Invasive Cardiac/Pulmonary Hemodynamics
Critical Thinking with Critical Patients

Disclosures

NO RELEVANT FINANCIAL RELATIONSHIPS TO DISCLOSURE

Objectives

1. Interpret pertinent medical information provided by cardiac and pulmonary imaging and apply this information in the assessment of critical care patients.
2. Discuss invasive cardiac and pulmonary lines/tubes and their use in evaluating and monitoring patients for mobility.
3. Evaluate advanced cardiac and pulmonary hemodynamics and determine appropriate mobility programs for patients in the ICU.
Outline

Assessment of Cardiac Imaging/Procedures
• ECHO
  • Systolic vs. Diastolic Dysfunction
  • Left Heart Catheterization
  • Right Heart Catheterization
Clinical Reasoning with Invasive Cardiac Lines/Tubes
• Arterial Line
• Central Venous Line
• Swan-Ganz Catheter
Cardiac Case

Outline (cont.)

Assessment of Pulmonary Imaging/Procedure
• Chest Xray
• Computed Tomography (CT)
• Pulmonary function Tests
• Auscultation
• Arterial Blood Gas
Clinical Reasoning with Pulmonary Lines/Tubes
• Mechanical Ventilation
• Modes of ventilation
• Hemodynamic Considerations with Positive Pressure
• Mechanics of Breathing
Pulmonary Case
Conclusion/Questions

Cardiac Imaging/Procedures

ECHOCARDIOGRAPHY (ECHO)
LEFT HEART CATHETERIZATION (LHC)
RIGHT HEART CATHETERIZATION (RHC)
ECHOCARDIOGRAPHY (ECHO)
- Detailed cardiac ultrasound for diagnostic purposes
- TTE vs. TEE

ECHO Basics

**LEFT SIDE**
- Gross LV size/Wall thickness
- EF
- Mitral and Aortic Valves
- LA size

**RIGHT SIDE**
- Gross RV size and function
- Tricuspid and Pulmonic Valves
- RA size

Which of the following could be an indicator of "heart failure"?

- Ejection Fraction (EF) of 25%
- Normal right ventricular systolic function
- E/A ratio 2.4 with elevated left atrial volume
- Mildly elevated right atrial pressure
Left Ventricular Dysfunction

High Pressures
- Hypertrophy
- Diastolic Dysfunction (DD)
- Preserved E

Large Volumes
- Dilatation
- Systolic Dysfunction (SD)
- Reduced EF

LV Systolic Dysfunction

ASSESSMENT ON ECHO

LV SD on ECHO

<table>
<thead>
<tr>
<th>ECHO Parameter</th>
<th>Normal</th>
<th>Abnormal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ejection Fraction (EF)</td>
<td>55-70%</td>
<td>&lt;40%</td>
</tr>
<tr>
<td>LV End Diastolic Vol Index (EVID)</td>
<td>15-75 mL/m²</td>
<td>&gt;87</td>
</tr>
<tr>
<td>LV End Systolic Vol Index (ESVID)</td>
<td>12-30 mL/m²</td>
<td>&gt;37</td>
</tr>
<tr>
<td>Stroke Volume</td>
<td>60-120 mL</td>
<td>&lt;60</td>
</tr>
</tbody>
</table>
LV Assessment on ECHO

LV SD on ECHO

LV Diastolic Dysfunction

ASSESSMENT ON ECHO
Qualifications of DD on ECHO

- Increased LV Hypertrophy
- Hyperdynamic LVEF
- Atrial Dilation
- Mitral Valve Regurgitation
- Elevated Pulmonary Pressures

Mitral Valve Inflow: DD

<table>
<thead>
<tr>
<th></th>
<th>Valu e</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>Early Transmitral Velocity</td>
</tr>
<tr>
<td>A</td>
<td>Late Diastolic Transmitral velocity</td>
</tr>
<tr>
<td>E/A</td>
<td>Mitral inflow E/A ratio</td>
</tr>
<tr>
<td>LA Voli</td>
<td>Left Atrial Volume Index</td>
</tr>
</tbody>
</table>
### Grading of DD

<table>
<thead>
<tr>
<th>Type</th>
<th>Impaired relaxation</th>
</tr>
</thead>
<tbody>
<tr>
<td>E/A</td>
<td>0.4 - 0.9</td>
</tr>
<tr>
<td>LA Vol Index</td>
<td>Normal +/−</td>
</tr>
</tbody>
</table>

Symptoms of CHF

**Type I**

"Pseudonormalization"

E/A: 1.5 - 2.0

LA Vol Index: Normal to high

**Type II**

Restrictive filling: Reversible with Valsalva

E/A > 2

LA Vol Index > 34

**Type III**

Restrictive filling: Non-reversible with Valsalva

E/A > 2

LA Vol Index > 34

**Type IV**

Case Application

<table>
<thead>
<tr>
<th>Findings</th>
<th>LV normal dx, Upper septal hypertrophy (sigmoid septum), LV wall motion normal EF &gt; 55%, LV EF normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Ventricle</td>
<td>LV EF 55%</td>
</tr>
<tr>
<td>Right ventricle</td>
<td>RV moderately to severely dilated.</td>
</tr>
<tr>
<td>Left Atrium</td>
<td>LA mildly dilated</td>
</tr>
<tr>
<td>Right Atrium</td>
<td>RA mildly dilated</td>
</tr>
<tr>
<td>LV Stroke Dimension</td>
<td>5.5 cm</td>
</tr>
<tr>
<td>LA Valves BP</td>
<td>84/60 mmHg</td>
</tr>
<tr>
<td>LA Valves ED BP</td>
<td>84/60 mmHg</td>
</tr>
</tbody>
</table>

How would a Valsalva affect blood velocity through the mitral valve?

- Decreases atrial and ventricular contractility
- Decreased EF
- Increases atrial contractility
- Decreases preload = decreased velocity
The “Who” of DD/HFpEF

MOST COMMON
- Elderly females
- Hypertensive
- Diabetic

OFTEN
- Obese
- Coronary Artery Disease
- Atrial Fibrillation
- Aortic Stenosis
- Hyperlipidemia

The “Who” of DD/HFpEF

PREVALENCE
- Asymptomatic mild LV diastolic dysfunction was seen in 21% and moderate or severe diastolic dysfunction in 7%

PROGNOSIS
- Increased all cause mortality in patients with DD
- 5-year mortality
  - 20% for mild/severe DD
  - ~9% for mild DD
The “Who” of DD/HFpEF

PREVALENCE

- Asymptomatic mild LV diastolic dysfunction was seen in 21% and moderate or severe diastolic dysfunction in 7%.
- CHF from primary DD accounts for about 45% of CHF cases in patients younger than 45. Nearly 60% in patients older than 85 years.

PROGNOSIS

- Increased all-cause mortality in patients with DD.
- Five-year mortality:
  - 20% for mod/severe DD
  - ~9% for mild DD

Diastolic Dysfunction Disrespected

- Multiple factors to diagnosis.
- Often remains “subclinical” due to mostly exertional symptoms in early stages.
- No clear guidelines for treatment when diagnosed.

Clinical Cardiology: New Frontiers

*New Concepts in Diastolic Dysfunction and Diastolic Heart Failure: Part I*

Diagnosis, Prognosis, and Measurements of Diastolic Function

Michel R. Zile, MD, Erik L. Brouwer, MD
**DD vs SD**

### Decreased peak exercise SV by up to 26%

### Decrease peak exercise oxygen consumption (VO2) by 48%

### Increase peak exercise left atrial pressure 3.6x control
What does it all mean?
Clinical Application

- Increase in exertion dyspnea
- Increase in early fatigue
- Poor prognosis

What does it all mean?
Clinical Application

- Awareness of afterload
- Awareness of HR
- Consistent evaluation of symptoms throughout exertion
- Exercise hemodynamics are a key in possible early detection of DD

Clinical Resource
Right Ventricle Assessment

"RIGHT VENTRICLES MATTER TOO!"

RV Dysfunction
ASSESSMENT ON ECHO

RV Function on ECHO: TAPSE

T - Tricuspid
A - Annular
P - Plane
S - Systolic
E - Excursions
RV Function on ECHO: TAPSE

- Measure excursion of TV during systole
- TAPSE < 1.7 cm is highly suggestive of RV dysfunction.
Left Heart Catheterization (LHC)
- Assessment of blood flow through coronary arteries
- Assessment of LV wall motion
- LV end diastolic pressures (LVEDP)

- Left Main (LM)
- Lateral Circumflex (LCx)
- OM1-2
- Left Anterior Descending (LAD)
- D1-2
- Right Coronary Artery (RCA)
- Posterior Descending Artery (PDA)
- LV Gram

Assess % blockage of each vessel
Assess LVEDP
  - Normal 6-12 mmHg
  - LVEDP >20 mmHg doubles risk of mortality in surgery
Assess LV Ventriculogram for motion/kinesis
**LHC Interpretation**

**Right Heart Catheterization (RHC)**
- Assessment of right and left sided pressures
- Detailed overview of cardiac function

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Atrial Pressure (RA)</td>
<td>0-8 mmHg</td>
</tr>
<tr>
<td>Right Ventricular Pressure</td>
<td>15-25/2-10 mmHg</td>
</tr>
<tr>
<td>Pulmonary Artery Pressure</td>
<td>35-80/15-35 mmHg</td>
</tr>
<tr>
<td>Pulmonary Capillary Wedge Pressure (PCWP/LA)</td>
<td>4-12 mmHg</td>
</tr>
<tr>
<td>Cardiac Output</td>
<td>4.5 L/min</td>
</tr>
<tr>
<td>Cardiac Index</td>
<td>2.5-4.5 mL/m2/min</td>
</tr>
<tr>
<td>SvO2 (PA saturation/“Mixed” venous saturation)</td>
<td>60-75%</td>
</tr>
</tbody>
</table>

**Hemodynamics**
- Arterial Pressure: 111/69
- Left ventricular systolic pressure: 111
- **Normal heart rate:** 60-100 bpm

**Angiography**
- Left ventricular angiography revealed normal left ventricular function.
- Right coronary angiography revealed a large and dominant vessel with 10% stenosis of the LAD just after a small acute marginal branch which itself has 90% stenosis. There are very small right ventricular branches present. The large right coronary artery emerges left main coronary artery.
- Left coronary angiography revealed left main coronary artery.
- The first diagonal was small with the remainder of the mid and apical segments without significant disease. The first diagonal is very small with a very small second diagonal with 50% disease. The posterior was non-diagnostic. The RCA was patent, and the remainder of the posterior marginal branches was present, just after the second diagonal. The left main coronary artery was patent.
- There is then 50% stenosis of the left anterior descending artery. There is 50% stenosis of the left anterior descending artery. There is then 50% stenosis of the left anterior descending artery. There is then 50% stenosis of the left anterior descending artery. There is then 50% stenosis of the left anterior descending artery. There is then 50% stenosis of the left anterior descending artery. There is then 50% stenosis of the left anterior descending artery. There is then 50% stenosis of the left anterior descending artery. There is then 50% stenosis of the left anterior descending artery.
Findings:
- RA: mean 8 mmHg with prominent elevated V wave
- RV: 56/16 mmHg
- PA: 50/27 mmHg (mean 35 mmHg)
- PCWP: mean 26 mmHg with prominent elevated V wave
- TPG: 11 mmHg
- CO: 3.46 L/min (Fick, with an assumed O2 consumption), 3.80 L/min (TD)
- CI: 1.72 L/min per meter squared (Fick, with an assumed O2 consumption), 1.1
- Arterial sat: 99% (assumed from peripheral O2 sat), PA sat 40%, Hgb 13 g/dl

RHC Interpretation
Arterial Line

Clinical Application: Waveform variation

Central Venous Line (CVL)

- CVP
  - Blood return to right atrium
  - Heart's ability to eject blood
  - AOK right atrial [RA] pressure
  - Normal?
    - > 4-8 mmHg
- SvcO2
  - Oxygen saturation central venous blood
  - SVC only
    - 70-80
Clinical Application: CVL

- Decreased cardiac output
- Increased blood volume
- Venous dilation
- Changing from supine to stand
- Forced expiration
- Muscle contraction
- Normal inspiration

Swan Ganz Catheter (SGC)

- Pulmonary Artery Pressure (PAP)
- Pulmonary Capillary Wedge Pressure (PCWP)
- Measure of LAP
- Cardiac Index (CI)
- SvO2

Clinical Application

- Pulmonary Artery Pressure (PAP)
  - Systolic HF?
  - PE?
  - COPD?
  - Mitral regurgitation?
  - Diastolic HF?
- Pulmonary Capillary Wedge Pressure (PCWP)
  - Systolic HF?
  - PE?
Right Heart Waveforms
- RA
- RV
- PA
- Wedge

Cardiac Case

65 year old obese female who presented to the ER with progressive SOB, leg swelling, orthopnea, and decreased UOP.
She has a PMH of CAD s/p MI in 2008, CHF, HTN, HLD, COPD, ICD in situ. Previous Echo had EF 30-35% in 2010. Bedside Echo showing worsening LV function.

She was given 3 x IV bolus in ED but reported worsening SOB and minimal improvement in BP.
She was then started on a vasopressors for BP support and transported to a medical center for further management.
Cardiac Case (Cont.)

On presentation to larger medical center, pt continues to report dyspnea. Started on inotropic support for presumed cardiogenic shock. Transferred to CCU for further management. Arterial line and central line placed for invasive monitoring.

VS on arrival to CCU:

- HR 120 bpm
- RR 22
- BP 90/52 on milrinone 0.375 mcg and levophed 0.04 mcg
- Temp 98.6°F
- SpO2 88% on 8 L Oxymizer

Cardiac Case (Cont.)

Increased evidence of low cardiac output despite inotropic therapy.

- The patient was transferred to the coronary care unit for further evaluation and therapy:
  - Decrease in pulmonary hypertension and evidence of reduced filling pressures.

Brief Fluid/Intoxication note:

- Hemodynamic:
  - SVR:
  - CO:
  - PVV:
  - MAP: 75 on 6 L Oxymizer
Cardiac Case (Cont.)

Patient taken to CCL for R/LHC. Formal ECHO completed at bedside. Results below.

**CONCLUSIONS**

- LV SD
- LV DD
- LA dilation
- RV dysfunction

**Summary**

- LV systolic dysfunction: mitral/ps com/pres probably elevated
- LV diastolic dysfunction: mitral/ps com/pres probably elevated
- no significant AR
- mild MR
- mild TR
- right atrium systolic pressure 55 mmHg
- no sign of acute RV pressure
- LV EF: 40%
- LA dilation
- RV dilation

**Hemodynamics**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA (mmHg)</td>
<td>30</td>
</tr>
<tr>
<td>PAP d (mmHg)</td>
<td>25</td>
</tr>
<tr>
<td>CVP (mmHg)</td>
<td>12</td>
</tr>
<tr>
<td>PCWP (mmHg)</td>
<td>24</td>
</tr>
<tr>
<td>CI (l/min/m²)</td>
<td>2.8</td>
</tr>
<tr>
<td>SVR (dynes/sec/cm)</td>
<td>960</td>
</tr>
<tr>
<td>SV (ml/beat)</td>
<td>40.1</td>
</tr>
<tr>
<td>PVR (dynes/sec/cm)</td>
<td>27</td>
</tr>
<tr>
<td>SV02 (%)</td>
<td>49</td>
</tr>
</tbody>
</table>

**Cardiac Case (Cont.)**

[Image of a chest X-ray]
Cardiac Case (Cont.)

- PT consultation day 1 in CCU.
- SGC, CVL, Aline in situ. Pt supported on milrinone at 0.5 mcg.

Hemodynamics with mobility

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA pressure</td>
<td>39/24</td>
<td>PA pressure</td>
<td>48/24</td>
</tr>
<tr>
<td>CVP</td>
<td>12</td>
<td>CVP</td>
<td>10</td>
</tr>
<tr>
<td>HR</td>
<td>106</td>
<td>HR</td>
<td>121</td>
</tr>
<tr>
<td>BP (Aline)</td>
<td>102/57</td>
<td>BP (Aline)</td>
<td>96/56</td>
</tr>
<tr>
<td>RR</td>
<td>27</td>
<td>RR</td>
<td>28</td>
</tr>
<tr>
<td>SpO2</td>
<td>94</td>
<td>SpO2</td>
<td>92</td>
</tr>
</tbody>
</table>
Clinical Application

- Thorough Chart review
- ECHO, CXR, L/RHC, etc.
- Increased depth of understanding of pathophysiology = Enhanced clinical reasoning during assessment
- Use your lines
  - CVP for volume status and tolerance of exertion
  - SGC for up to date hemodynamics. Are they compensated vs. decompensated
- Attempt to correlate subjective symptoms to objective evidence

Cardiac References/Resources

4. http://www.onlinejacc.org/content/17/5/1065
6. https://www.ahajournals.org/doi/pdf/10.1161/CIR.0b013e31829e8776
8. https://www.cardioserv.net/rv‐function‐tap‐s‐wave/
Mr. Gold is a 71 yo male with PMH most significant for COPD, GERD, DM, frequent falls, dependent upon supplemental O2 for all functional tasks, hiatal hernia repair, and s/p right hip ORIF ~ 3 years ago. Pt presented to the ED with 3 days h/o of progressive dyspnea and productive cough of thick tan colored sputum. Upon presentation to ED patient became increasingly lethargic, demonstrating inability to protect his airway. Pt intubated for airway protection in ED and transferred to ICU for further care and management. Pt is intubated and sedated on medical ventilation. Pt supported on
FUNCTION OF THE PULMONARY SYSTEM

OXYGENATION
VENTILATION

RESPIRATORY SYSTEM

- AIRWAY STRUCTURES
- UPPER
- LOWER
- PULMONARY CIRCULATION
- MUSCULOSKELETAL

AIRWAY ANATOMY

UPPER AIRWAY
LOWER AIRWAY
VENTILATION PERFUSION MATCHING

V/Q MATCHING
SHUNTING
DEAD SPACE
VENTILATION

VENOUS BLOOD
O₂ = 49
CO₂ = 45

INSPIRED AIR
O₂ = 150
CO₂ = 0

V/Q = 0
R-L Shunt
V/Q = 1
Normal
V/Q = ∞
Dead Space

REVIEW MUSCULOSKELETAL STRUCTURES

ANTERIOR MUSCULOSKELETAL THORAX
VENTILATION

MECHANICS OF BREATHING

THE BIG PICTURE

HEMODYNAMICS OF THE PULMONARY SYSTEM

RESPIRATORY RATE (RR)

TIDAL VOLUME (Vt)

MINUTE VENTILATION (MV)

Vt x RR = MV
ANTERIOR POSTERIOR

AUSCULTATION LANDMARKS

AUSCULTATION

<table>
<thead>
<tr>
<th>CHARACTERISTIC OF AUSCULTATION</th>
<th>PHASE OF RESPIRATORY CYCLE</th>
<th>LOCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRACKLES/RALES</td>
<td>Soft, high-pitched, and discontinuous</td>
<td>Early inspiration with COPD pathology</td>
</tr>
<tr>
<td>WHEEZE</td>
<td>High-pitched and continuous</td>
<td>Heard most often with expiration but may be occur during inspiration.</td>
</tr>
</tbody>
</table>

ICU MONITOR

PERIPHERAL ARTERIAL BLOOD SATURATION
RESPIRATORY RATE
CENTRAL VENOUS PRESSURE
END TIDAL CO2
ARTERIAL BLOOD GAS EVALUATION OF OXYGENATION
EVALUATION OF VENTILATION

- pH:
  - Acidosis: < 7.35
  - Alkalosis: > 7.45
- pCO2:
  - High: Respiratory Acidosis
  - Low: Respiratory Alkalosis
- HCO3:
  - Low: Metabolic Acidosis
  - High: Metabolic Alkalosis

MECHANICAL VENTILATION

- Mode of Ventilation
- Tidal Volume
- Respiratory Rate
- Airway Compliance

CENTRAL VENOUS PRESSURE

- Clinical Implication
  - Monitoring of Right Sided Heart Pressure
INTERVENTION OPTIONS

- POSITIONING
- PULMONARY TOILET
- INSPIRATORY MUSCLE TRAINING
- MANUAL THERAPY/FACILITATION
- EDUCATIONAL/ADAPTATIVE TECHNIQUES

REFERENCES


