Hemodynamic Theory and Interpretation
Disclosures

Speaker’s Bureau:
• None

Honorarium:
• None

Consultant:
• None

Stockholder:
• None

Grant/Research Support:
• None

Medical/Scientific Boards:
• None
Topics

- Hemodynamic Theory
- Hemodynamic Equipment
- Hemodynamic Terminology
- Waveform Interpretation
- Thermal Dilution Cardiac Output
Hemodynamic Theory
Why do we record pressures?

Draw conclusions about the health and function of the cardiac and vascular systems:

Used to diagnose:
- Aortic and mitral stenosis
- Congestive heart failure
- Pulmonary hypertension
- Restrictive and constrictive cardiomyopathy
Column of Fluid Theory

• Uninterrupted column of normal saline (absent of any blood or contrast).
• Blood pressure pushes on the column of fluid in the catheter.
Types of Pressure

Residual (static) Pressure: Pressure that the fluid volume exerts on the blood vessel or chamber. This is the pressure that we want to measure.

Dynamic Pressure: This is a pressure artifact that is caused by the kinetic movement of blood.

Hydrostatic Pressure: This is the effect of gravity upon the fluid in the artery OR catheter.
EQUIPMENT
Components of Hemodynamic Pressure Monitoring

- The transducer
- Catheter, pressure tubing connecting the patient to the transducer
- flush system
- monitor
Wheatstone Bridge Mechanical Transducer

How it works

• pressure applied to the transducer, diaphragm is pushed, stretches the wires attached to it.
• As the wires stretch, this changes the resistance and flow of current through them.
• system senses change in current, and reflects this as a change in pressure on our monitors.

FIG. 7.7. Schematic representation of a strain-gauge pressure transducer. Pressure is transmitted through port P and acts on diaphragm D, which is vented to atmospheric pressure on its opposite side. Pressure on the diaphragm stretches and therefore increases the resistance of wires $G_1$ and $G_2$, while having the opposite effect on $G_3$ and $G_4$. The wires are electrically connected as shown in Fig. 7.8.

For every 1cm that the transducer is above or below the phlebostatic axis, approx. 0.74 mmHg is added or subtracted from the actual pressure. A 10cm makes an approximate 7.4mmHg difference.
Top of transducer that connects to the line to the patient

Open Air reference point that is to be at the phlebostatic axis. Turn stopcock up, tell monitor to zero, and when zero, turn it back to this position.

Always zero after leveling transducer at phlebostatic axis.

Transducer “meat” that includes the Wheatstone bridge

Flush “exhaust” port, always turned “off” except to flush
Tubing Length and Composition

- Tubing length:
  - short as reasonably possible
  - Too much tubing: friction and resistance of the fluid column
  - Suggested total tubing length is 3 – 4 feet

- Tubing Compliance
  - stiff, but not absolutely rigid
  - Too soft of tubing will absorb pressure
## Correctable Sources of Artifact

<table>
<thead>
<tr>
<th>Artifact</th>
<th>Possible Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure recording drops below zero</td>
<td>Improper leveling, Improper Zero</td>
</tr>
<tr>
<td>No waveform</td>
<td>Monitor not working, Transducer incorrectly connected, Stopcocks in incorrect position, Catheter kinked or clotted, Patient is asystolic</td>
</tr>
<tr>
<td>Over dampened waveform</td>
<td>Air or Clot it tubing, Catheter tip positioned against vessel wall, Improper tubing is used, Contrast is in catheter/pressure tubing</td>
</tr>
<tr>
<td>Underdamped waveform</td>
<td>Improper tubing used, Tiny bubble in tubing, Transducer is broken</td>
</tr>
</tbody>
</table>
under damping

after flushing transducer
Remember: Sudden ventricularization or dampening of a pressure could indicate ostial lesions!
Hemodynamic Terminology
Cardiac output is influenced by:

- Heart rate
- Stroke volume
- Preload (diastolic filling)
- Contractility (fiber stretch)
- Afterload (arterial pressure)
- Contractile force
- Ventricular size
Preload

Preload is defined as the length tension of the myocardial fibers at the end of diastole
• measured by LVEDP, PCW
Starlings Law of the Heart and Contractility

Stroke volume vs. preload (venous return)

- Sympathetic stimulation
- Normal contractility
- Low contractility (heart failure)

Functional outcome
Afterload resistance the heart has to overcome in order to eject blood from the heart
- Represents myocardial wall tension
- Measured by vascular resistance

Afterload is influenced by: Aortic diastolic pressure, Arterial compliance, Blood volume and viscosity, Aortic valve function
Hemodynamic Waveform Interpretation
Wiggers diagram:
A review of all waveforms in relation to each other

- Mitral valve closure  #1
- Isometric ventricular contraction
- Opening of aortic valve  #2
- Systolic ejection (LVET)
  - rapid vent. ejection
  - reduced vent. ejection
- Aortic valve closure  #3
- Isovolumic vent. relaxation
- Mitral valve opening  #4
- Diastasis (DFP)
  - rapid filling
  - slow filling
  - atrial contraction
ATRIAL PRESSURES

Left and Right Atrial Pressures
Atrial Waveforms

- **a wave**
  - atrial contraction.
  - Identified as the first positive deflection after the p-wave
- **x₁ descent**
  - atrial relaxation
- **c wave**
  - AV valve closure –
  - positive deflection after the beginning of the QRS.
  - Caused by ventricular contraction and bulging of TV
- **x₂ descent**
  - Continued atrial relaxation
- **v wave**
  - atrial filling due to ventricular contraction
  - positive deflection normally occurring between the T–P interval
- **y descent**
  - Atrial emptying - passive ventricular filling
Interpreting Right Atrial Pressures

- Both LA (PAW) & RA pressures are read the same way during end expiration (a, v, m)

- "a" wave (atrial contraction)
  - 3-7 mmHg

- "v" wave (atrial filling contraction)
  - 2-8 mmHg

- Mean (time average)
  - 1-5 mmHg
Right Atrial Pressure and Normal Respiratory Variation:

• pressure in the thorax and lungs drop when we inhale

• causes the pressures of the right atrium to decrease as well

• Right heart pressures: most accurate when recorded at end exhalation
Right Atrial Pressures and the Ventilated Patient

• Breathing is assisted by ventilation, the normal decrease in thoracic pressure does not occur. Rather, the force of the air INCREASES thoracic pressure.

• In this situation, there will be an increase in atrial a, v, and mean pressures with inhalation.

• Only pressures recorded on end exhalation should be measured and used for calculations on a patient that is receiving ventilator support.
Respiratory Variation
PULMONARY CAPILLARY WEDGE PRESSURE
Pulmonary Capillary Wedge Pressure

- Direct measurement of the Left Atrial pressure is problematic
  - Accomplished either by transeptal puncture or retrograde crossing of the mitral valve.
  - Both approaches have increased risk of patient injury and adverse outcomes.
PCWP
PCW pressures: time delay, corrected by shifting the pressures when comparing them to the LV diastolic pressures for valve function.
LV and PCW simultaneous
VENTRICULAR PRESSURES

Right and Left Ventricle
End Diastolic Pressure

- End diastolic pressure (EDP):
  - Represents ventricular preload
  - The EDP is also the point where the AV valves are forced closed at the beginning of isovolumetric contraction.
  - Aligns with the end of the QRS complex
Isovolumetric Contraction

- Isovolumetric Contraction:
  - Pressure: forces opening of the semilunar valves.
  - Before the ventricle can force blood out, it must first increase its tension and pressure to overcome vascular resistance and afterload.
Peak Systolic Pressure

• Peak Systolic Pressure:
  – pressure required to open the semilunar valve, and to eject blood.
  – afterload
• **Isovolumetric relaxation:**
  – Following systole, the ventricle quickly decreases its pressure/tension before the AV valves can open.
  – This period of rapid decrease in pressure, but no change in volume, is called isovolumetric relaxation.
End Systolic Pressure

- End systolic (ESP):
  - pressure that exists when the ventricle is fully relaxed, has least amount of volume
Wiggers diagram: A review of all waveforms in relation to each other

- Mitral valve closure #1
- Isometric ventricular contraction
- Opening of aortic valve #2
- Systolic ejection
  - rapid vent. ejection
  - reduced vent. ejection
- Aortic valve closure #3
- Isovolumetric relaxation
- Mitral valve opening #4
- Diastasis (DFP)
  - rapid filling
  - slow filling
  - atrial contraction

Note: Whenever the pressure lines cross a valve is either opening or closing.
# Normal Ventricular Pressures

<table>
<thead>
<tr>
<th>Right Ventricle</th>
<th>Left Ventricle</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Peak Systolic (systolic):</strong></td>
<td><strong>Peak Systolic (systolic):</strong></td>
</tr>
<tr>
<td>• 15-30 mmHg</td>
<td>• 100-140 mmHg</td>
</tr>
<tr>
<td><strong>Diastolic:</strong></td>
<td><strong>Diastolic:</strong></td>
</tr>
<tr>
<td>1-5 mmHg</td>
<td>• 2-12 mmHg</td>
</tr>
<tr>
<td><strong>End Diastolic:</strong></td>
<td><strong>End Diastolic:</strong></td>
</tr>
<tr>
<td>1-7 mmHg</td>
<td>• 5-12 mmHg</td>
</tr>
</tbody>
</table>

Typically measured on a 50 mmHg scale.

200 mmHg scale. Diastolic pressures may be measured on 50 mmHg scale for comparison.

The right ventricle pressures are affected by respiratory cycles like the atria. The left ventricular pressures are not normally affected by respiratory variation.
Ventricular Recordings
Ventricular DP/DT

No means in the ventricle!
• BUT there is an important calculation that should be performed:
  – Dp/Dt : comparison of the maximum pressure during isovolumetric contraction and the pressure is produces.
  – A decrease in this number indicated a decrease in contractility and possibly ventricular failure.

Normal RV DP/DT: 648 ± 159 mmHg/second
Normal LV DP/DT: > 1200 mmHg/second
RV Analysis

Systolic = 24
Diastolic = 0
End Diastolic = 4

Which Scale is Used?
LV Analysis

Which Scale is Used?

Systolic = 117
Diastolic = 0
End
Diastolic = 13
ARTERIAL WAVEFORMS

Aortic, Systemic, and Pulmonary Arteries
PA Waveform

- **Peak Systolic Pressure:**
  - a reflection of the volume and velocity of the blood ejecting from the ventricle

- **Dicrotic Notch:**
  - This is a “ripple” in the pressure tracing that is caused by the closure of the pulmonic valve.

- **Diastolic Pressure:**
  - diastolic pressure is the lowest pressure produced by the artery during ventricular diastole, and is a reflection of pulmonic vascular resistance.
Normal Arterial Pressures

Aortic Pressures:
- Peak Systolic: 100 – 140 mmHg
- Diastolic: 60 – 90 mmHg
- Mean: 70 – 105 mmHg

Typically measured on a 200 mmHg scale.

Pulmonary Artery Pressures:
- Peak Systolic: 15-30 mmHg
- Diastolic: 4-13 mmHg
- Mean: 20-25 mmHg

Typically measured on a 50 mmHg scale.

The pulmonary artery pressures are affected by respiratory cycles. Aortic pressures are not normally affected by respiratory variation.
Pulmonary and Aortic Pressures
AORTA AND PERIPHERAL ARTERIES
Peripheral Artery Pressure Amplification

Peripheral arterial pressure that is measuring higher than the ascending aortic pressure.

- What is being recorded is a physiologic result of blood moving into smaller blood vessels, which creates a secondary wave that pulsates backwards causing and amplification in systolic pressure.
  
  • must be taken into consideration when comparing a femoral pressure to an LV pressure for Aortic Valve Stenosis.
Pressure Amplification in the periphery

Ascending Aortic Pressure is Pink. Femoral Arterial Pressure is Yellow.
Pressure Amplification ins Systemic System

BP (mmHg)
PRESSURE GROUPINGS AND ALTERATIONS
Four Pressures should normally be equal on pullback across a valve

1. Left Ventricle syst. = Arterial syst.

2. The PA wedge pressure is a special case where normally PA-edp = PAW mean = LA mean = LV-edp

3. RV systolic = PA systolic

4. RV-EDP = Right Atrial “mean"

1. LV syst. = AO syst.

2. PAW = LV-edp

3. RV syst. = PA syst

4. RV diast. = RA
Identify normal and abnormal pressure levels

<table>
<thead>
<tr>
<th>Right Heart</th>
<th>Pressures in mm Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAW =</td>
<td>12,12,10 (a,v,m)</td>
</tr>
<tr>
<td>PA =</td>
<td>25/10, 15 (S/D, m)</td>
</tr>
<tr>
<td>RV =</td>
<td>25/0, 4 (s/bd, ed)</td>
</tr>
<tr>
<td>RA =</td>
<td>5,5,4 (a,v,m)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Left Heart</th>
<th>Pressure in mm Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>LA =</td>
<td>12,12,10 (a,v,m)</td>
</tr>
<tr>
<td>AO =</td>
<td>130/80, 100 (s/d, m)</td>
</tr>
<tr>
<td>LV =</td>
<td>130/0, 8 (s/bd, ed)</td>
</tr>
</tbody>
</table>

These are the only 4 numbers you need to remember: 4mmHg, 10mmHg, 25mmHg, & 130 mmHg
Identify Catheter Location on pullback

- Know the normal pullback sequence through cardiac chambers

- LV-AO
- PAW-PA
- PA-RV
- RV-RA
Identify Catheter Location by fluoroscopy

- RA - SVC - IVC - left cardiac border
- PA – 2
  nd knob
- LA – 3
  rd knob
- PAW - lung bed
- LV - apex
- AO – knob

- RHC
- LHC
Questions?
Hemodynamic Theory and Interpretation