Current Practice in Pediatric and Neonatal Extracorporeal Life Support

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Conflict of Interest Disclosure
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I have no financial relationships with a commercial entity producing healthcare-related products and/or services relevant to the content I am presenting.
ECMO
Extracorporeal Membrane Oxygenation

- Aortic Arch
- Right Atrium
- Blood Perfusion
- Blood Drainage
- Heparin
- Gas Source
- Heat Exchanger
- Reservoir
- Membrane Lung
- Roller pump
Early Beginnings

- May 6, 1953 Dr. Gibbon performed the first extracorporeally assisted repair of an ASD
- Problematic past a few hours in the OR and did not translate well to the ICU setting.
- Two innovations created a breakthrough.
  - The invention of silicone
  - Controlled anticoagulation
ECMO outside the OR

- Dr. J.D. Hill reported on the first successful ECMO patient in 1972
- Dr. Bob Bartlett in 1975 treated a meconium aspiration and resultant pulmonary hypertension.
- Esperanza received ECMO for 72 hours and then was decannulated successfully.
- Published reports showed survival rates of 75% in neonatal diseases previously associated with a 10% survival.
Efficacy of ECMO

- Medical community sought RCT to determine effectiveness of therapy
- 1985 controversial study by Dr. Bartlett “randomized play the winner”
- 1989 Boston Childrens performed two phase trial which showed a 97% survival for ECMO compare to 60% control group.
- Largest RCT in the UK 1993-1995. (60% in ECMO vs 40% standard therapy).
ELSO: Extracorporeal Life Support Organization

- 1986: 19 institutions were providing ECMO
- 1989: a steering committee formed and created the bylaws to form ELSO.
- Purpose:
  - Pool common data
  - Compare outcomes
  - Exchange ideas for optimal use of ECMO support
- ELSO Registry: allowed for participating institutions to compare outcomes with the national and international centers.
- 2018: 700 Institutions listed as part of ELSO!
ELSO Registry Data

- In 2012-2013 adult ECMO cases worldwide overtook pediatric and neonatal cases for the first time.
- Chapters include EuroELSO, Latin American ELSO, Asia Pacific ELSO, Southwest Asia and Africa ELSO.
- In June 2018 the 100,000th patient was reported to the ELSO registry.

<table>
<thead>
<tr>
<th></th>
<th>Neonatal 2017</th>
<th>Pediatric 2017</th>
<th>Adult 2017</th>
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<tbody>
<tr>
<td>Respiratory</td>
<td>715</td>
<td>514</td>
<td>2,732</td>
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<tr>
<td>Cardiac</td>
<td>419</td>
<td>780</td>
<td>3,337</td>
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<tr>
<td>ECPR</td>
<td>124</td>
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Neonatal Respiratory Runs by Diagnosis 2013 to Present

<table>
<thead>
<tr>
<th>DIAGNOSIS</th>
<th>%SURVIVED</th>
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<tbody>
<tr>
<td>CDH</td>
<td>51%</td>
</tr>
<tr>
<td>MAS</td>
<td>92%</td>
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<tr>
<td>PPHN</td>
<td>73%</td>
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<tr>
<td>RDS</td>
<td>76%</td>
</tr>
<tr>
<td>SEPSIS</td>
<td>48%</td>
</tr>
<tr>
<td>PNEUMONIA</td>
<td>57%</td>
</tr>
<tr>
<td>AIR LEAK</td>
<td>81%</td>
</tr>
<tr>
<td>OTHER</td>
<td>65%</td>
</tr>
</tbody>
</table>
Neonatal Cardiac Runs by Diagnosis 2013 to Present

### Neonatal Cardiac Runs

- **Congenital Defect**
  - % Survived: 45%

- **Cardiac Arrest**
  - % Survived: 41%

- **Cardiogenic Shock**
  - % Survived: 48%

- **Cardiomyopathy**
  - % Survived: 63%

- **Myocarditis**
  - % Survived: 51%

- **Other**
  - % Survived: 53%
Pediatric Respiratory Runs by Diagnosis 2013 to Present

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>% Survived</th>
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<tbody>
<tr>
<td>Viral PNA</td>
<td>72%</td>
</tr>
<tr>
<td>Bacterial PNA</td>
<td>68%</td>
</tr>
<tr>
<td>Aspiration PNA</td>
<td>67%</td>
</tr>
<tr>
<td>ARDS post-op/trauma</td>
<td>64%</td>
</tr>
<tr>
<td>ARDS NOT post-op</td>
<td>65%</td>
</tr>
<tr>
<td>Acute Resp. Failure</td>
<td>62%</td>
</tr>
<tr>
<td>Other</td>
<td>58%</td>
</tr>
</tbody>
</table>
Pediatric Cardiac Runs by Diagnosis 2013 to Present

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<thead>
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<tr>
<td>CARDIAC ARREST</td>
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</tr>
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<td>CARDIOGENIC SHOCK</td>
<td>56%</td>
</tr>
<tr>
<td>CARDIOMYOPATHY</td>
<td>64%</td>
</tr>
<tr>
<td>MYOCARDITIS</td>
<td>75%</td>
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<tr>
<td>OTHER</td>
<td>58%</td>
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</tbody>
</table>

Pie chart and table show the survival rates for different cardiac diagnoses.
Extracorporeal Life Support

a.k.a. ECMO

- Severe respiratory failure, refractory to maximal medical management, with potentially reversible etiology
- High likelihood of death without ECLS and
- High likelihood of survival with ECLS
- High likelihood = 80%
Neonatal ECMO - Selection Criteria

• Receiving maximal conventional support
• Oxygen Index > 0.4 for > 4 hours
• Oxygen index > 0.2 for > 24 hours and lack of improvement of persistent decompensation
• Severe, unresponsive hypoxic resp failure with acute decompensation (PaO2 < 40) unresponsive to intervention.
• Gestational age > 33 weeks
• Reversible underlying process
• Negative cranial ultrasound
• No uncontrolled bleeding
Pediatric ECMO - Selection Criteria

- PIP > 40 cm H2O
- FIO2 = 1.0
- Oxygen index > 0.25
- Diffuse infiltrates
- Air leaks
Common Diagnosis - Neonatal

- CDH
- Beta strep sepsis
- Persistent pulmonary hypertension of the newborn (PPHN)
- Meconium aspiration syndrome (MAS)
- Respiratory distress syndrome
Common Diagnosis - Pediatric

- ARDS
- Cardiac Surgery
ECMO vs. Cardiopulmonary Bypass

• ECMO
  – longer duration than bypass
  – support while allowing lungs to rest

• Bypass
  – short term
  – support for performing procedure, i.e. surgery
Types of ECMO Support

- VA
- VA + V
- VV
- VVDLC
- VVDL + V

Veno - arterial
Veno - arterial plus venous
Veno - venous
Veno - venous double lumen catheter
Veno - venous double lumen catheter plus venous
Cannulation

• OR team comes to NICU
• Surgeon preps area
• for cannulation

• Patient is sedated/
• paralyzed for the
• Procedure

• Vessel(s) intended for
• cannulation exposed
Initiation of Support

• Circuit primed with blood and additives
• Circuit is attached to cannula(s)

• Oxygen attached to the oxygenator adds oxygen
• + removes CO2 from the blood

• Blood with a Sat of 100% is returned +
• appropriate PCO2 returns
• to the patient
Starting Support

• Pump flow started slowly – .05 -.1 ml

• Cannula placement is confirmed by CXR

• Pump flow and sweep (oxygen) flow are adjusted to provide adequate support

• Typical pump flows for NB 100-150 cc/kg

• Heparin is infused into the circuit to maintain anticoagulation

• Clotting times measured Q 1 hr. aiming for ~200 sec.
Venous Arterial

• Drainage catheter
  – inserted into right IJ
  – advanced to right vena cava

• Return catheter
  – inserted into right carotid artery
  – blood flow is directed into mid aortic arch
Cannulas

• Wire wound into walls
  – Limits kinking
  – Shorter = less resistance

• Heparin coated

• Thin wall for higher blood flow capability

• Adults cannulas typically 18 fr -25 fr
Venous and Arterial Cannulas
VA Cannulation
Veno - venous DLC

- Drainage side has multiple ports
- Return side has one distal opening
- Drainage side comprises 2/3 of total lumen
Veno - venous DLC
VA ECMO

Venous cannula
inserted into right IJ
advanced to right atrium, drains
desaturated blood

Arterial cannula
inserted into right carotid artery
infuses fully saturated blood into
the arterial circulation
Veno-Venous Double lumen Cannula

Double lumen cannula
Re-circulation

• Occurs with VV DLC
• Venous side takes return flow back into catheter
• 10 to 30% re-circulation is expected
• Position catheter to minimize re-circulation
  – position drainage ports anteriorly
  – direct return flow toward tricuspid valve
Re-circulation

Double lumen Cannula

Inflow Lumen

Drainage Lumen

Venous drainage from the patient

Recirculation from oxygenated to venous drainage site

5 cm

Oxygenated blood to the patient
Avalon Elite Bi-Caval Dual Lumen
Avalon Elite Bi-Caval Dual Lumen
Avalon Elite Bi-Caval Dual Lumen
Avalon Elite Bi-Caval Dual Lumen - Disadvantages

• Difficult to insert
  – fluoroscopy
• Large cannula
  – Not for small patients
• Cost
Veno - venous + venous

- Cephalod portion of IJ is also cannulated
- promotes drainage
- reduces likelihood of cerebral venous congestion
- May decrease incidence of intra-ventricular hemorrhage
Advantages of VV Support

- Pulmonary perfusion is maintained
- Bronchial and thebesian perfusion is maintained with oxygenated blood
- Arterial circulation is not invaded
- Blood flow remains pulsatile
- Faster cannulation procedure
Disadvantages of VV Support

- Catheter position may be problematic
- Re-circulation
- Lower SaO2
- Does not support blood pressure
- Limited catheter size (14 Fr)
  - high reinfusion pressure
  - increased incidence of hemolysis
  - limited flow rate
Advantages of VA Support

• Independent of cardiac function
• near 100% bypass may be achieved
• Improved oxygenation (up to 100% SaO2)
• Allows minimal positive pressure ventilation
• FIO2 may be decreased to 0.21
Disadvantages of VA Support

- Requires arterial cannulation
- Increased chance of embolism
- Carotid artery repair/ligation required
- Loss of pulsatile blood flow
- Loss of pulmonary blood flow
Advantages of Veno - venous Support

• Two separate venous cannulas
  – lower re-infusion pressures
• Maintains pulsatile blood flow
• Decreased risk of embolism
• Arterial system is not cannulated / repaired

• Easily converted to VA
Disadvantages of Veno - venous Support

- Dependent upon cardiac function
- SaO2 in mid 80’s
- May require increased ventilatory support
- May be some re-circulation
Sweep Flow

- Analogous to minute ventilation
- Increased sweep flow = increased CO2 removal
- Decreased sweep flow = decreased CO2 removal
- FIO2 set with blender
- May add carbogen (95/5)
Sweep Flow FIO2

\[
FIO2 = \frac{(\text{LPM} \times \text{FIO2}) + (\text{LPM} \times \text{FIO2})}{\text{Total Flow}}
\]

\[
FIO2 = \frac{(1.0 \text{ LPM} \times 0.6) + (0.5 \text{ LPM} \times 0.95)}{1.5 \text{ LPM}}
\]

\[
FIO2 = 0.71
\]
Maximum Sweep Flow

- Maximum flow of gas across membrane lung
- 3 x surface area of the lung
- Neonatal lung surface area = 0.8 meters
- Maximum sweep flow = 2.4 LPM
Gas Exchange During ECMO

• Gas diffuses across membrane
  – transfer from gas phase to blood phase
  – exchange results from pressure gradient

• Oxygenation exchange
  – gas phase PO2 = 760
  – blood phase PO2 = 40

• Carbon dioxide exchange
  – gas phase PCO2 = 0
  – blood phase PCO2 = 45
Oxygen Exchange

• Independent of sweep flow
• oxygen exchange is dependent upon:
  – O2 concentrations
  – membrane diffusion characteristics
  – blood path thickness
  – pump flow rate
  – membrane surface area
Carbon Dioxide Exchange

• Independent of blood flow
• carbon dioxide exchange is dependent upon:
  – gas diffusion gradient
  – sweep gas flow rate
  – membrane surface area
Factors Influencing Oxygenation

- VA ECMO
- Increased ECMO flow
- Decreased PA - LA flow
- Hemoglobin
- CaO2
Factors Influencing Oxygenation

- VV ECMO
- Increased ECMO flow without change in systemic flow
- Hb
- CaO2
- Cardiac output
Roller Pump vs Centrifugal Pump
Roller pumps

• Advantages
  – Constant flow by volume displacement
  – Lower hemolysis
  – Less effected by patient issues

• Disadvantages
  – Flow dependent on gravity
  – Risk of raceway rupture
  – Potential to be under occluded
Centrifugal Pump

- Unlike roller pumps, centrifugal pumps are non-occlusive.
- Pre-load and after-load dependent:
  - Flow is not determined by the rotational rate alone.
  - Flow meter must be attached after the outflow to determine flow.
Centrifugal Pump Concept

- Object spins in a fluid environment
- Area of low pressure is generated
- Fluid enters the pump at the center
- Fluid is dispersed to the periphery of the pump and exits the outflow to the circuit
Centrifugal Pump

• Cones are magnetically coupled with the motor
• As cone rotates a pressure differential results in the movement of blood
• Negative pressure at the inlet port pulls blood in
• Positive press at the outlet propels blood forward
Centrifugal Pumps

• Flow dependent on preload and afterload
  - Reduced volume status (hypovolemia)
    • same RPM = lower flow
  - Increased blood pressure (↑ afterload)
    • same RPM = lower flow
Preload

- Muscle length prior to contractility
- Dependent on ventricular filling
- End diastolic volume (EDV) - higher the EDV the higher the preload
- Determining factor - venous return
  - Atrial pressure is a surrogate
Preload

• Affected by
  – venous blood pressure
  – rate of venous return.

• Venous return
  – affected by venous tone
  – volume of circulating blood.
Afterload

• Tension (or the *arterial pressure*) against which the ventricle must contract.
  – arterial pressure increases, afterload also increases.

• Afterload for the left ventricle is determined by aortic pressure

• Afterload for the right ventricle is determined by pulmonary artery pressure
Afterload

• Affected by
  – MAP
  – SVR
  – “Cannula or circuit kink or clot”
Monitoring

- **Patient**
  - Hemodynamics and VS
  - ACT
- **Circuit**
  - Clotting
  - Pressure
    - Pre/post membrane
    - Bladder pressure
Maquet Cardiohelp

• Improved flow capability
• Less hemolysis
• Monitoring
• Simplicity
  – pump head
  – circuit
• Transport
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Unit</th>
<th>Value</th>
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<tbody>
<tr>
<td>(\dot{v})</td>
<td>lpm</td>
<td>4.25</td>
</tr>
<tr>
<td>(C)</td>
<td>rpm</td>
<td>3250</td>
</tr>
<tr>
<td>(p_{\text{Ven}})</td>
<td>mmHg</td>
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<tr>
<td>(p_{\text{Art}})</td>
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<td>(\Delta p)</td>
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</tr>
<tr>
<td>(T_{\text{Ven}})</td>
<td>°C</td>
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</tr>
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**CardioHelp**
HLS 5 Circuit Modified
Complications - Patient

- Bleeding (heparinization)
- Low flow – ↓ RPM, identify cause.
  - Most common, hypovolemic
  - Give volume quickly
- HIT
  - Activates platelets and causes thrombosis
  - Bilvalirudin
Complications - Circuit

- Circuit Disconnect
- Dislodged cannula

- Hemolysis
  - Decrease RPMs if able to reasonably support the patient at lower flows

- Clots

- Air in circuit

- Kink or malposition of tubing/cannula
  - Precautions to avoid kinks in circuit
  - Avoid bending leg or turning head if neck cannulation
  - Extreme caution with linen changes

- Circuit reaction
Weaning ECMO

• Why was patient placed on ECMO?

• What’s different now?
• Has original problem resolved?
• Are there complications indicating continued support?
• Do risks of ECMO outweigh benefits?
Weaning VA ECMO

• Wean pump flow
  – Decrease flow 10 to 30 ml/min
  – Wean to 25% predicted cardiac output

• PaCO2 will decrease due to increased blood to gas exposure time
• Maintain post membrane PaCO2 approx 40 mm Hg
• May require increased carbogen flow
Weaning VV ECMO

- Weaning pump flow does **not** alter PaCO2
- Decrease sweep flow 1/4 LPM at a time
- Clamp and circulate through bridge when sweep flow = 0
- Flush each cannula Q 5 min
- De-cannulate if stable
Thank You