

Cardiovascular Hemodynamics Study Guide

An In-Depth Review by Dr. Alice Matthews

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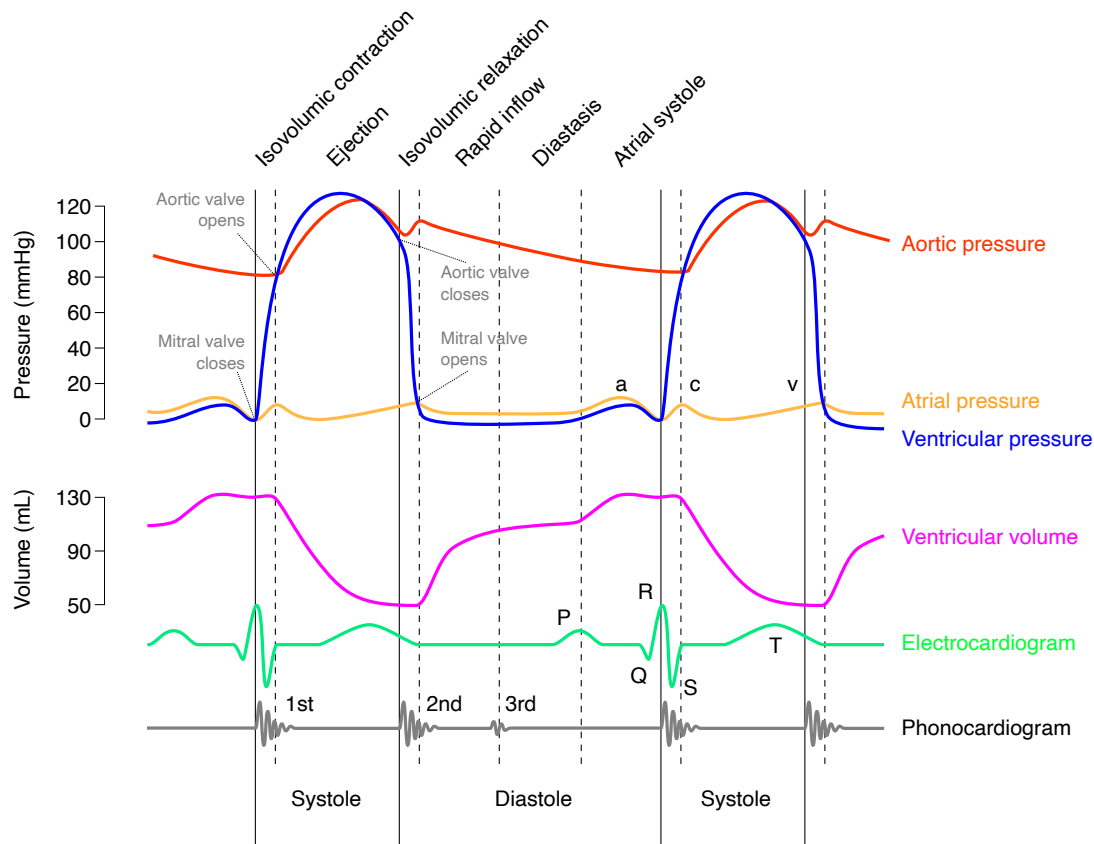
Based on ASE, AHA/ACC Guidelines and Current Echo Practice

PART 1: THE CARDIAC CYCLE

The Wiggers Diagram: The One Diagram That Explains Everything

Every hemodynamic measurement in this guide connects to a specific moment on the diagram below. When you measure a pressure gradient with Bernoulli, you are measuring the gap between two curves on this diagram. When you hear S1, you are hearing the mitral and tricuspid valves snap shut at the exact point where the LV pressure curve begins its steep climb. When an exam question asks “what happens during isovolumetric relaxation,” the answer is visible here: the aortic valve has just closed (S2), the mitral valve has not yet opened, and the LV pressure is in free fall with all four valves sealed.

Study this diagram until you can draw it from memory. If you can point to any moment on the time axis and explain what the pressures are doing, which valves are open, what the ECG shows, and what sound you would hear, you understand the cardiac cycle. Every formula that follows in Parts 2 through 4 is simply a way to *measure* something that is already *visible* on this diagram.



{Diagram: CC BY-SA 4.0, Wikimedia Commons. Top to bottom: ECG, aortic/LV/LA pressures, LV volume, heart sounds.}

(Key landmarks to memorize: (1) S1 marks MV/TV closure and the start of systole. (2) The LV-Aortic crossover opens the aortic valve. (3) The aortic valve closure marks the end of systole. (4) S2 marks AV/PV closure and the start of diastole. (5) The LA-LV crossover opens the mitral valve for filling. (6) At no point are all four valves open simultaneously.)

The Seven Phases Explained

Phase 1: Atrial Systole (Atrial Kick)

In plain English: This is the last little push of blood into the ventricle right before the big squeeze. On your echo, this is the **A-wave** on mitral Doppler.

The atrium contracts, pushing the final 20% of blood into the ventricle. The ECG P-wave triggers this. LV pressure rises to end-diastolic pressure (~8 mmHg). The LA pressure curve shows the **a-wave** (atrial contraction). An S4 heart sound may be heard here (always abnormal in adults). In atrial fibrillation, this phase is lost entirely, reducing cardiac output.

Phase 2: Isovolumetric Contraction

In plain English: The heart is squeezing with all doors shut, building up pressure like a water balloon about to burst. You hear **S1** here. On echo, this is where you start your **dP/dt** measurement on the MR jet.

All four valves are closed. The ventricle contracts but no blood moves because the LV pressure has not yet exceeded aortic diastolic pressure (~80 mmHg). Pressure rises rapidly from ~8 to ~80 mmHg in approximately 29 ms. **S1 occurs** (closure of the mitral and tricuspid valves). This is a pure pressure-building phase with zero flow.

Phase 3: Rapid Ejection

In plain English: The aortic valve flies open and blood rockets into the aorta. This is the moment you are capturing when you measure **peak aortic velocity** with CW Doppler for Bernoulli.

LV pressure exceeds aortic pressure, forcing the aortic valve open. Blood accelerates into the aorta. LV pressure peaks at ~120 mmHg. The LA pressure dips (**x-descent**) as the LV base pulls the atrial floor downward. This is the highest-flow phase of the cardiac cycle.

Phase 4: Reduced Ejection

In plain English: The heart is running out of steam. Blood is still moving forward but slowing down, like a ball at the top of its arc. On echo, this is near the end of the **LVOT VTI** tracing.

Contractile force diminishes as the myocardium repolarizes (T-wave on ECG). Blood continues flowing via inertia, but at a slower rate. The LA pressure gradually rises (**v-wave**) as pulmonary veins fill the atrium against a closed mitral valve. LV volume reaches its minimum: the end-systolic volume (~50 mL).

Phase 5: Isovolumetric Relaxation

In plain English: All doors slam shut again. The heart is relaxing but nothing is flowing yet. You hear **S2** here. On echo, the **IVRT** you measure on tissue Doppler happens during this exact phase.

The aortic valve closes, producing **S2** and the **dicrotic notch** on the aortic pressure tracing (brief pressure bump from elastic recoil). All four valves are again closed. LV pressure plummets from ~80 to ~12 mmHg. No blood flows. This is the “reset” phase before filling begins.

Phase 6: Rapid Filling (Early Diastole)

In plain English: The mitral valve opens and blood pours in. This is the biggest gush of filling and it is exactly the **E-wave** you see on your PW mitral Doppler. Most of the ventricle fills right here.

LV pressure drops below LA pressure, the mitral valve opens, and blood rushes in. **70-80% of ventricular filling occurs in this phase.** Active ventricular relaxation creates a suction effect. The LA pressure drops (**y-descent**). This corresponds to the **E-wave** on mitral Doppler. An S3 may be heard (normal under 40, abnormal in older adults).

Phase 7: Diastasis (Slow Filling)

In plain English: Almost nothing is happening. The heart is waiting for the next beat. This quiet pause is the first thing to disappear when the heart rate goes up, which is why tachycardia hurts diastolic filling.

LA and LV pressures nearly equalize. Minimal additional blood enters the ventricle. The atrium acts as a passive conduit from the pulmonary veins. At fast heart rates, this phase shortens first, which is why tachycardia reduces diastolic filling time. **Key rule:** At no point are all four valves open simultaneously.

PART 2: CORE HEMODYNAMIC FORMULAS

Simplified Bernoulli Equation

$$\Delta P = 4V^2$$

What this means: The pressure gradient (in mmHg) across any obstruction equals four times the peak velocity squared (in m/s). This converts a Doppler velocity measurement into a pressure difference.

Analogy: Think of a garden hose. If you put your thumb over the end (creating a stenosis), the water speeds up. The faster the water shoots out, the more pressure is pushing it through that narrow opening. Bernoulli says: measure the speed, and you know the pressure.

When to use the modified form: If the proximal velocity (V_1) exceeds 1.5 m/s, use the full equation:

$$\Delta P = 4(V_2^2 - V_1^2)$$

Clinical application: A peak aortic jet velocity of 4.5 m/s yields a peak gradient of $4 \times 4.5^2 = 81$ mmHg, consistent with severe aortic stenosis.

Continuity Equation

$$AVA = \frac{CSA_{LVOT} \times VTI_{LVOT}}{VTI_{AV}}$$

Where $CSA_{LVOT} = \pi \times (d/2)^2$ and d = LVOT diameter (cm), measured in the parasternal long axis view.

What this means: Blood volume passing through the LVOT must equal the volume passing through the aortic valve. If the valve is narrowed, blood speeds up to maintain the same flow. By measuring the speed increase, we calculate how narrow the valve is.

Analogy: Picture a river flowing into a narrow canyon. The same amount of water enters and exits, but in the canyon it flows much faster. If you know the river's width and speed before the canyon, and the speed inside it, you can calculate exactly how narrow the canyon is. That is the continuity equation applied to the aortic valve.

Clinical application: This is the primary method for calculating aortic valve area. An AVA below 1.0 cm^2 indicates severe aortic stenosis.

Dimensionless Index (DVI)

$$DVI = \frac{VTI_{LVOT}}{VTI_{AV}}$$

What this means: The dimensionless index compares the velocity through the LVOT to the velocity through the aortic valve. In a normal heart, these are similar (ratio close to 1.0). As the valve narrows, blood accelerates across it, and the ratio drops. A DVI below 0.25 indicates severe aortic stenosis.

Analogy: Think of two sections of highway. In the open stretch (LVOT), traffic moves at normal speed. In a construction zone (stenotic valve), traffic is forced to speed up. If traffic in the construction zone is moving 4 times faster than the open road, the road has narrowed to about a quarter of its original width ($DVI = 0.25$).

Clinical application: DVI is a quick screen for aortic stenosis severity that avoids measuring the LVOT diameter, which is the single biggest source of error in the continuity equation (because the diameter is squared). If $DVI < 0.25$, the valve is severely stenotic regardless of what the LVOT diameter measures.

DVI	Interpretation
> 0.50	Normal
0.25–0.50	Moderate AS
< 0.25	Severe AS

Mitral Valve Area by Pressure Half-Time

$$MVA = \frac{220}{PHT}$$

Where PHT = pressure half-time (ms), the time for the peak mitral gradient to fall by half. Also: $PHT = 0.29 \times DT$ (deceleration time).

What this means: A tight valve keeps a pressure difference across it for a long time because blood trickles through slowly. A wide-open valve lets pressure equalize quickly. The longer it takes for pressure to drop by half, the smaller the valve opening.

Analogy: Imagine draining a bathtub. A big drain empties fast (short pressure half-time, large valve area). A clogged drain takes forever (long pressure half-time, small valve area). The number 220 is just the calibration constant that converts the drain speed into the opening size.

Clinical application: MVA below 1.0 cm^2 indicates severe mitral stenosis.

Ejection Fraction

$$EF = \frac{EDV - ESV}{EDV} \times 100\%$$

Where EDV = end-diastolic volume (mL) and ESV = end-systolic volume (mL).

What this means: Ejection fraction tells you what percentage of blood the ventricle actually pumps out with each beat. If the LV holds 120 mL at its fullest and 50 mL remain after contraction, then $EF = (120-50)/120 = 58\%$, meaning the heart ejects 58% of its contents each beat.

Analogy: Think of squeezing a sponge full of water. A healthy sponge (normal EF) wrings out more than half the water. A stiff, damaged sponge (low EF) barely squeezes any water out, even though it is full. The percentage of water you squeeze out is the ejection fraction.

Clinical application: EF is the single most common measure of systolic function. It is measured by Simpson's biplane method (tracing the LV cavity in apical 4-chamber and 2-chamber views at end-diastole and end-systole).

Classification	LVEF
Normal (men / women)	52–72% / 54–74%
Preserved (HFpEF)	$\geq 50\%$
Mildly reduced (HFmrEF)	41–49%
Reduced (HFrEF)	$\leq 40\%$

Stroke Volume and Cardiac Output

$$SV = CSA_{LVOT} \times VTI_{LVOT}$$

$$CO = SV \times HR$$

$$CI = CO/BSA$$

What this means: Stroke volume is the amount of blood ejected in one heartbeat, measured by multiplying the cross-sectional area of the outflow tract by the distance blood travels in one beat (VTI, the velocity-time integral). Cardiac output is simply stroke volume times heart rate: how much blood per minute. Cardiac index adjusts cardiac output for body size so you can compare a small person to a large person fairly.

Analogy: Imagine a fire hose. The cross-section of the hose is the CSA. The VTI is how far the water travels in one pump stroke. Multiply them and you get the volume per pump (stroke volume). Now multiply by how many times the pump cycles per minute (heart rate), and you get the total flow (cardiac output). A bigger person needs a bigger hose, so cardiac index accounts for body surface area.

Clinical application: Stroke volume is essential for calculating regurgitant volumes, shunt ratios (Qp:Qs), and monitoring cardiac function. A stroke volume index (SV/BSA) below 35 mL/m² suggests low-flow states and is important in grading aortic stenosis with reduced EF.

Parameter	Normal Range
Stroke volume	60–100 mL
Stroke volume index	33–47 mL/m ²
Cardiac output	4–8 L/min
Cardiac index (CO/BSA)	2.5–4.0 L/min/m ²

dP/dt (Rate of Pressure Rise)

$$dP/dt = \frac{32 \text{ mmHg}}{\Delta t}$$

Measured from the MR jet using CW Doppler. Δt = time between the 1 m/s and 3 m/s points on the ascending limb. Using Bernoulli: at 1 m/s the pressure is 4 mmHg, at 3 m/s it is 36 mmHg, so the difference is 32 mmHg.

What this means: This measures how fast the ventricle builds up pressure during early contraction. A healthy ventricle generates pressure rapidly. A failing ventricle builds pressure slowly.

Analogy: Think of inflating a balloon. A strong person blows it up quickly (high dP/dt). A weak person inflates it slowly (low dP/dt). The MR jet acts as a built-in pressure gauge that lets us time how quickly the ventricle “inflates.”

Normal: > 1000 mmHg/s. Values below 1000 suggest impaired LV contractility. Requires MR to be present.

Myocardial Performance Index (Tei Index)

$$MPI = \frac{IVCT + IVRT}{ET}$$

Where IVCT = isovolumetric contraction time, IVRT = isovolumetric relaxation time, ET = ejection time.

What this means: The Tei index compares “wasted time” (when valves are closed and no blood moves) to “productive time” (when the valve is open and blood is actually flowing). A healthy heart spends most of its time ejecting. A sick heart spends more time with valves closed, building and releasing pressure inefficiently.

Analogy: Imagine you are a DoorDash driver. Your productive time is when you are actually driving to deliver food (ejection time). Your wasted time is when you are sitting in the restaurant waiting for the order to be ready (IVCT + IVRT). An efficient driver (Tei < 0.40) spends most of the shift delivering. A struggling driver (Tei > 0.50) spends too much time just waiting around.

Normal LV Tei: < 0.40. **Normal RV Tei:** < 0.55. Values above these thresholds indicate global ventricular dysfunction.

Fractional Shortening

$$FS = \frac{LVIDd - LVIDs}{LVIDd} \times 100\%$$

Where LVIDd = LV internal dimension at end-diastole and LVIDs = LV internal dimension at end-systole, both measured by M-mode in the parasternal long-axis view.

What this means: Fractional shortening measures how much the LV diameter shrinks during contraction. It is essentially a one-dimensional version of ejection fraction. Normal FS is 30–45%.

Analogy: Imagine measuring how far a rubber band stretches and then snaps back. If it starts at 5 cm and contracts to 3 cm, it shortened by 2 out of 5 cm, or 40%. A strong rubber band (healthy LV) snaps back a lot. A worn-out one (weak LV) barely moves. FS does the same measurement on the heart’s diameter.

Clinical application: Quick bedside assessment of systolic function when Simpson’s biplane EF is not available. Less accurate than EF in patients with regional wall motion abnormalities (e.g., post-MI) because it only samples one slice of the ventricle.

Qp:Qs (Shunt Ratio)

$$Qp : Qs = \frac{SV_{pulmonary}}{SV_{systemic}} = \frac{CSA_{RVOT} \times VTI_{RVOT}}{CSA_{LVOT} \times VTI_{LVOT}}$$

What this means: This ratio compares how much blood flows through the lungs (Qp, pulmonary flow) versus the body (Qs, systemic flow). In a normal heart with no holes, these are equal (ratio = 1.0). If there is a left-to-right shunt (ASD, VSD, PDA), extra blood recirculates through the lungs, making Qp larger than Qs.

Analogy: Imagine a house with two water loops: one for the garden (lungs) and one for the kitchen (body). Normally, the same amount of water runs through both. If there is a leak connecting the two, water recirculates through the garden loop. A Qp:Qs of 2.0 means twice as much water flows through the garden as the kitchen. That extra flow wears out the garden pipes (pulmonary hypertension).

Qp:Qs	Interpretation
1.0	Normal (no shunt)
1.0–1.4	Small shunt (usually observed)
1.5–1.9	Moderate shunt (consider closure)
≥ 2.0	Large shunt (intervention recommended)

Clinical application: Essential for evaluating ASD, VSD, and PDA. A Qp:Qs ≥ 1.5 is generally the threshold for considering surgical or percutaneous closure.

Regurgitant Fraction

$$RF = \frac{RVol}{SV_{total}} \times 100\%$$

Where SV_{total} = forward stroke volume through the regurgitant valve and $RVol$ = regurgitant volume (the portion that leaks backward).

Alternatively: $RVol = SV_{regurgitant\ valve} - SV_{competent\ valve}$

What this means: Regurgitant fraction tells you what percentage of each heartbeat's output leaks backward through a leaky valve instead of going forward to the body. A normal valve has 0% regurgitation. A severely leaking valve sends half or more of each beat's blood backward.

Analogy: Think of bailing water out of a leaky boat. You scoop 10 buckets out (total stroke volume), but 4 buckets leak right back in through the hole (regurgitant volume). Your regurgitant fraction is 40%, meaning 40% of your effort is wasted. With a really bad leak (≥ 50%), you are losing more than you are gaining.

RF	Severity
< 30%	Mild
30–49%	Moderate
≥ 50%	Severe

LA Volume Index (LAVI)

$$LAVI = \frac{LA\ Volume}{BSA}$$

LA volume is measured by the biplane area-length method or the biplane Simpson's method from apical 4-chamber and 2-chamber views at end-systole (just before mitral valve opening).

What this means: The left atrium stretches over time when filling pressures are chronically elevated. LAVI is the size of the left atrium adjusted for body size. It acts as a long-term "memory" of diastolic function, similar to how HbA1c reflects long-term blood sugar rather than a single reading.

Analogy: Imagine a balloon that is slowly being over-inflated day after day. Even if today's pressure seems normal (pseudonormal pattern), the balloon stays stretched. LAVI captures that chronic stretch. A normal-sized atrium ($\leq 34 \text{ mL/m}^2$) tells you pressures have been fine for weeks. An enlarged atrium ($> 34 \text{ mL/m}^2$) tells you something has been wrong for a while, even if today looks okay.

LAVI (mL/m^2)	Classification
≤ 34	Normal
35–41	Mildly dilated
42–48	Moderately dilated
> 48	Severely dilated

Clinical application: LAVI $> 34 \text{ mL/m}^2$ is one of the four key parameters in the ASE diastolic function algorithm (along with E/e', TR velocity, and septal e'). It is also an independent predictor of atrial fibrillation, stroke, and heart failure.

PART 3: DOPPLER HEMODYNAMICS

The Doppler Equation

$$\Delta F = \frac{2 \times F_0 \times V \times \cos \theta}{c}$$

Where F_0 = transmitted frequency, V = blood velocity, θ = angle between beam and flow, and $c = 1540 \text{ m/s}$ (speed of sound in tissue).

What this means: When sound bounces off moving blood cells, its frequency shifts. Blood moving toward the transducer returns a higher frequency (positive shift). Blood moving away returns a lower frequency (negative shift). The machine measures this shift and calculates velocity.

Analogy: Think of an ambulance siren. As it races toward you, the pitch sounds higher. The moment it passes and drives away, the pitch drops. That is the Doppler effect. Your ultrasound machine is "listening" to blood cells the same way you hear that siren, using the pitch change to calculate how fast the blood is moving.

Critical rule: Keep the Doppler angle under 20 degrees for cardiac imaging. At 60 degrees, $\cos(60^\circ) = 0.5$, which means you underestimate velocity by 50%. In echocardiography, the machine assumes $\theta = 0^\circ$, so the sonographer must align the beam parallel to flow.

Doppler Modes

Mode	Range Resolution	Velocity Limit	Best For
Pulsed Wave (PW)	Yes (sample volume)	Limited by Nyquist	LVOT VTI, mitral E/A waves
Continuous Wave (CW)	No (entire beam path)	Unlimited	High-velocity jets (AS, MR, TR)
Color Flow	Yes (2D map)	Limited by Nyquist	Regurgitation, PISA, flow direction

Mitral Inflow: E/A Ratio

Measured at the mitral leaflet tips using PW Doppler in the apical 4-chamber view.

- **E-wave** = early diastolic passive filling (Phase 6, rapid filling)
- **A-wave** = late diastolic filling from atrial contraction (Phase 1, atrial kick)

Diastolic Function Grading

Parameter	Normal	Grade I	Grade II	Grade III
E/A ratio	0.8–1.5	< 0.8	0.8–1.5	> 2.0
DT (ms)	150–220	> 240	150–200	< 150
IVRT (ms)	60–90	> 90	> 90	< 70
Septal e' (cm/s)	≥ 8	< 8	< 8	< 8
E/e' (average)	< 14	< 14	≥ 15	≥ 15

- **Grade I (impaired relaxation):** Delayed relaxation, normal filling pressures.
- **Grade II (pseudonormal):** Looks normal on mitral inflow alone. Use Valsalva or tissue Doppler to unmask.
- **Grade III (restrictive):** Severely elevated filling pressures, poor prognosis.

E/e' Ratio (Filling Pressure Estimate)

$$E/e' = \frac{\text{Mitral E velocity (cm/s)}}{e' \text{ velocity (cm/s)}}$$

E/e' Value	Interpretation
< 8	Normal filling pressures
8–14	Indeterminate (use additional parameters)
≥ 15	Elevated filling pressures

Why it works: The E-wave depends on both LV relaxation and LA pressure. The e' depends mainly on relaxation alone. Dividing E by e' cancels the relaxation component, leaving a number that primarily reflects filling pressure.

Analogy: Think of running outdoors versus on a treadmill. Outdoors (E-wave), you get the wind at your back pushing you faster (filling pressure helps). On a treadmill (e'), there is no wind, just your own legs (relaxation alone). If your outdoor speed is way higher than your treadmill speed, you know it is the wind (elevated filling pressure), not your fitness. That is what E/e' measures.

PART 4: VALVULAR HEMODYNAMICS

Stenosis vs. Regurgitation

Feature	Stenosis	Regurgitation
Definition	Valve fails to open fully	Valve fails to close fully
Flow	Forward flow accelerated	Retrograde leak
Doppler finding	Increased forward velocity	Retrograde jet on color
Chamber effect	Pressure overload (upstream)	Volume overload (receiving)
Key measurement	Valve area, gradient	EROA, regurgitant volume

Aortic Stenosis Grading (ASE)

Parameter	Mild	Moderate	Severe
Peak velocity (m/s)	< 3.0	3.0–3.9	≥ 4.0
Mean gradient (mmHg)	< 20	20–39	≥ 40
Valve area (cm ²)	> 1.5	1.0–1.5	< 1.0
Indexed AVA (cm ² /m ²)	—	—	< 0.6

Mitral Stenosis Grading (ASE)

Parameter	Mild	Moderate	Severe
Valve area (cm ²)	> 1.5	1.0–1.5	< 1.0
Mean gradient (mmHg)	< 5	5–10	> 10
PA systolic (mmHg)	< 30	30–50	> 50

Tricuspid Stenosis Grading

Parameter	Significant
Mean gradient (mmHg)	≥ 5
Valve area (cm ²)	< 1.0
Inflow VTI (cm)	> 60

Tricuspid stenosis is rare. Most commonly caused by rheumatic disease or carcinoid syndrome.

Pulmonic Stenosis Grading

Parameter	Mild	Moderate	Severe
Peak velocity (m/s)	< 3.0	3.0–4.0	> 4.0
Peak gradient (mmHg)	< 36	36–64	> 64

Mitral Regurgitation Grading (ASE)

Parameter	Mild	Moderate	Severe
EROA (cm ²)	< 0.20	0.20–0.39	≥ 0.40
RVol (mL/beat)	< 30	30–59	≥ 60
Regurgitant fraction (%)	< 30	30–49	≥ 50
Vena contracta (cm)	< 0.3	0.3–0.69	≥ 0.7

Aortic Regurgitation Grading (ASE)

Parameter	Mild	Moderate	Severe
EROA (cm ²)	< 0.10	0.10–0.29	≥ 0.30
RVol (mL/beat)	< 30	30–59	≥ 60
Vena contracta (cm)	< 0.3	0.3–0.6	> 0.6
Pressure half-time (ms)	> 500	200–500	< 200

Tricuspid Regurgitation and PA Pressure

TR is the key to estimating pulmonary artery systolic pressure (PASP) noninvasively:

$$PASP = 4V_{TR}^2 + RAP$$

Where V_{TR} = peak TR jet velocity (m/s) by CW Doppler and RAP = estimated right atrial pressure (mmHg).

What this means: During systole, the RV and PA are connected (pulmonic valve is open), so PASP equals RVSP. The TR jet tells us the pressure difference between RV and RA (using Bernoulli). Adding the RA pressure (estimated from IVC size) gives us the total RV/PA systolic pressure.

Analogy: Imagine a balloon (RV) connected to a tube (PA) with a small leak (TR jet) going back into a bucket (RA). The faster the leak squirts, the higher the pressure inside the balloon. Measure the squirt speed (TR velocity), convert it to pressure

(Bernoulli), and add the baseline water level in the bucket (RAP). Now you know the balloon pressure (PASP) without poking a needle into it.

RAP estimation from IVC:

IVC Diameter	Inspiratory Collapse	Estimated RAP
≤ 2.1 cm	> 50%	3 mmHg
≤ 2.1 cm	< 50%	8 mmHg
> 2.1 cm	> 50%	8 mmHg
> 2.1 cm	< 50%	15 mmHg

TR severity grading:

Parameter	Mild	Moderate	Severe
Vena contracta (cm)	< 0.3	0.3–0.69	≥ 0.7
EROA (cm ²)	< 0.20	0.20–0.39	≥ 0.40
Hepatic vein flow	Systolic dominant	Systolic blunting	Systolic reversal

Pulmonic Regurgitation

Parameter	Significant
Jet width / annulus width	> 50%
PR pressure half-time (ms)	< 100
Dense CW Doppler signal	Yes

PR end-diastolic velocity can estimate PA diastolic pressure:

$$PA_{diastolic} = 4V_{PR,end-diastolic}^2 + RAP$$

PISA Method (Proximal Isovelocity Surface Area)

Used to quantify regurgitation severity for any valve.

$$EROA = \frac{2\pi r^2 \times V_{aliasing}}{V_{max,regurg}}$$

Where r = aliasing hemisphere radius (cm), $V_{aliasing}$ = Nyquist velocity (cm/s), and $V_{max,regurg}$ = peak regurgitant jet velocity by CW Doppler (cm/s).

What this means: As blood converges toward a leaky valve, it accelerates and forms concentric shells of equal velocity (like layers of an onion). On color Doppler, the point where velocity exceeds the Nyquist limit creates a visible aliasing boundary (the PISA hemisphere). By measuring this hemisphere, we calculate the actual size of the leak (EROA).

Analogy: Imagine water circling toward a drain in a sink. Close to the drain, the water spins fastest. If you could see the ring where water hits exactly 5 mph, you could calculate the size of the drain opening. PISA does the same thing: it finds the “speed ring” (aliasing boundary) and works backward to calculate the size of the valve leak.

Practical tip: Reduce the Nyquist limit (baseline shift) to enlarge the PISA hemisphere, making the radius easier to measure. This does not affect accuracy.

Regurgitant volume: $RVol = EROA \times VTI_{regurg}$

PART 5: QUICK REFERENCE

Normal Chamber Pressures (mmHg)

Location	Sys	Dia	Mean
Right atrium	—	—	0–8
Right ventricle	15–30	0–8	—
Pulmonary artery	15–30	4–14	9–16
Left atrium	—	—	2–12
Left ventricle	90–140	5–12	—
Aorta	90–140	60–90	70–105

Normal Valve Areas

Valve	Normal (cm ²)
Aortic	2.5–4.0
Mitral	4.0–6.0
Tricuspid	7.0–9.0
Pulmonic	2.5–4.0

Aortic Root / Ascending Aorta

Location	Normal (cm)
Aortic annulus	1.8–2.6
Sinuses of Valsalva	2.1–3.5
Sinotubular junction	1.7–3.4
Ascending aorta	< 3.6 (M) / < 3.4 (F)

Chamber Dimensions (ASE)

Parameter	Men	Women
LVIDd (cm)	4.2–5.8	3.8–5.2
LVIDs (cm)	2.5–4.0	2.2–3.5
IVSd (cm)	0.6–1.0	0.6–0.9
LV mass (g/m ²)	≤ 115	≤ 95
LAVI (mL/m ²)	≤ 34	≤ 34
RV basal (cm)	≤ 4.1	≤ 4.1
RA area (cm ²)	≤ 18	≤ 18
TAPSE (cm)	≥ 1.7	≥ 1.7
RV S' (cm/s)	≥ 10	≥ 10

Key Normal Values

Parameter	Normal
LVEF (M / F)	52–72% / 54–74%
Fractional shortening	30–45%
Stroke volume	60–100 mL
SV index	33–47 mL/m ²
Cardiac output	4–8 L/min
Cardiac index	2.5–4.0 L/min/m ²
E/A ratio	0.8–1.5
Septal e'	≥ 8 cm/s
Lateral e'	≥ 10 cm/s
E/e' (average)	< 14
IVRT	60–90 ms
Deceleration time	150–220 ms
dP/dt	> 1000 mmHg/s
Tei index (LV / RV)	< 0.40 / < 0.55
LA volume index	≤ 34 mL/m ²
Qp:Qs (no shunt)	1.0
PASP (estimated)	< 35 mmHg
PA mean	9–16 mmHg
RVSP	< 35 mmHg

Critical Doppler Values

Measurement	Where	Normal
LVOT VTI	PW, A5C	18–22 cm
LVOT diam	PLAX	1.8–2.2 cm
Peak AV vel	CW, A5C/SSN	< 2.5 m/s
Mitral E	PW, MV tips	60–100 cm/s
Mitral A	PW, MV tips	40–70 cm/s
Septal e'	TDI, A4C	≥ 8 cm/s
Lateral e'	TDI, A4C	≥ 10 cm/s
TR peak vel	CW, A4C	< 2.8 m/s

Elevated Filling Pressures (ASE 2016)

Evaluate all 4 criteria:

1. Average E/e' ≥ 15
2. Septal e' < 8 or lateral e' < 10 cm/s
3. TR velocity > 2.8 m/s
4. LAVI > 34 mL/m²

3–4 positive = elevated | **2** = indeterminate | **0–1** = normal

References Used

[Chamber Quantification \(ASE 2015\)](#) | [Diastolic Function \(ASE 2016\)](#) | [Valvular Heart Disease \(ACC/AHA 2020\)](#) | [Native Valvular Regurgitation \(ASE 2017\)](#) | [Right Heart Assessment \(ASE 2010\)](#) | [Wiggers Diagram Teaching \(Silverthorn 2022\)](#)

{Wiggers diagram image: CC BY-SA 4.0, Wikimedia Commons. Source.} | {[All current ASE guidelines at asecho.org/guidelines](https://asecho.org/guidelines)}

