Cardiogenic Shock: Mechanical Management

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Disclosures

• Speakers’ Bureau
  — Novartis
• May discuss investigational products or off-label use

Objectives

• Review etiology and pathophysiology of shock; specifically differentiating cardiogenic shock from other types
• Describe mechanical treatment options for cardiogenic shock
• Cases of cardiogenic shock treated with mechanical support
What is Shock?

• Circulatory shock - a condition where there is low perfusion to the tissues causing organ damage
  – Definition does not specify the cause of low perfusion

Shock Pathophysiology

Something

Low Perfusion

- Metabolic acidosis
- Endothelial dysfunction
- Cellular injury
- Cell death

Shock Pathophysiology

Something

Low Perfusion

Pressors
Inotropes
Fluids
Bicarbonate
Calcium

- Metabolic acidosis
- Endothelial dysfunction
- Cellular injury
- Cell death
Shock Pathophysiology

- Low Perfusion
  - Metabolic acidosis
  - Endothelial dysfunction
  - Cellular injury
  - Cell death

Pressors
Inotropes
Fluids
Bicarbonate
Calcium

Types of Shock

- Hypovolemic
- Distributive
  - Septic
  - Neurogenic
- Cardiogenic
- Other
  - Acute RV failure, tamponade

Common Features

- Acute presentation
  - Ill-appearing patient
  - Rapid deterioration
- Hypotension is common though the absence of hypotension should not rule out shock
- End organ damage (rising creatinine, elevated liver enzymes, altered mentation)
- Poor perfusion → anaerobic metabolism
  → lactic acidosis
Distinguishing Types of Shock

Identify Shock Patient

Pure Hypovolemic Shock

Other Shock

- Bleeding, decreased PO intake, diarrhea, vomiting
- Dry mucous membranes
- Normal BNP
- Normal CXR

Hypovolemic

Assess Volume Status

- History
- Physical exam
- Labs (CBC, chemistry, BNP, chest X-Ray)

Distributive Shock

- Triggered by infection, CNS injury, endocrine derangement, anaphylaxis
- High cardiac output
- Excess of inflammatory agents (cytokines)

Cardiogenic Shock

- Commonly a history of heart failure or cardiac disease
- Severe decompensated heart failure

Treatment

- Correct the underlying reason for volume loss
- IV fluids, blood product transfusion

Distinguishing Types of Shock

Identify Shock Patient

Pure Hypovolemic Shock

Other Shock

Distributive Shock

Cardiogenic Shock

- Commonly a history of heart failure or cardiac disease
- Severe decompensated heart failure – pump failure
Septic vs. Cardiogenic Shock

**Septic History/Physical**
- Infectious symptoms
  - Site specific infection symptoms (abscess, cellulitis, urine symptoms, productive cough)
  - "Pink" warm to touch, neck veins flat or not elevated
- SIRS (systemic inflammatory response syndrome) criteria
  - T >38°C (100.4°F) or <36°C (96.8°F)
  - HR >90
  - RR > 20 breaths/minute
  - Leukocytosis – WBC >12K/microliter or bands present

**Cardiogenic History/Physical**
- Congestive symptoms
  - Orthopnea, edema, weight gain, increased abdominal girth
  - Hypotension, tachycardia, narrow pulse pressure
  - Elevated jugular venous pulse, hepatojugular reflux
  - Cool to touch, mottled extremities, poor cap refill
  - Thready pulses
  - S3
  - Crackles/dullness at lung bases

**Septic vs. Cardiogenic Shock**

**Septic Lab/Studies**
- Leukocytosis
- Elevated procalcitonin
- Positive cultures
- Elevated AST/ALT
- Normal BNP
- CXR normal or ARDS

**Cardiogenic Lab/Studies**
- Elevated BNP
- Mildly elevated troponin
- Hyponatremia
- CXR with pulmonary congestion, pleural effusions

**Echocardiography**
- Echo with hyperdynamic findings
- Echo of HFrEF
Evolution of Cardiogenic Shock

**INSULT**

- Systemic Blood Pressure ↑
- Cardiac Output ↓
- Cardiac Output < BP ↓
- Renin-Angiotensin System ↑
  - ADH/Vasopressin ↑
  - Aldosterone ↑
- Sympathetic nervous system ↑
  - Contractility ↑
  - Heart Rate ↑
- Ventricular Mass ↑
  - Myocyte hypertrophy
  - Dilation
  - Increased wall stress
- Ventricular End Diastolic Volume ↑
- Increase in intracardiac pressures
- SVR ↑
- Cardiac Output ↓

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Diagnostic Pitfalls

- Patients do not always “read the book”
- If hypovolemic shock is not improving despite adequate volume resuscitation, reconsider assessment
- SIRS criteria are not specific
  - Cardiogenic shock patients frequently trigger the SIRS criteria protocol in my institution
- Patients can have more than one kind of shock
  - Infection may trigger cardiogenic shock in a stable heart failure patient
  - Advanced cardiogenic shock can look like distributive shock
- Physical exam can be misleading

Pulmonary Artery Catheter

Hemodynamics:
- Pressures measurements
  - Right atrial
  - Right ventricular
  - Pulmonary artery
  - Pulmonary capillary wedge
- Mixed venous blood sampling
- Fick cardiac output (CO)
- Temperature sensor
  - Thermodilution CO

Derived Calculations:
- Systemic Vascular Resistance (SVR)
- Pulmonary Vascular Resistance (PVR)
- Transpulmonary gradient (TPG)

Measurements Related to Shock

- Volume assessment
  - Right atrial pressure (RAP)
  - Pulmonary capillary wedge pressure (PCWP)
- Cardiac output/Cardiac Index
- Vasoconstriction or vasodilation
  - Systemic blood pressure, mean arterial pressure (MAP)
  - Systemic vascular resistance (SVR)
    - SVR = (MAP – RAP)/CO
Hemodynamics of Shock

<table>
<thead>
<tr>
<th></th>
<th>RA</th>
<th>PCWP</th>
<th>Cardiac Index</th>
<th>SVR</th>
</tr>
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<tbody>
<tr>
<td>Normal Range</td>
<td>(2-6)</td>
<td>(6-12)</td>
<td>(2.5-4)</td>
<td>(800-1200)</td>
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<tr>
<td>Hypovolemic</td>
<td>Low</td>
<td>Low</td>
<td>Normal to high</td>
<td>Normal to high</td>
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<tr>
<td>Distributive</td>
<td>Low to normal</td>
<td>Low to normal</td>
<td>High</td>
<td>Low</td>
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<tr>
<td>Cardiogenic (left heart)</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Cardiogenic (isolated right heart)</td>
<td>High</td>
<td>Low to normal</td>
<td>Low</td>
<td>Normal to high</td>
</tr>
</tbody>
</table>

Approach to Cardiogenic Shock

- Assess and confirm clinical picture
- History and physical congruent with typical cardiogenic shock → Initiate treatment
- Central line and arterial line
- Foley catheter to monitor urine output
- History and physical equivocal → Consider right heart catheterization
  - If low CI, consider retaining the catheter

Treat the Hemodynamics

- Low cardiac output → IV Inotropes
  - Dobutamine, Milrinone, lower doses of dopamine
- High SVR → Vasodilators
  - Nitroglycerin, nitroprusside, hydralazine, ACE inhibitors/angiotensin receptor blockers
- High filling pressures → Diuretics, mechanical volume removal
Medically Refractory Cardiogenic Shock

- Clinically
  - Cardiac Index ≤ 1.8
  - Escalating doses of inotropes and diuretics
    - Tachyphylaxis to inotropes
    - Diuretic resistance
  - Decreased urine output
  - Hypotension
  - Lactic acidosis
  - Increased arrhythmias
  - Increasing liver enzymes

Refractory Cardiogenic Shock

- Patients with advanced heart failure may have limited physiologic reserve
- Progress to multi-organ dysfunction syndrome (MODS) despite optimal medical management

Shock Pathophysiology

- PUMP FAILURE
  - Low Perfusion
  - Pressors
  - Inotropes
  - Fluids
  - Bicarbonate
  - Calcium
- Metabolic acidosis
- Endothelial dysfunction
- Cellular injury
- Cell death
Helping the Pump

- Many devices available and being developed to augment or replace circulation
  - Percutaneous devices
  - External pumps
    - Peripheral cannulation
    - Central cannulation
  - Durable implantable pumps
    - Left ventricular assist devices
    - Total artificial heart

Treatments for acute shock

Treatments for relatively stable patients

Intra-Aortic Balloon Pump (IABP)

- Gated to the cardiac cycle
- Inflates in diastole
- Deflates in systole
  - Lowers afterload

IABP

- Easily placed in a cardiac catheterization lab
  - Low profile – 8 F sheath
- Commonly used for heart failure after acute MI
- Can be used for cardiogenic shock without new ischemic injury
  - Very modest augmentation of CO
  - Lowers SVR
  - Particularly useful if severe MR
- Do not use if significant aortic insufficiency
- Tachyarrhythmias limit effect
AMI Case

- 44 year old man experiences out of hospital arrest, brought into ER under CPR
- Initial rhythm is VF
- ACLS protocol -> successful cardioversion
- EKG shows ST elevation across precordial and lateral leads
- He had chest pain earlier that day and was seen at another ER and discharged
- Cath team is activated
- 100% occlusion of his midLAD
- LVEF 40%
- RA 15
- PCWP 19
- CO/CI 4.22/1.94
- BP 136/90 (mean 108)
- SVR 1763
- Trop >50 CK 2925

AMI Case

- Clinical course
  - Nitroprusside gtt started
  - Percutaneous intervention in the cath lab
    - Stent to mid LAD with good angiographic result
  - IABP placed
  - Nitroprusside weaned
  - Patient transferred to ICU on low dose dopamine
- Good neurologic recovery
- LVEF recovered to 55%
- Back to work 6 months later as a police officer

Temporary Ventricular Assist Device (VAD)

- Tandem Heart
- Impella
  - Left sided VAD
- HeartMate PHP
  - Investigational in U.S.
- Centrimag
- CardioHelp
- Work independent of rhythm
- Mechanically circulation blood
  - All devices now are continuous flow
Tandem Heart

• 21 Fr inflow cannula
  – Venous access to LA by transseptal puncture
• 15/17 Fr arterial cannula in the femoral artery
• 4L/min flow
• Up to 14 days of use
• Pump is external
  – Centrifugal flow

Tandem Heart Limitations

• Large cannula
  – Access complications
    • Limb ischemia
• Transseptal puncture
  – Uncommon procedure in cath lab compared to femoral access
  – Possible tamponade

Impella LVAD

• Axial flow, small pump
  – 2.5
  – CP
  – 5.0 (surgically placed)
    • Femoral
    • Axillary
• Contraindicated
  – LV thrombus
  – Severe AS
Impella Limitations

- Data is for short term support
  - Assisted percutaneous interventions
  - Assisted ventricular arrhythmia ablation
- Original FDA approval was for 6 hours of use
  - ≤ 4 days for CP
  - ≤ 6 days for 5.0 *
- Complications include access issues, hemolysis, pump failure, pump migration
- Femoral access site limits mobility
  *OFF-LABEL use does occur. UC Davis record is >60 days on Impella 5.0

Axillary Impella Placement

- Surgical implant
- Position more stable
- Allows for ambulation

AF CASE

- 41 yo man with a history of AFib presents with fatigue, edema, shortness of breath
- Palpitations X weeks
- EKG shows AF with RVR
- BP 120/70 HR 150s
- Echo LVEF 10%, LVEDD 5.4 cm
- Cath: normal coronaries
- Attempts to start medications for rate control cause worsening hypotension
- Cardiogenic shock
- Intubated and transferred
- Inotropes/pressors
AF CASE

• Right Heart Catheterization (Dopamine, Norepinephrine)
  – RA 27 ↑↑
  – PCWP 41 ↑↑
  – Systemic BP 117/88 (MAP 74)
  – CO/CI 4.13/1.8 ↓↓
  – SVR 910 dynes

• Diagnosis: Cardiogenic shock due to suspected tachycardia mediated cardiomyopathy

AF Case

• Clinical Course
  – Impella CP placed via femoral artery
  – Pressors/inotropes weaned
  – Attempts at cardioversion were unsuccessful
  – Impella removed
  – AV node ablation
  – Biventricular pacemaker implanted
  – Repeat echocardiogram showed LVEF improve to 35%
  – Patient discharged

Impella RP

• Similar technology to Impella LVAD
• Placed via venous access
• Pumps blood from RV to PA
HeartMate PHP

- Commercially available in Europe (CE Mark 2015)
- 13 F introducer sheath
  - Catheter expands to 24F
- Less hemolysis than Impella
- 4-5 liters per minute

Is There Data for Percutaneous LVAD?

- Large randomized controlled trial data not available
- Meta-analysis on percutaneous LVADs vs. IABP (European Heart Journal 2009) in cardiogenic shock
  - Three trials included total of 100 patients
  - Tandem Heart and Impella 2.5 vs. IABP

Meta-Analysis

- Hemodynamics (Cardiac index, MAP, PCWP) better in VAD group
- Overall mortality is high 44%
  - No difference between LVAD and IABP
- More blood produce transfusion in LVAD group
- Trend toward more limb ischemia in the LVAD group (driven by tandem heart)
VA ECMO - CARDIOHELP

- Small pump and oxygenator
  - Up to 7L/flow
- Peripheral cannulation
  - Large bore cannula in vein and artery
- Provides biventricular support
- Portable

VA ECMO CASE

- 35 yo man with known non-ischemic dilated cardiomyopathy
  - Leaves hospital where he was being supported on inotropes
  - Flies to Sacramento and presents to ER in severe heart failure
- Echo LVEF 10% LVEDD 8.6 cm, RV dilated and hypokinetic

- HR 120 BP 112/100
- Edematous, cool to touch
- Inotrope started
- PEA arrest while central line is being placed
- AST 4114
- Creatinine 1.4 -> 2.1
- Lactic acid 5.8

VA ECMO CASE

- Code blue called
- Surgical consult
  - VA ECMO placed
- Hemodynamics stabilized
- Dialysis to treat acute tubular necrosis
- Advanced heart failure consult team deems that he is not a psychosocial candidate for advanced heart failure therapies (active substance abuse, no family support)
- Care withdrawn after 7 days
Data for VA ECMO in Cardiogenic Shock

- Series 1: Post-operative cardiogenic shock
  - 60% weaned from ECMO
  - 23% discharged to home
- Series 2: All cardiogenic shock
  - 40% discharged to home
- Series 3: All cardiogenic shock, single center
  - 50% discharged to home
- Series 4: Refractory cardiac arrest, single center
  - 25% discharged home

CentriMag

- FDA approved since 2008
- Centrifugal flow pump
  - Up to 10L/flow
- External device for short-term circulatory support
- Magnetically levitated blood pump
- Central cannulation

Common Uses

- Temporary LV support after open heart surgery if unable to wean heart-lung bypass
- RV support after LVAD
- Biventricular temporary support
- With an oxygenator, you can use as venous – arterial ECLS
- Dialysis machine can be spliced into it
CentriMag Configurations

Post-Op Case

- 38 yo man with severe MR and AI admitted electively for MVR and AVR
- LVEF 60% but LVEDD 7.2 cm
- Post-op unable to wean off bypass (long pump run, vulnerable LV, possible ischemic injury from coronary compression)
- RV function appeared good
- LVAD Centrimag placed (LV apex to Aorta)

- POD 1 – stable
- POD 2 – Develops signs of acute RV failure
  - Acidosis (Lactic acid 11, Bicarb 15) pH 7.23
  - AST 2027 ALT 214
  - Creatinine 1 to 1.3
  - UOP dropping <30 hour
- Centrimag RVAD added
  - Acute PE likely the cause
    - Thrombus in the RA on TEE

Post-Op Case

- Determination was made that RV was recovering on RVAD, but the LV was not recovering
- Patient returned to OR LVAD exchanged for Heartmate II LVAD, RVAD was removed and RV function was adequate
- Patient eventually discharged from hospital with only HeartMate II support
What to use when?

<table>
<thead>
<tr>
<th></th>
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<th>BIV Failure</th>
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<td>✔️</td>
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</table>

Principles of Patient Selection

1. Confirm that it is cardiogenic shock
   - Low cardiac output
   - Complex patient – try to elucidate which organ derangements are from heart failure and which are from existing co-morbidities that will not be corrected from improved cardiac output
2. Decide which ventricles need support (LV or RV or both?)
3. Discuss your exit strategy
   - Temporary support is temporary
   - Where do you go next? Recovery, durable VAD, transplant
4. Counsel family on the timeline
   - What will happen if recovery doesn’t occur

Summary

- Shock is an acute condition with high morbidity and mortality if untreated
- Recognizing the underlying reasons for the shock is critical to synthesizing a treatment plan
- Acute cardiogenic shock can be treated with medical therapy, but medically refractory cases can be treated with mechanical circulatory assist with improvement in mortality
- Mechanical circulatory assist devices are ideally implanted with cardiothoracic surgery and advanced heart failure cardiologist input