# Is it low flow, low gradient aortic stenosis, or are my measurements wrong?

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ECHO AUSTRALIA

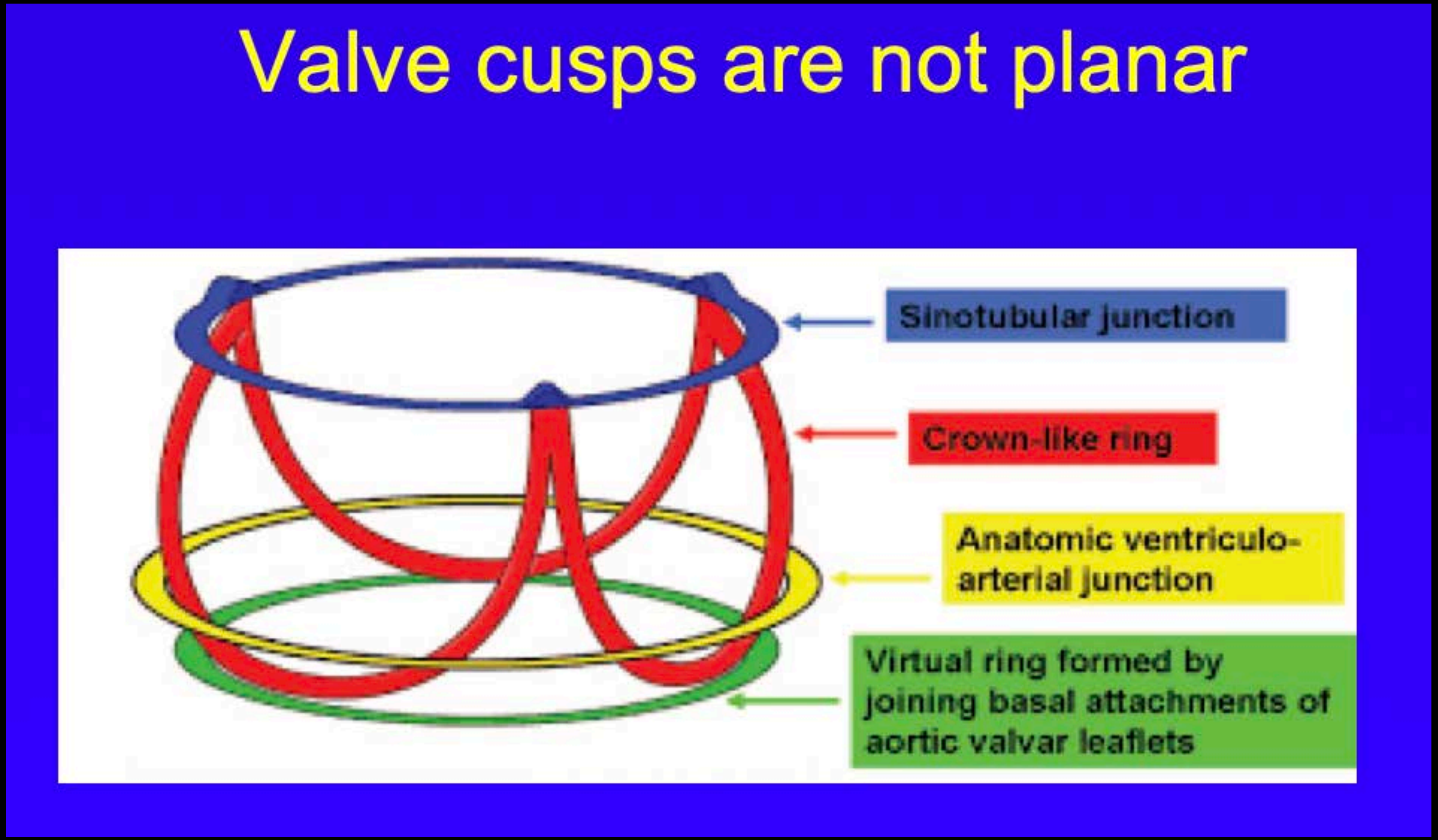
17-19 March 2025

No disclosures

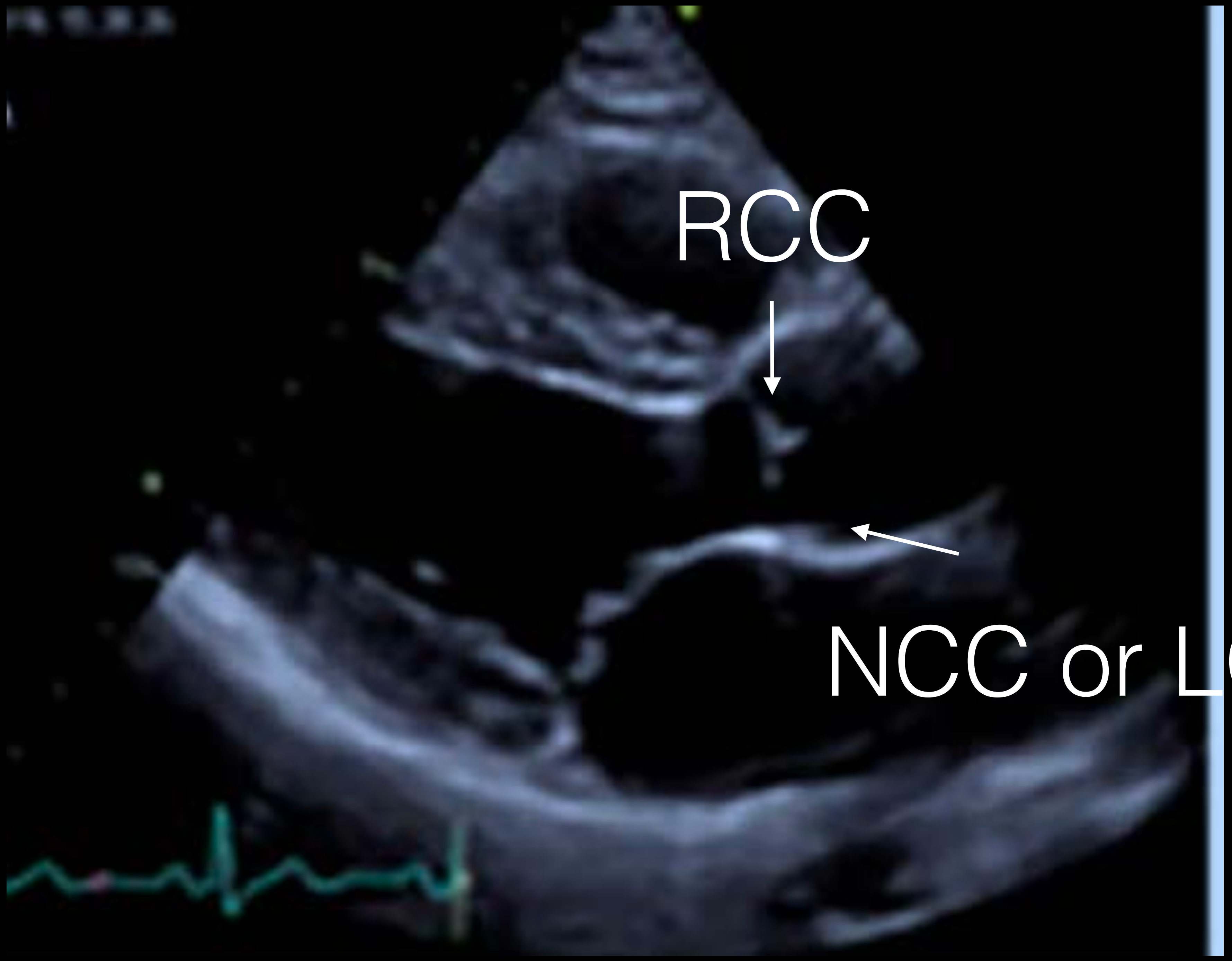
# Summary

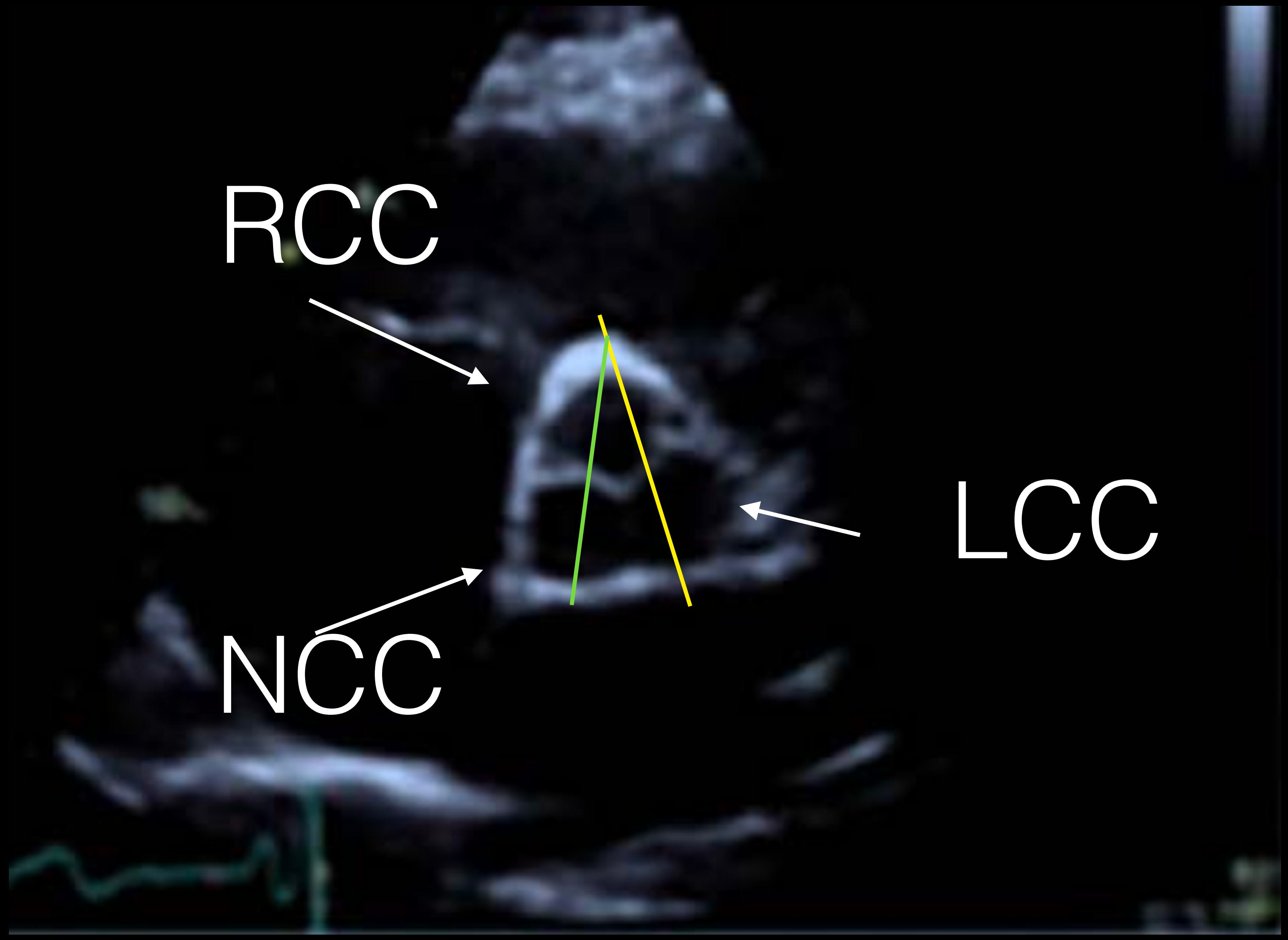
- Anatomy
- Etiology
- Machine settings
- Routine echo protocol
    - Measurements
    - Calculations
- What is low gradient AS and how do we confirm it?

# Anatomy


Valve cusps are not planar
Sinotubular junction
Crown-like ring
Anatomic ventriculo-arterial junction
Virtual ring formed by joining basal attachments of aortic valvar leaflets

# Anatomy





Insertion of cusps

# Aortic stenosis (AS)

- Prevalence is increasing
- Significantly contributes to cardiovascular morbidity and mortality world-wide
- In **high income countries** AS is typically due to calcification of the AV resulting in a narrowed oriface and elevated pressure gradient
    - Rheumatic heart disease and infective endocarditis being the **most common world wide**
- Incidence increases with age
- Echocardiography is crucial for diagnosis as it is the primary non-invasive imaging modality
    - To minimise misdiagnosis it is vital to follow a strict protocol
    - However 5-10% of patients with severe AS do not meet normal defining criteria

# Aortic stenosis (AS)

Prolonged subclinical phase (aortic sclerosis)

- Calcium build up, but no significant gradient (AV Vmax <2.5m/s)

As the disease progresses

- the valve narrows
- left ventricular pressure rises
- LVH

Leading to the classic triad of AS symptoms - heart failure, syncope and angina

## British Society of Echocardiography Practical Guidelines 2021

Guidelines and Recommendations | Open access | Published: 12 March 2021

**Echocardiographic assessment of aortic stenosis: a practical guideline from the British Society of Echocardiography**

Liam Ring MRCP, Benoy N. Shah MD FRCP, Sanjeev Bhattacharyya MD, Allan Harkness MSc, Mark Belham MD FRCP, David Oxborough PhD, Keith Pearce, Bushra S. Rana FRCP, Daniel X. Augustine MD, Shaun Robinson MSc & Christophe Tribouilloy MD PhD

*Echo Research & Practice* **8**, G19–G59 (2021) | Cite this article

## American Society of Echo Guidelines 2017

EACVI/ASE CLINICAL RECOMMENDATIONS

**Recommendations on the Echocardiographic Assessment of Aortic Valve Stenosis: A Focused Update from the European Association of Cardiovascular Imaging and the American Society of Echocardiography**

Helmut Baumgartner, MD, FESC, (Chair), Judy Hung, MD, FASE, (Co-Chair), Javier Bermejo, MD, PhD, John B. Chambers, MB BChir, FESC, Thor Edvardsen, MD, PhD, FESC, Steven Goldstein, MD, FASE, Patrizio Lancellotti, MD, PhD, FESC, Melissa LeFevre, RDCS, Fletcher Miller Jr., MD, FASE, and Catherine M. Otto, MD, FESC, *Muenster, Germany; Boston, Massachusetts; Madrid, Spain; London, United Kingdom; Oslo, Norway; Washington, District of Columbia; Liège, Belgium; Bari, Italy; Durham, North Carolina; Rochester, Minnesota; and Seattle, Washington*

# Echo measurements in AS

**Table 3** Suggested reporting template for AS.

Demographics
- Height, weight, body surface area (BSA).
- Blood pressure, heart rate and rhythm.

Aortic valve morphology
- Tricuspid/bicuspid/unicuspid
- Severity and extent of calcification

LVOT
- Dimensions and VTI
- Report any change in the LVOTd from previous studies

Aortic stenosis severity
- Aortic valve Vmax; mean gradient: include window from which maximal values were obtained
- Change in AV Vmax from previous echo study
- Aortic valve area
- Description of severity (mild/moderate/severe/very severe)

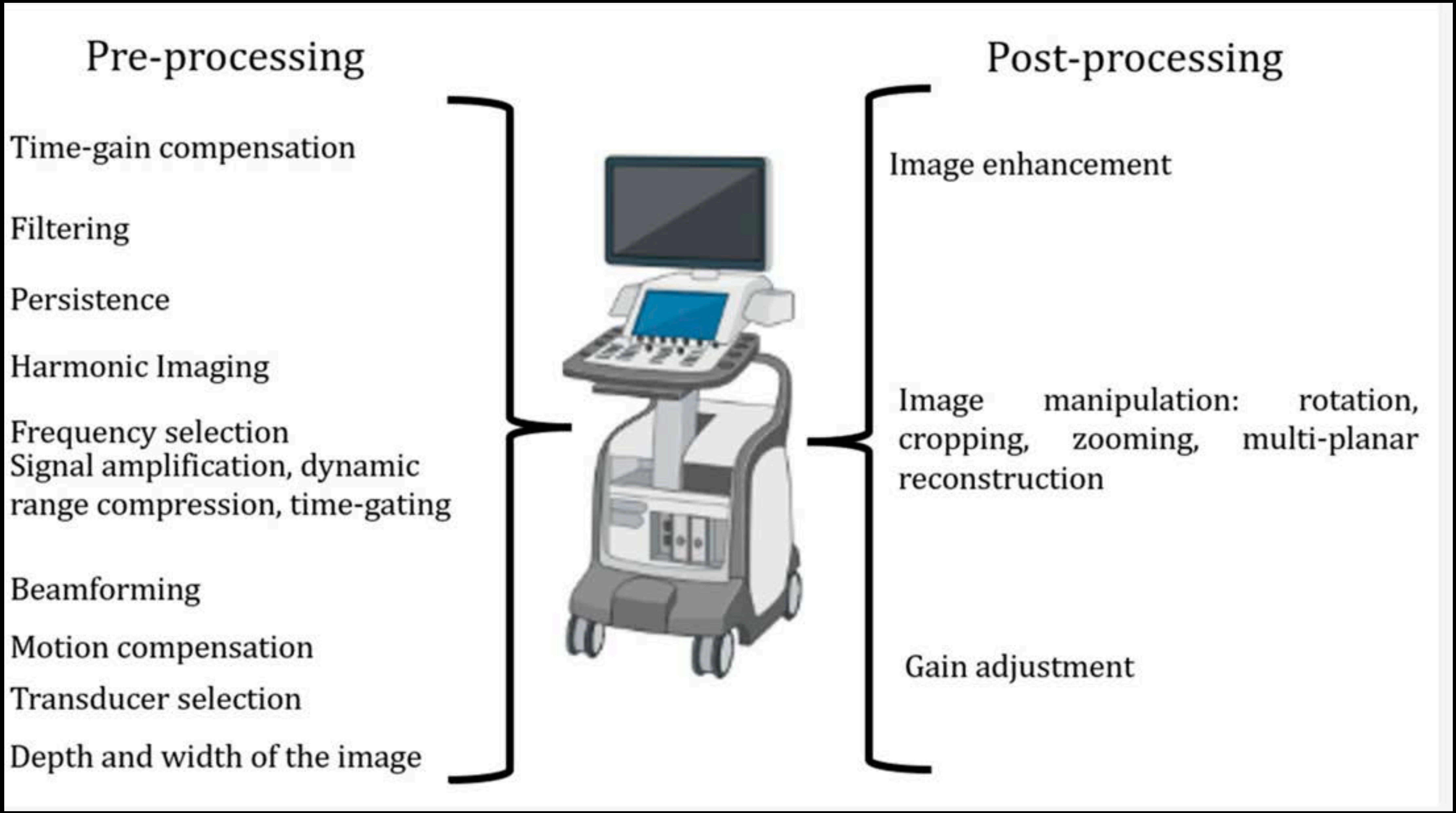
Additional prognostic markers
- Left ventricular ejection fraction
- Global longitudinal strain
- Indexed LV mass
- High probability of pulmonary hypertension (see specific BSE guidance)

Aortic regurgitation – note presence and severity (see specific BSE guidance)

Aorta – measure size (see specific BSE guidance and reference intervals)

British Society of Echocardiography Practical Guidelines 2021

# Machine settings

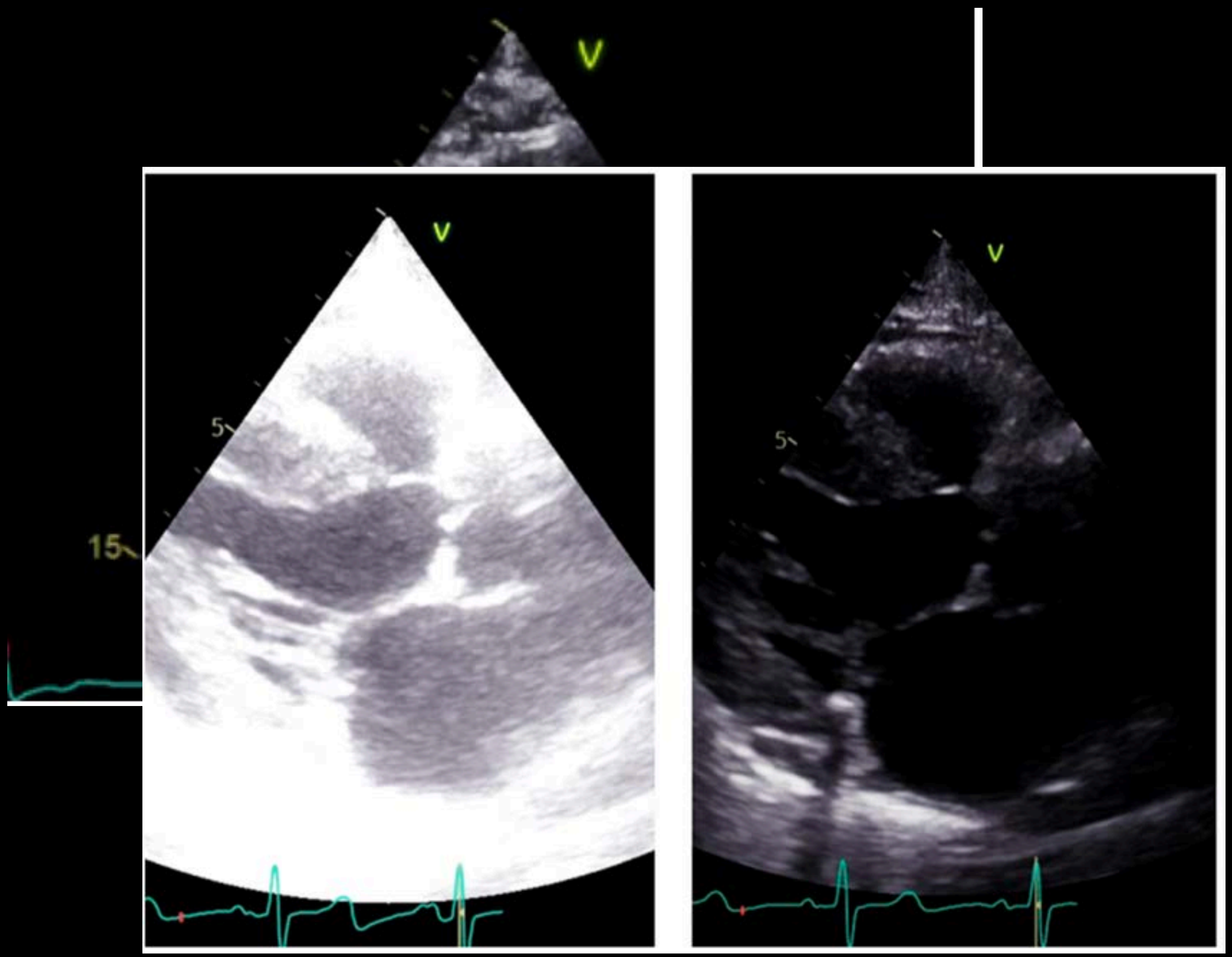



Canciello et al Pitfalls and tips in the assessment of aortic stenosis by transthoracic echocardiography, Diagnostics, 2023.

# Standard TTE images for the assessment of AS

PLAX

- LV dimensions and LV mass
- AV appearance (calcification, mobility, closure (eccentric?)
- LVOT diameter
- Colour - turbulence and AR
- Aortic measurements



# LVOT diameter

- PLAX zoom of AV - Aim for the image that transects the RCC hinges point and interleaflet triangle posteriorly

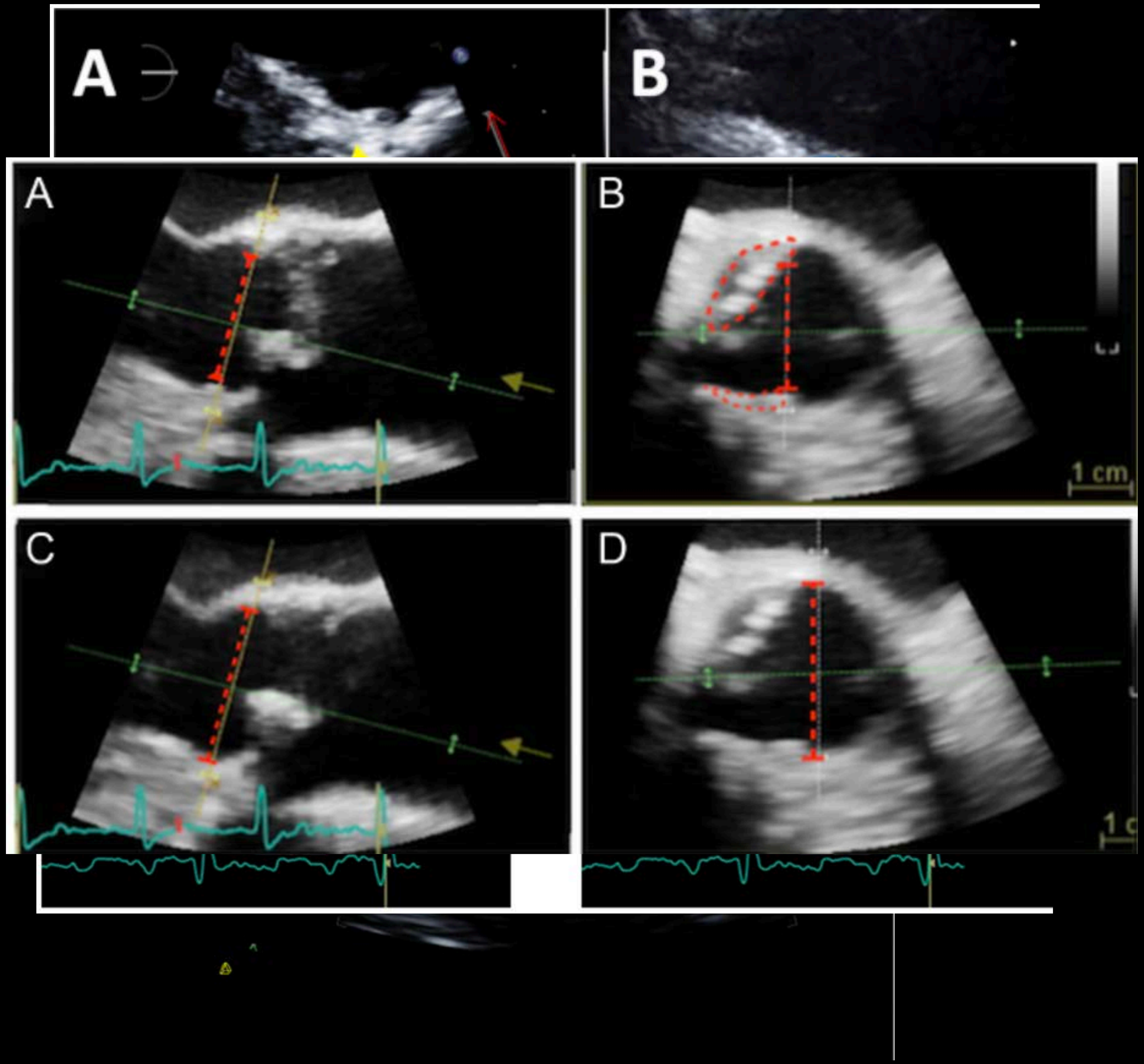
- Adjust gains to optimise blood tissue interface

- Mid-systole

- Inner-inner edge

    - 2-5mm below the annulus at the site where the PW Doppler sample will be for the LVOT VTI measurement to avoid pre-valvular acceleration

- Recommendations suggest off axis imaging to avoid ectopic calcification

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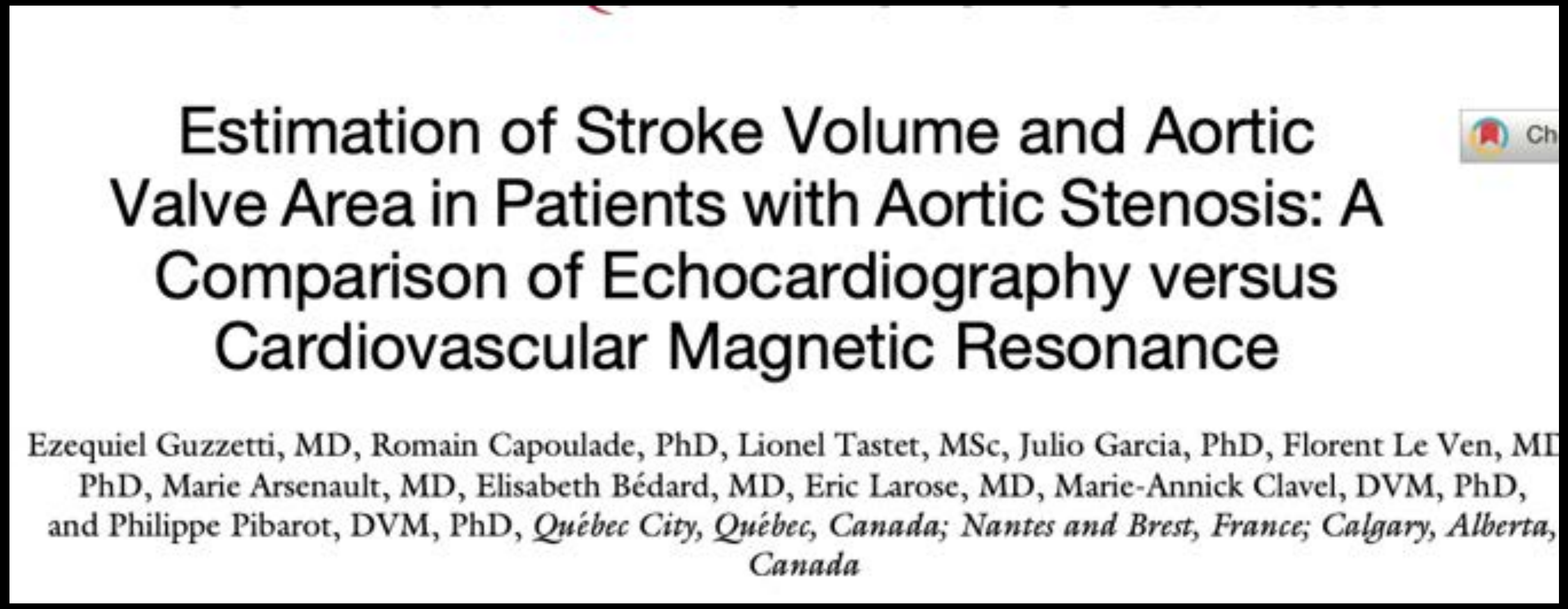
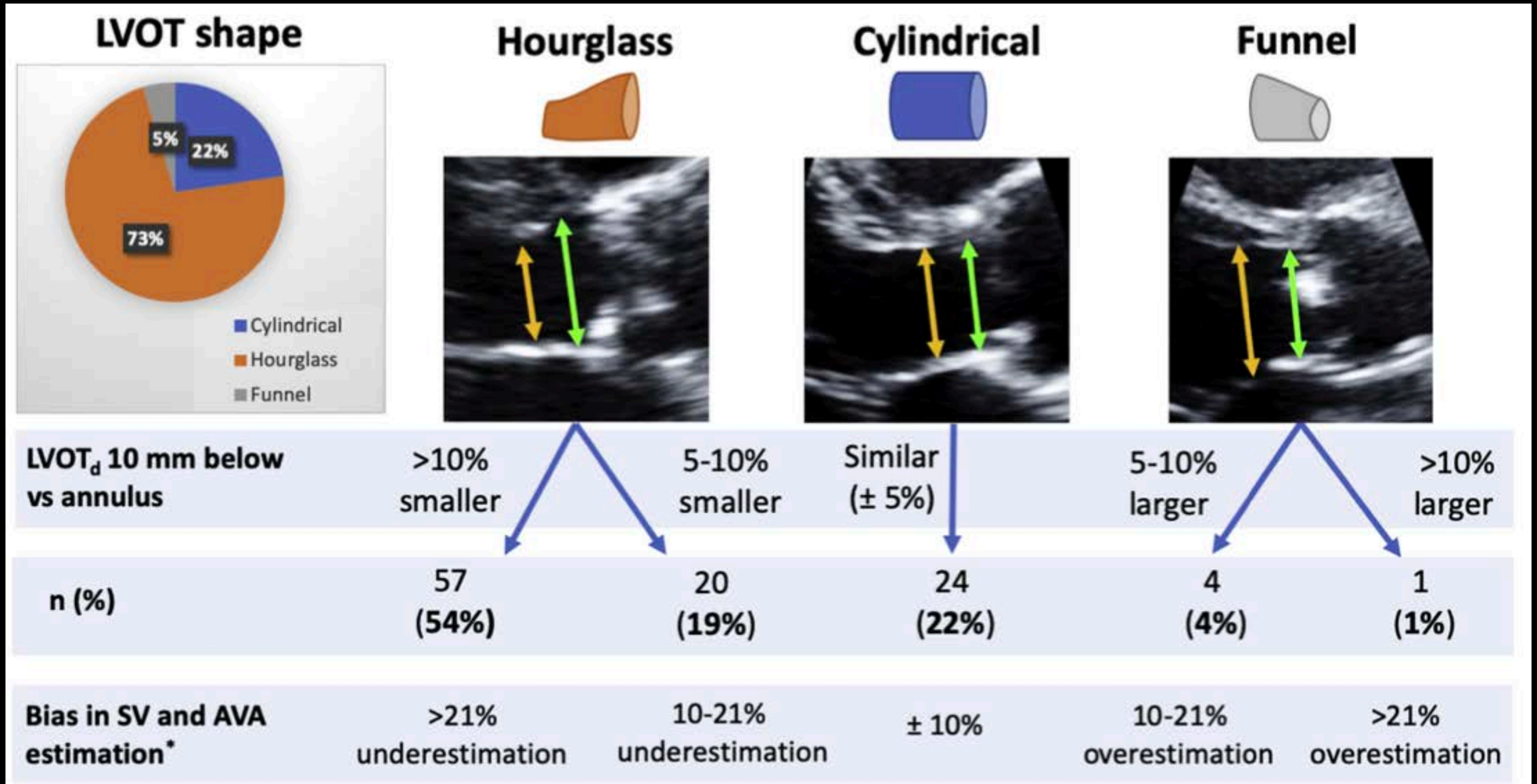


Estimation of Stroke Volume and Aortic Valve Area in Patients with Aortic Stenosis: A Comparison of Echocardiography versus Cardiovascular Magnetic Resonance

Ezequiel Guzzetti, MD, Romain Capoulade, PhD, Lionel Tastet, MSc, Julio Garcia, PhD, Florent Le Ven, MD, PhD, Marie Arsenault, MD, Elisabeth Bédard, MD, Eric Larose, MD, Marie-Annick Clavel, DVM, PhD, and Philippe Pibarot, DVM, PhD, *Québec City, Québec, Canada; Nantes and Brest, France; Calgary, Alberta, Canada*

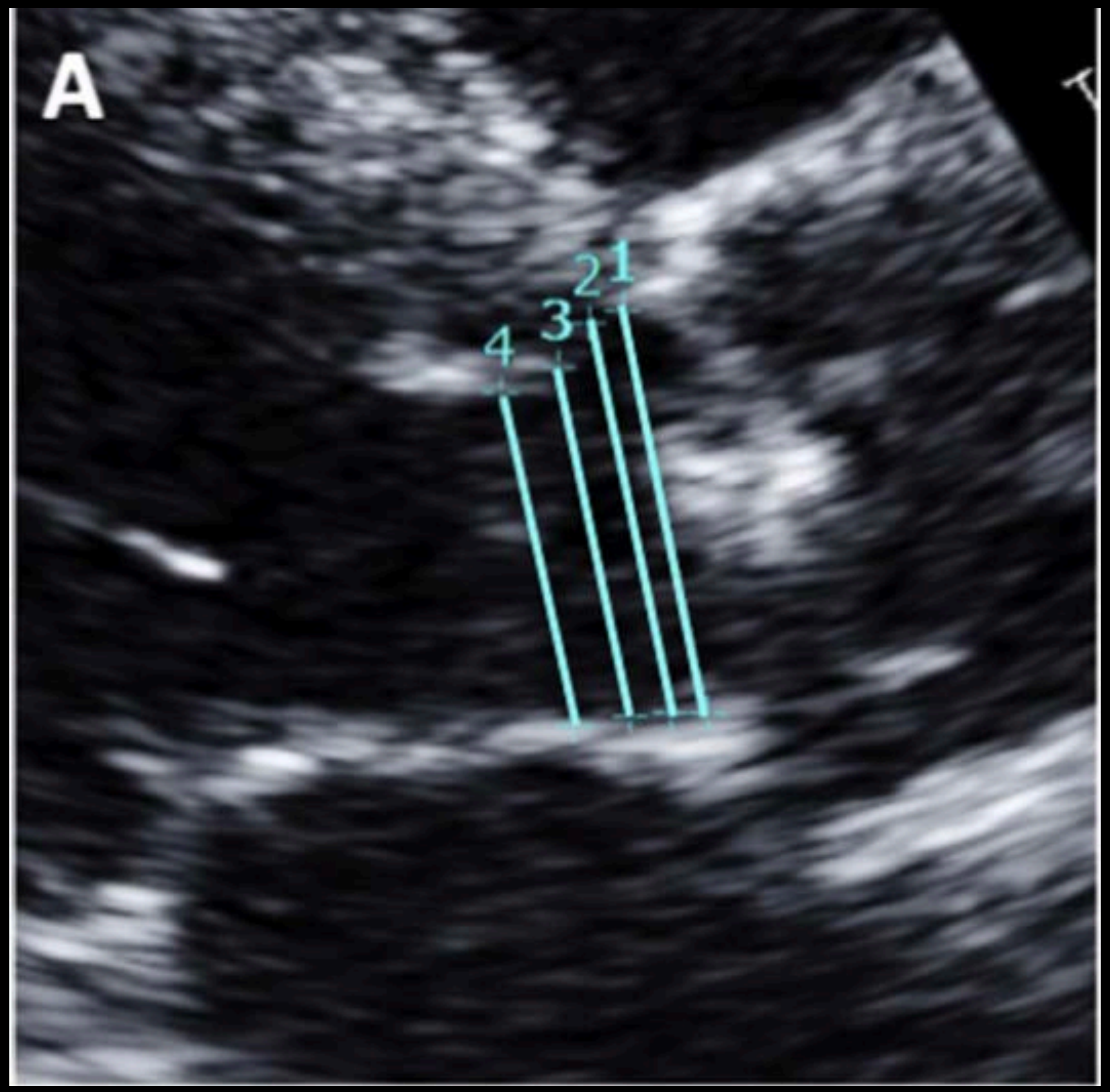



73% of patients had a hour glass shaped LVOT

Difference of >5% between LVOTd at the annulus and 10mm below the annulus

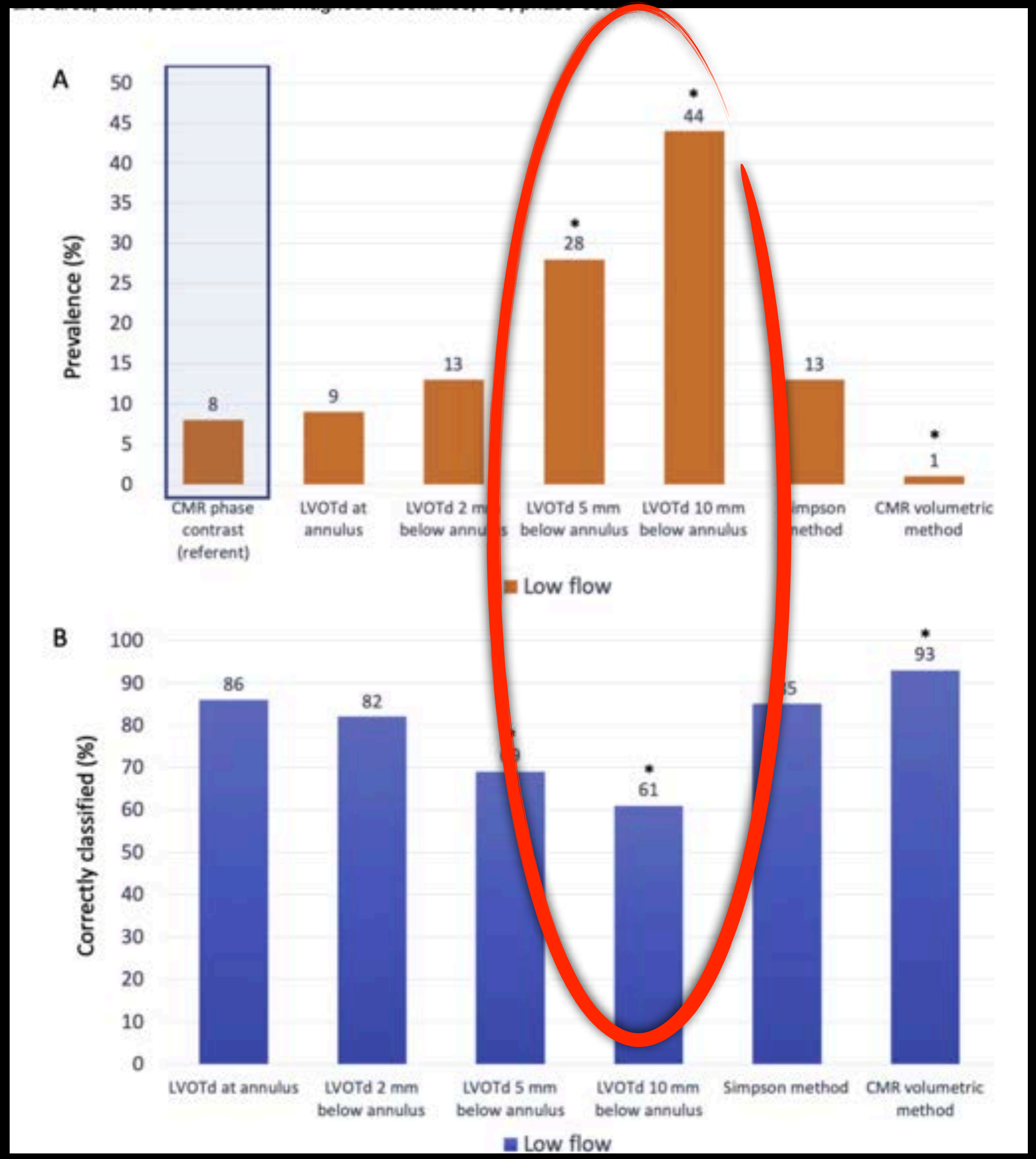
Resulting in >10% error in SV and AVA

# LVOT diameter

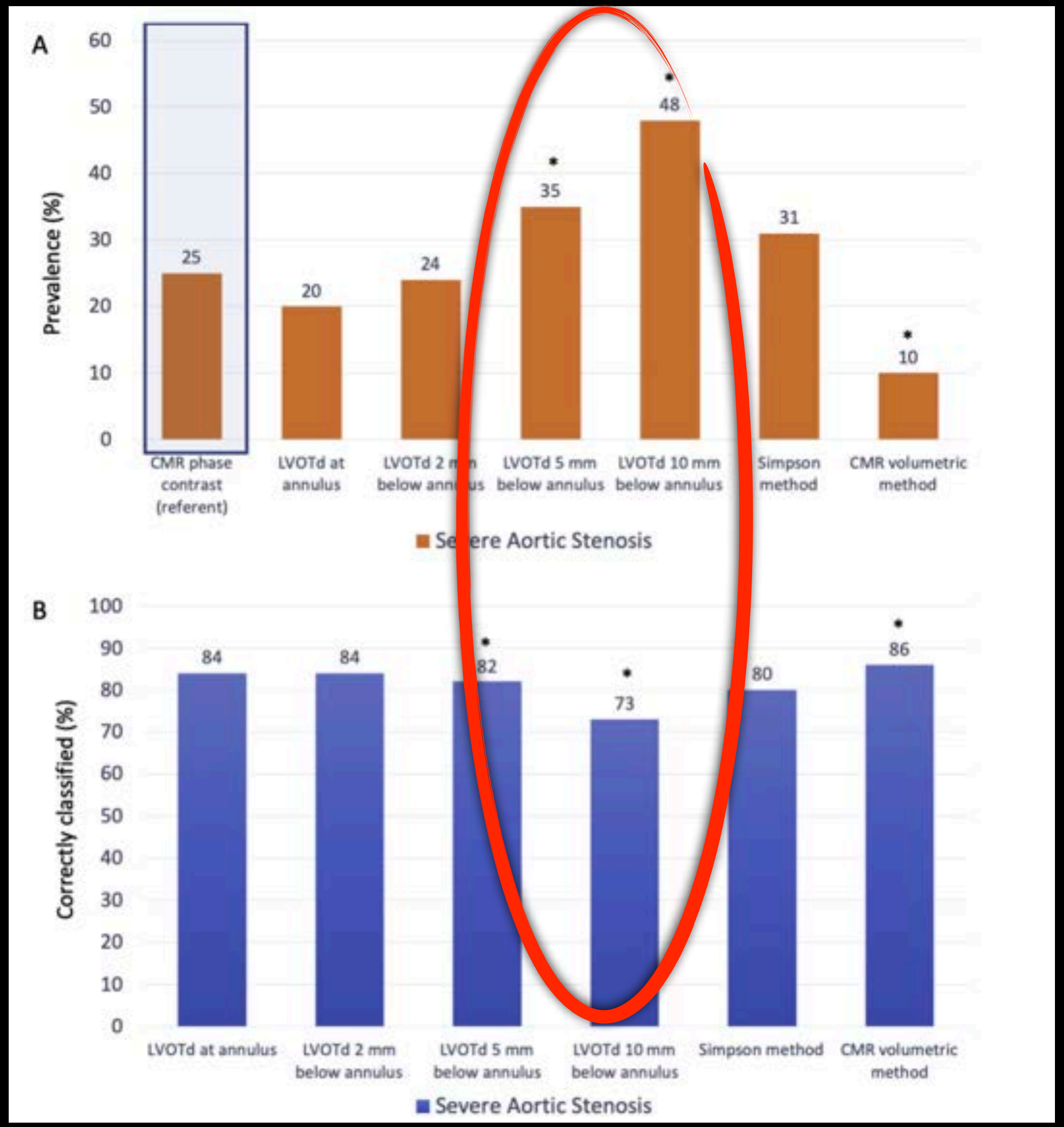



LVOTd measured at annulus, 2mm, 5mm and 10mm

## Prevalence of low flow




## Prevalence of Severe AS




Measuring 5 and 10 mm below the annulus resulted in significant underestimation of SV and AVA by up to 15.9%

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# Predicted LVOT diameter

Calculate predicted LVOTd using the formula:

$$LVOTd = (5.7 \times BSA) + 12.1$$

LVOTd should be within 2mm of predicted LVOTd

- In obese patients the predicted LVOTd may be overestimated

# Standard TTE images for the assessment of AS

M-Mode

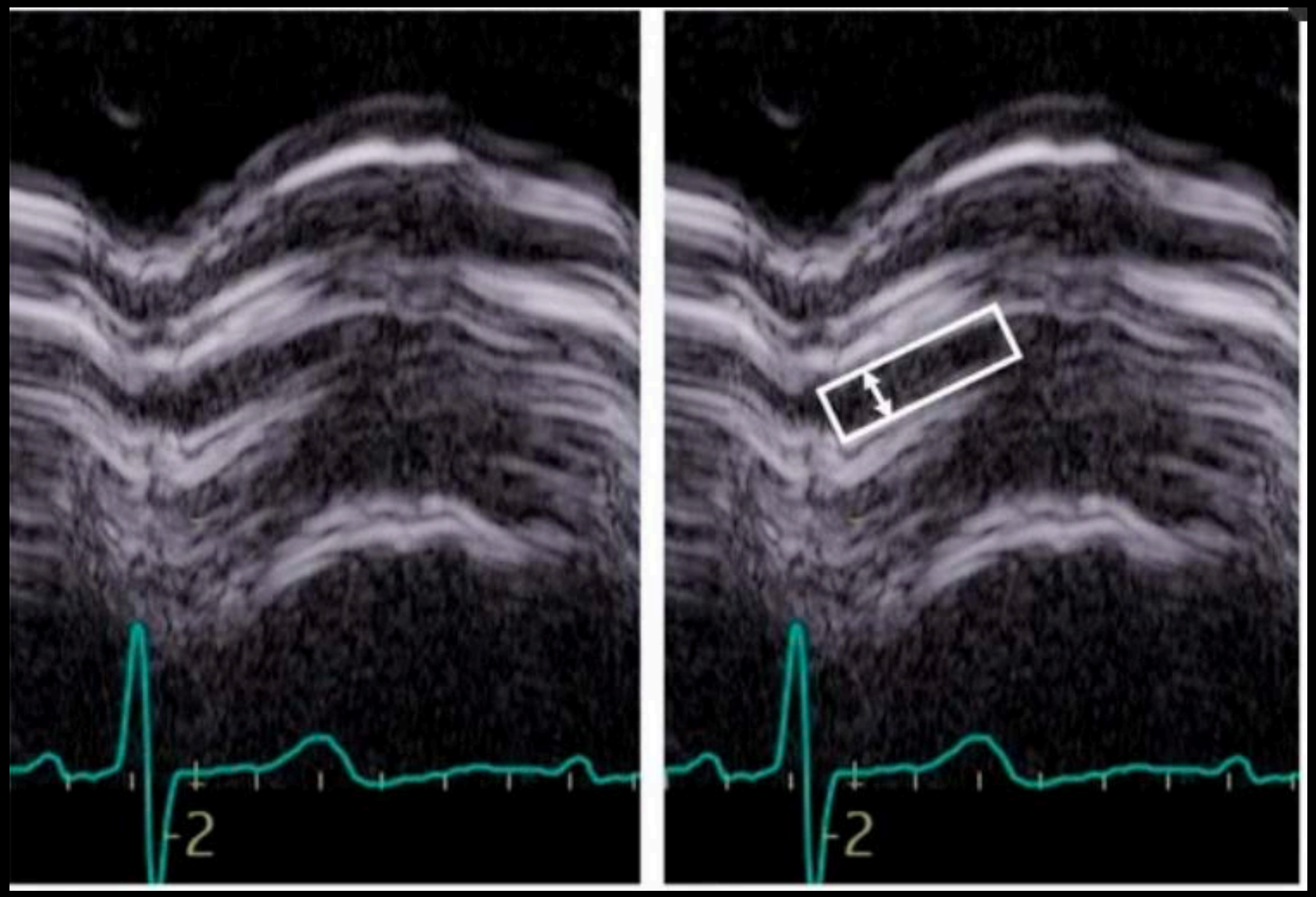
- High temporal resolution
- Eccentric closure of AV - suggestive of bicuspid AV
- Systolic leaflet seperation

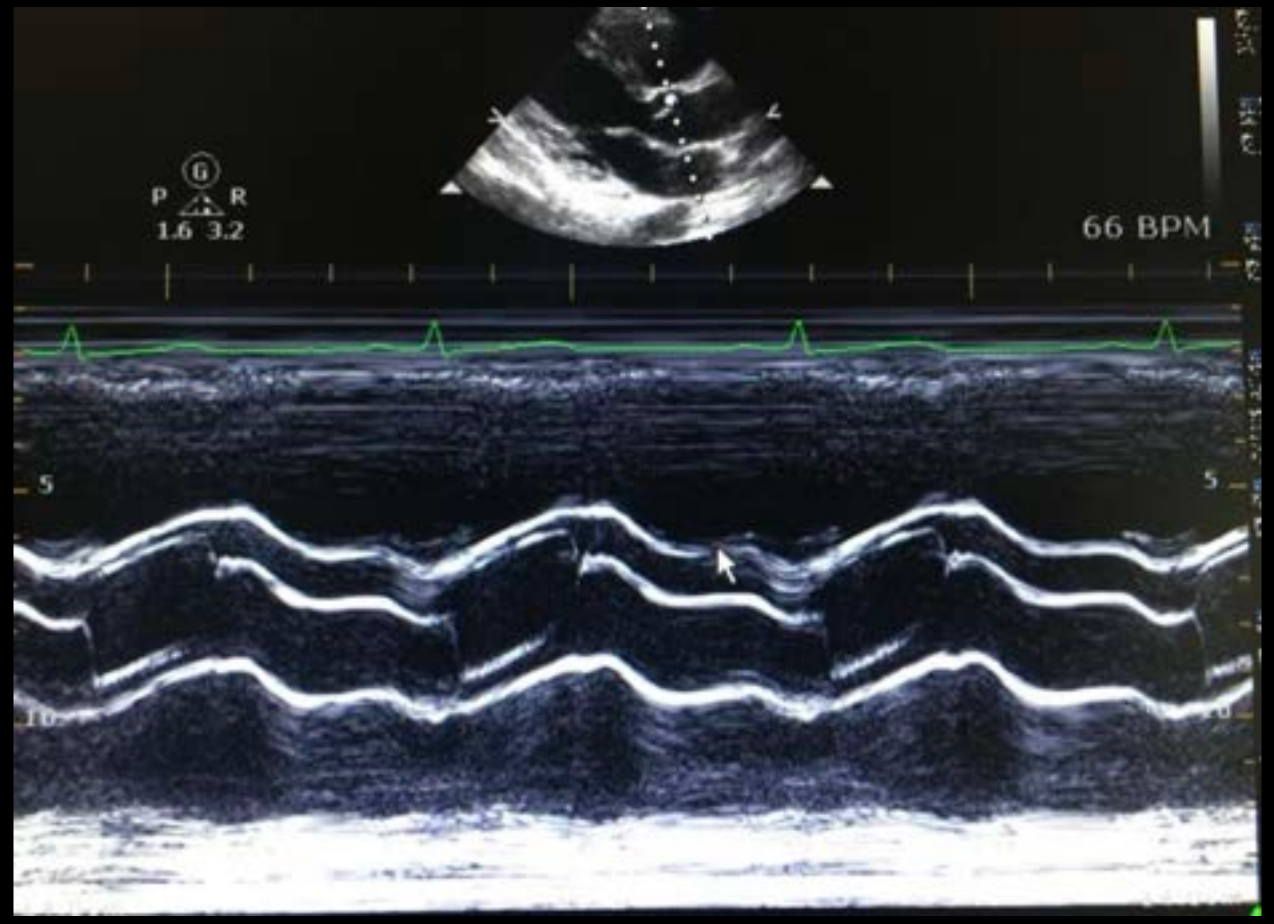
of ≥15mm excludes

Severe AS

- If <15mm then it could vary from

mild-severe AS



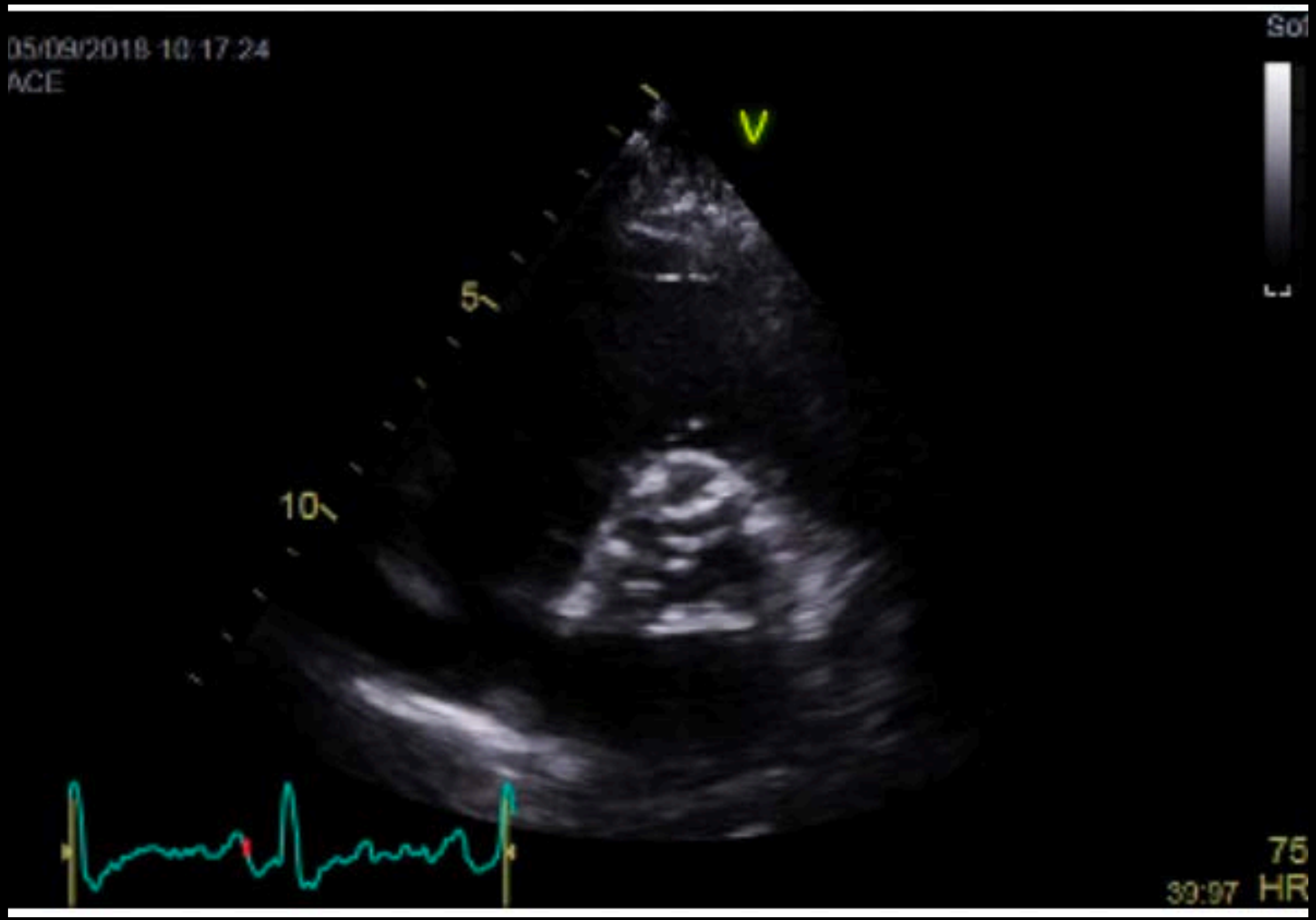


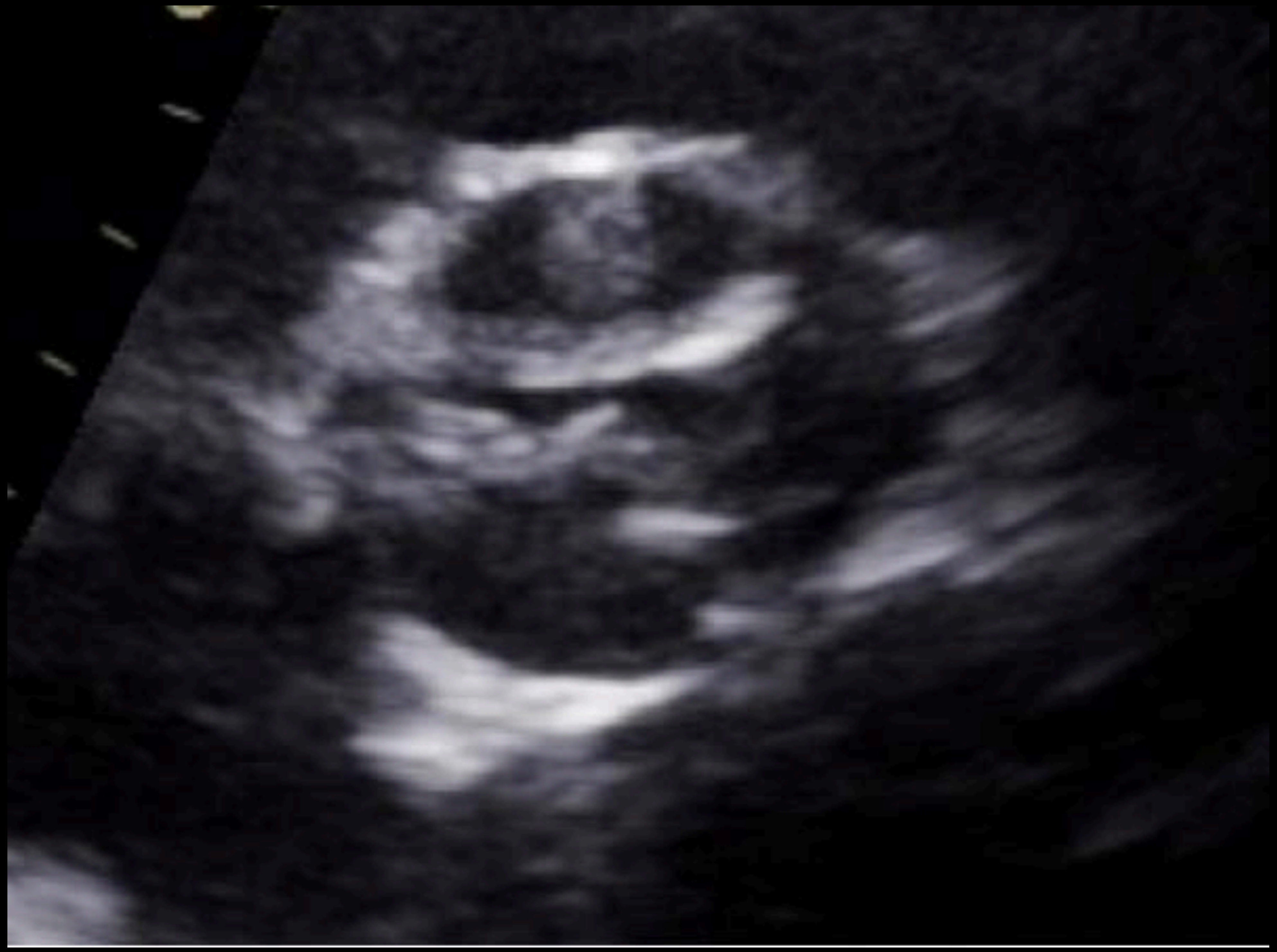

Canciello et al Pitfalls and tips in the assessment of aortic stenosis by transthoracic echocardiography, Diagnostics, 2023.

# Standard TTE images for the assessment of AS

PSAX

- Appearance of AV - calcification, mobility, number of cusps
- Colour for AR

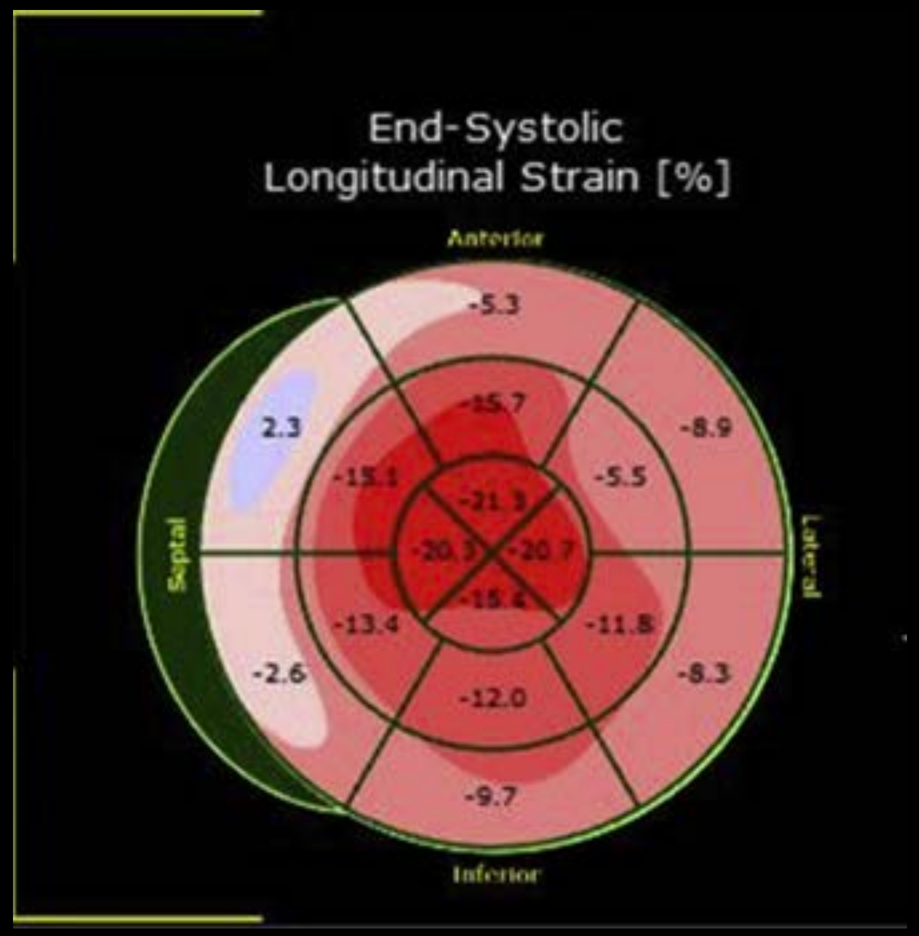


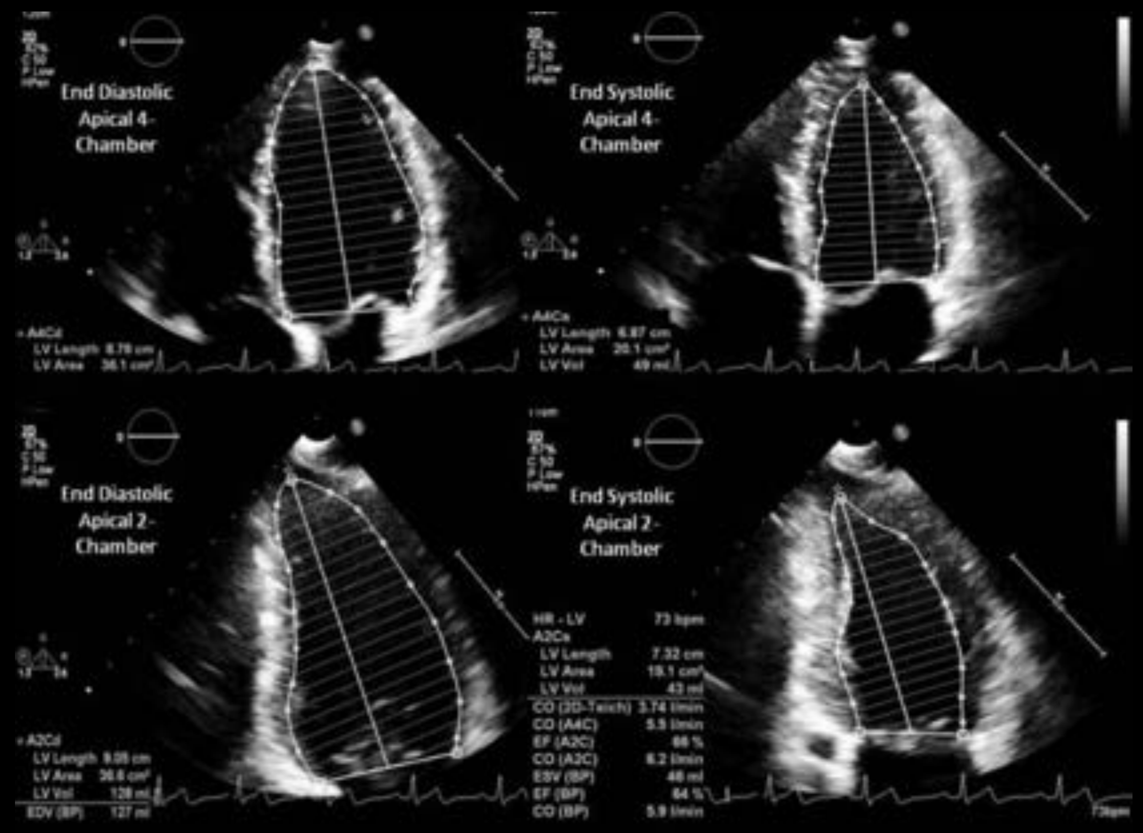



# Standard TTE images for the assessment of AS

Apical imaging (4ch, 5ch, 2ch and 3Ch)

- LVEF
- GLS
- Appearance of AV - calcification and mobility
- Colour - AR and turbulence

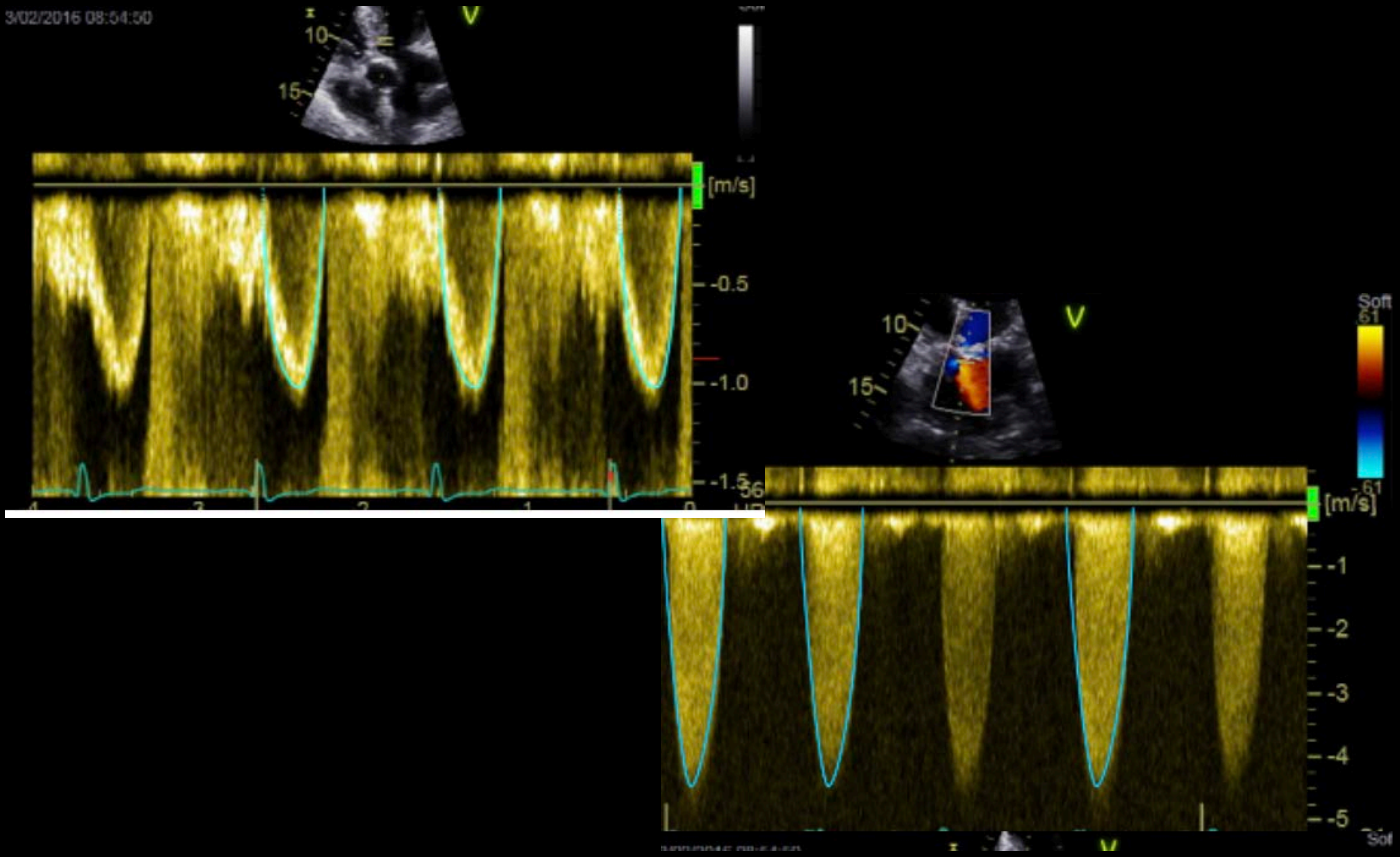


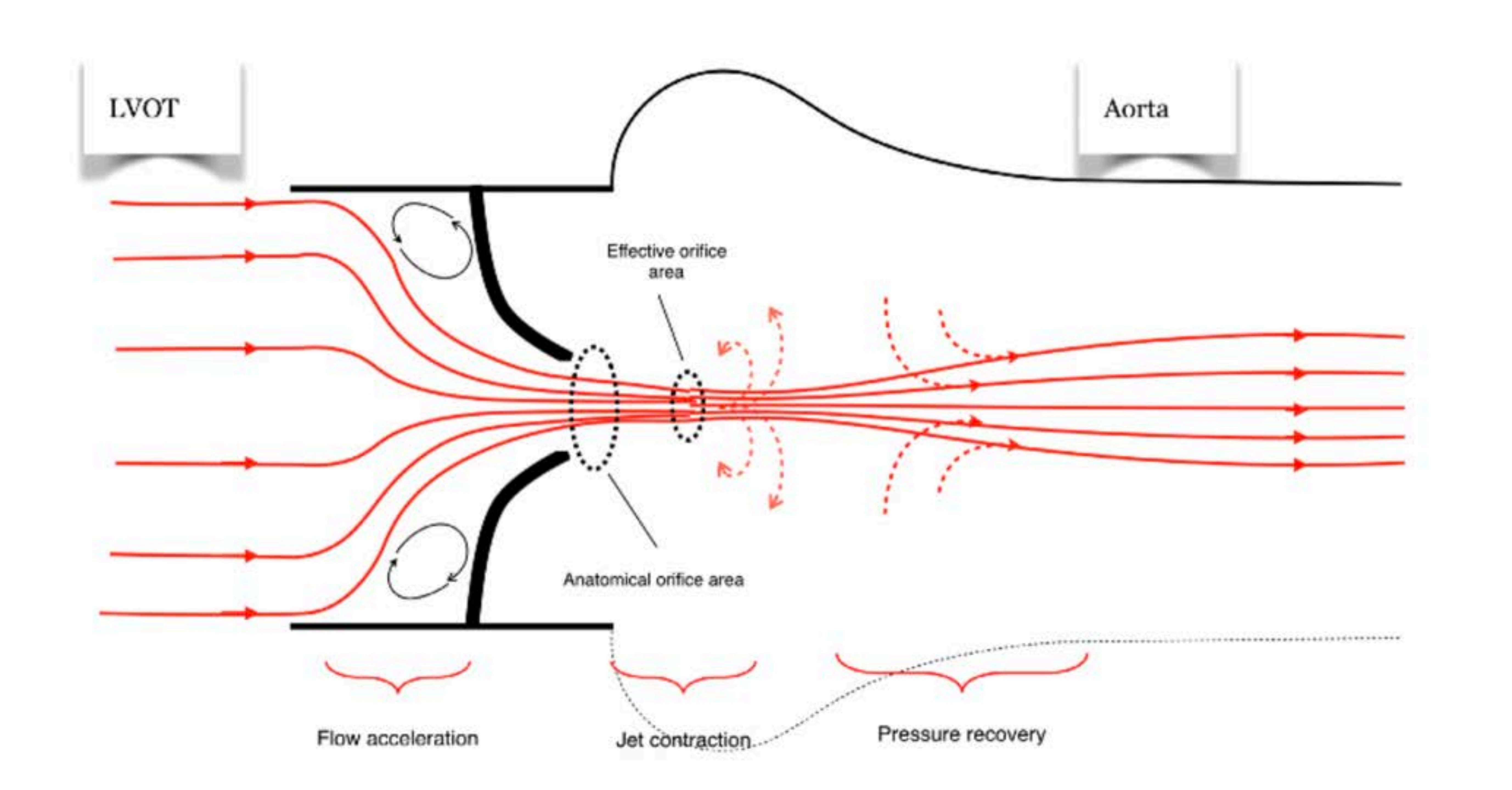
# Standard TTE images for the assessment of AS

Apical

- PW Doppler
- CW Doppler



# Haemodynamics in AS

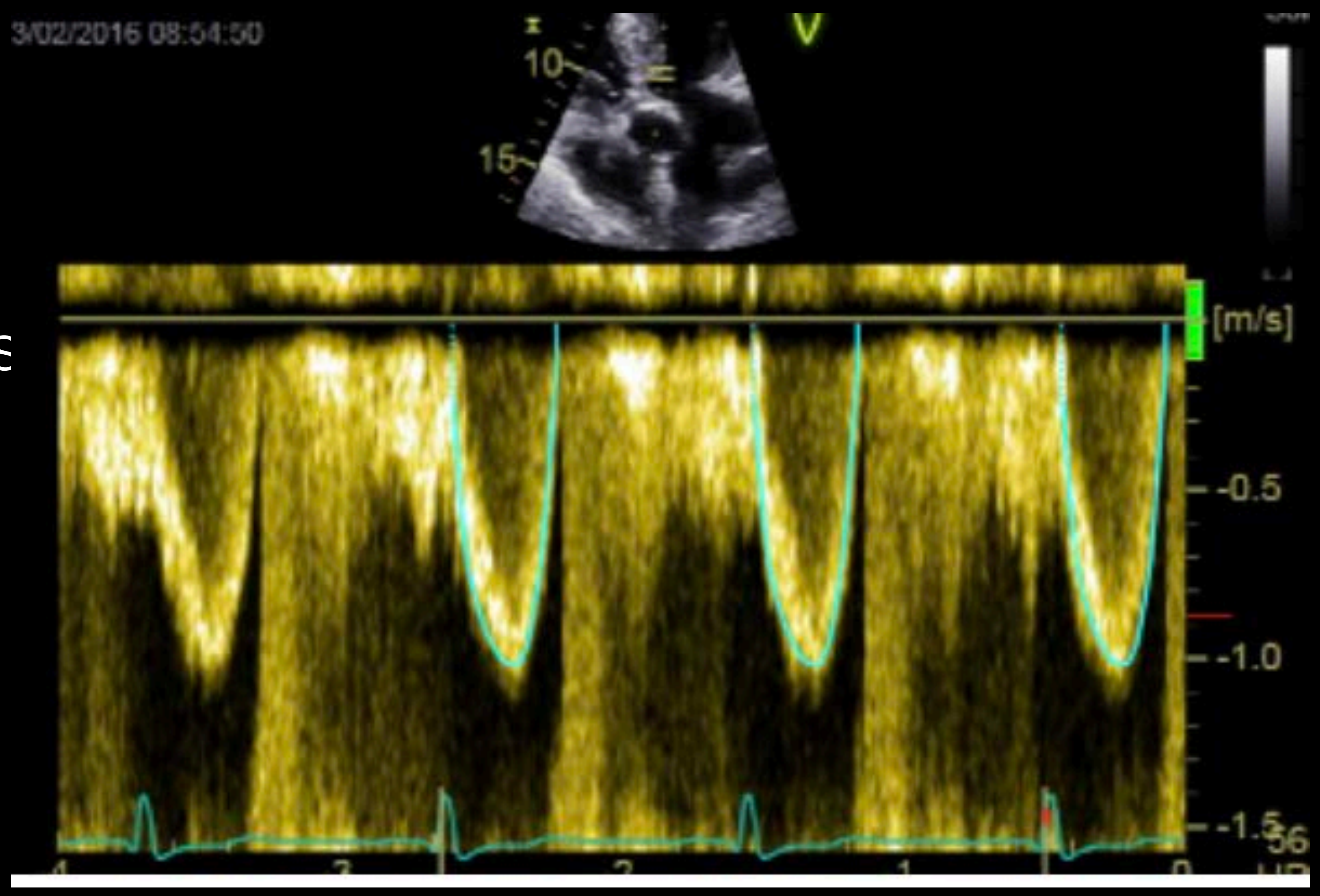


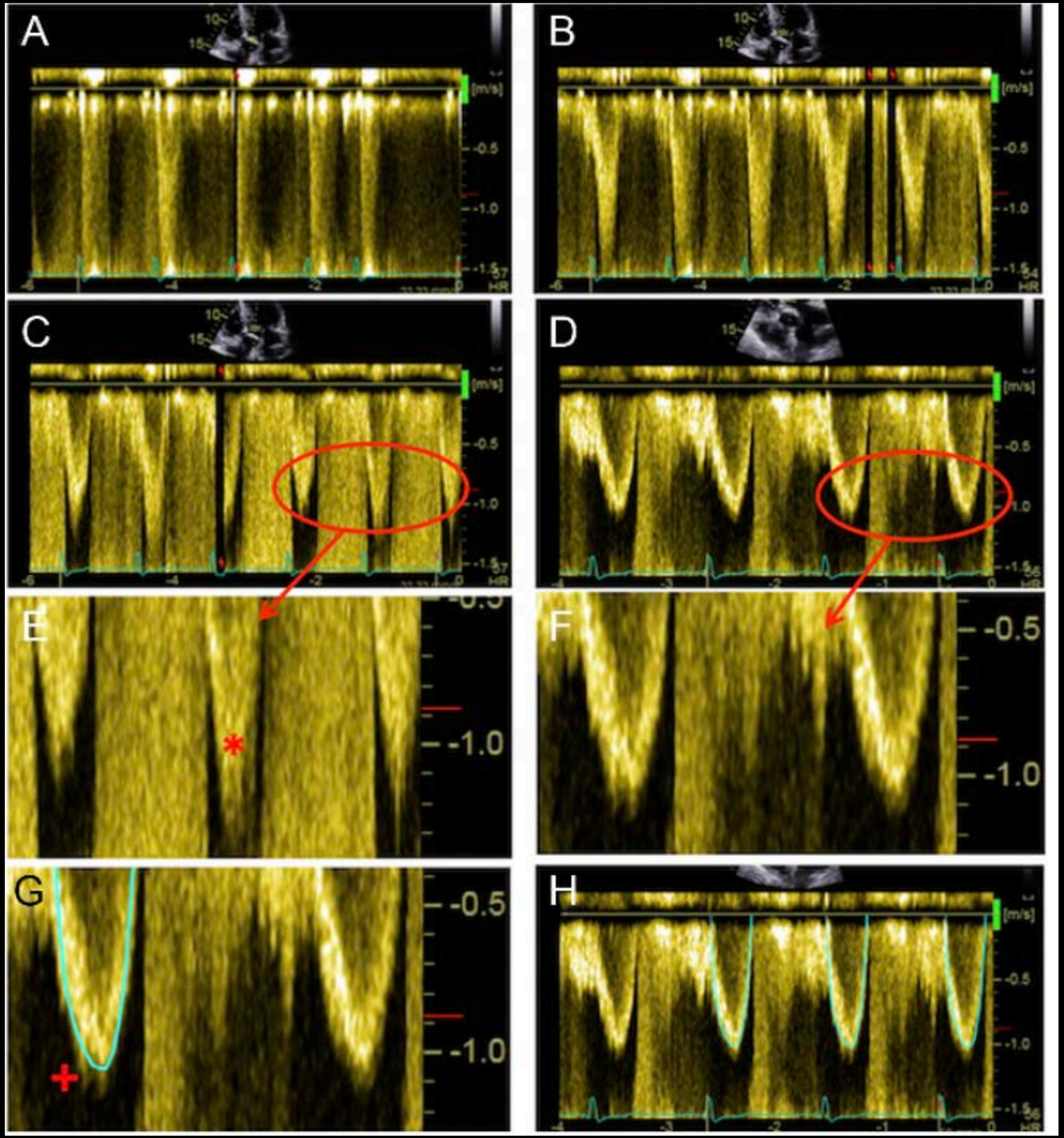

Ring, L., Shah, B.N., Bhattacharyya, S. *et al.* Echocardiographic assessment of aortic stenosis: a practical guideline from the British Society of Echocardiography. *Echo Res Pract* **8**, G19–G59 (2021). https://doi.org/10.1530/ERP-20-0035

# Standard TTE images for the assessment of AS

## LVOT Velocity

- PW Doppler, sample volume 3-5mm
- Apical
- Sample volume just on left side of valve and moved slowly towards the apex to obtain laminar flow and AV closing click
- Adjust baseline and scale to maximise size of velocity curve
- Sweep speed 50-100mm/s
- Low wall filter settings
- Smooth velocity curve with well defined peak and narrow velocity range at peak velocity
- Trace modal velocity for VTI and record Vmax from peak






# LVOT PW Doppler

Ring, L., Shah, B.N., Bhattacharyya, S. *et al.* Echocardiographic assessment of aortic stenosis: a practical guideline from the British Society of Echocardiography. *Echo Res Pract* **8**, G19–G59 (2021). https://doi.org/10.1530/ERP-20-0035

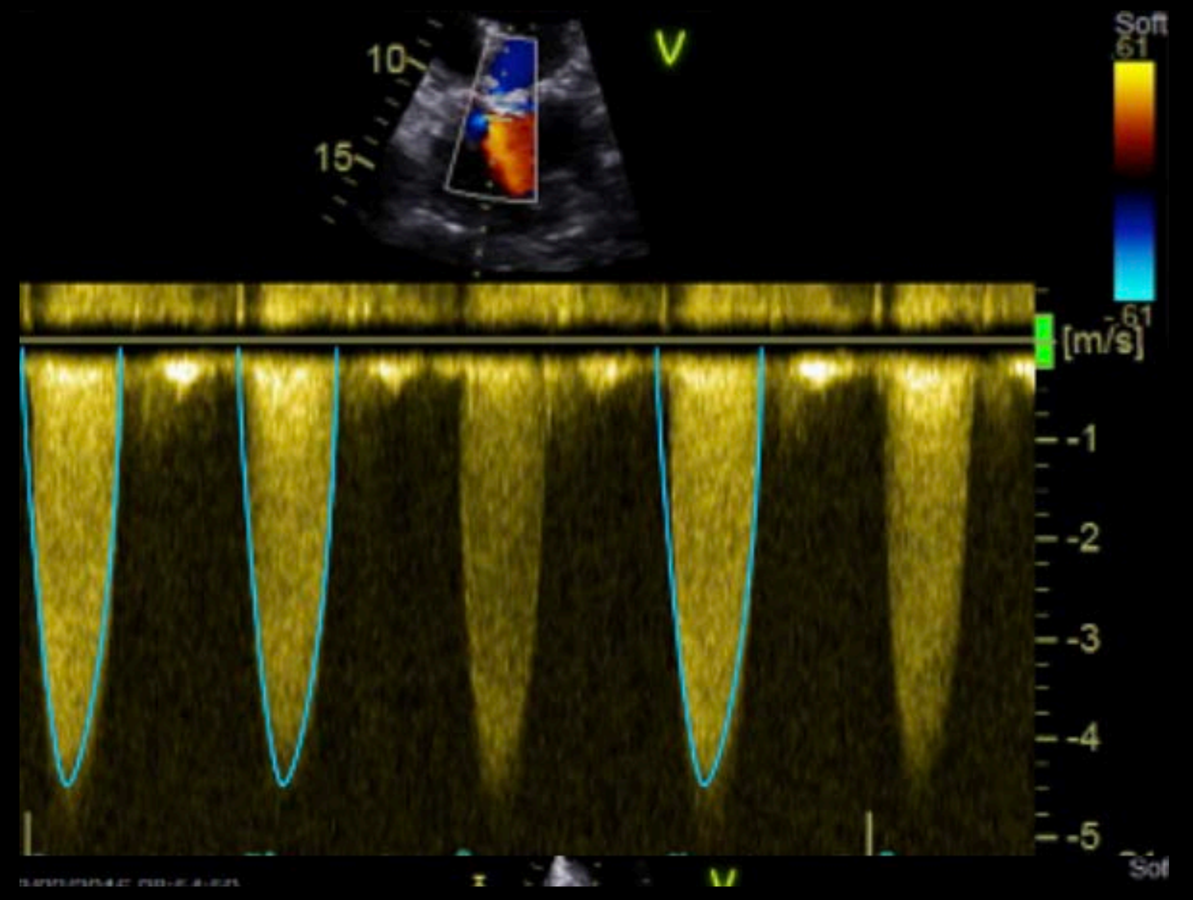
# Standard TTE images for the assessment of AS

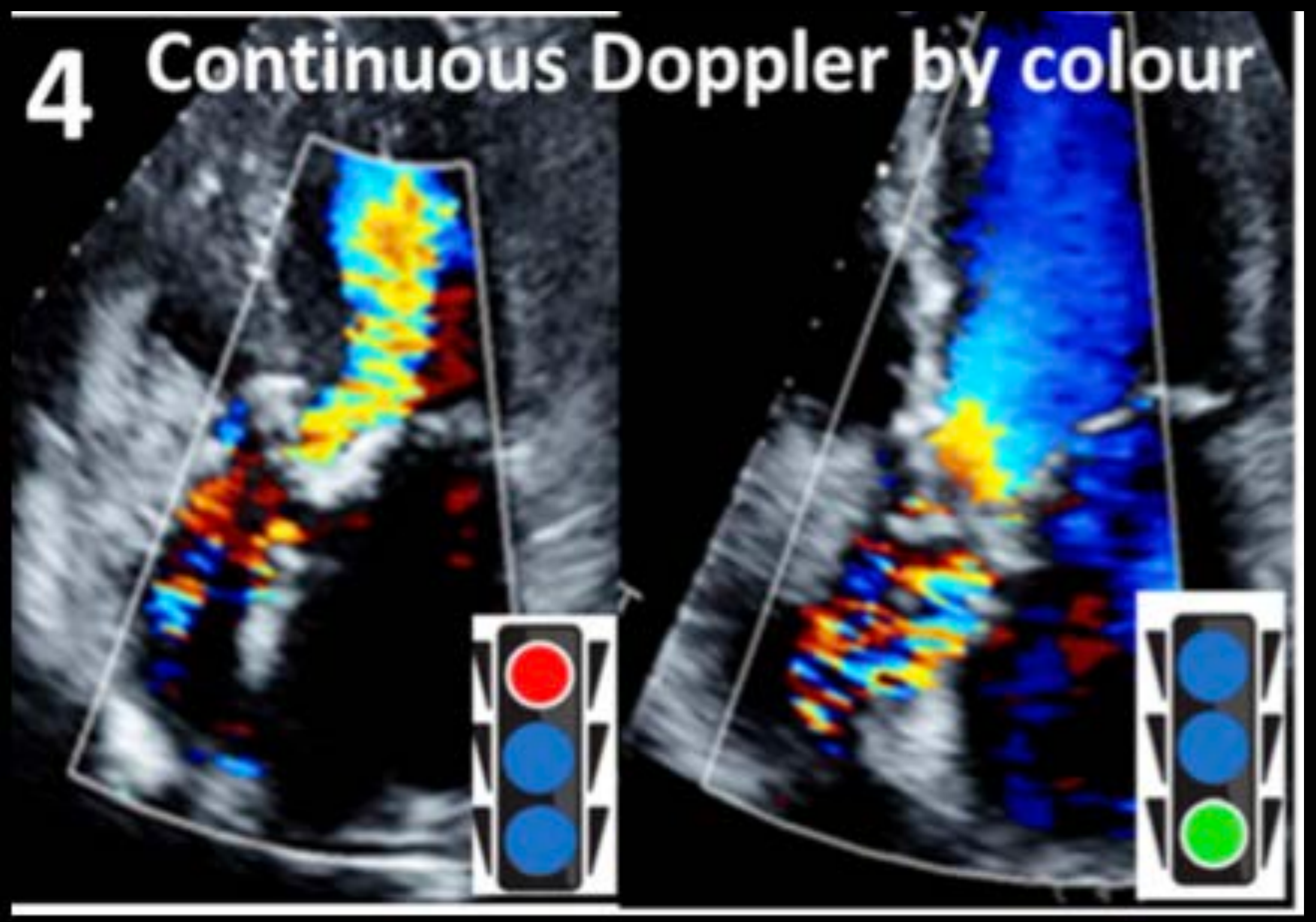
## AS Jet Velocity

- CW Doppler from multiple acoustic windows
- Decrease gain, increase wall filter
- Adjust baseline and scale to maximise size of velocity curve
- Sweep speed 50-100mm/s
- When measuring
    - avoid noise and fine linear signals
    - VTI traced from outer edge of dense signal - also gives mean PG

AV V max is the strongest predictor of clinical outcome

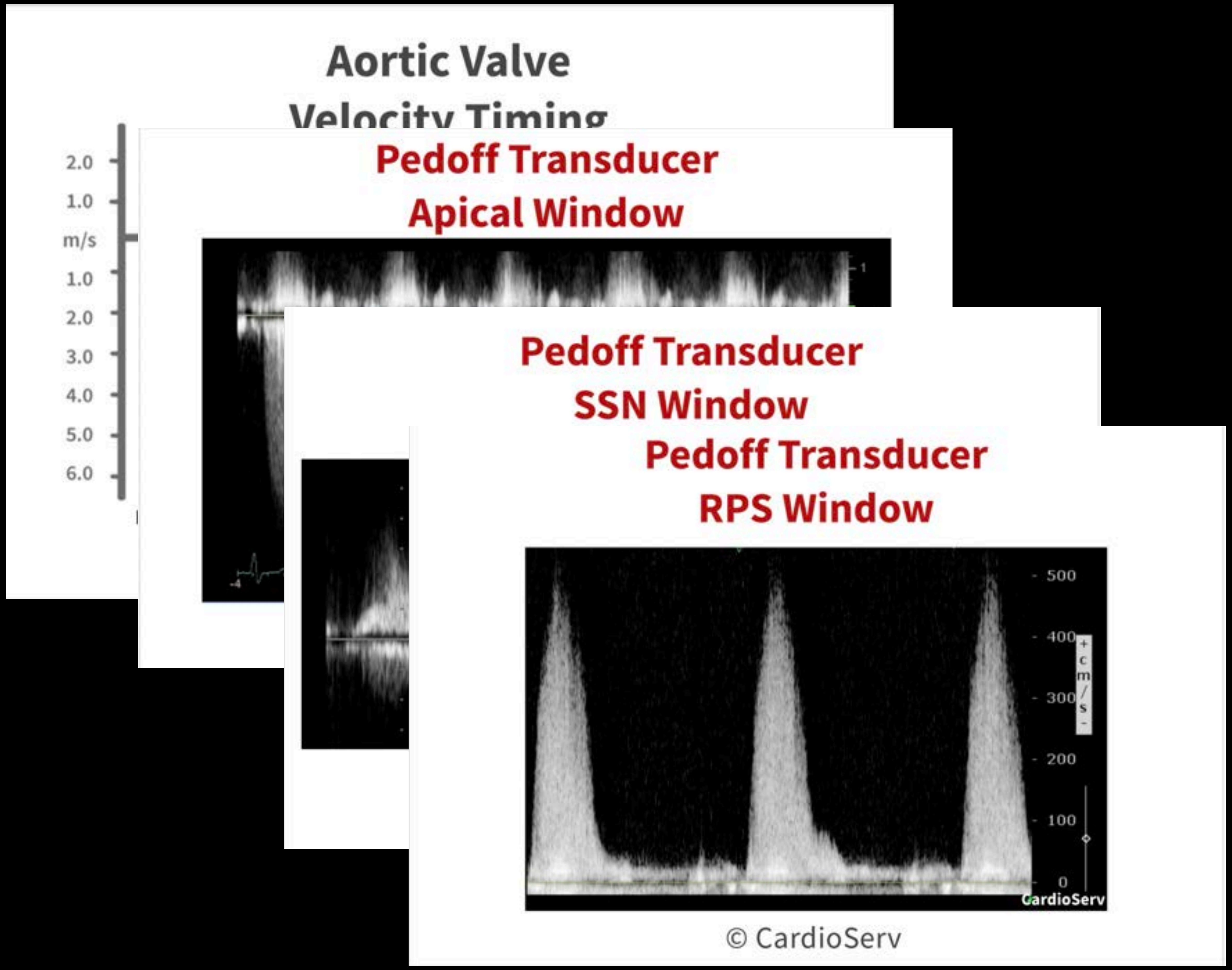
**Flow dependant



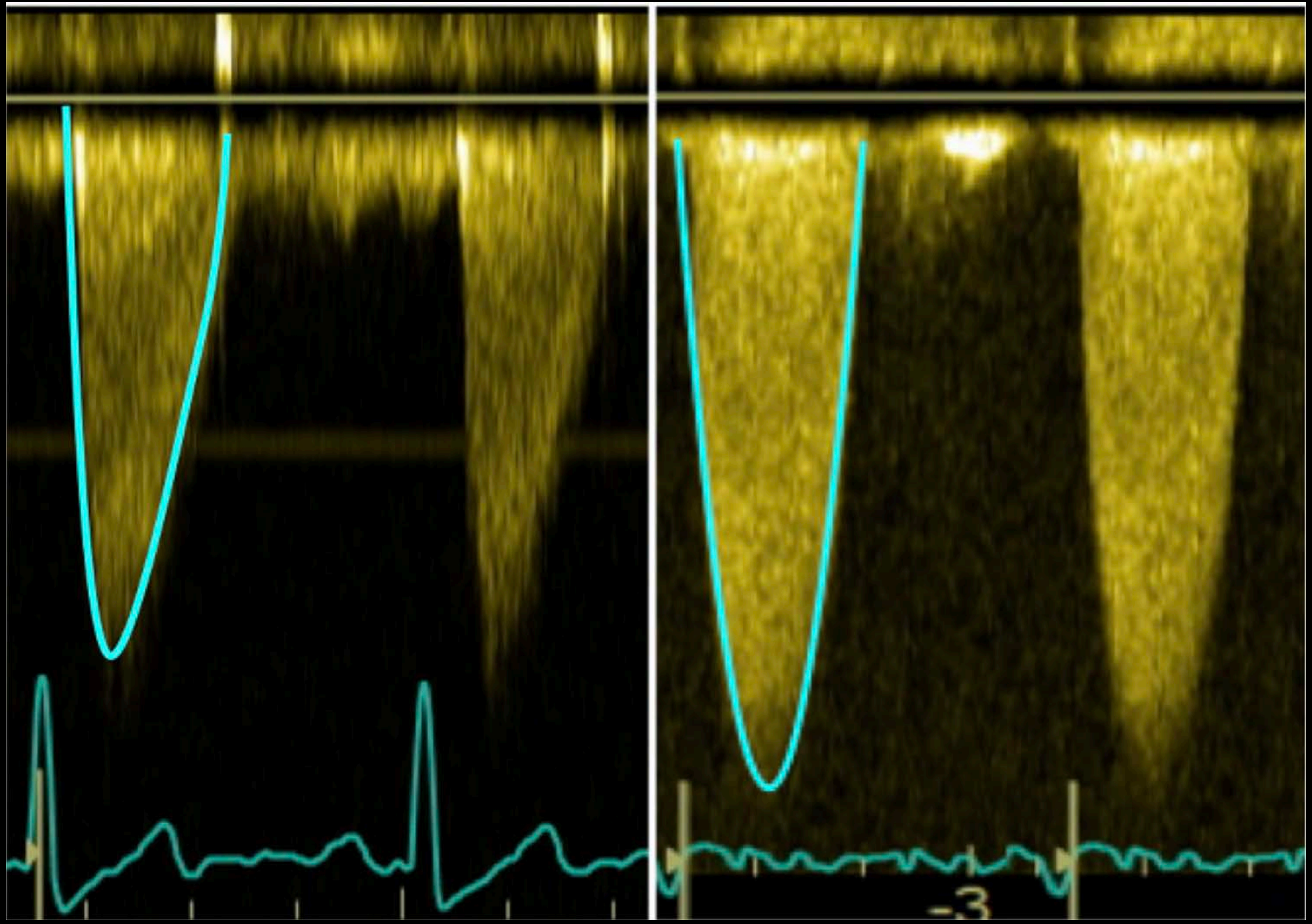



# Pedof

- From all imaging windows including suprasternal, supraclavicular and right parasternal
- Take your time and have patience
- Close your eyes and listen



# CW Doppler Waveform - Shape

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# Standard TTE images for the assessment of AS

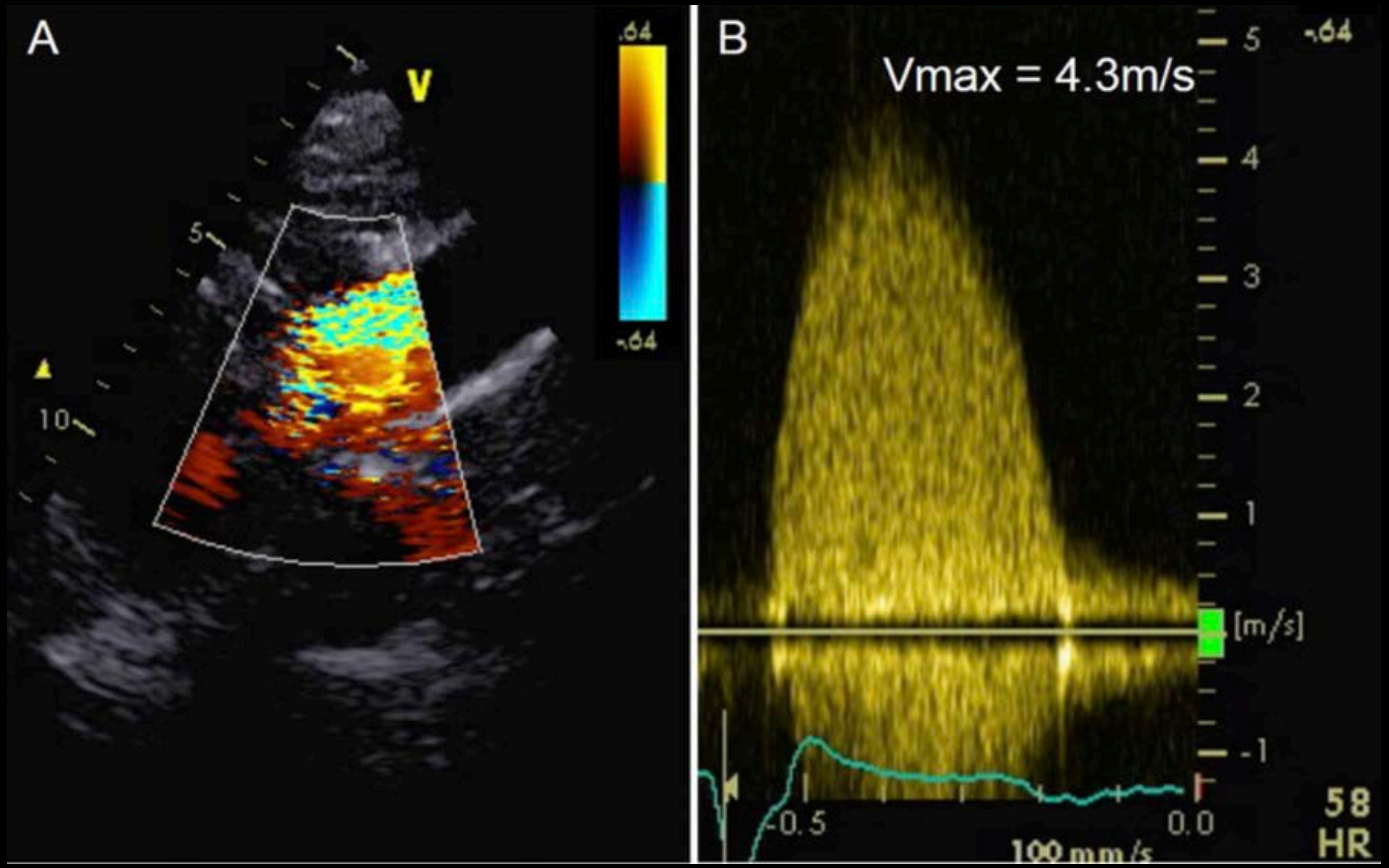
Suprasternal Notch

- Colour - turbulence, coarctation
- Aortic pathology
- CW Doppler

# Standard TTE images for the assessment of AS

Right parasternal view

- Colour - turbulence
- Aortic pathology
- CW Doppler



# Haemodynamics in AS

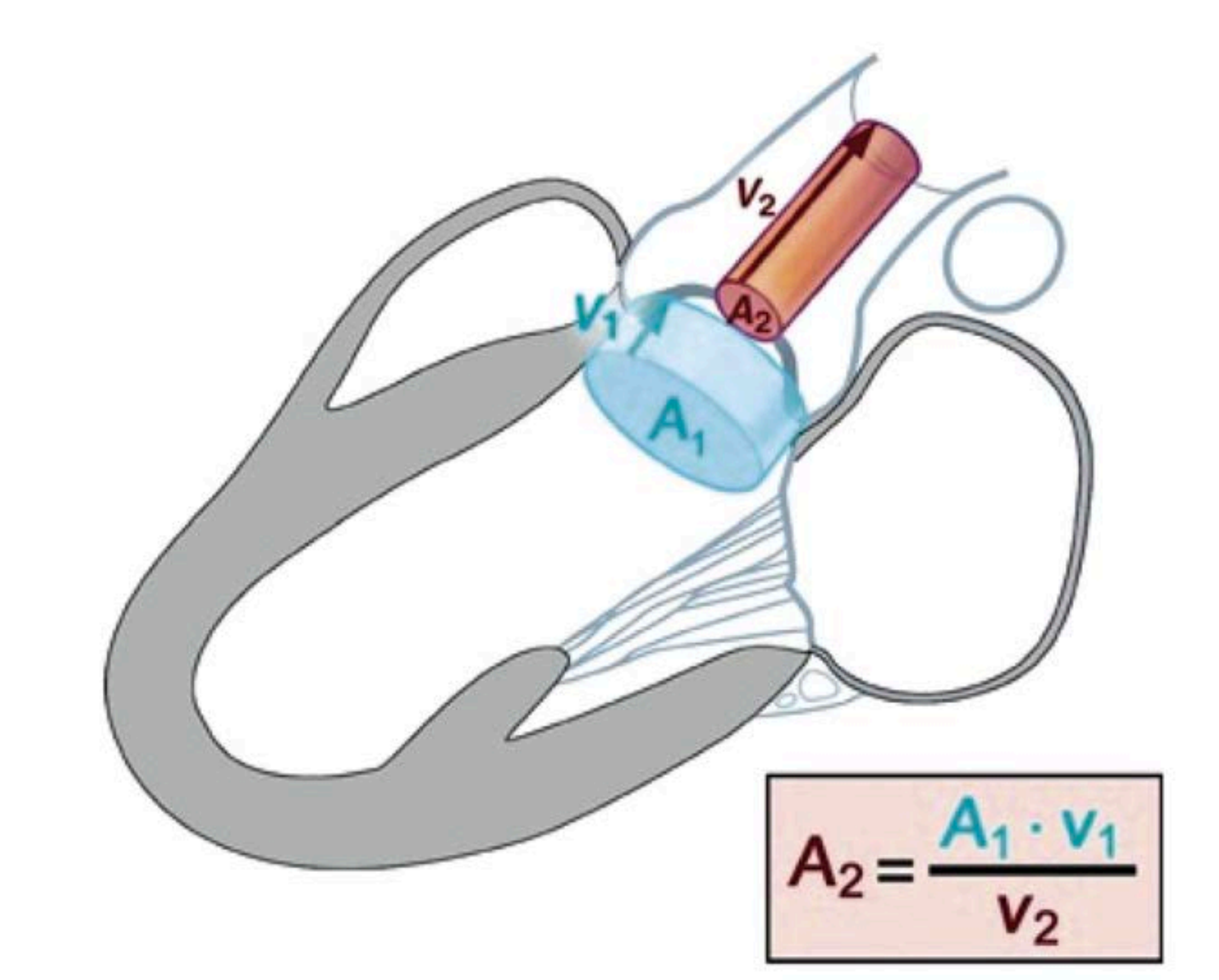


Figure 4 Schematic diagram of continuity equation.

We have our LVOTd, LVOT VTI and AV VTI, now we can calculate the AVA

$$SV_{LVOT} = SV_{AV}$$

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

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

$$AVA = \frac{(0.785 \times D^2{}_{LVOT}) \times VTI_{LVOT}}{VTI_{AV}}$$

*Measurement error
**assumes LVOT area is circular

# Summary of measurements/calculations

**Table 2** Measures of AS severity obtained by Doppler-echocardiography

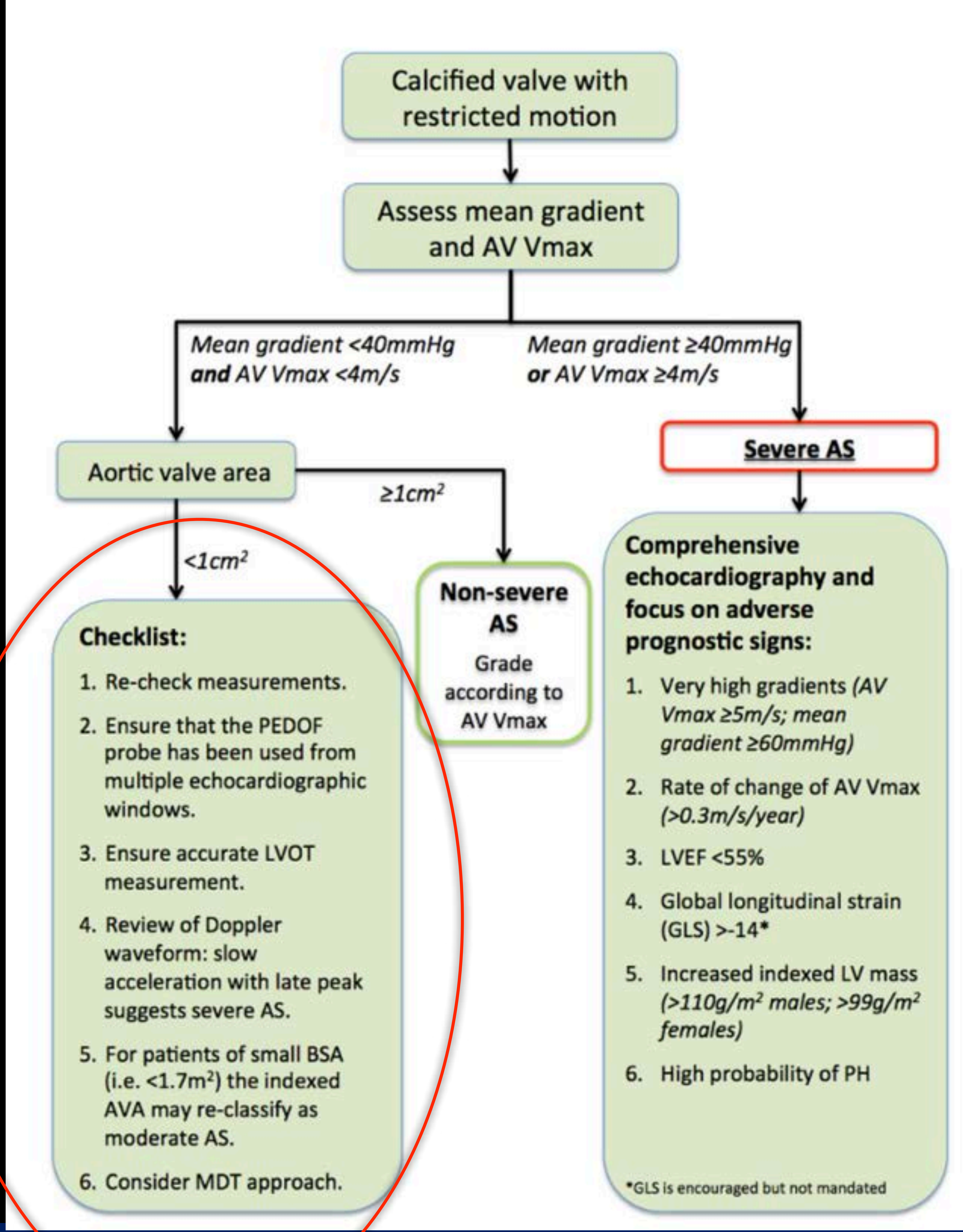
| | Units | Formula/method | Cut-off for severe | Concept | Advantages | Limitations |
|---|---|---|---|---|---|---|
| AS jet velocity[12-15] | m/s | Direct measurement | 4.0 | Velocity increases as stenosis severity increases | Direct measurement of velocity. Strongest predictor of clinical outcome | • Correct measurement requires parallel alignment of ultrasound beam<br>• Flow dependent. |
| Mean gradient[12-14] | mmHg | $\Delta P = \sum 4v^2/N$ | 40 | Pressure gradient calculated from velocity using the Bernouli equation | • Mean gradient is obtained by tracing the velocity curve<br>• Units comparable to invasive measurements | • Accurate pressure gradients depend on accurate velocity data<br>• Flow dependent |
| Continuity equation valve area[16-18] | $cm^2$ | $AVA = (CSA_{LVOT} \times VTI_{LVOT})/VTI_{AV}$ | 1.0 | Volume flow proximal to and in the stenotic orifice is equal | • Measures effective orifice area<br>• Feasible in nearly all patients<br>• Relatively flow independent | Requires LVOT diameter and flow velocity data, along with aortic velocity. Measurement error more likely |
| Simplified continuity equation[18,19] | $cm^2$ | $AVA = (CSA_{LVOT} \times V_{LVOT})/V_{AV}$ | 1.0 | The ratio of LVOT to aortic velocity is similar to the ratio of VTIs with native aortic valve stenosis | Uses more easily measured velocities instead of VTIs | Less accurate if shape of velocity curves is atypical |
| Velocity ratio[19,20] | None | $VR = \frac{V_{LVOT}}{V_{AV}}$ | 0.25 | Effective AVA expressed as a proportion of the LVOT area | Doppler-only method. No need to measure LVOT size, less variability than continuity equation | Limited longitudinal data. Ignores LVOT size variability beyond patient size dependence |
| Planimetry of anatomic valve area[21,22] | $cm^2$ | TTE, TEE, 3D-echo | 1.0 | Anatomic (geometric) CSA of the aortic valve orifice as measured by 2D or 3D echo | Useful if Doppler measurements are unavailable | Contraction coefficient (anatomic/effective valve area) may be variable. Difficult with severe valve calcification |
| LV % stroke work loss[23] | % | $\%SWL = \frac{\Delta P}{\Delta P + SBP} \cdot 100$ | 25 | Work of the LV wasted each systole for flow to cross the aortic valve, expressed as a % of total systolic work | Very easy to measure. Related to outcome in one longitudinal study | Flow-dependent, Limited longitudinal data |

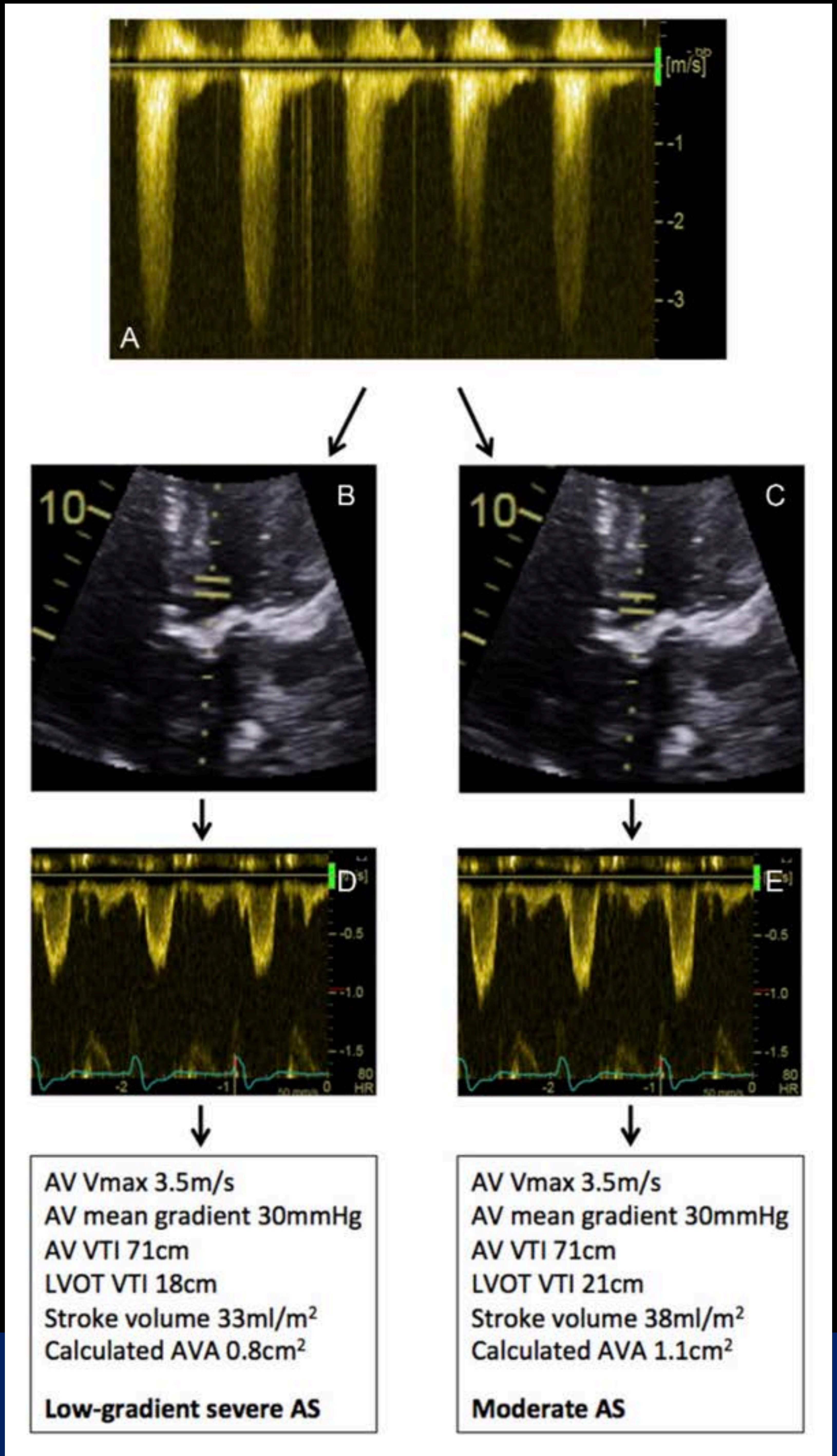
# Criteria for aortic stenosis

| Grading of severity | Echocardiographic indices | | |
|---|---|---|---|
| | AV Vmax (m/s) | Mean gradient (mmHg) | AVA ($cm^2$) |
| Aortic sclerosis | <2.5 | – | – |
| Mild | 2.5–2.9 | <20 | >1.5 |
| Moderate | 3–3.9 | 20–39 | 1–1.5 |
| Severe | 4–4.9 | 40–59 | <1 |
| Very severe | ≥5 | ≥60 | ≤0.6 |

BSE Guidelines 2021

# Low-gradient AS



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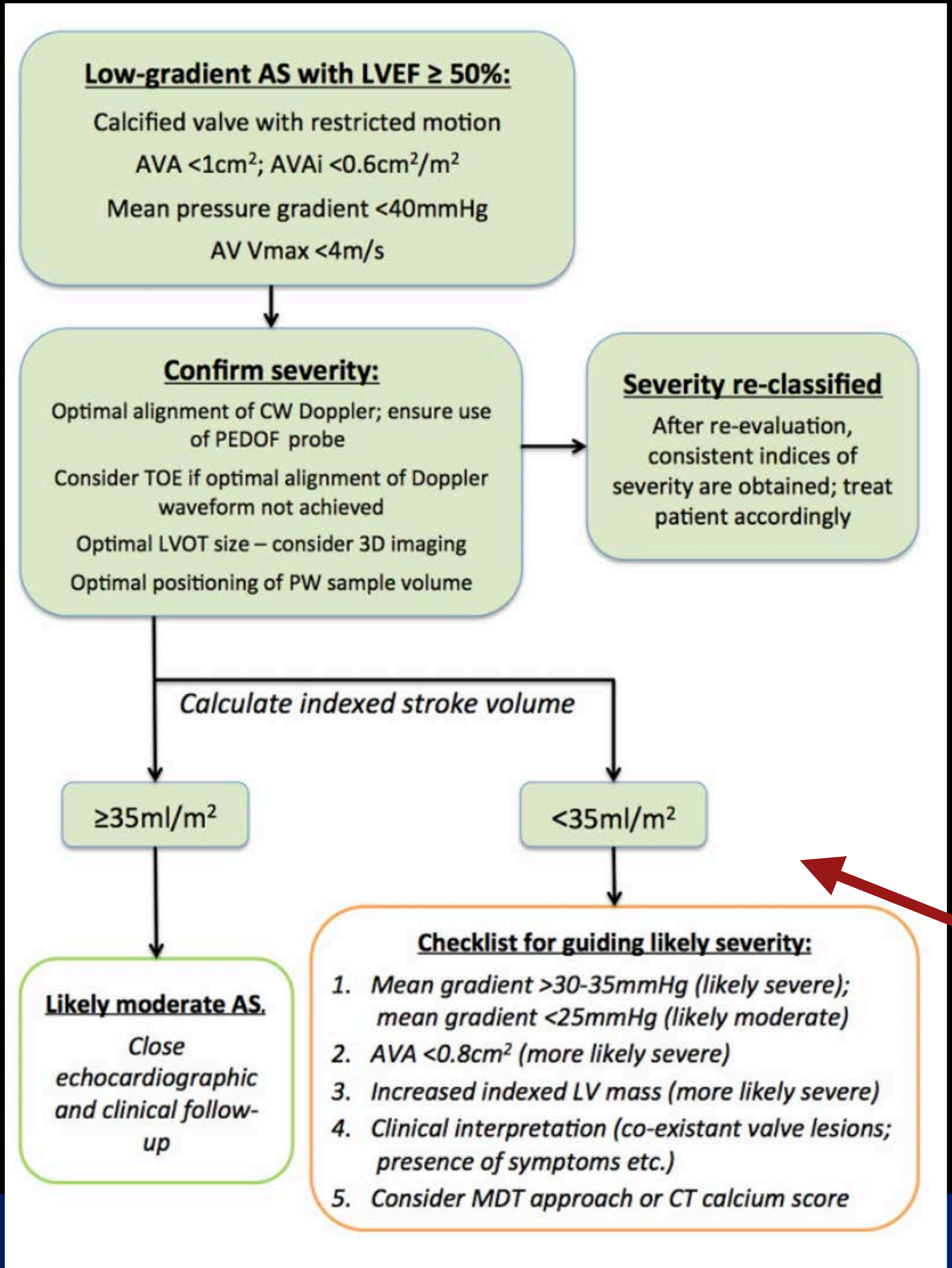
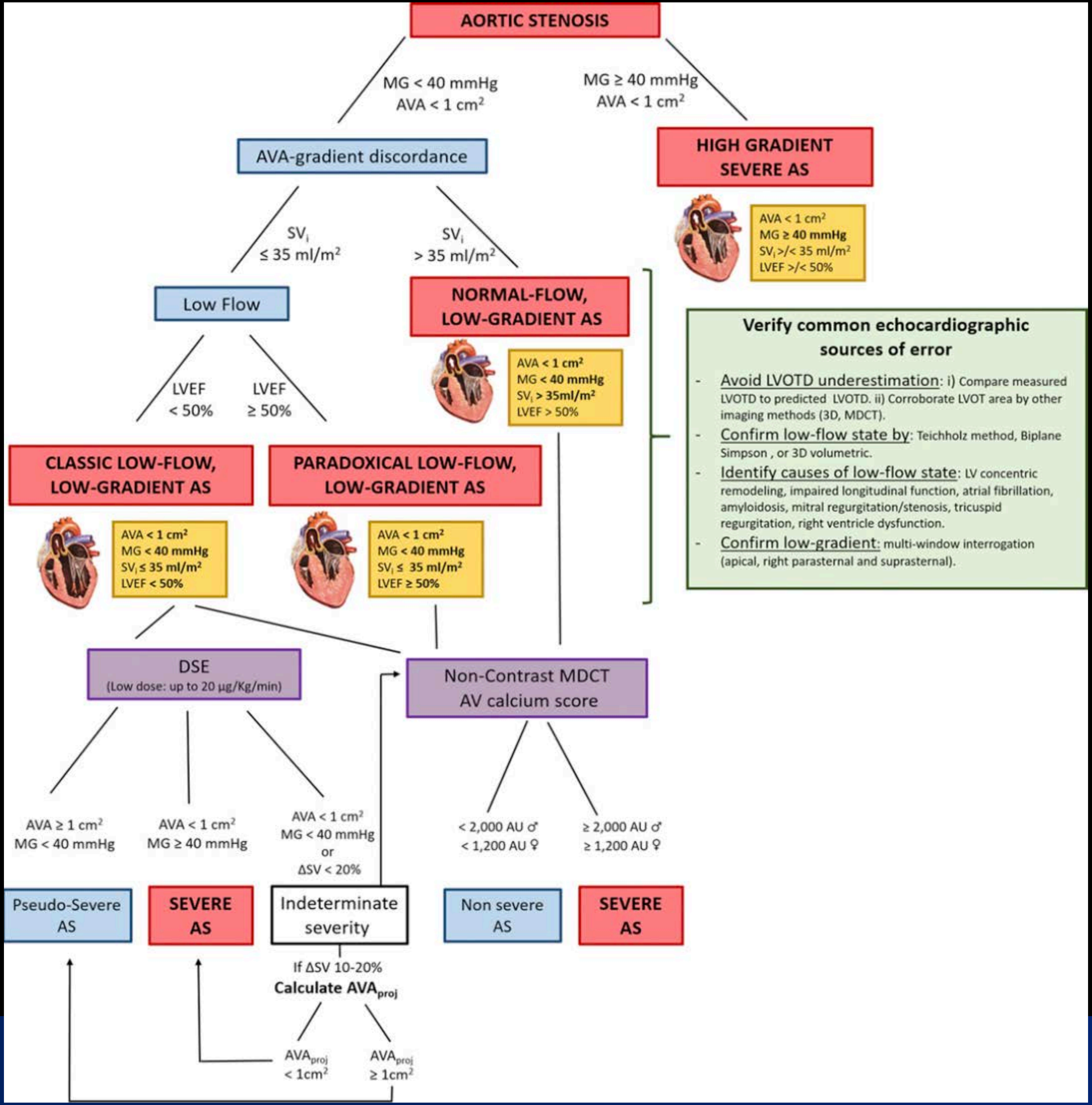
# Low-gradient AS with LVEF ≥ 50%




Paradoxical low-flow
Low-gradient AS

# Criteria which increase the likelihood of severe AS in those with normal EF, AVA <1.0cm/m$^2$ and mean PG <40mmHg

| | | |
|---|---|---|
| (1) Clinical criteria: | | |
| Physical examination consistent with severe aortic stenosis | | |
| Typical symptoms without other explanation | | |
| Elderly patient (>70 years) | | |
| (2) Qualitative imaging data: | | |
| LVH (additional history of hypertension to be considered) | | |
| Reduced LV longitudinal function without other explanation | | |
| (3) Quantitative imaging data: | | |
| Mean gradient 30–40 mmHg* | | |
| AVA ≤0.8 cm$^2$ | | |
| Low flow (SVi <35 mL/m$^2$) confirmed by other techniques than standard | | |
| Doppler technique (LVOT measurement by 3D TEE or MSCT; CMR, invasive data) | | |
| Calcium score by MSCT† | | |
| Severe AS likely: | men ≥2000 | women ≥1200 |
| Severe AS very likely: | men ≥ 3000 | women ≥1600 |
| Severe AS unlikely: | men <1600 | women <800 |



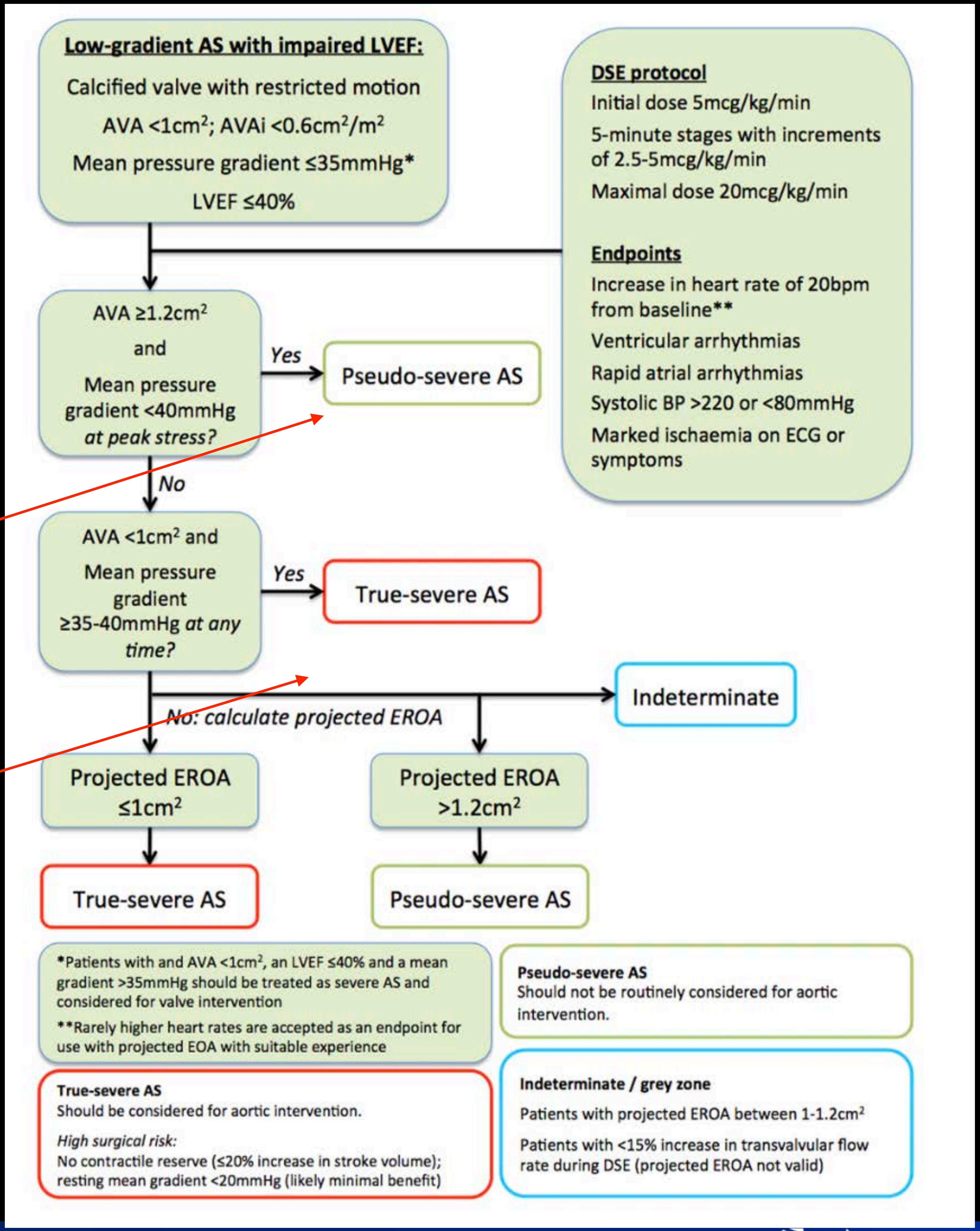

Silva I, Salaun E, Côté N, Pibarot P. Confirmation of aortic stenosis severity in case of discordance between aortic valve area and gradient. Case Reports. 2022 Feb 2;4(3):170-7.

# Low Flow, Low-gradient AS (LVEF < 50%)

- AVA can be more reliable as less flow dependant
- Difficult to differentiate moderate and severe AS as the valve opens less due to reduced SV
    - Dobutamine stress echo (DSE)
    - CT calcium score if DSE indeterminant
    - MDT approach to resolve challenging cases

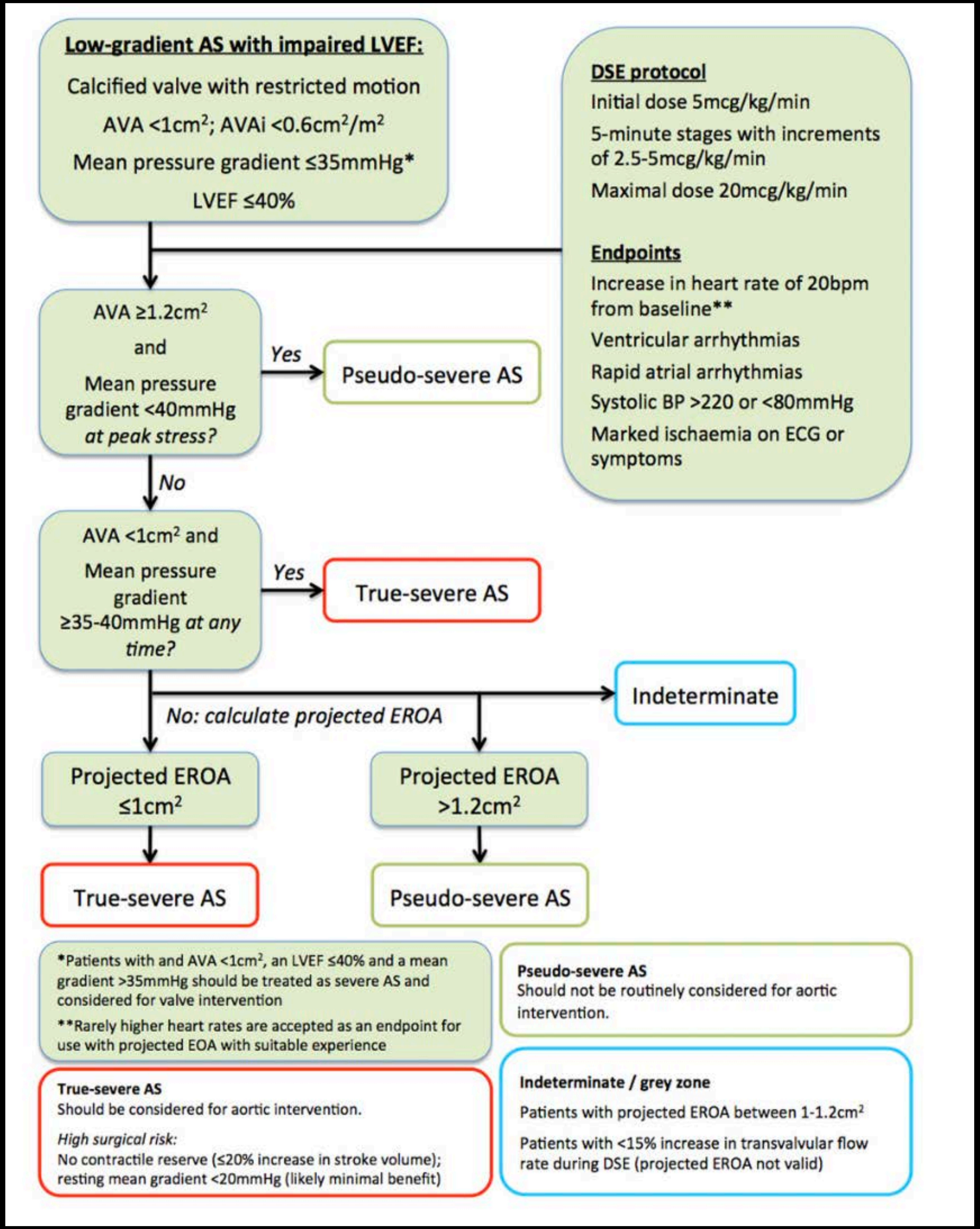
# Dobutamine SE - good contractile reserve

- DSE typically causes a 20% increase in SV (known as contractile reserve)
- Pseudo-severe AS - AVA increases at peak stress $\geq$1.2cm$^2$, mean PG remains <40mmHg
- True severe AS - mean gradient increases to $\geq$35-40mmHg, AVA remains <1cm$^2$
    - These patients have improved survival with AVR



# Dobutamine SE - No contractile reserve

- In ~1/3 patients the SV doesn't increase by 20%
- Have high peri-procedural mortality and poor long term outcome with medical therapy
- AVR may improve LV function and outcome



# Projected flow area (EOA-Proj)

If AVA and meanPG remain the same

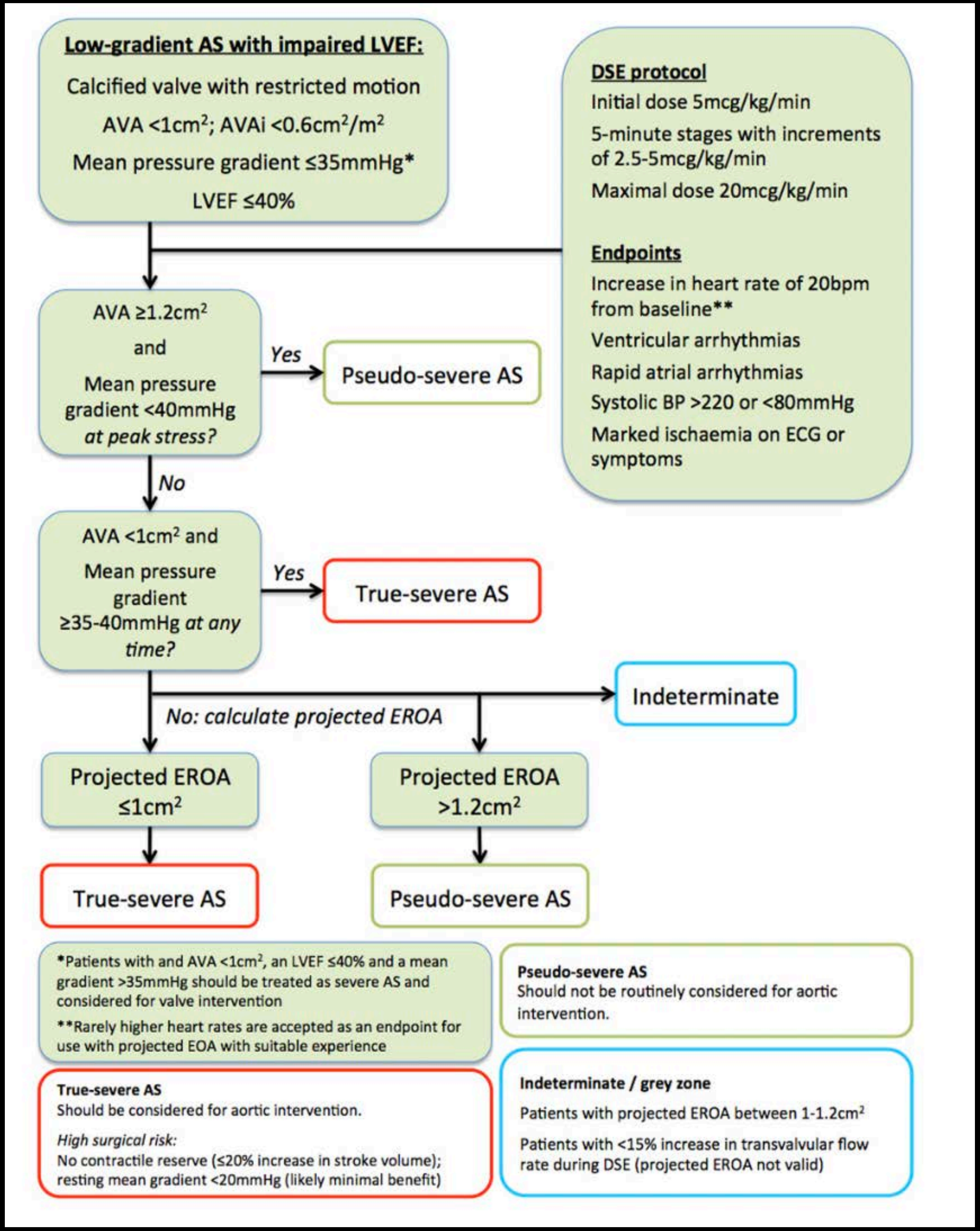
- Use data from DSE to predict what the AVA would be at normal transvalvular flow rates

$$AVA_{proj} = \frac{AVA_{peak} - AVA_{rest}}{Q_{peak} - Q_{rest}} \times (250 - Q_{rest}) + AVA_{rest}$$

- Q = mean transvalvular flow rate

- Increasing flow rate will lead to changes in mean PG and AVA

- Requires flow rate on DSE to increase by ≥15%



# Pressure Recovery

- Increase in pressure downstream of the AV resulting in lower transvalvular pressure gradients
- If not corrected for may lead to underestimation of AVA
- Accentuated in those with small aortas (<30mm) or AVA 0.8-1.2cm$^2$

$$AVA_{pr} = \frac{(AAA \times AVA_{Dopp})}{(AAA - AVA_{Dopp})}$$

(AAA is the cross sectional area of the proximal ascending aorta)

# Complimentary cardiac CT

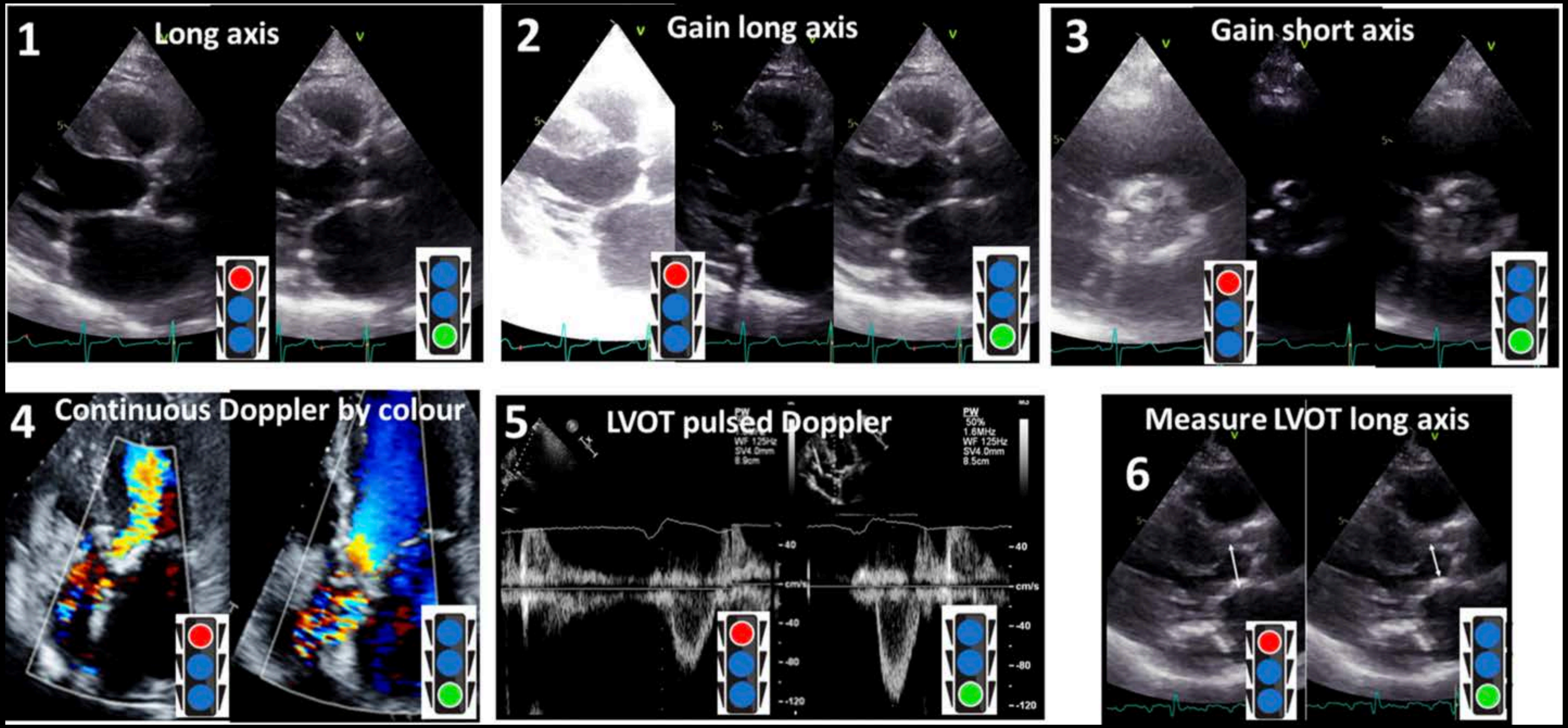
- Growing interest in defining AS severity if discordant echo measurements
- BSE advises caution in the use of CT ca score in setting of low-gradient AS with impaired LVEF

# Conclusion

- 5-10% of patients with severe AS do not meet normal defining criteria -> Low flow, low gradient AS

Check machine settings

Check measurements
-LVOT Diameter
-LVOT VTI
-AV Vmax




Canciello et al Pitfalls and tips in the assessment of aortic stenosis by transthoracic echocardiography, Diagnostics, 2023.

Thank you