Low Cardiac Output in the Pediatric Patient

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Low Cardiac Output in the Pediatric Patient: Should Dr. Bohn give this talk?

Low Cardiac Output in the Pediatric Patient

• What is the low cardiac output syndrome (LCOS)?
• What about other etiologies of low cardiac output in the pediatric patient?
• Management strategies
Etiologies of Low Cardiac Output

- Sepsis
- Chronic (cardiomyopathy)
- Acute (myocarditis)
- Weaning from CPB
- Progressive postoperative failure
- Pulmonary hypertension
- Refractory arrhythmias
- Post Cardiac arrest
Low Cardiac Output in the Pediatric Patient

- **What is the low cardiac output syndrome (LCOS)?**
- What about other etiologies of low cardiac output in the pediatric patient?
- Management strategies
LCOS: Landmark reports


Efficacy and Safety of Milrinone in Preventing Low Cardiac Output Syndrome in Infants and Children After Corrective Surgery for Congenital Heart Disease

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Background—Low cardiac output syndrome (LCOS), affecting up to 25% of neonates and young children after cardiac surgery, contributes to postoperative morbidity and mortality. This study evaluated the efficacy and safety of prophylactic milrinone in pediatric patients at high risk for developing LCOS.

Methods and Results—The study was a double-blind, placebo-controlled trial with 3 parallel groups (low dose, 25-μg/kg bolus over 60 minutes followed by a 0.25-μg/kg per min infusion for 35 hours; high dose, 75-μg/kg bolus followed by a 0.75-μg/kg per min infusion for 35 hours; or placebo). The composite end point of death or the development of LCOS was evaluated at 36 hours and up to 30 days after randomization. Among 238 treated patients, 25.9%, 17.5%, and 11.7% in the placebo, low-dose milrinone, and high-dose milrinone groups, respectively, developed LCOS in the first 36 hours after surgery. High-dose milrinone significantly reduced the risk the development of LCOS compared with placebo, with a relative risk reduction of 55% (P=0.023) in 238 treated patients and 64% (P=0.007) in 227 patients without major protocol violations. There were 2 deaths, both after infusion of study drug. The use of high-dose milrinone reduced the risk of the LCOS through the final visit by 48% (P=0.049).

Conclusions—The use of high-dose milrinone after pediatric congenital heart surgery reduces the risk of LCOS. (Circulation. 2003;107:996-1002.)
Figure 3. Time to development of LCOS/death through final visit. Six additional patients developed LCOS after discontinuation of study drug infusion.
PRIMACORP
Primary Endpoint Per Protocol (n=227)

- Placebo: 26.7%, (n=75)
- Low Dose: 17.7%, (n=79)
- High Dose: 9.6%, (n=73)

RRR=64%, P=.007

RRR=34%, P=.183

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Is there a hormonal component to the LCOS?
Is there a hormonal component to the LCOS?

Klein NEJM 2001

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Is there a hormonal component to the LCOS?

- T3
  - ↑ myocardial contractility
  - ↓ afterload
  - ↑ HR
  - ↑ renal Na+ reabsorption
    - ↑ blood volume
  - ↑ cardiac output
A randomized, double-blind, placebo-controlled pilot trial of triiodothyronine in neonatal heart surgery

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Objective: This study was undertaken to evaluate the effect of triiodothyronine replacement on the early postoperative course of neonates undergoing aortic arch reconstruction.

Methods: We performed a randomized, double-blind, placebo-controlled trial of triiodothyronine supplementation in neonates undergoing either a Norwood procedure or two-ventricle repair of interrupted aortic arch and ventricular septal defect. Patients were assigned to receive a continuous infusion of triiodothyronine (0.05 μg/kg/h) or placebo for 72 hours after cardiopulmonary bypass. Primary end points were a composite clinical outcome score and cardiac index at 48 postoperative hours.

Results: We enrolled 42 patients (triiodothyronine n = 22, placebo n = 20). Baseline characteristics were similar in the treatment groups. Study drug was discontinued prematurely because of hypertension (n = 1) and ectopic atrial tachycardia (n = 1), both cases in the triiodothyronine group. Free and total triiodothyronine levels were higher in the triiodothyronine group than in the placebo group at 24, 48, and 72 postoperative hours (P < .001). The median clinical outcome scores were 2.0 (range 0-4) with triiodothyronine and 2.0 (range 0-7) with placebo (P = .046). Compared with those in the placebo group, neonates assigned to triiodothyronine had shorter median time to negative fluid balance (2.0 vs 2.5 days, P = .027). Cardiac index values were 2.11 ± 0.64 L/min · m² with triiodothyronine and 2.05 ± 0.72 L/min · m² with placebo (P = .81). Heart rate and diastolic blood pressure were not influenced by triiodothyronine supplementation, but systolic blood pressure was higher in the triiodothyronine group (P < .001). No serious adverse events were attributed to triiodothyronine administration.

Conclusion: Triiodothyronine supplementation was safe and resulted in more rapid achievement of negative fluid balance after aortic arch reconstruction. Cardiac index at 48 hours was not significantly improved.

Low cardiac output syndrome is a common complication of neonatal cardiac surgery.1 Contributing factors include myocardial ischemia during aortic crossclamping, the effects of cardioplegia, the inflammatory reaction to cardiopulmonary bypass (CPB), hypothermia, and reperfusion injury.2 Low cardiac output syndrome is associated with increased morbidity and mortality.3,4 Early recognition and management of low cardiac output syndrome are important for improving outcomes.5,6

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Figure 2. Systolic blood pressure (A) was higher in the T3 group ($P < .001$) during the early postoperative period, as was mean blood pressure (B) ($P = .02$). Error bars represent 95% confidence intervals.
### TABLE 3. Results of the composite clinical outcome score

<table>
<thead>
<tr>
<th>Outcome</th>
<th>$T_3$ (n = 22)</th>
<th>Placebo (n = 20)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite clinical score</td>
<td>2.0 (0-4)</td>
<td>2.0 (0-7)</td>
<td>.046</td>
</tr>
<tr>
<td>Time until first negative fluid balance (d)</td>
<td>2.0 (1-4)</td>
<td>2.5 (2-3)</td>
<td>.027</td>
</tr>
<tr>
<td>Time until sternal closure (d)</td>
<td>2.5 (0-6)</td>
<td>4.0 (0-6)</td>
<td>.14</td>
</tr>
<tr>
<td>Time until first extubation (d)</td>
<td>6.0 (3-17)</td>
<td>6.0 (4-13)</td>
<td>.38</td>
</tr>
<tr>
<td>In-hospital death* (No.)</td>
<td>0</td>
<td>0</td>
<td>&gt;.999</td>
</tr>
<tr>
<td>Extracorporeal membrane oxygenation (No.)</td>
<td>0</td>
<td>2 (10%)</td>
<td>.22</td>
</tr>
</tbody>
</table>

Each subcomponent of the clinical score is also presented. Results are presented as median with range as appropriate. *One patient randomly assigned to the placebo group died at home 5 weeks after hospital discharge; 1 patient was randomly assigned to the placebo group but excluded post hoc before initiation of study drug and died in the hospital.
I. Extent of the problem
   A. One quarter of newborns will decrease their cardiac index to 2.0 L/min/m² after CPB

II. Exclude residual disease
   A. Transesophageal echocardiography and intracardiac catheters provide important anatomic and physiologic data for planning the need for reintervention

III. **Optimize preload**
   A. Monitor filling pressure and interpret values in light of underlying cardiac disease

IV. **Enable R-L shunting for right heart failure**
   A. Newborn after right ventriculotomy (TOF and truncus arteriosus)
   B. Baffle fenestration in patients undergoing a Fontan operation helps preserve cardiac output and oxygen delivery and reduces right atrial pressure
   C. Preserving a R-3L shunt in patients with known elevation in pulmonary vascular resistance may preserve cardiac output during postoperative pulmonary hypertensive crises or during CPR

A. **Catecholamines**
   1. Dopamine (5–15 g/kg/min) supports cardiac output and preserves aortic perfusion pressure during weaning from CPB; dobutamine may reduce afterload
   2. Prolonged high-dose epinephrine after CPB in neonates is associated with myocardial necrosis and marked diastolic dysfunction and is increasingly avoided

B. **Afterload reduction**
   1. Milrinone, a phosphodiesterase inhibitor, increases cardiac output and lowers filling pressures; nitrates are commonly employed as vasodilators
   2. Phenoxybenzamine is a potent β-blocker and has been advocated as part of the postoperative management of patients with hypoplastic left heart syndrome but has a long duration of action
   3. Nitric oxide is a selective pulmonary vasodilator that will reduce afterload on the right heart

VI. **Rhythm**
   A. A-V sequential pacing is important for arrhythmias, such as JET or complete heart block
   B. Atrio-biventricular pacing may improve hemodynamics substantially in patients with complete right or left bundle branch block

VII. **Ventilation/cardiorespiratory interactions**
   A. Positive pressure ventilation reduces left ventricular afterload but decreases preload and may raise pulmonary vascular resistance and RV afterload
   B. Negative pressure ventilation (Hayek oscillator) may augment R heart function

VIII. **Hypothermia**
   A. Core body temperature to 34–35°C for patients in low cardiac output

X. **Mechanical support**
   A. Extracorporeal membrane oxygenation
   B. Ventricular assist device

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Distinct Hemodynamic Patterns of Septic Shock at Presentation to Pediatric Intensive Care

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What’s Known on This Subject

Both warm and cold shock have been observed in pediatric septic shock. Outcomes worsen exponentially as shock persists. Guidelines recommend that therapy be tailored to individual hemodynamics, and targeting a central venous oxygen saturation of >70% may offer an advantage.

What This Study Adds

Noninvasive, ultrasound, cardiac output measurement is practical and reproducible in the PICU. Cases of pediatric septic shock exhibit central venous desaturation even with high cardiac output. Distinct patterns of shock are seen in cases with different causes and times to assessment.

ABSTRACT

OBJECTIVE. Early aggressive resuscitation is accepted best practice for severe pediatric sepsis. Targeting of therapy to individual hemodynamic patterns is recommended, but assessment of patterns is difficult early in the disease process. New technologies enabling earlier hemodynamic assessment in shock may inform choices for vasoactive drugs in fluid-resistant cases.

METHODS. This was a prospective observational study of 30 children with suspected fluid-resistant septic shock (minimum: 40 mL/kg) admitted to the PICU of a tertiary care children’s hospital between July 2004 and July 2005. Children were classified according to admission diagnosis (community-acquired sepsis or central venous catheter-associated infection) and assessed within 4 hours after the onset of shock with a noninvasive cardiac output device. Cardiac index and systemic vascular resistance index were measured for all patients. Central venous oxygen saturation was measured for patients with accessible central venous lines at the time of hemodynamic measurements (typically at the superior vena cava-right atrium junction).

RESULTS. Fluid-resistant septic shock secondary to central venous catheter-associated infection was typically “warm shock” (15 of 16 patients; 94%), with high cardiac index and low systemic vascular resistance index. In contrast, this pattern was rarely seen in community-acquired sepsis (2 of 14 patients; 14%), where a normal or low cardiac index was predominant.

CONCLUSIONS. The hemodynamic patterns of fluid-resistant septic shock by the time children present to the PICU are distinct, depending on cause, with little overlap. If these findings can be reproduced, then targeting the choice of first-line vasoactive infusions in fluid-resistant shock (vasopressors for central venous catheter-associated infections and inotropes for community-acquired sepsis) should be considered. Pediatrics 2008; 122:752–759.
FIGURE 2
Noninvasive assessment of CO during resuscitation of a child with septic shock. The suprasternal position is being used during interrogation of the aortic valve. A clear waveform can be seen, from which hemodynamic parameters are calculated.
FIGURE 5
Initial cardiovascular parameters according to group. Superior vena cava oxygen saturation (SCVO₂), cardiac index (CI), and SVRI in CVC and CA sepsis are shown. Both groups showed incomplete resuscitation from shock. The majority of superior vena cava oxygen saturation values were <70% (CVC: 69%, 11 of 16 cases; CA: 83%, 10 of 12 cases). Hemodynamic patterns were distinct, with the CVC group demonstrating warm shock and the CA group predominantly cold shock.
FIGURE 6
SVRI and cardiac index (CI) in 30 cases of fluid-resistant septic shock. Ranges for CI and SVRI values are shown. The red box indicates warm shock (high cardiac index and low SVRI).
FIGURE 7
Superior vena cava oxygen saturation and cardiac index values at presentation to the PICU with septic shock (N = 30). Individual values and means and 95% confidence intervals are shown for CA sepsis and CVC-associated sepsis. It should be noted that some cases with high cardiac output have evidence of significant central venous desaturation.
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Is there an algorithm to treat LCOS in the patient without congenital heart disease?
Is there an algorithm to treat LCOS in the patient without congenital heart disease?

Septic Shock

FLUIDS, FLUIDS!

Establish CVL; measure venous O₂ sat and lactate

Low SVR, NI CVP
Good SV,
SV₀₂ > 70%
(warm shock)

NE ± DA
Vasopressin
Stress steroids

Low SVR, high CVP
Poor SV,
SV₀₂ < 70%

Dopamine, NE+Dob
Vasopressin
Milrinone
Stress steroids

Start Dopamine (DA)

NI to increased SVR;
high CVP, Poor SV,
SV₀₂ <70%
(cold shock)

Titrate Epi?
SNP, NTG+Dob
Milrinone
BNP, DA
Stress steroids

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Management strategies

1. Most important monitor: a good intensivist doing frequent physical exams.
2. Proactive NOT reactive approach to the patient; continual re-assessment of the clinical trajectory and the management plan.
3. Biomarkers: serial lactate and ScVO2, trends more important than absolute values
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