Volume Management and Blood Conservation
Cardiopulmonary Bypass

Jeffrey B. Riley CCP

AATS13#: AATS 93rd Annual Meeting
Minneapolis MN
Disclosure

- Perfusionist
- Officer: American Society of Extracorporeal Technology (AmSECT)
- National Perfusionist Appreciation Week
- International Consortium for Evidence Based Perfusion
Outline

• List the issues associated with volume management during cardiac surgery and cardiopulmonary bypass (CPB)

• Focus on minimizing heart-lung machine (HLM) priming volume and foreign surface area

• Demonstrate how to avoid dilutional coagulopathies during cardiac surgery

• Discuss the components of a multidisciplinary cardiac surgery blood management program
Evidence and Recommendations

<table>
<thead>
<tr>
<th>Precision</th>
<th>Treatment Effect</th>
<th>Class I</th>
<th>Class IIa</th>
<th>Class IIb</th>
<th>Class III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>Should be performed</td>
<td>Is reasonable</td>
<td>May be considered</td>
<td>May be harmful</td>
<td></td>
</tr>
<tr>
<td>Level A</td>
<td>Presence of multiple randomized clinical trials</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level B</td>
<td>Single randomized trial or nonrandomized studies</td>
<td></td>
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<tr>
<td>Level C</td>
<td>Expert consensus</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evidence</td>
<td>Size of benefit of treatment effect</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Multidisciplinary Teams

Creation of multidisciplinary surgical teams for blood management.

Class of Recommendation IIa

Level of Evidence (B)


<table>
<thead>
<tr>
<th>CCP Responsibility</th>
<th>Pre-CPB</th>
<th>Initiate CPB</th>
<th>Cross-Clamp</th>
<th>Warming</th>
<th>Reperfuse</th>
<th>Wean CPB</th>
<th>Post-CPB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication</td>
<td>Surgeon briefing</td>
<td>Complete the major communication points between the surgeon and perfusionist by communication protocol; Principles of sterile cockpit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Collect ECC lines from surgical field; Team debrief</td>
</tr>
<tr>
<td>Safety</td>
<td>Review medical record; Right size ECC; Avoid SIRS</td>
<td>Target flow rate achieved; ECC and oxygenator function WNL</td>
<td>Monitor CPS flow, pressure and time intervals</td>
<td>Avoid cerebral hyperthermia; Avoid GME</td>
<td>Maintain myocardial and cerebral reperfusion pressures</td>
<td>Cooperate with anesthesia and surgeon to wean</td>
<td>Monitor patient recovery; Be prepared to re-initiate CPB, VAD or ECMO</td>
</tr>
<tr>
<td>Coagulation</td>
<td>Review patient history; Measure in-vitro HDR; Monitor amount and time of heparin dose; Measure change in ACT; Protect ECC surfaces; Document coagulation effects of hemodilution</td>
<td>Process cardiotomy suction blood; Consider heparinase TEG; Preserve platelets and clotting factors</td>
<td>TEG-directed transfusion of coagulation factors and platelets</td>
<td>Process residual ECC blood</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hemodynamics</td>
<td>Document arterial cannula patency</td>
<td>Maintain pressure – flow – resistance; Control viscosity; Maintain SVR WNL; Avoid venous hypertension; Monitor hemoglobin concentration and colloidal oncotic pressure; Guarantee adequate perfusion; Monitor fluid balance between UO and UF</td>
<td>Maintain alpha-stat during reperfusion and warming; Control PaCO₂ to avoid pulmonary hypertension and cerebral blood flow autoregulation</td>
<td>Monitor cardiac index and renal function</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ventilation</td>
<td>Monitor pH and respiratory component PaCO₂</td>
<td>Employ alpha-stat 32 – 37 °C; Employ pH-stat below 32 °C; Convert to alpha-stat prior to circulatory arrest</td>
<td>Monitor cardiac index and renal function</td>
<td>Monitor respiratory acidosis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metabolism</td>
<td>Monitor pH and metabolic component [HCO₃⁻]</td>
<td>Predict post-dilutional [Hb]; Monitor cardiac index to maintain greater than 1.7 l/min/m²; Maintain SVO₂ greater than 65% at normothermia; Monitor DO₂, VO₂ and extraction ratio; Avoid metabolic acidosis</td>
<td>Monitor metabolic acidosis wash-out</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>Monitor patient temperature</td>
<td>Confirm target temperature; Observe safe cooling temperature gradients; Do not reduce arterial blood below 13.5 °C</td>
<td>Time start of warming with surgeon; Observe safe warming temperature gradients; Do not exceed 37.5 °C arterial blood</td>
<td>Monitor patient body temperature after-drop</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:** Evidence-based; multidisciplined team approach
# Recommendations for CPB Map

## Oxygenator Ventilation

_The clinical team should manage adult patients undergoing moderate hypothermic CPB with alpha-stat pH management._

<table>
<thead>
<tr>
<th>Class of Recommendation</th>
<th>Level of Evidence</th>
<th>J Thor Cardiovasc Surg</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>(A)</td>
<td>2006;132:283-90</td>
</tr>
</tbody>
</table>

## Reduction of Hemodilution

_Efforts should be made to reduce hemodilution, including reduction of prime volume, to avoid subsequent allogeneic blood transfusion._

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## Avoidance of Hyperthermia

_Limiting arterial line temperature to 37°C might be useful for avoiding cerebral hyperthermia._

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<tr>
<td>IIa</td>
<td>(B)</td>
<td>2006;132:283-90</td>
</tr>
</tbody>
</table>
Cardiopulmonary Bypass (CPB)

- Arterial line
- Venous line
- Oxygenator/Reservoir
- Arterial Filter
- Pump
- Cardioplegia Delivery System
Perfusion Care Plan
Consistent with AmSECT Standards and Guidelines

- Patient assessment – prepare for briefing
- Find baseline $\text{DO}_2$
- Estimate CPB target blood flow
- Select CPB oxygenator and tubing
- Predict post-dilution [Hb] and $\text{DO}_2$
- Plan for cerebral and myocardial protection
- Plan fluids, ultrafiltration and renal protection

Q30. Renal dysfunction is associated with a cardiopulmonary bypass nadir DO2 Index less than ____ mL O2/min/m2.

a. 153  
b. 212  
c. 272  
d. 305
**Perfusion Care Plan**

Consistent with AmSECT Standards and Guidelines

- Pre-Op Cath Lab or ECHO Report and Labs
  \[
  DO_2I = CI \times [Hb]_{Initial} \times 13.6
  \]

- Estimated On-CPB
  \[
  DO_2I = CI \times [Hb]_{Post-Dilution} \times 13.6 > 272 \text{ mL O}_2/\text{min/m}^2
  \]

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**AmSECT S&G for Perfusion Practice (#10)**

<table>
<thead>
<tr>
<th>Class of Recommendation</th>
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<th>ICEBP and <a href="http://www.AmSECT.org">www.AmSECT.org</a></th>
</tr>
</thead>
<tbody>
<tr>
<td>Guideline 10.2: Calculating oxygen delivery and consumption may be useful in evaluating and optimizing gas exchange: Oxygen Delivery</td>
<td>(B)</td>
<td></td>
</tr>
</tbody>
</table>

Minicircuits (reduced priming volume in the minimized CPB circuit) reduce hemodilution and are indicated for blood conservation, especially in patients at high risk for adverse effects of hemodilution (eg, pediatric patients and Jehovah’s Witness patients).

Class of Recommendation I
Level of Evidence (A)
Ann Thorac Surg 2011;91:944-982

Reduction of Hemodilution
Efforts should be made to reduce hemodilution, including reduction of prime volume, to avoid subsequent allogeneic blood transfusion.

Class of Recommendation I
Level of Evidence (A)
J Thor Cardiovasc Surg 2006;132:283-90

Attenuation of the Inflammatory Response
Reduction of circuit surface area and the use of biocompatible surface–modified circuits might be useful effective at attenuating the systemic inflammatory response to CPB and improving outcomes.

Class of Recommendation IIa
Level of Evidence (B)
J Thor Cardiovasc Surg 2006;132:283-90

## Procedure Distribution

### 2011:Q1 - 2013:Q1

<table>
<thead>
<tr>
<th>Procedure Group (n)</th>
<th>Includes Procedures</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valve (1,696)</td>
<td>Mitral, aortic, pulmonary and tricuspid: repairs and/or replacements</td>
<td>39%</td>
</tr>
<tr>
<td>CABG (635)</td>
<td>Coronary artery and internal mammary artery bypass and coronary unroofing procedures</td>
<td>21%</td>
</tr>
<tr>
<td>Adult Congenital (503)</td>
<td>Ebstein repair, tetralogy repair, ASD closure, revision Glenn, Fontan and septal myectomy procedures</td>
<td>44%</td>
</tr>
<tr>
<td>Aorta (331)</td>
<td>Aortic root enlargements and replacements, hemi and total arch replacement, descending aorta replacement procedures with and without DHCA</td>
<td>30%</td>
</tr>
<tr>
<td>Transplant/VAD/Other (225)</td>
<td>Heart, lung and heart-lung transplant, placement of left ventricular assist devices</td>
<td>30%</td>
</tr>
<tr>
<td>Valve + CABG (462)</td>
<td>Valve procedures with coronary artery bypass procedures</td>
<td>39%</td>
</tr>
<tr>
<td>Reoperation (497; 13%)</td>
<td>First to fifth time redo mediastinal incisions</td>
<td>34%</td>
</tr>
</tbody>
</table>

3,852 total procedures with 34% of patients being female. Redo procedures are also 34% female.
% Overall Use of FX15 Oxygenator

% FX15 Oxygenator
Manufacturer Recommendation

15 Oxy

p < 0.0001

15 Oxy
Increase the % Overall Selection of FX 30 Reservoir

% Selection FX 30 Reservoir


6.1% 7.5% 6.6% 10.4% 7.2% 8.8% 11.6% 10.3% 14.6%

p = 0.0001
Increase of Operating Room Hemoglobin Nadir

<table>
<thead>
<tr>
<th>Year</th>
<th>Quarter</th>
<th>Hemoglobin Nadir gm/dL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>Q1</td>
<td>8.38</td>
</tr>
<tr>
<td>2011</td>
<td>Q2</td>
<td>8.38</td>
</tr>
<tr>
<td>2011</td>
<td>Q3</td>
<td>8.32</td>
</tr>
<tr>
<td>2011</td>
<td>Q4</td>
<td>8.62</td>
</tr>
<tr>
<td>2012</td>
<td>Q1</td>
<td>8.58</td>
</tr>
<tr>
<td>2012</td>
<td>Q2</td>
<td>8.63</td>
</tr>
<tr>
<td>2012</td>
<td>Q3</td>
<td>8.56</td>
</tr>
<tr>
<td>2012</td>
<td>Q4</td>
<td>8.80</td>
</tr>
<tr>
<td>2013</td>
<td>Q1</td>
<td>8.76</td>
</tr>
</tbody>
</table>

*p < 0.0001*
Decrease in Blood Transfusions

% Patients Receiving No Blood During Hospital Stay

- 2011:Q1: 48.5%
- 2011:Q2: 47.6%
- 2011:Q3: 48.1%
- 2011:Q4: 50.7%
- 2012:Q1: 47.4%
- 2012:Q2: 57.1%
- 2012:Q3: 51.7%
- 2012:Q4: 54.6%
- 2013:Q1: 55.9%

p = 0.0108
Reducing Costs: Average RBC Units per Patient for Hospital Stay

In conjunction with several multi-modal, multidisciplinary blood elimination techniques and projects

| Quarter / BSA Group | 2011:Q1 | 2013:Q1 | Savings
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>1.50 &lt; BSA &lt; 1.74</td>
<td>1.8 U RBC / Pt</td>
<td>1.2 U RBC / Pt</td>
<td>$200,430 @ 262 Pts</td>
</tr>
<tr>
<td>1.75 &lt; BSA &lt; 1.99</td>
<td>1.4 U RBC / Pt</td>
<td>0.7 U RBC /Pt</td>
<td>$167,076 @ 208 Pts</td>
</tr>
</tbody>
</table>

Notes:
- Pt is patient(s).
- Qtr (Q) is one quarter of the year or three months.
- U RBC is one unit of allogeneic red blood cells (330 cc).
- $ is US Dollars. One U RBC costs $1,275 to deliver to patient bed side.
Avoid Dilutional Coagulopathy
Hemoconcentration

- Undesired CPB profile – long runs, complex surgery
  - Hemodilution and excessive ATS processing
  - Protein concentrations are low
- ACT is unusually prolonged
  - Maintain adequate heparin level: IIb(B)*
  - Platelet count and function
    - Thromboelastography
- Acute Normovolemic Hemodilution: IIb(B) – part of a multi-dimensional program

Conventional Ultrafiltration (Caveat)

Conventional or zero-balance ultrafiltration during CPB.

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Cardiopulmonary Bypass (CPB)

- Arterial line
- Venous line
- Oxygenator/Reservoir
- Arterial Filter
- Pump
- Cardioplegia Delivery System
Remove Crystalloid
Additional Techniques

• Vacuum-assisted venous drainage: IIb(B)*

Table 1. Methodologies and policies from the American College of Cardiology/American Heart Association Task Force on Practice Guidelines

<table>
<thead>
<tr>
<th>Classification of recommendations</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I: Conditions for which there is evidence, general agreement, or both that a given procedure or treatment is useful and effective</td>
<td>Level A: Data derived from multiple randomized clinical trials</td>
</tr>
<tr>
<td>Class II: Procedure-treatment should be performed-administered</td>
<td>Level B: Data derived from a single randomized trial or nonrandomized studies</td>
</tr>
<tr>
<td>Class IIA: Additional studies with focused objectives needed</td>
<td>Level C: Consensus opinion of experts</td>
</tr>
<tr>
<td>Class IIB: Additional studies with broad objectives needed; additional registry data would be helpful</td>
<td></td>
</tr>
<tr>
<td>Class III: Procedure-treatment should not be performed-administered because it is not helpful and might be harmful</td>
<td></td>
</tr>
</tbody>
</table>


Class of Recommendation | Level of Evidence | Ann Thorac Surg
-------------------------|-------------------|-------------------------
IIb                      | (B)               | 2011;91:944-982*
CPB Fluid and Blood Management
Summary Recommendations

• Form multidisciplinary teams to:
  • minimize ECC prime volume and surface area
  • right-size ECCs to maximize nadir [Hb] and DO₂
  • eliminate allogeneic blood product transfusion
  • avoid dilutional coagulopathy

• P&Ps should be guided by and incorporate multidisciplinary standards, guidelines and recommendations based on evidence and expert consensus

• Study and benchmark your practice: TQM (Class IIa Level B)