The importance of optimizing perfusion to improve outcome

Christoph T. Starck, MD
Senior Consultant Cardiac Surgeon
Disclosures…

- **Sorin:** Speaker honoraria, travel expenses
- **Medtronic:** Consulting honoraria, travel expenses
- **Biotronik:** Consulting honoraria, Research support
- **St. Jude Medical:** Research support
- **Cook Medical:** Workshop honoraria, consulting honoraria, Research support
What is the surgeon`s interest in extracorporeal circulation?

As long as the pump runs…

why should the surgeon care…?
Hippocratic oath & Declaration of Geneva

WMA Declaration of Geneva


AT THE TIME OF BEING ADMITTED AS A MEMBER OF THE MEDICAL PROFESSION:
I SOLEMNLY PLEDGE to consecrate my life to the service of humanity;
I WILL GIVE to my teachers the respect and gratitude that is their due;
I WILL PRACTICE my profession with dignity;
THE HEALTH OF MY PATIENT will be my first consideration;
I WILL BE true to my benefactors, society in general, even after the patient has died;
I WILL MAINTAIN by all means in my power, the honour and the noble traditions of the medical profession;
MY COLLEAGUES will be my sisters and brothers;
I WILL NOT PERMIT considerations of age, disease or disability, creed, ethnic origin, gender, nationality, political affiliation, race, sexual orientation, social standing or any other factor to intervene between my duty and my patient;
I WILL MAINTAIN the utmost respect for human life;
Best results in cardiac surgery

The Value of Public Reporting

Cardiothoracic surgeons have long recognized the importance of data and analytics outcomes in achieving quality improvement. Public reporting has been shown to lead to significant improvements in performance and patient care. The Society of Thoracic Surgeons (STS) has been a leader in promoting public reporting to drive quality improvement and patient outcomes.

Public Reporting Information in Annals Supplement

For more detailed information about public reporting, check out the special supplement included in the January issue of Annals of Thoracic Surgery.

The STS Adult Cardiac Surgery Database, which began in 1996, has been a valuable resource for surgeons and their patients. The database has been instrumental in improving outcomes and enhancing patient care. The STS has been a leader in promoting public reporting to drive quality improvement and patient outcomes.

The Value of Public Reporting

Public reporting has been shown to lead to significant improvements in performance and patient care. The Society of Thoracic Surgeons (STS) has been a leader in promoting public reporting to drive quality improvement and patient outcomes.

The STS Adult Cardiac Surgery Database, which began in 1996, has been a valuable resource for surgeons and their patients. The database has been instrumental in improving outcomes and enhancing patient care. The STS has been a leader in promoting public reporting to drive quality improvement and patient outcomes.

Public Reporting Information in Annals Supplement

For more detailed information about public reporting, check out the special supplement included in the January issue of Annals of Thoracic Surgery.

The STS Adult Cardiac Surgery Database, which began in 1996, has been a valuable resource for surgeons and their patients. The database has been instrumental in improving outcomes and enhancing patient care. The STS has been a leader in promoting public reporting to drive quality improvement and patient outcomes.

Public Reporting Information in Annals Supplement

For more detailed information about public reporting, check out the special supplement included in the January issue of Annals of Thoracic Surgery.

The STS Adult Cardiac Surgery Database, which began in 1996, has been a valuable resource for surgeons and their patients. The database has been instrumental in improving outcomes and enhancing patient care. The STS has been a leader in promoting public reporting to drive quality improvement and patient outcomes.

Public Reporting Information in Annals Supplement

For more detailed information about public reporting, check out the special supplement included in the January issue of Annals of Thoracic Surgery.

The STS Adult Cardiac Surgery Database, which began in 1996, has been a valuable resource for surgeons and their patients. The database has been instrumental in improving outcomes and enhancing patient care. The STS has been a leader in promoting public reporting to drive quality improvement and patient outcomes.

Public Reporting Information in Annals Supplement

For more detailed information about public reporting, check out the special supplement included in the January issue of Annals of Thoracic Surgery.

The STS Adult Cardiac Surgery Database, which began in 1996, has been a valuable resource for surgeons and their patients. The database has been instrumental in improving outcomes and enhancing patient care. The STS has been a leader in promoting public reporting to drive quality improvement and patient outcomes.

Public Reporting Information in Annals Supplement

For more detailed information about public reporting, check out the special supplement included in the January issue of Annals of Thoracic Surgery.

The STS Adult Cardiac Surgery Database, which began in 1996, has been a valuable resource for surgeons and their patients. The database has been instrumental in improving outcomes and enhancing patient care. The STS has been a leader in promoting public reporting to drive quality improvement and patient outcomes.

Public Reporting Information in Annals Supplement

For more detailed information about public reporting, check out the special supplement included in the January issue of Annals of Thoracic Surgery.

The STS Adult Cardiac Surgery Database, which began in 1996, has been a valuable resource for surgeons and their patients. The database has been instrumental in improving outcomes and enhancing patient care. The STS has been a leader in promoting public reporting to drive quality improvement and patient outcomes.

Public Reporting Information in Annals Supplement

For more detailed information about public reporting, check out the special supplement included in the January issue of Annals of Thoracic Surgery.

The STS Adult Cardiac Surgery Database, which began in 1996, has been a valuable resource for surgeons and their patients. The database has been instrumental in improving outcomes and enhancing patient care. The STS has been a leader in promoting public reporting to drive quality improvement and patient outcomes.

Public Reporting Information in Annals Supplement

For more detailed information about public reporting, check out the special supplement included in the January issue of Annals of Thoracic Surgery.

The STS Adult Cardiac Surgery Database, which began in 1996, has been a valuable resource for surgeons and their patients. The database has been instrumental in improving outcomes and enhancing patient care. The STS has been a leader in promoting public reporting to drive quality improvement and patient outcomes.

Public Reporting Information in Annals Supplement

For more detailed information about public reporting, check out the special supplement included in the January issue of Annals of Thoracic Surgery.

The STS Adult Cardiac Surgery Database, which began in 1996, has been a valuable resource for surgeons and their patients. The database has been instrumental in improving outcomes and enhancing patient care. The STS has been a leader in promoting public reporting to drive quality improvement and patient outcomes.

Public Reporting Information in Annals Supplement

For more detailed information about public reporting, check out the special supplement included in the January issue of Annals of Thoracic Surgery.

The STS Adult Cardiac Surgery Database, which began in 1996, has been a valuable resource for surgeons and their patients. The database has been instrumental in improving outcomes and enhancing patient care. The STS has been a leader in promoting public reporting to drive quality improvement and patient outcomes.

Public Reporting Information in Annals Supplement

For more detailed information about public reporting, check out the special supplement included in the January issue of Annals of Thoracic Surgery.

The STS Adult Cardiac Surgery Database, which began in 1996, has been a valuable resource for surgeons and their patients. The database has been instrumental in improving outcomes and enhancing patient care. The STS has been a leader in promoting public reporting to drive quality improvement and patient outcomes.

Public Reporting Information in Annals Supplement

For more detailed information about public reporting, check out the special supplement included in the January issue of Annals of Thoracic Surgery.

The STS Adult Cardiac Surgery Database, which began in 1996, has been a valuable resource for surgeons and their patients. The database has been instrumental in improving outcomes and enhancing patient care. The STS has been a leader in promoting public reporting to drive quality improvement and patient outcomes.

Public Reporting Information in Annals Supplement

For more detailed information about public reporting, check out the special supplement included in the January issue of Annals of Thoracic Surgery.

The STS Adult Cardiac Surgery Database, which began in 1996, has been a valuable resource for surgeons and their patients. The database has been instrumental in improving outcomes and enhancing patient care. The STS has been a leader in promoting public reporting to drive quality improvement and patient outcomes.

Public Reporting Information in Annals Supplement

For more detailed information about public reporting, check out the special supplement included in the January issue of Annals of Thoracic Surgery.

The STS Adult Cardiac Surgery Database, which began in 1996, has been a valuable resource for surgeons and their patients. The database has been instrumental in improving outcomes and enhancing patient care. The STS has been a leader in promoting public reporting to drive quality improvement and patient outcomes.

Public Reporting Information in Annals Supplement

For more detailed information about public reporting, check out the special supplement included in the January issue of Annals of Thoracic Surgery.

The STS Adult Cardiac Surgery Database, which began in 1996, has been a valuable resource for surgeons and their patients. The database has been instrumental in improving outcomes and enhancing patient care. The STS has been a leader in promoting public reporting to drive quality improvement and patient outcomes.

Public Reporting Information in Annals Supplement

For more detailed information about public reporting, check out the special supplement included in the January issue of Annals of Thoracic Surgery.

The STS Adult Cardiac Surgery Database, which began in 1996, has been a valuable resource for surgeons and their patients. The database has been instrumental in improving outcomes and enhancing patient care. The STS has been a leader in promoting public reporting to drive quality improvement and patient outcomes.

Public Reporting Information in Annals Supplement

For more detailed information about public reporting, check out the special supplement included in the January issue of Annals of Thoracic Surgery.

The STS Adult Cardiac Surgery Database, which began in 1996, has been a valuable resource for surgeons and their patients. The database has been instrumental in improving outcomes and enhancing patient care. The STS has been a leader in promoting public reporting to drive quality improvement and patient outcomes.
Main outcome variables in cardiac surgery...

Cardiac Surgery

ECC

Anesthesia
Main outcome variables in cardiac surgery...
Association of Center Volume With Outcomes: Analysis of Verified Data of European Association for Cardio-Thoracic Surgery Congenital Database

Andrzej Kansy, MD, PhD, Tjark Ebels, MD, PhD, Christian Schreiber, MD, PhD, Zdzislaw Tobota, MD, and Bohdan Maruszewski, MD, PhD

Department of Cardiothoracic Surgery, The Children’s Memorial Health Institute, Warsaw, Poland; Department of Cardiovascular Surgery, University Hospital Groningen, Netherlands; and Department of Cardiovascular Surgery, German Heart Centre, Munich, Germany

Plot of Means,
($\beta=0.98$, adjusted $R^2=0.95$, $p<0.02$)
Cardiac surgery: Volume - Outcome

The surgeon’s relationship towards blood...
Major Bleeding, Transfusions, and Anemia: The Deadly Triad of Cardiac Surgery

Marco Ranucci, MD, FESC, Ekaterina Baryshnikova, BD, Serenella Castelvecchio, MD, FESC, and Gabriele Pelissero, MD, PhD; for the Surgical and Clinical Outcome Research (SCORE) Group

Departments of Cardiothoracic, and Vascular Anesthesia and Intensive Care, Scientific Directorate, IRCCS Policlínico San Donato, Milan, Italy

Operative mortality rate (%)

- No preoperative anemia
- Preoperative anemia

P < 0.001

- 9215 patients (CABG, Valve & Combined procedures)
- 50.8% transfused
- short term mortality: >8-fold higher, if ≥5 units RBC transfused

Karkouti et al. Transfusion 2004
Surgical Outcomes and Transfusion of Minimal Amounts of Blood in the Operating Room

Victor A. Ferraris, MD, PhD; Daniel L. Davenport, PhD; Sibu P. Saha, MD, MBA; Peter C. Austin, PhD; Joseph B. Zwischenberger, MD


- Non-cardiac surgery 2005-2009
- 173 U.S. hospitals
- 941,496 patients
- 48,291 patients received transfusions
- 15,186 patients received 1 RBC unit
- 11,855 pairs: 1 RBC vs. 0 RBC

Table 3. Outcome Comparisons Between Propensity-Matched Groups

<table>
<thead>
<tr>
<th>Postoperative Complication</th>
<th>No Transfusion (n=11,855)</th>
<th>Transfusion a (n=11,855)</th>
<th>P Value c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortality, %</td>
<td>5.2</td>
<td>6.1</td>
<td>.005</td>
</tr>
<tr>
<td>Wound problems, %</td>
<td>9.7</td>
<td>11.4</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Pulmonary, %</td>
<td>11.7</td>
<td>15.3</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Renal, %</td>
<td>5.5</td>
<td>6.8</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>CNS, %</td>
<td>1.3</td>
<td>1.3</td>
<td>.91</td>
</tr>
<tr>
<td>Cardiac, %</td>
<td>2.0</td>
<td>2.4</td>
<td>.06</td>
</tr>
<tr>
<td>Sepsis, %</td>
<td>8.2</td>
<td>10.6</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Return to OR, %</td>
<td>11.4</td>
<td>12.1</td>
<td>.09</td>
</tr>
<tr>
<td>Composite morbidity, %</td>
<td>30.1</td>
<td>34.2</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Postoperative length of stay, mean (SD), d</td>
<td>10.3 (14.3)</td>
<td>11.8 (14.7)</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>
Costs of RBC units...

Shander et al. Transfusion 2010
But...

…it is not only the evil surgeon.
Main outcome variables in cardiac surgery...
Additive Effect on Survival of Anaesthetic Cardiac Protection and Remote Ischemic Preconditioning in Cardiac Surgery: A Bayesian Network Meta-Analysis of Randomized Trials

Alberto Zangrillo,1,2 Mario Musu,3 Teresa Greco,3 Ambra Licia Di Prima,1 Andrea Matteazzi,1 Valentina Testa,1 Pasquale Nardelli,1 Daniela Febres,1 Fabrizio Monaco,1 Maria Grazia Calabrò,1 Jun Ma, Gabriele Finco,1 Giovanni Landoni1,4*

1 Department of Anesthesia and Intensive Care, IRCCS San Raffaele Scientific Institute, Milan, Italy, 2 Vita-Salute San Raffaele University, Milan, Italy, 3 Department of Medical Sciences “M. Aresu”, Cagliari University, Cagliari, Italy, 4 Center for Anesthesiology, Beijing Anzhen Hospital, Capital Medical University, Beijing, China

2878 abstracts retrieved

2711 titles/articles not eligible for inclusion (not relevant to the studies question)

167 articles eligible for inclusion and detailed assessment

112 trials excluded because of prespecified criteria:
- 58 articles without mortality data
- 18 articles with overlapping population
- 16 articles not limited to cardiac surgery
- 9 non-randomized controlled trials
- 7 articles with all patients receiving halogenated anesthetics
- 4 articles with non adults patients

55 articles finally included in the network meta-analysis
Table 2. Posterior distribution of the probability to be the best and the worst for each anesthetic agents, derived by Bayesian hierarchical model.

<table>
<thead>
<tr>
<th>Anesthetic agents</th>
<th>Probability to be the best</th>
<th>Probability to be the second</th>
<th>Probability to be the third</th>
<th>Probability to be the worst</th>
<th>SUCRA index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remote-Volatile</td>
<td>0.9646</td>
<td>0.02805</td>
<td>0.005187</td>
<td>0.002187</td>
<td>98.5</td>
</tr>
<tr>
<td>Volatile</td>
<td>0.01549</td>
<td>0.802</td>
<td>0.173</td>
<td>0.009503</td>
<td>60.8</td>
</tr>
<tr>
<td>Remote-TIVA</td>
<td>0.01918</td>
<td>0.1636</td>
<td>0.5309</td>
<td>0.2863</td>
<td>30.5</td>
</tr>
<tr>
<td>TIVA</td>
<td>0.0007</td>
<td>0.006303</td>
<td>0.2909</td>
<td>0.7021</td>
<td>10.2</td>
</tr>
</tbody>
</table>
Main outcome variables in cardiac surgery...

ECC
Extracorporeal circulation

„Harmful events occur in the extracorporeal blood circuit“

(John H. Gibbon, 1958)

John H. Gibbon, Jr.
(1903-1973)
Renal function and open-heart surgery

Introduction

Postoperative acute renal failure is a frequent complication of open-heart surgery, associated with a high mortality rate. While the acute circulatory and respiratory complications of open-heart surgery can be successfully managed, the prognosis and mortality of renal complications remain disappointing. In the postoperative period following open-heart surgery there is a close correlation between the degree of renal impairment and the postoperative mortality rate (Table 1).

Table 1: Incidence and mortality of renal dysfunction after open-heart surgery

<table>
<thead>
<tr>
<th>Renal function</th>
<th>Incidence</th>
<th>Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serum creatinine less than 136 μmol/l</td>
<td>2%</td>
<td>0.8%</td>
</tr>
<tr>
<td>Serum creatinine 136–220 μmol/l</td>
<td>21%</td>
<td>10.6%</td>
</tr>
<tr>
<td>Serum creatinine 220–440 μmol/l</td>
<td>34%</td>
<td>23.5%</td>
</tr>
<tr>
<td>Serum creatinine exceeding 440 μmol/l</td>
<td>36%</td>
<td>88.8%</td>
</tr>
</tbody>
</table>

The low mortality of open-heart surgery in general and the high mortality associated with renal complications raise the question of how to prevent renal complications and to lower mortality. The main differences between open-heart surgery and other types of operation are:

1) the frequent occurrence of postoperative cardiac dysfunction and circulatory problems;
2) the use of cardiopulmonary bypass during the operation;
3) the use of postoperative artificial ventilation.

It is therefore possible that these features of open-heart surgery contribute to the incidence of postoperative renal complications. Each of them can influence the renal function and special attention should be directed to forestall a negative influence on renal function.

The object of this review is to discuss the influences on renal function during cardiac surgery and how to try to optimize renal function postoperatively by appropriate management during extracorporeal circulation.
Long-Term Cerebral Outcome After Open-Heart Surgery
A Five-Year Neuropsychological Follow-up Study

K. A. Sotaniemi, M.D., Ph.D., H. Mononen, M.A., and T. E. Hokkanen, M.D., Ph.D.

Figure 4. Postoperative NP-Index change scores after a short (<2h; N of pat. 22) and a long (≥2h; N of pat. 22) perfusion times. (*:p < .05; **:p < .01; ***:p < .001)
Optimizing Perfusion...

- Reduction of hemodilution
- Reduction of microbubbles
- Suction blood management
- Reduction foreign surface area
Optimized Perfusion

Reduction of hemodilution

• Reduction priming volume
• Retrograde autologuous priming
• Reduction cardioplegia volume

Suction blood management

• Cell saver
• Suction blood separation

Reduction of microbubbles

• Dynamic bubble trap (DBT)
• Airfree venous cannulation

Reduction foreign surface area

• Reduction of tubing length
• 3/8`` tubing
• DBT instead of arterial filter
• (biocompatible surfaces)
Hemodilution

This is fine…!

Is this fine, too?
Hematocrit on Cardiopulmonary Bypass and Outcome After Coronary Surgery in Nontransfused Patients

Marco Ranucci, MD, Daniela Conti, MD, Serenella Castelvecchio, MD, Lorenzo Menicanti, MD, Alessandro Frigiola, MD, Andrea Ballotta, MD, and Gabriele Pelosi, MD

Departments of Cardiothoracic and Vascular Anesthesia and Intensive Care Unit and Cardiac Surgery, and Scientific Directorate, IRCCS Policlinico S. Donato, Milan, Italy

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

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

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

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

(Ann Thorac Surg 2010;89:11–8) © 2010 by The Society of Thoracic Surgeons
In conclusion, the preoperative HCT is a morbidity risk factor in coronary operations only if it triggers a low value of HCT on CPB. The adoption of adequate measures to contain the intraoperative decrease of the HCT seems advisable, and it is important to comment that the use of blood cardioplegia produced a protective effect in our patient population.
Pathophysiology of CPB-related Hemostatic System Abnormalities

HEMODILUTION
- CPB prime (crystalloid/colloid)
- Cardioplegia volume
- Extensive use of cell salvage systems (loss of platelets/coagulation factors)

ACTIVATION
- Contact activation
  - XIIa, Kallkrein
- Tissue Factor activation
  - Tissue Injury
  - Monocyte-related
  - Pericardial blood
- Activation of fibrinolysis
  - Increased tPA via:
    - endothelial cells
    - pericardial cavity
  - Intrinsic activation
  - Heparin or Protamine

CONSUMPTION
- Thrombin-mediated
- Plasmin-mediated
- Inflammation-mediated:
  - Elastase
  - Complement
  - Leukocyte-platelet complexes
- Mechanical (ECC):
  - oxygenator, cardiotomy suction, roller/centrifugal pump, filter

Despotis et al. Anesthesiology 1999
Haemodilution-induced profibrinolytic state is mitigated by fresh-frozen plasma: implications for early haemostatic intervention in massive haemorrhage

D. Bolliger¹ ² ³, F. Szlam¹, J. H. Levy¹, R. J. Molinari² and K. A. Tanaka¹ *

Table 1 In vitro dilution model in healthy volunteers. Data are means (so); per cent change relative to baseline value. Values for haemoglobin, haematocrit, and platelet count were identical for the dilution with saline and FFP. P-values were obtained by ANOVA followed by Bonferroni’s post hoc test. *P<0.05 vs baseline. FFP, fresh-frozen plasma; PT, prothrombin time; INR, international normalized ratio; aPTT, activated partial thromboplastin time; TAFI, tissue-activatable fibrinolysis inhibitor.
The effect of retrograde autologous priming volume on haemodilution and transfusion requirements during cardiac surgery


Table 1: Demographic and procedure-related data

<table>
<thead>
<tr>
<th></th>
<th>RAP</th>
<th>Control</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>498</td>
<td>255</td>
<td>-</td>
</tr>
<tr>
<td>Males/females</td>
<td>341/157</td>
<td>191/64</td>
<td>0.07</td>
</tr>
<tr>
<td>Age (years)</td>
<td>65.3 ± 14.6</td>
<td>63.8 ± 14.2</td>
<td>0.19</td>
</tr>
<tr>
<td>Additive EuroSCORE</td>
<td>5.8 ± 3.5</td>
<td>5.8 ± 3.5</td>
<td>0.96</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>168.9 ± 8.8</td>
<td>170.2 ± 9.5</td>
<td>0.05</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>76.6 ± 15</td>
<td>80.2 ± 15.9</td>
<td>0.002</td>
</tr>
<tr>
<td>BSA (m²)</td>
<td>1.86 ± 0.20</td>
<td>1.91 ± 0.21</td>
<td>0.002</td>
</tr>
<tr>
<td>Diabetes</td>
<td>70 (14.5)</td>
<td>34 (13.6)</td>
<td>0.74</td>
</tr>
<tr>
<td>Preoperative haematocrit (%)</td>
<td>38.9 ± 4.4</td>
<td>40.5 ± 4.6</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Preoperative creatinine (mg d l⁻¹)</td>
<td>1.01 ± 0.35</td>
<td>1.07 ± 0.73</td>
<td>0.13</td>
</tr>
<tr>
<td>CPB time (min)</td>
<td>89 ± 34</td>
<td>97 ± 39</td>
<td>0.005</td>
</tr>
<tr>
<td>Aortic cross-clamp time (min)</td>
<td>53 ± 26</td>
<td>60 ± 29</td>
<td>0.003</td>
</tr>
<tr>
<td>Redo surgery</td>
<td>30 (6.0)</td>
<td>17 (6.7)</td>
<td>0.73</td>
</tr>
<tr>
<td>Procedure</td>
<td>-</td>
<td>-</td>
<td>0.043</td>
</tr>
<tr>
<td>CABG</td>
<td>243 (48.8)</td>
<td>111 (43.5)</td>
<td>0.17</td>
</tr>
<tr>
<td>Single valve</td>
<td>101 (20.3)</td>
<td>52 (20.4)</td>
<td>0.97</td>
</tr>
<tr>
<td>CABG + valve(s)</td>
<td>70 (14.1)</td>
<td>48 (18.8)</td>
<td>0.088</td>
</tr>
<tr>
<td>Multiple valves</td>
<td>29 (5.8)</td>
<td>6 (2.4)</td>
<td>0.032</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>55 (11)</td>
<td>38 (14.9)</td>
<td>0.13</td>
</tr>
<tr>
<td>IABP</td>
<td>9 (1.8)</td>
<td>7 (2.7)</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Values presented as mean ± SD. Categorical data presented as n (%). RAP: retrograde autologous priming; BSA: body surface area; CPB: cardiopulmonary bypass; IABP: intra-aortic balloon pump.

Table 2: Volumetric data

<table>
<thead>
<tr>
<th></th>
<th>RAP</th>
<th>Control</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAP volume (ml)</td>
<td>498 ± 221</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cardioplegia volume (ml kg⁻¹)</td>
<td>11.9 ± 4.6</td>
<td>12.5 ± 9.2</td>
<td>0.26</td>
</tr>
<tr>
<td>Effective priming volume (ml)</td>
<td>747.8 ± 262</td>
<td>1288 ± 170</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Anaesthesia fluids (ml)</td>
<td>578 ± 331</td>
<td>637 ± 312</td>
<td>0.04</td>
</tr>
<tr>
<td>Haemofiltration, n (%)</td>
<td>30 (6.0)</td>
<td>14 (5.5)</td>
<td>0.87</td>
</tr>
<tr>
<td>Nadir haematocrit (%)</td>
<td>26.78 ± 3.99</td>
<td>25.79 ± 3.64</td>
<td>0.001</td>
</tr>
<tr>
<td>End-haematocrit (%)</td>
<td>29.36 ± 3.61</td>
<td>29.19 ± 2.96</td>
<td>0.52</td>
</tr>
<tr>
<td>Transfusion rate (%)</td>
<td>130 (26.1)</td>
<td>85 (33.3)</td>
<td>0.038</td>
</tr>
<tr>
<td>Intraoperative PRBC (units/patient)</td>
<td>0.58 ± 1.11</td>
<td>0.89 ± 1.42</td>
<td>0.001</td>
</tr>
<tr>
<td>Intraoperative FFP (units/patient)</td>
<td>0.19 ± 0.80</td>
<td>0.40 ± 1.27</td>
<td>0.006</td>
</tr>
<tr>
<td>Autotransfusion (ml)</td>
<td>1448 ± 213</td>
<td>1588 ± 329</td>
<td>0.007</td>
</tr>
</tbody>
</table>

Values presented as mean ± SD. Categorical data presented as n (%). RAP: retrograde autologous priming; PRBC: packed red blood cells; FFP: fresh frozen plasma.
# Effect of RAP

## Table 4: Independent predictors of intraoperative blood transfusion requirements

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds ratio</th>
<th>95% CI</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPB time</td>
<td>1.027</td>
<td>1.016-1.037</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>BSA</td>
<td>0.009</td>
<td>0.001-0.077</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Female gender</td>
<td>0.479</td>
<td>0.234-0.981</td>
<td>0.044</td>
</tr>
<tr>
<td>Preoperative Hct</td>
<td>0.602</td>
<td>0.538-0.673</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>RAP volume</strong></td>
<td>0.997</td>
<td>0.996-0.999</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Age</td>
<td>1.084</td>
<td>1.054-1.115</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Model statistics: stepwise backward logistic regression (likelihood ratio)—Naegelkerke $R^2 = 0.71$—probability of $F$ to remove: $P > 0.1$. CI: confidence interval; CPB: cardiopulmonary bypass; Hct: haematocrit; RAP: retrograde autologous priming.

Vandewiele et al. ICVTS 2013
Microbubbles

Brown et al. Stroke 2000;31:707-713
Microbubbles

• «Pump Head»: Neurologic & neurocognitive dysfunctions („pump head“)

• Postoperative delirium

• Microbubbles = foreign bodies

• Endothelial damage

• Capillary obstruction (Ischemia)

• Activation of coagulation & immune system
Initial results of an optimized perfusion system

CT Starck,¹ D Bettex,¹ C Felix,² D Reser,¹ T Dreizler,¹ P Hasenclever¹ and V Falk¹

Table 2. Operative data

<table>
<thead>
<tr>
<th>Operation</th>
<th>OPS (n=30)</th>
<th>SPS (n=30)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVR</td>
<td>8</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>MV Repair</td>
<td>8</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>MV Replacement</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>CABG</td>
<td>3</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Combination procedure</td>
<td>8</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Operative time (min)</td>
<td>235±78</td>
<td>206±62</td>
<td>n.s.</td>
</tr>
<tr>
<td>Bypass time (min)</td>
<td>125±43</td>
<td>104±33</td>
<td>0.037</td>
</tr>
<tr>
<td>Cross-clamp time (min)</td>
<td>90±35</td>
<td>60±34</td>
<td>0.002</td>
</tr>
<tr>
<td>Effective priming volume (ml)</td>
<td>776±447</td>
<td>1610±40</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Retrograde autologous priming (ml)</td>
<td>447±389</td>
<td>0±0</td>
<td>0.004</td>
</tr>
<tr>
<td>Hemoglobin drop after the onset of CPB (g/l)</td>
<td>2.7±1.2</td>
<td>4.2±0.8</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Maximal hemoglobin drop on CPB (g/l)</td>
<td>3.3±1.2</td>
<td>4.8±0.9</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

OPS: optimized perfusion system; SPS: standard perfusion system; AVR: aortic valve replacement; MV: mitral valve; CABG: coronary artery bypass grafting; CPB: cardiopulmonary bypass.
<table>
<thead>
<tr>
<th></th>
<th>OPS (n=30)</th>
<th>SPS (n=30)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest tube drainage 24h postoperatively (ml)</td>
<td>490±350</td>
<td>506±271</td>
<td>n.s.</td>
</tr>
<tr>
<td>CRP postoperative day 1 (mg/l)</td>
<td>48.0±22.7</td>
<td>50.1±21.5</td>
<td>n.s.</td>
</tr>
<tr>
<td>CRP postoperative day 2 (mg/l)</td>
<td>121.0±59.4</td>
<td>164.0±50.5</td>
<td>0.003</td>
</tr>
<tr>
<td>Maximal increase of creatinine (µmol/l)</td>
<td>17.4±42.4</td>
<td>35.2±59.1</td>
<td>n.s.</td>
</tr>
<tr>
<td>Maximum creatinine postoperative (µmol/l)</td>
<td>95.7±50.3</td>
<td>130.9±72.6</td>
<td>0.004</td>
</tr>
<tr>
<td>Length of ICU stay (h)</td>
<td>37.0±37.3</td>
<td>34.3±27.5</td>
<td>n.s.</td>
</tr>
<tr>
<td>Length of hospital stay (d)</td>
<td>8.1±3.0</td>
<td>11.4±6.7</td>
<td>0.023</td>
</tr>
</tbody>
</table>

OPS: optimized perfusion system; SPS: standard perfusion system; h: hours; CRP: C-reactive protein; ICU: intensive care unit; d: days.
Figure 1. Hemoglobin drop (g/l) after the onset of cardiopulmonary bypass, which was significantly lower (p<0.0001) in the OPS group (SPS: standard perfusion system; OPS: optimized perfusion system).

Figure 2. C-reactive protein concentration (mg/l) on postoperative day 2 revealing a significant difference (p=0.003) between the SPS and the OPS groups (SPS: standard perfusion system; OPS: optimized perfusion system).
The „One-Size-Fits-All“-Problem...
The role of the circulation is to deliver adequate oxygen and nutrients to meet tissue metabolic demands.
Individualized therapy...
Management during extracorporeal circulation to prevent renal dysfunction

The basic function of cardiopulmonary bypass is to provide an adequate flow of oxygenated blood to tissues in need and to prevent damage to organs. One of the organs vulnerable to damage during perfusion is the kidney. Renal function may be considered to be an important circulatory parameter.

The changes in serum creatinine induced by open-heart surgery are shown in Figure 1. Only 3% of the patients had the same postoperative as preoperative serum creatinine value. An increased serum creatinine was seen in 48% of the patients postoperatively, while 49% had a decreased serum creatinine. Thus the effect of cardiac surgery on renal function is not exclusively negative. The flow rate and the kind of flow (nonsystolic and pulsatile) during cardiopulmonary bypass largely determines the renal response to cardiac surgery.

(a) Flow rate
An inadequate flow rate used during cardiopulmonary bypass can have severe adverse effects in the postoperative period, even when hypothermia is used. An inadequate flow rate leads to an activation of vasomotor mechanisms consisting of:
1) inhibition of adrenergic activity in vessels leading to vasoconstriction and a raised systemic vascular resistance;
2) activation of the sympathetic system with venuous and arterial constriction leading to a decreased venous blood capacity and a raised systemic vascular resistance; and
3) activation of the hormonal system (norepinephrine, epinephrine, renin, angiotensin, aldosterone, and vasopressin).

A higher flow employed after a period of inadequate flow will reverse the raised systemic vascular resistance and the decreased venous capacity of blood. The activated hormonal mechanism will remain because of the decreased metabolism (hypothermia, no pulmonary blood flow) and can adversely influence postoperative cardiac performance. All of these hormones are reported to be increased during and following cardiopulmonary bypass; however, the extent of the rise is variable. The relationship between the flow rate used and the magnitude of hormonal activation during cardiopulmonary bypass in each study is not clear. The lowest blood flow is more important than the mean or the highest blood flow for the activation of vasoconstrictor mechanisms and this was not seen in the studies.

The renal response to cardiac surgery was used
O₂ delivery and CO₂ production during cardiopulmonary bypass as determinants of acute kidney injury: time for a goal-directed perfusion management?

Filip de Somer¹, John W Mulholland², Megan R Bryan², Tommaso Aloisio³, Guido J Van Nooten¹ and Marco Ranucci¹"
Figure 1 Graph showing acute kidney injury rate according to decile distribution of nadir oxygen delivery (DO₂) level during cardiopulmonary bypass (CPB).
Figure 2 Acute kidney injury rate according to decile distribution of nadir DO$_2$/VCO$_2$ ratio during CPB.
Table 3 Multivariable stepwise forward logistic regression analysis for acute kidney injury and any damage-independent predictors

<table>
<thead>
<tr>
<th>Acute kidney injury severity</th>
<th>Factor</th>
<th>( \beta ) coefficient</th>
<th>Odds ratio (95% CI)</th>
<th>( P ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute kidney injury stage 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EuroSCORE</td>
<td>0.034</td>
<td>1.035 (1.016 to 1.054)</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>CPB duration (minutes)</td>
<td>0.008</td>
<td>1.008 (1.002 to 1.015)</td>
<td>0.012</td>
<td></td>
</tr>
<tr>
<td>Nadir DO(_2) &lt; 262 mL/minute/m(^2)</td>
<td>1.135</td>
<td>3.111 (1.531 to 6.319)</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>Model 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EuroSCORE</td>
<td>0.035</td>
<td>1.036 (1.017 to 1.055)</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>CPB duration (minutes)</td>
<td>0.008</td>
<td>1.008 (1.002 to 1.014)</td>
<td>0.007</td>
<td></td>
</tr>
<tr>
<td>Nadir DO(_2)/VCO(_2) ratio &lt; 5.3</td>
<td>1.062</td>
<td>2.893 (1.452 to 5.763)</td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td>Any acute kidney injury</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EuroSCORE</td>
<td>0.026</td>
<td>1.026 (1.008 to 1.045)</td>
<td>0.005</td>
<td></td>
</tr>
<tr>
<td>CPB duration (minutes)</td>
<td>0.009</td>
<td>1.009 (1.003 to 1.015)</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
<td>Nadir DO(_2) &lt; 262 mL/minute/m(^2)</td>
<td>0.767</td>
<td>2.154 (1.205 to 3.849)</td>
<td>0.010</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)CPB: cardiopulmonary bypass; CI: confidence interval; DO\(_2\): oxygen delivery; VCO\(_2\): carbon dioxide production.
Figure 4: Acute kidney injury rates in patient groups according to the critical values of DO₂, DO₂/VCO₂ ratio, and hematocrit, with sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV).
Table 4: Univariate association (linear regression and Student’s t-test) between study variables and ICU and postoperative hospital lengths of stay

<table>
<thead>
<tr>
<th>Variables</th>
<th>β coefficient</th>
<th>Constant</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICU length of stay (days)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nadir DO₂ (mL/minute/m²)</td>
<td>-0.020</td>
<td>8.532</td>
<td>0.014</td>
</tr>
<tr>
<td>Peak VCO₂ (mL/minute/m²)</td>
<td>0.034</td>
<td>1.297</td>
<td>0.355</td>
</tr>
<tr>
<td>Nadir DO₂/VCO₂ ratio</td>
<td>-0.458</td>
<td>5.703</td>
<td>0.136</td>
</tr>
<tr>
<td>Postoperative hospital length of stay (days)</td>
<td>β coefficient</td>
<td>Constant</td>
<td>P value</td>
</tr>
<tr>
<td>Factor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nadir DO₂ (mL/minute/m²)</td>
<td>-0.055</td>
<td>29.39</td>
<td>0.001</td>
</tr>
<tr>
<td>Peak VCO₂ (mL/minute/m²)</td>
<td>0.001</td>
<td>14.15</td>
<td>0.996</td>
</tr>
<tr>
<td>Nadir DO₂/VCO₂ ratio</td>
<td>-0.516</td>
<td>17.02</td>
<td>0.428</td>
</tr>
</tbody>
</table>

Statistical analysis per cutoff value

<table>
<thead>
<tr>
<th>Variables</th>
<th>β coefficient</th>
<th>Constant</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICU length of stay (days)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nadir DO₂ &lt; 262 mL/minute/m²</td>
<td>4.2 ± 8.7</td>
<td>2.5 ± 4.4</td>
<td>0.019</td>
</tr>
<tr>
<td>Nadir DO₂ ≥262 mL/minute/m²</td>
<td>17.6 ± 14.1</td>
<td>12.4 ± 12.1</td>
<td>0.001</td>
</tr>
<tr>
<td>Postoperative hospital length of stay (days)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nadir DO₂/VCO₂ ratio &lt; 5.3</td>
<td>3.4 ± 6.9</td>
<td>2.9 ± 5.6</td>
<td>0.476</td>
</tr>
<tr>
<td>Nadir DO₂/VCO₂ ratio ≥5.3</td>
<td>15.3 ± 13.2</td>
<td>13.4 ± 12.6</td>
<td>0.198</td>
</tr>
</tbody>
</table>

*DO₂: oxygen delivery; VCO₂: carbon dioxide production.
Optimizing Perfusion = Teamwork

Cardiac Surgeon

Anesthesiologist

Perfusionist
Conclusion

- Perfusion management and strategy influences outcome
- No „One-Size-Fits-All“ solution
- Adaption of perfusion to metabolic needs of the patient
- Optimizing perfusion is teamwork
- Optimizing perfusion is a continuous process
Thank you...

starck@dhzb.de

Deutsches Herzzentrum Berlin
Stiftung des bürgerlichen Rechts
Augustenburger Platz 1
13353 Berlin

Telefon: +49 30 4593-1000
Telefax: +49 30 4593-1003
E-Mail: info@dhzb.de
www.dhzb.de