Hemodynamic of HF in ACHD

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Right Heart Catheterization
Indications

- Heart failure
- Acute MI
- Acute or chronic pulmonary disease
- Screening for unspecified respiratory disease
- Hypotension
- Valvular heart disease
- Mechanical complications
- Endomyocardial fibrosis
- Congenital heart disease
- Complications of transplanted heart
Right Heart Catheterization
Swan Ganz Catheter

Right Heart Catheterization
Right Atrial Pressure

- **“a” wave**
  - Atrial systole
- **“c” wave**
  - Protrusion of TV into RA
- **“x” descent**
  - Relaxation of RA
  - Downward pulling of tricuspid annulus by RV contraction
- **“v” wave**
  - RV contraction
  - Height related to atrial compliance & amount of blood return
  - Smaller than a wave
- **“y” descent**
  - TV opening and RA emptying into RV
Right Heart Catheterization
Inspiratory Effect on Right Atrial Pressure

- Normal physiology
  - Inhalation: Intrathoracic pressure falls $\rightarrow$ RA pressure falls
  - Exhalation: Intrathoracic pressure increases $\rightarrow$ RA pressure increases

Right Heart Catheterization
Abnormalities in RA Tracing

• **Low mean atrial pressure**
  – Hypovolemia
  – Improper zeroing of the transducer

• **Elevated mean atrial pressure**
  – Intravascular volume overload
  – Right ventricular failure
    • Valvular disease (TS, TR, PS, PR)
    • Myocardial disease (RV ischemia, cardiomyopathy)
    • Left heart failure (MS, MR, AS, AI, cardiomyopathy)
  – Increased pulmonary vascular resistance (PE, COPD, primary pulmonary HTN)
  – Pericardial effusion with tamponade physiology
  – Atrial myxoma

Right Heart Catheterization
Abnormalities in RA Tracing

- Elevated mean atrial pressure

Right Heart Catheterization
Abnormalities in RA Tracing

- **Elevated a wave**
  - Tricuspid stenosis
  - Decreased RV compliance due to RV failure
- **Cannon a wave**
  - A-V asynchrony (3rd degree AVB, VT, V-pacer)
- **Absent a wave**
  - Atrial flutter or fibrillation
- **Elevated v wave**
  - TR
  - RV failure
  - Reduced atrial compliance (restrictive myopathy)
- **Equal a and v waves**
  - Tamponade
  - Constrictive physiology

Right Heart Catheterization
Abnormalities in RA Tracing

- **Prominent x descent**
  - Tamponade
  - Subacute/chronic constriction
  - RV ischemia
- **Prominent y descent**
  - TR
  - Constrictive pericarditis
  - Restrictive myopathy
- **Blunted x descent**
  - Atrial fibrillation
  - RA ischemia
- **Blunted y descent**
  - TS
  - RV ischemia
  - Tamponade

Right Heart Catheterization
Swan Ganz Catheter

Right Heart Catheterization
Right Ventricular Pressure

- **Systole**
  - Isovolumetric contraction
    - From TV closure to PV opening
  - Ejection
    - From PV opening to PV closure

- **Diastole**
  - Isovolumetric relaxation
    - From PV closure to TV opening
  - Filling
    - From TV opening to TV closure
    - Early Rapid Phase
    - Slow Phase
    - Atrial Contraction ("a" wave)
Right & Left Heart Catheterization
Abnormalities in RV Tracing

• **Systolic pressure overload**
  – Pulmonary HTN
  – Pulmonary valve stenosis
  – Right ventricular outflow obstruction
  – Supravalvular obstruction
  – Significant ASD or VSD
  – Increased pulmonary vascular resistance

Right & Left Heart Catheterization
Abnormalities in RV Tracing

• Systolic pressure overload
  – Pulmonary HTN
  – Pulmonary valve stenosis
  – Right ventricular outflow obstruction
  – Supravalvular obstruction
  – Significant ASD or VSD
  – Increased pulmonary vascular resistance

• Systolic pressure reduced
  – Hypovolemia
  – Cardiogenic shock
  – Tamponade

Right & Left Heart Catheterization
Abnormalities in RV Tracing

- **End-diastolic pressure overload**
  - Hypervolemia
  - CHF
  - Diminished compliance
  - Hypertrophy
  - Tamponade
  - Tricuspid regurgitation
  - Pericardial constriction

Right & Left Heart Catheterization
Abnormalities in RV Tracing

• End-diastolic pressure overload
  – Hypervolemia
  – CHF
  – Diminished compliance
  – Hypertrophy
  – Tamponade
  – Tricuspid regurgitation
  – Pericardial constriction

• End-diastolic pressure reduced
  – Hypovolemia
  – Tricuspid stenosis
Right Heart Catheterization
Swan Ganz Catheter

Right Heart Catheterization
Pulmonary Artery Pressure

- Biphasic tracing
  - Systole
  - Diastole

- Pulmonary HTN
  - Mild: $\text{PAP} > 20 \text{ mm Hg}$
  - Moderate: $\text{PAP} > 35 \text{ mm Hg}$
  - Severe: $\text{PAP} > 45 \text{ mm Hg}$
Right Heart Catheterization
Abnormalities in PA Tracing

• Elevated systolic pressure
  – Primary pulmonary HTN
  – MS
  – MR
  – CHF
  – Restrictive myopathy
  – Left-to-right shunt
  – Pulmonary disease

Right Heart Catheterization
Abnormalities in PA Tracing

- Elevated systolic pressure
  - Primary pulmonary HTN
  - MS
  - MR
  - CHF
  - Restrictive myopathy
  - Left-to-right shunt
  - Pulmonary disease

- Reduced systolic pressure
  - Hypotension
  - Pulmonary artery stenosis
  - Pulmonic stenosis
  - Supra or subvalvular stenosis
  - Ebstein’s anomaly
  - Tricuspid stenosis
  - Tricuspid atresia

Right Heart Catheterization
Abnormalities in PA Tracing

- **Reduced pulse pressure**
  - Right heart ischemia
  - RV infarction
  - Pulmonary embolism
  - Tamponade

- **PA diastolic pressure > PCW pressure**
  - Pulmonary disease
  - Pulmonary embolus
  - Tachycardia

Right Heart Catheterization
Swan Ganz Catheter

Right Heart Catheterization
Pulmonary Capillary Wedge Pressure

- “a” wave
  - Atrial systole
- “c” wave
  - Protrusion of MV into LA
- “x” descent
  - Relaxation of LA
  - Downward pulling of mitral annulus by LV contraction
- “v” wave
  - LV contraction
  - Height related to atrial compliance & amount of blood return
  - Higher than a wave
- “y” descent
  - MV opening and LA emptying into LV

Right Heart Catheterization
Inspiratory Effect on Right Atrial Pressure

Right Heart Catheterization
Left Atrial and PCW Pressure

- PCW tracing “approximates” actual LA tracing but is slightly delayed since pressure wave is transmitted retrograde through pulmonary veins
Right Heart Catheterization
Right vs Left Atrial Pressure

- Normal LA pressure slightly higher than RA pressure
Right Heart Catheterization
Abnormalities in PCWP Tracing

- **Low mean pressure**
  - Hypovolemia
  - Improper zeroing of the transducer

- **Elevated mean pressure**
  - Intravascular volume overload
  - Left ventricular failure
    - Valvular disease (MS, MR, AS, AR)
    - Myocardial disease (LV ischemia, cardiomyopathy)
    - Left heart failure secondary to HTN
  - Pericardial effusion with tamponade
  - Atrial myxoma

Right Heart Catheterization
Abnormalities in PCWP Tracing

- **Elevated a wave**
  - Mitral stenosis
  - Decreased LV compliance due to LV failure / valve disease
- **Cannon a wave**
  - A-V asynchrony (3rd degree AVB, VT, V-pacer)
- **Absent a wave**
  - Atrial flutter or fibrillation
- **Elevated v wave**
  - MR
  - LRV failure
  - Ventricular septal defect
- **Equal a and v waves**
  - Tamponade
  - Constrictive physiology

Right Heart Catheterization
Abnormalities in PCWP Tracing

- **Prominent x descent**
  - Tamponade
  - Subacute/chronic constriction

- **Prominent y descent**
  - MR
  - Constrictive pericarditis
  - Restrictive myopathy

- **Blunted x descent**
  - Atrial fibrillation
  - LA ischemia

- **Blunted y descent**
  - MS
  - LV ischemia
  - Tamponade
Right Heart Catheterization
Abnormalities in PCWP Tracing

- Severe Mitral Regurgitation

Right Heart Catheterization Abnormalities in PCWP Tracing

- PCWP not equal to LV end diastolic pressure
  - Mitral stenosis
  - Atrial myxoma
  - Cor triatriatum
  - Pulmonary venous obstruction
  - Decreased ventricular compliance
  - Increased pleural pressure

Left Heart Catheterization
Pigtail Catheter

Right Heart Catheterization
Left Ventricular Pressure

• **Systole**
  – **Isovolumetric contraction**
    • From MV closure to AoV opening
  – **Ejection**
    • From AoV opening to AoV closure

• **Diastole**
  – **Isovolumetric relaxation**
    • From AoV closure to MV opening
  – **Filling**
    • From MV opening to MV closure
    • Early Rapid Phase
    • Slow Phase
    • Atrial Contraction (“a” wave”)
Right Heart Catheterization
Right vs Left Ventricular Pressure

- Diastolic amplitude similar between RV and LV tracings
- Systolic amplitude higher for LV than RV
- Duration of systole, isovolumetric contraction, and isovolumetric relaxation is longer for LV compared to RV
- Duration of ejection is shorter for LV than RV
Right & Left Heart Catheterization
Abnormalities in LV Tracing

- **Systolic pressure overload**
  - Systemic HTN
  - Aortic valve stenosis
  - Left ventricular outflow obstruction
  - Supravalvular obstruction
  - Significant ASD or VSD

- **Systolic pressure reduced**
  - Hypovolemia
  - Cardiogenic shock
  - Tamponade

Right & Left Heart Catheterization
Abnormalities in LV Tracing

- Severe Aortic Stenosis

Right & Left Heart Catheterization
Abnormalities in LV Tracing

- **End-diastolic pressure overload**
  - Hypervolemia
  - CHF
  - Diminished compliance
  - Hypertrophy
  - Tamponade
  - Mitral regurgitation
  - Pericardial constriction

- **End-diastolic pressure reduced**
  - Hypovolemia
  - Mitral stenosis

Arterial Pressure Monitoring
Central Aortic and Peripheral Tracings

- **Pulse pressure** = Systolic − Diastolic
- Mean aortic pressure typically < 5 mm Hg higher than mean peripheral pressure
- Aortic waveform varies along length of the aorta
  - Systolic wave increases in amplitude while diastolic wave decreases
  - Mean aortic pressure constant
  - Dicrotic notch less apparent in peripheral tracing

Arterial Pressure Monitoring
Abnormalities in Central Aortic Tracing

• Systolic pressure elevated
  – Systemic hypertension
  – Atherosclerosis
  – Aortic insufficiency

• Systemic pressure reduced
  – Hypovolemia
  – Aortic stenosis
  – Heart failure

Arterial Pressure Monitoring
Abnormalities in Central Aortic Tracing

• **Widened pulse pressure**
  - Systemic hypertension
  - Aortic insufficiency
  - Significant patent ductus arteriosus
  - Ruptured sinus of Valsalva aneurysm

• **Reduced pulse pressure**
  - Tamponade
  - Heart failure
  - Cardiogenic shock
  - Aortic stenosis

Arterial Pressure Monitoring
Abnormalities in Central Aortic Tracing

• **Pulsus bisferiens**
  – Hypertrophic obstructive cardiomyopathy
  – Aortic insufficiency

Arterial Pressure Monitoring
Abnormalities in Central Aortic Tracing

- Pulsus alternans
  - Pericardial effusion
  - Cardiomyopathy
  - CHF

Arterial Pressure Monitoring
Abnormalities in Central Aortic Tracing

- Pulsus paradoxus
  - Tamponade
  - COPD
  - Pulmonary embolism

Arterial Pressure Monitoring
Abnormalities in Central Aortic Tracing

- Spike and dome configuration
  - Hypertrophic obstructive cardiomyopathy

# Hemodynamic Parameters

## Reference Values

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Left Heart Catheterization
Left Ventricular Diastole

MV opens
MV closes
S1

Left Heart Catheterization
Left Ventricular Systole

2. A patient with a chest pain syndrome comes to cardiac catheterization. Previous history includes angina pectoris, cigarette smoking, and emphysema. Which of the following would be an indication for right heart catheterization?

A. First-degree AV block.
B. Left bundle branch block.
C. Positive stress test.
D. Dyspnea at rest.
E. Right axis deviation on electrocardiogram.
A patient with a chest pain syndrome comes to cardiac catheterization. Previous history includes angina pectoris, cigarette smoking, and emphysema. Which of the following would be an indication for right heart catheterization?

A. First-degree AV block.
B. Left bundle branch block.
C. Positive stress test.
D. Dyspnea at rest.
E. Right axis deviation on electrocardiogram.
3. You are performing a cardiac catheterization procedure and need to be certain your pulmonary capillary wedge pressure is correct. Which of the following is the most reliable way to confirm that a presumed wedge pressure is a correct wedge pressure?

A. The catheter tip does not move with cardiac motion.
B. The waveform has classic A and V deflections.
C. Obtain a blood sample for oximetry from the catheter tip when wedged.
D. The mean PA pressure exceeds mean PCW pressure.
E. The T wave on the electrocardiogram follows the V wave on the wedge pressure tracing.
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D. The mean PA pressure exceeds mean PCW pressure.
E. The T wave on the electrocardiogram follows the V wave on the wedge pressure tracing.
Cardiac Output Measurement

• **Definition:** Quantity of blood delivered to the systemic circulation per unit time

• **Techniques**
  – Fick-Oxygen Method
  – Indicator-Dilution Methods
    • Indocyanine Green
    • Thermodilution
Cardiac Output Measurement
Fick Oxygen Method

• **Fick Principle**: The total uptake or release of any substance by an organ is the product of blood flow to the organ and the arteriovenous concentration difference of the substance.

• As applied to lungs, the substance released to the blood is oxygen, oxygen consumption is the product of arteriovenous difference of oxygen across the lungs and pulmonary blood flow.

\[
\text{Oxygen consumption} = \frac{Q_p}{\text{Arteriovenous O}_2 \text{ difference}}
\]

• In the absence of a shunt, systemic blood flow (Qs) is estimated by pulmonary blood flow (Qp).

Cardiac Output Measurement
Fick Oxygen Method: AV $O_2$ Difference

- **Sampling technique**
  - *Mixed venous sample*
    - Collect from pulmonary artery
    - Collection from more proximal site may result in error with left-right shunting
  - *Arterial sample*
    - Ideal source: pulmonary vein
    - Alternative sites: LV, peripheral arterial
      - If arterial desaturation ($SaO2 < 95\%$) present, right-to-left shunt must be excluded

- **Measurement**
  - Reflectance (optical absorbance) oximetry

Cardiac Output Measurement

Thermodilution Method

\[
CO = \frac{V_I (T_B - T_I) \left( S_I \times C_I / S_B \times C_B \right)}{\int_0^\infty \Delta T_B \, dt} \times 60
\]

\( V_I \) = volume of injectate
\( S_I, S_B \) = specific gravity of injectate and blood
\( C_I, C_B \) = specific heat of injectate and blood
\( T_I \) = temperature of injectate
\( \Delta T_B \) = change in temperature measured downstream

Cardiac Output Measurement
Thermodilution Method

• Sources of Error (± 15%)
  – Unreliable in tricuspid regurgitation
  – Baseline temperature of blood in pulmonary artery may fluctuate with respiratory and cardiac cycles
  – Loss of injectate with low cardiac output states (CO < 3.5 L/min) due to warming of blood by walls of cardiac chambers and surrounding tissues. The reduction in $\Delta T_B$ at pulmonary arterial sampling site will result in overestimation of cardiac output
  – Empirical correction factor (0.825) corrects for catheter warming but will not account for warming of injectate in syringe by the hand

Stroke Volume

- Volume of blood ejected in a single contraction
- Volumetric analysis requires 3-dimensional analysis to calculate end-diastolic and end-systolic volume

\[
\text{Stroke volume} = \text{End-diastolic volume} - \text{End-systolic volume}
\]

- Estimation based on cardiac output

\[
\text{Stroke volume} = \frac{\text{Cardiac output}}{\text{Heart rate}}
\]

Hemodynamic Principles

1. In the cardiac catheterization laboratory, cardiac output is measured using the Fick principle or thermodilution technique. Which of the following statements is correct?

A. Using an assumed O\textsubscript{2} consumption of 125 ml/m\textsuperscript{2} is acceptable and results in minimal variability in cardiac output compared with direct measurements of O\textsubscript{2} consumption.

B. The thermodilution method underestimates cardiac output in patients with low forward flows (cardiac outputs <3.5 L/min).

C. The thermodilution method underestimates cardiac output in the presence of important tricuspid regurgitation.

D. O\textsubscript{2} saturation measured in blood collected from a central line in the right atrium is an acceptable substitute for a pulmonary artery sample when calculating the AV O\textsubscript{2} difference.

E. A high cardiac output will produce a large area under the temperature-time curve in thermodilution determinations.
Hemodynamic Principles

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E. A high cardiac output will produce a large area under the temperature-time curve in thermodilution determinations.
Hemodynamic Principles
An Overview

• Pressure measurement
• Right and left heart catheterization
• Cardiac output measurement
  – Fick-oxygen method
    • Arterial-venous oxygen difference
  – Indicator-dilution methods
    • Indocyanine green
    • Thermodilution
• Vascular resistance
• Shunt detection and measurement
• Gradients and valve stenoses
Vascular Resistance

Poiseuille’s Law

\[ Q = \frac{\pi (P_i - P_o) r^4}{8 \eta L} \]

Q = volume flow
Pi – Po = inflow – outflow pressure
r = radius of tube
L = length of tube
\( \eta \) = viscosity of the fluid

Resistance = \[ \frac{\Delta P}{Q} \] = \[ \frac{8 \eta L}{\pi r^4} \]

In vascular system, key factor is radius of vessel

**Vascular Resistance Definitions**

**Systemic vascular resistance**

\[
SVR = \frac{\overline{Ao} - \overline{RA}}{Q_s}
\]

**Pulmonary vascular resistance**

\[
PVR = \frac{\overline{PA} - \overline{LA}}{Q_p}
\]

**Normal reference values**

<table>
<thead>
<tr>
<th>Woods Units</th>
<th>Metric Units</th>
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<td>10 – 20</td>
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**Definitions**

- **SVR** (Systemic Vascular Resistance): \(\frac{\text{Ao} - \text{RA}}{Q_s}\)
- **PVR** (Pulmonary Vascular Resistance): \(\frac{\text{PA} - \text{LA}}{Q_p}\)

Vascular Resistance
Systemic Vascular Resistance

- **Increased**
  - Systemic HTN
  - Cardiogenic shock with compensatory arteriolar constriction

- **Decreased**
  - Inappropriately high cardiac output
    - Arteriovenous fistula
    - Severe anemia
    - High fever
    - Sepsis
    - Thyrotoxicosis
Vascular Resistance

Pulmonary Vascular Resistance

- Increased
  - Primary lung disease
  - Eisenmenger syndrome
  - Elevated pulmonary venous pressure
    - Left-sided myocardial dysfunction
    - Mitral / Aortic valve disease

- Decreased
3. The patient is a 42-year-old woman who presents with mild dyspnea. She has gained considerable weight and feels that it is the primary reason for the new symptoms. Her initial exam suggests no CHF, but a pulmonic flow murmur is heard. The second heart sound is clearly widely split. She has a right bundle branch block on her ECG. An echocardiogram is obtained that reveals an enlarged RA and RV. By Doppler/echocardiogram, a left-to-right shunt is noted across the atrial septum. Using saline contrast a few microcavitations appear on the left side of the heart. A cardiac catheterization is performed to assess size of shunt and pulmonary pressures.
Hemodynamic Principles

3. The cardiac catheterization revealed:
   Pressures (mmHg): RA: mean 7, RV: 45/6, PA: 45/25, mean 33, PCW: mean 10, LV: 120/5, Aortic: 120/80, mean 95.
   Hemoglobin: 13 mg/dl, Oxygen consumption: 250 ml/min.
   LA angiogram: Consistent with secundum atrial septal defect.

   Using these data, the pulmonary blood flow was determined to be 7.1 liters/min and the systemic blood flow was found to be 4.3 liters/min.
   Select the correct answer based on the findings at cardiac catheterization.

A. The Qp/Qs suggests that no therapy is required at this time.
B. The PVR/SVR ratio suggests the elevated PA pressure is due to Eisenmenger’s syndrome, and it is too late to consider ASD closure.
C. The PVR/SVR ratio is low enough that she would be a candidate for ASD closure at this time.
D. There are inadequate data to decide the patient’s operability.
E. Endocarditis prophylaxis is highly recommended to prevent endocarditis given these hemodynamics.
Hemodynamic Principles
An Overview

- Pressure measurement
- Right and left heart catheterization
- Cardiac output measurement
  - Fick-oxygen method
    - Arterial-venous oxygen difference
  - Indicator-dilution methods
    - Indocyanine green
    - Thermodilution
- Vascular resistance
- Shunt detection and measurement
- Gradients and valve stenoses
Shunt Detection & Measurement
Indications

- Arterial desaturation (<95%)
  - Alveolar hypoventilation (Physiologic Shunt) corrects with deep inspiration and/or $O_2$
    - Sedation from medication
    - COPD / Pulmonary parenchymal disease
    - Pulmonary congestion
  - Anatomic shunt (Rt $\rightarrow$ Lf) does not correct with $O_2$
- Unexpectedly high PA saturation (>80%) due to Lf $\rightarrow$ Rt shunt
Shunt Detection & Measurement Methods

- Shunt Detection
  - Indocyanine green method
  - Oximetric method
- Shunt Measurement
  - Left-to-Right Shunt
  - Right-to-Left Shunt
  - Bidirectional Shunt
Shunt Detection & Measurement

Methods

• Shunt Detection
  – Indocyanine green method
  – Oximetric method

• Shunt Measurement
  – Left-to-Right Shunt
  – Right-to-Left Shunt
  – Bidirectional Shunt
Shunt Detection & Measurement

Oximetric Methods

- Obtain O2 saturations in sequential chambers, identifying both step-up and drop-off in O2 sat
- Insensitive for small shunts (< 1.3:1)

Shunt Detection & Measurement
Oximetry Run

- IVC, L4-5 level
- IVC, above diaphragm
- SVC, innominate
- SVC, at RA
- RA, high
- RA, mid
- RA, low
- RV, mid
- RV, apex
- RV, outflow tract
- PA, main
- PA, right or left
- Left ventricle
- Aorta, distal to ductus

• RA receives blood from several sources
  – SVC: Saturation most closely approximates true systemic venous saturation
  – IVC: Highly saturated because kidneys receive 25% of CO and extract minimal oxygen
  – Coronary sinus: Markedly desaturated because heart maximizes O2 extraction

• Phlamm Equation: Mixed venous saturation used to normalize for differences in blood saturations that enter RA

\[
\text{Mixed venous saturation} = \frac{3 \times (\text{SVC}) + \text{IVC}}{4}
\]
Shunt Detection & Measurement Methods

- Shunt Detection
  - Indocyanine green method
  - Oximetric method
- Shunt Measurement
  - Left-to-Right Shunt
  - Right-to-Left Shunt
  - Bidirectional Shunt
# Shunt Detection & Measurement

## Detection of Left-to-Right Shunt

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<th>Level of shunt</th>
<th>Mean $\Delta O_2$ % Sat</th>
<th>Mean $\Delta O_2$ Vol %</th>
<th>Minimal $Q_pQ_s$ detected</th>
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</thead>
<tbody>
<tr>
<td>Atrial (SVC/IVC $\rightarrow$ RA)</td>
<td>$\geq 7$</td>
<td>$\geq 1.3$</td>
<td>1.5 – 1.9</td>
<td>ASD, PAPVR, VSD with TR, Ruptured sinus of Valsalva, Coronary fistula to RA</td>
</tr>
<tr>
<td>Ventricular (RA $\rightarrow$ RV)</td>
<td>$\geq 5$</td>
<td>$\geq 1.0$</td>
<td>1.3 – 1.5</td>
<td>VSD, PDA with PR, Coronary fistula to RV</td>
</tr>
<tr>
<td>Great vessel (RV $\rightarrow$ PA)</td>
<td>$\geq 5$</td>
<td>$\geq 1.0$</td>
<td>1.3</td>
<td>Aorto-pulmonary window, Aberrant coronary origin, PDA</td>
</tr>
<tr>
<td>ANY LEVEL (SVC $\rightarrow$ PA)</td>
<td>$\geq 7$</td>
<td>$\geq 1.3$</td>
<td>1.3</td>
<td>All of the above</td>
</tr>
</tbody>
</table>

Shunt Detection & Measurement
Oximetric Methods

- **Fick Principle**: The total uptake or release of any substance by an organ is the product of blood flow to the organ and the arteriovenous concentration difference of the substance.
  - Pulmonary circulation (Qp) utilizes PA and PV saturations

\[
O_2 \text{ content} = 1.36 \times \text{Hgb} \times O_2 \text{ saturation}
\]

\[
PBF = \frac{O_2 \text{ consumption}}{(PvO_2 - PaO_2) \times 10}
\]
• **Fick Principle**: The total uptake or release of any substance by an organ is the product of blood flow to the organ and the arteriovenous concentration difference of the substance.
  – Systemic circulation (Qs) utilizes MV and Ao saturations

\[
\text{O}_2 \text{ content} = 1.36 \times \text{Hgb} \times \text{O}_2 \text{ saturation}
\]

\[
\text{SBF} = \frac{\text{O}_2 \text{ consumption}}{(\text{AoO}_2 - \text{MVO}_2) \times 10}
\]
**Shunt Detection & Measurement**

**Oximetric Methods**

- **Fick Principle**: The total uptake or release of any substance by an organ is the product of blood flow to the organ and the arteriovenous concentration difference of the substance.
  - Pulmonary circulation (Qp) utilizes PA and PV saturations
  - Systemic circulation (Qs) utilizes MV and Ao saturations

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\text{O}_2 \text{ content} = 1.36 \times \text{Hgb} \times \text{O}_2 \text{ saturation}
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\]

\[
\text{SBF} = \frac{\text{O}_2 \text{ consumption}}{\left(\text{AoO}_2 - \text{MVO}_2\right) \times 10}
\]
Effective Pulmonary Blood Flow: flow that would be present if no shunt were present

Requires
- \( MV = PA \) saturation
- \( PV - PA = PV - MV \)

\[
\text{Effective Pulmonary Blood Flow} = \frac{O_2 \text{ consumption}}{(PV - MV O_2) \times 10} = \frac{O_2 \text{ consumption}}{(PV - Pa O_2) \times 10}
\]

Shunt Detection & Measurement
Left-to-Right Shunt

- Left to right shunt results in step-up in $O_2$ between MV and PA
- Shunt is the difference between pulmonary flow measured and what it would be in the absence of shunt (EPBF)
- Systemic Blood Flow = EPBF

Left-Right Shunt = Pulmonary Blood Flow – Effective Blood Flow

\[
\text{Qp / Qs Ratio} = \frac{\text{PBF}}{\text{SBF}} = \frac{(\text{AoO}_2 - \text{MVO}_2)}{(\text{PvO}_2 - \text{PaO}_2)}
\]

Shunt Detection & Measurement
Left-to-Right Shunt

- ASD
- VSD
- Coronary Cameral Fistula
- Ruptured Sinus of Valsalva
- Partial Anomalous Pulmonary Venous Return
- Aorto Pulmonary Window
- PDA
- Aberrant Coronary Origin

Shunt Detection & Measurement Methods

• Shunt Detection
  – Indocyanine green method
  – Oximetric method

• Shunt Measurement
  – Left-to-Right Shunt
  – Right-to-Left Shunt
  – Bidirectional Shunt
Shunt Detection & Measurement

Effective Pulmonary Blood Flow

- **Effective Pulmonary Blood Flow**: flow that would be present if no shunt were present

- Requires
  - \( PV = Ao \) saturation
  - \( PV - MV = Ao - MV \)

\[
\text{Effective Pulmonary Flow} = \frac{O_2 \text{ consumption}}{(Pv - MV O_2) \times 10} = \frac{O_2 \text{ consumption}}{(Ao - MV O_2) \times 10}
\]

Shunt Detection & Measurement
Right-to-Left Shunt

- Left to right shunt results in step-down in $O_2$ between PV and Ao
- Shunt is the difference between systemic flow measured and what it would be in the absence of shunt (EPBF)
- Pulmonary Blood Flow = EPBF

$$\text{Right-Left Shunt} = \frac{O_2 \text{ consumption}}{(\text{AoO}_2 - \text{MVO}_2) \times 10} - \frac{O_2 \text{ consumption}}{(\text{PvO}_2 - \text{MVO}_2) \times 10}$$

$$\frac{Q_p}{Q_s} \text{ Ratio} = \frac{\text{PBF}}{\text{SBF}} = \frac{(\text{AoO}_2 - \text{MVO}_2)}{(\text{PvO}_2 - \text{PaO}_2)}$$

Shunt Detection & Measurement
Right-to-Left Shunt

- Tetralogy of Fallot
- Eisenmenger Syndrome
- Pulmonary arteriovenous malformation
- Total anomalous pulmonary venous return (mixed)
Shunt Detection & Measurement Methods

• Shunt Detection
  – Indocyanine green method
  – Oximetric method

• Shunt Measurement
  – Left-to-Right Shunt
  – Right-to-Left Shunt
  – Bidirectional Shunt
Bidirectional Shunts

- **Left-to-Right Shunt**
  
  \[
  Q_p (MV O_2 \text{ content} - PA O_2 \text{ content})
  = \frac{(MV O_2 \text{ content} - PV O_2 \text{ content})}{(MV O_2 \text{ content} - PV O_2 \text{ content})}
  \]

- **Right-to-Left Shunt**
  
  \[
  Q_p (PV O_2 \text{ content} - SA O_2 \text{ content}) (PA O_2 \text{ content} - PV O_2 \text{ content})
  = \frac{(SA O_2 \text{ content} - PV O_2 \text{ content}) (MV O_2 \text{ content} - PV O_2 \text{ content})}{(SA O_2 \text{ content} - PV O_2 \text{ content}) (MV O_2 \text{ content} - PV O_2 \text{ content})}
  \]

* If pulmonary vein not entered, use 98% x O_2 capacity.

- Transposition of Great Arteries
- Tricuspid atresia
- Total anomalous pulmonary venous return
- Truncus arteriosus
- Common atrium (AV canal)
- Single ventricle
Shunt Detection & Measurement
Limitations of Oximetric Method

• Requires steady state with rapid collection of O\textsubscript{2} samples
• Insensitive to small shunts
• Flow dependent
  – Normal variability of blood oxygen saturation in the right heart chambers is influenced by magnitude of SBF
  – High flow state may simulate a left-to-right shunt
• When O\textsubscript{2} content is utilized (as opposed to O\textsubscript{2} sat), the step-up is dependent on hemoglobin.

1. A patient undergoes right and left heart catheterization. The patient is breathing room air, hemoglobin is 13.6 gm/dl, and measured oxygen consumption is 250 ml/minute. The systemic arterial oxygen content is 195 ml/liter and the mixed venous oxygen content is 145 ml/liter. Which of the following is the correct cardiac output?

A. 5.0 liters/minute.
B. 5.3 liters/minute.
C. 5.8 liters/minute.
D. 6.2 liters/minute.
E. 6.5 liters/minute.
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E. 6.5 liters/minute.
2. The following oxygen saturations were obtained during cardiac catheterization from a patient with a suspected shunt. The saturations shown are the means of multiple values.

<table>
<thead>
<tr>
<th>Location</th>
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<tr>
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</tr>
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<td>79%</td>
</tr>
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<td>75%</td>
</tr>
<tr>
<td>Pulmonary artery</td>
<td>80%</td>
</tr>
<tr>
<td>Pulmonary vein</td>
<td>99%</td>
</tr>
<tr>
<td>High right atrium</td>
<td>70%</td>
</tr>
<tr>
<td>Low right atrium</td>
<td>83%</td>
</tr>
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<td>78%</td>
</tr>
<tr>
<td>Left atrium</td>
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</tr>
<tr>
<td>Aorta</td>
<td>98%</td>
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Which of the following is the correct location and $Q_P/Q_S$ ratio?

A. 3-to-1 shunt at the atrial level.
B. 2-to-1 shunt at the ventricular level.
C. Bidirectional shunting at the atrial level with a 1.8-to-1 left to right shunt and 1.2-to-1 right-to-left shunt.
D. 2-to-1 at the atrial level.
E. 3-to-1 at the ventricular level.
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D. 2-to-1 at the atrial level.
E. 3-to-1 at the ventricular level.
3. A 40-year-old obese woman is admitted to the hospital with shortness of breath and you are asked to consult. She has ruddy cheeks and perhaps mild cyanosis, but there is no clubbing. Her jugular venous pulse is not elevated and lungs are clear. A right ventricular heave is palpated, as is the second heart sound along the left sternal border. Her left ventricular apex is not displaced. Auscultation shows a soft systolic murmur along the left sternal border that radiates slightly toward the left with an S3 present, but you cannot distinguish whether it is a left or right-sided S3. The pulmonary component of her second heart sound is loud. There is no hepatomegaly or edema. Her echocardiogram is of marginal quality, but there is marked enlargement of the right atrium and right ventricle. Agitated saline injection results in filling of the left heart structures immediately through what appears to be a secundum atrial septal defect (ASD).
Cardiac catheterization shows the following hemodynamics and oxygen saturations:

### Pressures (mmHg):
- RA: a=15, v=13, mean=14
- RV: 50/15
- PA: 50/25 mean=32
- PCW: mean=10
- LV: 130/10
- Aorta: 115/60 mean=78

### Saturations:
- SVC: 60%
- IVC: 70%
- RA: 80%
- RV: 79%
- PA: 79%
- Ao: 97%
- LA: 97%
- PV: 98%

Oxygen consumption: 275 ml/min
Hemoglobin: 15.0 gm%

Which of the following is the most appropriate assessment and management of this patient?
A. The patient has excessively high pulmonary vascular resistance and irreversible pulmonary hypertension, thus it is too late to consider surgical closure of her ASD.

B. Her pulmonary hypertension is primarily due to the increased pulmonary blood flow with a mild increase in pulmonary vascular resistance. Her PVR/SVR ratio falls within the acceptable range, and surgical closure of the ASD is appropriate.

C. Although her pulmonary hypertension is mostly due to increased pulmonary blood flow, the elevated right atrial pressure indicates right heart failure and thus she would not benefit from surgical closure.

D. The patient has a balanced shunt (Qp/Qs = 1.1) and should undergo surgery to prevent further deterioration in her condition and progressive cyanosis in the future.

E. None of the above is correct.
A. The patient has excessively high pulmonary vascular resistance and irreversible pulmonary hypertension, thus it is too late to consider surgical closure of her ASD.

B. Her pulmonary hypertension is primarily due to the increased pulmonary blood flow with a mild increase in pulmonary vascular resistance. Her PVR/SVR ratio falls within the acceptable range, and surgical closure of the ASD is appropriate.

C. Although her pulmonary hypertension is mostly due to increased pulmonary blood flow, the elevated right atrial pressure indicates right heart failure and she would not benefit from surgical closure.

D. The patient has a balanced shunt (Qp/Qs = 1.1) and should undergo surgery to prevent further deterioration in her condition and progressive cyanosis in the future.

E. None of the above is correct.

**Calculate PVR / SVR**

> 0.5  Risk of surgery increased

> 0.7  No benefit from surgery
A 52-year-old man undergoes catheterization for unexplained right ventricular dilatation seen on echocardiography. His spiral CT scan and a radionuclide ventilation perfusion scan are normal. Oximetry is performed during right and left heart catheterization. The following saturations are noted:

- Left ventricle: 96%
- Aorta: 96%
- Main pulmonary artery: 80%
- Right ventricular outflow tract: 80%
- Right ventricular apex: 79%
- High-right atrium: 74%
- Mid-right atrium: 84%
- Low-right atrium: 79%
- SVC: 64%
- IVC: 70%
4. Which of the following is the most likely diagnosis?

A. Partial anamolous pulmonary venous return with a $Q_P/Q_S$ less than 1.5.
B. Atrial septal defect with a $Q_P/Q_S$ between 1.5 and 2.0.
C. Patent ductus arteriosus.
D. Bi-directional shunt.
E. Atrial septal defect with a $Q_P/Q_S$ greater than 2.0.
Hemodynamic Principles

4. Which of the following is the most likely diagnosis?

A. Partial anomalous pulmonary venous return with a $Q_p/Q_s$ less than 1.5.
B. Atrial septal defect with a $Q_p/Q_s$ between 1.5 and 2.0.
C. Patent ductus arteriosus.
D. Bi-directional shunt.
E. Atrial septal defect with a $Q_p/Q_s$ greater than 2.0.
Given the following information, calculate the approximate left-to-right shunt in a patient with a secundum ASD: SVC oxygen saturation = 55%, IVC oxygen saturation = 65%, RA oxygen saturation = 78%, PA oxygen saturation = 75%, aortic oxygen saturation = 95%, oxygen consumption = 280 ml/min, hemoglobin = 13.0. Assume a PV oxygen saturation of 95%.

A. The left-to-right shunt is 3.7 liters/min.
B. The left-to-right shunt is 2.8 liters/min.
C. The left-to-right shunt is 2.4 liters/min.
D. The left-to-right shunt is 3.0 liters/min.
5. Given the following information, calculate the approximate left-to-right shunt in a patient with a secundum ASD: SVC oxygen saturation = 55%, IVC oxygen saturation = 65%, RA oxygen saturation = 78%, PA oxygen saturation = 75%, aortic oxygen saturation = 95%, oxygen consumption = 280 ml/min, hemoglobin = 13.0. Assume a PV oxygen saturation of 95%.

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B. The left-to-right shunt is 2.8 liters/min.
C. The left-to-right shunt is 2.4 liters/min.
D. The left-to-right shunt is 3.0 liters/min.
6. Calculation of the $Q_P/Q_S$ (pulmonary blood flow/systemic blood flow) ratio provides information regarding relative shunt size. In a patient with an atrial septal defect and a left-to-right shunt, but no right-to-left shunt, select the minimal amount of information required to determine the $Q_P/Q_S$ ratio.

A. The SVC (superior vena cava) oxygen saturation, the PV (pulmonary venous) oxygen saturation, and the oxygen consumption.

B. The PA (pulmonary artery) oxygen saturation, the AO (aortic) oxygen saturation, and the MV (mixed venous) oxygen saturation.

C. The PA oxygen saturation, the AO oxygen saturation, and the oxygen consumption.

D. The MV oxygen saturation, the PV oxygen saturation, and the oxygen consumption.

E. The MV oxygen saturation, the PA oxygen saturation, and the oxygen consumption.
Hemodynamic Principles

6. Calculation of the $Q_P/Q_S$ (pulmonary blood flow/systemic blood flow) ratio provides information regarding relative shunt size. In a patient with an atrial septal defect and a left-to-right shunt, but no right-to-left shunt, select the minimal amount of information required to determine the $Q_P/Q_S$ ratio.

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B. The PA (pulmonary artery) oxygen saturation, the AO (aortic) oxygen saturation, and the MV (mixed venous) oxygen saturation.

C. The PA oxygen saturation, the AO oxygen saturation, and the oxygen consumption.

D. The MV oxygen saturation, the PV oxygen saturation, and the oxygen consumption.

E. The MV oxygen saturation, the PA oxygen saturation, and the oxygen consumption.
7. A 45-year-old woman presents with a murmur heard by her gynecologist. She is asymptomatic. On exam she has wide splitting of the second heart sound and a pulmonic flow murmur. On echocardiography, she has evidence for an enlarged right atrium and right ventricle. Injecting agitated saline contrast, a small number of "bubbles" are seen in the left atrium. The septum is well seen, and there is no secundum atrial septal defect. Pulmonary pressure is estimated to be normal. A sinus venosus ASD is suspected and flow through an anomalous pulmonary vein to the SVC is suggested.
7. Select the correct answer given the following information. The high SVC oxygen saturation is 60%; the IVC oxygen saturation is 70%. The PA saturation is 80%; the AO saturation is 95%. Assume a PV saturation of 95%. The oxygen consumption is 250 ml/min.

A. The $Q_p/Q_s$ ratio is about 2.2.
B. The $Q_p/Q_s$ ratio is about 1.8.
C. The $Q_p/Q_s$ ratio is about 1.6.
D. The $Q_p/Q_s$ ratio is about 2.0.
E. There is inadequate information to determine the shunt ratio.
7. Select the correct answer given the following information. The high SVC oxygen saturation is 60%; the IVC oxygen saturation is 70%. The PA saturation is 80%; the AO saturation is 95%. Assume a PV saturation of 95%. The oxygen consumption is 250 ml/min.

A. The $Q_p/Q_s$ ratio is about 2.2.
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C. The $Q_p/Q_s$ ratio is about 1.6.
D. The $Q_p/Q_s$ ratio is about 2.0.
E. There is inadequate information to determine the shunt ratio.
8. Because of advances in therapy, many children with congenital heart disease are living longer and well into adulthood. Therefore, the recognition and treatment of congenital heart disease in adults is becoming important for adult cardiologists. Which of the following conditions is associated with a left-to-right shunt?

A. Scimitar syndrome
B. Persistent left superior vena cava syndrome
C. IVC interruption with azygous continuation
D. Shone syndrome
E. Williams Syndrome
Because of advances in therapy, many children with congenital heart disease are living longer and well into adulthood. Therefore, the recognition and treatment of congenital heart disease in adults is becoming important for adult cardiologists. Which of the following conditions is associated with a left-to-right shunt?

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D. Shone syndrome
E. Williams Syndrome
Hemodynamic Principles
An Overview

• Pressure measurement
• Right and left heart catheterization
• Cardiac output measurement
  – Fick-oxygen method
    • Arterial-venous oxygen difference
  – Indicator-dilution methods
    • Indocyanine green
    • Thermodilution
• Vascular resistance
• Shunt detection and measurement
• Gradients and valve stenoses
Valve Stenoses
Gorlin Formula Derivation

Hydraulic Principle # 1
(Toricelli’s Law)

\[ F = A \cdot V \cdot C \]

- \( F \) = flow rate
- \( A \) = area of orifice
- \( V \) = velocity of flow
- \( C_c \) = coefficient of orifice contraction

Hydraulic Principle # 2

\[ V^2 = C_v^2 \cdot 2 \, g \, h \]

- \( V \) = velocity of flow
- \( C_v \) = coefficient of velocity
- \( g \) = acceleration gravity constant
- \( h \) = pressure gradient in cm H\(_2\)O

\[ A = \frac{\text{Flow}}{C_c \, C_v \cdot \sqrt{2 \, g \, h}} \]

- \( A \) = area of orifice
- \( C \) = coefficient
- \( 44.3 \) = value

\[ = \frac{\text{Flow}}{C \cdot 44.3 \cdot \sqrt{h}} \]
Valve Stenoses
Two Catheter Technique
Valve Stenoses
Gorlin Formula Derivation

\[ A = \frac{\text{Flow}}{C \cdot 44.3 \sqrt{h}} \]

Flow has to be corrected for the time during which there is cardiac output across the valve.

- Aortic
- Pulmonic
- Tricuspid
- Mitral

Gorlin Formula:

\[ A = \frac{\text{CO} / (\text{DFP or SEP}) \cdot \text{HR}}{C \cdot 44.3 \sqrt{\Delta P}} \]

Constant:
- Aortic, Tricuspid, Pulmonic: \( C = 1.0 \)
- Mitral: \( C = 0.85 \)
- VSD, PDA: \( C = 1.0 \)
Valve Stenoses
The “Quick Valve Area” Formula

Gorlin Formula:

\[ A = \frac{CO}{(DFP \text{ or } SEP) \cdot HR} \]
\[ C \cdot 44.3 \cdot \sqrt{\Delta P} \]

Quick Valve Area Formula (Hakki Formula):

Determine peak gradient across valve.

\[ A = \frac{CO}{\sqrt{\text{Peak gradient}}} \]
### Aortic Valve Stenosis

Calculating Valve Area

**Step 1:** Planimeter area and calculate SEP

<table>
<thead>
<tr>
<th>Area of gradient (mm²)</th>
<th>Length of SEP (mm)</th>
<th>Gradient Deflection (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average deflection = _____ mm
Aortic Valve Stenosis
Calculating Valve Area

Step 2: Calculate mean gradient

Mean gradient = Average deflection \times \text{Scale Factor}
\begin{align*}
\text{(mm Hg)} & \quad \text{(mm deflection)} & \quad \text{(mm Hg / mm deflection)} \\
\end{align*}

Step 3: Calculate average systolic period

Average SEP = \frac{\text{Average SEP (mm)}}{\text{Paper speed (mm / sec)}}
\begin{align*}
\text{(sec / beat)} & \quad \text{(mm)} & \quad \text{(mm / sec)} \\
\end{align*}

Step 4: Calculate valve area

Valve area = \frac{Q \ (cm^3 / min)}{[\text{Average SEP (sec / beat) \times HR (beat / min)]}}
\begin{align*}
\text{(cm)} & \quad \text{(cm^3 / min)} & \quad \text{[Average SEP (sec / beat) \times HR (beat / min)]} \\
\text{2} & \quad \text{3} & \quad \text{4} & \quad \text{5} \\
\end{align*}
\begin{align*}
44.3 \times \sqrt{\text{mean gradient}}
\end{align*}
Aortic Stenosis
Reference Values

Aortic valve area

Normal 3.0 cm²
Mild stenosis > 1.0 cm²
Moderate stenosis 0.7 – 1.0 cm²
Moderate-severe stenosis 0.5 – 0.7 cm²
Severe stenosis ≤ 0.5 cm²

Aortic Stenosis
Pitfalls in Gorlin Formula

• Hydraulic principles
  – Gorlin formula substitutes pressure for velocity
• Low cardiac output
• Mixed valvular disease
• Pullback hemodynamics
• Improper alignment
Aortic Stenosis
Pitfalls in Gorlin Formula

- Hydraulic principles
- Low cardiac output
  - Distinguish true anatomic stenosis from aortic psuedostenosis, a physiologic state in which there is insufficient flow through the valve secondary to decreased LV pressure (valve partially opens)
  - Nitroprusside or dobutamine to distinguish conditions
- Mixed valvular disease
- Pullback hemodynamics
- Improper alignment
• 75 consecutive patients with isolated AS
• Compare Gorlin AVA and continuity equation (Doppler) AVA
• Doppler AVA systematically larger than Gorlin AVA (0.10 ± 0.17 cm$^2$, p<0.0001)
• AVA difference was accentuated at low flow states (cardiac index < 2.5 L/min/m$^2$)

Aortic Stenosis
Gorlin Conundrum

Symptomatic low-gradient, low-output AS
- AVA < 0.5 cm²
- Mean gradient ≤ 30 mm Hg
- LVEF ≤ 0.45

Fixed AS
Dobutamine induced increases in peak velocity, mean gradient, and valve resistance with no change in AVA

Relative AS
Dobutamine induced increases in AVA (≥ 0.3 cm²) without significant change in peak velocity, mean gradient, or valve resistance

No Contractile Reserve
Dobutamine induced no change in any hemodynamic variable

Aortic Stenosis
Gorlin Conundrum

- 32 patients with low-output, low-gradient AS and an EF < 40% received dobutamine infusion in cath lab
- Dobutamine continued until:
  - Peak dose 40 ug/kg/min
  - Mean gradient > 40 mm Hg
  - HR > 140
  - 50% increase in CO
- 21 patients had AVR at discretion of MD
- All patients with final AVR ≤ 1.2 cm² at peak dobutamine infusion and a mean gradient > 30 mm Hg were found to have severe AS at time of surgery
- 15 patients showed contractile reserve (SV > 20%), 1 died perioperatively and 12 were alive in Class I or II at median 32 month follow-up

Aortic Stenosis
Low-Flow, Low-Gradient AS

- Low-Gradient
  - Mean gradient < 30 mm Hg
  - AVA < 1.0 cm²
- Low-Flow
  - Diminished forward stroke volume
  - Not necessarily diminished LVEF

Aortic Stenosis
Pitfalls in Gorlin Formula

• Hydraulic principles
• Low cardiac output
• **Mixed valvular disease**
  - AS & AI: CO underestimates transvalvular flow → Gorlin underestimates AVA
  - AS & MR: CO overestimates forward stroke volume → Gorlin overestimates AVA
• Pullback hemodynamics
• Improper alignment
Aortic Stenosis
Pitfalls in Gorlin Formula

• Hydraulic principles
• Low cardiac output
• Pullback hemodynamics
  – Peak-to-peak gradient larger than mean gradient
  – Large (≥ 7 Fr) catheter may obstruct lumen and overestimate severity
  – Pullback of catheter may reduce severity
  – Augmentation in peripheral systolic pressure by > 5 mm Hg during pullback → AVA ≤ 0.5 cm²

• Improper alignment
Aortic Stenosis Test Question

- Right heart catheterization
  - RA (a, v, mean): 7, 6, 5
  - RV: 25 / 5
  - PA: 25 / 11, mean 15; Sat = 76%
  - PCW (a, v, mean): 12, 11, 10
- Left heart catheterization
  - LV: 176 / 16; Sat = 96%
  - Ao: 100 / 66, mean 84; Sat = 96%
- O2 consumption: 225 mL/min
- BSA = 1.87 m²
- Hgb = 14.7 g/dL
- Pulse = 70 bpm
- LVEF = 69%

- Paper speed = 25 mm/sec
- Paper scale = 20 mm Hg / 10 mm Hg
Aortic Stenosis
Pitfalls in Gorlin Formula

- Hydraulic principles
- Low cardiac output
- Pullback hemodynamics
- Improper alignment

<table>
<thead>
<tr>
<th></th>
<th>LV-Aortic</th>
<th>Unaltered LV-FA</th>
<th>Aligned LV-FA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gradient</td>
<td>31</td>
<td>37</td>
<td>22</td>
</tr>
<tr>
<td>Area (cm²)</td>
<td>1.07</td>
<td>1.01</td>
<td>1.24</td>
</tr>
</tbody>
</table>
Aortic Stenosis
Increasing Cardiac Output

Cardiac Output (L/min)

Mean Gradient Across Valve

Area = \frac{CO}{(SEP \times HR)}

44.3 \times \sqrt{\text{gradient}}

AVA = 1.0

AVA = 0.7

AVA = 0.5

AVA = 0.3

HR = 80

0 50 100 150 200 250 300

0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0

Cardiac Output (L/min)
Aortic Stenosis
Increasing Gradient

Cardiac Output (L/min) vs Mean Gradient Across Valve

Area = \frac{\text{CO}}{(\text{SEP} \times \text{HR})} \times \frac{44.3 \times \sqrt{\text{gradient}}}{\text{CO} / (\text{SEP} \times \text{HR})}

\text{HR} = 80

AVA = 0.3, 0.5, 0.7, 1.0

AVA = 0.5
AVA = 0.3
AVA = 0.7
AVA = 1.0
AVA = 0.3
Aortic Stenosis
Increasing Pulse

Cardiac Output (L/min)

Area = \frac{CO}{(SEP \times HR)} \times 44.3 \times \sqrt{gradient}

HR = 60
Aortic Stenosis
Increasing Pulse

Cardiac Output (L/min)

Area = \frac{CO}{(SEP \times HR)} \times \sqrt{gradient}

HR = 80

AVA = 0.5
AVA = 0.3
AVA = 0.7
AVA = 1.0

Mean Gradient Across Valve

4.0 2.0 AVA = 1.0 AVA = 0.7 AVA = 0.5

0 50 100 150 200 250 300

44.3
Aortic Stenosis
Increasing Pulse

Cardiac Output (L/min) vs. Mean Gradient Across Valve

Area = \( \frac{CO}{(SEP \times HR)} \times 44.3 \times \sqrt{\text{gradient}} \)

HR = 100
Aortic Stenosis
Impact of Bradycardia on Fixed Stenosis

Cardiac Output (L/min)

Area = \frac{CO}{(SEP \times HR)} \times \sqrt{\text{gradient}}

HR = 100

\Delta P = 25
Aortic Stenosis

Impact of Bradycardia on Fixed Stenosis

Cardiac Output (L/min)

\[ \text{Area} = \frac{\text{CO}}{44.3 \times \sqrt{\text{gradient}}} \times \frac{1}{\text{SEP} \times \text{HR}} \]

\[ \Delta P = 40 \]

\[ \text{HR} = 80 \]
# Mitral Stenosis
## Calculating Valve Area

### Step 1: Planimeter area and calculate DFP

<table>
<thead>
<tr>
<th>Area of gradient (mm$^2$)</th>
<th>DFP (mm)</th>
<th>Gradient Deflection (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
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<tr>
<td>#3</td>
<td></td>
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<td>#4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average gradient = _____ mm
Mitral Stenosis
Calculating Valve Area

Step 2: Calculate mean gradient

\[
\text{Mean gradient} = \frac{\text{Average deflection}}{\text{Scale Factor}} \quad (\text{mm Hg}) \times (\text{mm Hg} / \text{mm deflection})
\]

Step 3: Calculate average systolic period

\[
\text{Average SEP} = \frac{\text{Average DFP (mm)}}{\text{Paper speed (mm/sec)}} \quad (\text{sec/beat})
\]

Step 4: Calculate valve area

\[
\text{Valve area} = \frac{Q (\text{cm}^3/\text{min})}{[\text{Average DFP (sec/beat)} \times \text{HR (beat/min)}]} \quad (\text{cm}^2)
\]

\[
37.7 \times \sqrt{\text{mean gradient}}
\]
# Mitral Stenosis

## Reference Values

**Mitral valve area**

<table>
<thead>
<tr>
<th>Type</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>4.0 – 6.0 cm²</td>
</tr>
<tr>
<td>Mild stenosis</td>
<td>&gt; 2.0 cm²</td>
</tr>
<tr>
<td>Moderate stenosis</td>
<td>1.0 – 2.0 cm²</td>
</tr>
<tr>
<td>Severe stenosis</td>
<td>&lt; 1.0 cm²</td>
</tr>
</tbody>
</table>

Pulmonary capillary wedge tracing
  - Mean PCWP < mean PAP
  - PCW O₂ sat > 95% or > Art O₂ sat

Alignment mismatch

Calibration errors

Cardiac output determination

Early diastasis
Mitral Stenosis
Pitfalls in Gorlin Formula

- **Pulmonary capillary wedge tracing**
- **Alignment mismatch**
  - LV & PCW traces do not match LV & LA traces because transmission of LA pressure back thru PV and capillary bed delayed 50-70 msec
  - Realign tracings
    - Shift PCW tracing leftward by 50-70 msec
    - V wave should peak immediately before LV downslope
- **Calibration errors**
- **Cardiac output determination**
- **Early diastasis**
Mitral Stenosis
Pitfalls in Gorlin Formula

- Pulmonary capillary wedge tracing
- Alignment mismatch
- **Calibration errors**
  - Errors in calibration and zero
  - Quick check: switch transducers between catheters and see if gradient identical
- **Cardiac output determination**
- **Early diastasis**
Mitral Stenosis
Pitfalls in Gorlin Formula

- Pulmonary capillary wedge tracing
- Alignment mismatch
- Calibration errors
- Cardiac output determination
  - Measure CO at same time gradient measured
  - Fick and thermodilution measure “forward” flow but Gorlin formula relies on total flow (antegrade and retrograde) across valve
  - In setting of MR, Gorlin formula will underestimate actual anatomic stenosis
- Early diastasis
Mitral Stenosis
Pitfalls in Gorlin Formula

- Pulmonary capillary wedge tracing
- Alignment mismatch
- Calibration errors
- Cardiac output determination
- Early diastasis
  - If PCWP and LV diastolic pressures equalize early, the "gradient" will appear to disappear early in diastole. The diastolic filling period (DFP) used in the calculation should include all of the nonisovolumic diastole.
Mitral Stenosis
Increasing Cardiac Output

Cardiac Output (L/min)

Mean Gradient Across Valve

HR = 80

Area = \( \frac{CO}{(SEP \times HR)} \)

\( 37.7 \times \sqrt{\text{gradient}} \)
Mitral Stenosis
Increasing Mean Gradient

Cardiac Output (L/min)

Mean Gradient Across Valve

HR = 80

Area = \( \frac{CO}{(SEP \times HR)} \) 

\[
37.7 \times \sqrt{\text{gradient}}
\]
Mitral Stenosis
Increasing Pulse

Cardiac Output (L/min) = \frac{CO}{(SEP \times HR)}

Area = \frac{37.7 \times \sqrt{gradient}}{\text{MVA}}
Mitral Stenosis
Increasing Pulse

Cardiac Output (L/min) vs. Mean Gradient Across Valve (mm Hg)

Area = \( \frac{\text{CO}}{(\text{SEP} \times \text{HR})} \times \frac{1}{37.7 \times \sqrt{\text{gradient}}} \)

- MVA = 4.0
- MVA = 2.0
- MVA = 1.0
- MVA = 0.7
- MVA = 0.5
- MVA = 0.3

HR = 80
Mitral Stenosis
Increasing Pulse

Cardiac Output (L/min) vs. Mean Gradient Across Valve (mm Hg)

MVA = 4.0
MVA = 2.0
MVA = 1.0
MVA = 0.7
MVA = 0.5
MVA = 0.3

HR = 100
Area = \frac{CO}{(SEP \times HR)} \times 37.7 \times \sqrt{\text{gradient}}

\text{CO} / (\text{SEP} \times \text{HR})

\text{Area} = \frac{\text{CO}}{(\text{SEP} \times \text{HR})} \times 37.7 \times \sqrt{\text{gradient}}
Mitral Stenosis
Impact of Tachycardia on Fixed Stenosis

Cardiac Output (L/min)

Mean Gradient Across Valve (mm Hg)

MVA = 4.0  MVA = 2.0  MVA = 1.0  MVA = 0.7

HR = 60

\( \Delta P = 12 \)
Mitral Stenosis
Impact of Tachycardia on Fixed Stenosis

Cardiac Output (L/min)

Mean Gradient Across Valve (mm Hg)

MVA = 4.0  MVA = 2.0  MVA = 1.0

MVA = 0.7
MVA = 0.5
MVA = 0.3

HR = 80

$\Delta P = 16$
Mitral Stenosis
Impact of Tachycardia on Fixed Stenosis

Cardiac Output (L/min)

Mean Gradient Across Valve (mm Hg)

Δ P = 20
Hemodynamic Principles

1. A 71 yo woman is referred for cardiac catheterization to evaluate her aortic valve. She complains of progressive DOE but denies chest pain. She has a history of 2 prior MIs and has inferior Q-waves on her ECG. A murmur of aortic stenosis was first noted about 14 years ago, and 3 years ago a soft diastolic murmur consistent with aortic insufficiency was detected. Her echo shows moderate LV enlargement with inferior akinesis and decreased LV function. By echo the aortic valve gradient is 20 mmHg, and the valve area is calculated to be 1.3 cm². She has mild to moderate aortic regurgitation and no mitral regurgitation by echo. Because her referring physician is concerned about the severity of her aortic valve disease as a potential cause for her symptoms and left ventricular dysfunction, she is referred for cardiac catheterization. During the catheterization, her cardiac output measured by the Fick method is 5.0 L/min and her mean aortic valve gradient is 16 mmHg. Biplane left ventriculography and coronary angiography are performed.
1. Which of the following is the most appropriate step in the analysis of these hemodynamic data?

A. The Gorlin formula should not be used to calculate valve area because it is less accurate when a low gradient is present.

B. Using the Fick cardiac output in the Gorlin formula will overestimate her actual valve area.

C. She should receive a dobutamine infusion and then recalculate the valve area with the new hemodynamics.

D. The Gorlin formula can be used to calculate her aortic valve area, but the angiographic output determined from the left ventriculogram should be used.

E. The correct valve area is calculated using the Gorlin formula and the difference between the angiographic output and forward output.
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E. The correct valve area is calculated using the Gorlin formula and the difference between the angiographic output and forward output.
Hemodynamic Principles

2. A patient with hypertrophic obstructive cardiomyopathy has a premature ventricular contraction during cardiac catheterization. Which one of the following responses would be seen on the beat after the premature ventricular contraction which would not be seen in a patient with valvular aortic stenosis?

A. An increase in the peak-to-peak gradient between the aorta and left ventricle.
B. An increase in the maximum instantaneous gradient between the aorta and left ventricle.
C. A decrease in the pulse pressure of the aortic pressure.
D. An increase in the left ventricular systolic pressure.
E. An increase in the aortic systolic pressure.
A patient with hypertrophic obstructive cardiomyopathy has a premature ventricular contraction during cardiac catheterization. Which one of the following responses would be seen on the beat after the premature ventricular contraction which would not be seen in a patient with valvular aortic stenosis?

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C. A decrease in the pulse pressure of the aortic pressure.
D. An increase in the left ventricular systolic pressure.
E. An increase in the aortic systolic pressure.
3. In patients in whom low cardiac output and low ejection fraction are associated with aortic stenosis, which calculation provides the strongest confirmation of fixed valvular obstruction?

A. Aortic valve area, Gorlin formula.
B. Planimetry of orifice area.
C. Aortic valve resistance.
D. Peak-to-peak left-ventricular-to-aortic gradient.
E. Aortic valve area, Hakki formula.
3. In patients in whom low cardiac output and low ejection fraction are associated with aortic stenosis, which calculation provides the strongest confirmation of fixed valvular obstruction?

A. Aortic valve area, Gorlin formula.
B. Planimetry of orifice area.
C. Aortic valve resistance (Mean gradient / CO) > 250
D. Peak-to-peak left-ventricular-to-aortic gradient.
E. Aortic valve area, Hakki formula.
4. To secure the diagnosis of aortic stenosis, what is the best technique to obtain the most accurate hemodynamic data?

A. Left ventricular and femoral artery pressures.
B. Left ventricular and ascending aortic pressures.
C. Aortic and left atrial pressures.
D. Left ventricular pressure at the apex and left ventricular pressure at the outflow tract.
E. Left ventricular and right ventricular pressures.
Hemodynamic Principles

4. To secure the diagnosis of aortic stenosis, what is the best technique to obtain the most accurate hemodynamic data?

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D. Left ventricular pressure at the apex and left ventricular pressure at the outflow tract.
E. Left ventricular and right ventricular pressures.
Hemodynamic Principles

5. A 78-year-old woman has increasing shortness of breath, DOE, and mild pedal edema. Physical examination demonstrates irregular pulse with moderate neck vein distension, a diastolic murmur over the left sternal border radiating to the apex, a brief systolic murmur at the apex, a quiet left precordium, and +1 pitting edema. Echocardiography suggests restricted transmitral flow and marked mitral annular calcification with a nondilated ventricle. Which of the following data sets most accurately characterizes the hemodynamics of this patient's mitral valve disease?

A. RA pressure = 10 mmHg; RV pressure = 60/12 mmHg; PA pressure = 30/16 mmHg; LVEDP = 16 mmHg.
B. RA pressure = 5 mmHg; RV pressure = 30/6 mmHg; PA pressure = 30/12 mmHg; LVEDP = 6 mmHg.
C. RA pressure = 15 mmHg; RV pressure = 80/16 mmHg; PA pressure = 80/40 mmHg; LVEDP = 18 mmHg.
D. RA pressure = 20 mmHg; RV pressure = 36/20 mmHg; PA pressure = 36/20 mmHg; LVEDP = 20 mmHg.
E. RA pressure = 5 mmHg; RV pressure = 60/6 mmHg; PA pressure = 20/10 mmHg; LVEDP = 10 mmHg.
Hemodynamic Principles

5. A 78-year-old woman has increasing shortness of breath, DOE, and mild pedal edema. Physical examination demonstrates irregular pulse with moderate neck vein distension, a diastolic murmur over the left sternal border radiating to the apex, a brief systolic murmur at the apex, a quiet left precordium, and +1 pitting edema. Echocardiography suggests restricted transmitral flow and marked mitral annular calcification with a nondilated ventricle. Which of the following data sets most accurately characterizes the hemodynamics of this patient's mitral valve disease?

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B. RA pressure = 5 mmHg; RV pressure = 30/6 mmHg; PA pressure = 30/12 mmHg; LVEDP = 6 mmHg.
C. RA pressure = 15 mmHg; RV pressure = 80/16 mmHg; PA pressure = 80/40 mmHg; LVEDP = 18 mmHg.
D. RA pressure = 20 mmHg; RV pressure = 36/20 mmHg; PA pressure = 36/20 mmHg; LVEDP = 20 mmHg.
E. RA pressure = 5 mmHg; RV pressure = 60/6 mmHg; PA pressure = 20/10 mmHg; LVEDP = 10 mmHg.
6. Excluding coronary artery disease, which of the following additional conditions may be present and obscure the presumptive diagnosis of aortic stenosis?

A. Mitral regurgitation.
B. Mitral stenosis.
C. Bilateral iliac stenoses.
D. Right ventricular pressure overload.
E. Hypertrophic obstructive cardiomyopathy.
6. Excluding coronary artery disease, which of the following additional conditions may be present and obscure the presumptive diagnosis of aortic stenosis?

A. Mitral regurgitation.
B. Mitral stenosis.
C. Bilateral iliac stenoses.
D. Right ventricular pressure overload.
E. Hypertrophic obstructive cardiomyopathy.
7. A symptomatic 35-year-old woman with congenital aortic stenosis undergoes echocardiography and cardiac catheterization. Her echocardiogram shows an aortic valve gradient of 54 mmHg. However, at catheterization the mean gradient recorded by simultaneous pressures is only 25 mmHg. Which of the following is not an explanation for the discrepancy between the gradient values?

A. A femoral artery pressure was used instead of a central aortic pressure during the catheterization.
B. The physiological recorder’s internal calibration was used to standardize the pressure transducers.
C. The left ventricular catheter was positioned in the left ventricular outflow tract.
D. There was a difference in physiologic conditions during the two determinations.
E. Echocardiography is inaccurate in estimating aortic valve gradients at high flow.
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D. There was a difference in physiologic conditions during the two determinations.
E. Echocardiography is inaccurate in estimating aortic valve gradients at high flow.
Hemodynamic Principles

8. Carabello’s sign refers to:

A. The reduced peripheral arterial pressure compared to the LV systolic pressure
B. An increment of 5 mm Hg or more in the peripheral pressure associated with the pullback of catheter from LV into aorta
C. A narrowing of the pulse pressure observed with simultaneous LV and Ao tracings following a PVC
D. The change in pulse pressure observed in patients with aortic stenosis during inspiration
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C. A narrowing of the pulse pressure observed with simultaneous LV and Ao tracings following a PVC

D. The change in pulse pressure observed in patients with aortic stenosis during inspiration
9. A patient with aortic stenosis is referred to you for a second opinion to see if aortic valve replacement is warranted. Specifically, you must compare the risk of the operation with the potential benefit.

A. A 68 year old patient with CHF, LVEF=20%, an AVA of 0.6 cm², an mean transvalvular gradient of 60 mm Hg.
B. A 67 year old patient with CHF, LVEF=20%, an AVA of 0.6 cm², an mean transvalvular gradient of 25 mm Hg in whom dobutamine doubles his CO and increases the valve gradient such that the calculated AVA remains 0.6 cm².
C. A 66 year old patient with CHF, LVEF=20%, an AVA of 0.6 cm², an mean transvalvular gradient of 25 mm Hg in whom dobutamine doubles his CO with little change in the gradient.
D. A 74 year old man who is symptomatic with normal LV function, a valve area of 0.9 cm², and a mean transvalvular gradient of 70 mm Hg.
E. An 80 year old otherwise healthy man, asymptomatic, with a valve area of 0.7 cm² and a mean transvalvular gradient of 70 mm Hg.
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E. An 80 year old otherwise healthy man, asymptomatic, with a valve area of 0.7 cm² and a mean transvalvular gradient of 70 mm Hg.
10. What accounts for the change in the patient’s hemodynamics between the left and right frame?
The End