LVAD and Mechanical Support
Post-operative Care

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AATS/STS Cardiothoracic Therapy Critical Care Symposium
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Post-operative Care

• Temporary Mechanical Circulatory Support (MCS) devices
  – Extracorporeal VAD systems requiring operative implantation
  – Extracorporeal percutaneous VAD systems
  – ECMO

• Long-term durable MCS devices
  – Implantable VAD systems
    • Pulsatile devices
    • Continuous-flow (CF) devices
      – Unique management issues related to CF devices
Pulsatile and Continuous-flow VADs

Post-Operative Care: Major Complications Associated with VAD Therapy

- **Bleeding**
  - Early
  - Late: GI bleeding

- **Stroke / Neurological dysfunction**
  - Ischemic stroke
  - Hemorrhagic stroke

- **Infection / Sepsis**
  - Device-related
    - Percutaneous lead
    - Pump pocket
  - Localized non-device related

- **Right heart failure**
  - Inotropes
  - RVAD

- **Arrhythmias**

- **Device malfunctions**
Post-operative Care: Overview

- **Management of coagulation**
  - Prevention of bleeding complications
  - Optimizing organ function perioperatively
  - Prevention of thromboembolic complications

- **Infection prophylaxis and treatment**
  - Antibiotic prophylaxis
  - Nutritional support

- **Prevention and management of right heart failure**
  - Perioperative optimization of RV function
  - Intra-operative and postoperative prevention / management strategies

- **Management of device-related issues**
  - Setting optimal device performance
  - Management of device complications

- **Prevention and management of arrhythmias**
Post-operative Care: Coagulation

- Bleeding and coagulopathy are the most frequent major post-operative complication
- Preoperative evaluation and assessment of risk: MELD score
- Preoperative optimization of organ function / hematologic factors / Pharmacology
- Intra-operative management
- Post-operative anticoagulation strategies
  - Early
    - Anticoagulation
      - Heparin
      - Non-heparin alternatives
    - Anti-platelet therapy
  - Late
    - Anticoagulation
      - Warfarin
    - Anti-platelet therapy
- Late bleeding complications
  - Gastrointestinal bleeding
### Adverse Events (n = 281)

<table>
<thead>
<tr>
<th>Adverse Event</th>
<th>Overall (181.8 Patient-Years)</th>
<th>0–30 Days (21.7 Patient-Years)</th>
<th>&gt;30 Days (160.2 Patient-Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Patients With Event, n (%)</td>
<td>No. of Events</td>
<td>Event Rate*</td>
</tr>
<tr>
<td><strong>Bleeding</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Requiring surgery</td>
<td>72 (26)</td>
<td>82</td>
<td>0.45</td>
</tr>
<tr>
<td>Requiring ≥2 U PRBC only</td>
<td>148 (53)</td>
<td>303</td>
<td>1.67</td>
</tr>
</tbody>
</table>

*Event Rate: Number of events per patient-year.*
Predictors of Bleeding in Patients Undergoing LVAD Implant

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Unadjusted TBPE±SE</th>
<th>P</th>
<th>Adjusted TBPE±SE</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body surface area</td>
<td>−14.2±22.4</td>
<td>0.53</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Age</td>
<td>−0.12±0.39</td>
<td>0.76</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Preop RV MCS</td>
<td>48±17</td>
<td>0.0047</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Preop LV MCS</td>
<td>43±12</td>
<td>0.0004</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Preop renal replacement</td>
<td>87±18</td>
<td>&lt;0.0001</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Preop ventilatory support</td>
<td>67±11</td>
<td>&lt;0.0001</td>
<td>46±12</td>
<td>0.0001</td>
</tr>
<tr>
<td>Preop postcardiotomy shock</td>
<td>32±19</td>
<td>0.085</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Prior sternotomy</td>
<td>12±11</td>
<td>0.26</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Preop RA pressure, per 1 mm Hg</td>
<td>1.3±0.89</td>
<td>0.15</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Preop PVR, per WU</td>
<td>−4.2±3.2</td>
<td>0.20</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Preop MELD score, per 5 units</td>
<td>20±4.0</td>
<td>&lt;0.0001</td>
<td>15.1±3.8</td>
<td>0.0001</td>
</tr>
<tr>
<td>Preop hemoglobin, per 1 mg/dL</td>
<td>−6.7±2.6</td>
<td>0.012</td>
<td>−9.7±2.3</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Preop platelets, per 1 K/mm$^3$</td>
<td>−0.28±0.06</td>
<td>&lt;0.0001</td>
<td>−0.16±0.06</td>
<td>0.0043</td>
</tr>
<tr>
<td>Preop PTT, per 1 s</td>
<td>0.24±0.26</td>
<td>0.34</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Intraop heparin, per 1000 U</td>
<td>0.23±0.57</td>
<td>0.68</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Cardiopulmonary bypass time, per 1 min</td>
<td>0.90±13</td>
<td>&lt;0.0001</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Scatterplot of preoperative MELD score vs TBPE. Fitted line based on regression analysis is also shown.

Model for End-Stage Liver Disease Score Predicts Left Ventricular Assist Device Operative Transfusion Requirements, Morbidity, and Mortality

Jennifer C. Matthews, MD, MS; Francis D. Pugani, MD, PhD; Jonathan W. Haft, MD; Todd M. Koelling, MD; David C. Naffel, PhD; Keith D. Aaronson, MD, MS

Circulation 2010;121:214-220
Gastrointestinal bleeding rates in recipients of nonpulsatile and pulsatile left ventricular assist devices

Sheri Crow, MD, MS, Ranjit John, MD, Andrew Boyle, MD, Sara Shumway, MD, Kenneth Liao, MD, PhD, Monica Colvin-Adams, MD, Carol Toninato, RN, Emil Missov, MD, Marc Pritzker, MD, Cindy Martin, MD, Daniel Garry, MD, PhD, William Thomas, PhD, and Lyle Joyce, MD, PhD

J Thorac Cardiovasc Surg Jan 2009

<table>
<thead>
<tr>
<th>TABLE 3. Postimplant characteristics</th>
<th>Nonpulsatile (N = 55)</th>
<th>Pulsatile (N = 46)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate (beats/min)</td>
<td>84.2 ± 1.6 49</td>
<td>68.2 ± 1.6 42</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Mean arterial pressure (mm Hg)</td>
<td>81.1 ± 1.8 49</td>
<td>84.8 ± 1.9 42</td>
<td>.1727</td>
</tr>
<tr>
<td>Pulse width (mm Hg)</td>
<td>32.2 ± 1.5 49</td>
<td>59.0 ± 2.6 42</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Creatinine (mg/dL)</td>
<td>1.3 ± 0.1 51</td>
<td>1.3 ± 0.1 44</td>
<td>.5588</td>
</tr>
<tr>
<td>Sodium (mEq/L)</td>
<td>140.1 ± 0.3 51</td>
<td>140.7 ± 0.4 43</td>
<td>.3055</td>
</tr>
<tr>
<td>Albumin (g/dL)</td>
<td>3.9 ± 0.1 50</td>
<td>3.9 ± 0.1 39</td>
<td>.8043</td>
</tr>
<tr>
<td>Alanine aminotransferase (U/L)</td>
<td>38.2 ± 6.5 51</td>
<td>33.1 ± 2.9 38</td>
<td>.5221</td>
</tr>
<tr>
<td>Aspartate aminotransferase (U/L)</td>
<td>50.7 ± 4.8 51</td>
<td>40.4 ± 3.1 37</td>
<td>.1034</td>
</tr>
<tr>
<td>Total bilirubin (mg/dL)</td>
<td>1.5 ± 0.7 49</td>
<td>0.8 ± 0.1 38</td>
<td>.3239</td>
</tr>
<tr>
<td>International normalized ratio</td>
<td>2.0 ± 0.1 51</td>
<td>1.6 ± 0.1 23</td>
<td>.0100</td>
</tr>
<tr>
<td>Activated partial thromboplastin time (seconds)</td>
<td>42.0 ± 1.6 46</td>
<td>40.9 ± 8.0 9</td>
<td>.8946</td>
</tr>
</tbody>
</table>

All values represent an average from two subsequent follow-up visits 1 month apart.
Severely Impaired von Willebrand Factor-Dependent Platelet Aggregation in Patients With a Continuous-Flow Left Ventricular Assist Device (HeartMate II)

Jolanta Klovaite, MD,* Finn Gustaås, MD, PhD,† Svend A. Mortensen, MD, DMSc,‡ Kåre Sander, MD, DMSc,§ Lars B. Nielsen, MD, PhD, DMSc*§

Copenhagen, Denmark

- HM II patients with bleeding complications with abnormally low HMW vWF
- Resolved after txp
Non-surgical bleeding in patients with ventricular assist devices could be explained by acquired von Willebrand disease

Ulrich Geisen, Claudia Heilmann, Friedhelm Beyersdorf, Christoph Benk, Michael Berchtold-Herz, Christian Schlensak, Ulrich Budde, Barbara Zieger

Department of Clinical Chemistry, University Medical Center Freiburg, Freiburg, Germany
Department of Cardiovascular Surgery, University Medical Center Freiburg, Freiburg, Germany
Aesculap Hamburg, Hamburg, Germany
Department of Pediatrics and Adolescent Medicine, University Medical Center Freiburg, Freiburg, Germany

Parameters of VWF function in long-term analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>VAD (B/VAI, n = 3, HMII, n = 4)</th>
<th>HTX (n = 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;10 weeks after operation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VWF:CB/VWF:Ag</td>
<td>0.4 ± 0.1 (n = 6)</td>
<td>0.9 ± 0.2 (n = 2)</td>
</tr>
<tr>
<td>VWF:RCo/VWF:Ag</td>
<td>0.5 ± 0.1 (n = 7)</td>
<td>0.7 ± 0.1 (n = 3)</td>
</tr>
<tr>
<td>Large VWF multimers</td>
<td>Reduced or missing in all tested (n = 4)</td>
<td>Normal (n = 3)</td>
</tr>
</tbody>
</table>

Fig. 3. Analysis of VWF multimers of a VAD patient compared to a sample of a normal person. VWF multimers are separated by electrophoresis according to their size on low-resolution SDS-agarose gels. Smaller multimers run faster through the gel and appear, therefore, in the lower part of the gel. Note the missing bands in the upper part of the gel in the VAD patients' lane. This is reflected by densitometry curves in the right part of the figure (grey line, normal control sample; black line, VAD patient's sample).
Post-operative Care: Management of Coagulation

- Correct abnormalities with specific blood component therapy
  - Point of care systems - TEG
- Minimize transfusion
  - Reduce sensitization in transplant eligible patients
  - Reduce / prevent pulmonary injury and RV failure
  - Infectious complications
- Operative strategies to minimize risk of post-operative bleeding and coagulopathy
  - Reduce CPB times
  - “Off pump” versus “On pump” techniques
  - Perform majority of implant without CPB – aortic anastomosis, tunneling of percutaneous lead
  - Meticulous surgical technique
  - Maintain normothermia
  - Minimize pre-peritoneal pocket dissection
- Strategies utilizing delayed sternal closure
  - Benefits / risks
Prevention and Management of Neurological Complications - Stroke

- Surgical technique
  - “Off pump” versus “On pump”
  - Meticulous removal LV thrombus
  - Excision atrial appendage / thrombus

- Anticoagulation management

- Other sources
  - Cerebrovascular disease
  - Atrial fibrillation
  - Ventricular arrhythmias
  - Aortic disease
  - Left ventricular thrombus
  - Prosthetic valves
  - Native valve disease
  - PFO
Extended Mechanical Circulatory Support With a Continuous-Flow Rotary Left Ventricular Assist Device

Francis D. Pagan, MD, PhD,* Leslie W. Miller, MD,† Stuart D. Russell, MD,‡
Keith D. Aaronson, MD,* Ranjit John, MD,§ Andrew J. Boyle, MD,§ John V. Conte, MD,‡
Roberta C. Bogac, MD,¶ Thomas E. MacGillivray, MD,¶ Yoshifumi Naka, MD,#
Donna Mancini, MD,# H. Todd Massey, MD,** Leway Chen, MD,** Charles T. Kledell, MD,††
Juan M. Aranda, MD,‡† Nader Moazami, MD,‡‡ Gregory A. Ewald, MD,‡‡ David J. Farrar, PhD,§§
O. Howard Frazier, MD,¶ for the HeartMate II Investigators†

Ann Arbor, Michigan; Washington, DC; Baltimore, Maryland; Minneapolis, Minnesota; Houston, Texas; Boston,
Massachusetts; New York and Rochester, New York; Gainesville, Florida; St. Louis, Missouri; and Pleasanton, California

Adverse Events (n = 281)

<table>
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<tr>
<th>Cumulative Support Duration (Patient-Years)</th>
<th>Overall 181.8</th>
<th>0–30 Days 21.7</th>
<th>&gt;30 Days 160.2</th>
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<td>Adverse Event</td>
<td>Patients With Event, n (%)</td>
<td>No. of Events</td>
<td>Event Rate*</td>
</tr>
<tr>
<td>Stroke</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ischemic</td>
<td>15 (5)</td>
<td>16</td>
<td>0.09</td>
</tr>
<tr>
<td>Hemorrhagic</td>
<td>9 (3)</td>
<td>9</td>
<td>0.05</td>
</tr>
<tr>
<td>Spinal cord infarct</td>
<td>1 (&lt;1)</td>
<td>1</td>
<td>0.01</td>
</tr>
</tbody>
</table>
Low Thromboembolism and Pump Thrombosis With the HeartMate II Left Ventricular Assist Device: Analysis of Outpatient Anti-coagulation

Andrew J. Boyle, MD, Stuart D. Russell, MD, Jeffrey J. Teuteberg, MD, Mark S. Slaughter, MD, Nader Moazami, MD, Francis D. Pagani, MD, O. Howard Frazier, MD, Gerald Heatley, MS, David J. Farrar, PhD, and Ranjit John, MD

A. Thrombotic Events

- Ischemic Stroke
- Pump Thrombosis

B. Hemorrhagic Events

- Hemorrhagic Stroke
- Bleeding Requiring Surgery
- Bleeding Requiring PRBC

INR Range at Time of Event

Events per patient-year
Postoperative Heparin Is Not Required For Transitioning Patients with a HeartMate II Left Ventricular Assist System to Long-Term Warfarin Therapy

Mark S. Slaughter, MD, Yoshifumi Naka, MD, Ranjit John, MD, Andrew Boyle, MD, John V. Conte, MD, Stuart D. Russell, MD, Keith D. Aaronson, MD, David J. Farrar, PhD, Francis D. Pagani, MD.
Post-operative Care: Management of Infection

- Management of intravascular catheters
  - Remove/replace all preoperative lines if feasible including IABP
- Antibiotic prophylaxis – 48 hrs
  - Broad spectrum
  - Vancomycin, Rifampin, Levofloxacin
- Care of the percutaneous lead
  - Stabilization-Education
  - Routine care
- Influence of device selection on post-operative risk of infection
- Device-related infections
  - Percutaneous lead infections
  - Pump pocket infections
Post-operative Care: Management of Right Heart Failure

• Identification of patients at risk
  – Prognostic models to identify patients at risk

• Prevention
  – Preoperative optimization of RV function
  – IABP support
  – Bridge to bridge strategies

• Post-operative care
  – RV inotrope support
  – Reduce RV afterload
    • Pulmonary vasodilation NO/ iloprost
    • Optimize LV unloading (primarily effective in the setting of low PVR)

• Determining need for RVAD support

• Selection of devices for RV support
  – Permanent support
  – Temporary support
**The Right Ventricular Failure Risk Score**

A Pre-Operative Tool for Assessing the Risk of Right Ventricular Failure in Left Ventricular Assist Device Candidates

Jennifer Cowger Matthews, MD,* Todd M. Koelling, MD,* Francis D. Pagani, MD, PhD;†
Keith D. Aaronson, MD, MS*

*Ann Arbor, Michigan

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### Right Ventricular Failure Risk Score and Likelihood of RV Failure by Score Strata

<table>
<thead>
<tr>
<th>Risk Score</th>
<th>n</th>
<th>RV Failure (n)</th>
<th>No RV Failure (n)</th>
<th>Likelihood Ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤3.0</td>
<td>142</td>
<td>29</td>
<td>113</td>
<td>0.49 (0.37–0.64)</td>
</tr>
<tr>
<td>4.0–5.0</td>
<td>25</td>
<td>15</td>
<td>10</td>
<td>2.8 (1.4–5.9)</td>
</tr>
<tr>
<td>≥5.5</td>
<td>30</td>
<td>24</td>
<td>6</td>
<td>7.6 (3.4–17.1)</td>
</tr>
</tbody>
</table>

Risk Score is derived by summing points awarded for the presence of a vasopressor requirement (4 points), AST ≥80 IU/l (2 points), bilirubin ≥2.0 mg/dl (2.5 points), and creatinine ≥2.3 mg/dl (3 points).
Risk Score Derived from Pre-operative Data Analysis Predicts the Need for Biventricular Mechanical Circulatory Support

J. Raymond Fitzpatrick III, MD,a John R. Frederick, MD,a Vivian M. Hsu, MD,a Elliott D. Kozin, BA, Mary Lou O’Hara, MSN,a Elan Howell, BSN,a Deborah Dougherty, BSN,a Ryan C. McCormick, BS,a Carine A. Laporte, BA, Jeffrey E. Cohen, BA,a Kevin W. Southerland, BS,a Jessica L. Howard, BS,a Mariell L. Jessup, MD,b Rohinton J. Morris, MD,a Michael A. Acker, MD,a and Y. Joseph Woo, MDa

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds ratio</th>
<th>95% confidence interval</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiac index ≤2.2 liters/min/m²</td>
<td>5.7</td>
<td>1.3–24.4</td>
<td>0.0192</td>
</tr>
<tr>
<td>RVSWI ≤0.25 mm Hg · liter/m²</td>
<td>5.1</td>
<td>2.1–12.2</td>
<td>0.0002</td>
</tr>
<tr>
<td>Severe pre-VAD RV dysfunction</td>
<td>5.0</td>
<td>2.0–12.5</td>
<td>0.0006</td>
</tr>
<tr>
<td>Creatinine ≥1.9 mg/dl</td>
<td>4.8</td>
<td>1.9–12.0</td>
<td>0.0010</td>
</tr>
<tr>
<td>Previous cardiac surgery</td>
<td>4.5</td>
<td>1.7–11.8</td>
<td>0.0023</td>
</tr>
<tr>
<td>SBP ≤96 mm Hg</td>
<td>2.9</td>
<td>1.2–6.9</td>
<td>0.0162</td>
</tr>
</tbody>
</table>

RV FAILURE RISK SCORE = 18 • (CI) + 18 • (RVSWI) + 17 • (creatinine) + 16 • (previous cardiac surgery) + 16 • (RV dysfunction) + 13 • (SBP).

A score < 50 predicts successful LVAD support, and a score ≥ 50 predicts need for BiVAD (sensitivity and specificity of 83% and 80%, respectively)
Complications: Hypotension

- **Tamponade**
- **Low intravascular volume**
  - Low CVP
  - Low LVAD flows
- **RV failure**
  - High CVP
  - Low LVAD

Inadequate filling conditions
- Rotary pumps can generate large negative pressure at inlet
- Obstruction of inlet cannula (Suction event)
- Distortion of right ventricle and tricuspid
LV Collapse
Post-operative Care: Management of Arrhythmias

- Etiology of post-operative arrhythmias
  - Ischemic burden
  - Catecholamine support
  - Mechanical irritation from VAD

- Prevention / Prophylaxis
  - Anti-arrhythmic therapy
    - Amiodarone
  - ICD therapy

- Influence of arrhythmias on VAD filling

- Management strategies for patients with:
  - Giant cell myocarditis
  - Sarcoidosis
Post-operative Care: Optimizing Device Performance / Myocardial Recovery

- MCS devices
  - Pulsatile devices
  - Continuous-flow devices
    - Consideration for Setting RPM speeds
      - Optimize septal position – reduce risk of RV failure
      - Optimize hemodynamics

- Full versus Partial LV unloading strategies
  - Consequences of AV closure / opening
    - Impact on late development of AI
    - Impact on risk of stroke
  - Impact on myocardial recovery

- Identify potential candidates for myocardial recovery
  - Optimize device position at implantation
    - LV apical drainage to maximize LV unloading
  - Optimize hemodynamics
  - Eliminate other causes to prevent recovery
    - Unsuspected tamponade / hypovolemia
    - Pulmonary injury / hypoxia
    - Uncorrected valvular or coronary artery disease
Post-operative Care: Management of Device Malfunction

• Recognizing most frequent types of malfunctions
  – Temporary MCS devices
    • Drive systems
  – Implantable, durable MCS devices
    • Internal components
      – Pump (Mechanical failure never seen in any rotary device)
      – Percutaneous lead fracture
    • External components

• Impact of device selection on rates of malfunction
  – Implantable, durable MCS devices
    • Pulsatile versus continuous-flow systems

• Recognizing most frequent causes of device mishaps
  – Patient related
    • Battery life
    • Controller and driveline abuse
  – Thrombus
Post-operative Care: Other Topics

• Multi-disciplinary approach
  – VAD education
  – Nutrition
  – Rehab / Ambulation
  – Post-operative care strategies