Hemodynamic Monitoring

The primary goal of monitoring hemodynamics is to gain information on cardiac output and perfusion. Our ability to monitor hemodynamics, both invasively and non-invasively, allows for dynamic interventions in the care of critically ill patients. A strong understanding of hemodynamics is the foundation of managing a critically ill patient and provides common metrics for clinicians to discuss a patient’s current condition and need for interventions.

The Cardiac Cycle & Key Definitions
A solid understanding of the cardiac cycle and key definitions is the foundation of understanding hemodynamics.

<table>
<thead>
<tr>
<th>The Cardiac Cycle</th>
<th>Atria</th>
<th>Ventricles</th>
<th>AV Valves</th>
<th>Semilunar Valves</th>
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<tbody>
<tr>
<td>Atrial Systole</td>
<td>Contract</td>
<td>Relax</td>
<td>Open</td>
<td>Closed</td>
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<tr>
<td>Early Ventricular Systole</td>
<td>Relax</td>
<td>Contract and pump blood to lungs and body</td>
<td>Forced Closed</td>
<td>Closed</td>
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<tr>
<td>Late Ventricular Systole</td>
<td>Relax</td>
<td>Contract and pump blood to the lungs and body</td>
<td>Closed</td>
<td>Forced Open</td>
</tr>
<tr>
<td>Early Ventricular Diastole</td>
<td>Relax and begin passively filling with blood</td>
<td>Relax</td>
<td>Closed</td>
<td>Closed</td>
</tr>
<tr>
<td>Late Ventricular Diastole</td>
<td>Relax, passively fill with blood</td>
<td>Relax</td>
<td>Open</td>
<td>Closed</td>
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Key Definitions

<table>
<thead>
<tr>
<th>Definition</th>
<th>Clinical Considerations</th>
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<tr>
<td>Cardiac Output (CO)</td>
<td>The volume of blood pumped through the heart per minute (L/min)</td>
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<tr>
<td>Cardiac Index (CI)</td>
<td>CO adjusted for body surface area (BSA)</td>
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### Stroke Volume (SV)
- The volume of blood pumped out of the left ventricle (LV) per heart beat
- Normal range is 60-90 mL
- Calculation: $SV = \text{End-diastolic volume (EDV)} - \text{end-systolic volume (ESV)}$

### End Diastolic Volume (EDV)
- Volume of blood in the right or left ventricle at the end of diastole (filling)
- Normal is about 120 mL

### End Systolic Volume (ESV)
- Volume of blood in the right or left ventricle at the end of systole (contraction)
- Normal is about 50 mL

### Preload
- The amount of ventricular stretch at the end of diastole
- Also known as the left ventricular end-diastolic pressure (LVEDP)

### Afterload
- The amount of resistance the heart must overcome to open the aortic valve and push the blood volume out into the systemic circulation
- Also known as the systemic vascular resistance (SVR)

### Contractility
- The ability of the heart to contract and generate force

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### Measuring Hemodynamics

**Invasive Methods**

- **Central venous pressure (CVP)**
  - Blood pressure in vena cava/right atrium
  - Reflects right ventricular (RV) function and venous return to right side of heart
  - Measure via catheter positioned in the vena cava

- **Pulmonary artery pressure (PAP)**
  - Blood pressure in pulmonary artery
  - May be measured during right heart catheterization or introduction of a catheter into the pulmonary artery (i.e. Swan Ganz Catheter)

- **Mixed Venous Oxygen Saturation (SvO₂)**
  - Reflects the balance between oxygen delivery and oxygen consumption (VO₂)
  - Depends on arterial blood saturation (SaO₂), the balance between VO₂ and CO, and hemoglobin (Hgb) levels
    - SvO₂ ≥70% (drawn from a pulmonary artery catheter)
    - ScvO₂ ≥ 65% central venous oxygen saturation (drawn from a central venous catheter)
• **Intra-arterial blood pressure monitoring**
  o Measures arterial blood pressure continuously via arterial catheter

**Non-Invasive Methods**

• **Arterial blood pressure**
  o Blood pressure monitored via blood pressure cuff; arterial pressure is measured at its peak, systolic blood pressure (SBP), and trough, diastolic blood pressure (DBP).

• **Systemic mean arterial pressure (MAP)**
  o The mean perfusion pressure throughout cardiac cycle
  o Calculated as follows:

\[
MAP = \frac{(SBP + 2 \cdot DBP)}{3}
\]

• **Transthoracic echocardiogram (TTE)**
  o Echocardiography provides visualization of the cardiac chambers, valves, pericardium, and overall cardiac function.
  o Allows for measurement of left ventricular ejection fraction (LVEF) and estimates of SV and CO based on measurement of LV outflow tract (LVOT), LVOT velocity and heart rate

**Perfusion Indicators**

**Capillary Refill Time (CRT) (Bridges, 2017)**
CRT is the time required for blood flow (and color) to return to the distal capillaries after the release of compression sufficient to cause blanching of the fingertip or knee. A longer CRT indicates reduced capillary perfusion. CRT helps determine perfusion status, independent of changes in systemic hemodynamics.

• Threshold value: 4-4.5 seconds or 2 seconds for young adult men, 2.9 seconds for young adult women, and 4.5 seconds for older adults.
• Sites of measurement: index fingertip (distal phalanx) or center of the knee. (Knee CRT is longer than fingertip CRT).
• Compression time: 5-15 seconds; use one compression time for all measurements.
• Compression firmness: firm enough to cause blanching (a thin white crescent) at the tip of the clinician’s fingernail.
• Repeat measurement at least twice, wait one minute between measurements and average the two values.

**Skin Mottling (Bridges, 2017)**
Skin mottling, or patchy discoloration, often observed on the knee and anterior leg, is an indicator of hypoperfusion (in the absence of microvascular clotting). Changes in skin perfusion may occur independent of changes in systemic hemodynamics. The Skin Mottling System (SMS)
incorporates a 6-point scale to quantify the extent of mottling on the leg (when positioned at heart level).

- SMS 0 – 1: None or modest mottling
- SMS 2 – 3: Mild or moderate mottling
- SMS 4 – 5: Severe mottling

**CRT and SMS in Septic Shock Assessment (Bridges, 2017)**

- CRT and SMS may remain abnormal despite normalization of system hemodynamics (MAP, HR, CVP, CI and ScvO₂).
- An abnormal CRT and SMS at hour 6 of septic shock resuscitation, and failure of CRT or SMS to improve during resuscitation, indicate increased risk of morbidity and mortality.
- CRT and SMS are not endpoints of resuscitation; they are dynamic indicators and should be monitored repeatedly over the resuscitation period.

**Passive Leg Raise**

Passive leg raise may be used to assess preload responsiveness by using the patient’s own blood volume to mimic a fluid bolus (Mikkelsen, Gaieski, & Johnson, 2016).

- Position the patient in the semi-recumbent position with the head and torso elevated at 45 degrees.
- Obtain a baseline measurement (i.e. baseline CO).
- Lower the patient’s upper body and head to the horizontal position and raise and hold the legs at 45 degrees for one minute.
- Obtain subsequent measurement.
- A 10% increase in CO has been shown to predict fluid responsiveness.

**References:**


