Anesthetic Considerations for Complex Congenital Heart Disease

The Single Ventricle vs. the Laparoscope

2014 Pediatric Anesthesiology
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No Disclosures
Objectives

• Review the pathophysiology of the single ventricle
• Describe optimal anesthetic techniques at various stages of single ventricle palliation
• Discuss anesthetic management for common non-cardiac procedures
• Discuss the impact of laparoscopic surgery on single ventricle physiology
HLHS Stages

Pre-op

Stage 1
a

Stage 2

Stage 3
Un-Palliated HLHS

www.chla.org

http://hopeforhailey.blogspot.com
Questions to ask when approaching the patient with un-palliated HLHS

1. Why me??!!
2. Is the atrial septum open or “restrictive”?  
3. Status of the ductus?
4. Is there adequate systemic perfusion?  
5. Is the circulation balanced?
Balancing Qp/Qs
\[
\frac{Qp}{Qs} = \frac{(SaO2 - SvO2)}{(SpvO2 - SpaO2)}
\]

- Let’s assume...complete mixing and parallel circulations...then \(SaO2=SpaO2\)
  - \(\frac{Qp}{Qs} = \frac{(SaO2 - SvO2)}{(SpvO2 - SpaO2)}\)
- Now Let’s assume...\(SpvO2\) is 100%...ideally
  - \(\frac{Qp}{Qs} = \frac{(SaO2 - SvO2)}{(SpvO2 - SpaO2)}\)
- That leaves \(SvO2\) as the variable of interest.

Adolf Eugen Fick
<table>
<thead>
<tr>
<th>Clinical</th>
<th>Qp:Qs</th>
<th>Cause</th>
<th>Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>SpO2 85%</td>
<td>1:1</td>
<td>Good Balance</td>
<td>Nothing</td>
</tr>
<tr>
<td>SvO2 70%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SpO2 70%</td>
<td>1:1</td>
<td>Low cardiac output</td>
<td>Improve CO</td>
</tr>
<tr>
<td>SvO2 40%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SpO2 80%</td>
<td>2:1</td>
<td>Over Circulated</td>
<td>Increase PVR Reduce SVR</td>
</tr>
<tr>
<td>SvO2 40%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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</tr>
<tr>
<td>SvO2 20%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SpO2 60%</td>
<td>0.5:1</td>
<td>Under Circulated</td>
<td>Reduce PVR Increase SVR</td>
</tr>
<tr>
<td>SvO2 40%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Key Points

• SpO2 may be misleading
  – *more blood flow to the lungs will preserve SaO2 at the expense of systemic perfusion, i.e. High SpO2/low SvO2*
  – *Others will tolerate increased PBF, i.e. High SpO2/High SvO2*

• Need to know SvO2

• If you don’t have SvO2 data use...
  – NIRS, serum lactate, UOP, physical exam

• Target a Qp/Qs of <1.5:1

• Balancing Qp/Qs is largely dependent on resistance of each circuit, i.e. SVR and PVR
• Review the pathophysiology of the single ventricle
• Describe optimal anesthetic techniques at various stages of single ventricle palliation
• Discuss anesthetic management for common non-cardiac procedures
• Discuss the impact of laparoscopic surgery on single ventricle physiology
Un-palliated Physiology

• **Goal:** Balance Qp:Qs
• **Anesthetic Technique**
  – Prostins
  – Narcotic and NMB
  – Be weary of changes in PVR with intubation
  – Minimize O2 – *even brief exposure to oxygen can be lethal*
  – Normocarbia to permissive hypercarbia
  – Target – 7.4/40/40, PCV 40 and follow lactates
Managing PBF

Hypercarbia versus Hypoxia for managing PBF.

**Figure 40-6** The impact of inspired gas mixtures on hemodynamics and oxygen delivery. Neonates with hypoplastic left heart syndrome anesthetized and intubated in a crossover study comparing hypercarbia (FiO₂ 2.7%) versus hypoxia (FiO₂ 17%). Although both gas mixtures reduced Qp:Qs (A), only hypercarbia increased oxygen delivery (B), systolic blood pressure (C), or diastolic blood pressure (D). (Data from Tabbutt S, Ramamoorthy C, Montenegro LM, et al: Impact of inspired gas mixtures on preoperative infants with hypoplastic left heart syndrome during controlled ventilation. *Circulation* 104:1159–1164, 2001.)
Stage I Palliation

- Atrial septal defect
- Hypoplastic aorta
- Patent ductus arteriosus
- Hypoplastic left ventricle
Comparison of Shunt Types in the Norwood Procedure for Single-Venticle Lesions
Diagram representing the hemodynamic difference between the Classical Norwood (utilizing a BT shunt) and the RV conduit. Each trace represents the systemic blood pressure recording with the shunt initially occluded and then opened at the point marked by the asterisk (*).
Sano – Pros/Cons

**Pros**
- Higher postoperative diastolic blood pressure
- Smaller pulse pressure
- Improved coronary blood flow and systemic perfusion
- Lower early mortality in some series and the simplified early postoperative course
- Less prone to sudden circulatory collapse

**Cons**
- Ventriculotomy
- Smaller pulmonary arteries
- Earlier cyanosis and need for SIIP
- Volume load on ventricle?
- Time to stage II palliation is shorter because of early onset of cyanosis due in part to variable pulmonary blood flow across the conduit and lower net pulmonary blood flow
### Peri-operative Management

**mBTS**
- **Diastolic BP**
  - Maintenance is critical
- **PVR**
  - PVR has less impact due to fixed shunt
- **Thrombosis**
  - Auscultate the shunt murmur
  - Continue anticoagulation

**Sano**
- **Diastolic BP**
  - Maintenance is less critical
- **PVR**
  - Control of PVR is important to limit volume on ventricle
- **Thrombosis**
  - Less common

### Both
- Minimize FiO2 to maintain SpO2 at 75-85%
- Maintain SVR, MAP and Intravascular Volume
- Have a rescue plan in place
• In theory, more stable due to stented PDA and fixed PVR.
• Some centers use only as salvage procedure.
  – High risk, premies, head bleeds
• Risk of unrecognized retrograde aortic arch obstruction
Stage II Palliation

Bidirectional Glenn for HLHS

Superior vena cava connected to pulmonary artery
“Glenn” Physiology

• Creates a “series” circuit.
• Unloads volume of Qp from ventricle.
• PBF from a secure native source - SVC
• Balanced - with ~50% CO returning from SVC to lungs and ~50% returning via IVC to heart.
• “Passive” PBF – affected by a several physiological variables including intra-thoracic pressure, venous pressure, acid/base, pH and pCO2
Effect of carbon dioxide on systemic oxygenation, oxygen consumption, and blood lactate levels after bidirectional superior cavopulmonary anastomosis
Ventilation Strategies to Optimize PVR

- “Passive” PBF is impeded by elevated PVR and increased intra-thoracic pressures
- Ventilation strategies that “normalize” FRC will minimize PVR and thus optimize PBF.
- Ventilation that results in excessive lung volumes or atelectasis will increase PVR.
Anesthetic Considerations

- Goal: Maintain adequate intravascular volume, minimize PVR and promote PBF.
  - Anticipate slow inhalation induction
  - Be weary of recent URIs.
  - Ventilate with low I:E ratio, low RR, normal Tidal volumes, +/- PEEP
  - Maintain normal acid/base status and normocarbia
  - Increasing FiO2 OK
Why Glenn’s are my Favorite

• Relative to SIP patients
  – A ventricle that has been relieved of a significant volume of work
  – A secure, native source of PBF
  – PBF that will increase slightly as the child grows without adding any additional work on the heart.

• Relative to SIIIP patients
  – Decreases in PBF will result in lower sats but CO will be preserved via IVC return
  – After Fontan, decreased PBF results in lower sats and lower CO
  – Much lower venous pressures than SIIIP
Stage III - Fontan

A. Classical Fontan
   - Right auricle used as a conduit to the RPA
   - ASD closed
   - Tricuspid valve closed

B. Lateral tunnel (intra-atrial baffle)
   - Anastomosis of enlarged cardiac end of SVC to RPA
   - Placement of baffle inside right atrium, forming a channel with a decreased diameter

C. Extra-cardiac conduit
   - Gore-tex conduit
   - RA closed

*Circulation* I-158, September, 2007
PBF in Fontan Phys.

- Not “passive”
- Actively maintained by the respiratory and cardiac cycle.
- PBF is augmented by the negative intrathoracic pressure during inspiration.
- Dependent on the cardiac cycle with optimal flow occurring during late systole and early diastole

If you must PPV

- PPV = ↓ PBF

- Optimal PPV strategy:
  - Increasing FiO₂ is OK
  - Low respiratory rates
  - Short inspiratory times
  - Minimize inspiratory pressures
  - “Physiologic” PEEP
  - Larger tidal volumes


J Cardiothorac Vasc Anesth. 2011 Apr;25(2):320-34
Cardiac Output

- Baffle pressure: 10-15 mm Hg
- Unobstructed venous return
- Adequate preload
- Low intrathoracic pressures
- PVR
  - PVR < 2 Wood units
  - MPAP < 15 mm Hg
  - Unobstructed vessels

Sinus rhythm
Competent AV valve
Normal ventricle: Systolic and diastolic function
No outflow obstruction
Anesthetic Considerations

- **Goal:** Maintain PBF, minimize PVR and promote CO
  - Minimize NPO
  - ↓ afterload = ↓ Preload >> Hypotension
  - Maintain Preload
  - Anticipate volume requirement and larger EBL
  - Maintain NSR
Objectives

• Review the pathophysiology of the single ventricle

• Describe optimal anesthetic techniques at various stages of single ventricle palliation

• Discuss anesthetic management for common non-cardiac procedures

• Discuss the impact of laparoscopic surgery on single ventricle physiology
Non-cardiac surgery in single ventricles at MCJCHV

- We reviewed a cohort of 71 patients with complex single ventricle CHD.
- They required 173 non-cardiac anesthetics (252 procedures) over a 4.5 year span.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>No. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gastrostomy</td>
<td>69 (27.4)</td>
</tr>
<tr>
<td>Fundoplication/fundoplasty</td>
<td>59 (23.4)</td>
</tr>
<tr>
<td>PICC procedure</td>
<td>32 (12.7)</td>
</tr>
<tr>
<td>Airway endoscopy</td>
<td>19 (7.5)</td>
</tr>
<tr>
<td>Central catheter placement/replacement</td>
<td>14 (5.6)</td>
</tr>
<tr>
<td>MRI/CT</td>
<td>14 (5.6)</td>
</tr>
<tr>
<td>Various ear, nose, and throat</td>
<td>7 (2.8)</td>
</tr>
<tr>
<td>Exploratory laparotomy</td>
<td>6 (2.4)</td>
</tr>
<tr>
<td>Enterostomy/enterostomy closure</td>
<td>5 (2.0)</td>
</tr>
<tr>
<td>Minor urologic</td>
<td>4 (1.6)</td>
</tr>
<tr>
<td>Upper or lower GI endoscopy</td>
<td>4 (1.6)</td>
</tr>
<tr>
<td>Bowel resection</td>
<td>3 (1.2)</td>
</tr>
<tr>
<td>Various other</td>
<td>16 (6.3)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>252 (100)</strong></td>
</tr>
</tbody>
</table>

- Intraoperative instability was associated with palliation before stage II, more invasive procedures, and pre-operative ACEI.

HLHS and Feeding/Reflux Surgery

- Between July 2006–December 2009, 39 out of 64 HLHS patients underwent g-tube +/- Nissen.

- Regional anesthesia, performed in half of cases, was associated with increased induction instability and the need for intraoperative inotropic drugs.

<table>
<thead>
<tr>
<th>Perioperative events</th>
<th>N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extubated in OR</td>
<td>31 (79.5)</td>
</tr>
<tr>
<td>Induction instability</td>
<td>27 (69.2)</td>
</tr>
<tr>
<td>Maintenance instability</td>
<td>26 (66.7)</td>
</tr>
<tr>
<td>Emergence instability</td>
<td>19 (48.7)</td>
</tr>
<tr>
<td>Recovery instability</td>
<td>15 (38.5)</td>
</tr>
<tr>
<td>Unplanned ICU admission</td>
<td>5 (12.8)</td>
</tr>
<tr>
<td>24-h escalation of respiratory management</td>
<td>9 (23.1)</td>
</tr>
<tr>
<td>24-h escalation of hemodynamic management</td>
<td>6 (15.4)</td>
</tr>
<tr>
<td>Postoperative evidence of decreased perfusion</td>
<td>4 (10.3)</td>
</tr>
<tr>
<td>Extracorporeal membrane oxygenation</td>
<td>2 (5.1)</td>
</tr>
<tr>
<td>30-days mortality</td>
<td>1 (2.7)</td>
</tr>
</tbody>
</table>

Pediatr Cardiol. 2012 June; 33(5): 697–704
Non-cardiac Anesthesia for the Inter-stage SV: Questions to ask?

- Is the child medically optimized?
- Does the procedure need to be done now?
- Induction plan?
- Airway?
  - Ventilation: PPV?
- Monitoring plan?
- Maintenance plan?
- Analgesia Plan?
  - Including post op
- Emergence/Extubation?
- Recovery: Where?
  - Post op ICU?
- What could possibly go Wrong?
  - Anticipate and plan for the worst case scenario.
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“Laparoscopic surgery has been referred to as both the greatest advance since ether anaesthesia and the biggest unaudited free-for-all in the history of surgery”.

Respiratory Changes
Pulmonary Mechanics

**Compliance vs. Insufflation Pressure**

**Graph:**
- **COM**_
  - **COMPdyn = 3.06 - 0.099 insufflation pressure**
  - **Insufflation pressure (cm H₂O)**
  - **COMPdyn (ml·cm⁻¹ H₂O)**

**Graph:**
- **Compliance (ml·cmH₂O⁻¹)**
  - **control**
  - **insufflation**
  - **exsufflation**

Paediatric Anaesthesia 2003 13: 785–789
*Anaesthesia and Intensive Care; Jun 1999*
Pulmonary Mechanics

Figure 1
Percentage change from baseline pulmonary measurements at $P_{\text{max}}$ and following ventilator change(s). $P_{\text{max}}$, maximum insufflation pressure; PIP, peak inspiratory pressure; COMPdyn, dynamic compliance; Vt, tidal volume.

IAP  PIP  FRC/VC/CV/Tv
CO₂ absorption increases with increasing intra-abdominal insufflation pressures (IAP).

*Pediatrics.* 2005 Dec;116(6):e785-91
• CO₂ absorption increases with insufflation time and in younger age patients.
etCO$_2 \neq$ pCO$_2$

- etCO$_2$ is not an accurate reflection of pCO$_2$ in patients with CHD.

- Contributing factors
  - R>L shunting
  - High PAP
  - Increased PBF

- Hyperventilation may be ineffective in correcting ↑ CO$_2$

*JCVA, Vol 20, No 2 (April), 2006*
*Journal of Pediatric Surgery, Vol 36, No 8 (August), 2001*
TABLE 5. Effects of Video-Surgical Procedures Longer Than 100 Minutes in Neonates

<table>
<thead>
<tr>
<th></th>
<th>Surgery &lt;100 Min</th>
<th>Surgery &gt;100 Min</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Postoperative body temperature, °C</td>
<td>35.8 ± 0.5</td>
<td>34.1 ± 1.1</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>PIP increase, cm H₂O</td>
<td>2.7 ± 3.4</td>
<td>9 ± 4.1</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Frequency of incidents, %</td>
<td>11.4 (n = 4)</td>
<td>42.8 (n = 6)</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>Frequency of postoperative intensive care, %</td>
<td>25.7 (n = 9)</td>
<td>71.4 (n = 10)</td>
<td>&lt;.05</td>
</tr>
</tbody>
</table>

Data are mean ± SD.
Cardiovascular Changes
Cardiac Output

- Biphasic response to IAP
  - Initial increase in venous return leading to increased CO
  - Followed by decreased venous return and decreased CO

ABF ↓ >50%

SV ↓ >50%

J Appl Physiol 86:1651-1656, 1999
Anesth Analg 1998; 86:
Haemodynamic variables before, during and after CO₂ insufflation for laparoscopic fundoplication. All values are expressed as mean ± SD. Baseline = before insufflation; 20 = 20 min after start of CO₂ insufflation; 35 = 35 min after start of CO₂ insufflation; 70 = 70 min after start of CO₂ insufflation; 12 min after desufflation = end of surgery. *P < 0.05 (versus baseline), **P < 0.01 (versus baseline), ***P < 0.001 (versus baseline), ††P < 0.01 (12 min after desufflation versus 70 min after start of CO₂ insufflation).
Afterload

• ↑ IAP
  – Aortic Compression
  – Splanchnic Vasoconstriction
  – Activation of Sympathoadrenal system
  – ↑↑ SVR

• SVRI increased up to 162% at IAP of 10 mmHg in healthy children, reversed with exsufflation
Preload

- At lower IAPs, preload is augmented by recruitment of volume from the splanchnic bed and return via the IVC.

- At higher IAPs, the IVC collapses, impeding venous return, reducing CO and further increasing Afterload.

*J Appl Physiol 86:1651-1656, 1999*
Myocardial Size/Function

- **LV size/function:**
  - Influenced by two factors during pneumoperitoneum:
    - Increased afterload
      - decreased shortening fraction, fractional area change and LV EDV
    - Increased IAP
      - 20% of IAP transmitted to chest cavity from diaphragm displacement

All studies were done in patients with 2 ventricles.

Only case reports/series describing outcomes in single ventricle patients.
Pre-SIIP Patient

- Increased afterload on an already overloaded ventricle
- Venous return that’s easily compromised by IAP and retractors
- Diastolic hypotension
  - anesthetic effect??
    - Coronary perfusion compromised
- Diminished PBF
  - Hypercarbia that cannot be “blown” off
  - Potential for elevated PVR
Glenn Patient

- Still only one ventricle but now less volume loaded
  - In theory....IAP and SVR is better tolerated
- Compromised venous return
  - Decrease PBF
  - Some evidence that circulation is shifted to upper compartment > Increased PBF
- Respiratory Effects
  - Impede PBF in Glenn patient
- HyperCarbia
  - Elevated PVR > Decreased PBF
  - Increased cerebral circulation > Increased PBF
<table>
<thead>
<tr>
<th>IAP</th>
<th>&lt;5mmHg</th>
<th>5-10mmHg</th>
<th>10-12 mmHg</th>
<th>15-20 mmHg</th>
<th>&gt;20 mmHg</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO/Cl</td>
<td>NC/↑</td>
<td>NC/↑⁵</td>
<td>↓13%⁴</td>
<td>↓</td>
<td>↓55%¹</td>
</tr>
<tr>
<td>Venous Return³</td>
<td>↑</td>
<td>↑/NC</td>
<td>NC/↓</td>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>Contractility²</td>
<td></td>
<td></td>
<td>NC/↓</td>
<td>↓</td>
<td></td>
</tr>
<tr>
<td>Afterload</td>
<td>↑</td>
<td>↑</td>
<td>↑↑⁴</td>
<td>↑↑</td>
<td>↑↑</td>
</tr>
<tr>
<td>Wall Motion</td>
<td></td>
<td></td>
<td>↓²</td>
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<tr>
<td>HR</td>
<td>↑</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>MAP</td>
<td>NC/↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
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</tbody>
</table>
Renal Changes
• IAP associated with:
  • Pressure dependent reversible decrease in renal blood flow
  • Decreased GFR
  • Decreased UOP

• **UOP cannot be used as surrogate of perfusion during laparoscopy.**

Ure et al, Seminars in Pediatric Surgery, Vol 16, No 4, 2007
IAP and Anuria

- IAP of 8 mmHg
- 7 of 8 infants developed anuria within 45 minutes

Older children: 3 of 22 developed anuria at IAP of 8mmHg within 45 minutes

CRISIS RESOURCE MANAGEMENT

CRM KEY POINTS

- Call for Help Early
- Anticipate and Plan
- Use Available Information
- Use Cognitive Aids
- Mobilize Resources
- Allocate Attention Wisely
- Communicate Effectively
- Distribute the Workload
- Establish Role Clarity
- Designate Leadership

Crew Resource Management

<table>
<thead>
<tr>
<th>Situational Awareness</th>
<th>Coordination</th>
</tr>
</thead>
<tbody>
<tr>
<td>(How to achieve, maintain, &amp; recover)</td>
<td>(Teamwork &amp; Conflict Resolution)</td>
</tr>
<tr>
<td>Communication</td>
<td>Decision Making</td>
</tr>
<tr>
<td>(Barriers &amp; Efficiency)</td>
<td>(Risk Management &amp; Problem Solving)</td>
</tr>
<tr>
<td>Task Management</td>
<td>Mission Planning</td>
</tr>
<tr>
<td>(Standards, Priorities, Delegation)</td>
<td>(Before, During, &amp; After)</td>
</tr>
</tbody>
</table>

Image of a plane on the water and a man holding a sword.