Veno- arterial ECMO—
Focus on Cardiogenic Shock
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Executive Director of Florida Hospital CVI
Disclosures

- No relevant financial conflicts
- I will discuss the off-label use of oxygenators, pumps, and cannulas
Questions & learning objectives...ECLS & cardiogenic shock

What are the outcomes with current practice for patients with cardiogenic shock?

What are the physiological goals of ECLS in cardiogenic shock... what are the biological and clinical markers of success?

How does “emergent” ECLS in the patient with cardiogenic shock change the options and the risk profile of subsequent durable LVAD implantation and transplant?
46 y.o. presented with respiratory distress and inferior STEMI

Cath –RCA occlusion– underwent BMS with reperfusion, 100% circ and 90% ramus

IABP placed via L F

ECHO
Cath Lab Disasters

- VT/VF arrest
- E-CPR ECMO code activated
- VA ECMO initiated via RFV, RFA
- CTICU
  - Cooling protocol
  - Right leg ischemia—perfusion catheter placed
  - Minimal ejection, clot in LV
  - Anticoagulation—cath lab for impella placement to decompress LV
Cath Lab Emergencies

- Neuro intact/negative head CT
- Improved pulmonary edema/ improved organ function
- OR 2 days later—MVR, tricuspid annuloplasty, CABG X 3, open chest, Impella in place, ECMO decannulated
Cath Lab Emergencies

- Day 2, washout, Impella removal, chest closure, IABP placement, femoral artery repair
- Multiple complications
  - Delirium
  - Ileus
  - ARF
- D/C home POD 28, Cr 1.4 normal ambulation
Why talk about ECLS now?

- Dramatic increase in ECLS worldwide
- Labor and resource-intensive therapy that requires multidisciplinary approach
- Evolving technology with expanding indications and contraindications
- Certain Conditions such as Acute Respiratory Failure and Cardiogenic Shock persist with high mortality
Rapidly expanding ECLS utilization

ELSO International Registry Report

Centers by Year
Increase in ECLS utilization

- Increased indications
  - 2009 H1N1 pandemic
    - 12,000 deaths
    - 323 ECLS cases

- Durable LVADs
  - Destination therapy
  - Bridge to transplant
History of Extracorporeal Circulation

- Three major groups
  - Kobolow – NIH
  - Hill – UCSF
  - Bartlett – The Brigham, IC-Irvine, Michigan

- 1971 – 1\textsuperscript{st} adult survivor
- 1972 – 1\textsuperscript{st} pediatric survivor
- 1975 – 1\textsuperscript{st} neonatal survivor
Definition of Shock

• In 1852, shock was defined as “a rude unhinging of the machinery of life.” Probably no better definition exists to describe the devastating effects of this process on a patient, but a more recent definition calls shock “the collapse and progressive failure of the cardiovascular system.”

• Shock left untreated may be fatal. It must be recognized and treated immediately, or the patient will likely die.
Cardiogenic shock

Organ hypoperfusion caused by left ventricular, right ventricular or biventricular dysfunction

Clinical criteria
- Persistent hypotension
- Clinical signs of hypoperfusion
  - Cooled extremities
  - Decreased urine output
  - Altered mental status

Hemodynamic criteria
- Systolic blood pressure less than 80-90 mmHg or mean arterial pressure 30 mm lower than the baseline
- Cardiac index less than 1.8 L/m/m² or less than 2.0-2.2 L/m/m² with inotropic support
- Elevated filling pressures
  - LVEDP greater than 18 mmHg
  - RVEDP greater than 10-16 mmHg
Etiologies of CS

- **Pump Failure** (threat of failure)
  - Acute MI
  - Mechanical complications of Acute MI
    - Post-Infarct VSD
    - Ruptured Papillary Muscle
  - Massive PE
  - Decompensated Heart Failure
Cath lab Emergencies

- Outcomes with surgery for pump failure indications
  - Profound shock—40-60% mortality
  - Post infarct VSD—23-53% mortality
    - Lower mortality in patients who could tolerate delayed intervention
  - Ruptured papillary muscle—20-40% mortality
  - No significant changes in outcomes over the last 3 decades

- Mortality Etiology
  - MOSF
  - Neurologic
  - Sequela of persistent hypoperfusion—low cardiac output +/- impact of inotropic/vasoconstrictor agents
Cardiogenic Shock, Clinical Challenge

~7% of AMI’s Suffer Cardiogenic Shock

Mortality Remains ≥ 50% @ 6 months for Shock

~1M US Heart Attacks (AMI) / year

~70,000 US AMI Shock Patients / year

>30K AMI Shock Deaths / year

Goldberg et al. NEJM 1999; 340:1162
JAMA, Jul. 27, 2005; 294(4):448-54

Hochman, JAMA 285: 190, 2001
Hochman et al, NEJM 1999; 341:625-624
Mortality/Morbidity

- The historic mortality rates from cardiogenic shock are 80-90%; more recent studies have reported somewhat lower in-hospital mortality rates, in the range of 56-67%.
Prognosis of Patients with AHF admitted to the ICU

355 patients admitted to the CCU/ICU for acutely decompensate heart failure
Cardiogenic Shock Kills

Time trends in hospital case fatality rates (CFR) in patients with acute myocardial infarction ± cardiogenic shock in the Worcester (MA, USA) metropolitan area.
Why Change?

Because the tools we are using do not work.

Intra-aortic balloon pump

IABP – Shock II trial

Number at risk

<table>
<thead>
<tr>
<th>IABP</th>
<th>301</th>
<th>181</th>
<th>171</th>
<th>165</th>
<th>161</th>
<th>159</th>
<th>154</th>
<th>152</th>
<th>149</th>
<th>147</th>
<th>146</th>
<th>144</th>
<th>136</th>
<th>45</th>
<th>21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>299</td>
<td>174</td>
<td>166</td>
<td>165</td>
<td>159</td>
<td>154</td>
<td>154</td>
<td>152</td>
<td>147</td>
<td>147</td>
<td>146</td>
<td>144</td>
<td>140</td>
<td>55</td>
<td>29</td>
</tr>
</tbody>
</table>

Days after randomisation

Mortality (%)

40%

50%

p=0.94; log-rank test
Relative risk 1.02, 95% CI 0.88-1.39

12 month mortality
Current evidence from randomized clinical trials in cardiogenic shock in the era of percutaneous coronary intervention.

### Revascularization (PCI/CABG)

<table>
<thead>
<tr>
<th>Trial</th>
<th>Follow-up</th>
<th>n/N</th>
<th>Relative risk 95% CI</th>
<th>Relative risk 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHOCK</td>
<td>1-year</td>
<td>76/152</td>
<td>0.80 (0.66;0.98)</td>
<td>0.82 (0.70;0.98)</td>
</tr>
<tr>
<td>SMASH</td>
<td>30 days</td>
<td>22/32</td>
<td>0.87 (0.66;1.29)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>103/184</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Catecholamines

<table>
<thead>
<tr>
<th>Trial</th>
<th>Follow-up</th>
<th>n/N</th>
<th>Relative risk 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOAP II (CS subgroup)</td>
<td>28 days</td>
<td>64/145</td>
<td>0.75 (0.55;0.93)</td>
</tr>
</tbody>
</table>

### Glycoprotein IIb/IIIa inhibitors

<table>
<thead>
<tr>
<th>Trial</th>
<th>Follow-up</th>
<th>n/N</th>
<th>Relative risk 95% CI</th>
<th>Relative risk 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRAGUE-7</td>
<td>In-hospital</td>
<td>15/40</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### NO synthase inhibitors

<table>
<thead>
<tr>
<th>Trial</th>
<th>Follow-up</th>
<th>n/N</th>
<th>Relative risk 95% CI</th>
<th>Relative risk 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRIUMPH</td>
<td>30 days</td>
<td>97/201</td>
<td>1.14 (0.91;1.45)</td>
<td>1.05 (0.85;1.29)</td>
</tr>
<tr>
<td>SHOCK-2</td>
<td>30 days</td>
<td>24/59</td>
<td>1.16 (0.59;2.69)</td>
<td></td>
</tr>
<tr>
<td>Cotter et al.</td>
<td>30 days</td>
<td>4/15</td>
<td>0.40 (0.13;1.05)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>125/275</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### IABP

<table>
<thead>
<tr>
<th>Trial</th>
<th>Follow-up</th>
<th>n/N</th>
<th>Relative risk 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>IABP-SHOCK I</td>
<td>30 days</td>
<td>7/19</td>
<td>1.28 (0.45;3.72)</td>
</tr>
</tbody>
</table>

### LVAD

<table>
<thead>
<tr>
<th>Trial</th>
<th>Follow-up</th>
<th>n/N</th>
<th>Relative risk 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thiele et al.</td>
<td>30 days</td>
<td>9/21</td>
<td>0.95 (0.48;1.90)</td>
</tr>
<tr>
<td>Burkhoff et al.</td>
<td>30 days</td>
<td>9/19</td>
<td>1.33 (0.57–3.10)</td>
</tr>
<tr>
<td>Seyfarth et al.</td>
<td>30 days</td>
<td>6/13</td>
<td>1.00 (0.44–2.29)</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>24/53</td>
<td>1.06 (0.68–1.66)</td>
</tr>
</tbody>
</table>

Holger Thiele et al. Eur Heart J 2010;eurheartj.ehq220

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Therapies

Coronary revascularization
Vasopressor and inotropic therapy
Mechanical circulatory support
Early Revascularization in Acute Myocardial Infarction Complicated by Cardiogenic Shock

Overall 30-Day Survival in the Study

- Revascularization (n = 152)
  - Survival = 53%

- Medical therapy (n = 150)
  - Survival = 44%

p = 0.11

SHOCK Trial Mortality

30 days: P = 0.11
6 months: P = 0.027
1 year: P < 0.03

Revasc Med Rx

Society of Critical Care Medicine
The Intensive Care Professionals
Figure 5. Long-term follow-up of the SHOCK trial cohort. Early revascularization (ERV) is associated with sustained benefit.
TIMELINESS

Sometimes late isn't better than never.
Evolution of Shock from AMI

Frequently, shock develops after presentation for myocardial infarction.

- **SHOCK Registry**
  - At presentation: 25% in shock
  - Within 24 hours: 75%
    (median delay = 7 hours)

- **GUSTO Trial**
  - At presentation: 11% in shock
  - After admission: 89%

*GUSTO J Amer Coll Cardiol. 1995;26:668-74*
Figure 1. Current concept of CS pathophysiology.
Patients with ST segment elevation MI who have cardiogenic shock and are less than 75 years of age should be brought immediately or secondarily transferred to facilities capable of cardiac catheterization and rapid revascularization (PCI or CABG) if it can be performed within 18 hours of onset of shock. (Level of Evidence: A)
National Registry of MI Early Revascularization is Underutilized in Cardiogenic Shock

Despite ACC/AHA recommendation to treat patients < 75 years of age aggressively with early mechanical revascularization, in 2001, two years after the guidelines were published, only 41% of patients with cardiogenic shock complicating AMI were treated with primary PTCA and only 3.1% underwent early CABG.

These data demonstrate significant underutilization of guideline recommended therapy.

6. Coronary Artery Bypass Graft Surgery: Recommendations

6.1. CABG in Patients With STEMI

**Class I**

Urgent CABG is indicated in patients with STEMI and coronary anatomy not amenable to PCI who have ongoing or recurrent ischemia, cardiogenic shock, severe HF, or other high-risk features.\(^{150-152}\) (Level of Evidence: B)

CABG is recommended in patients with STEMI at time of operative repair of mechanical defects.\(^{153-157}\) (Level of Evidence: B)

**Class IIa**

The use of mechanical circulatory support is reasonable in patients with STEMI who are hemodynamically unstable and require urgent CABG. (Level of Evidence: C)

**Class IIb**

Emergency CABG within 6 hours of symptom onset may be considered in patients with STEMI who do not have cardiogenic shock and are not candidates for PCI or fibrinolytic therapy. (Level of Evidence: C)
Differentiating Shock vs HF

- Cardiogenic Shock
  - High CVP
  - Low CI
  - High SVRI
  - Low VO2

- Heart Failure
  - High CVP
  - Low CI
  - High SVRI
  - Normal VO2
Ideal Goals of Cardiac Support

Common Themes

Ideal Cardiac Support
Safe, Simple Use
Systemic Hemodynamic Support
Myocardial Protection

Prophylactic
Reperfuse the body quickly (EASE)
Save the heart (decompress)

Emergent
Decompressing the LV is the cornerstone of recovery
Ventricular Unloading

- Direct Ventricular Unloading
- Reduces wall tension and myocardial \( \text{O}_2 \) demand\(^{1-6}\)
- Increases \( \text{O}_2 \) supply\(^{6,10}\)
- Reduces inotrope dependence\(^7\)

2. Dixon et al, JACC, 2009
4. Valgimigli et al, Cath Cardio Interventions, 2005
5. Reesink et al., CHEST, 2004
6. Sauren et al., Artificial Organs, 2007
7. Recover I Trial Summary, 2008 TCT; N=17
8. Kawashima, D, et.al., ASAIO, 2010
10. Remmelink, Cath Cardio Interventions, 2007
<table>
<thead>
<tr>
<th>Table 2 Comparison of devices</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IABP</strong></td>
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<tr>
<td>---</td>
</tr>
<tr>
<td>Pump mechanism</td>
</tr>
<tr>
<td>Cannula size</td>
</tr>
<tr>
<td>Insertion technique</td>
</tr>
<tr>
<td>Haemodynamic support</td>
</tr>
<tr>
<td>Implantation time</td>
</tr>
<tr>
<td>Risk of limb ischaemia</td>
</tr>
<tr>
<td>Anticoagulation</td>
</tr>
<tr>
<td>Haemolysis</td>
</tr>
<tr>
<td>Post-implantation management complexity</td>
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<tr>
<td>Optional active cooling in post-cardiopulmonary resuscitation patients</td>
</tr>
</tbody>
</table>

ECMO, extracorporeal membrane oxygenation; IABP, intra-aortic balloon pump; +, ++, ++++, ++++, relative quantitative grading concerning time (implantation time), risk (risk of limb ischaemia), intensity (anticoagulation), post-implantation management complexity, and severity (haemolysis). Modified from Ouwee and Henriques.¹⁶
Table 5  Meta-analysis of RCTs: effects of left ventricular assist devices—TandemHeart\textsuperscript{55,56} and Impella PL2.5 pump\textsuperscript{63}—in comparison with the effects of IABP on haemodynamics; 30-day-mortality and adverse events in patients with cardiogenic shock, mainly due to myocardial infarction

<table>
<thead>
<tr>
<th></th>
<th>Thiele et al.\textsuperscript{55}</th>
<th>Burkhoff et al.\textsuperscript{56}</th>
<th>Seyfarth et al.\textsuperscript{63}</th>
<th>Pooled (fixed effect model) Mean difference/relative risk</th>
<th>P-value</th>
<th>Pooled (random effects model) Mean difference/relative risk</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LVAD  (n = 21) IABP  (n = 20)</td>
<td>LVAD  (n = 19) IABP  (n = 14)</td>
<td>LVAD  (n = 13) IABP  (n = 13)</td>
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<tr>
<td><strong>Haemodynamics</strong></td>
<td></td>
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</tr>
<tr>
<td>Cl $\pm$ SD ($\text{L min}^{-1} \text{ m}^{-2}$)</td>
<td>23 ± 0.6</td>
<td>1.8 ± 0.4</td>
<td>2.2 ± 0.6</td>
<td>2.1 ± 0.2</td>
<td>22 ± 0.6</td>
<td>1.8 ± 0.7</td>
<td>0.35 (0.14; 0.55)</td>
</tr>
<tr>
<td>MAP $\pm$ SD (mmHg)</td>
<td>76 ± 10</td>
<td>70 ± 16</td>
<td>91 ± 16</td>
<td>72 ± 12</td>
<td>87 ± 18</td>
<td>71 ± 22</td>
<td>12.1 (6.3; 17.9)</td>
</tr>
<tr>
<td>PCWP $\pm$ SD (mmHg)</td>
<td>16 ± 5</td>
<td>22 ± 7</td>
<td>16 ± 4</td>
<td>25 ± 3</td>
<td>19 ± 5</td>
<td>20 ± 6</td>
<td>−6.2 (−8.0; −4.3)</td>
</tr>
<tr>
<td><strong>Clinical outcome</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30-day mortality, n (%)</td>
<td>9 (43)</td>
<td>9 (45)</td>
<td>9 (47)</td>
<td>5 (36)</td>
<td>6 (46)</td>
<td>6 (46)</td>
<td>1.06 (0.68; 1.66)</td>
</tr>
<tr>
<td><strong>Reported adverse events</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leg ischaemia, n (%)</td>
<td>7 (33)</td>
<td>0 (0)</td>
<td>4 (21)</td>
<td>2 (14)</td>
<td>1 (8)</td>
<td>0 (0)</td>
<td>2.59 (0.75; 8.97)</td>
</tr>
<tr>
<td>Bleeding, n (%)</td>
<td>19 (90)</td>
<td>8 (40)</td>
<td>8 (42)</td>
<td>2 (14)</td>
<td></td>
<td></td>
<td>2.35 (1.40; 3.93)</td>
</tr>
<tr>
<td>Fever of sepsis, n (%)</td>
<td>17 (81)</td>
<td>10 (50)</td>
<td>4 (21)</td>
<td>5 (36)</td>
<td></td>
<td></td>
<td>1.38 (0.88; 2.15)</td>
</tr>
</tbody>
</table>

Cl, cardiac index; IABP, intra-aortic balloon pump; LVAD, left ventricular assist device; MAP, mean arterial pressure; PCWP, pulmonary capillary wedge pressure. From Cheng et al.\textsuperscript{60} For details on the statistical analysis please refer to the original publication.
“ECMO in advanced refractory AMI-CS is associated with acceptable outcomes in a well-selected population.

ECMO in patients with an acute decompensation of a chronic cardiomyopathy should be carefully considered to avoid futile support.”

Kaplan-Meier survival curve of all patients supported on ECMO for cardiogenic shock (subsequent management strategies included revascularization, VAD, or heart transplantation)

Use of ECMO to reduce Mortality

Schematic presentation of the enrollment status of the patients. ECMO, extracorporeal membrane oxygenator. * vs. †, p = .347;

Early extracorporeal membrane oxygenator-assisted primary percutaneous coronary intervention improved 30-day clinical outcomes in patients with ST-segment elevation myocardial infarction complicated with profound cardiogenic shock
Cannulation and initiation of flow ... vascular access, gas exchange, and flow

Do what you need to get what you want ... perfusion w/o ischemia
adequate hemodynamics
“viable patient”

Engineering should inform the discussion around patient care ...

“Thought algorithms” vs “protocols”

ECMO: simple operation, complex procedure
“Truisms” about ECLS/ECMO ...

ECMO resuscitates the moribound ... it cannot reanimate the dead ... question of patient viability or myocardial recovery

ECMO remains a non-durable technology ...

ECLS is a simple procedure, extracorporeal technologies are a complex management paradigm

ECLS accomplishes nothing (it is non-therapeutic), but facilitates everything
Patient Selection - Exit Strategy

- Bridge to Recovery
- Bridge to Transplant
- Bridge to VAD

Exclusion Criterion
- Permanent end organ dysfunction
- Advanced age
- Aortic insufficiency
- Out of hospital arrest
The 30-day mortality rate in patients with witnessed OHCA undergoing ECLS treatment can be significantly improved if ECLS support is established within the first 30 min after admission ...rdECMO

Basic ECMO...
Cannulation...clinical need determines strategy

- Femoral vein to IJ (traditional VV)
- Femoral vein to femoral artery (traditional VA)
- Femoral vein and RIJ to femoral artery (VVA)
- RIJ dual lumen and subclavian artery ("walking hybrid")
- RA to Ao (central VA). "ambulatory CPB" (VAD)
- RA to PA...right heart bypass (VAD)
- PA to LA...right heart bypass (VAD)
- RIJ dual lumen cannula (VV Avalon DLC)
- RIJ dual lumen and femoral artery (VVA "sedate hybrid")
- Femoral artery to RA (AV) ...reverse "pumpless" arterio-venous cannulation (pECLA)

Membrane oxygenator (Quadrox)

Centrifugal blood pump (Centrimag or Rotaflow), roller pump, or "native flow" (cardiac output)

Anticoagulation (heparin ACT "point of care", TEG)

Personnel (MCS service line or ECMO specialists)
Cardiopulmonary collapse (circulatory arrest)

\[ \text{CPR} \]

“salvage” ECLS

“moratorium of decision” ... end organ injury

“bridge to recovery” ... myocardial injury

“bridge to definitive therapy” ... non-durable to durable support

“emergent” ECLS

Cardiogenic shock (INTERMACs I)
Cannulation ...

Peripheral veno-arterial ECLS

RA/femoral vein...retrograde femoral a. (ECMO)
RA...antegrade right subclavian a. (8mm Dacron graft/ECMO)
LA/femoral trans-septal ...retrograde femoral a.

Central veno-arterial ECLS

RA to pulmonary a. (right heart)
LA to aorta (VAD)
RA to aorta (ECMO)

(...application and deployment)
Femoral cannulation for veno-arterial (VA) ECMO...

RA/IVC drainage from CFV access (23/25F)...
venous return limits flow

Arterial inflow (17F) ... “downsize”

Distal arterial inflow (6F) ... “downsize”

...“open” versus “percutaneous” access?
*no complications
*exit strategy
Retrograde arterial flow ... LVEF and cerebral perfusion, LVEDP!

Distal malperfusion ...

The patient ... sedate and non-ambulatory

Blood path and directional flow ...
Determine blood flow requirements ...

<table>
<thead>
<tr>
<th>Age</th>
<th>Flow Rate (mL/min/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neonate</td>
<td>100 to 150</td>
</tr>
<tr>
<td>Pediatric</td>
<td>75 to 120</td>
</tr>
<tr>
<td>Adult</td>
<td>50 to 80</td>
</tr>
</tbody>
</table>

**Assumptions:** “flow is laminar viscous and incompressible ... and the flow is through a constant circular cross-section ...”

**In reality:**
Flow is rarely laminar ... 
Hct and temp affect viscosity ... 
The cross sectional area is a composite of fixed (cannula) and variable (vessels) components
...standardized system to describe the pressure-flow characteristics of a given cannula ... if specific flows are needed to support a given patient, an arterial and venous cannula of an adequate M-number can be chosen from a given nomogram that will support flow at acceptable pressures.
Cannulation ...

16F (5.3mm)
18F (6.0mm)
20F (6.7mm)
22F (7.3mm)
18F (6.0mm)
20F (6.7mm)
22F (7.3mm)
24F (8.0mm)
28F (9.3mm)

55 cm (21.6”)
68 cm (26.8”)
Femoral VA ECMO … low EF

non-physiological: retrograde blood path with limited pulmonary blood flow (oxygenator)

decreased LV pre-load … myocardial recovery

increased LVEDP … capillary leak and acute lung injury

gas exchange … membrane oxygenator

cannulation … limb ischemia

This is not cardiopulmonary bypass … there is no venous reservoir
VA ECLS - Advantages

- Bedside/ICU/Cath lab deployment
- Inexpensive (relative to VAD/Impella)
- Minimally invasive (peripheral cannulation)
- Biventricular support
- Respiratory/Gas Exchange Support
VA-ECLS - Disadvantages

- Labor intensive
  - Close PTT monitoring
  - Continuous bedside equipment monitoring
- Patient potentially immobilized
- LV distension
  - Limits LV recovery
  - Pulmonary Edema/Injury
- Higher risk of stroke
- Limb ischemia with Fem-Fem cannulation
  - 5 Fr cannula in SFA
Cardiac/Cerebral Hypoxia

- Fem-Fem VA ECLS
- LV Ejection in the setting of pulmonary failure
- Hypoxic blood perfusion of Coronary vessels and carotids

- Monitor Right Arm sPO2 and ABG to best approximate coronary blood flow oxygenation
- Improve RV drainage (with larger/more venous cannula)
- LV Venting
VA ECMO is not CPB ... any decrease in pre-load is at the expense of increased afterload

Left ventricular stasis ... elevated LVEDP with pulmonary edema and LV thrombus

Vent, apical cannulation, septostomy, anticoagulation, or.. “hybrid procedure” ... VA ECMO and antegrade technology

Importance of Obtaining an ECHO to guide interventions
Femoral VA ECMO ... with myocardial recovery

limited retrograde blood path with significant pulmonary blood flow (oxygenator)

increased LV pre-load ... myocardial recovery

decreased LVEDP ... no lung injury

gas exchange ... mixed ... membrane oxygenator and lungs

cannulation ... lower limb ischemia
Cannulation strategy

- Traditionally femoral arterial access
  - 10-16% complication rate (primarily limb ischemia)\(^1\)

- Subclavian arterial cannulation as alternative
  - Offers mobility, root and brain perfusion
  - Also has 15% complication rate\(^2\)
    - Bleeding, hematoma, arm hyperperfusion, Venous hypertension and arm swelling

RIJ-subclavian VA ECMO

antegrade blood path with significant pulmonary blood flow (oxygenator)

increased LV pre-load ... myocardial recovery

decreased LVEDP ...

gas exchange ... mixed ...membrane oxygenator and lungs

cannulation ... upper limb ischemia or over-perfusion syndrome
Subclavian Artery Cannulation for Venoarterial Extracorporeal Membrane Oxygenation.
Javidfar, Jeffrey; Brodie, Daniel; Costa, Joseph; Miller, Joanna; Jurrado, Julissa; LaVelle, Matthew; Newmark, Alexis; Takayama, Hiroo; Sonett, Joshua; Bacchetta, Matthew

RIJ dual lumen VV-subclavian Arterial ECMO ... hybrid ECMO (venoveno-arterial)

antegrade flow ... mixed cardiopulmonary disease

“hybrid” VVA, or full VV, or full VA support technology ... not salvage

ambulatory

Brodie and Bacchetta (2011) NEJM
Cannulation ...

**Peripheral veno-arterial ECLS**

RA/femoral vein...retrograde femoral a. (ECMO)
RA...antegrade right subclavian a. (8mm Dacron graft/ECMO)
LA/femoral trans-septal ...retrograde femoral a.

**Central veno-arterial ECLS**

RA to pulmonary a. (right heart)
LA to aorta (VAD)
RA to aorta (ECMO)

(...application and deployment)
Central cannulation ...
Central cannulation ...
Mini-thoracotomy Cannulation

- To date, 8 patients
  - 4 deaths
    - All emergent cannulation, no neuro recovery
  - 4 alive
    - All 4 ambulated on ECLS
    - 3 bridge to durable LVAD (1 subsequently transplanted)
    - 1 bridge to recovery
ECMO Complications
CHECKING FOR THROMBUS FORMATION
Clotted Oxygenator
Kinked Venous Line
Impaired Circulation
Clotted Peripheral Arterial Cannulation Site
POSSIBLE ECMO ISSUES

- Elevated Free Hgb (>0.1g/dL)/ Elevated LDH (>600U/L)
- Access Insufficiency
- Bleeding at Cannulation Site
- Pump Failure
- Dislodged Cannulation Site
- Cardiac Arrest/CPR
Elevated Free Hgb (>0.1g/dL)/ Elevated LDH (>600U/L)

- Intravascular hemolysis
- Noisy pump head (possible thrombosis)
- Visible access insufficiency (line chatter/kicking/chugging)

- Identify specimens sent to main lab as ecmo patient due to frequent hemolysis issues.
Access Insufficiency

- Visible access insufficiency (line chatter, kicking, chugging)
- Access insufficiency without visible manifestations (Suction Events)

**Causes**
- Hypovolemia
- Cardiac Tamponade
- Pump Speed too high (RPM setting)
- Pt coughing or straining
- Positional (Turning, head position with IJ cannulation)
- Acute vasodilation (Sedation Bolus)
- Severe aortic regurgitation or severe pulmonary hemorrhage (VA ecmo)
IVC CHATTER
Bleeding at Cannulation Site

- Visible blood loss at cannulation site
- Ecchymosis & edema at insertion site
- Sudden drop in H&H

Management
- Thrombotic Dressings (Surgicell)
- Pressure at site
- Cessation of anticoagulation (Heparin)
- Repair & re-cannulation
- Correct bleeding causes
  - Plt, Cryoprecipitate, FFP, Protamine
Pump Failure

- Catastrophic loss of power
- Electrical motor failure
- Pump head/centrifugal pump disengaged

Management
- Clamp circuit & Call for help
- Address cause & re-establish pump function or change console
- Engage Emergency Drive Unit (Hand Crank)
Cannulation and initiation ... ten general rules and painful lessons

1. re-think “application” ... why am I doing this and what do I hope to accomplish

2. re-think “deployment” ... “this” cannulation strategy ... “now?”

3. Got heparin? (0.5 mg/kg) ... plan an anticoagulation strategy

4. Crystalloid prime ... or colloid prime (FFP)

5. Look at your lines ... air, clamps, length, and entry points

6. Come up slowing ... establish flow, then increase flow

7. Remember the patient ... inotropes and airway (minute ventilation is 15L/min ... sweep is 10L ...!!!)

8. Most disasters happen five minutes after the celebration begins .. This is a human endeavor

9. Any surgical bleeding is unacceptable

10. Have an exit strategy
- Exit Strategy

- Bridge to Recovery
- Bridge to Transplant
- *Bridge to VAD*

- Exclusion Criterion
  - Permanent end organ dysfunction
  - Advanced age
  - Aortic insufficiency
  - Out of hospital arrest
... mortality assessment of pre-operative risk factors that might serve as targets for goal-directed interventions meant to improve LVAD candidate survival (age, albumin, renal and hepatic insufficiency, center experience)

“... preserved end-organ function, however preoperatively achieved, might be the most important predictor of successful LVAD outcome.”

Low risk < 1.58
Medium risk: 1.58 to 2.48
High risk > 2.48

Can pre-operative ECMO alter the patient risk profile of LVAD implantation …

Or does it simply make the numbers better… with the additional morbidity of a pre-implant procedure?
The Right Ventricular Failure Risk Score (RVFRS): A pre-operative tool for assessing the risk of right ventricular failure in left ventricular assist device candidates

Vasopressor requirement (4)
AST > 80 (2)
Bilirubin > 2 (2.5)
Cr > 2.3 (3)

Low risk (OR 0.5) RVFRS < 3 (90% six mo survival)
High risk (OR 7.6) RVFRS > 5.5 (66% six mo survival)

Pre ECMO RVFRS score ... 11.5
Post ECMO RVFRS score ... 2.5

Can pre-operative ECMO convert a patient at high risk for biventricular support into a “conventional” LVAD recipient?

ECLS and cardiogenic shock...

Deployment of ECMO technologies in the context of medical futility generally results in futile deployment of technology...it is rarely “the device”

ECMO technology generally restores physiology but may not alter survival depending upon the specifics of deployment

ECMO can support patients awaiting good clinical decision making ... it is ineffective in supporting bad clinical decisions
Cath Lab Disasters—shift the focus from getting to the OR quickly to establishing adequate perfusion

- Focus on hemodynamic status
  - CPR/arrest
  - Shock
  - *Stable/ mild hypoperfusion*

- Candidacy Assessment-- Would they have been a candidate for intervention in an elective situation??
  - Life expectancy
  - Baseline function

- Organ Function
  - Neurologic
  - Cardiac (ventricular function)
  - Pulmonary
  - Renal
  - Hepatic
eCPR Patient Selection - Exit Strategy

- Bridge to Recovery
- *Bridge to Transplant*
- Bridge to VAD

Exclusion Criterion
- Permanent end organ dysfunction
- Advanced age
- Aortic insufficiency
- Out of hospital arrest
Case Report

- 57 yo male with HTN, CRI presents with 3 days of worsening chest pain
- Admitted from ED with positive enzymes and pulmonary edema
- Cath reveals RCA occlusion and posterior VSD, LVEF 35%.
- Intubated and IABP for shock
Case Report

- Underwent attempt surgical repair
- Recurrent edema and shock with TEE demonstrating repair breakdown
- Reoperation with second attempted repair
- Recurrent VSD necessitating VA ECMO with central cannulation
HVAD sewing rings attached at mitral and tricuspid annuli
Total Artificial Heart
Two HVAD devices