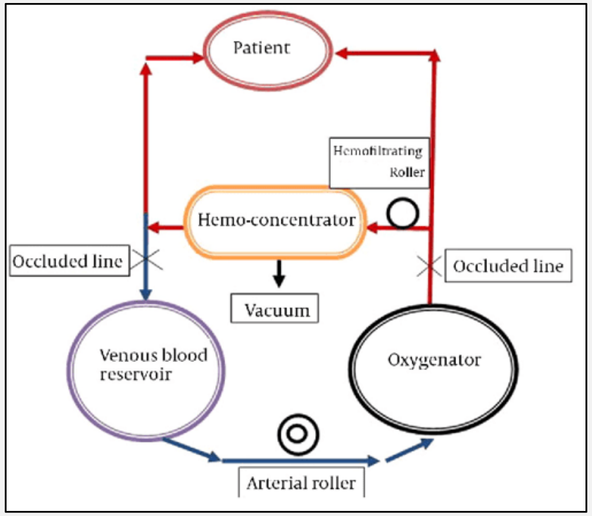
Héparine bolus
300 $UI.kg^{-1}$
Héparine en continu
100 $UI.kg^{-1}.h^{-1}$

ACT toutes les 30 min si > 400 s

Ultrafiltration

Ultrafiltration conventionnelle (CUF)	Ultrafiltration modifiée (MUF)
Pendant la CEC surtout après déclampage Veine -> hémofiltre -> réservoir Volémie constante, compensation du volume filtré par transfusion (PFC et/ou CGR)	A la fin de la CEC, avant l'ablation des canules, pendant 15-20 min Canule aortique -> hémofiltre -> canule veineuse compensation par le sang du réservoir





Ultrafiltration conventionnelle (CUF)

Recherche bibliographique de 1990 à 2018 : 90 études cliniques ou publications

L’hémofiltration en chirurgie cardiaque pédiatrique :

- Améliore la fonction myocardique
- Réduit la surcharge liquidienne et les saignements
- Réduit les cytokines pro-inflammatoires
- Améliore la fonction pulmonaire et la compliance

Review Article

World Journal for Pediatric and Congenital Heart Surgery
2019, Vol. 10(6) 778-788
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Ultrafiltration in Pediatric Cardiac Surgery Review

Joel Bierer, MD[1], Roger Stanzel, PhD, CPC[2], Mark Henderson, CPC, CCP[2], Suvro Sett, MD[1], and David Horne, MD[1]

Abstract

Introduction: The use of cardiopulmonary bypass in pediatric cardiac surgery is associated with significant inflammation, fluid overload, and end-organ dysfunction yielding morbidity and mortality. For decades, various intraoperative ultrafiltration techniques such as conventional ultrafiltration, modified ultrafiltration (MUF), zero-balance ultrafiltration (ZBUF), and combination techniques (ZBUF-MUF) have been used to mitigate these toxicities and promote improved postoperative outcomes. However, there is currently no consensus on the ultrafiltration technique or strategy that yields the most benefit for infants and children undergoing open heart surgery. **Methods:** A librarian-conducted PubMed literature search from 1990 to 2018 yielded 90 clinical studies or publications on the various forms of ultrafiltration and the impact on physiologic markers and clinical outcomes. All publications were reviewed, summarized, and conclusions synthesized. The data sets were not combined for systematic or meta-analysis due to significant heterogeneity in study protocols and patient populations. **Results:** Modified ultrafiltration significantly promotes improved myocardial function, reduction in fluid overload, and reduced bleeding and transfusion complications. Furthermore, ZBUF has shown a consistent reduction in inflammatory cytokines and improved pulmonary function and compliance. There is conflicting evidence that MUF, ZBUF, and ZBUF-MUF culminate in reduced ventilation time and intensive care unit stay. **Conclusion:** Various modes of ultrafiltration have been shown to be associated with improved physiologic function or clinical outcomes in pediatric cardiac surgery. There are some inconsistent trial results that can be explained by heterogeneity in ultrafiltration, clinical staff preferences, and institution protocols. Ultrafiltration has some essential benefit as it is ubiquitously used at pediatric heart centers; however, the optimal protocol could be yet identified.

Keywords
congenital, pediatric, cardiac, open-heart, cardiovascular surgery, modified, conventional, zero-balance, ultrafiltration, cardiopulmonary, bypass, inflammation

Submitted May 08, 2019; Accepted July 18, 2019.

Introduction

Children undergoing heart surgery requiring cardiopulmonary bypass (CPB) are subject to significant hemodilution and systemic inflammatory response from circuit exposure.[1,2] These insults culminate in capillary leak syndrome, associated tissue edema, and organ dysfunction leading to increased morbidity and mortality.[2] In the 1980s, conventional ultrafiltration (CUF) was developed to remove excess fluid during the rewarming phase of CPB. Conventional ultrafiltration, postoperative diuresis, and even peritoneal dialysis did not significantly resolve the fluid overload state, morbidity, or mortality. In 1991, Naik et al developed modified ultrafiltration (MUF) facilitating large volumes of filtrate to be removed in an efficient manner, which seemed to improve postoperative clinical outcomes.[3,4]

Improved cardiopulmonary function, reduced postoperative bleeding, and diminished inflammatory syndromes were hypothesized to be a result of MUF's superior ability to remove fluid, concentrate coagulation factors, and extract inflammatory cytokines. This translated into some observations of improved clinical outcomes as cardiopulmonary function was optimized by reduced tissue edema.[5] Furthermore, reduced blood loss and transfusion requirements were thought to be related to coagulation factor and fibrinogen

[1] Division of Cardiac Surgery, Department of Surgery, Dalhousie University, Halifax, Nova Scotia, Canada
[2] Department of Clinical Perfusion, Nova Scotia Health Authority, Halifax, Nova Scotia, Canada

Corresponding Author:
David Horne, IWK Health Centre, 2nd Floor Children's Site, PO Box 9700, Halifax, Nova Scotia, Canada B3K 6R8.
Email: david.horne@iwk.nshealth.ca

Joel Bierer etal. J Pediatr Congenit Heart Surg 2019

Ultrafiltration modifiée (MUF)


Modified ultrafiltration and postoperative course in patients undergoing repair of tetralogy of Fallot

Étude randomisé (2021) 79 patients opérés de T4F

CUF (n = 40) *VS* CUF + MUF (n = 39)

CUF + MUF

- ↑ Hématocrite postopératoire
- ↓ Durée ventilation mécanique
- ↓ Inotropes
- ↓ taux d'interleukine-6 et de troponine-T

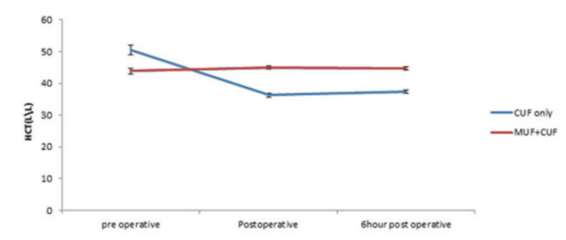


FIGURE 1 Comparison of Average Hematocrit (HCT) between CUF only and MUF + CUF groups. Adjusted mean (adjusted for pre-operative HCT) are reported at postoperative and 6 hour postoperative

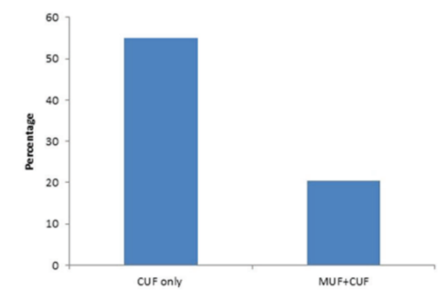


FIGURE 2 Comparison of the duration of mechanical ventilation > 10 h between CUF only and MUF + CUF groups

Talwar S et al. J Card Surg. 2021

Ultrafiltration


Medicine

Effects of modified ultrafiltration and conventional ultrafiltration combination on perioperative clinical outcomes in pediatric cardiac surgery

A meta-analysis

8 essais - 405 patients (2020)

CUF *VS* CUF + MUF

- volume d'ultrafiltrat

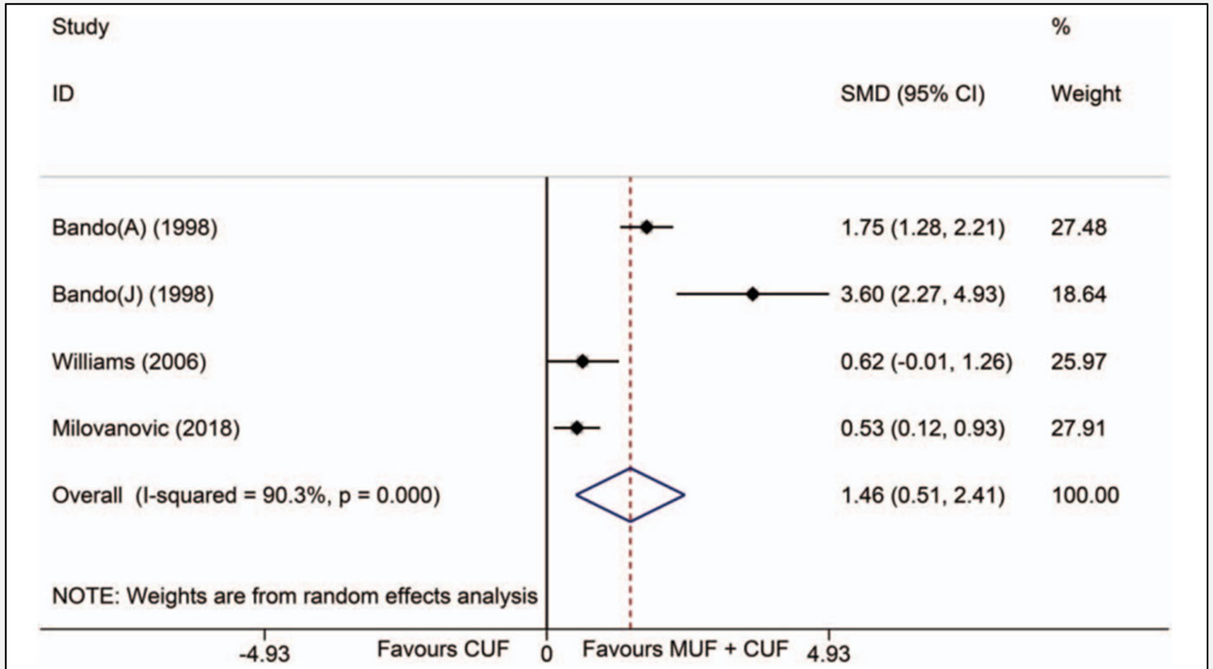


Figure 4. Forest plot of ultrafiltration volume between MUF plus CUF and CUF alone in pediatric cardiac surgery. CI=confidence interval, CUF=conventional ultrafiltration, MUF=modified ultrafiltration, SMD=standard mean difference.

Hu J et al. 2021

Ultrafiltration

8 essais - 405 patients (2020)

CUF *VS* CUF + MUF

- Hématocrite post opératoire

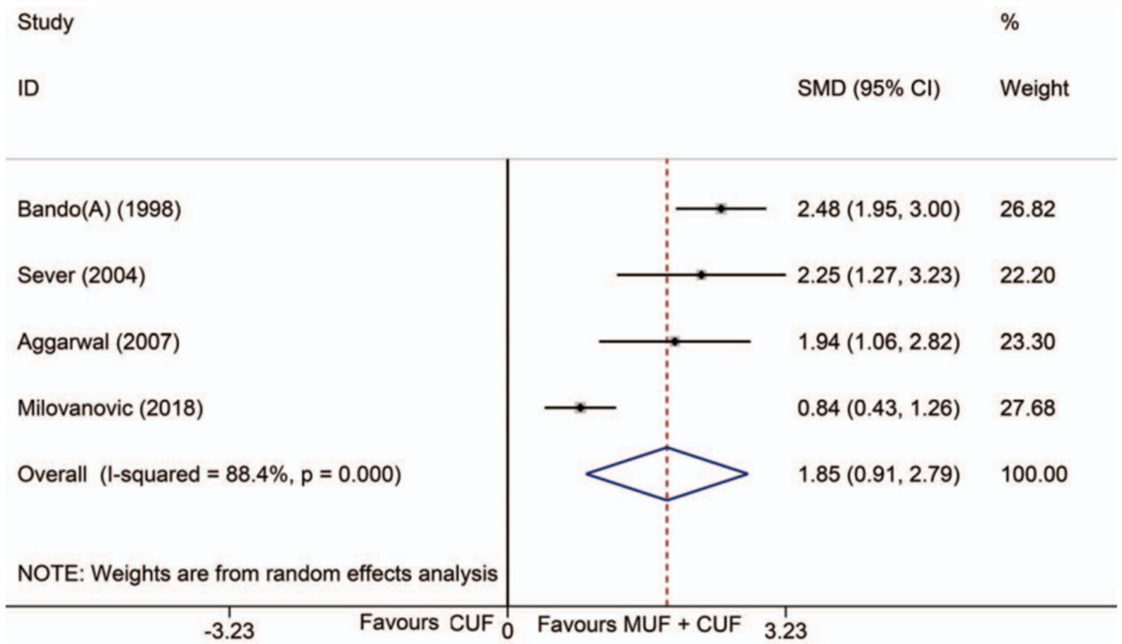


Figure 3. Forest plot of post-cardiopulmonary bypass hematocrit between MUF plus CUF and CUF alone in pediatric cardiac surgery. Bando (A): published in *Ann Thorac Surg* by Bando. CI, confidence interval, CUF = conventional ultrafiltration, MUF = modified ultrafiltration, SMD, standard mean difference.

Hu J et al. 2021

Hémodiafiltration

Hémodialyse + hémofiltration

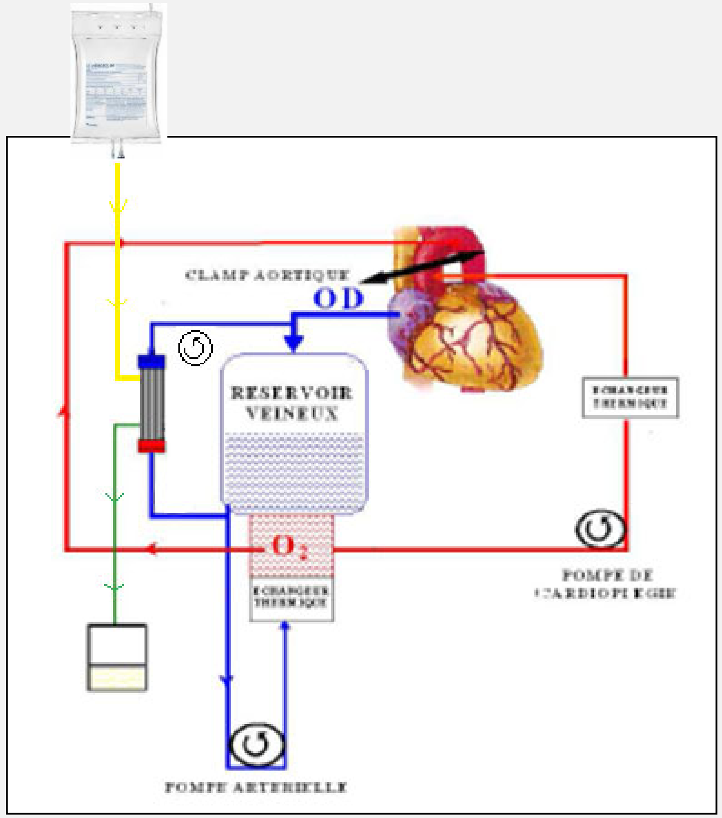
diffusif et convectif

Correction de l'hyperkaliémie
(priming et per CEC)

Hémosol B0 Poche 5000 ml Gambro

Na^+	140 $mmol.l^{-1}$
Ca^{2+}	1.75 $mmol.l^{-1}$
Mg^{2+}	0.5 $mmol.l^{-1}$
Cl^-	109.5 $mmol.l^{-1}$
Lactate	3 $mmol.l^{-1}$
$HCO3^-$	32 $mmol.l^{-1}$

Pauvre en lactate
Pas de K^+
Pas de glucose



Conduite de la CEC pédiatrique

$\underline{DO_2}$ (AKI)

Adulte > 280 $ml.min^{-1}.m^{-2}$

Pédiatrie > 353 $ml.min^{-1}.m^{-2}$

Patients cyanogènes ?

$\underline{VCO_2}$ (Hyperlactatémie)

Adulte < 60 $ml.min^{-1}.m^{-2}$

Pédiatrie : ?

QR (DO_2 /VCO_2) < 5.0 : ?

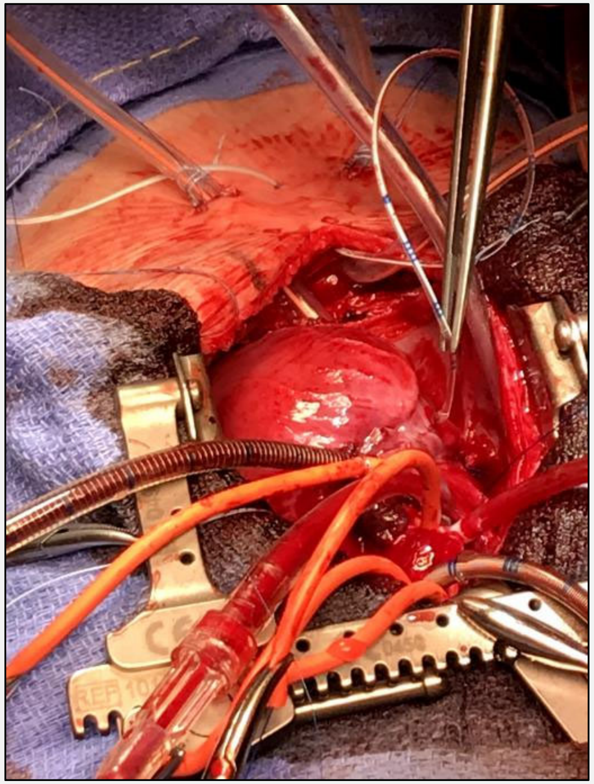
Sevrage de la CEC

L'hématocrite

- Respect de l'hématocrite physiologique du nouveau-né : 42 – 45%
- Ventricules peu compliants, difficultés pour réaliser une transfusion importante après arrêt de la CEC
- Anticiper une hémodilution obligatoire au moment de la transfusion plaquettaire (50 ml …)

Sevrage de la CEC

Pression de remplissage (POG)



Sevrage de la CEC

<u>Homéostasie ionique</u>

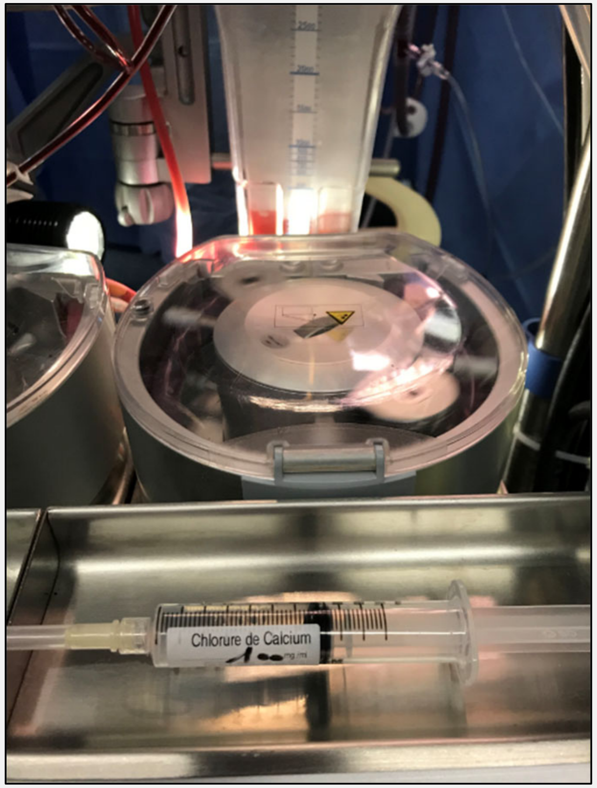
- Corriger l'hypocalcémie

Faible capacité de stockage

(contractilité sous la dépendance du Ca^{2+} extra cellulaire)

- Corriger l'hyperkaliémie

(Hémodiafiltration, bicar)



Sevrage de la CEC

Homéostasie thermique

- Eviter l'effet de l'hypothermie sur l'hémostase
- Eviter l'effet de l'hypothermie sur les résistances vasculaires périphériques
- Le frisson postopératoire augmente la VO_2

L'hyperthermie postopératoire augmente aussi la VO_2
(11% pour chaque °C)

A retenir…

Les enfants ont des besoins métaboliques élevés : débit de CEC autour de $3 l.min^{-1}.m^{-2}$

Cœur peu compliant : Le monitorage des pressions de remplissage est une aide précieuse

Le VAVD permet de réduire le priming et la taille des canules mais sans dépasser -90 mmHg

Transfusion de CGR récents ou déplasmatisés / ultra-filtration $100 ml.kg^{-1}$

Hypothermie en pédiatrie = Statégie pH-stat

Corriger l'hypocalcémie au fur et à mesure mais attention dans le priming au sang

Monitorer les pressions de perfusion de la cardioplégie (efficacité / innocuité)

NIRS et gaz du sang en continu indispensables

Merci de votre attention

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