Update on Screening for Critical Congenital Heart Disease

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Disclosures

I have no relevant financial relationships with the manufacturers of any commercial products and/or providers of commercial services discussed in this CME activity.
Objectives

• Define congenital heart disease (CHD) and critical congenital heart disease (CCHD)

• Outline importance of screening for CCHD

• Review equipment and technique for CCHD screening by pulse oximetry

• Describe the impact and limitations of screening
Normal cardiac anatomy
What is congenital heart disease (CHD)?

- Gross structural abnormality of the heart or intrathoracic great vessels that is actually or potentially of functional importance
  - Mitchell et al, Circulation 1971

- Occurs in 9 per 1000 live births
  - Botto et al. Pediatrics, 2001

- Most common serious birth defect
# Most common CHD lesions

<table>
<thead>
<tr>
<th>Lesion</th>
<th>Frequency</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventricular septal defect</td>
<td>30%</td>
<td>L→R shunt</td>
</tr>
<tr>
<td>Atrial septal defect</td>
<td>10%</td>
<td>L→R shunt</td>
</tr>
<tr>
<td>Patent ductus arteriosus</td>
<td>10%</td>
<td>L→R shunt</td>
</tr>
<tr>
<td>Pulmonary stenosis</td>
<td>7%</td>
<td>Obstructive lesion</td>
</tr>
<tr>
<td>Coarctation of the aorta</td>
<td>7%</td>
<td>Obstructive lesion</td>
</tr>
<tr>
<td>Aortic stenosis</td>
<td>6%</td>
<td>Obstructive lesion</td>
</tr>
<tr>
<td>Tetralogy of Fallot</td>
<td>6%</td>
<td>Cyanotic lesion</td>
</tr>
<tr>
<td>D-Transposition of the Great Arteries</td>
<td>4%</td>
<td>Cyanotic lesion</td>
</tr>
<tr>
<td>Other</td>
<td>20%</td>
<td>(including Single ventricle lesions)</td>
</tr>
</tbody>
</table>
What is critical CHD?

- Lesions that require surgical or catheter intervention in first year of life
- Makes up 25% of all heart defects
- Leading cause of infant death
## Incidence per live births

<table>
<thead>
<tr>
<th>CCHD</th>
<th>Incidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Congenital hearing loss</td>
<td>2-4/1000</td>
</tr>
<tr>
<td>Congenital hypothyroidism</td>
<td>0.4/1000</td>
</tr>
<tr>
<td>Cystic fibrosis</td>
<td>0.4/1000</td>
</tr>
<tr>
<td>Phenylketonuria</td>
<td>1/10,000-1/20,000</td>
</tr>
<tr>
<td>Congenital adrenal hyperplasia</td>
<td>1/15,000</td>
</tr>
<tr>
<td>Galactosemia</td>
<td>1/60,000</td>
</tr>
</tbody>
</table>
## Critical CHD lesions

<table>
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<tr>
<th>D-Transposition of the great arteries</th>
<th>Pulmonary atresia/intact ventricular septum</th>
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<tr>
<td>Tetralogy of Fallot</td>
<td>Double outlet right ventricle</td>
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<tr>
<td>Hypoplastic left heart syndrome</td>
<td>Single ventricle</td>
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<td>Truncus arteriosus</td>
<td>Coarctation of the aorta</td>
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<td>Tricuspid atresia</td>
<td>Interrupted aortic arch</td>
</tr>
<tr>
<td>Total anomalous pulmonary venous return</td>
<td>Ebstein’s anomaly of the tricuspid valve</td>
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How do we diagnose CCHD?

- Antenatal ultrasound
- Clinical symptoms in nursery
  - Tachypnea
  - Absent or weak femoral pulses
  - Murmur
  - Cyanosis from hypoxemia
  - Shock
- Can be asymptomatic in newborn period
The problem

- 25% of infant CCHD were not diagnosed until after discharge from the newborn nursery
- Incidence of severe physiologic compromise from unrecognized CCHD estimated 1/15,000-1/26,000 live births
- Acute hemodynamic compromise increases risks
  - Impaired cardiovascular function
  - Brain injury from ischemia and reperfusion
  - Impacts survival and recovery during cardiothoracic surgery

Fetal circulation

- Placenta
- Umbilical Cord
- Umbilical Vein
- Umbilical Arteries
- Foramen Ovale
- Pulmonary Artery
- Ductus Venosus
- Ductus Arteriosus
- Aorta
- Lung
- Liver
- Left Kidney

Oxygen-rich Blood
Oxygen-poor Blood
Mixed Blood
Normal postnatal cardiac structure

Tetralogy of Fallot

Transposition of GA

AO = Aorta
PA = Pulmonary Artery
LA = Left Atrium
RA = Right Atrium
LV = Left Ventricle
RV = Right Ventricle
Transitional circulation

Change in hemodynamics from fetal to post-natal life

• Pulmonary changes
  – Pulmonary blood flow
  – Pulmonary vascular resistance

• Closure of the ductus arteriosus (fetal connection from pulmonary artery to descending aorta)
How good are we at early diagnosis?

- Prenatal diagnosis
- Clinical diagnosis before hospital discharge
- Diagnostic gap – Babies discharged before diagnosis of CCHD

Brown et al, Heart 2006
Antenatal ultrasound

• Routine obstetrical ultrasound for fetal anatomical evaluation performed at 18-22 weeks gestation
• Referral for fetal echocardiogram if cardiac abnormality is suspected
• Detection rates for fetal cardiac anomalies vary widely (15-48% reported)
• Largely dependent on the skill of the sonographers performing obstetric ultrasound
Why only 50% diagnosed antenatally?

- Limited prenatal care
- Maternal obesity
- Abdominal scars
- Amniotic fluid volume
- Gestational age
- Examiner experience
- Anomaly evolves in utero
- Anomaly not easily detected by the 4 chamber view

ISUOG. Ultrasound Obstet Gynecol, 2006
How are diagnoses missed prenatally? (including major ones!)

Standard for Routine Screening Fetal Ultrasound
“The basic cardiac examination includes a 4-chamber view of the fetal heart. If technically feasible, an extended basic cardiac examination can also be attempted to evaluate both outflow tracts.”

Guidelines for Standard Examination of the fetus (Level 1 ultrasound) published by the American Institute of Ultrasound in Medicine, American College of Radiology (2003), and the American College of Obstetricians and Gynecologists (2004)
Lesions can easily be missed!

<table>
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<tr>
<th>Dx by 4-Ch view alone</th>
<th>Dx Missed on 4-Ch view alone</th>
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<tr>
<td>Complete AV Canal</td>
<td>D-Transposition of the Great Arteries *†</td>
</tr>
<tr>
<td>Single ventricle lesions (e.g., HLHS, Tricuspid atresia) †</td>
<td>Tetralogy of Fallot *†</td>
</tr>
<tr>
<td>Ebstein anomaly of tricuspid valve</td>
<td>Truncus Arteriosus</td>
</tr>
<tr>
<td>Possibly VSD</td>
<td>Double outlet right ventricle (DORV) †</td>
</tr>
<tr>
<td></td>
<td>Pulmonary stenosis †</td>
</tr>
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<td>Aortic stenosis †</td>
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<tr>
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<td>VSD (perimembranous, subarterial)</td>
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*Most common cyanotic CHDs

† Possibly ductal-dependent
Neonates (<30d) undergoing cardiac surgery for CCHD

Antenatal Diagnosis

Year | No | Yes
--- | --- | ---
2008 | 35 | 10
2009 | 30 | 15
2010 | 25 | 20
2011 | 20 | 15
2012 | 15 | 10
Was there a prenatal diagnosis?

SLCH data, 2008-2012
What about physical exam and clinical presentation?
Clinical signs

• None
• Tachypnea
  • Many other etiologies
• Absent or weak femoral pulses
  • Only occurs after the ductus arteriosus has closed
• Murmur
  • Occur in up to 77% of newborns
  • Often not pathologic
  • Some CCHD lesions do not have murmurs
Cyanosis

• Clinical sign of hypoxemia
• Cyanosis
  • Difficult to detect clinically
  • 4-5 grams of deoxygenated hemoglobin needed to produce visible cyanosis
  • Dependent on hemoglobin levels
• Hypoxemia results from
  • Mixing of systemic and venous circulations
  • Parallel circulations

Mean threshold for detecting cyanosis is 69%
Can we close the diagnostic gap?

- Prenatal diagnosis – 50%
- Clinical diagnosis before hospital discharge – 25%
- Diagnostic gap – 25%

Babies discharged before diagnosis of CCHD

Brown et al, Heart 2006
Pulse oximetry screening for CCHD

- Hypoxemia occurs in many forms of CCHD
- Pulse oximetry can detect hypoxemia not visible clinically
- Can identify differences in pre- and post-ductal saturations
- Pulse oximetry is quick, easy and safe
Pulse oximetry screening targets CCHD lesions with desaturation

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* Targets for CCHD pulse oximetry screening
Pulse oximetry screening for CCHD

- Supported by AAP, AHA, ACC, MOD
- Sept 2010 - Secretary’s Advisory Committee on Heritable Disorders in Newborns and Children (SACHDNC) recommended CCHD be added to uniform screening
- Sept, 2011 – Health and Human Services Secretary Kathleen Sebelius endorsed adding CCHD screening to the recommended universal screening panel
- 2013 – Missouri and Illinois passed legislation to add CCHD screening to routine newborn screening tests
Does pulse oximetry work as a screening test?

• Comprehensive review of studies involving ~230,000 babies shows pulse oximetry
  – Highly specific test for CCHD – 99.9%
  – Moderate sensitivity – 76.5%
  – Low false positive rate – 0.14%
  – Lower false positive rate with testing after 24 hours of life – 0.05%

• Meets criteria for universal screening

Pulse oximetry screening for CCHD

Pulse oximetry can reduce the diagnostic gap

- Diagnostic gap
- Pulse oximetry screening
- Clinical Diagnosis in nursery
- Prenatal diagnosis
Pulse oximetry improves the detection of CCHD

Some babies with CCHD will not be identified by pulse ox screening!!!
(Coarctation, interrupted aortic arch, others)
The $13 Test That Saved My Baby’s Life. Why Isn’t it Required For Every Newborn?
CCHD Screening Progress - 2014

= Active Legislation
Legislation Enacted
Regulatory Addition to NBS Panel
Multi-Center Screening or Pilot Project
CCHD screening recommendations: Who and When?

• Who?
  – All infants in the well baby nursery
  – Infants in intermediate care nurseries/other units if discharged in 1st week of life

• When?
  – Screen on second day of life, after 24 hours of age
    • Can intervene before ductus closes
    • Decreases false positives
  – While infant is awake and quiet
  – Time with other newborn care (i.e. hearing screen)

Kemper et al. Pediatrics, 2011
CCHD screening recommendations: Equipment

- Oximeter that is FDA approved for neonatal use
- Validated in low perfusion conditions
- Motion tolerant
- Reports functional oxygen saturation
- Disposable or reusable probes are okay

Kemper et al. Pediatrics, 2011
CCHD screening recommendations: Applying probe

Disposabale Probe

Reusable Probe

“Star to the Sky”

“Raise the (Red) Bar”
CCHD screening recommendations: Getting a reliable reading

• Place on a warm extremity

• After placing the probe, wait 30 seconds before recording the number

• Ensure there is an adequate waveform before recording the number

• If the baby is crying this can affect the reading, try to calm before recording the number
CCHD screening recommendations: Passing criteria

- **Pass**
  - saturation $\geq 95\%$ in either extremity with $\leq 3\%$ difference

- **Positive screen**
  - Saturation $< 90\%$
  - Saturation $< 95\%$ in both extremities on 3 measures separated by an hour
  - $> 3\%$ difference on 3 measures, separated by an hour

Kemper et al. Pediatrics, 2011
CCHD screening recommendations: Positive screens

- Comprehensive evaluation for a cause (pulmonary, infectious, etc)

- Echo in the absence of other etiology
  - Read by pediatric cardiologist
  - May require transfer to another institution
  - Telemedicine

- Do not replace echo with other evaluations (CXR, EKG, hyperoxia test)

- When possible, consult a pediatric cardiologist before obtaining the echo

- Follow-up should be arranged prior to discharge and results of screening communicated to primary care provider

Kemper et al. Pediatrics, 2011
CCHD screening recommendations: Documentation and reporting

• Standard way of documenting results – include retests when needed and disposition for babies with positive (referred) screens

• Report results to parent

• Send to primary care physician

• No reporting to IDPH
Newborn CCHD screening data collection progress - 2014
What are the challenges to pulse oximetry screening?

- Education – providers, staff, families, healthcare administrators
- Equipment
- Personnel time
- Work flow
- Documentation
- Availability of echocardiogram and cardiology
- Reporting
What have we learned?

• More studies validate results of pulse oximetry screening
• Earlier screening reliability
• False positive screens identify hypoxemic infants
  – Non-critical cardiac lesions
  – Early onset sepsis
• High acceptability to parents and staff
• False positive tests did not increase parental anxiety
• More echocardiograms are performed for clinical concerns than pulse oximetry screens
Feasibility and costs

- Estimate ~1200 babies with CCHD will be identified by screening, 20 death averted
- No additional staff or burden to clinical services
- Average time to complete screening is 5 – 9 minutes
- Cost per patient screen $5.10 - $13.50
- Net cost $6.30 per newborn includes savings when readmission avoided ($0.50 per baby with reusable probes)
- US and European studies show pulse oximetry screening likely to be cost effective and may be cost-saving
Last September, my husband Dan and I took our 4-week-old daughter for a hike near our home in New York’s Hudson River Valley. Violet slept in her baby carrier as we snatched up apples and enjoyed views of just-turning fall leaves. Toward the end of the day, Dan turned to me and said, “I feel like we’re getting the hang of this new-baby thing!” We laughed. Violet was a great baby—calm, bright-eyed—but everything was still cloudless newsprint. “I don’t think it’s going to be quite that easy,” I told him.

It wasn’t.

Less than 24 hours later, I sat in the front seat of an ambulance as it raced, sirens blaring, to a nearby children’s hospital. Violet’s tiny body was strapped to an adult-sized gurney and I could see her kitten-like cry while two paramedics worked desperately to keep oxygen in her body.

Humans are supposed to have blood oxygen levels of nearly 100 percent. That morning, when we arrived at the pediatrician’s office, Violet’s “well baby” visit, her level had dropped to 75 percent. By the end of the day, even after Violet had been put on a ventilator, that was down to 18 percent. Forget what you’ve heard about baby blues; our girl was going.

As we werelearned, Violet had been born with a form of critical congenital heart defect (CHD) that prevented her heart from pumping enough oxygen-rich blood to the rest of her body. During the months she spent growing inside me, Violet’s heart never divided into all four chambers; it also never formed one of the essential valves. The medical term for her anatomy is “single ventricle physiology,” but the simplest way to explain it is to say that Violet has only half a heart.

A pediatric cardiologist was able to perform a balloon catheterization to stabilize Violet. Afterwards, she lay unconscious, hooked up to a million wires and tubes, I stared at her and wondered: How could we have missed that something was so wrong?

I’ll probably never stop asking that question, even though Violet’s heartbeat had been strong and steady at every prenatal checkup and all through my labor. Some congenital heart defects are detected with prenatal ultrasonograms, but Violet’s didn’t show up on any of mine. We have no family history of CHD, and its cause is often mysterious. Nevertheless, we should have known more. Hospital nurseries can measure babies’ oxygen levels 24 hours after birth. That test, called a pulse oximetry screening, is noninvasive, taken fewer than 10 minutes, and costs less than $15 per baby, but has only been part of the federally recommended newborn screening panel since 2011. Whether that federal recommendation gets followed varies by state and even by hospital. (At least 10 states have yet to require the test as of July 2014 and even those that do have always enforce it.)

New York, the state we live in, was in the process of mandating the “pulse ox” screening—but still, Violet never got the test.

If we hadn’t had that pediatric checkup, if Violet’s oxygen level had plunged too low while she slept the right before; if we didn’t live within an hour’s drive of a top children’s hospital—our world would have broken apart that September day. Getting the pulse ox screening wouldn’t have changed the course of Violet’s treatment, but we wouldn’t have had to nearly lose her before we knew that something was wrong.

Yet our family is one of the lucky ones. During our stay in the pediatric intensive care unit, Violet underwent the first of three expected open-heart surgeries, which will reconstruct her circulation over the course of the next few years. She is now a strong 1-year-old who smiles, babbles, and talks.

And by the time she is 5, Violet should be as healthy as any kid on the playground. She will always have just half a heart. But I carry her other half in mine.
What have we learned? Reporting through WUSM/SLCH

• Quality Improvement Database

• Anyone can enter data

• Numbers of:
  • Infants screened
  • Infants with sats <90%, 90-94% on 3 screens, and >3% difference on 3 screens
  • Parents declined
  • Number evaluated with echo, referred for evaluation, and diagnosed with CCHD

• Data entered will be reported to the state until patient specific reporting is required (Missouri hospitals)

• cchdscreen.wustl.edu
CCHD QI database report
March 1, 2013 – August 31, 2014

- Total babies screened with pulse oximetry: 11,747
- Parent declined screening: 4
- Saturations under 90%: 2
- Saturations 90-94%: 5
- Pre-/post-ductal gradient over 3%: 5
- Total “referral rate”: 0.1%
- Diagnosed with CCHD: none
- ECHO results (when known): Normal, pulmonary hypertension, PFO
What we don’t know yet -

- Validation of pulse oximetry equipment
- Lives saved and health outcomes after screening
- Determine thresholds for high altitudes
- Timing for babies discharged early
- Regional practices and incidence of CCHD
- Rate and outcomes of false negatives
- Detection of other conditions
- Cost effectiveness/savings
- Role for peripheral perfusion index to augment pulse oximetry results
Pulse oximetry improves the detection of CCHD

Some babies with CCHD will not be identified by pulse ox screening!!!

(Coarctation, interrupted aortic arch, others)
Take home messages:

♥ Pulse oximetry detects desaturation
♥ Desaturation (hypoxemia) is not normal and may be a sign of:
  ♥ CCHD
  ♥ Non-critical CHD
  ♥ Early onset sepsis
  ♥ Other conditions
♥ Pulse oximetry is a good screening test for CCHD
♥ Pulse oximetry combined with physical examination improves early diagnosis for infants with CCHD
♥ Pulse oximetry will not identify all babies with CCHD
Acknowledgements

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