G. AORTIC STENOSIS (AS)

THE FACTS

DEFINITION

Aortic stenosis (AS) is a narrowing/thickening/obstruction of the aortic valve (AOV) that impedes systolic flow traveling from the left ventricle, through the AOV, into the aorta.

- AS is the most common primary valve disease.
- Echo is the #1 tool to evaluate AS; cardiac cath is no longer recommended, except in rare cases.
- Aortic ***stenosis***—thickened AOV *with* decreased excursion (peak velocity > = 2.6 m/s).
- Aortic ***sclerosis***—thickened AOV *without* decreased excursion (peak velocity < = 2.5 m/s); a sclerotic valve may or may not become stenotic in the future.

3 MOST COMMON ETIOLOGIES OF VALVULAR AS

1-CALCIFIC AS of a normal trileaflet AOV.

- Most common etiology in the U.S.
- 65+ years old (aka degenerative AS).
- The AOV has a fibrocalcific nature. The calcific changes are usually central and at the basal parts of the cusps; the stenosis originates at the sinuses of Valsalva and extends medially to the AOV cusps.

2-Congenital BICUSPID AS with superimposed calcific changes.

- Bicuspid aortic valve (BAV) may be stenotic without calcific changes in adolescents; and usually becomes symptomatic between the ages of 20 – 50 years.
- Adults with bicuspid AS usually present with asymmetric mild/moderate/severe calcific changes; these changes are a reliable predictor of the outcome (heart failure, need for prosthetic valve, and death).
- Usually the left and right coronary cusps fuse, so there is a large anterior cusp (both coronary arteries arise from this cusp 80% of the time) and a small posterior cusp.
- When viewed from the SAX, the BAV has two cusps that appear as a football-shaped opening.
- A raphe (underdeveloped cusp that is fused to one of the cusps) may be present and can give the appearance of a third cusp when closed.
- Evaluate the BAV patient for a co-existing aortic aneurysm (dilatation), aortic dissection (tear), or aortic coarctation (narrowing of the aorta, usually in the vicinity of the aortic isthmus). Approximately 50% of patients with aortic coarctations have co-existing BAV.

3-RHEUMATIC AS

- Most common etiology worldwide.
- AOV cusp edges become fibrotic and contract, then fusion of the commissures results in a triangular systolic orifice, and later calcification.
- The stenosis originates at the cusps and moves out (opposite etiology of calcific AS).
- Rheumatic heart disease usually affects the mitral valve and the AOV.


RHEUMATIC AS

OTHER TYPES OF AS

- Supravalvular AS (SVAS) is a narrowing of the aorta, typically at the sinotubular junction, that may/may not extend into the ascending aorta. SVAS is rare; causes include Williams syndrome.
- Subvalvular AS is a left ventricular outflow tract obstruction (LVOTO) that can be fixed (discrete congenital membrane or muscular band) or dynamic (hypertrophic cardiomyopathy).

AS: THE FACTS

MURMUR

The AS murmur is a systolic crescendo decrescendo murmur best heard at the right upper sternal border that may radiate up to the carotids.

COMPLICATIONS

a. Left ventricular pressure overload creates left ventricular hypertrophy, dilatation, and possible heart failure.

b. AS cusp abnormalities and areas of turbulent flow may increase the risk of infective endocarditis.

SIGNS & SYMPTOMS

- Chest pain
- Decreased cardiac output
- Heart failure
- Infarct
- Irregular rhythms
- Myocardial or cerebral syncope
- Pulmonary edema
- Sudden death

TREATMENT OPTIONS

a. Serial echocardiograms track changes in the:

- AS (peak velocity, mean PG, and aortic valve area)
- Chamber size
- Left ventricular hypertrophy
- Systolic function
- Diastolic function

b. AOV replacement is performed if the patient develops symptoms and/or the AS progresses; ideally before the patient goes into heart failure.

c. The mini-thoracotomy is a robotically assisted surgery that offers a minimally invasive method through a small incision in the chest used for AOV replacement (and other valvular procedures, such as atrial septal defect repair, aortic aneurysm repair, and coronary artery bypass grafting without the aid of cardiopulmonary bypass). This reduces post-operative discomfort, scarring, and recovery time.

d. Transcatheter AOV replacement (TAVR) is another minimally invasive procedure that uses a balloon catheter with a stent-mounted valve crimped on its tip. The TAVR is thread from the femoral artery in the groin, into the aorta, and across the AOV (in the opposite direction to normal blood flow). Once the compressed valve is placed over the diseased AOV, the balloon at the end of the catheter is inflated. The expanded valve pushes aside the diseased leaflets and becomes anchored in the valve opening.

- Assessment of the valve, calcification, and annulus diameter are crucial.
- Transesophageal echo (TEE) is superior to TTE; however, multi-slice computed topography (MSCT) is the test of choice.
- TAVR is preferred in high risk surgical patients in an attempt to improve quality of life.

ASSESS & REPORT

- Level of the obstruction (subvalvular, valvular, supravalvular).
- Number of cusps (unicuspid, bicuspid, trileaflet, quadricuspid).
- Cusp mobility/thickness/calcification.
- Presence/absence of commissural fusion.
- Left ventricular ejection fraction (LVEF), size, and wall thickness.
- Recommended parameters: peak velocity, mean PG, and aortic valve area (AVA).
- Window where the peak velocity was acquired (for future comparison).

AS: 2D ECHO

BICUSPID AS

(1) Bicuspid AS results in a thickened, football-shaped opening with doming of the cusps; both systolic doming and diastolic doming (AOV prolapse) are possible.

(2) Presence of a raphe (underdeveloped cusp).

(1-2)

BAV

AS

(3) Thickened, calcified AOV cusps with doming and decreased excursion.

(4) Mitral annular calcification.

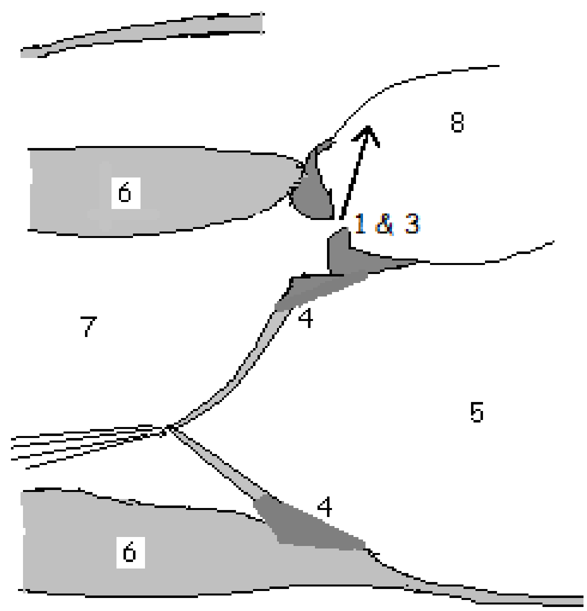
(5) Left atrial enlargement due to volume and pressure overload.

(6) AS increases afterload (resistance the heart pumps against) so the left ventricle works harder and contracts more forcefully to propel blood out of the heart, this results in left ventricular hypertrophy.

(7) Left ventricular dilatation with decreased left ventricular systolic function.

(8) Post stenotic dilatation of the aortic root and/or ascending aorta due to the high velocity AS jet striking the aortic root wall.

(3-8)



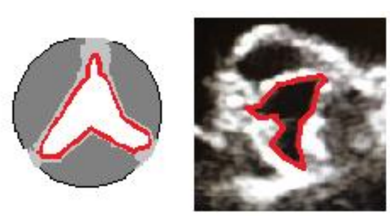
AVA BY PLANIMETRY

AOV planimetry is particularly useful during TEE or 3DE. TTE planimetry is possible if images allow it.

- SAX BASE
- Zoom, enhance, freeze, and planimeter the early systolic (maximum opening) AOV orifice (average 3+ beats).
- Tip: avoid excessive gain settings as this will underestimate the area.
- The machine/offline program will calculate the AVA.

PLANIMETRY

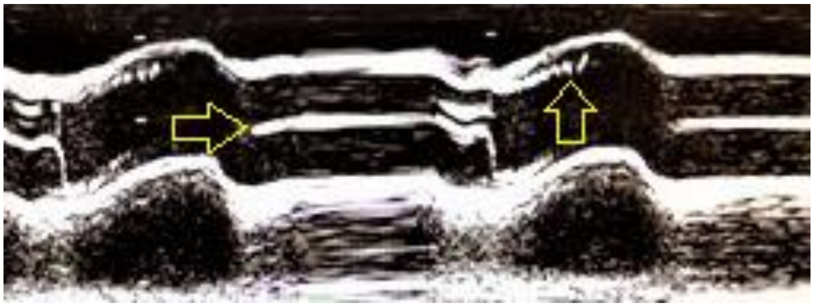
BAV



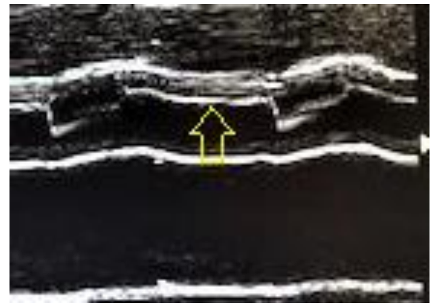
TRILEAFLET AOV

AS: M-MODE

AOV EXAMPLES



NORMAL AOV CENTRAL CLOSURE & SYSTOLIC FLUTTER



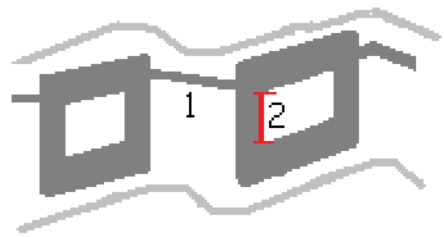
BAV WITH ECCENTRIC CLOSURE

BICUSPID AS

(1) BAV usually has an eccentric (off-center) closure line due to the size difference of the two cusps; however, 25% have a normal closure line.

(2) Decreased aortic cusp separation (ACS).

(1-2)



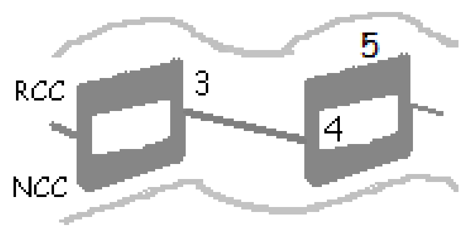
CALCIFIC/RHEUMATIC AS

(3) Bright, thick, dense cusps.

(4) Decreased ACS (normal range = 1.5 – 2.6 cm).

(5) Absent systolic flutter due to thick, calcified cusps.

(3-5)



ADDITIONAL FINDINGS

- Left ventricular dilatation
- Left ventricular hypertrophy
- Left atrial enlargement
- Post-stenotic dilatation of the AO root and/or AAO

CFD

a. AS creates turbulent systolic flow that travels from the left ventricle, through the narrowed AOV, into the aorta.

b. Aortic regurgitation is possible, evaluate appropriately.

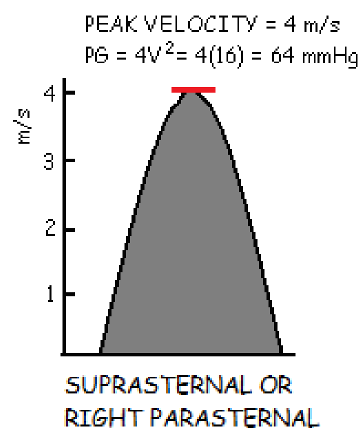
AS: DOPPLER

PEAK VELOCITY

- Peak velocity is the strongest predictor of clinical outcome; velocity increases as stenosis increases.
- In order to detect the AS peak velocity, it is vital to properly position the patient, optimize the Doppler angle, and compare steerable CWD and PEDOF from all views.
- According to the Intersocietal Accreditation Commission (IAC), the non-imaging CWD probe (PEDOF) must be utilized in the assessment of AS or suspected AS from multiple locations, to include the apex, suprasternal notch, and right parasternal border.
- PEDOF from the right parasternal window (patient in right lateral decubitus with the PEDOF probe at the right sternal border) frequently yields the greatest peak velocity.
- The PEDOF probe is strongly recommended; however, when the cusp opening is well visualized and the peak velocity is < 3 m/s, steerable CWD may be equivalent to PEDOF.
- AOV peak velocity > 4 m/s increases symptoms and mortality.

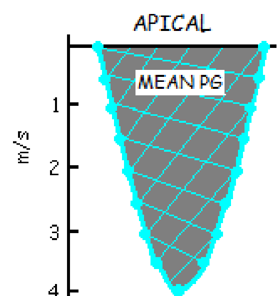
MAX PG

- Max PG provides the peak instantaneous PG; this is no longer a "recommended" parameter; however, it is still useful.
- Doppler echo does not measure pressure directly. Instead, Doppler measures velocity. Pressure and velocity are related, the greater the velocity → the greater the PG.
- In the echo lab, we use the Bernoulli equation to describe the relationship between pressure and velocity. The Bernoulli equation determines the PG between two areas.
- The actual Bernoulli equation is very complex, so I will describe the simplified Bernoulli equation [$P_1 - P_2 = PG = 4(V)^2$].
- P_1 and P_2 represent the pressure in the chambers proximal (P_1) and distal (P_2) to the stenotic valve.
- V represents the peak velocity between the two chambers.



MEAN PG

- The mean PG averages the instantaneous gradients across the open valve via the Bernoulli equation [$\Delta P = \Sigma\ 4V^2/N$].
- The best correlation between the echo lab and the cath lab is the mean PG, not the max PG.
- Trace the AOV peak velocity curve, start and finish at zero baseline, and the machine/offline program will calculate the mean PG.

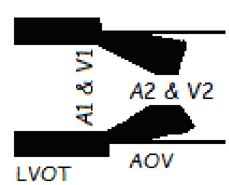


AVA BY THE CONTINUITY EQUATION

- The aortic valve area (AVA) is a measure of the AOV orifice area.
- The continuity equation is based on the theory that the volume through any cross-sectional area (CSA) equals the CSA multiplied by the flow velocity over the ejection period, or the velocity time integral (VTI).
- In other words, flow through a tube is constant, if the area decreases, then the velocity increases in order to maintain the flow.

SIMPLIFIED CONTINUITY EQUATION
(A = AREA, V = VELOCITY)

$$A2 = \frac{A1 \times V1}{V2}$$



AS: CONTINUITY EQUATION

CONTINUITY EQUATION (Velocity Time Integrals)—ASE recommendation

a. Acquire the LAX LVOT diameter (D_{LVOT}) and convert to LVOT cross sectional area (CSA_{LVOT}).

- $\mathbf{CSA_{LVOT} = \pi\,(D_{LVOT}/2)^2}$

b. Acquire the AOV peak velocity time integral (VTI_{AOV}) with CWD or PEDOF—trace the AOV peak velocity curve.

c. Acquire the LVOT peak velocity time integral (VTI_{LVOT}) with PWD—trace the LVOT peak velocity curve.

d. The machine/offline program will calculate the peak velocity, mean PG, and AVA.

- $(\text{VELOCITY TIME INTEGRAL}_{LVOT})\,(CSA_{LVOT}) = (\text{VELOCITY TIME INTEGRAL}_{AOV})\,(AVA)$
- $(VTI_{LVOT})\,(CSA_{LVOT}) = (VTI_{AOV})\,(AVA)$
- $\mathbf{AVA = \dfrac{(VTI_{LVOT})\,(CSA_{LVOT})}{(VTI_{AOV})}}$

For example, if D_{LVOT} = 2 cm, VTI_{AOV} = 124 cm, and VTI_{LVOT} = 23.8 cm, then

$$\textit{Convert } D_{LVOT} \text{ to } CSA_{LVOT} = \pi\,(D_{LVOT}/2)^2 = (3.14)\,(2\text{ cm}/2)^2 = 3.14\text{ cm}^2$$

$$AVA = \frac{(VTI_{LVOT})\,(CSA_{LVOT})}{(VTI_{AOV})} = \frac{(23.8\ \cancel{\text{cm}})\,(3.14\text{ cm}^2)}{(124\ \cancel{\text{cm}})} = 0.595 = \mathbf{0.60\ cm^2}$$

SIMPLIFIED CONTINUITY EQUATION (peak velocities)

a. Acquire the LAX LVOT diameter (D_{LVOT}). In the equation below, the D_{LVOT} is converted to an area $[(.785)\,(D_{LVOT})^2] = A_{LVOT}$.

b. Acquire the AOV peak velocity (V_{AOV}) with CWD or PEDOF.

c. Acquire the LVOT peak velocity (V_{LVOT}) with PWD.

d. The machine/offline program will calculate the peak velocity, max PG, and AVA.

- $(\text{AREA}_{LVOT})\,(\text{VELOCITY}_{LVOT}) = (AVA)\,(\text{VELOCITY}_{AOV})$
- $(A_{LVOT})\,(V_{LVOT}) = (AVA)\,(V_{AOV})$
- $AVA = \dfrac{(A_{LVOT})\,(V_{LVOT})}{(V_{AOV})}$
- $\mathbf{AVA = \dfrac{[(.785)\,(D_{LVOT})^2]\,(V_{LVOT})}{(V_{AOV})}}$

For example (*same patient as above*), if D_{LVOT} = 2 cm, V_{AOV} = 496 cm/s, and V_{LVOT} = 80.5 cm/s, then

$$AVA = \frac{[(.785)\,(D_{LVOT})^2]\,(V_{LVOT})}{(V_{AOV})} = \frac{[(.785)\,(2\text{ cm})^2]\,(80.5\ \cancel{\text{cm/s}})}{(496\ \cancel{\text{cm/s}})} = \frac{252.77}{496} = 0.509 = \mathbf{0.51\ cm^2}$$

AS: CONTINUITY EQUATION

If necessary, reposition the patient &/or use unconventional views to optimize the Doppler angle.
Normal sinus rhythm—average 3+ beats. Irregular rhythm—average 5+ consecutive beats, avoid post-extrasystolic beats.
Once all measurements are acquired, the machine/offline program will calculate the peak velocity, mean & max PG, and AVA.

(1) LVOT DIAMETER

- The LVOT diameter is a critical measurement because the value is squared in the continuity equation. This dimension rarely changes and should remain consistent during serial echo exams.
- Zoom, enhance (avoid areas of calcification), and freeze the LAX LVOT.
- Measure the systolic frame that yields the largest LVOT diameter (normal range 1.8 - 2.2 cm) proximal and parallel to the plane of the AOV (approximately 0.3 – 1 cm from the AOV orifice), from the inner edge of the septal endocardium to the edge of the anterior mitral valve leaflet.
- Ideally, acquire the LVOT diameter at the same level as the LVOT PWD measurement (3).
- NOTE: echo assumes a circular LVOT; however, most are oval. The multi-modality technique utilizes 3D multidetector computed tomography (MDCT) to acquire a precise LVOT measurement combined with the echo acquired VTI_{AOV} and VTI_{LVOT}. The data from the two exams is plugged into the continuity equation providing a more accurate AVA.

(1)

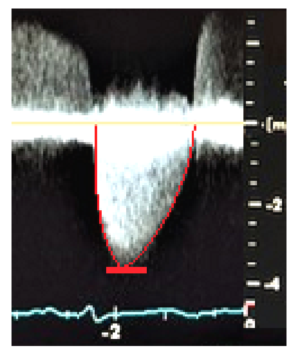
LVOT DIAMETER

(2) AOV

- Compare the 5C, 3C, suprasternal, and right parasternal.
- Compare steerable CWD (focus in the AOV) and PEDOF.
- Acquire the AOV peak velocity (V_{AOV}), preferably with opening and closing snaps.
- Acquire the AOV peak velocity time integral (VTI_{AOV}, planimeter the AOV velocity curve, start and finish at zero baseline).

(2)

AOV CWD FOCUS



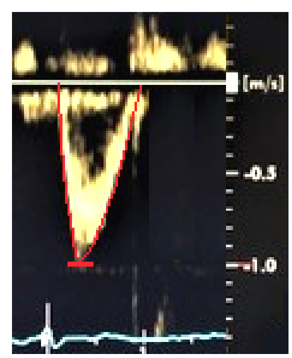
V_{AOV} & VTI_{AOV}

(3) LVOT

- Compare the 5C and 3C.
- PWD gate (3 – 5 mm sample size) within the LVOT, just proximal to the region of increased AOV flow, ideally in the same plane as the LVOT diameter (1).
- Tip: place the PWD gate within the AOV, slowly move into the LVOT and watch for a decrease in velocity.
- Acquire the LVOT peak velocity (V_{LVOT}).
- Acquire the LVOT peak velocity time integral (VTI_{LVOT}, planimeter the LVOT velocity curve, start and finish at zero baseline).

(3)

LVOT PWD GATE



V_{LVOT} & VTI_{LVOT}

AORTIC STENOSIS: SEVERITY SCALE *(with normal LVEF)*

DEGREE	PEAK VELOCITY (m/s)	MEAN PG (mmHg)	AVA (cm^2)	MAX PG (mmHg)
AORTIC SCLEROSIS	< = 2.5			
MILD AS	2.6 – 2.9	< 20	> 1. 5	27 - 34
MODERATE AS	3.0 – 4.0	20 - 40	1.0 - 1.5	36 – 64
SEVERE AS	> 4.0	> 40	< 1.0	> 64

AS: MORE NOTES!

a. If the AS results do not make sense, double check all of the measurements—particularly the LVOT diameter.

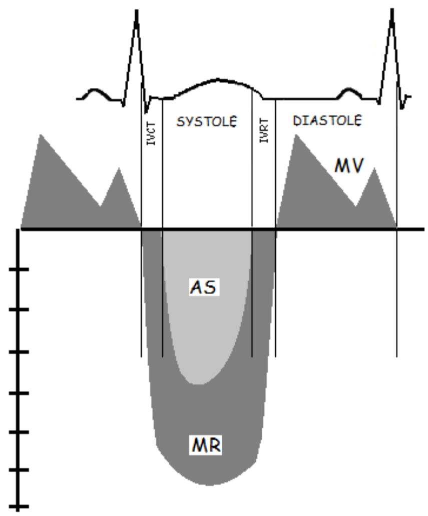
b. If you are certain that all of the measurements are correct, and the data still doesn't make sense, consider this…

- A poor Doppler angle will underestimate the peak velocity.
- AS can be overestimated by high cardiac output states (anemia, pregnancy, 3 - 4+ aortic regurgitation).
- AS can be underestimated by low cardiac output states (irregular rhythms, tachycardia, mitral regurgitation).
- Be careful not to confuse MR (encompasses IVCT, systole & IVRT) with AS (only systole).
- Remember, if just one AOV cusp is moving, it isn't severe!

c. **Reduced LVEF** underestimates the AOV peak velocity and seriously impacts the AS severity scale; with reduced LVEF, consider using the **AS velocity ratio** = V_{LVOT}/V_{AOV} (this is a unitless ratio).

- MILD AS > 0.5
- MODERATE AS 0.25 – 0.50
- SEVERE AS < 0.25

TIMING OF MV, MR & AS



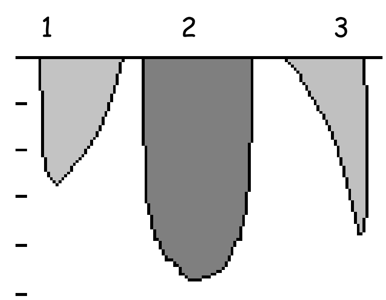
AS CWD VELOCITY CURVES

(1) MILD OBSTRUCTION: early systolic peak, velocity curve is more triangular in shape, typically lower velocity.

(2) SEVERE OBSTRUCTTION: peak velocity later in systole, velocity curve is rounded in shape, typically higher velocity.

(3) DYNAMIC SUBAORTIC LVOT OBSTRUCTION (LVOTO): late-peaking systolic jet with upward, concave appearance in early systole, sounds like a sponge being wrung out.

(1-3)



AS EXAMPLES

SCLEROSIS VS. STENOSIS

3C; AOV & MV ARE BOTH CALCIFIED (LIKELY RHEUMATIC)