Neonatal Single Ventricle Heart Disease – Recognition, Management, Counseling

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Disclosure

• No financial relationships to disclose
• FDA – nothing to disclose
Objectives

• Recognize presentation of critical heart disease
• Determine PGE$_1$-dependency
• Understand ideal pre-operative management in neonates with single ventricle
• Understand goals of palliative surgery
• Long-term outlook for patients with single ventricle
Disclaimer

- Single ventricle heart disease talk ➔
- “Critical Heart Disease in the Neonate”

- Much more likely to face “critical” heart disease
- All single ventricle infants can be treated like Critical Heart Disease
Congenital Heart Disease: an Overview

CHD (1:125)
~35,000 annually (USA)

Complex CHD (1:350)
~11,000 annually (USA)

Critical CHD (1:600)
~6,000 annually (USA)
What is Critical Heart Disease

- PGE$_1$ dependent
- Requires neonatal intervention
  - Surgery
    - TGA – Septostomy and arterial switch
    - HLHS – Norwood procedure
    - Pulmonary Atresia – shunt
  - Catheterization
    - Critical Aortic Stenosis – balloon valve dilation
What is Critical Heart Disease?

• $\text{PGE}_1$ dependent because...
• heart disease is stable during in utero circulation due to wide-open
  – \textit{Ductus venosus}
  – \textit{Ductus arteriosus}
  – Foramen ovale
Fetal Circulation
Fetal Circulation in Single Ventricle

- Ductus arteriosus as versatile role player
- PDA provides flow to LUNGS in right heart obstruction
- PDA as a conduit to BODY in left heart obstruction
Pink is good

• Too much pulmonary blood flow
  – Pink
  – At risk of poor systemic flow
  – Pulmonary edema
  – Metabolic acidosis
  – NEC
  – Shock
Purple is better

• And **blue** may be perfectly fine!
  – Check for metabolic acidosis
  – If normal lactate, then $O_2$ delivery is sufficient
  – Normal fetal $O_2$ sat = 60-75%

• **Blue** is better than **grey**!
  – Poor perfusion/lactic acidosis
Infant Cardiac Care Team

- Dedicated team of
  - Neonatologists
  - Cardiologists
  - Obstetricians
  - CV Surgeons

- Focus on early management and monitoring of infants with SV heart disease

- Texas Children’s Hospital: 30 pts/year

- 1-year survival: ~ 85%
What is Single Ventricle?

• Single Ventricle Physiology:
  – Aortic Sat = Pulmonary Artery Sat

• Normal Physiology:
  – **Aortic Sat** > **Pulmonary Artery Sat**

• Transposition Physiology
  – **Aortic Sat** < **Pulmonary Artery Sat**
Normal

\[ P_{A\text{a}} < P_{A\text{o}} \]

Transposition

\[ P_{A\text{a}} > P_{A\text{o}} \]

Single Ventricle

\[ P_{A\text{a}} = P_{A\text{o}} \]
Single Ventricle Physiology

• Doesn’t mean SV Anatomy
  – Seen in large VSDs, large PDAs, common atrium, etc

• Management is the same as in Single Ventricle Heart Disease:
  – *Optimize systemic output!*
Single Ventricle Anatomy

- Variety of congenital heart defects fall under heading “SV”
- Underdevelopment/atresia of right or left Inlet
  - Common Ventricular Inlet
- Underdevelopment/atresia of Outlet
- True common ventricle (less common)
Single Ventricle Anatomic Types

Normal

Outlet Obstruction

Inlet Obstruction
Single Ventricle Anatomy Types

• **Right Heart Obstruction**
  – Tricuspid Atresia
  – Pulm Atresia/IVS
  – Severe Ebstein’s Anomaly
  – DORV variants

• **Left Heart Obstruction**
  – HLHS
  – Aortic Atresia
  – Tricuspid atresia/TGA
  – DILV*
  – Unbalanced CAVC*
Presentation of **Right Heart Obstruction Type SV**

- Ductal constriction brings on cyanosis
- Often a gradual process
- **Perfusion, blood pressure, HR** often normal prior to complete constriction of ductus
Management of Right Heart Inlet Obstruction

- Ductal-dependent until proven otherwise

- Cardiac management involves PGE$_1$ until definitive palliation can take place
  - Ductal stenting
  - Blalock-Taussig Shunt
  - RVOT stenting

Tricuspid valve atresia, with normal great arteries
Right Heart Outflow Obstruction

• “Hypoplastic right heart syndrome”
• Ductus provides all pulmonary blood flow
• ASD allows complete mixing of systemic and pulmonary venous blood
SV – Right Heart Obstruction

- Ductal dependency for pulmonary blood flow
- ASD almost always large and right-to-left
- Await definitive therapy
  - Valve perforation
  - BT shunt
  - Ductal stent

“Hypoplastic Right Heart Syndrome”
Presentation of **Left Heart** Obstruction Type SV

- For left heart obstruction (HLHS), ductal constriction causes
  - Metabolic acidosis
  - Hypotension
  - Shock
  - Not cyanosis! (screening pulse-ox)
  - May present in first hours of life – or first days/week of life
Role of PGE$_1$ in Single Ventricle Neonates

• Most forms of SV are duct-dependent lesions
• PGE$_1$ not needed if patent systemic and pulmonary outlets present
  – And there is no aortic coarctation
  – And there is no pulmonary artery “coarctation”
• *if cyanosis or acidosis develop:
  – PGE$_1$
  – Echo to solidify anatomy
History of Prostaglandin

- Prostaglandins approved in US late 1970s
- Can be given in any vessel
  - Artery, vein, intraosseous
- Systemic & pulmonary vasodilator
- Side Effects:
  - Apnea
  - Fever
  - Hypotension
  - Seizures
  - Rash

Circulation 1976
Prostaglandin E₁ Rash

PGE₁ @ 0.05 mcg/k/min

PGE₁ @ 0.01 mcg/k/min

Courtesy of Gil Wernorovsky
Prostaglandin Use in SV Neonates

• Start low-dose: 0.01 mcg/kg/min

• In newborns in shock, may initiate PGE₁ at 0.05 mcg/kg/min.

• Infants require adequate intravascular volume to maintain blood pressure while on PGE₁.

• If adequate cardiac output, no acidosis, infants may feed while awaiting surgery.

• Avoid apnea, avoid intubation!

(less is more)
First Steps in Management

- Initial newborn assessment
- UVC/UAC if possible (not critical)
- PGE$_1$ infusion
- Monitor for acidosis or cyanosis
- In stable patient, with fetal diagnosis, limited echocardiogram can be performed within 12 hours to confirm anatomy
- Assess CNS, other organs
Initial Management of SV Neonate

• Genetic evaluation
  – Turner’s (45 X,0)
• Preoperative brain imaging
• Careful counseling of parents
  – Short term challenges
  – Long term outlook
Balanced Circulation?

- Goal of neonatal management of SV in 2012
  - *Maximize systemic output*
- “Balance” is misnomer
  - Usually unattainable
  - Usually undesirable
Table 2. Effects of respiratory maneuvers on pulmonary and systemic vascular resistance.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>PVR</th>
<th>SVR</th>
<th>$Q_p/Q_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase FiO$_2$</td>
<td>Decrease</td>
<td>Increase</td>
<td>Increase</td>
</tr>
<tr>
<td>Increase CO$_2$</td>
<td>Increase</td>
<td>Decrease</td>
<td>Decrease</td>
</tr>
<tr>
<td>Increase pH</td>
<td>Decrease</td>
<td>Increase</td>
<td>Increase</td>
</tr>
<tr>
<td>PEEP</td>
<td>Increase</td>
<td>Decrease</td>
<td>Decrease</td>
</tr>
</tbody>
</table>

Nelson et al, Cardiol Young 2004
1. Output trumps Qp:Qs ratio

1. High or low Qp:Qs ratio can lead to acidosis
How best to manage SV Neonate Pre-op?

- Review fetal circulation
- Fetal circulation
  - High PVR state
  - Low SVR state
- Mimic this physiology postnatally!
  - ↑PVR and ↓SVR
Three guiding principles
- High PVR
- Low SVR (placental)
- Circulation favors the brain
Fetal Circulation in HLHS

Fetal circulation:
- Nearly normal when PDA is large and ASD is open
- Arch flow is retrograde
- Systemic flow intact
- Pulmonary flow is restricted
Fetal Ultrasound - Normal
HLHS: Left-to-right atrial shunting
HLHS: Retrograde flow in aortic arch
Fetal Circulation in HLHS

Shillingford, Cardiol Young 2007
Fetal Circulation, cont

- Head circumference
- Fetal cerebral blood flow
- Does this have functional correlation?

Lower pulsatility in middle cerebral artery in left heart obstruction type SV
How to maintain fetal environment?

- PGE$_1$
- Low inspired O$_2$
  - Room air
  - Only use ↑O$_2$ when hypoxia
- Natural airway
  - Maintains higher CO$_2$
  - Elevates PVR
Avoid Intubation

• Use low-dose PGE$_1$ as a rule
• May use caffeine to help avoid/treat apnea
• Transport $\neq$ intubation for the ride!
• Preop mechanical ventilation associated with poor outcomes
# Mechanical Ventilation

<table>
<thead>
<tr>
<th>Preoperative Factors</th>
<th>Unadjusted Odds Ratio (95% CI)</th>
<th>p Value</th>
<th>Adjusted Odds Ratio (95% CI)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prolonged preoperative length of stay&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.98 (0.78–1.22)</td>
<td>0.82</td>
<td>0.84 (0.65–1.1)</td>
<td>0.2</td>
</tr>
<tr>
<td>Weight &lt; 2.5 kg</td>
<td>1.72 (1.30–2.27)</td>
<td>&lt;0.001</td>
<td>1.59 (1.22–2.08)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Female sex</td>
<td>1.08 (0.96–1.21)</td>
<td>0.18</td>
<td>1.02 (0.91–1.15)</td>
<td>0.71</td>
</tr>
<tr>
<td>Right dominant ventricle (versus left)</td>
<td>1.48 (1.13–1.93)</td>
<td>0.004</td>
<td>1.36 (1.01–1.82)</td>
<td>0.04</td>
</tr>
<tr>
<td>Total anomalous pulmonary venous return</td>
<td>2.21 (1.08–4.55)</td>
<td>0.03</td>
<td>1.61 (0.84–3.08)</td>
<td>0.15</td>
</tr>
<tr>
<td>Non-cardiac/genetic abnormality</td>
<td>1.61 (1.28–2.04)</td>
<td>&lt;.0001</td>
<td>1.5 (1.19–1.91)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Shock</td>
<td>1.66 (1.17–2.35)</td>
<td>0.004</td>
<td>1.52 (1.08–2.15)</td>
<td>0.02</td>
</tr>
<tr>
<td>Arrhythmia</td>
<td>1.31 (0.91–1.87)</td>
<td>0.15</td>
<td>1.24 (0.84–1.82)</td>
<td>0.29</td>
</tr>
<tr>
<td>Mechanical circulatory support</td>
<td>4.51 (1.52–13.39)</td>
<td>0.007</td>
<td>4.0 (1.57–10.18)</td>
<td>0.003</td>
</tr>
<tr>
<td>Mechanical ventilatory support</td>
<td>1.37 (1.1–1.7)</td>
<td>0.004</td>
<td>1.28 (1.03–1.6)</td>
<td>0.03</td>
</tr>
<tr>
<td>Neurologic deficit</td>
<td>1.81 (0.78–4.20)</td>
<td>0.17</td>
<td>1.33 (0.55–3.17)</td>
<td>0.53</td>
</tr>
</tbody>
</table>

*Hornick, ATS 2011*
Ventilator Management in SV Neonates

• Avoid “elective” intubation
• Use lowest rate/tidal volume possible
  – Avoid low CO₂
• Lowest mean airway pressure possible
  – Maximizes ventricular filling
• FiO₂ 21% -- goal saturations 75-80%
• Don’t drop guard after ETT in place!
In Unstable Neonate with SV

• **Cyanotic**
  - $\text{PaO}_2 < 30$; $\text{SaO}_2 < 75$
  - 100% $\text{FiO}_2$
  - CXR to assess lungs
    • PTX, Congestion
  - STAT echo to assess the atrial septum / pulm veins
  - Rule-out anemia

• **Acidotic**
  - Room Air
  - Intravascular volume
  - Increase PGE\textsubscript{1} to 0.025-0.05 mcg/kg/min
  - CXR ± AXR
  - STAT echo to assess ductus, ventricular function
Restrictive Atrial Septum in HLHS

• Causes pulmonary congestion
• Low cardiac output
• Metabolic/respiratory acidosis → poor gas exchange
• Cyanosis
• Emergency!
Cyanosis Despite \textit{PGE}_1
Restrictive Atrial Septum

- Outcomes are poor
- 40% survival by 1yr
- Pulmonary veins are arteriolized
  - High PVR
  - Chronic effusions

Glatz et al, ATS 2007
Other Considerations

• Poor ventricular function
  – May try inotropes/afterload reduction
    • Dopamine
    • Milrinone

• Severe atrioventricular valve regurgitation
  – Surgical problem
Surgical Palliation of Single Ventricle

• Achieves stable circulation
• Unobstructed systemic flow
• Restricted but stable pulmonary flow
• Wide open ASD
• (surgically-created fetal circulation)
Management of Single Ventricle (SV) heart disease has evolved tremendously since the 1950s:

- Blalock-Taussig Shunt: 1944
- Glenn Shunt: 1958 (dogs)
- Fontan Operation: 1971
- Norwood Operation for HLHS
History, cont

• Surgical advances were not thought of as ‘stages’ of palliation
• Operations as definitive *treatment* for congenital heart disease
• Certainly, much of what is now practiced will appear out of date in coming years
• Much of what is known owes to experiences, errors, limited successes of past 6 decades
Timing of Surgical Palliation

Once you hit "here"

There is no advantage in waiting
Timing of Surgery: Norwood

• Norwood palliation: for HLHS, other SV variants
• “Physiologic Repair of Hypoplastic Left Heart Syndrome”
• Achieves anatomically the desired ‘fetal physiology’
  – Restricted pulmonary blood flow
  – Unrestricted systemic blood flow

Norwood, NEJM 1983

Petit, CHD 2011
Modified Norwood Approaches

B. Modified Norwood with RV-PA conduit (“Sano”)

C. Hybrid Norwood
Timing of Surgery, cont.

• Our practice:
  – Once stable, perform thorough echocardiogram
  – Surgery within 1st week of life
  – Managed early post-op in cardiac ICU
  – Transitioned to step-down service
  – Discharge planned for 1st month of life
Late Presentation Single Ventricle

• Infants with some forms of SV may present several days-weeks postnatally

• **Cyanosis:**
  – Almost always prompts a cardiac workup
  – Tetralogy of fallot
  – Transposition
  – Pulmonary atresia
  – Tricuspid atresia
Late Presentation SV Disease

• Neonate presenting with **acidosis**:  
  – Work-up to evaluate number of systems  
  – **Infectious**: rule-out sepsis  
    • Viral/Bacterial  
  – **Metabolic**: rule-out inborn errors of metabolism  
  – **Endocrine**: rule-out CAH, other pathway errors  
  – **GI**: rule-out volvulus, enterocolitis  
  – **Cardiac**: rule out coarctation, left heart obstruction, myocarditis
Playing the Odds

- Endocrine: 1:15,000
- Metabolic: 1:8,000
- Infectious: 1:3,000
- GI: 1:2,500
- Cardiac: 1:125 (all forms of CHD)
  1:600 (ductal dependent CHD)

CRITICAL HEART DISEASE IS 3-4X MORE LIKELY THAN ALL OF THE ABOVE!
Late Presentation - Acidosis

• Unless another system is obviously affected, PGE$_1$ infusion should be ordered at same time as the echocardiogram
Case 1: 4 week old term infant

- Grunting respirations, pulse ox 95%
- Poor po feeding and vomiting x 3 weeks
- Poor urine output x 1 week
- Cool, mottled, but pink extremities
- Cap refill 3-4 seconds
Diagnosis?

• A) Septic shock
• B) Endocrine/metabolic disorder
• C) Right heart obstructive CHD
• D) Left heart obstructive CHD
• E) Who cares if it’s C or D, start the PGE$_1$ !!!
**Echo:** HLHS, depressed RV function, ductus arteriosus almost completely closed
Case 2: 1 day old term female

- Apgars 7/9
- Crying, vigorous
- Saturations 92%
Case 2: Plan of Action?

• $\text{PGE}_1$?
• Stat Echo?
• Recheck in am?
Case 2: cont

- Saturations drop to low-80s by 18 hours of life
- Lung disease? CXR $\rightarrow$ clear
- PGE$_1$ started $\rightarrow$ sats rise
- Echo $\rightarrow$ pulmonary atresia
Pulmonary Atresia
Case 2: plan?

• Now what?
• Transfer to regional cardiac center
  – Timing?
• Intubate for ‘safe transport’
  – Use low dose PGE₁ (0.01 mcg/k/min)
Big Picture: Single Ventricle Outcomes

• Usually 3 surgical steps to palliation
  – Norwood (neonate)
  – Glenn (3-5 months)
  – Fontan (2-4 years)

• 5-year survival: 65-75%

• Heart transplantation is the destination for all survivors

• Many complications, morbidities
Long Term Survival

• Careful family counseling is essential

• Common understanding among all team member is essential
Take Home Points

- For best neonatal outcomes:
  - Neonatology + Cardiology + CV Surgery must work as an integrated team
  - Common goal
  - Common understanding of challenges
  - Consistent approach within each team
    * not necessarily single approach across institutions!
Summary

• Critical heart disease is common
• More important to be attuned to Critical heart disease than “Single Ventricle”
• PGE$_1$ at low dose is safe, and may avoid intubation
• Avoid mechanical ventilation whenever possible
• Maintain fetal environment (high PVR, open PDA, open ASD) in critical heart disease
Thank You!