PISA Method — MR Quantification Worksheet

Proximal Isovelocity Surface Area | Bedside protocol, equations, severity, & pitfalls

PRINCIPLE

Blood converges toward the regurgitant orifice through concentric **hemispheric shells of equal velocity**. Color Doppler aliasing makes one such shell visible. By **conservation of flow**, flow at the PISA shell equals flow through the orifice.

$$2\pi r^2 \times V_{aliasing} = EROA \times V_{peak\ MR}$$

$$EROA\ (cm^2) = \frac{2\pi \times r^2 \times V_a}{V_{peak\ MR}}$$

$$RegVol\ (mL) = EROA \times VTI_{MR\ jet}$$

r	PISA radius at first aliasing shell (cm)
V_a	Aliasing velocity (cm/s) — baseline-shifted
$V_{peak\ MR}$	Peak MR jet velocity by CW (cm/s)
VTI_{MR}	VTI of MR jet by CW (cm)

BEDSIDE PROTOCOL

1. **Zoom apical 4-chamber** centered on the mitral valve.
2. **Shift color baseline** in the direction of the regurgitant jet to lower V_a → produces a clean hemisphere on the LV side. Target **V_a ≈ 30–40 cm/s**.
3. **Measure r** at **mid-systole**: orifice (vena contracta neck) to the first blue/red color reversal.
4. **CW Doppler** through the MR jet → record **$V_{peak\ MR}$** (typ. 4–6 m/s) and trace **VTI_{MR}**.
5. **Compute** EROA, then RegVol = EROA × VTI_{MR}.

Bedside shortcut: When V_a = 40 cm/s and V_{peak} = 5 m/s → **EROA ≈ r² / 2**.
e.g., r = 1.0 cm → EROA ≈ 0.5 cm² → severe.

SEVERITY CUTOFFS (ASE 2017)

ASE 2017 — Primary (degenerative) MR — full 4-grade system

Grade	EROA (cm²)	RegVol (mL)	RegFraction
I — Mild	< 0.20	< 30	< 30%
II — Moderate	0.20–0.29	30–44	30–39%
III — Mod-Severe	0.30–0.39	45–59	40–49%
IV — Severe	**≥ 0.40**	**≥ 60**	**≥ 50%**

Secondary (functional) MR

Grade	EROA (cm²)	RegVol (mL)
Non-severe	< 0.40	< 60
Severe	**≥ 0.40** *(COAPT: ≥ 0.30)*	**≥ 60** *(MITRA-FR: ≥ 30)*

Why secondary MR thresholds are lower: sick LV makes even smaller orifices prognostically heavy. COAPT used EROA > 0.30 cm²; MITRA-FR used > 0.20 cm². Also: PISA tends to **underestimate** in secondary MR (elliptical orifice).

Memory Anchors

- **EROA = 2πr²V_a ÷ V_{peak}** — flow in = flow out
- **r is squared** — 10% radius error → 20% EROA error
- **r²/2 rule**: V_a = 40, V_{peak} = 500 → EROA ≈ r²/2
- **Functional MR → PISA UNDERestimates** (crescent/elliptical orifice violates the hemisphere) — cross-check with 3D VCA
- **Always cross-check** with VC, PV flow, RegFraction

COMMON PITFALLS & INTERPRETATION

Pitfall	Effect & Fix
Eccentric / wall-hugging jet	**Hemisphere assumption fails.** Use 3D vena contracta area or volumetric methods.
Non-circular orifice (functional MR)	Crescent-shaped slit → PISA **underestimates** EROA. Confirm with 3D VCA / planimetry.
Single-frame (mid-systole)	If MR is early/late systolic, instantaneous EROA × VTI **overstates** volumetric burden.
r squared	Small calliper error → large EROA error. Use highest zoom; freeze on clearest hemisphere.
Funnel-shaped orifice	Apply **angle correction** α/180° (more common in TR with leaflet tenting).
Multiple jets	PISA assumes one orifice. Either sum jets (rough) or move to 3D / volumetric.
Severe MR with high LAP	Low LV–LA gradient → low V_{peak} → **falsely high** EROA. Cross-check carefully.
Wrong baseline shift	V_a too high → tiny PISA, hard to measure. V_a too low → oversized hemisphere, geometry distorts. Stay **30–40 cm/s**.

WORKED EXAMPLE

Given: r = 0.9 cm | V_a = 40 cm/s | $V_{peak\ MR}$ = 500 cm/s (5 m/s) | VTI_{MR} = 150 cm

Step 1 — PISA flow: 2π(0.9)² × 40 = 6.28 × 0.81 × 40 = **203 mL/s**
Step 2 — EROA: 203 ÷ 500 = **0.41 cm²** → **Severe**
Step 3 — RegVol: 0.41 × 150 = **61 mL** → **Severe**
Quick check (r²/2): 0.81 ÷ 2 = 0.40 cm² ✓

WHEN TO TRUST PISA — AND WHEN NOT

Trust PISA when…	Be skeptical when…
Central, single jet — primary MR (e.g., flail, prolapse)	Eccentric / Coandă jet hugging atrial wall
Clean hemispheric shell at V_a 30–40 cm/s	Crescent orifice (functional MR with tethering)
Holosystolic flow envelope on CW	Late-systolic MR (MVP) — PISA overstates RegVol
Findings concordant with VC width & PV flow	EROA & RegVol disagree, or discordant with VC / RegFraction

CROSS-CHECKS BEFORE CALLING SEVERITY

- **Vena contracta width** ≥ 0.7 cm (biplane) supports severe
- **3D vena contracta area** ≥ 0.4 cm² supports severe (best for functional MR)
- **Pulmonary vein flow** — systolic blunting/reversal supports severe
- **LA size / LV volumes** — chronic severe MR enlarges both
- **Quantitative volumetrics**: $SV_{MV\ inflow} - SV_{LVOT}$ = RegVol
- **RegFraction** = RegVol ÷ total LV SV (≥ 50% = severe)
- **CW jet density & contour** — dense, triangular, early-peaking favors severe

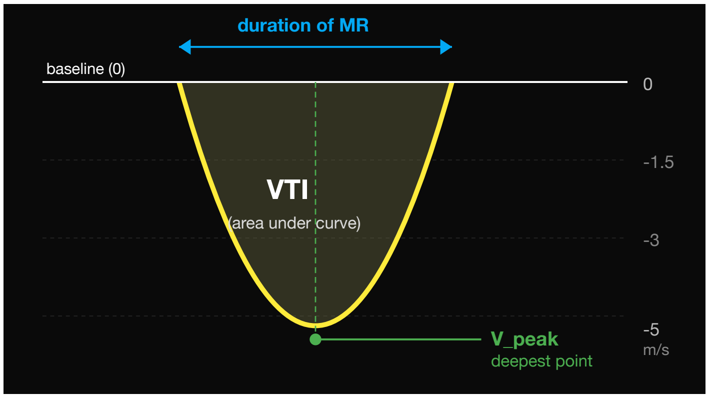
REPORT DOCUMENTATION LANGUAGE

- "PISA radius measured at mid-systole with V_a = ___ cm/s; EROA = ___ cm², RegVol = ___ mL"
- "Findings concordant with vena contracta width and pulmonary vein flow pattern"
- "PISA limited by [eccentric jet / non-circular orifice / late-systolic profile]; severity integrated from multiple parameters"

PISA — Reading the Echo Data

Where each number lives on the screen | The same trace gives you V_{peak} AND VTI — they are NOT the same thing

ANATOMY OF THE CW DOPPLER ENVELOPE



Same trace, two measurements: V_peak (a point) and VTI (an area)

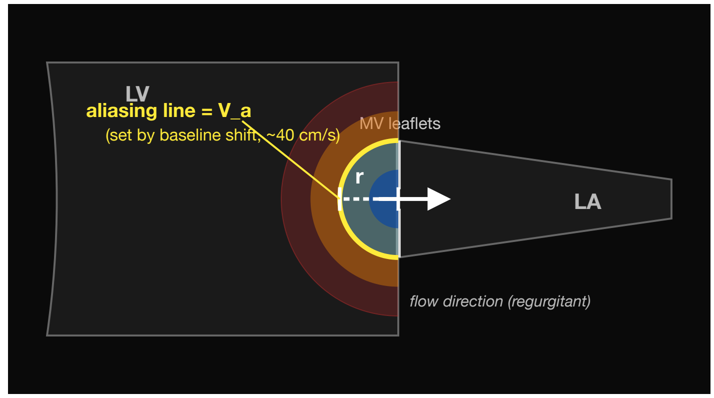
V_peak	Deepest point of the parabola	*denominator (EROA)*
VTI	Area enclosed by the trace	*multiplier (RegVol)*

Why VTI has units of cm (not cm/s): velocity (cm/s) × time (s) = distance (cm). VTI is the **distance a column of regurgitant blood travels per beat** — "stroke distance" of the leak. Multiply by area (EROA) and you get volume per beat.

Never forget

- **V_peak** = a single y-coordinate (the tip)
- **VTI** = the whole shaded blob (the area)
- For severe MR: V_peak typ. 4–6 m/s, VTI typ. 100–180 cm

ANATOMY OF THE COLOR PISA IMAGE



Hemispheric color shells converging on the regurgitant orifice

r	Orifice to first aliasing line (cm)	*numerator (squared!)*
V_a	Aliasing velocity at that shell (cm/s)	*numerator*

Setting V_a: shift the color baseline **in the direction of the regurgitant jet**. The number on the color scale at the new baseline IS your V_a. Target 30–40 cm/s — gives a clean, measurable hemisphere.

Never forget

- **r** is YOU measuring (with callipers, mid-systole)
- **V_a** is YOU choosing (the baseline shift)
- **V_peak & VTI** are the JET telling you (CW)

THE FOUR NUMBERS YOU NEED — AND WHERE TO GET THEM

r	Color zoom view, baseline-shifted, mid-systole	callipers on screen	*EROA numerator*
V_a	Read off color bar at new baseline	set to 30–40 cm/s	*EROA numerator*
$V_{peak\ MR}$	CW Doppler: deepest point of envelope	auto-traced or peak	*EROA denominator*
VTI_{MR}	CW Doppler: traced area under envelope	manual trace	*RegVol multiplier*

PISA — Worked Examples

Four cases, broken down step-by-step | Each one teaches a different lesson

CASE 1 67M with new murmur — TEE shows P2 flail (degenerative MR)

Echo data:
r = 1.0 cm | V_a = 40 cm/s | V_{peak} = 5 m/s (500) | **VTI** = 160 cm

1. **PISA flow rate** at the shell = $2\pi r^2 \times V_a$
   = 2 × 3.14 × (1.0)² × 40 = 6.28 × 1.0 × 40 = **251 mL/s**
2. **EROA** = PISA flow ÷ V_{peak} = 251 ÷ 500 = **0.50 cm²**
3. **RegVol** = EROA × VTI = 0.50 × 160 = **80 mL**
4. **Sanity check (r²/2 trick):** 1.0² ÷ 2 = 0.50 cm² ✓

Answer: EROA **0.50 cm²** + RegVol **80 mL** → **SEVERE primary MR** (both criteria met). Surgical referral.

Lesson #1 — The "5-and-40" trick: Whenever V_a = 40 cm/s and V_{peak} = 500 cm/s, the equation collapses to **EROA ≈ r² / 2**. Memorize this once and you'll never need a calculator at the bedside for textbook MR.
Math: 2π × 40 / 500 = 251/500 = 0.502 ≈ 0.5

CASE 2 54F asymptomatic, screening echo — mild rheumatic MR

Echo data:
r = 0.4 cm | V_a = 40 cm/s | V_{peak} = 5 m/s (500) | **VTI** = 110 cm

1. **PISA flow rate** = 2π × (0.4)² × 40 = 6.28 × 0.16 × 40 = **40.2 mL/s**
2. **EROA** = 40.2 ÷ 500 = **0.08 cm²**
3. **RegVol** = 0.08 × 110 = **8.8 mL**
4. **Sanity check (r²/2):** 0.16 ÷ 2 = 0.08 cm² ✓

Answer: EROA **0.08 cm²** + RegVol **9 mL** → **MILD MR**. Monitor.

Lesson #2 — r is SQUARED, not linear: Compare to Case 1 — r dropped from 1.0 to 0.4 (a **2.5×** change). EROA dropped from 0.50 to 0.08 — a **6.25×** change. Why? Because **2.5² = 6.25**. A 1 mm error in your calliper placement can move a patient between severity grades. **Zoom hard, freeze on the clearest hemisphere, measure twice.**

CASE 3 72F with AFib, RVR at 130 bpm — secondary MR

Echo data:
r = 0.7 cm | V_a = 40 cm/s | V_{peak} = 5 m/s (500) | **VTI** = 90 cm *(short systole)*

1. **PISA flow rate** = 2π × (0.7)² × 40 = 6.28 × 0.49 × 40 = **123 mL/s**
2. **EROA** = 123 ÷ 500 = **0.25 cm²** → moderate by primary cutoffs, but borderline-severe by functional cutoffs
3. **RegVol** = 0.25 × 90 = **22 mL** → mild by volume!
4. **Sanity check:** 0.49 ÷ 2 = 0.245 ✓

Answer: EROA says moderate (borderline-severe by the lower functional-MR thresholds). RegVol says mild. **Discordance — report both, integrate clinically.** In AFib RVR, average 5–10 cycles and re-image after rate control before committing to severity.

Lesson #3 — EROA and RegVol can DISAGREE: They tell you different things.
- **EROA** = how big is the hole (instantaneous orifice area)
- **RegVol** = how much actually leaks per beat (orifice × stroke distance)

A big hole open for a short time leaks less total volume than a smaller hole open longer. Tachycardia, late-systolic MR, or short ejection → low VTI → RegVol underestimates relative to EROA. **Always report both numbers.**

CASE 4 58M, day 5 post-MI, acute pulmonary edema — suspected papillary muscle rupture

Echo data:
r = 0.7 cm | V_a = 40 cm/s | V_{peak} = 3.8 m/s (380) *low!* | **VTI** = 80 cm

1. **PISA flow rate** = 2π × (0.7)² × 40 = **123 mL/s** *(same as Case 3 — same r)*
2. **EROA** = 123 ÷ **380** = **0.32 cm²** → calculation says approaching severe
3. **RegVol** = 0.32 × 80 = **26 mL**
4. **Sanity check fails!** r²/2 = 0.245 — but EROA came out 0.32. **Why? V_{peak} ≠ 500.**
   The trick only works at V_{peak} = 5 m/s. Here, lower V_{peak} → smaller denominator → LARGER EROA for the same r.

Clinical reality: Patient has acute severe MR (LV is hyperdynamic, LA is small & non-compliant, LAP is sky-high). The **low V_{peak} is itself a sign of severity** — LA pressure has risen so much that the LV-LA gradient is narrow. **Don't be reassured by a "modest" RegVol** — this is a surgical emergency.

Lesson #4 — Low V_{peak} changes the math AND the interpretation:
The math: EROA = $(2\pi r^2 V_a) \div V_{peak}$. If V_{peak} drops 25% (500 → 380), EROA inflates ~33%. The $r^2/2$ shortcut breaks.
The clinical read: low V_{peak} in acute MR doesn't mean the leak is mild — it means the LV-LA gradient is collapsing because LA pressure is enormous.
Cross-check with VC width, dense triangular early-peaking CW envelope, S-wave reversal in pulm veins, small hyperdynamic LV, and the **clinical picture (flash pulmonary edema)**.
Bottom line: trust the math but interpret with the patient.

CASE 5 48F with MVP and late-systolic murmur — PISA looks "severe" but isn't

The instantaneous-vs-time-averaged orifice problem. PISA measures EROA at *one moment* (peak convergence). The equation then assumes that orifice is open and leaking for *all* of systole. That works for holosystolic MR. It **overestimates** for late-systolic MR (classic MVP) because the orifice is only open during the last fraction of systole.

True RegVol = $\int$ EROA(t) · V(t) dt — PISA assumes EROA is constant across systole

Echo data (same patient as Case 1, but MVP instead of flail):
r = 1.0 cm **V_a** = 40 cm/s **V_{peak}** = 5 m/s (500) **VTI** = 70 cm *(short, late)*

1. **PISA flow rate** = $2\pi \times (1.0)^2 \times 40$ = **251 mL/s** *(same as Case 1)*
2. **EROA** = 251 ÷ 500 = **0.50 cm²** → "looks severe" by PISA EROA alone
3. **RegVol** = 0.50 × **70** = **35 mL** → only moderate by volume
4. **Why the disconnect?** CW envelope is dagger-shaped & late-peaking. Orifice is only open for ~40% of systole. The shorter VTI partially self-corrects RegVol — but PISA EROA still overstates the leak's true burden.

Answer: EROA **0.50 cm²** + RegVol **35 mL** → **moderate MR** (not severe). Don't trust PISA EROA alone in MVP. Cross-check with VC, 3D VC area, pulm vein flow, RegFraction.

Same EROA, different cardiac-cycle phase — very different leaks

	Holosystolic MR (e.g., flail / functional)	Late-systolic MR (classic MVP)
Orifice timing	Open entire systole (~0.30 s)	Open only last ~40% (~0.12 s)
CW envelope	Full parabolic, dense, holosystolic	Dagger-shaped, late-peaking, truncated
PISA EROA	0.50 cm²	0.50 cm² *(same!)*
VTI of MR jet	~150 cm	~70 cm
RegVol	75 mL → severe	35 mL → moderate
True severity	Severe	**PISA EROA overstates**

Mental model — "hose diameter vs how long the water flows"

Concept	Translation
EROA	Diameter of the hose — *how big is the leak orifice right now?*
VTI	How far a column of leaking blood travels per beat — captures both *velocity* AND *duration*
RegVol = EROA × VTI	Volume per beat — partially self-corrects for short orifice opening because VTI shrinks
Why it still overestimates in MVP	PISA reads *peak* EROA at one instant. Real EROA(t) is zero for half of systole → integral of flow is smaller than peak-EROA × VTI suggests

ASE 2017 guidance for late-systolic / biphasic MR

- Do NOT grade severity on PISA EROA alone
- Always compute RegVol = EROA × VTI (never EROA × estimated systolic time)
- Integrate with: VC width, 3D VC area, PV flow pattern, LA/LV size, RegFraction
- Consider 3D volumetric quantification — gold standard in MVP because it integrates flow over the actual leaking window

Lesson #5 — PISA assumes a constant orifice; MVP violates that:
The PISA equation snapshots EROA at one instant and treats the leak as if it were holosystolic. In MVP, the leak is late-systolic only — same instantaneous EROA, but the orifice is only open for ~40% of systole. **Result: PISA overstates severity.**
What to do: use RegVol (not EROA alone), cross-check with multiple parameters, and lean on 3D for definitive grading. **If the CW envelope is dagger-shaped instead of holosystolic, downgrade your trust in PISA EROA before you commit to severity.**

CASE 6 73F with class 3 dyspnea, ischemic CMP, secondary MR — PISA UNDERESTIMATES

The elliptical-orifice problem — mirror image of Case 5. Functional/secondary MR creates a **slit-shaped or crescentic orifice** (commissure-to-commissure leaflet tethering), not a circle. PISA's hemispheric assumption breaks: a flat 2D measurement of a non-circular orifice **underestimates** EROA. Direct from Mayo lecture (slide 73).

Echo data (real case):
r = 0.95 cm **V_a** = 31 cm/s **V_{peak}** = 4.8 m/s (480) **VTI** = 145 cm

1. **PISA flow rate** = $2\pi \times (0.95)^2 \times 31 = 6.28 \times 0.9025 \times 31$ = **176 mL/s**

2. **EROA** = 176 ÷ 480 = **0.37 cm²** → "moderate-severe" by PISA alone
3. **RegVol** = 0.37 × 145 = **53 mL** → moderate-severe
4. **3D vena contracta cross-check** = **0.72 cm²** → clearly SEVERE. True RegVol ≈ 0.72 × 145 = **104 mL**.

Answer: PISA EROA 0.37 / RV 53 mL **UNDERESTIMATED** the true severity by ~50%. 3D VCA = 0.72 cm² confirms severe secondary MR. **Refer for intervention (TEER vs surgery).**

Lesson #6 — The two-sided PISA failure: it OVERestimates in MVP and UNDERestimates in functional MR:
- **MVP (Case 5)**: instantaneous orifice, brief opening → PISA OVERstates
- **Functional MR (Case 6)**: elliptical/crescent orifice → PISA UNDERstates

What to do: in any secondary MR (ischemic or non-ischemic CMP, AFib-related atrial MR), **always cross-check PISA with 3D VCA**. If 3D VCA is > 2D PISA EROA, trust 3D. The discrepancy is biggest with central, biphasic jets and tethered leaflets.
PISA's sweet spot: central, holosystolic, *circular* orifice in primary MR (Cases 1–3). Outside that, integrate.

MULTIPLE JETS — SUMMING PISA

Two regurgitant jets with PISA radii r_1 and r_2 → **combined** $\mathbf{R = \sqrt{(r_1^2 + r_2^2)}}$

Example: $r_1 = 0.6$ cm, $r_2 = 0.4$ cm → combined $R = \sqrt{(0.36 + 0.16)} = \sqrt{0.52} = 0.72$ cm

THE THREE-STEP NEVER-FORGET RECIPE

1. **Color zoom + baseline shift** → measure **r**, read $\mathbf{V_a}$ off the scale
2. **CW through the jet** → note $\mathbf{V_{peak}}$ (deepest point), trace **VTI** (area under)
3. **Calculate:** EROA = $(2\pi r^2 V_a) \div V_{peak}$ → RegVol = EROA × VTI

Bedside shortcut: when $V_a = 40$, $V_{peak} = 500$ → **EROA ≈ r² / 2.** **Severe = EROA ≥ 0.40 cm².**

Beyond PISA — Cross-Checks & Integrative Assessment

Other semiquant signs | Continuity equation | 3D VCA | ASE 2017 integrative algorithm

SEMIQUANTITATIVE SIGNS OF SEVERE MR

Parameter	Severe MR	Specificity / note
Vena contracta width	**≥ 7 mm** (biplane average)	Specific for severe; intermediate 3–6.9 mm
3D vena contracta area	**≥ 0.40 cm²**	Best for elliptical/eccentric orifice; gold std for functional MR
Pulm vein systolic flow	**Reversal** (S-wave below baseline)	Highly specific for severe; blunting alone is non-specific
Mitral inflow E-wave	**> 1.2 m/s** + high E/A	Severe MR or restrictive filling
Mitral inflow (mild MR)	A-dominant pattern	Specific for *mild* MR (low E)
LA size	Enlarged (chronic)	Acute severe may have *normal* LA
LV size	Enlarged (chronic primary)	**Normal LV = specific for non-severe MR**

CW DOPPLER PROFILE — MILD VS SEVERE

Feature	Mild MR envelope	Severe MR envelope
Density	Faint, incomplete	Dense, full envelope
Shape	Symmetric, parabolic	Asymmetric, dagger-shaped
Peak	Mid-systolic	Early-peaking (severe), then sharp decline
Duration	Holosystolic but faint	Holosystolic + dense
If non-holosystolic	Mid-late = MVP | Early systolic only = secondary MR | **Both suggest LESS severe than the EROA implies**	

> **"Cut-off sign":** in acute severe MR, sharp early-systolic deceleration of the CW envelope reflects rapid LA pressure equalization — the V-wave of the LA pressure trace pushed up against the LV pressure curve. Strongly suggests severe + acute.

VARIABILITY & WHY QUANTITATION MATTERS

Thaden et al. Circ CV Imaging 2017: External echos read as ≤ moderate were re-read internally as **> moderate in 60%** of cases. With diagnostic quantitation, discordance dropped from **31% to 15%**. Quantitative parameters are the difference-maker between operators — not visual gestalt.

CONTINUITY EQUATION METHOD (QUANTITATIVE DOPPLER)

Independent of PISA. Compares total mitral inflow stroke volume to LVOT (forward) stroke volume. The difference is the regurgitant volume.

$$\mathbf{RegVol = SV_{MV\ inflow} - SV_{LVOT}}$$

$$\mathbf{SV = \pi\ (D/2)^2 \times VTI} \quad \textit{(annular cross-section × flow VTI)}$$

D_{LVOT}	LVOT diameter, PSLAX, mid-systole (cm)
VTI_{LVOT}	PW Doppler at LVOT, A5C view (cm)
D_{MV}	Mitral annulus diameter, A4C, early diastole (cm)
VTI_{MV}	PW Doppler at MV annulus, A4C (cm)

Then derive EROA

$$\mathbf{EROA = RegVol \div VTI_{MR\ jet}}$$

> **Worked example (from lecture):** SV_{MV} 218 mL – SV_{LVOT} 71 mL = **RegVol 147 mL**. With MR VTI 216 cm → **EROA = 0.68 cm²**.

Pitfalls of continuity equation

- **> mild AR** — LVOT SV is contaminated by regurgitant flow; use RVOT instead
- **Calcified annuli** — D² error magnifies (D is squared, like PISA radius)
- **Trace MODAL velocity** for mitral annular VTI (brightest line, not peak edge)
- **Learning curve** — reproducibility lower than PISA

3D VENA CONTRACTA AREA

Directly measures the regurgitant orifice in **cross-section** using 3D color Doppler MPR. No hemispheric assumption — ideal for non-circular orifices.

- **VCA ≥ 0.40 cm²** = severe
- Best for: **functional/secondary MR**, eccentric jets, biphasic jets
- In primary MR: 3D VCA and 2D PISA EROA agree (mean diff 0.04 cm²)
- In secondary MR: **3D VCA exceeds 2D PISA EROA by ~0.12 cm² on average** (Zeng et al. Circ CV Imaging 2011)

INTEGRATIVE APPROACH (ASE 2017)

Bucket	Components
2D Findings	Flail leaflet, LV enlargement, LA enlargement, mechanism
Semiquant Doppler	VC width, PV flow, mitral inflow, CW Doppler profile
Quant Doppler	EROA + RegVol + RegFraction (PISA, continuity, or 3D)

> **Algorithm:** Does MR meet specific criteria for mild OR severe? → Yes, label it. → If intermediate (or borderline), **perform quantitation always**. → If discordant or poor quality, label **indeterminate** and consider TEE/CMR.

PISA — Mechanism, Prognosis, & Surgical Indications

Carpentier classification | Repairability | Outcomes | When to operate

CARPENTIER CLASSIFICATION OF MR MECHANISM

Type	Leaflet motion	Etiologies	Repairability
Type I	Normal	Annular dilatation (atrial MR), leaflet perforation (endocarditis)	Potentially repairable
Type II	Excess (prolapse / flail)	Degenerative MVP, chordal rupture, papillary muscle rupture (acute MI)	Highly repairable
Type IIIA	Restricted in *both* systole & diastole	Rheumatic, mitral annular calcification (MAC), drug-induced (e.g., serotonin)	Not repairable → **replacement**
Type IIIB	Restricted in *systole only*	Ischemic CMP (papillary muscle displacement), nonischemic CMP (leaflet tethering)	Medical first; repair/replace 2nd line

Special cases:
• **SAM-mediated MR**: mid-late systolic timing (matches LVOT obstruction), typically *posteriorly directed*, dynamic (varies with loading conditions)
• **Endocarditis**: can produce multiple mechanisms simultaneously (perforation + flail + paravalvular)
• **Atrial functional MR**: Type I (annular dilatation) from chronic AFib + LA enlargement — growing recognition

PISA BY MR MECHANISM — WHAT TO EXPECT

Mechanism	PISA tendency	Why
Primary, holosystolic (flail, perforation)	Accurate	Circular orifice, constant area, high gradient
MVP (mid-late systolic)	OVEREstimates EROA	Brief opening, peak ROA snapshot × full VTI
Functional/secondary (Type IIIB)	UNDEREstimates EROA	Elliptical/crescent orifice violates hemisphere
Eccentric / wall-hugging	Unreliable	Coandă effect, distorted convergence
Acute severe (papillary rupture)	EROA inflated by low V_{peak}	High LAP narrows LV-LA gradient
Multiple jets	Underestimates if only one measured	Combined $R = \sqrt{(r_1^2 + r_2^2)}$

SURGICAL INDICATIONS — SEVERE PRIMARY MR (ACC/AHA + MAYO)

Class 1 (operate)

- **Symptomatic** severe primary MR — any LVEF (Stage D)
- **Asymptomatic with LV systolic dysfunction** — LVEF ≤ 60% **and/or** LVESD ≥ 40 mm (Stage C2). 2020 ACC/AHA makes this a Class 1 recommendation, not IIa.

Class 2a (reasonable in asymptomatic, normal LV function)

- **New-onset atrial fibrillation**
- **PASP > 50 mmHg** (rest)
- **Likelihood of a durable repair > 95% with expected mortality < 1%** at a primary or comprehensive Valve Center

Why these thresholds matter: in primary MR, the LV unloads into the LA. EF < 60% means systolic function is already abnormal (would be lower without the regurgitant pop-off). Wait too long → irreversible LV dysfunction post-op.

Severe secondary MR — very different pathway

- GDMT first (BB, ACEi/ARNI, MRA, SGLT2)
- CRT if eligible
- If still symptomatic: TEER (MitraClip) per COAPT criteria, or surgery in selected

PROGNOSIS BY EROA — THE DATA

Sarano NEJM 2005 / Circulation 2018 — primary MR survival under medical management

EROA	10-yr survival	Note
None / no MR	~83%	Reference
1–19 mm²	~70%	Mild
20–39 mm²	~62%	Moderate
≥ 40 mm² (≥ 0.40 cm²)	~40%	Severe — massive survival deficit, even asymptomatic

Topilsky Circulation 2012 — mid-late vs holosystolic MR

Pattern	5-yr CV events
Holosystolic MR	**40.4 ± 6.2%**
Mid-late systolic MR (MVP-pattern)	15.9 ± 4.7%

Bottom line: for the SAME EROA, mid-late systolic MR has dramatically better outcomes than holosystolic MR. Confirms that **PISA EROA alone in MVP overstates the prognostic burden**. Always integrate timing.

THE 30-SECOND BEDSIDE WORKFLOW

1. **Mechanism:** Carpentier type? Primary or secondary?
2. **Color Doppler:** jet area, eccentricity, flow convergence visible?
3. **Vena contracta:** ≥ 7 mm? < 3 mm?
4. **Pulm vein flow:** systolic blunting or reversal?
5. **Mitral inflow:** E > 1.2 m/s or A-dominant?
6. **CW envelope:** dense + dagger-shaped + holosystolic? Or symmetric + faint?
7. **PISA:** EROA + RegVol via the recipe
8. **Cross-check:** 3D VCA in functional MR; continuity equation if PISA limited
9. **2D context:** LV size, LA size, EF, PASP — do they match the severity grade?
10. **Final call:** ASE grade I–IV. Indeterminate → CMR.