Echocardiographic Assessment of Aortic Regurgitation

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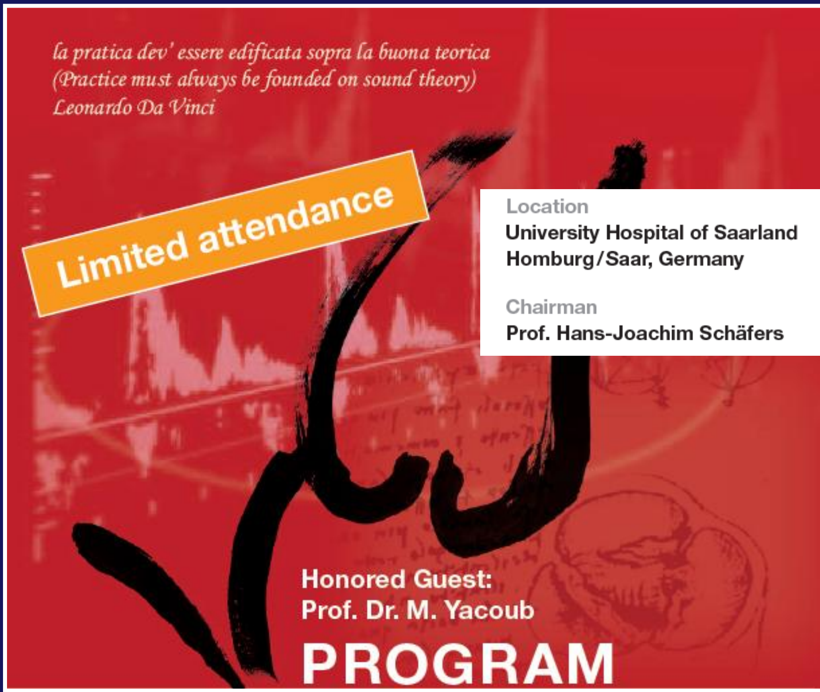

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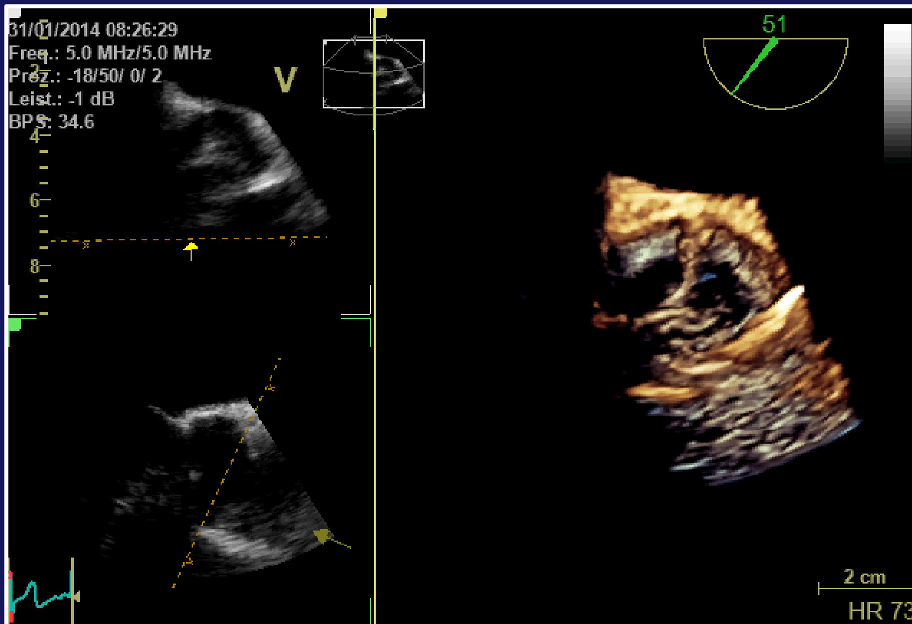


Practice must always be founded on sound theory.
Leonardo Da Vinci

EBAC

Declaration of Interests Policy and Rules

I declare for the last 3 years and the subsequent 12 month the following conflicts of interests:

Section I: Support for Research Activities - grant of the DEGUM
- no other financial research support

Section II: Support for Educational Activities - MIFO, GE Healthcare, Astra Zeneca, Servier, Novartis, Berlin-Chemie, Pfizer, Cardiac Dimensions, Abbott, Bayer, Kelcon

Section III: Honorarium for Promotional Activities - none

Section IV: Personal Financial Interests in Vommercial Activities - none

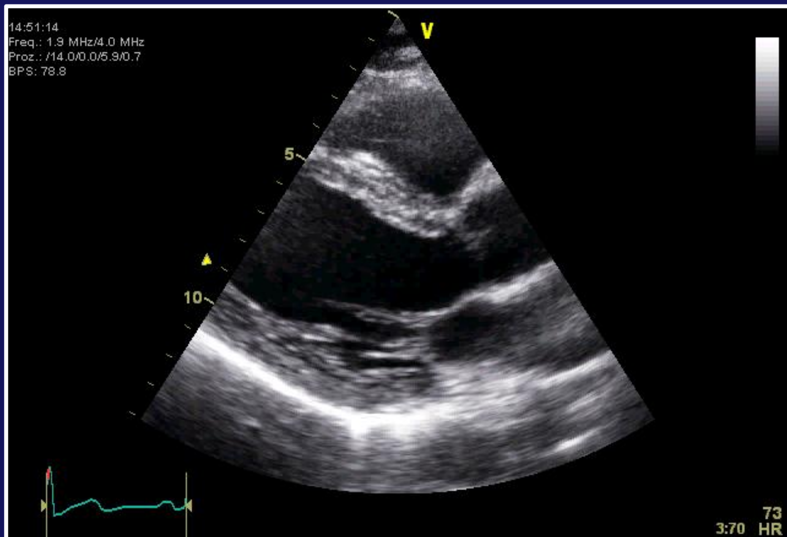
IB1; 2A11
Member of the German Society of Cardiology,
The German Society of Ultrasound, the German Society of Internal Medicine and the European Society of Cardiology/Cardiovascular Imaging
Secrretar of the DEGUM (German Society of Ultrasound in Medicine)

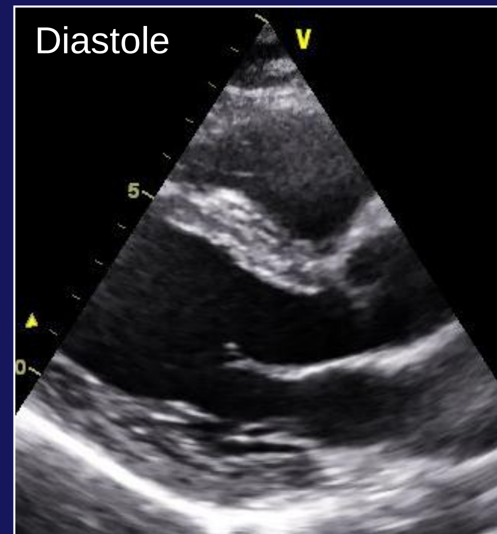
Echocardiographic Visualization of the Aortic Valve

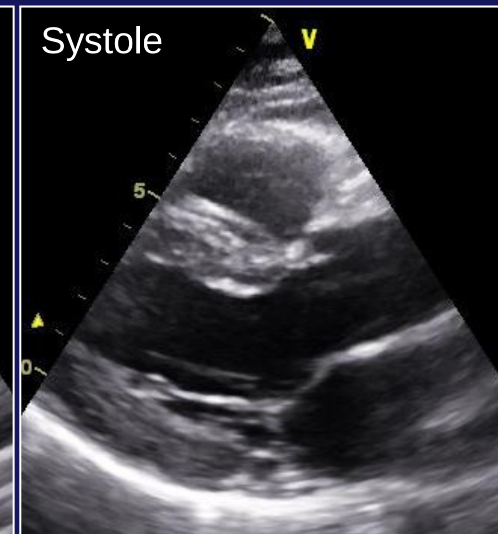
1. Conventional documentation of the aortic valve is possible in the parasternal, apical (using long axis view and 5-chamber view), subcostal, and suprasternal views
2. Using M-Mode the profile of cusp separation is quadrangular-shaped during systole.
3. The Doppler-spectra of the forward transvalvular flow is monophasic during systole.
4. Diastolic color jets into the left ventricle describe regurgitant flow.
5. Systolic turbulences into the ascending aorta describe stenotic flow.
6. 3D echocardiography enables better standardization and offers new views to the aortic valve. Thus it is actually a prerequisite to analyue aortc valve and aortic root.

Echocardiographic Assessment of Aortic Regurgitation

Standardized transthoracic examination in echocardiography





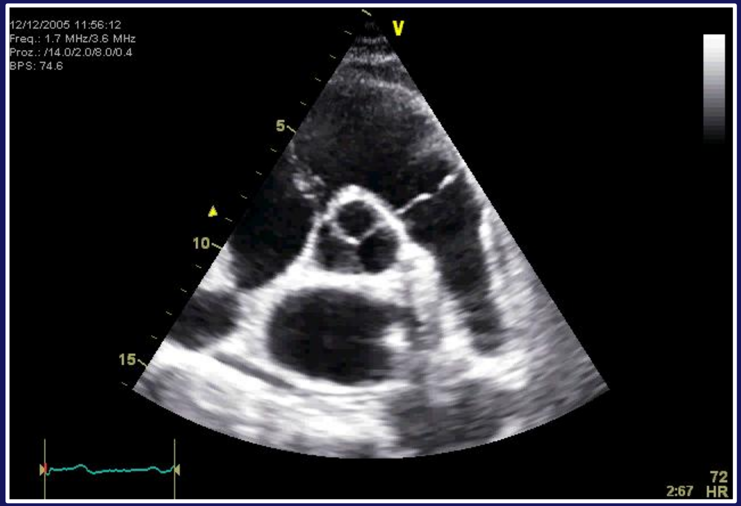


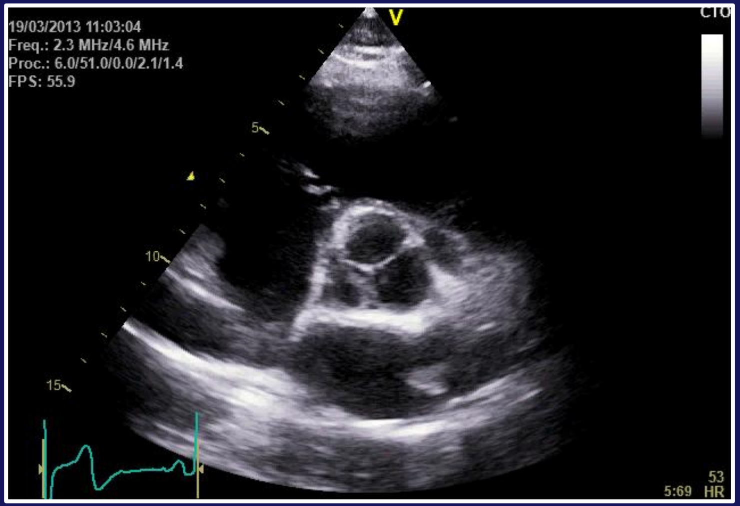
- the parasternal long axis – conventional 2D-image -

Characterization of left parasternal long axis via the following structures:

1. the free right ventricular wall,
2. a section of the right ventricular outflow tract (RVOT),
3. the basal and central anteroseptal region of the left ventricle,
4. the left ventricular cavity in the longitudinal section (LV),
5. the basal and central posterior region of the left ventricle,
6. the mitral valve (MV) sliced in the center of the valve plane,
7. the aortic valve (AV) sliced in the center of the valve plane,
8. the longitudinally intersected initial portion of the aortic root and the ascending aorta (Ao),
9. a longitudinal section of the left atrium (LA),
10. a cross section of the descending aorta.

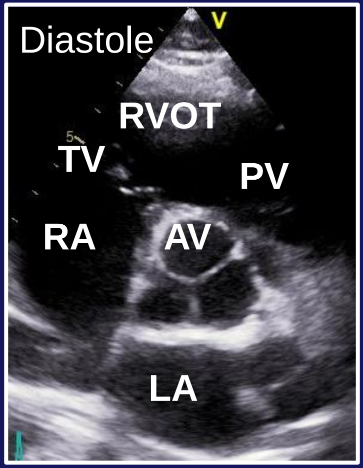
Standardized transthoracic examination in echocardiography



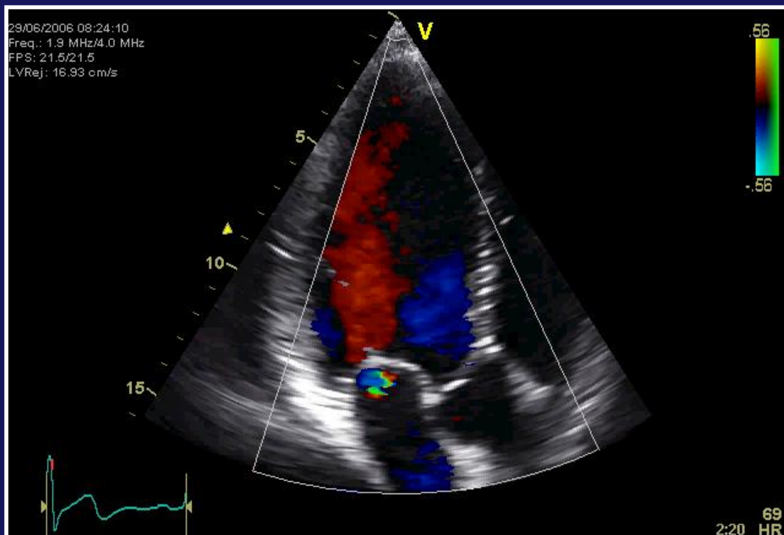


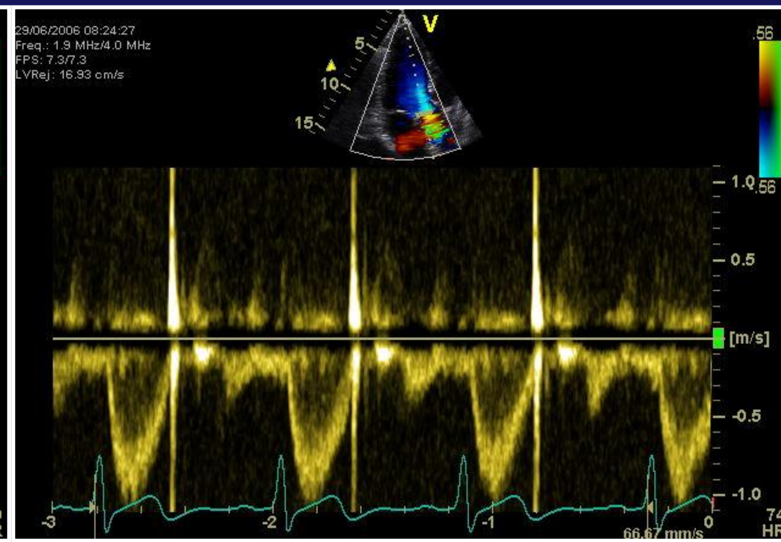
-the parasternal short axis at the level of the aortic valve: conventional 2D-image -

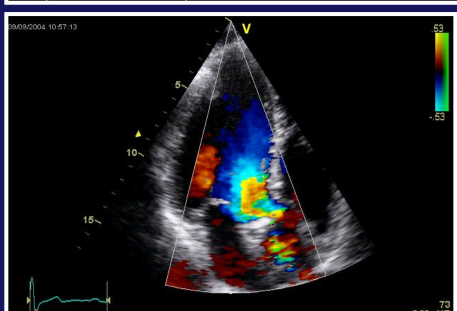
-The commissures of the aortic cusps form the „Mercedes-like star during diastole

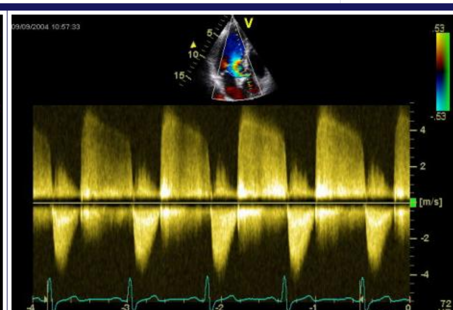


Standardized transthoracic examination in echocardiography
- the pulsed wave Doppler spectrum in the LVOT or at the aortic valve -





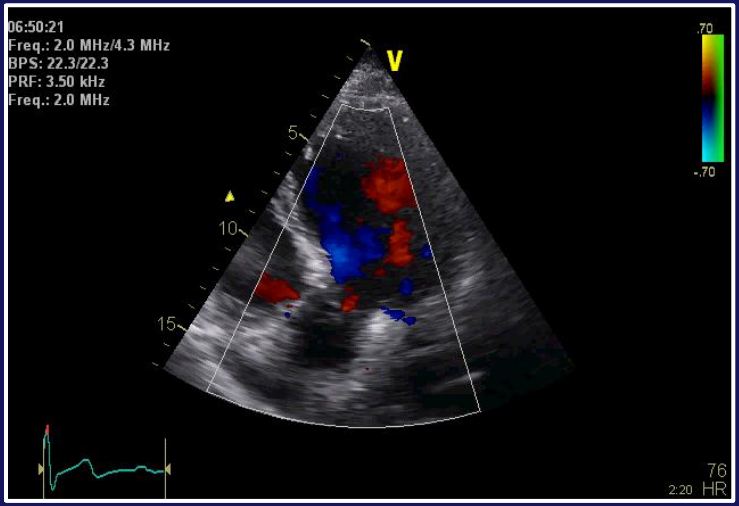


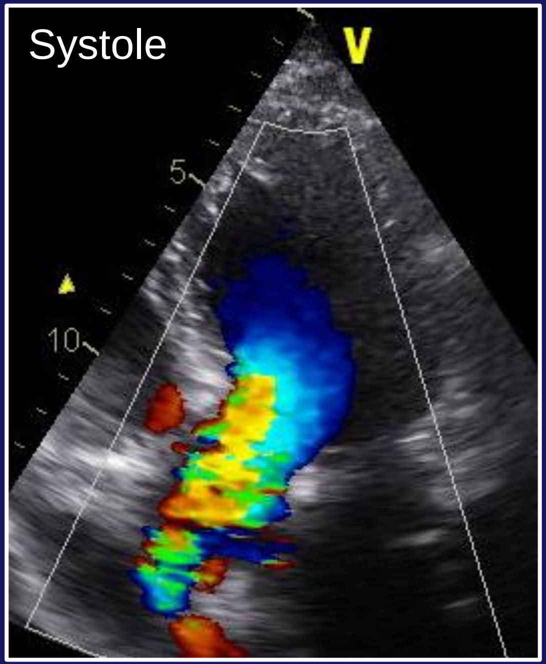


The sample volume of the pulsed wave Doppler has to be positioned about 5mm in front of the aortic annulus in the left ventricular outflow tract.

In the presence of turbulences at the aortic valve a continuous-wave Doppler-spectrum through the aortic valve has to be documented..

Standardized transthoracic examination in echocardiography
- the less important 5-chamber view -





The 5-chamber view can be used for the visualization of the central jet stream of stenotic or regurgitant turbulences. If the flow phenomena can be well analyzed using the continuous wave Doppler, this view is helpful. Using the pulsed wave Doppler in the LVOT this view has to be avoided because of insufficient standardization of the position of the sample volume.

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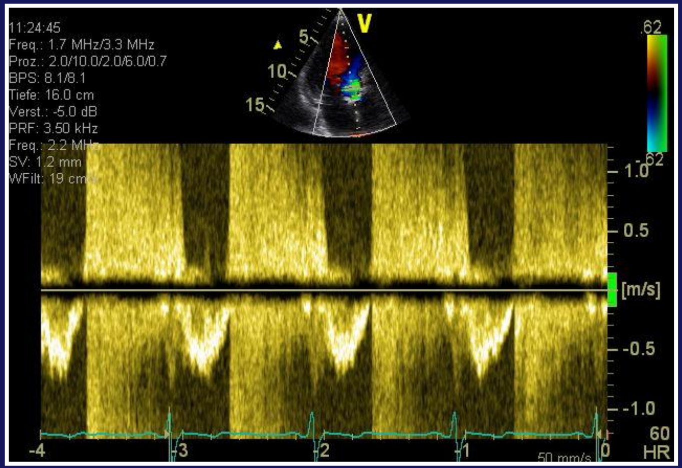
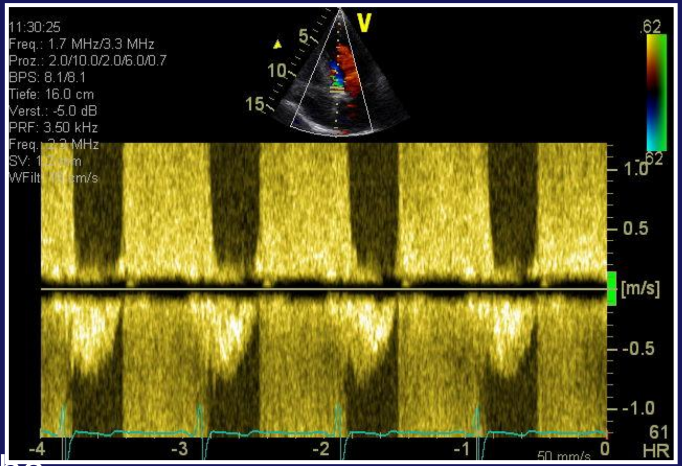
The quality of a pw-spectrum can be checked by the contours of the signal, because maximum velocities depicted with optimal Doppler angulation will show sharp contours

A

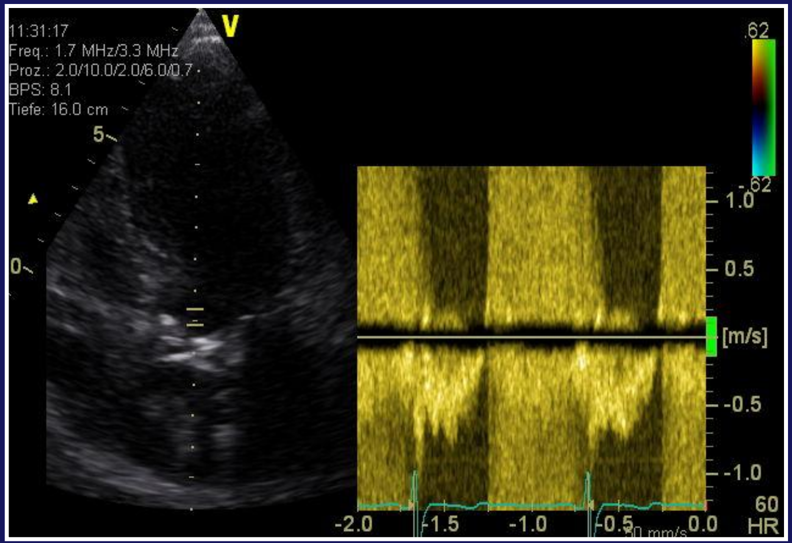


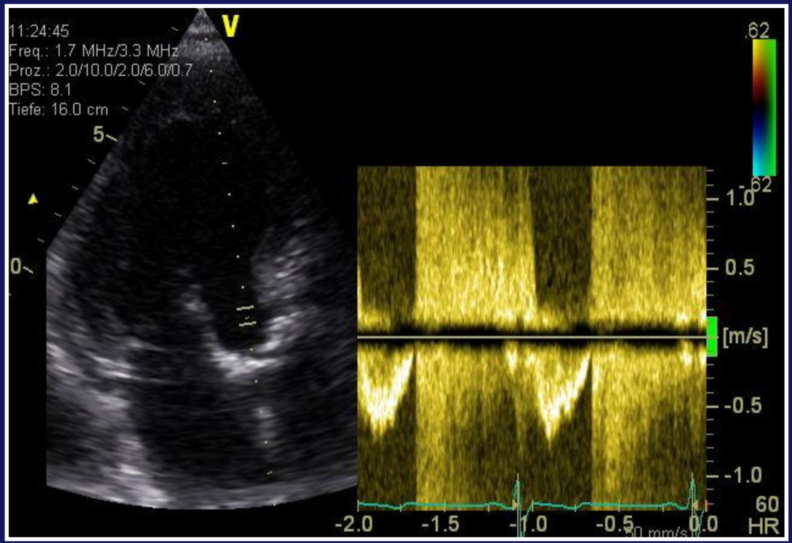
B



A „bad“ pw-spectrum does not show any contour, because Doppler angulation is oblique to the flow velocities. In this case maximum velocities will not be documented.

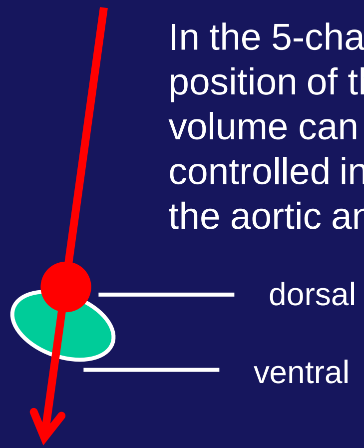
Image optimization
- principles of Doppler-echocardiography -



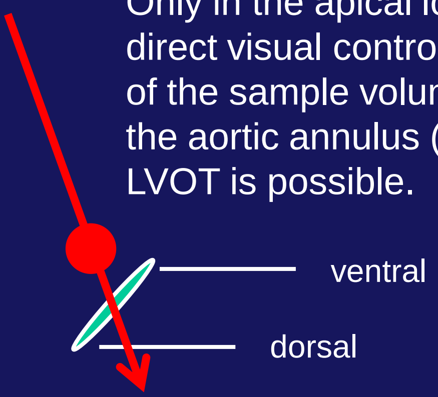


Conclusion:
It has to be standard, to use the apical long axis view for positioning of the sample volume during pw-Doppler in the LVOT.

In the 5-chamber view the position of the sample volume can not be controlled in relation to the aortic annulus.



Only in the apical long axis view a direct visual control of the positioning of the sample volume in relation to the aortic annulus (prifile view) in the LVOT is possible.



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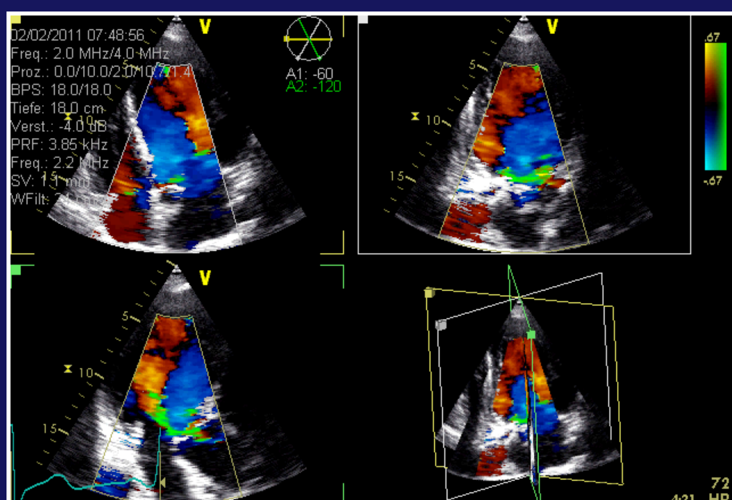
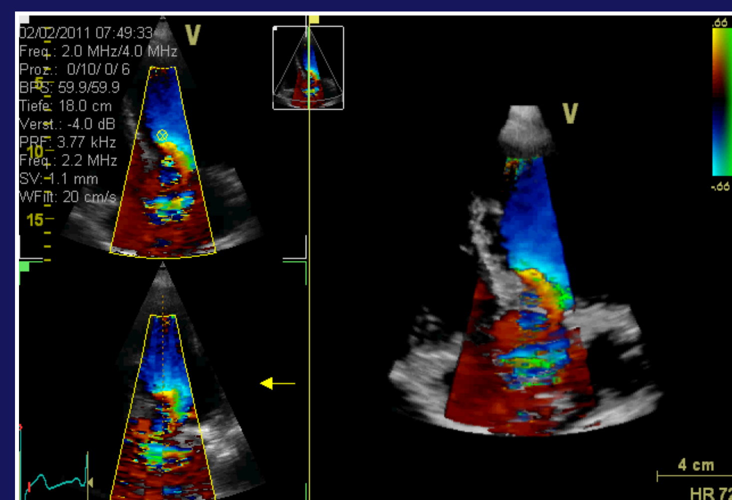
EUROPEAN SOCIETY OF CARDIOLOGY®
European Journal of Echocardiography (2010) **11**, 223–244
doi:10.1093/ejechocard/jeq030

RECOMMENDATIONS

European Association of Echocardiography recommendations for the assessment of valvular regurgitation. Part 1: aortic and pulmonary regurgitation (native valve disease)

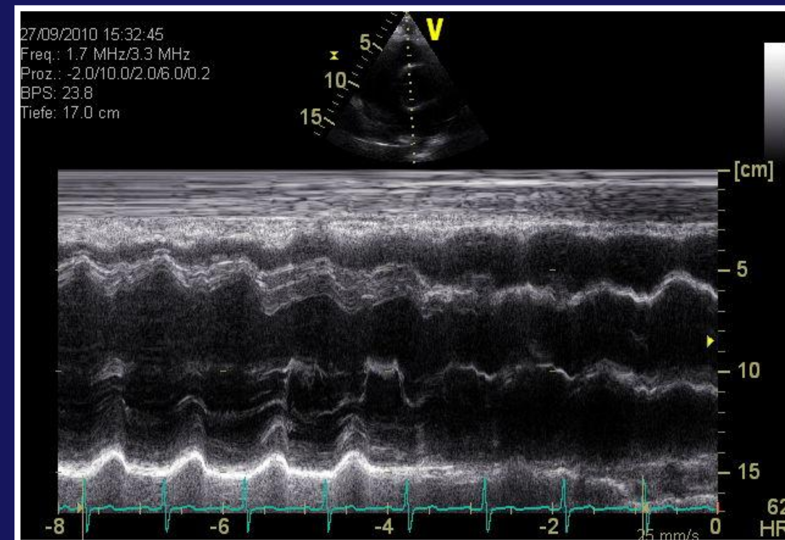
Patrizio Lancellotti (Chair)[1*], Christophe Tribouilloy[2], Andreas Hagendorff[3], Luis Moura[4], Bogdan A. Popescu[5], Eustachio Agricola[6], Jean-Luc Monin[7], Luc A. Pierard[1], Luigi Badano[8], and Jose L. Zamorano[9] on behalf of the European Association of Echocardiography





Analysis of the aortic regurgitation

1. Description of the morphology of the cavities – mainly of the left ventricle and the aortic root
2. Assessment of left ventricular function
3. Target parameter 1: regurgitant fraction
4. Substitute target parameters: planimetry of the effective regurgitant orifice
5. Assessment of qualitative and semiquantitative parameter
6. Secundary structural and functional data
7. Special investigations, e.g. TEE and stress



LV- and LA-dilatation; Reduced LV-function – if significant aortic regurgitation is present .

2	Ao Wurzel Diam	4.3 cm
	LA Diam	4.4 cm
	LA/Ao	1.03
1	IVSd	1.5 cm
	IVSs	2.0 cm
	LVIDd	7.2 cm
	LVIDs	5.2 cm
	LVPWd	1.7 cm
	LVPWs	2.1 cm
	EDV (Teich)	275 ml
	ESV (Teich)	132 ml
	EF (Teich)	52 %
	SV (Teich)	143 ml
	%FS	28 %

Key point
LV diameters, volumes, and ejection fraction should always be evaluated and reported. It is strongly recommended to index the LV diameters to the body surface area.

according to Lancelotti et al., Eur J Echocardiography 2010;11: 223-244

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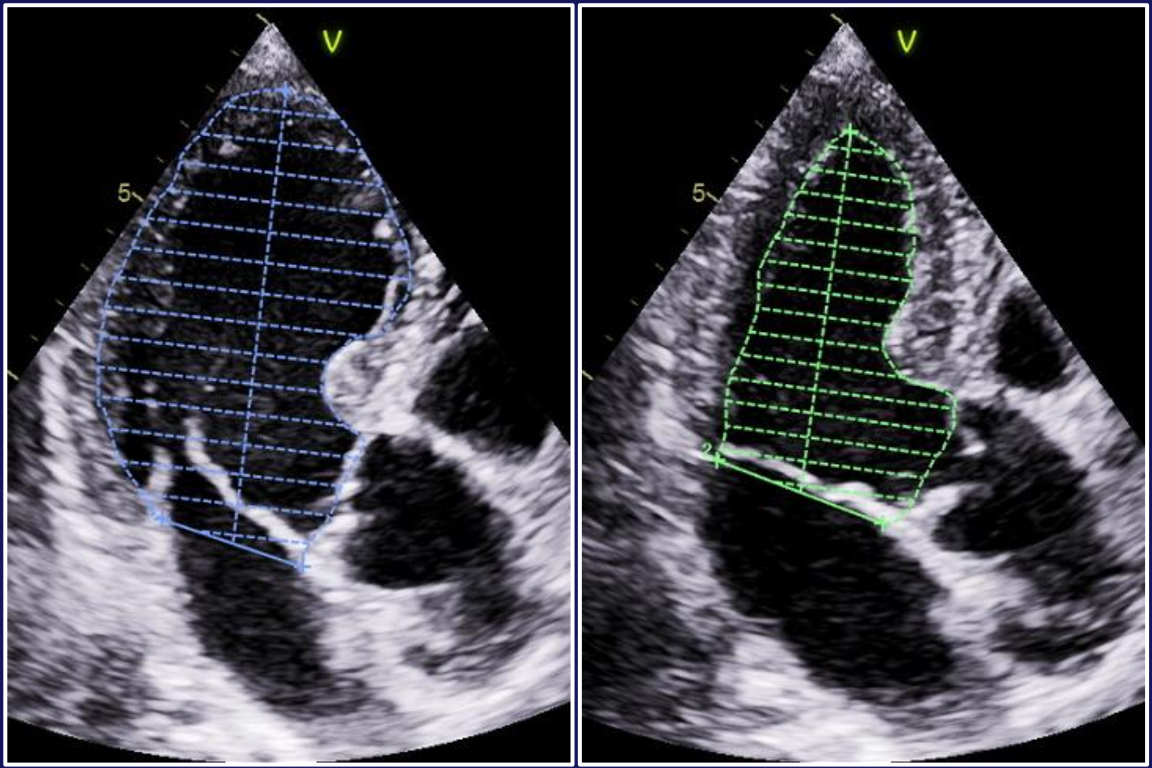
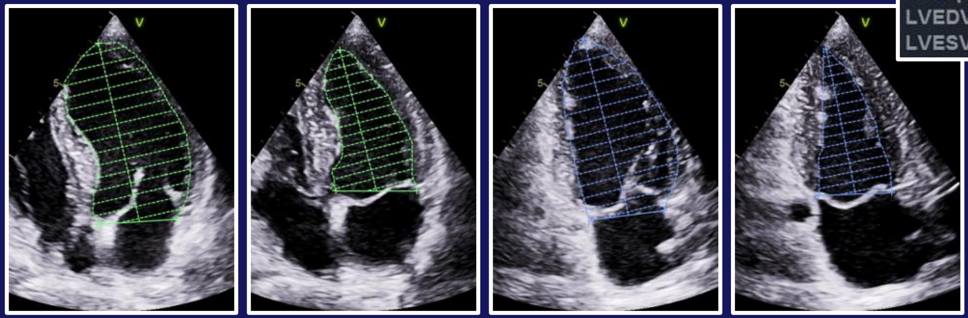


EF A-L LAX	60 %
LVEF MOD LAX	60 %
SV A-L LAX	135 ml
SV MOD LAX	130 ml
CO A-L LAX	9.42 l/min
CO MOD LAX	9.10 l/min

Preserved or sligthly reduced LV-function in the presence of a moderate aortic regurgitation

Monoplane analysis is not sufficient.

Biplane determination of systolic function by Simpson analysis should be mandatory in VHD.



EF Biplane	67 %
LVEDV MOD BP	199 ml
LVESV MOD BP	65 ml

The 2D-based biplane summation method of disc is the recommended approach for the estimation of LV volumes and ejection fraction.

Echocardiographic Assessment of Aortic Regurgitation

Table 1 Functional classification of AR lesions

Dysfunction	Echo findings
I: enlargement of the aortic root with normal cusps	Dilatation of any components of the aortic root (aortic annulus, sinuses of Valsalva, sinotubular junction)
IIa: cusp prolapse with eccentric AR jet	
Cusp flail	Complete eversion of a cusp into the LVOT in long-axis views
Partial cusp prolapse	Distal part of a cusp prolapsing into the LVOT (clear bending of the cusp body on long-axis views and presence of a small circular structure near the cusp free edge on short-axis views)
Whole cusp prolapse	Free edge of a cusp overriding the plane of aortic annulus with billowing of the entire cusp body into the LVOT (presence of a large circular or oval structure immediately beneath the valve on short-axis views)
IIb: free edge fenestration with eccentric AR jet	Presence of an eccentric AR jet without definite evidence of cusp prolapse
III: poor cusp quality or quantity	Thickened and rigid valves with reduced motion
	Tissue destruction (endocarditis)
	Large calcification spots/extensive calcifications of all cusps interfering with cusp motion

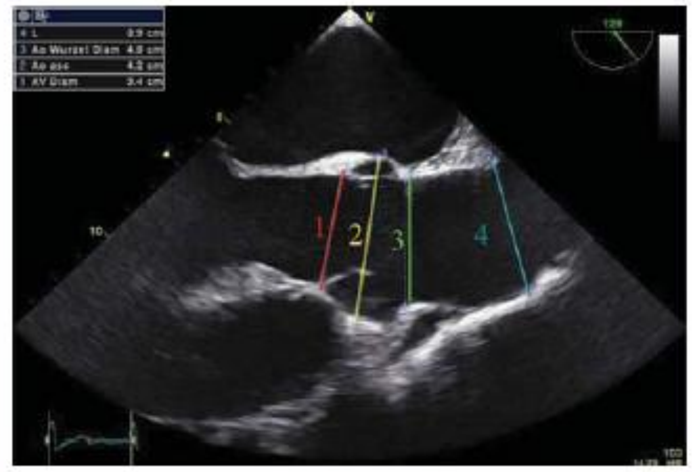
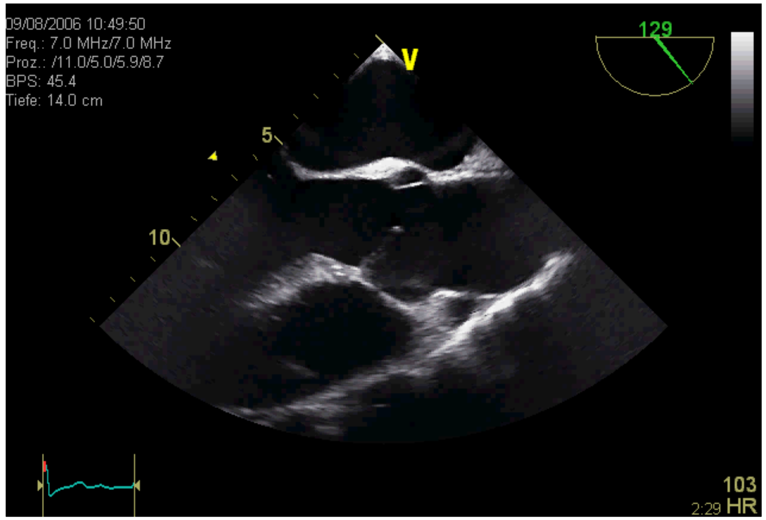


Figure 5 Measurements of the aortic diameters. 1, valve annulus; 2, aortic sinuses; 3, sinotubular junction; 4, proximal ascending aorta.



according to Lancelotti et al., Eur J Echocardiography 2010;11: 223-244

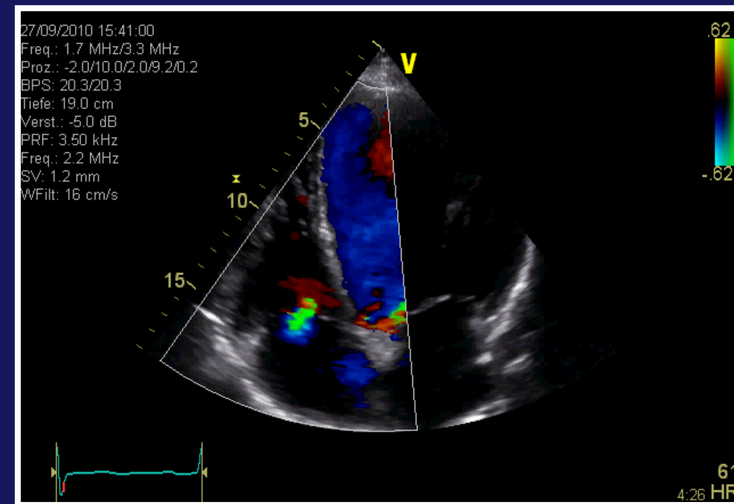
Echocardiographic Assessment of Aortic Regurgitation

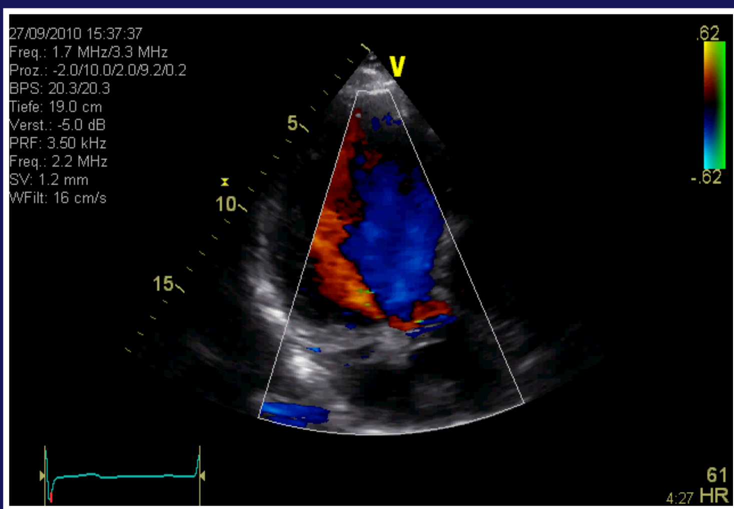
Key point

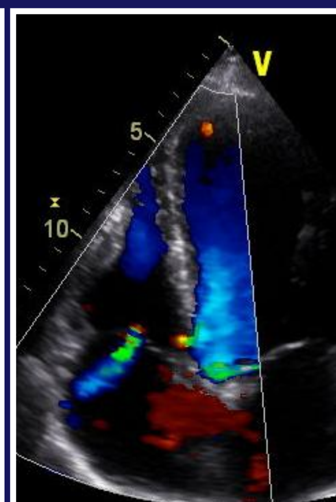
In patients with AR, careful aortic valve analysis is mandatory. The echo report should include information about the aetiology, the lesion process, and the type of dysfunction. The likelihood of valve repair should also be discussed in the case of pure AR.

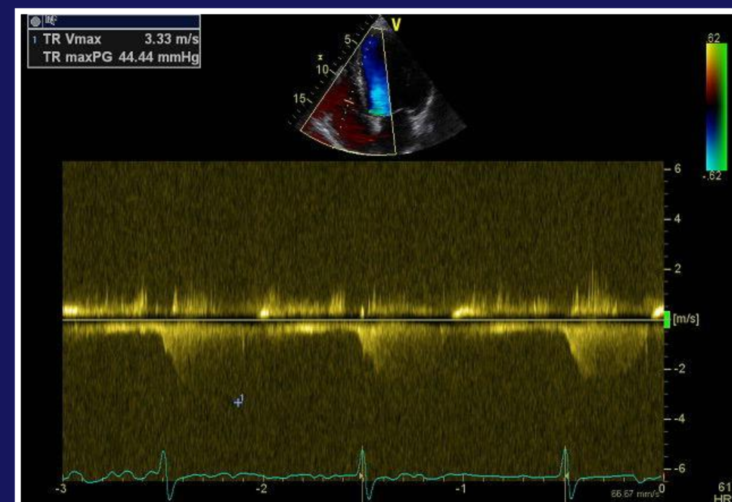
Key point

Additional echo findings are used as complementary findings to assess the severity of AR. The assessment of the morphology and dimension of the aortic root is mandatory.









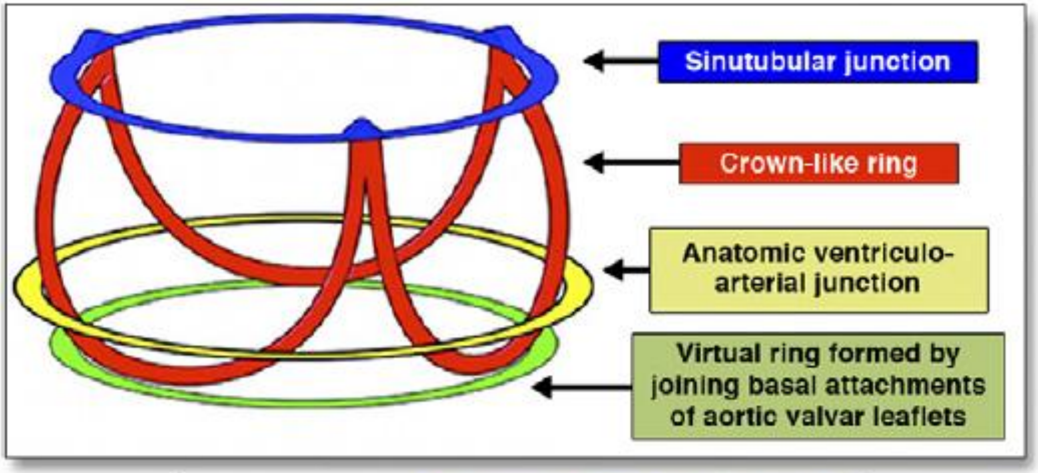
Indirect sequela of the valvular lesion: Increased sPAP

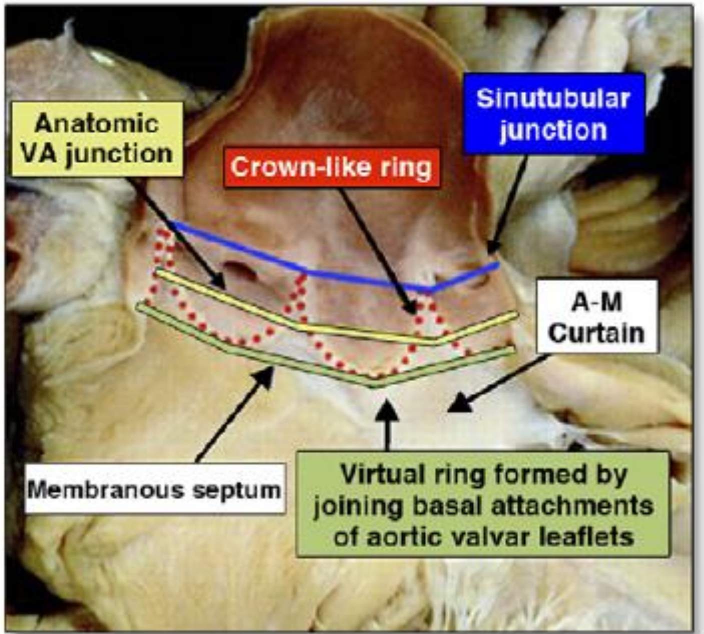
according to Lancelotti et al., Eur J Echocardiography 2010;11: 223-244

Functional Anatomy of Aortic Regurgitation: Echocardiography

What are the prerequisites to successful aortic valve repair?

- To have a substantial understanding of the mechanisms of aortic valve dysfunction
  - Normal, excessive or restricted cusp motion
  - Poor cusp quality or quantity
- To understand the anatomical features associated with post-operative results
  - Increased risk of reoperation after AV repair in Marfan pts and Type 3 AR (restrictive type)
  - Impact of cuspal configuration (bicuspid higher risk than tricuspid)
  - Impact of pericardial pathing (due to calcification)
  - Impact of commissural orientation (< 160° higher risk than > 160°)
  - Impact of anular size (> 29mm higher risk than < 29mm)



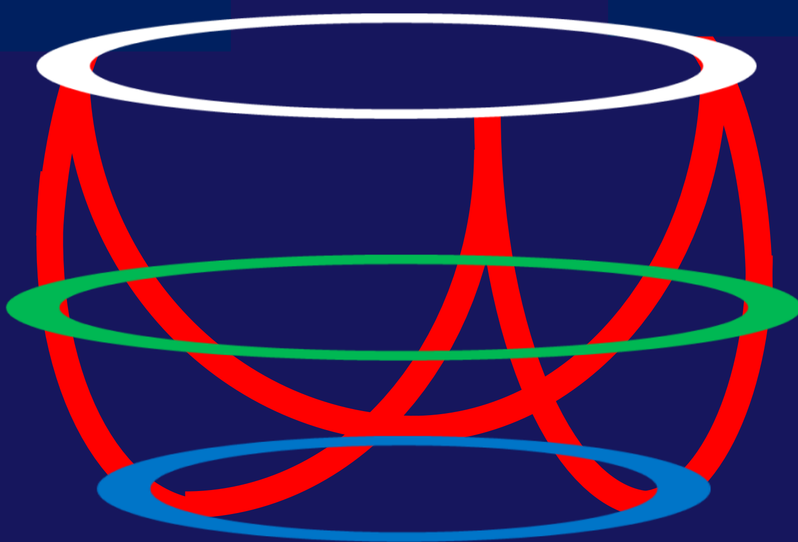


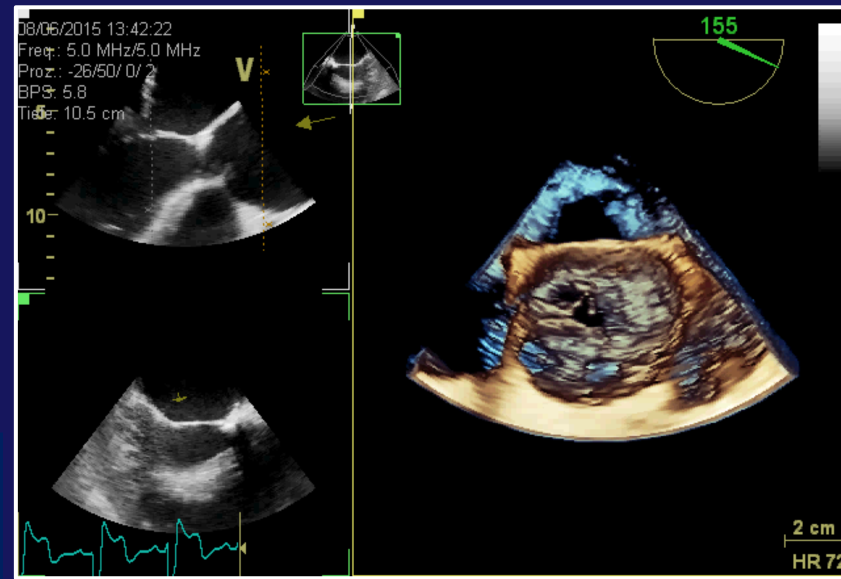
Aortic Root Anatomy:
(A) Diagram of aortic root anatomy showing coronet shape and location of various annular planes and coronary ostia relative to leaflet attachments.
(B) Imaging planes and leaflet attachments from (A) shown superimposed on postmortem specimen.
A-M aorto-mitral;
VA ventriculo-arterial.

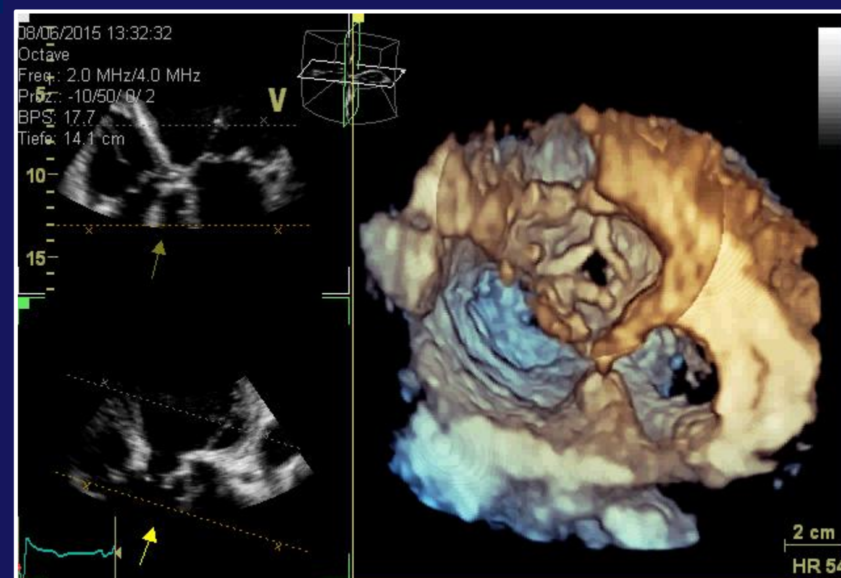
according to Piazza N, de Jaegere P, Schultz C, Becker AE, Serruys PW, Anderson RH. Anatomy of the aortic valvar complex and its implications for transcatheter implantation of the aortic valve. Circ Cardiovasc Interv 2008;1: 74–81.

Echocardiographic Assessment of Aortic Regurgitation

The anatomy of the aortic valve and the aortic root is complex. It can be better visualized multidimensional than in a two-dimensional images.







The aortic root: structure, function, and surgical reconstruction

Heart 2000;83:376–380

M J Underwood, G El Khoury, D Deronck, D Glineur, R Dion

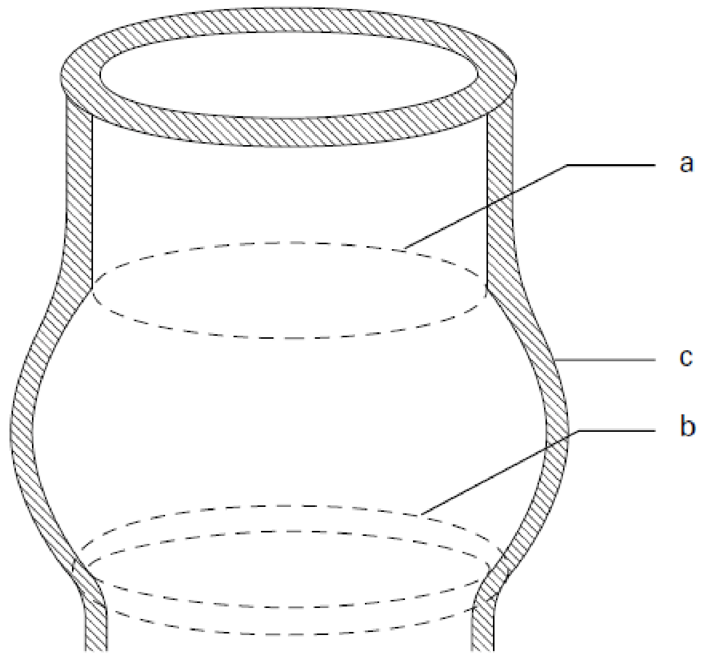


Figure 1 *Diagrammatical representation of the aortic root: (a) sinotubular junction; (b) basal ring (surgical annulus); (c) the sinuses of Valsalva.*

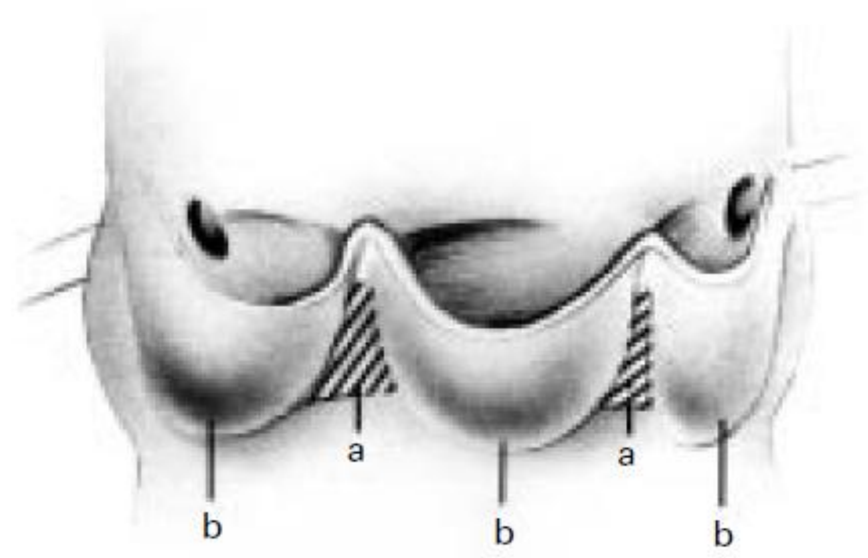


Figure 2 *Diagrammatic representation of the aortic root opened longitudinally through the left coronary sinus, demonstrating the interleaflet triangles (a) and the valve leaflets (b).*

Transesophageal Echocardiographic Evaluation During Aortic Valve Repair Surgery

(Anesth Analg 2010;111:59–70)

Michel J. Van Dyck, MD,* Christine Watremez, MD,* Munir Boodhwani, MD, MMSc,† Jean-Louis Vanoverschelde, MD, PhD,‡ and Gebrine El Khoury, MD†

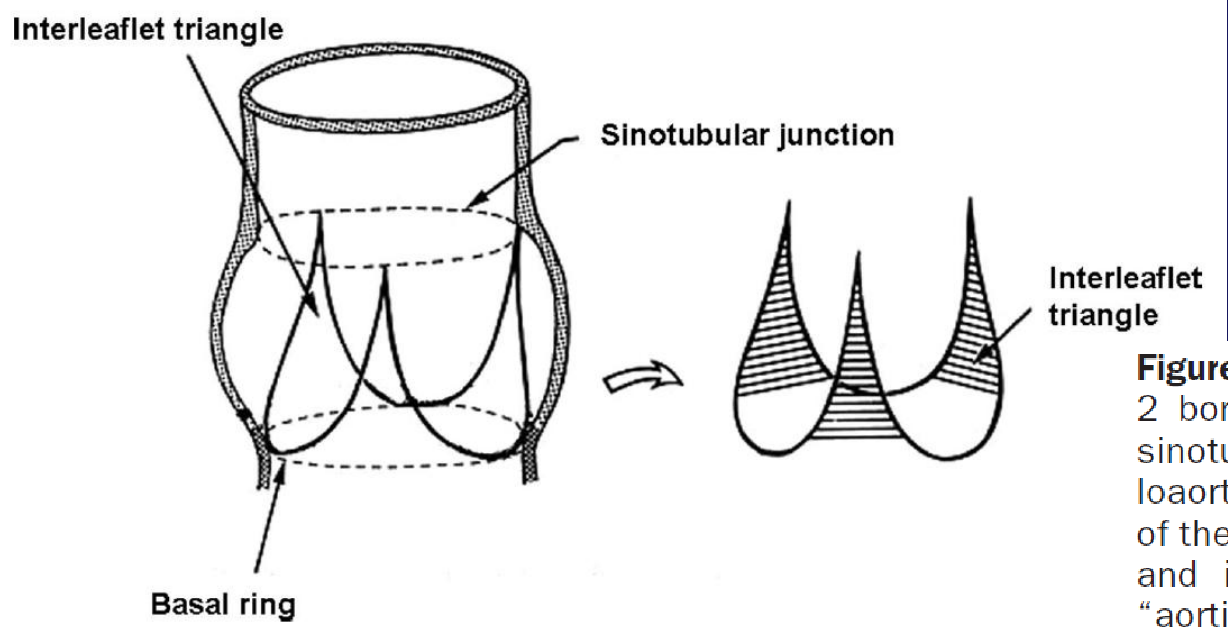


Figure 1. Diagram of the aortic root. The 2 borders of the root are drawn: the sinotubular junction and the ventriculoaortic junction. The basal attachment of the aortic cusps forms the basal ring and is also often described as the "aortic annulus." Inset: The crown-like shape of the valve attachments determines the presence of 3 interleaflet triangles. (Modified from Sutton et al.,[30] with permission.)

according to Van Dyck et al., Anest Analg 2010; 111:59-70

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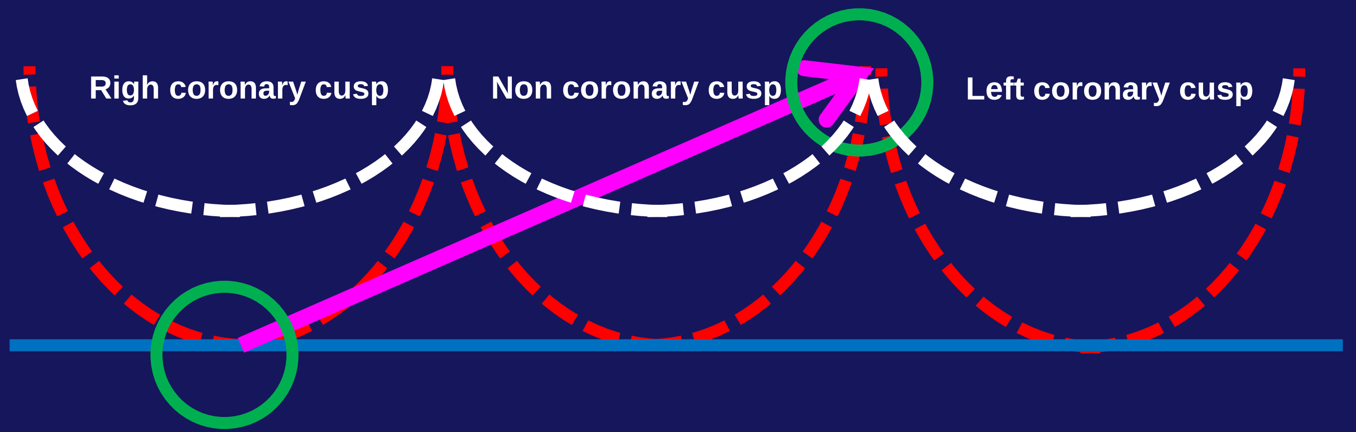

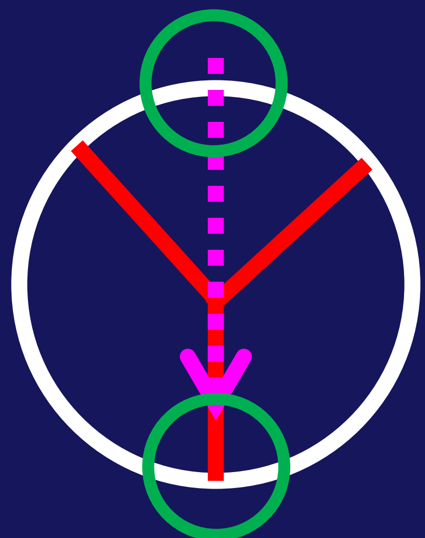

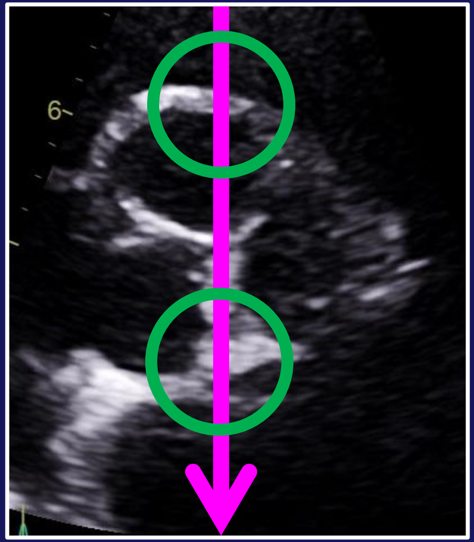

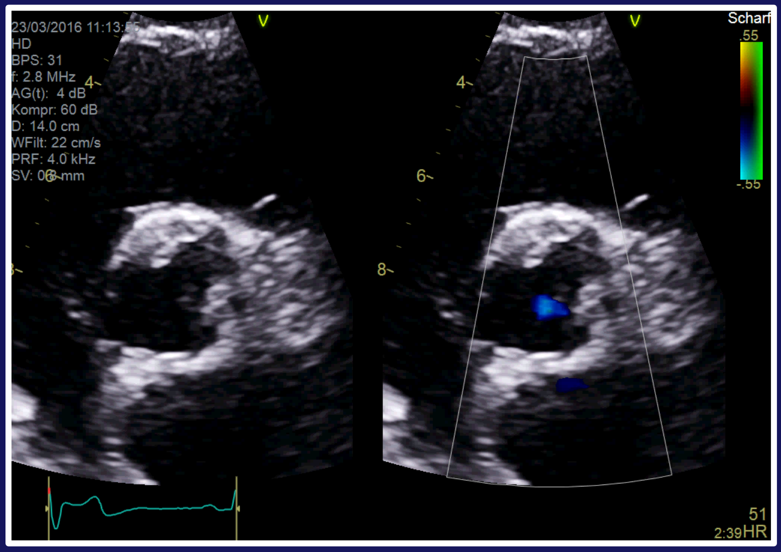

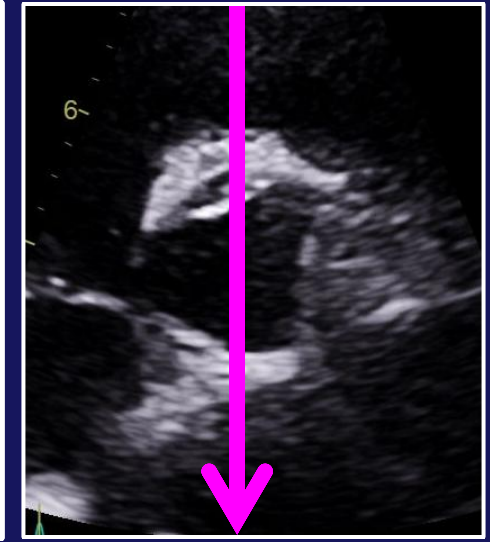

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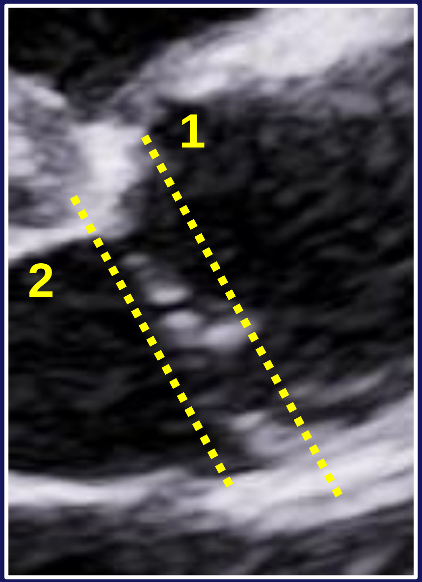
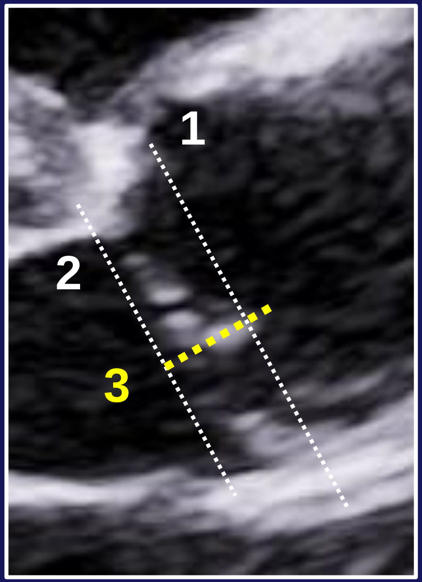
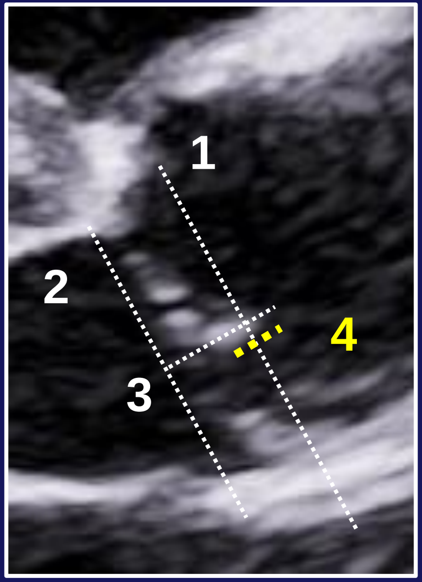


1= diameter at the level of the tpis of the „crown-like“ ring

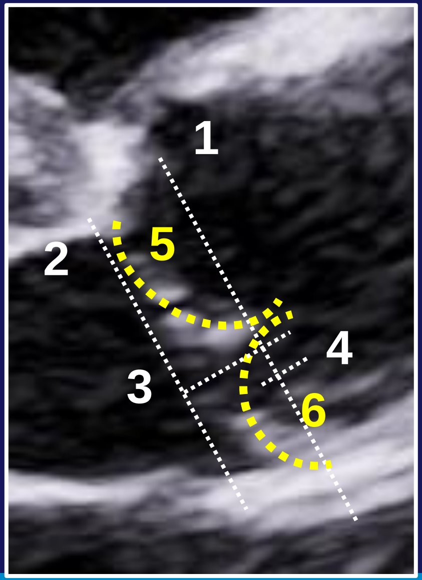
2= diameter at the level of the „hinge points“



3 = effective height



4 = coaptation-length

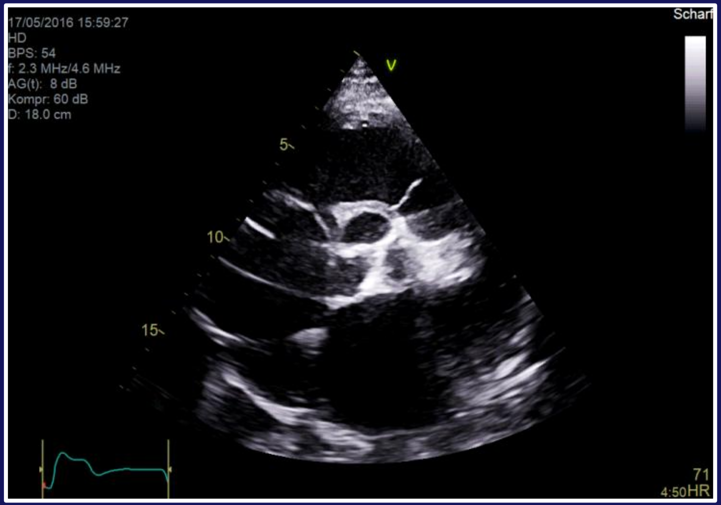


5 and 6 = geometric heights of the cusps
- Really visualized only for the right coronary cusp

Analysis of Aortic Valve: Cusp Movement and Calcification

The degree of mobility of the aortic valve:

- Grade 1 describes normal motion of the cusps
- Grade 2 describes excess motion of the cusps
- Grade 3 idescribes restrictive motion of the cusps



The degree of calcification of the aortic valve:

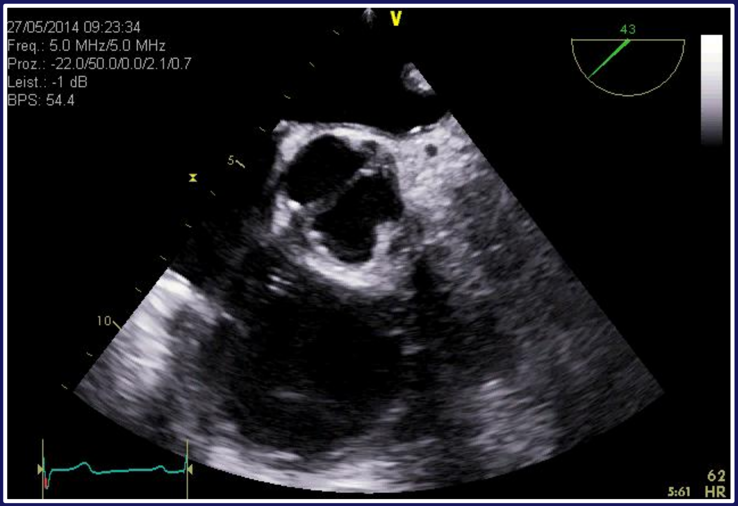
- Grade 1 describes no calcification
- Grade 2 describes isolated spots of calcification
- Grade 3 is characterized by large echogeneities due to calcification interfering with the motion of the cusps
- Grade 4 presents extensive calcification of all cusps with restiction of the cusp motion

e.g. restrictive motion of the cusps and grade 3 calcification

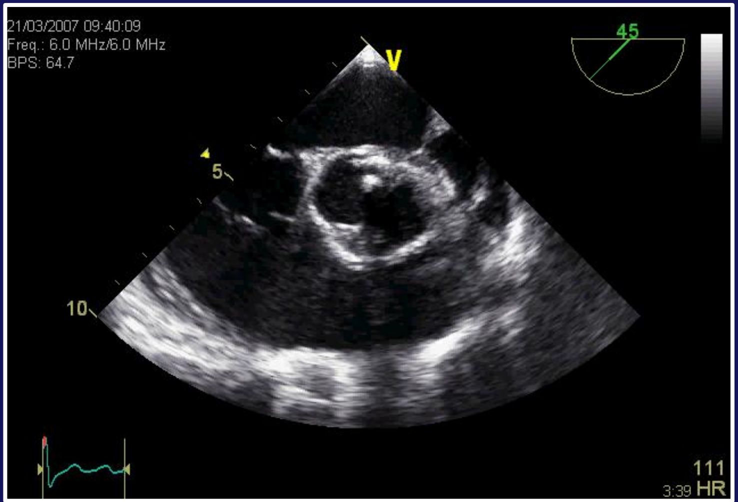
Analysis of Aortic Valve: Cusp Fusion and Fusion Orientation

In patients with bicuspid aortic valve it is important to describe the cusp fusion.

- Type 1 is the right-left coronary cusp fusion
- Type 2 is the right-noncoronary cusp fusion
- Type 3 is the left-noncoronary cusp fusion



A



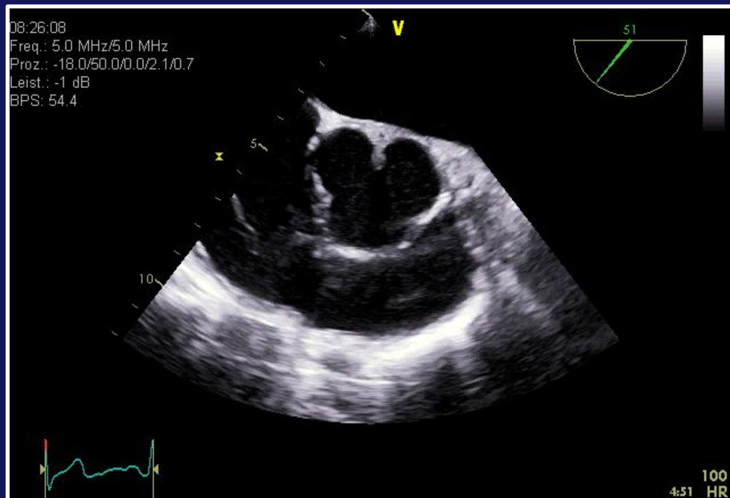
B

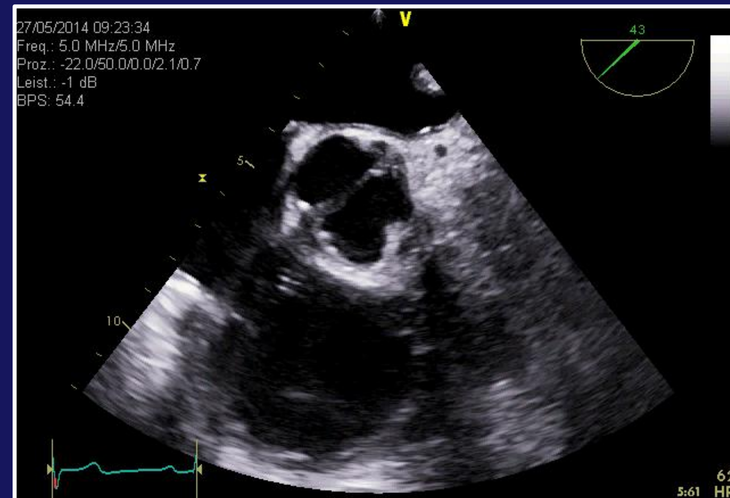
Examples of type 1 fusion with a 180° fusion orientation

A. small raphe
B. Calcification with stenotic compound

Analysis of Aortic Valve: Number of Cusps and Cusp Configuration

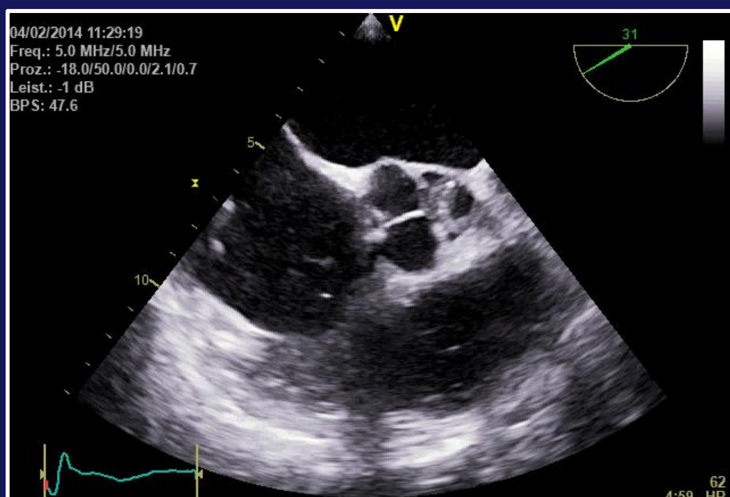
uni-
cuspid

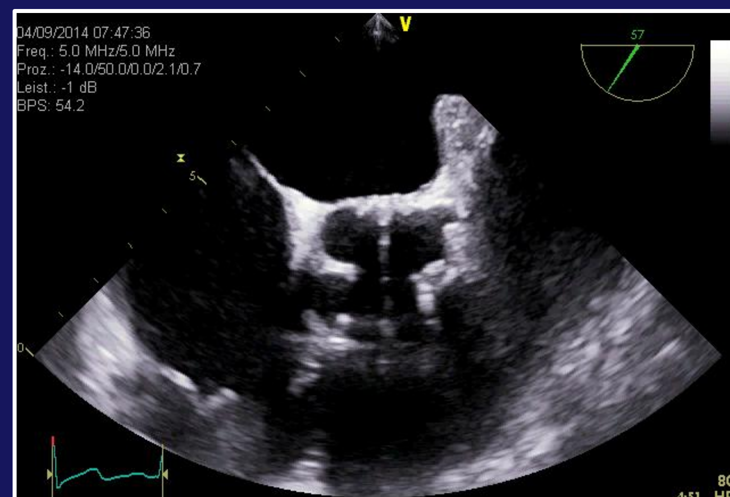




bi-
cuspid

normal
=
tri-
cuspid

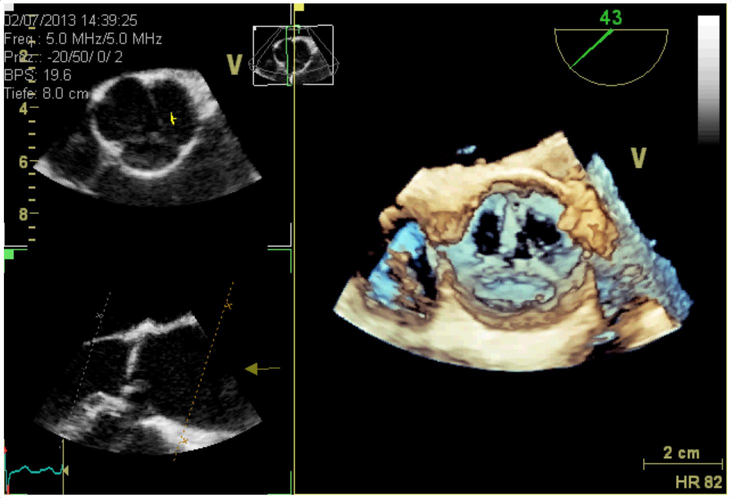


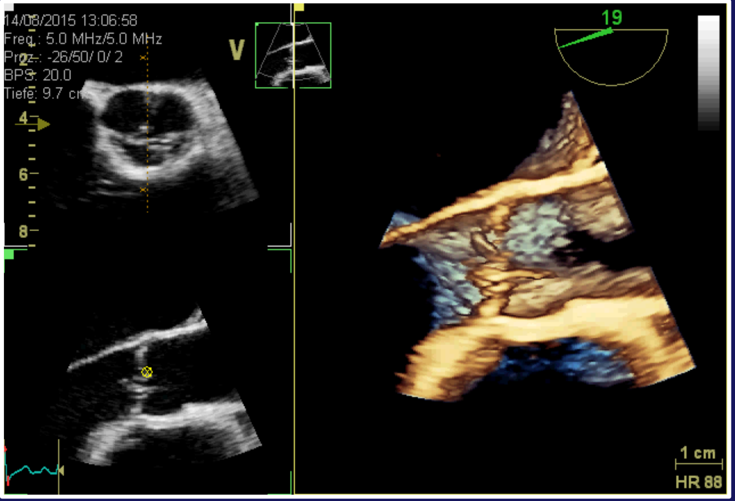


quadri-
cuspid

Anatomy of Aortic Regurgitation

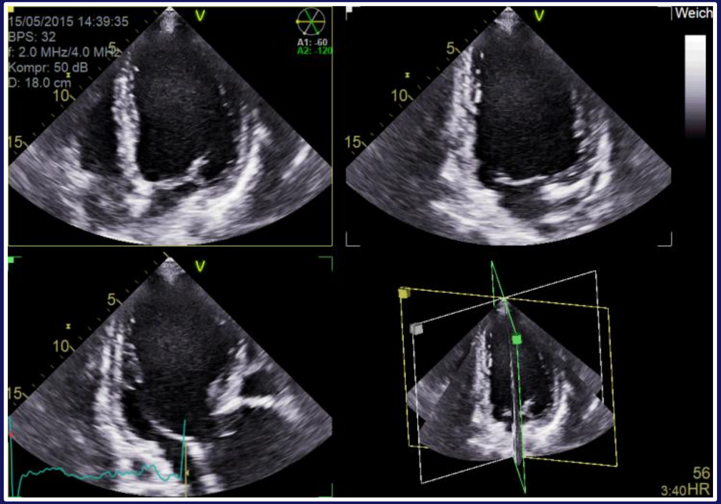
- Proximal aortic dilatation
  - Normally central regurgitation
- Cusp thickening or cusp restraction
  - Fusion/raphe in BAV
  - Degenerative disease
  - Rheumatic disease
  - Often combined with aortic stenosis
- Cusp destruction
  - Endocarditis
  - Trauma
- Cusp prolapse
  - Anulus or aortic root dilatation
  - Dissection
  - Normally excentric regurgitation

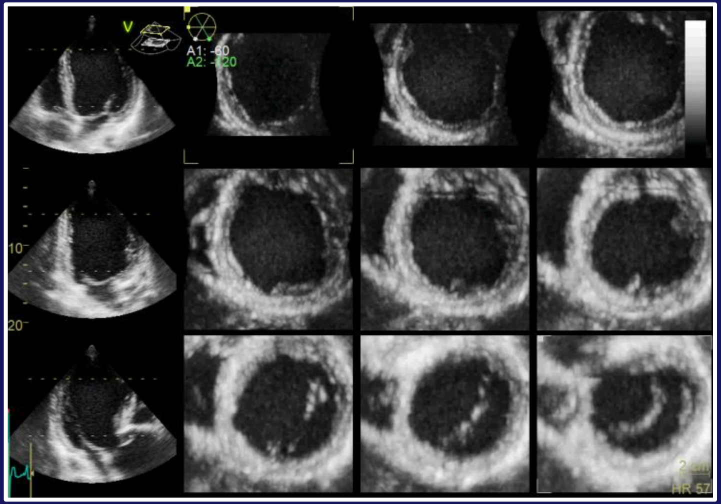




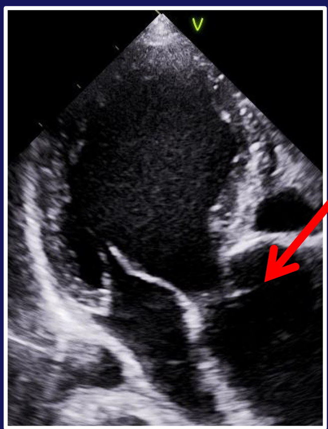
Pathophysiology of Chronic Aortic Regurgitation

- Primary volume overload
  - Primarily increased preload
  - With time, increased afterload
- Progressive ventricular dilatation
  - Chamber compliance increases due to the increase of total stroke volume
  - Only mild increase of intracavitary pressure
  - With time – if LV is severely enlarged – significant increase of intracavitary pressure
- Myocardial hypertrophy
  - Compensation for the increase of wall stress for maintainance of LV function

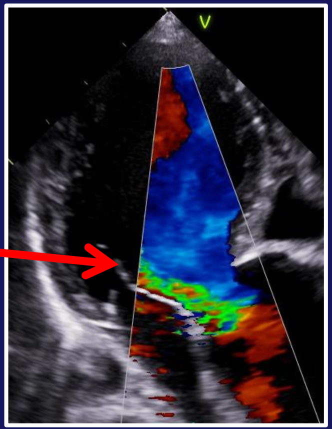


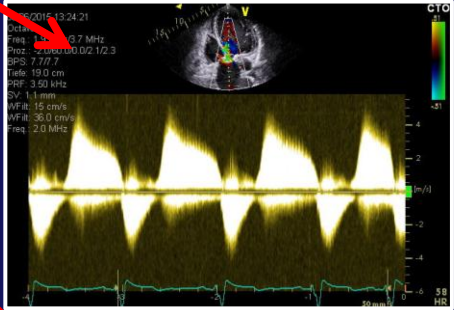


Grading of Aortic Regurgitation by Echocardiography



- Qualitative
  - Aortic valve morphology
  - Color flow AR-jet
  - cw-Doppler AR-signal
  - Diastolic flow reversal in the thoracic arteries
- Semiquantitative
  - Vena contracta jet width
  - Regurgitant oriffice area
- Quanatitative
  - Volume calculations by Doppler echocardiography
  - Regurgitant valume and regurgitant orifice calculations by PISA method





Echocardiographic Assessment of Aortic Regurgitation

American Society of Echocardiography: Recommendations for Evaluation of the Severity of Native Valvular Regurgitation with Two-dimensional and Doppler Echocardiography

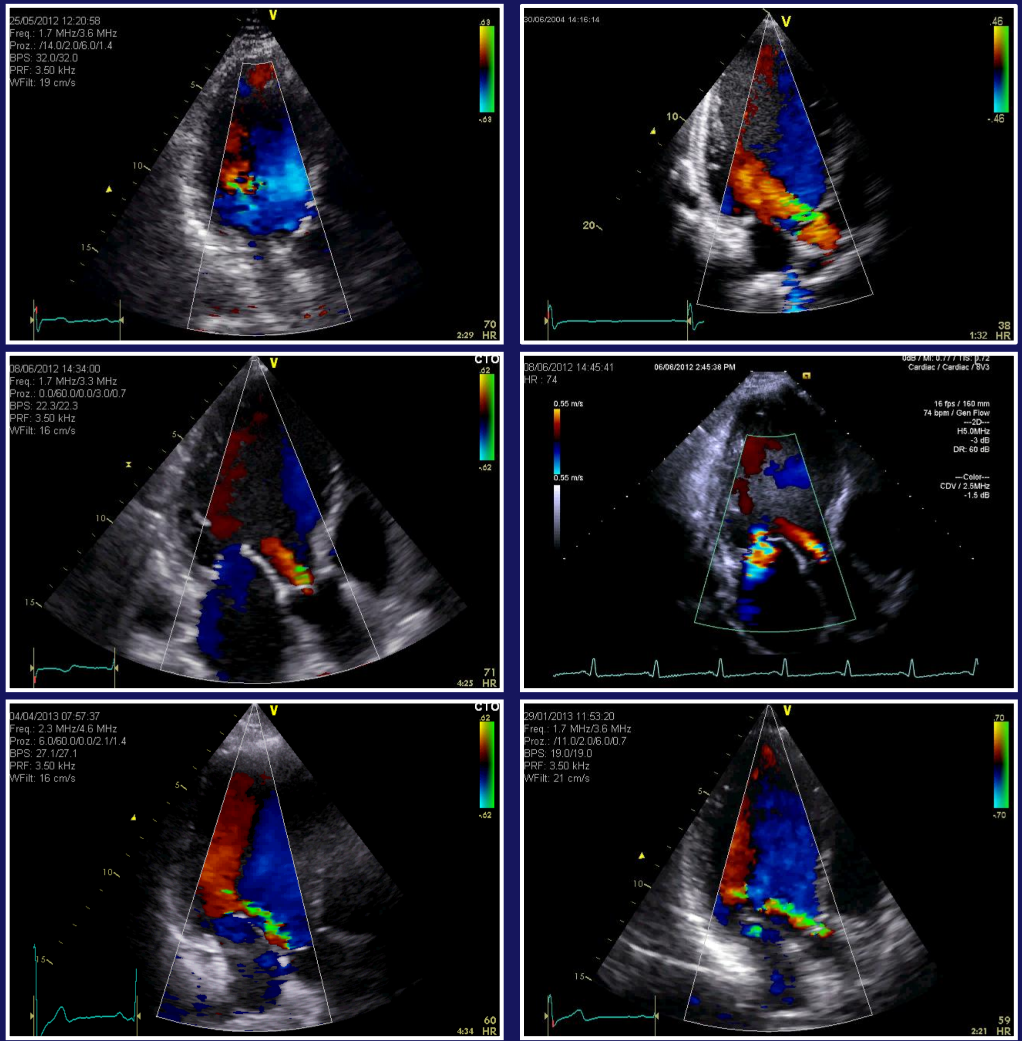
W. A. Zoghbi, M. Enriquez-Sarano, E. Foster, P. A. Grayburn, C. D. Kraft, R. A. Levine, P. Nihoyannopoulos, C. M. Otto, M. A. Quinones, H. Rakowski, W. J. Stewart, A. Waggoner and N. J. Weissman

Eur J Echocardiography (2003) **4,** 237–261

Table 4. Qualitative and quantitative parameters useful in grading aortic regurgitation severity.

Parameter	Mild	Moderate		Severe
Structural parameters				
LV size	Normal*	Normal or dilated		Usually dilated†
Aortic leaflets	Normal or abnormal	Normal or abnormal		Abnormal/flail, or wide coaptation defect
Doppler parameters				
Jet width in LVOT — color flow‡	Small in central jets	Intermediate		Large in central jets; variable in eccentric jets
Jet density — CW	Incomplete or faint	Dense		Dense
Jet deceleration rate — CW (PHT, ms)§	Slow >500	Medium 500–200		Steep <200
Diastolic flow reversal in descending aorta — PW	Brief, early diastolic reversal	Intermediate		Prominent holodiastolic reversal
Quantitative parameters¶				
VC width, cm‡	<0.3	0.3–0.60		>0.6
Jet width/LVOT width, %‡	<25	25–45	46–64	≥65
Jet CSA/LVOT CSA, %‡	<5	5–20	21–59	≥60
R Vol, ml/beat	<30	30–44	45–59	≥60
RF, %	<30	30–39	40–49	≥50
EROA, cm^2	<0.10	0.10–0.19	0.20–0.29	≥0.30

Special Aspects of Echocardiographic Assessment of the Severity of AR: It is not allowed to estimate severity according to the size of the jet area



Key point

The colour flow area of the regurgitant jet is not recommended to quantify the severity of AR. The colour flow imaging should only be used for a visual assessment of AR. A more quantitative approach is required when more than a small central AR jet is observed.

Estimation of the severity of valvular regurgitation: recommendations

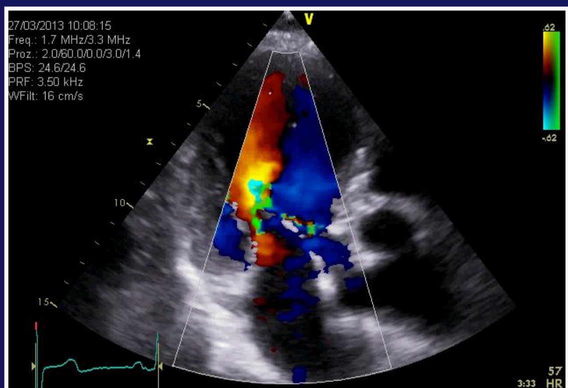
(1) The colour flow area of the regurgitant jet is not recommended to quantify the severity of valvular regurgitation.
(2) Both the vena contracta measurement and the PISA method are the recommended approaches to evaluate the severity of regurgitation when feasible.
(3) Adjunctive parameters should be used when there is discordance between the quantified degree of regurgitation and the clinical context.

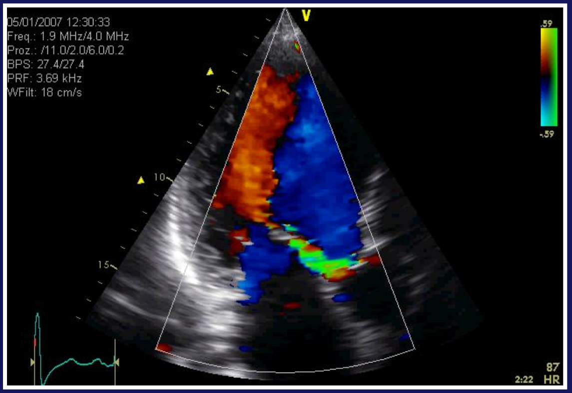
according to Lancelotti et al., Eur J Echocardiography 2010;11: 223-244

Special Aspects of Echocardiographic Assessment of the Severity of AR: It is not allowed to estimate severity according to the size of the jet area

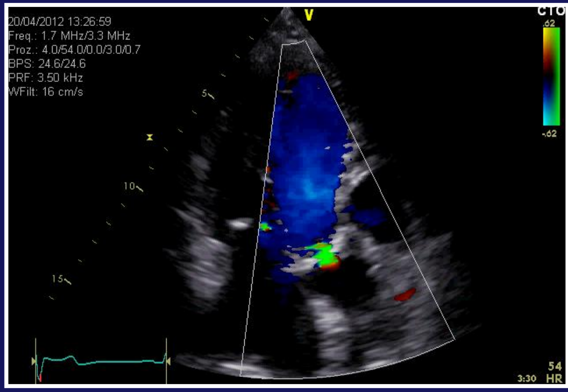
Estimation of the severity of valvular regurgitation: recommendations

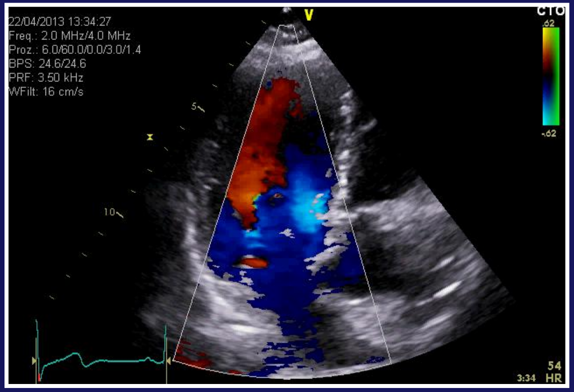
(1) The colour flow area of the regurgitant jet is not recommended to quantify the severity of valvular regurgitation.

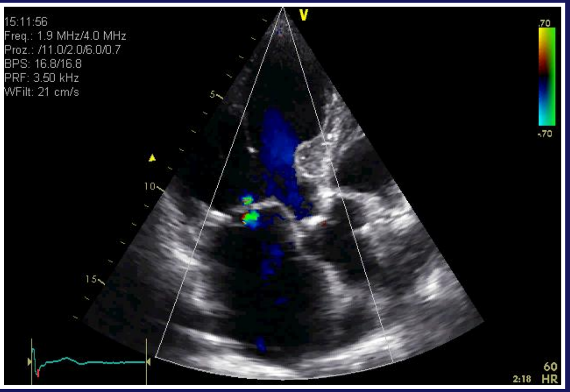




Quantification of the AR-severity according to the jet area is always wrong.







according to Lancelotti et al., Eur J Echocardiography 2010;11: 223-244

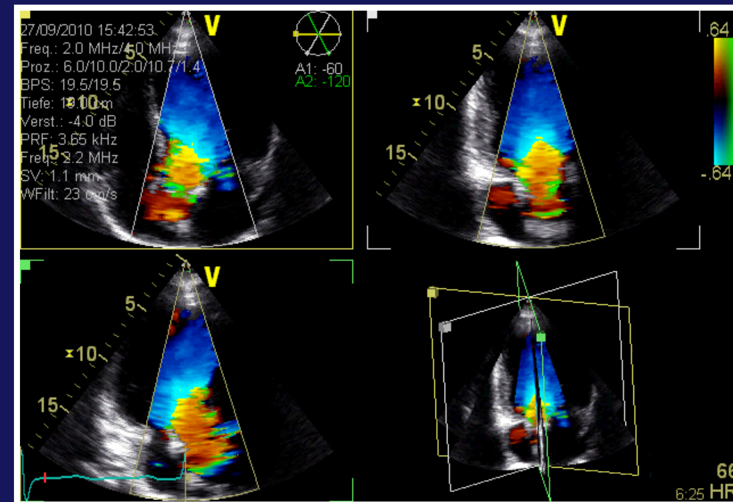
Semiquantitative grading of AR:

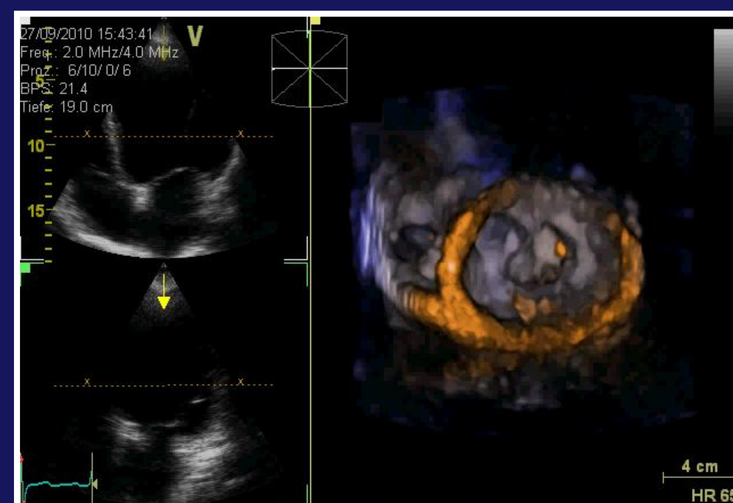
Methods if indirect grading of AR (semiquantification):

1. Pressure Half Time-Method – PHT
2. Vena contracta or proximal jet-width (or the ratio of $D_{jet\text{-}width}/D_{LVOT}$)
3. Regurgitant orifice area
4. (or the ratio of $area_{prox.\ jet}/area_{LVOT}$)
5. Reversal flow in the subclavian artery or the descending aorta

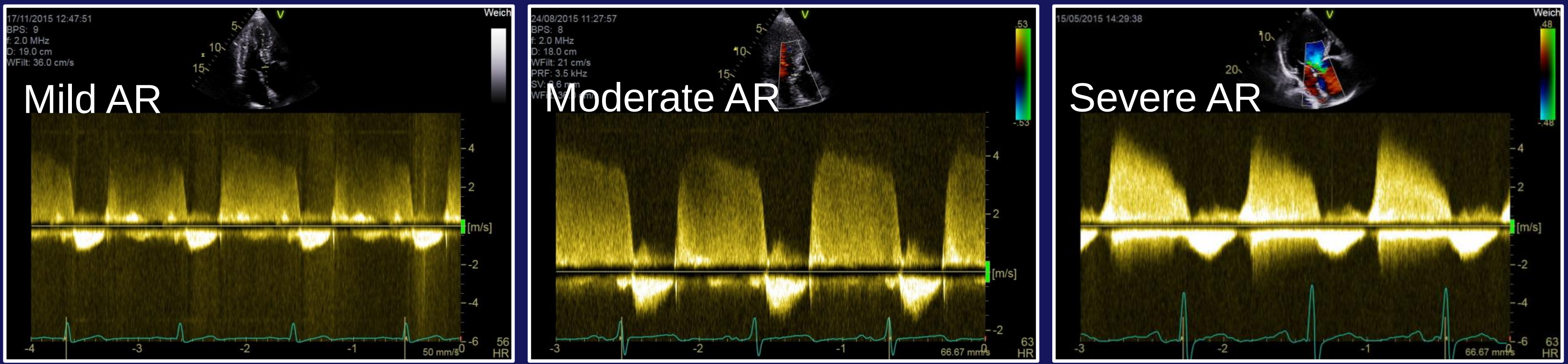
Key point

When feasible, the measurement of the vena contracta width is recommended to quantify AR. Intermediate vena contracta values (3–6 mm) need confirmation by a more quantitative method, when feasible. The vena contracta can often be obtained in eccentric jet. In the case of multiple jets, the respective values of vena contracta width are not additive. The assessment of the vena contracta by 3D echo is still reserved for research purposes.



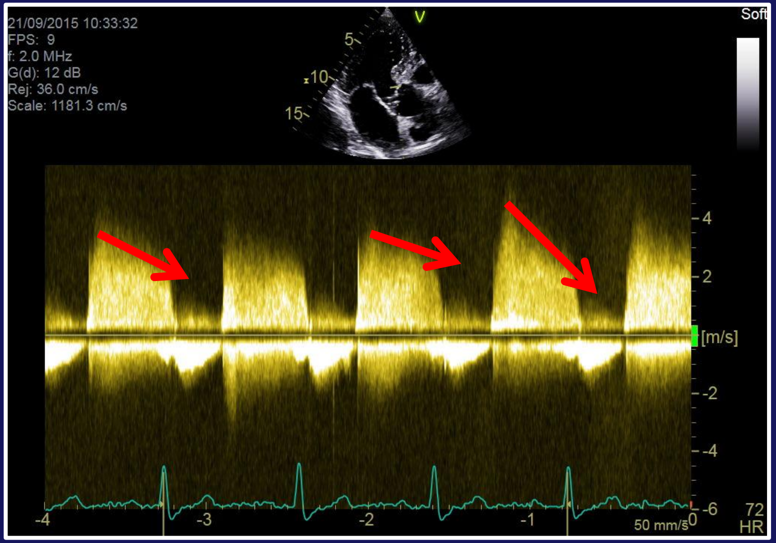


Jet density of the cw-AR-signal
The more intensive the signal, the higher the AR-severity

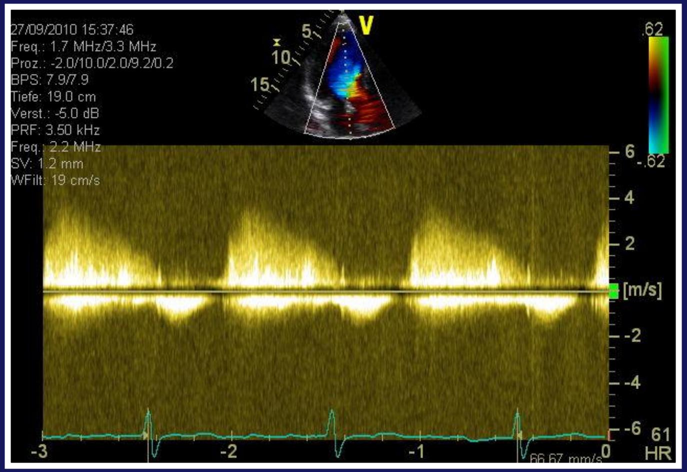


This approach is dependent on the continuance existennce of the AR-jet in place of the ultrasound beam during the complete diastole.

Due to ist methodological limitations this approach is not present in the current guidelines anymore

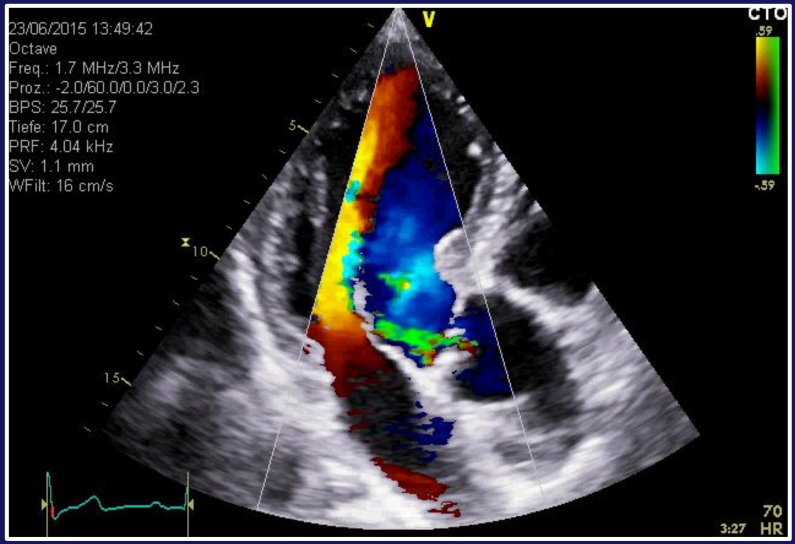


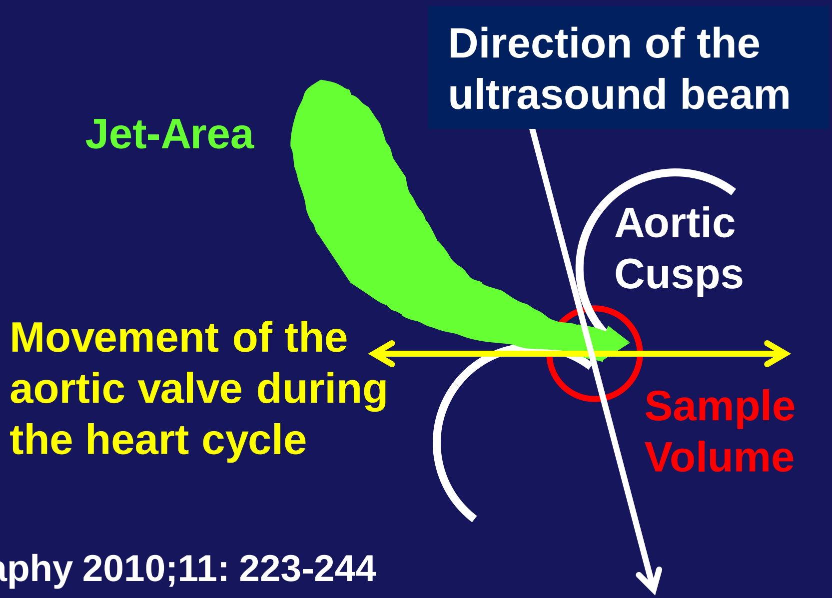
Echocardiographic Assessment of Aortic Regurgitation



Key point
The CW Doppler density of the AR jet does not provide useful information about the severity of AR. The assessment of the pressure half-time requires good Doppler beam alignment. A careful probe angulation is often needed. Because this parameter is influenced by chamber compliance and chamber pressures, it serves only as a complementary finding for the assessment of AR severity.

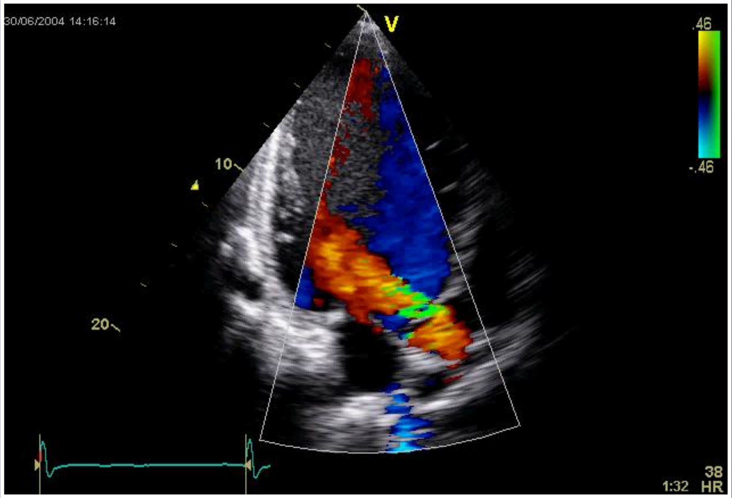
The intensity of the AR jet is extremely dependent on methodological factors (like PHT method). Thus, this approach of grading the AR severity is not always feasible and reliable.



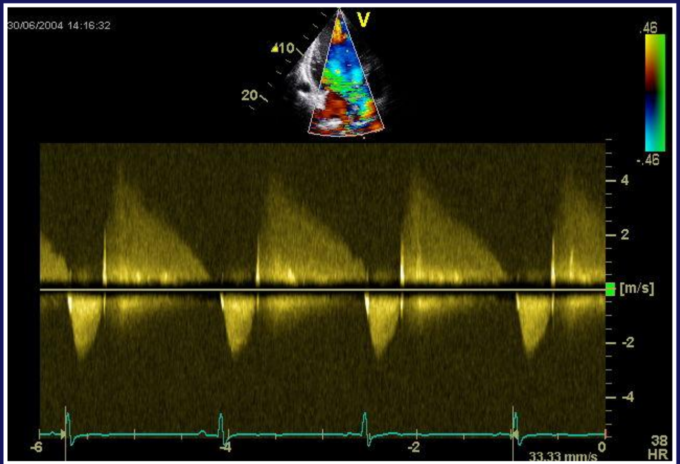


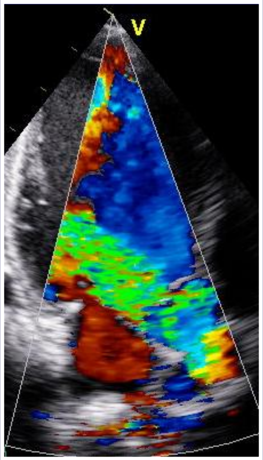
according to Lancelotti et al., Eur J Echocardiography 2010;11: 223-244

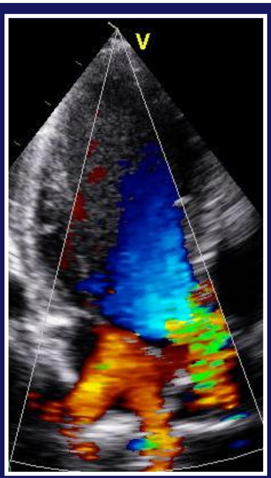
Semiquantitative Approach for AR-Grading: The „Pressure Half Time“-Method

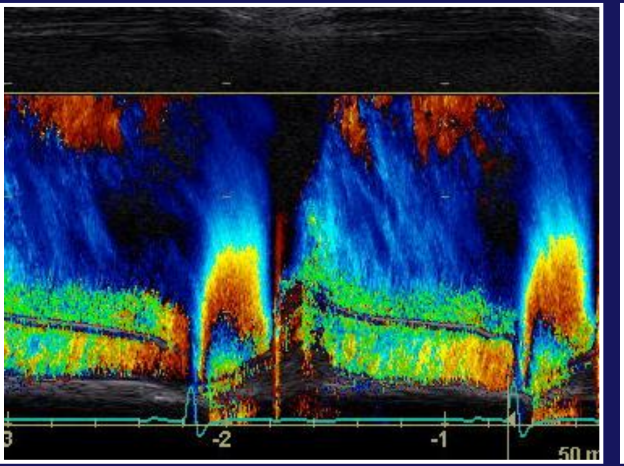


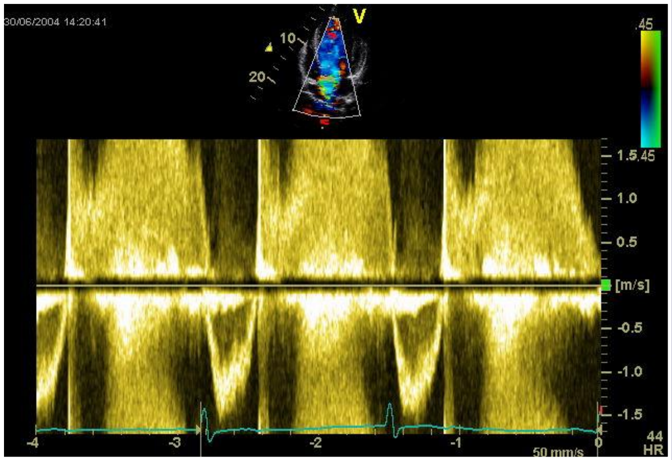
The alignement of the regurgitant jet has to be guaranteed during the complete diastole.

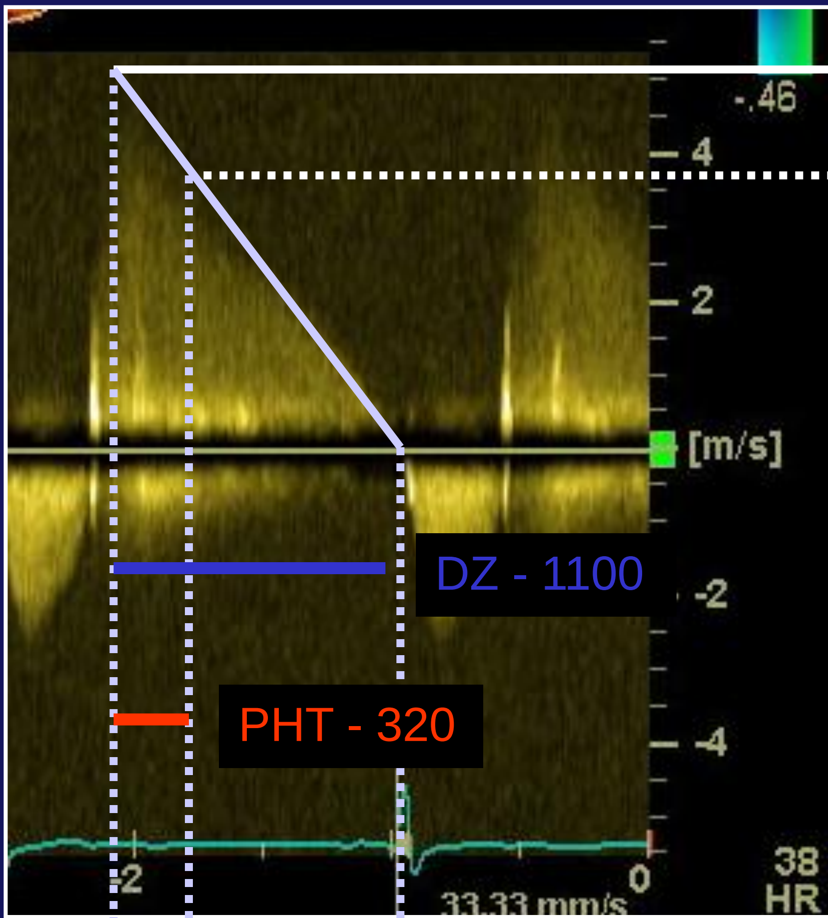












5m/sec

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

3.54 m/sec

DT x 0,29 = PHT [msec]

DT – deceleration time
PHT – „Pressure Half Time“

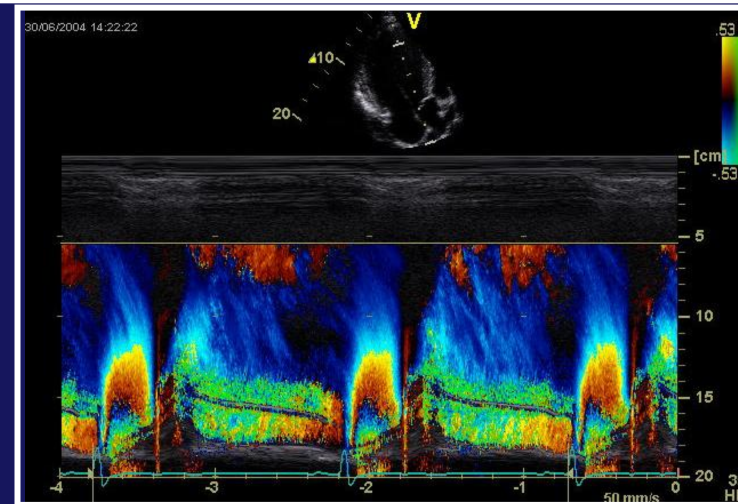
Example: 1100 x 0.29 = 320 msec
According to PHT moderate AR,
but due to the shape of the signal it is a severe AR, because DT is less than diastole.

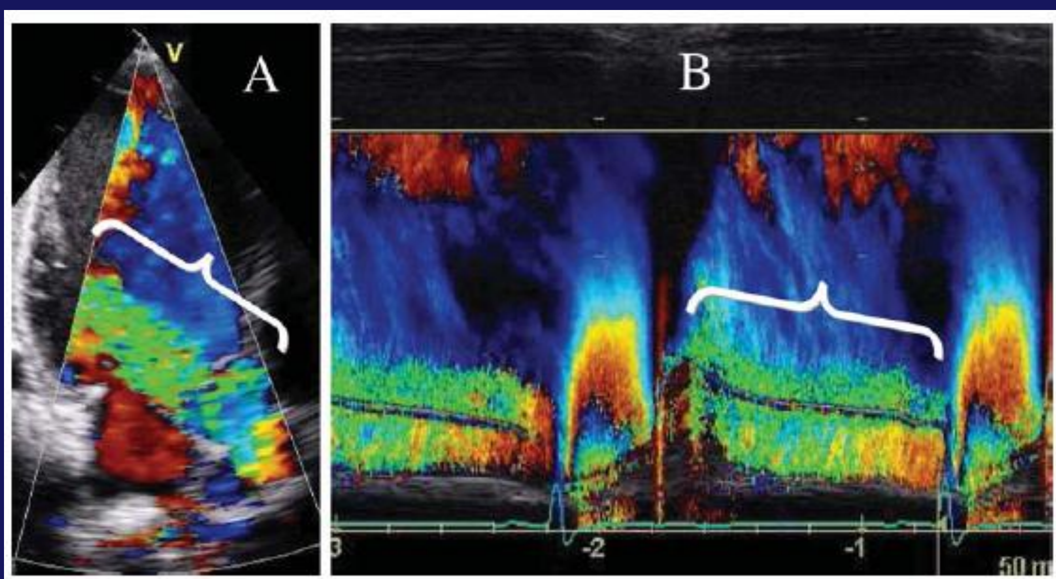
If DT < diastole, it can be assumed that enddiastolic aortic pressure is equal to enddiastolic atrial pressure.

Mild AR	- PHT > 500 msec
Moderate AR	- PHT 200 – 500 msec
Severe AR	- PHT < 200 msec

Echocardiographic Assessment of Aortic Regurgitation

The documentation of the correct alignement of the regurgitant signal can be checked by color-coded M-Mode.
If the turbulences of the aortic regurgitation are visible during the complete diastole, the alignement of the regurgitation is correct.
In addition a severe aortic regurgitation is likely.





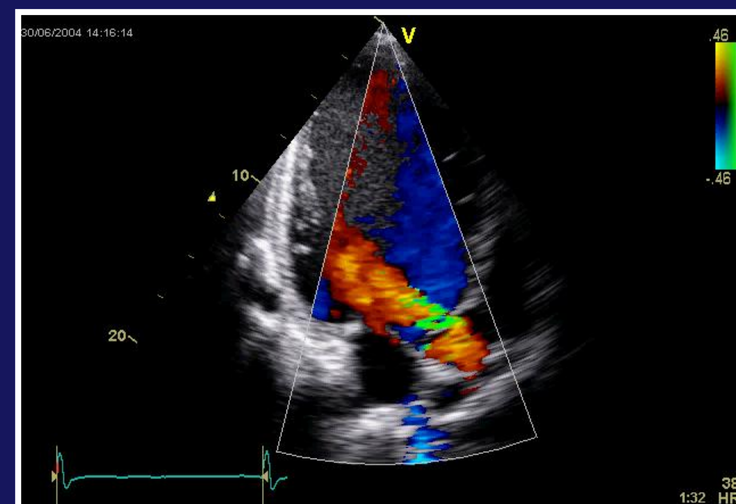


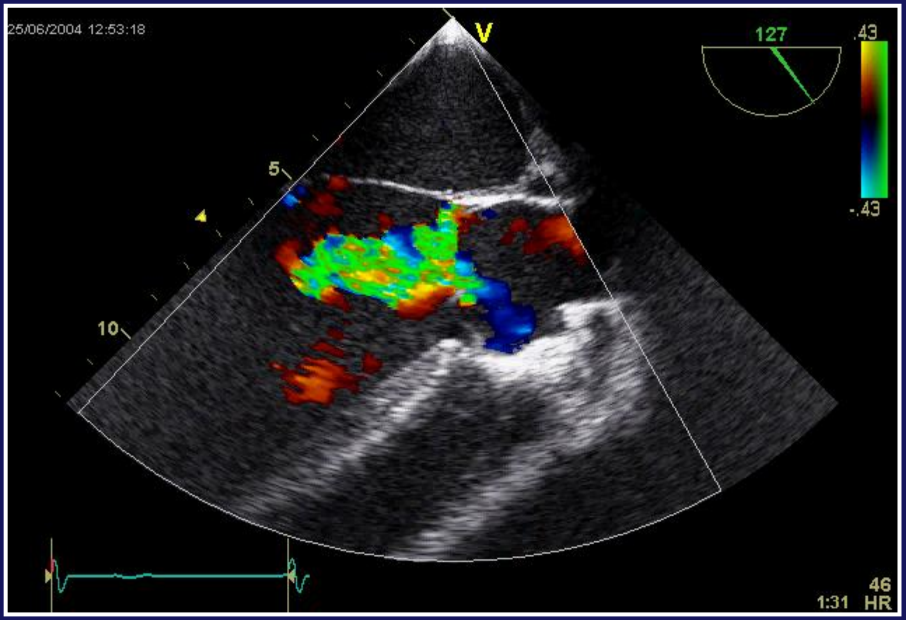
Figure 7 (A) Colour Doppler showing a severe aortic regurgitation; (B) colour-coded M-mode depicting the time dependency of flow signal during the heart cycle.

according to Lancelotti et al., Eur J Echocardiography 2010;11: 223-244

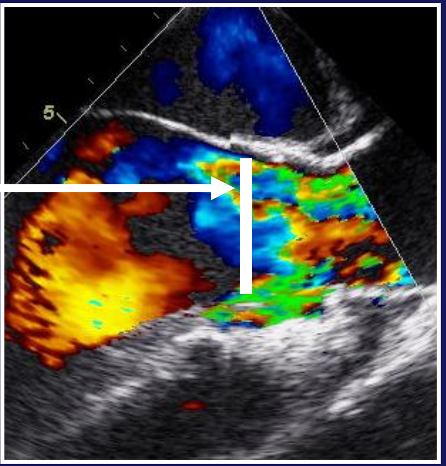
Semiquantitative Approach for AR-Grading: Diameter-Ratio of Proximal AR-Jet-Width in Relation to the LVOT-Width

Mild AR - Ratio < 30%
Moderate AR - Ratio = 30-50%
Severe AR - Ratio > 50%

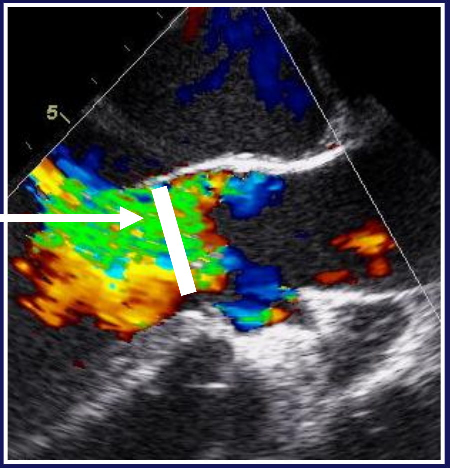
Obvious errors induced by the arrangement of the commissures



Diameter LVOT = 33mm

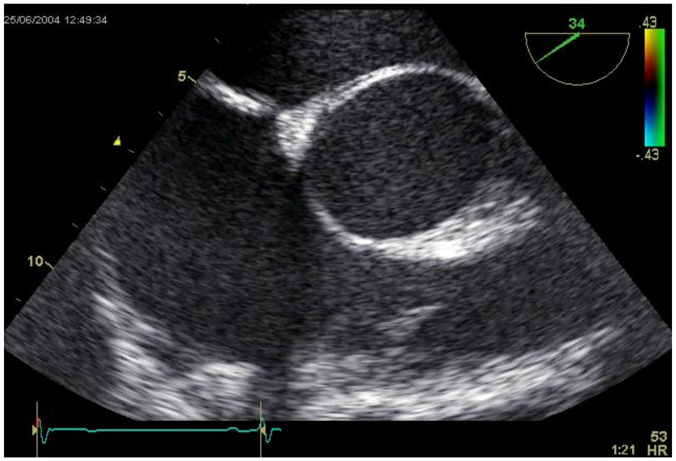


Diameter prox. AR-Jet-Width = 27 mm



$D_{AR\text{-}Jet}/D_{LVOT}$ = 82%

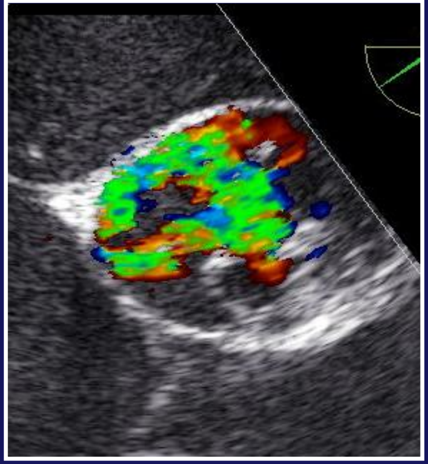
Semiquantitative Approach for AR-Grading: Area-Ratio of Proximal AR-Jet-Area in Relation to the LVOT-Area

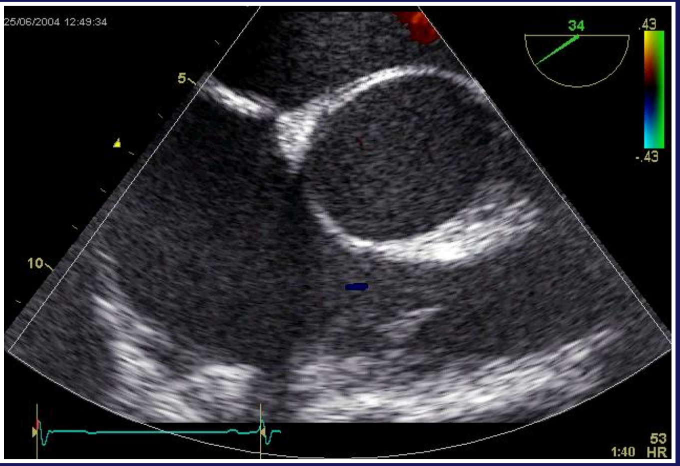


Mild AR - Ratio < 30%
Moderate AR - Ratio = 30-50%
Severe AR - Ratio > 50%

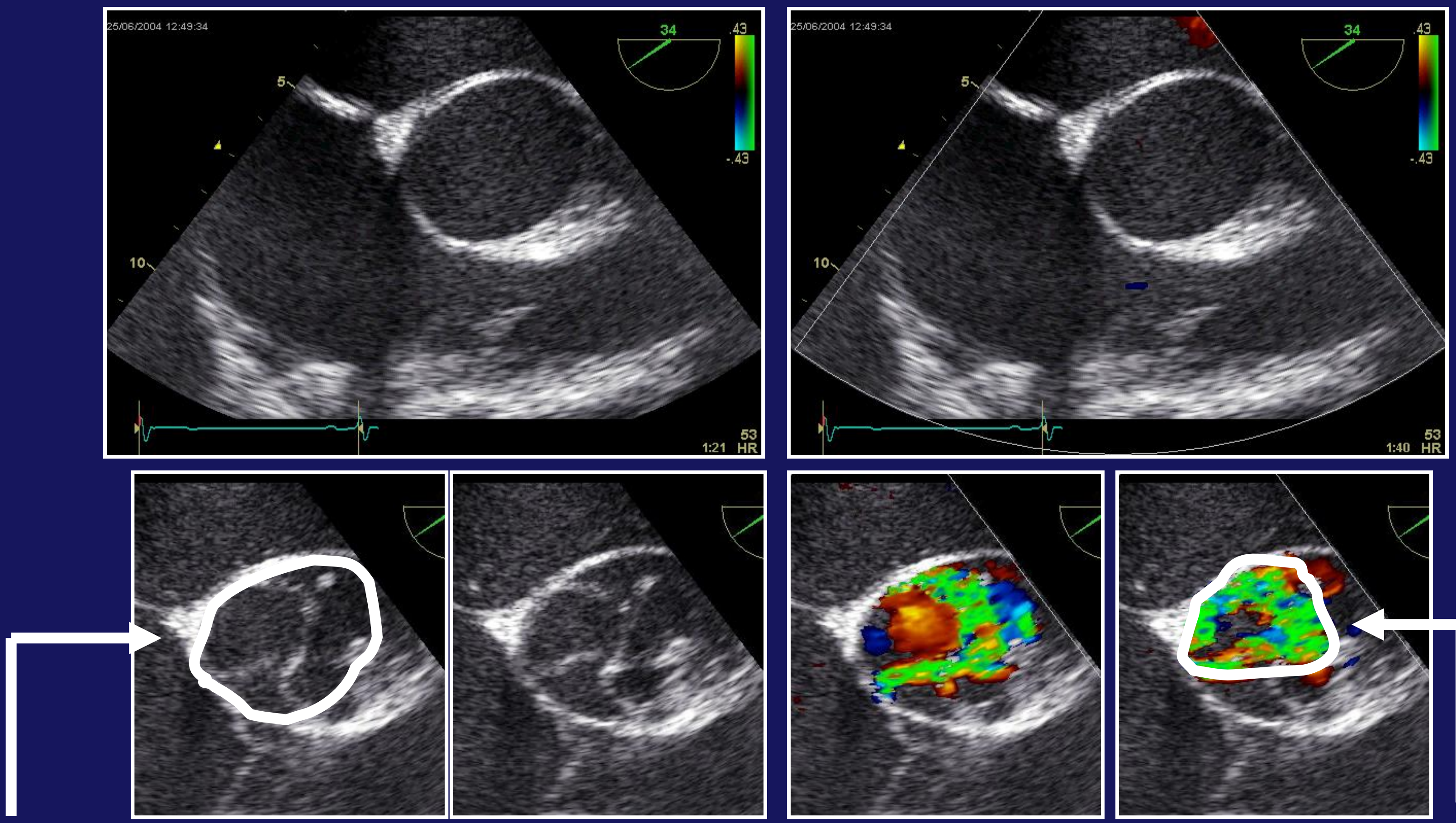
This approach is better than the diameter-ratio due to a minor interobserver variability.

Area of the proximal AR-jet displayed by a short axis view = EROA (effective regurgitation orifice area by planimetry)
Cause of the valvular lesion in this case:
⇒ prolapse and anulus dilatation





Semiquantitative Approach for AR-Grading: Area-Ratio of Proximal AR-Jet-Area in Relation to the LVOT-Area



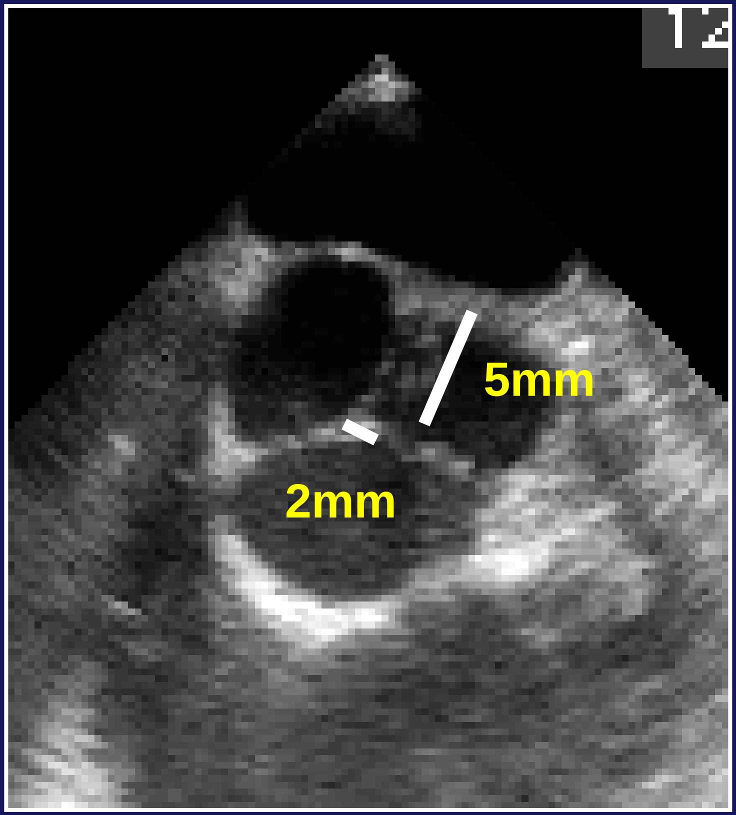
Area of the LVOT
= 280 mm^2

Ratio $Area_{AR\text{-}Jet}/Area_{LVOT}$
= 50%

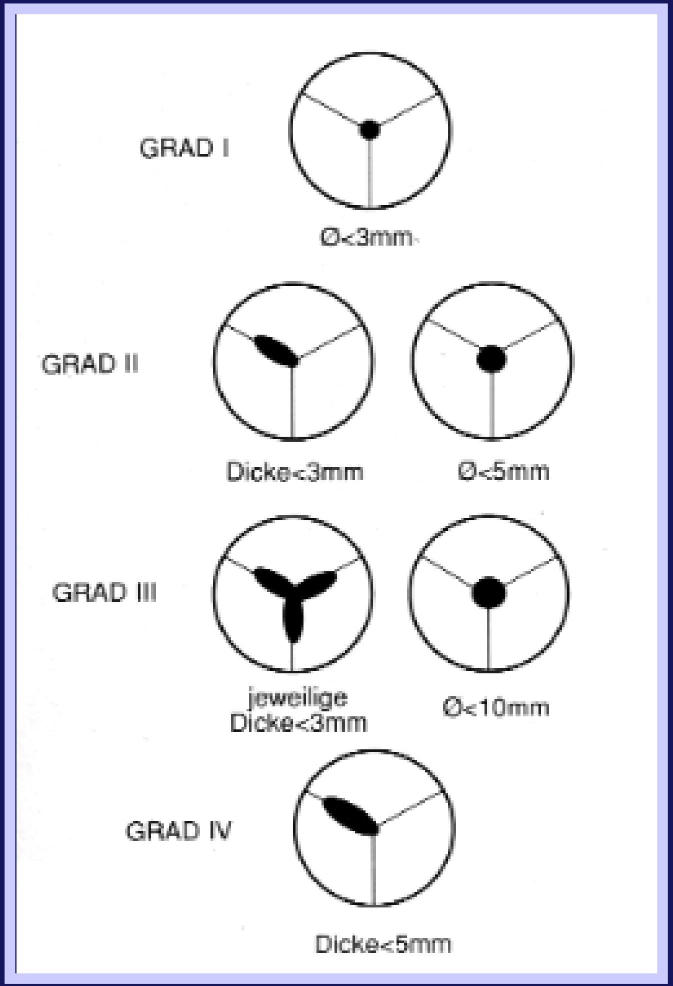
Area of the prox. AR-Jet
= 140 mm^2

Semiquantitative Approach for AR-Grading:

Simplified scheme for regurgitant orifice areas in short axis views



Ratio Area$_{AR\text{-}Jet}$/Area$_{LVOT}$
If Ratio > 50% - severe AR

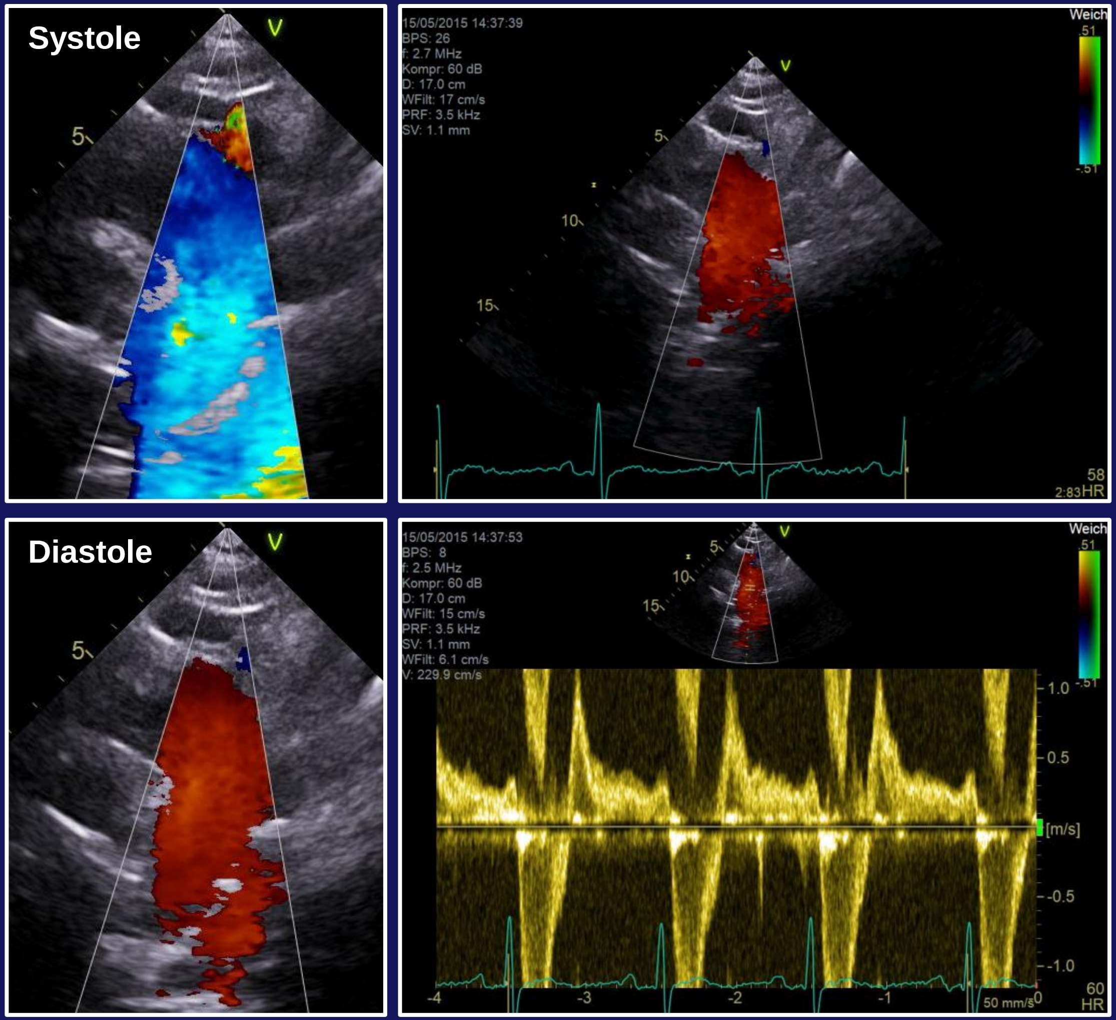


according to Fehske: Praxis der Doppler-Echokardiographie

Quantitative/ Semiquantitativ Approach for AR-Grading: Diastolic flow reversal in the descending aorta

Holodiastolic flow reversal is at least a moderate AR. If enddiastolic reverse velocity is > 0.2 (0.3) m/s, a severe ARcan be assumed. – But

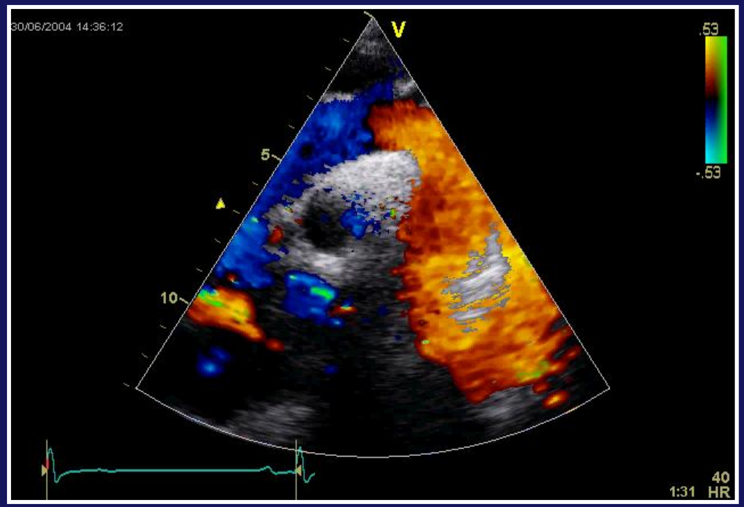
Turbulences in the aortic arch and the descending aorta cause often misinterpretation of the Doppler signals.
Flow reversal is extremly age-dependent due to the „Windkessel"- function of the aorta.

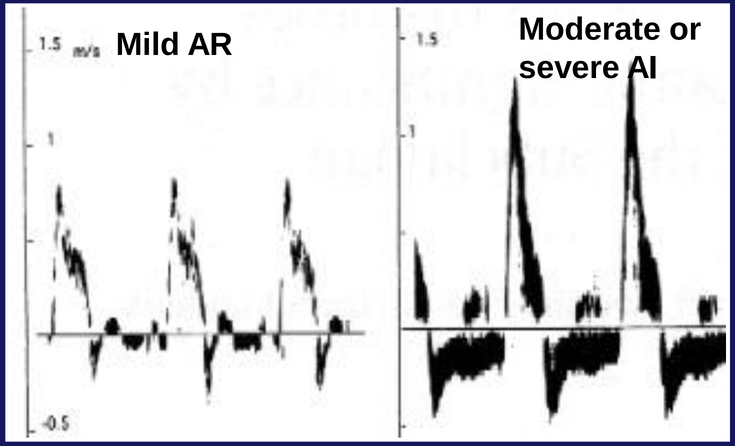


Quantitative/ Semiquantitativ Approach for AR-Grading: Diastolic flow reversal in the descending aorta

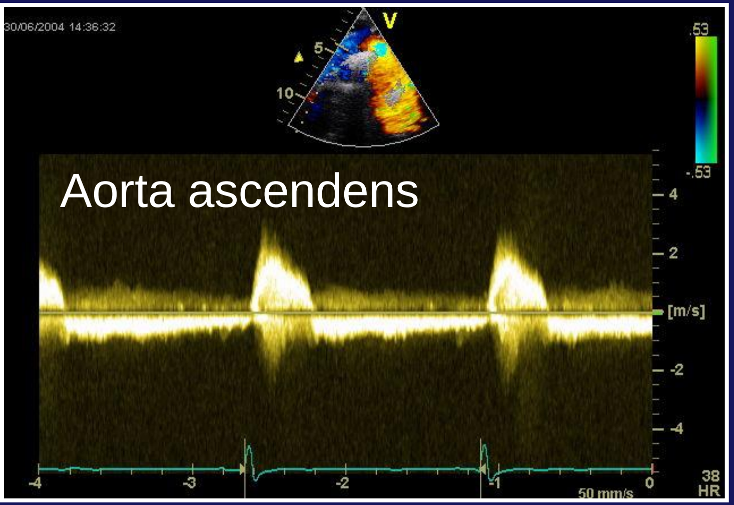
Young patients are able to compensate diastolic flow revesal completely.

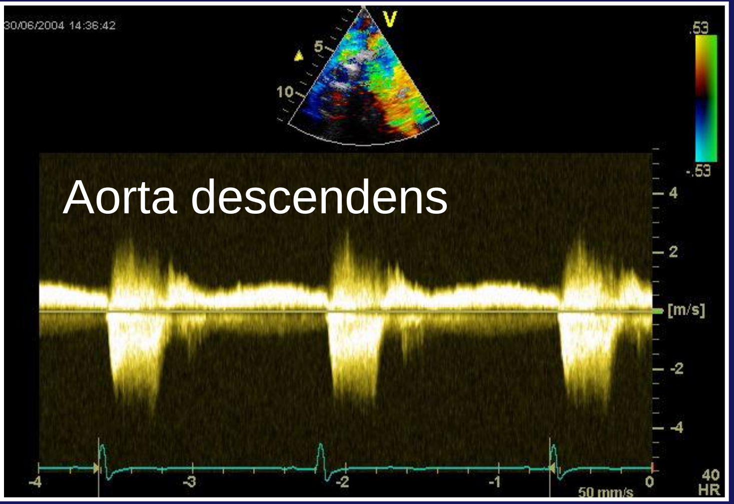
A better standardization of diastolic flow reversal can be achieved by documenting the flow profile of the left subclavian artery.





according to Omran et al., The Journal of Heart Valve Disease 1995;4:166-170





Echocardiographic Assessment of Aortic Regurgitation

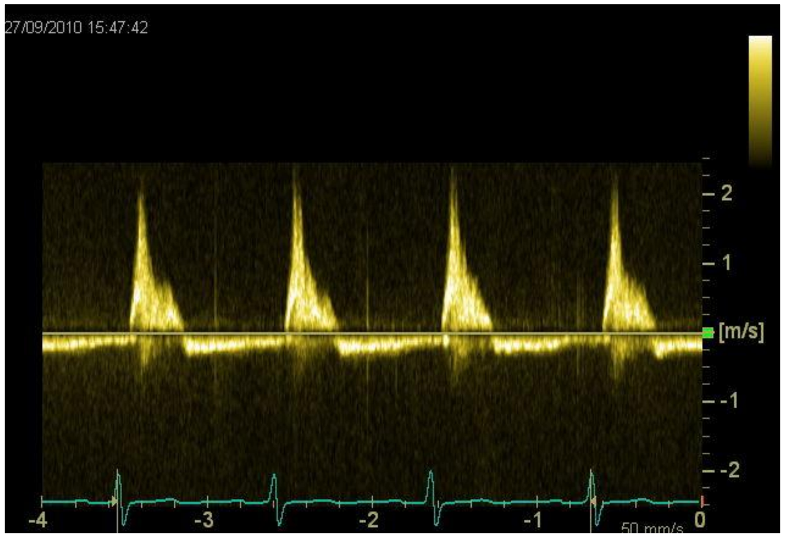
Key point

The measurement of the diastolic flow reversal in the descending aorta is recommended, when assessable. It should be considered as the strongest additional parameter for evaluating the severity of AR.

Numerical criteria for a svere aortic regurgitation:

1. $VTI_{dia}/VTI_{sys} > 50\%$
2. $V_{dia}/V_{sys} > 0.3$
3. $VTI_{dia} > 25$ cm

according to Omran et al.,
The Journal of Heart Valve Disease 1995;4:166-170



Holodiastolic flow reversal in the left subclavian artery – at least moderate AR

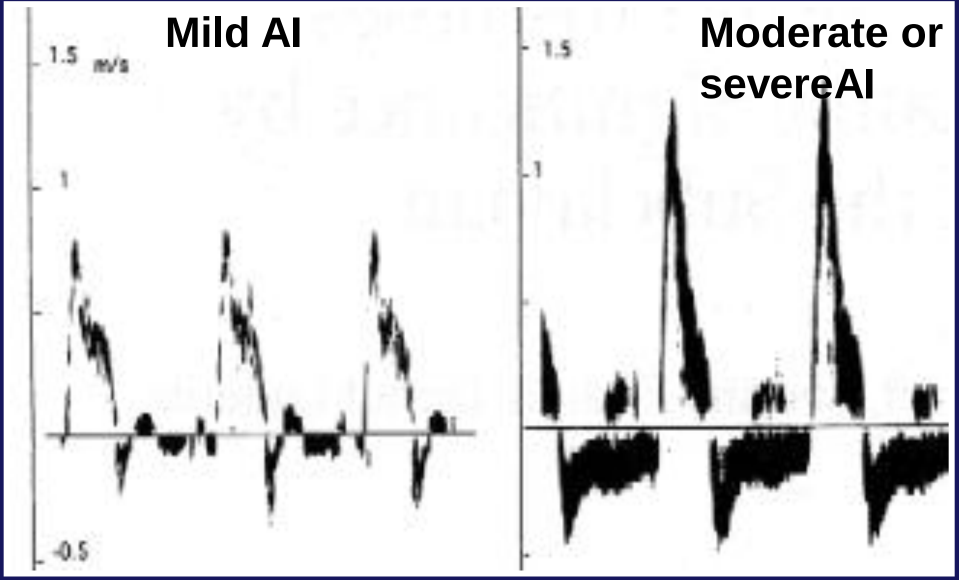


Table I: Maximum diastolic velocity (D), diastolic velocity time integral (dVTI), the ratio of diastolic and systolic maximum velocities (D/S) and the ratio of diastolic and systolic Velocity Time Integrals (RF) in the subclavian artery velocity curve.

Patients	D (cm/sec)	dVTI	D/S	RF (%)
Controls	-27 ± 10	-15 ± 14	0.1 ± 0.09	14 ± 12
AR 1+/2+	-25 ± 7	- 18 ± 13	0.1 ± 0.06	18 ± 15
AR 3+/4+	*-44 ± 11	*-90 ± 30	*0.52 ± 0.1	*75 ± 19

Insignificant (1+/2+) versus significant forms of aortic regurgitation (3+/4+ AR)* p<0.05

Echocardiographic Assessment of Aortic Regurgitation

Every grading of aortic regurgitation by qualitative or semiquantitative parameters is not sufficient in patients, in whom surgical interventions are discussed.
A quantitative approach should be performed and is mandatory.

For a quantitative approach in echocardiography all findings have to be consistent.

Table 2 Grading the severity of AR

Parameters	Mild	Moderate	Severe
Qualitative			
Aortic valve morphology	Normal/Abnormal	Normal/Abnormal	Abnormal/flail/large coaptation defect
Colour flow AR jet width[a]	Small in central jets	Intermediate	Large in central jet, variable in eccentric jets
CW signal of AR jet	Incomplete/faint	Dense	Dense
Diastolic flow reversal in descending aorta	Brief, protodiastolic flow reversal	Intermediate	Holodiastolic flow reversal (end-diastolic velocity >20 cm/s)
Semi-quantitative			
VC width (mm)	<3	Intermediate	>6
Pressure half-time (ms)[b]	>500	Intermediate	<200
Quantitative			
EROA (mm^2)	<10	10–19; 20–29[c]	≥30
R Vol (mL)	<30	30–44; 45–59[c]	≥60
+LV size[d]			

Only the regurgitant fraction is the correct quantitative parameter.

according to Lancelotti et al., Eur J Echocardiography 2010;11: 223-244

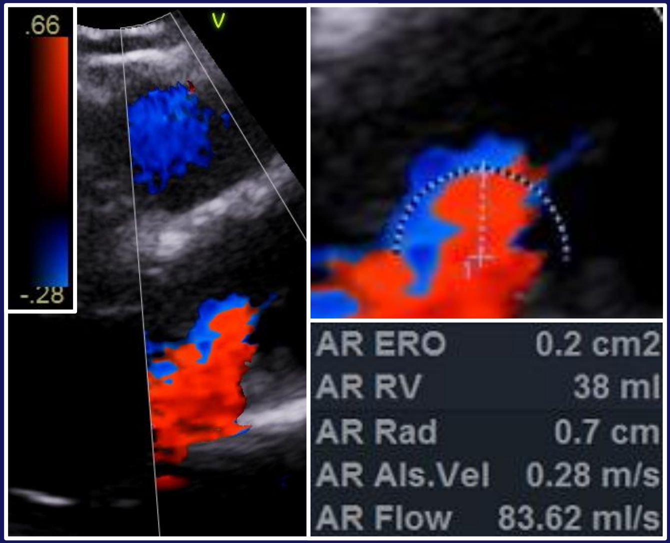
Echocardiographic Assessment of Aortic Regurgitation

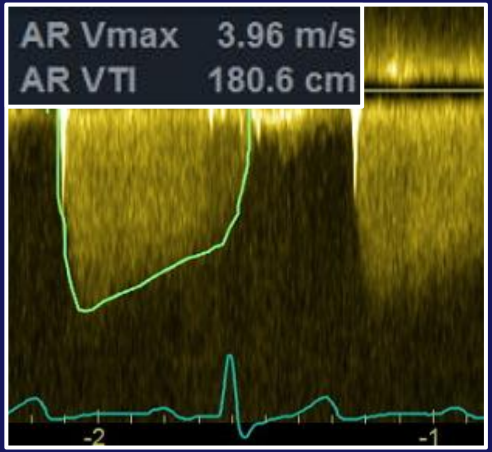
Despite I am co-author of this recommendation, I do not agree with the PISA-method in AR.

Key point

The PISA method is acceptably reproducible in mitral regurgitation, TR, and AR. The following steps are recommended: (1) optimize the colour flow imaging (Variance OFF) with a small angle from an apical or parasternal window, (2) expand the image using zoom or regional extension selection, (3) shift the colour flow zero baseline towards the regurgitant jet direction to obtain a hemispheric PISA, (4) use the cine mode to select the most satisfactory hemispheric PISA, (5) display the colour Doppler off when necessary to visualize the regurgitant orifice, (6) measure the PISA radius using the first aliasing, and (7) measure the regurgitant velocity.

The PISA method has several advantages. Instrumental and haemodynamic factors do not seem to substantially influence flow quantification by this approach. The aetiology of regurgitation or the presence of concomitant valvular disease does not affect the regurgitant orifice area calculation. Although less accurate, this method can still be used in eccentric jet without significant distortion in the isovelocity contours.[15]

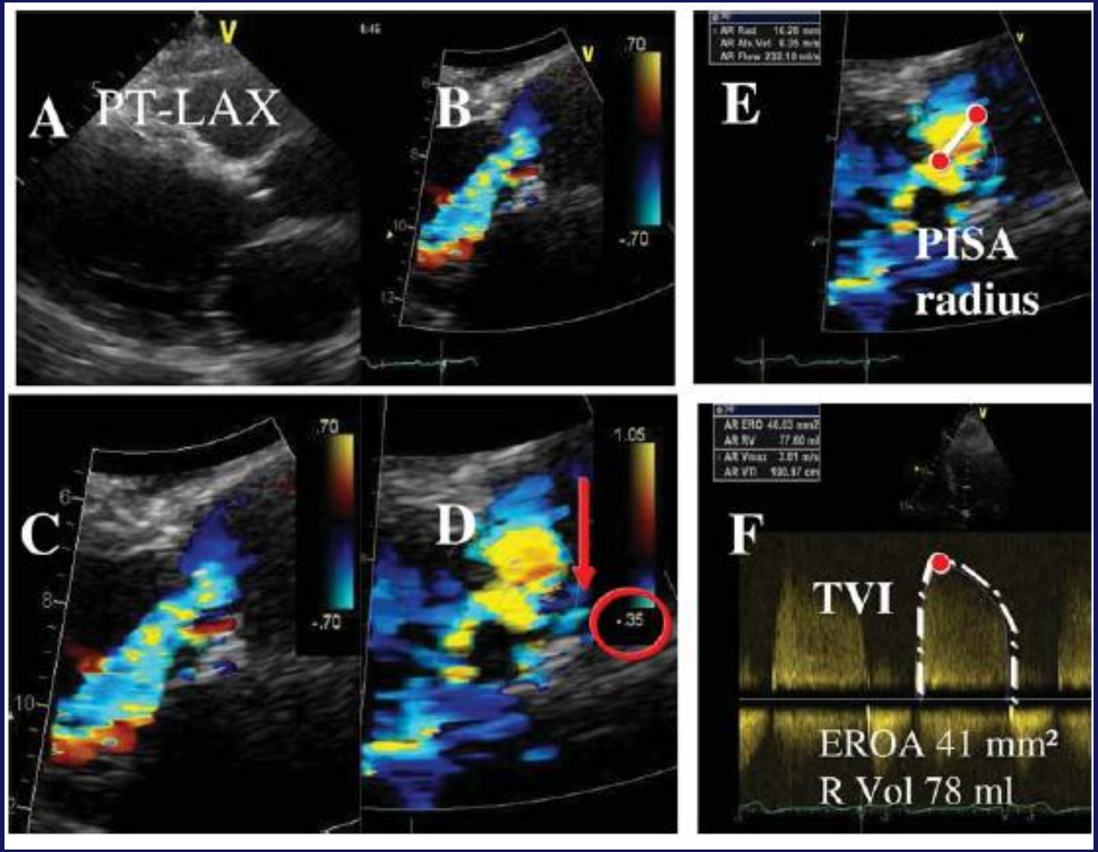




Despite its methodological limitations, the PISA method is a quantitative approach of AR-grading.

according to Lancelotti et al., Eur J Echocardiography 2010;11: 223-244

Echocardiographic Assessment of Aortic Regurgitation



Key point

When feasible, the PISA method is highly recommended to quantify the severity of AR. It can be used in both central and eccentric jets. In eccentric AR jets, we recommend to use the parasternal long-axis view to evaluate the flow convergence zone. An EROA $\geq$30 mm^2 or an R Vol $\geq$60 mL indicates severe AR.

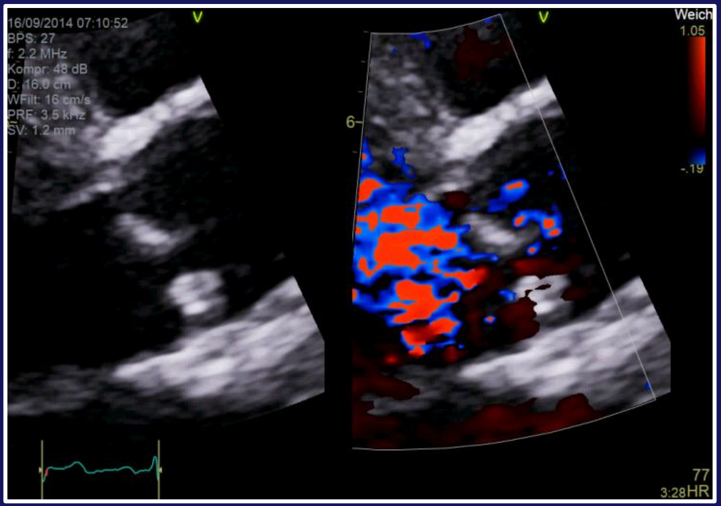
But:

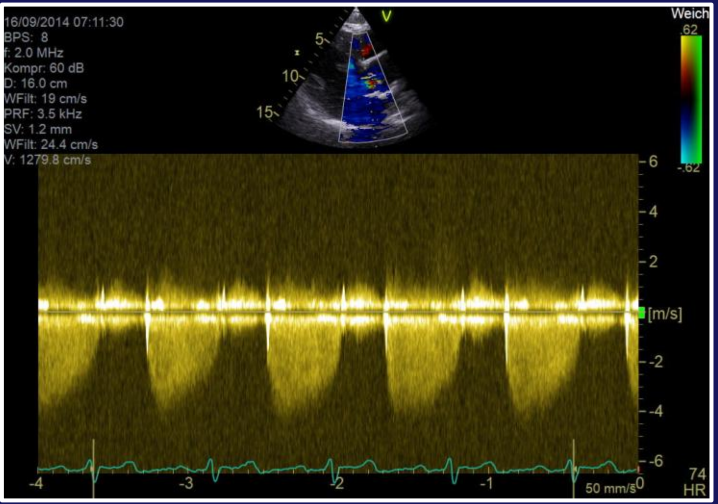
1. The Vena contracta-method is only feasible, if the jet orign is dot-shaped and spherical.
2. The proximal convergence zones are only well depicted, if Doppler angulation is correct.
3. If not, EROA and regurggitant volume willbe overestimated.

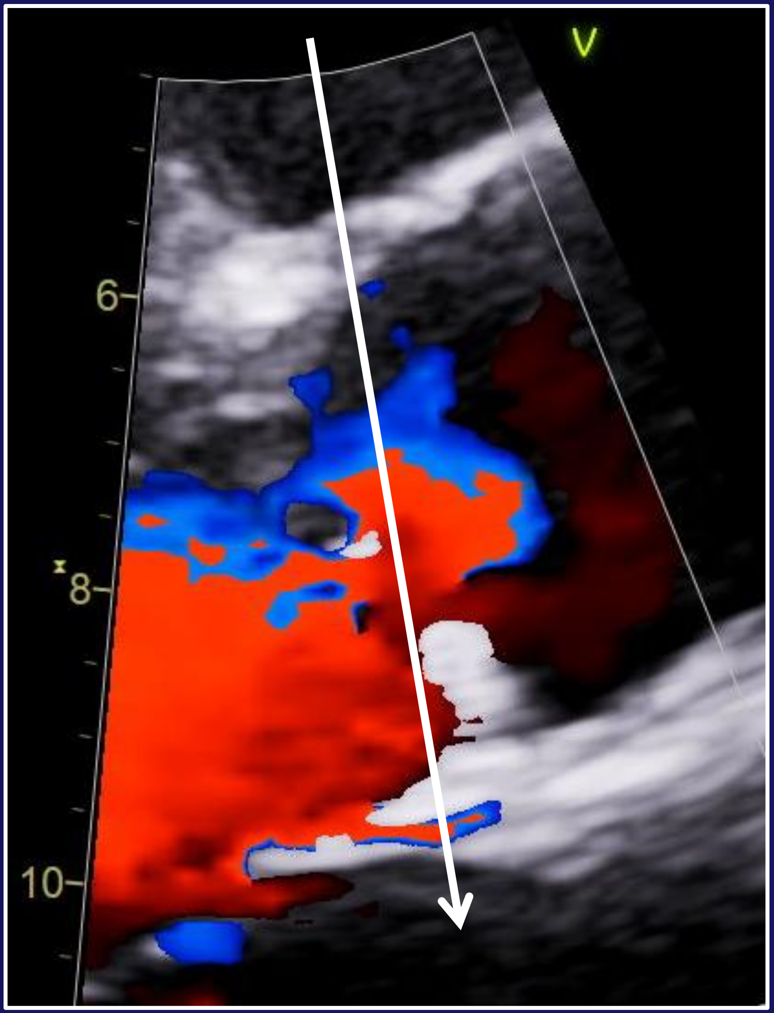
Figure 10 Quantitative assessment of aortic regurgitation (AR) severity using the proximal isovelocity surface area (PISA) method. Stepwise analysis of AR: (*A*) parasternal long-axis view (PT-LAX); (*B*) Colour flow display; (*C*) zoom of the selected zone; (*D*) downward shift of zero baseline to obtain a hemispheric PISA; (*E*) measure of the PISA radius using the first aliasing; (*F*) continuous-wave Doppler of AR jet allowing calculation the effective regurgitant orifice area (EROA) and regurgitant volume (R Vol). TVI, time–velocity integral.

according to Lancelotti et al., Eur J Echocardiography 2010;11: 223-244

Quantitative Approach for AR-Grading:
The PISA method – determination of EROA and RV







PISA method is only reliable for AR grading, if proximal convergence zones are well visualized by correct Doppler angulation (less than 30° deviation of the alignment).

Aortic Regurgitation:

quantitative approach to determine regurgitant volume and regurgitant fraction

$$RF_{AV} = \frac{100 \times (SV_{LVOT} - SV_{MV})}{SV_{LVOT}}$$

$$RF_{AV} = \frac{100 \times (SV_{LVOT} - SV_{RVOT})}{SV_{LVOT}}$$

RF_{AV} = regurgitant fraction

SV_{LVOT} = stroke volume determined by $D_{LVOT}^2 \times VTI_{LVOT}$

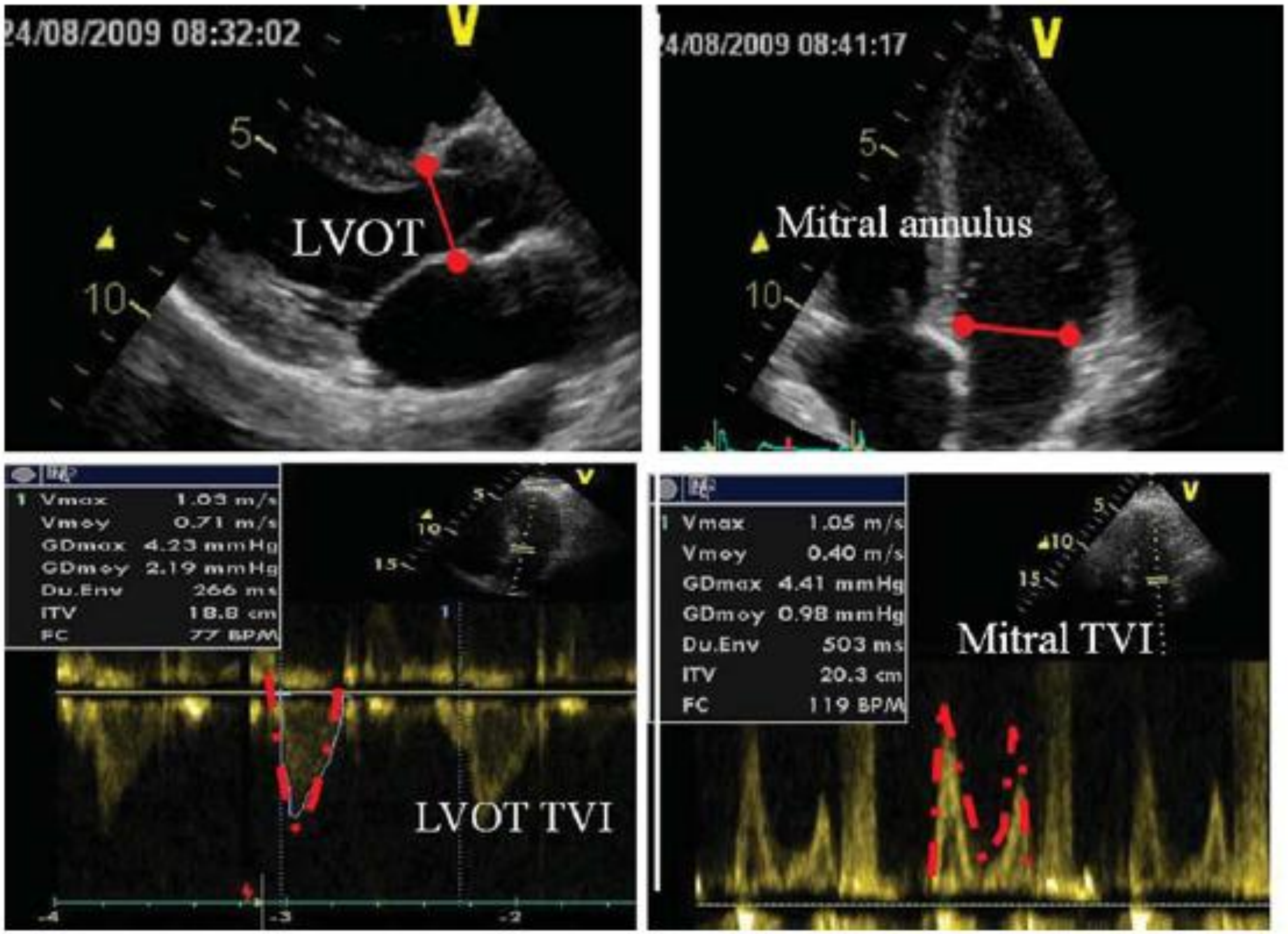
SV_{MV} = stroke volume determined by $D_{MV}^2 \times VTI_{MV}$

SV_{RVOT} = stroke volume determined by $D_{RVOT}^2 \times VTI_{RVOT}$

$(SV_{LVOT} - SV_{MV})$ = regurgitant volume of aortic regurgitation

$(SV_{LVOT} - SV_{RVOT})$ = regurgitant volume of aortic regurgitation

Echocardiographic Assessment of Aortic Regurgitation

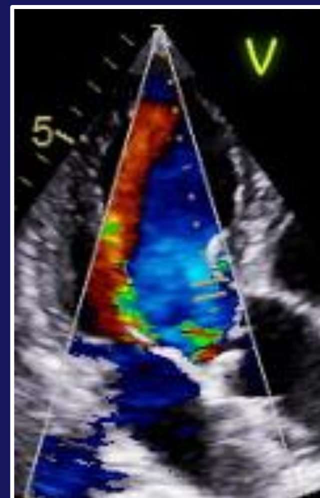


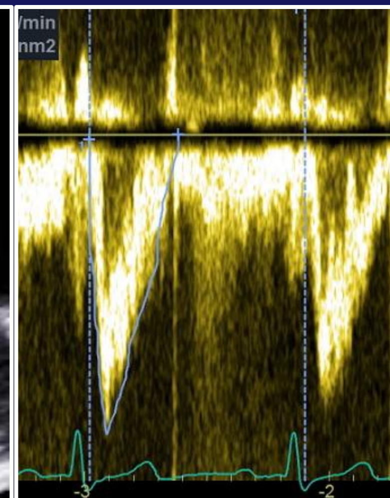
„A lot of methodological issues, which can be discussed in this figure of the recommendation paper.“
Thus –
prefer to determine the effective stroke volume by Doppler echocardiography using the RVOT- or PV- pw-signal.

according to Lancelotti et al., Eur J Echocardiography 2010;11: 223-244

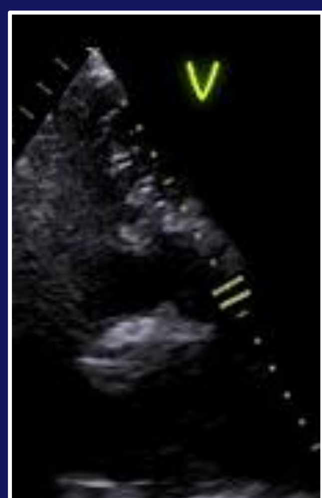
Figure 3 The quantitative assessment of aortic/pulmonary regurgitation severity by the Doppler volumetric method requires the measurement of the left ventricular outflow tract diameter (LVOT), the mitral annulus diameter and of two pulse wave velocity profiles (outflow tract and mitral inflow velocities). TVI, time–velocity integral.

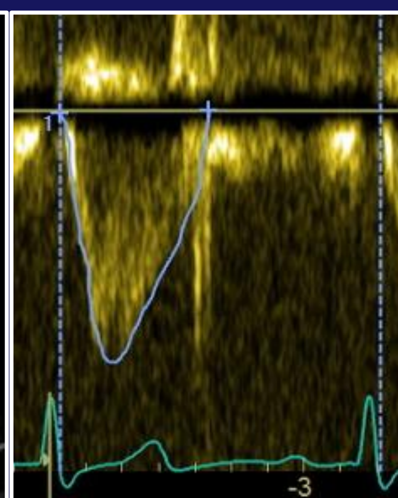
Quantitative Approach for AR-Grading: Total and effective stroke volume determination





LVOT Vmax	1.24 m/s
LVOT Vmean	0.72 m/s
LVOT maxPG	6.15 mmHg
LVOT meanPG	2.56 mmHg
LVOT VTI	26.2 cm
LVOT Env.Ti	364 ms
HR	68 BPM
LVSV Dopp	132 ml
LVSI Dopp	66.25 ml/m2
LVCO Dopp	8.98 l/min
LVCI Dopp	4.51 l/minm2



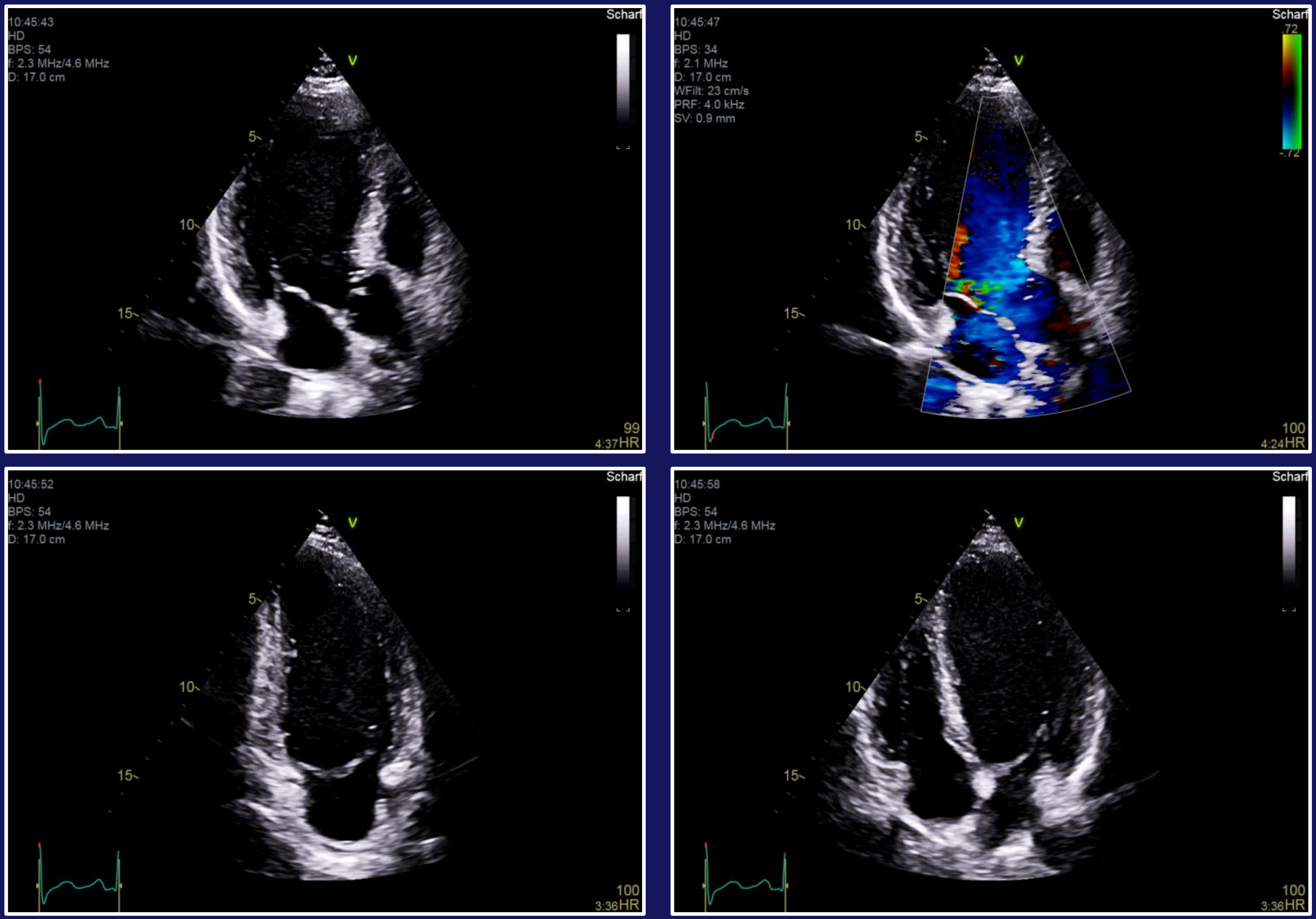


RVOT Vmax	0.69 m/s
RVOT Vmean	0.43 m/s
RVOT maxPG	1.91 mmHg
RVOT meanPG	0.90 mmHg
RVOT Env.Ti	410 ms
RVOT VTI	17.6 cm
HR	68 BPM
RVOT SV	101 ml
RVOT SI	50.78 ml/m2
RVOT CO	6.88 l/min
RVOT CI	3.46 l/minm2

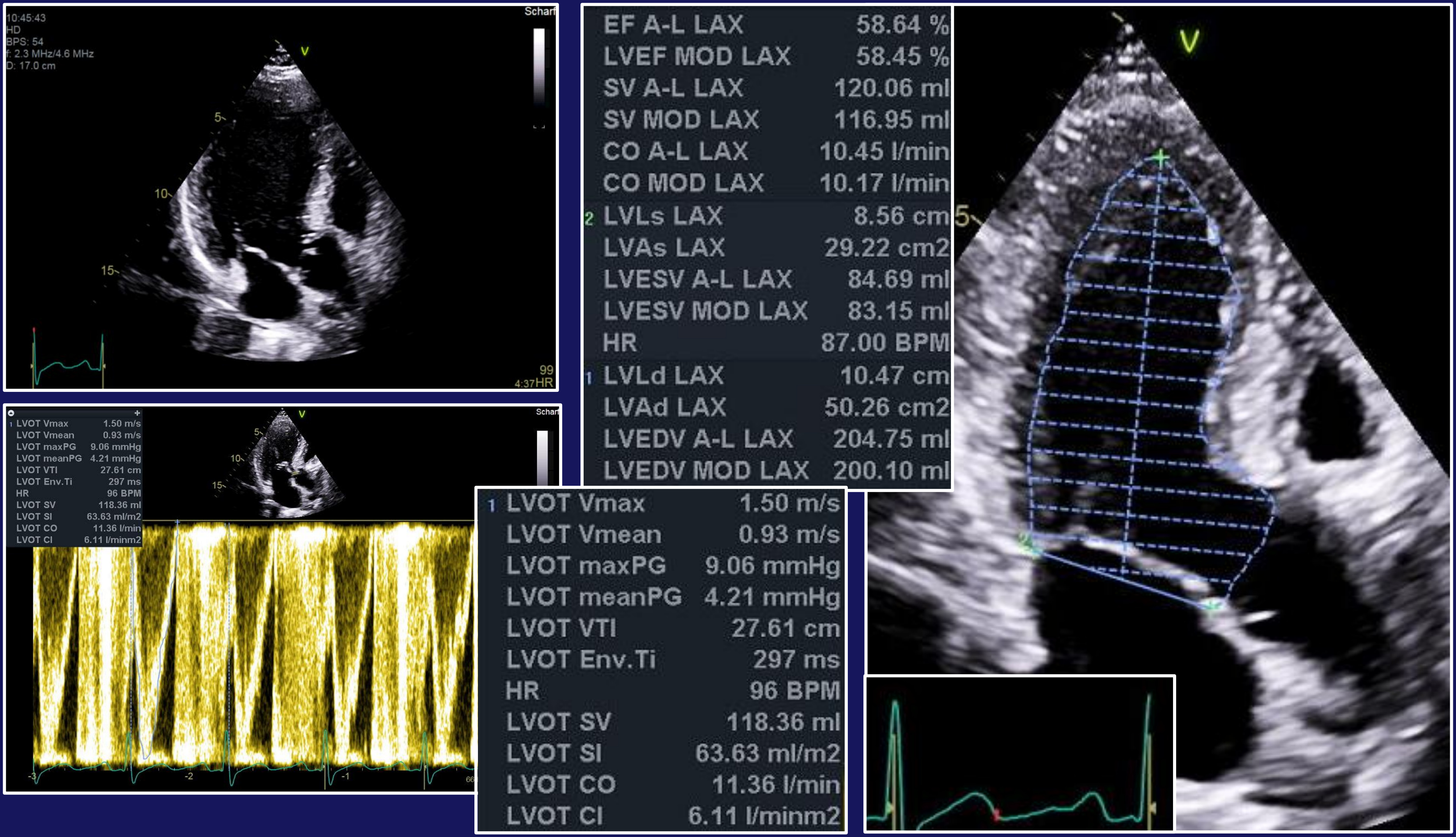
Compare total stroke volume by LVOT measurement with biplane planimetry of the LV.

Practical quantitative assessment of aortic regurgitation by echocardiography:

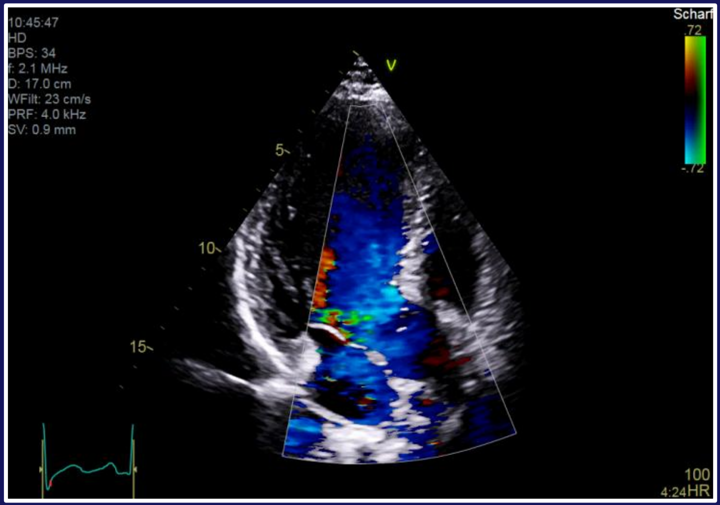
If the images are adaeqate, you can estimate very well.

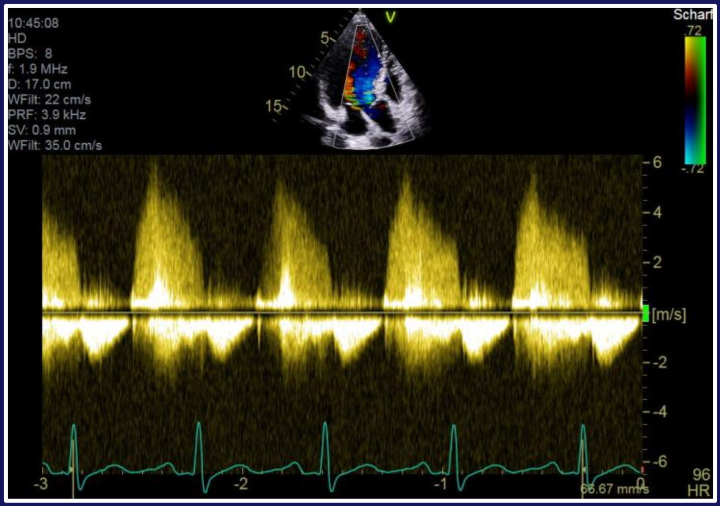


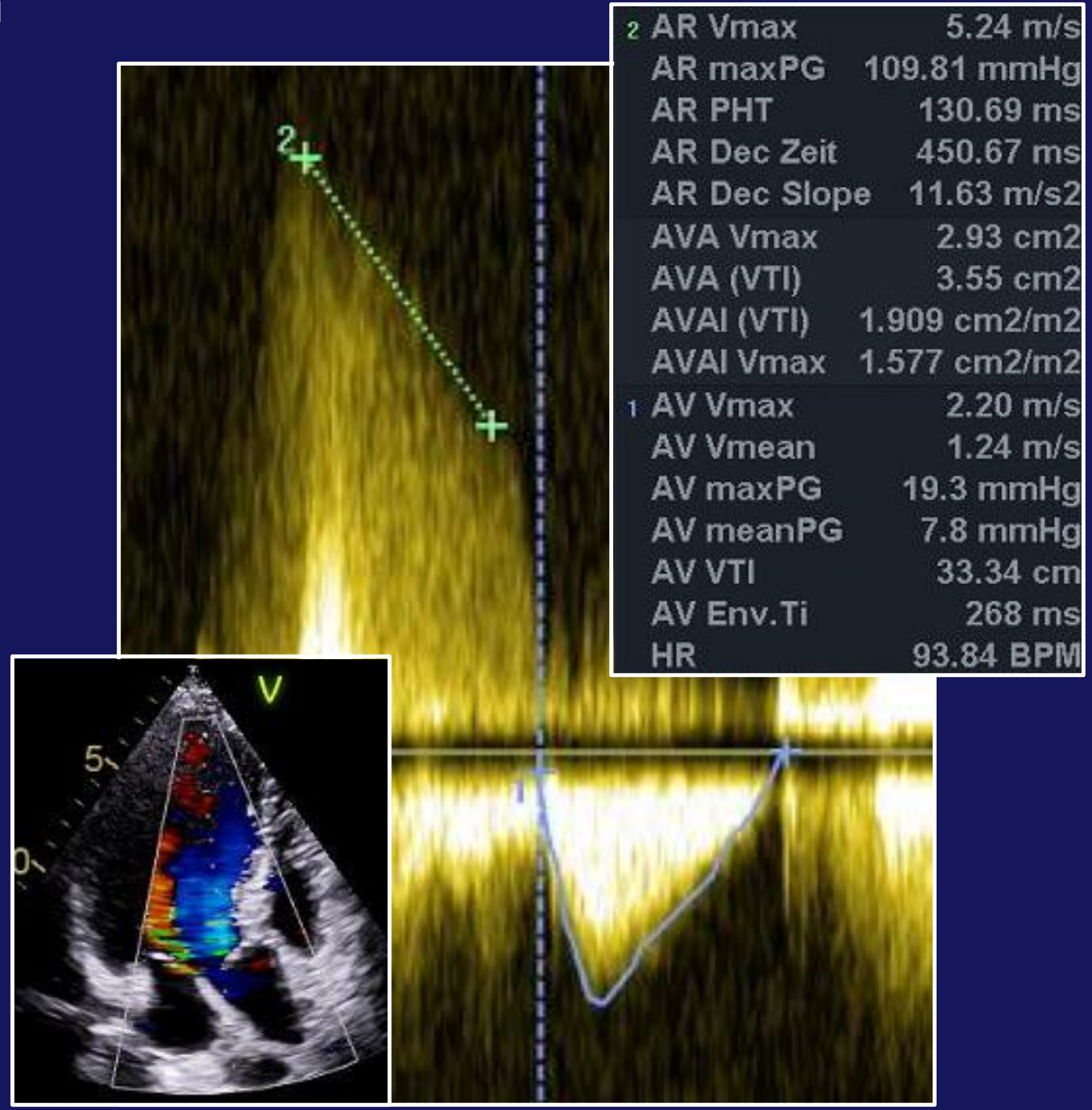
Echocardiographic Assessment of Aortic Regurgitation



Relevant aortic regurgitation due to PHT

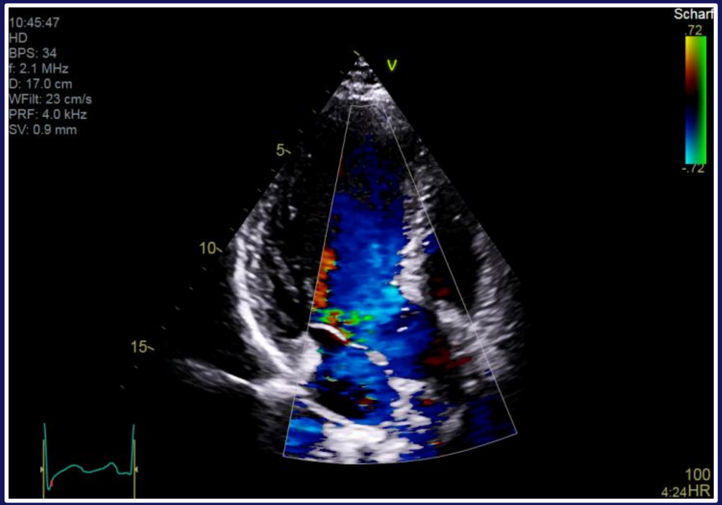


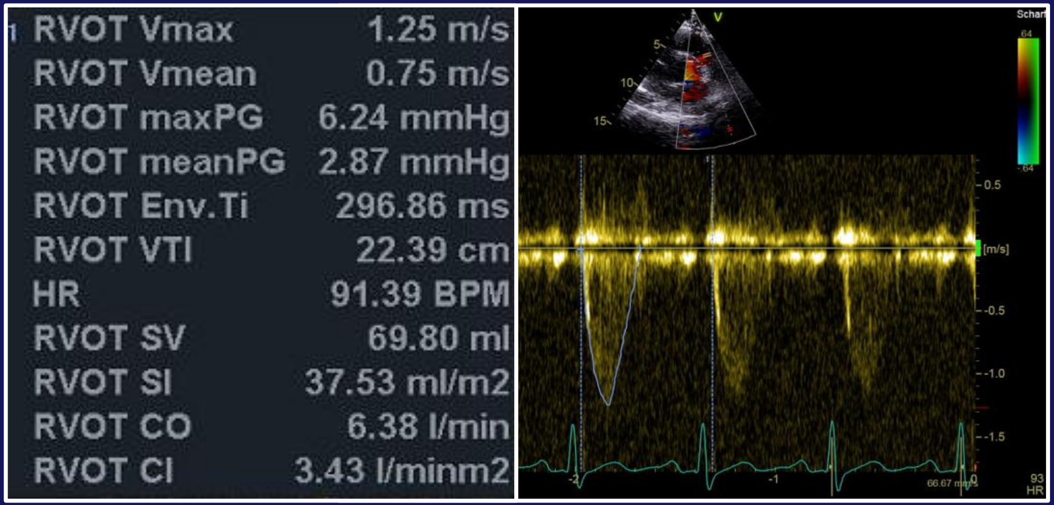


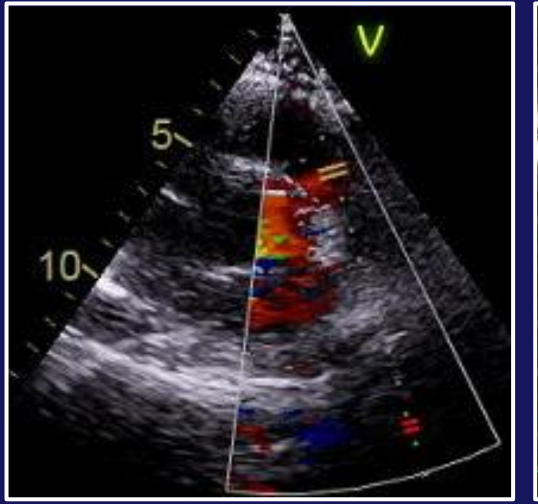


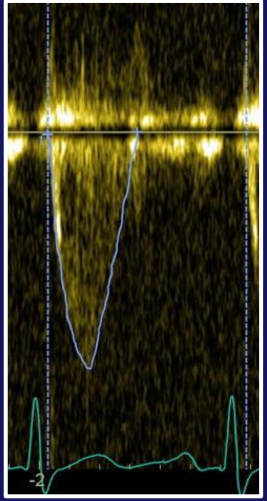
Relevant aortic regurgitation due to PHT

How to estimate?









Thus:

SV due to planimetry = total stroke volume
= 110 bis 120 ml

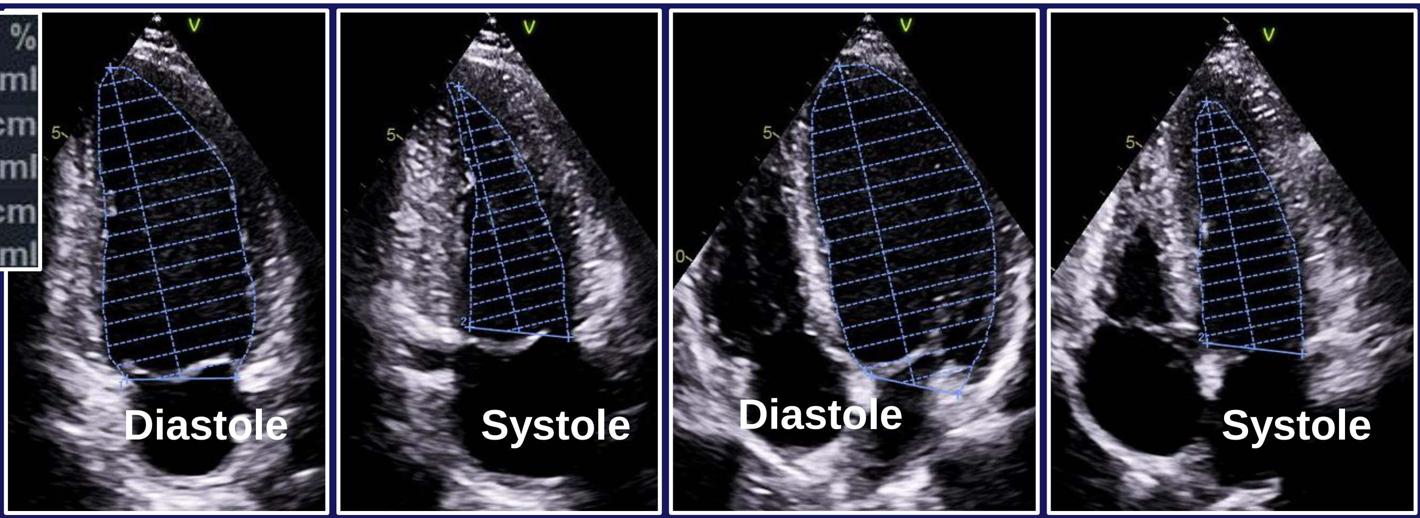
LVOT-SV = total stroke volume n
= 120 ml

RVOT-SV = effective stroke volume
= 70 ml

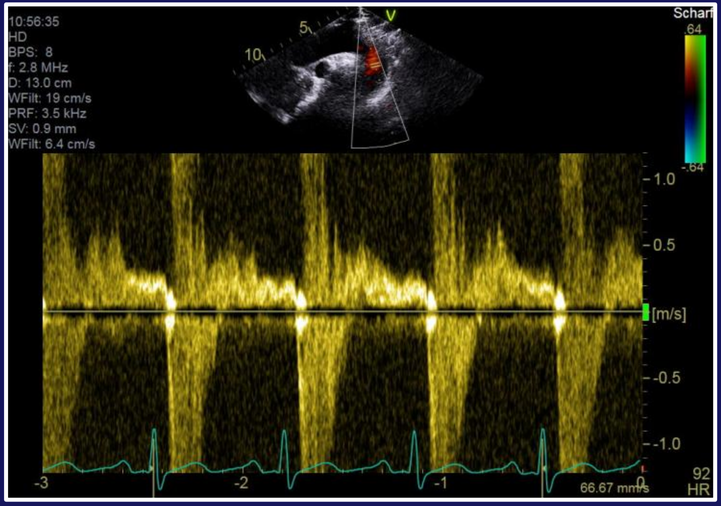
Regurgitant fraction = 42% (!!!)

Echocardiographic Assessment of Aortic Regurgitation

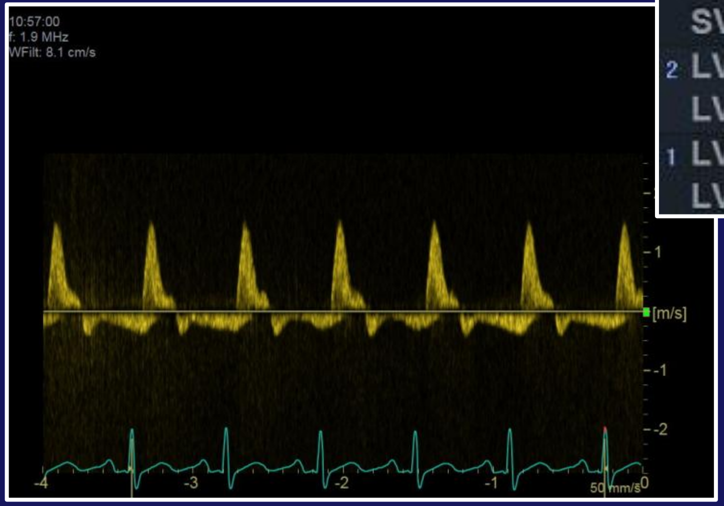
	LVEF MOD A4C	76 %
	SV MOD A4C	134 ml
2	LVLs A4C	8.3 cm
	LVESV MOD A4C	43 ml
1	LVLd A4C	10.8 cm
	LVEDV MOD A4C	177 ml



Descendens-Fluss mit enddiastolischer Rückfluss-Geschwindigkeit > 0.2 m/s



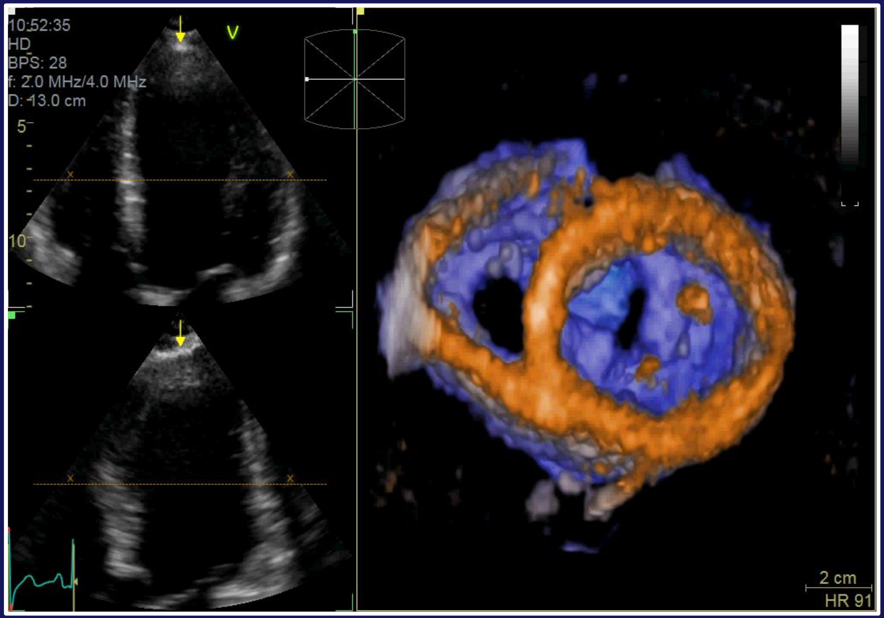
Subclavia-Fluss mit holodiastolischem Rückfluss

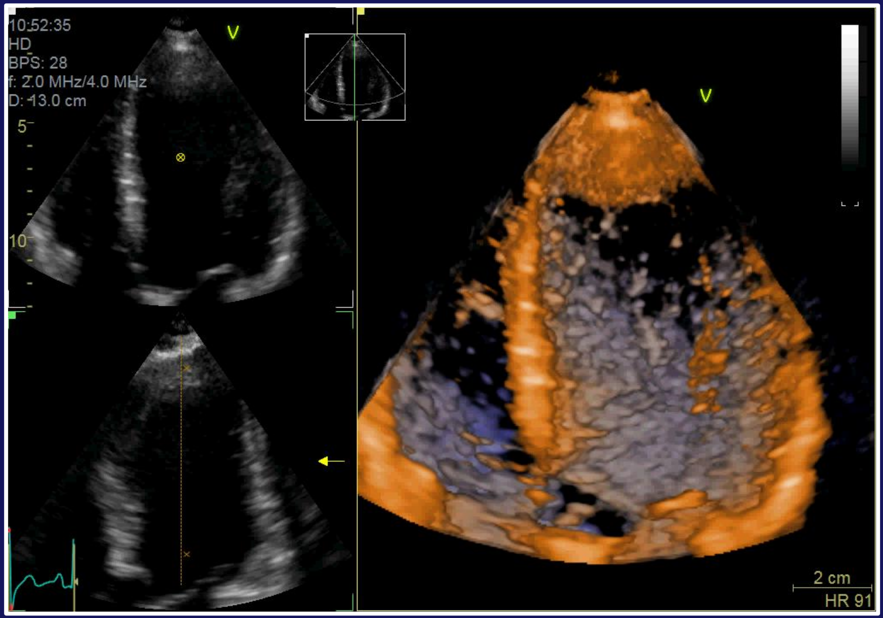


	EF Biplan	75 %
	LVEDV MOD BP	152 ml
	LVESV MOD BP	38 ml
	LVEF MOD A2C	75 %
	SV MOD A2C	98 ml
2	LVLs A2C	8.3 cm
	LVESV MOD A2C	33 ml
1	LVLd A2C	10.5 cm
	LVEDV MOD A2C	130 ml

LVEDV:
nur 155ml !
- Überprüfung mittels 3D-TTE.

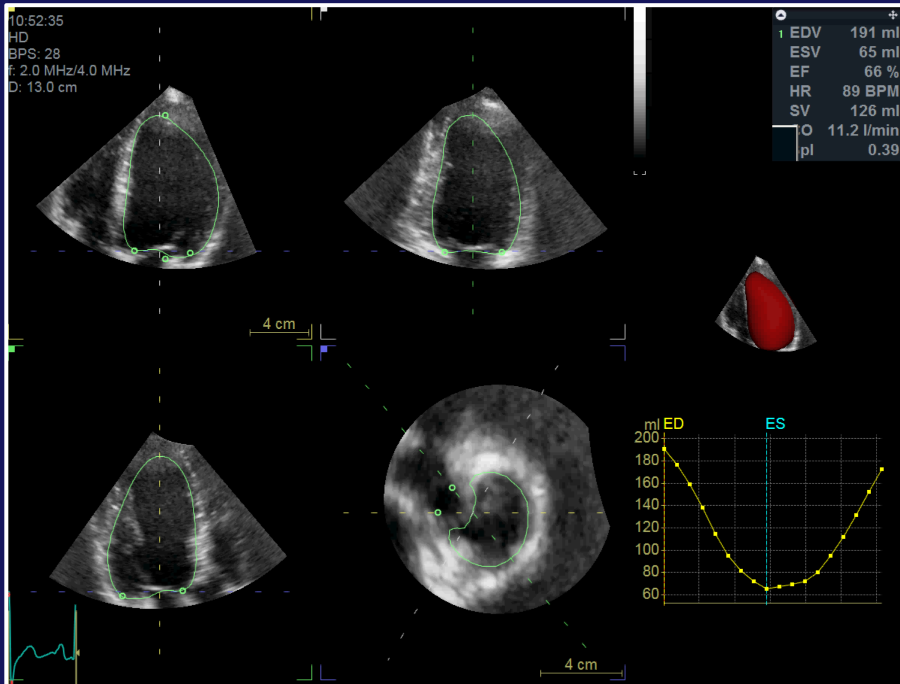
How to use modern echocardiography?
3D-echocardiography for volume analysis

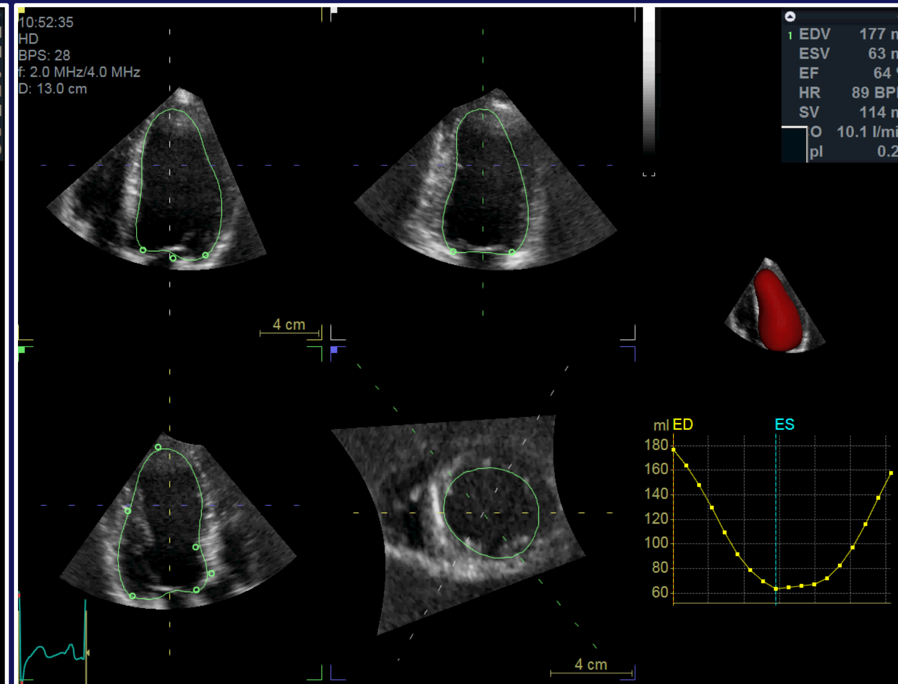


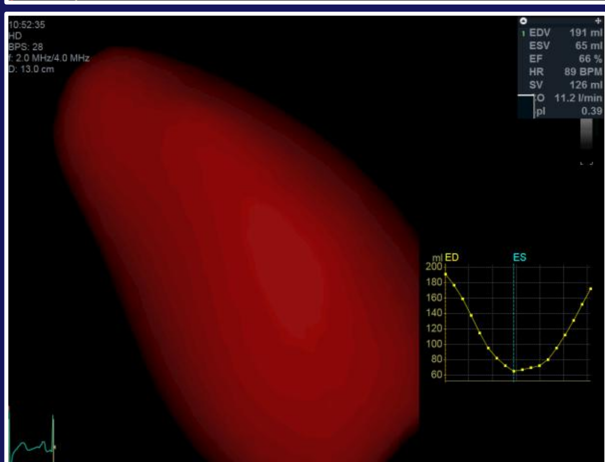


This is not a brilliant image quality – but this is reality.
If you want to assess LV- and RV-volumes,
the complete cavities have to be in the data set.

Echocardiographic Assessment of Aortic Regurgitation

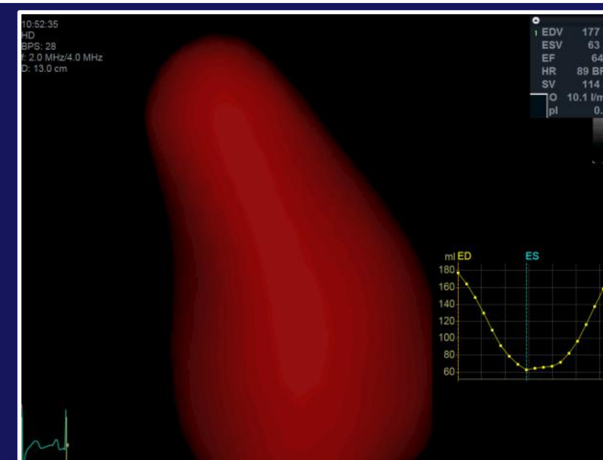




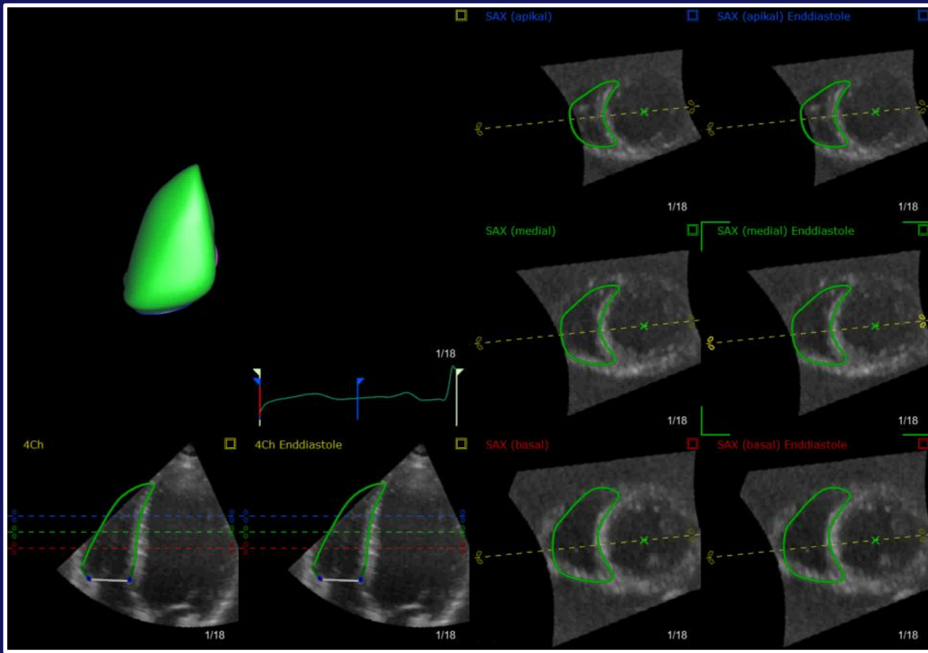


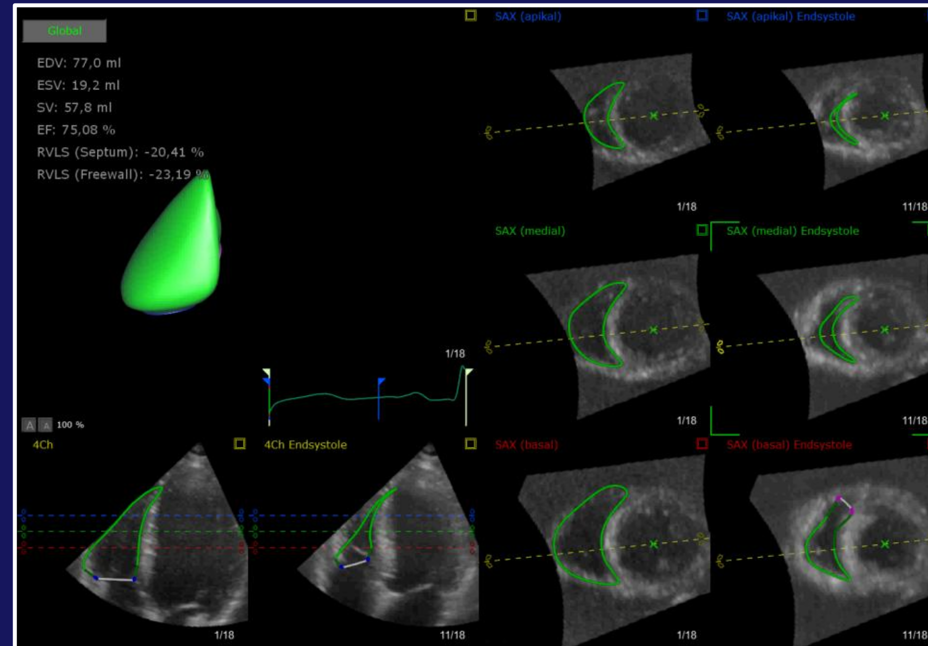
LVEDV – monoplane 210ml
LVEDV – biplane 150ml
LVEDV – 3D about 180-190ml;

Comparable results – biplane Simpson-analysis is underestimating LVEDV.



Volumen-Analysis of the right Ventricle



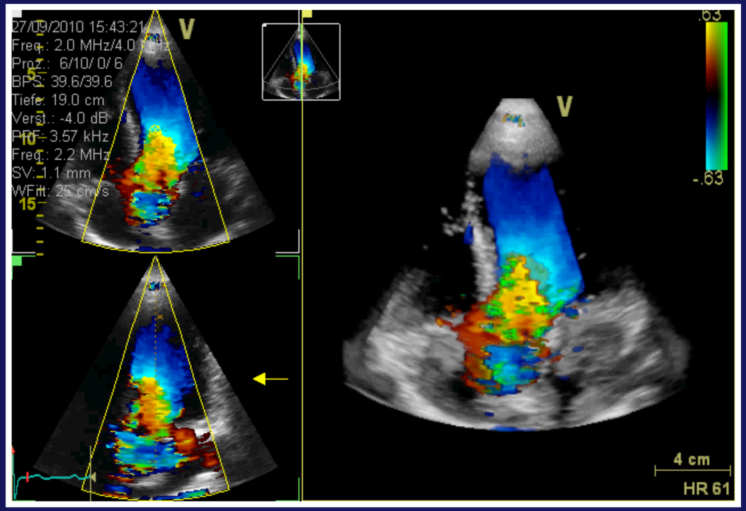


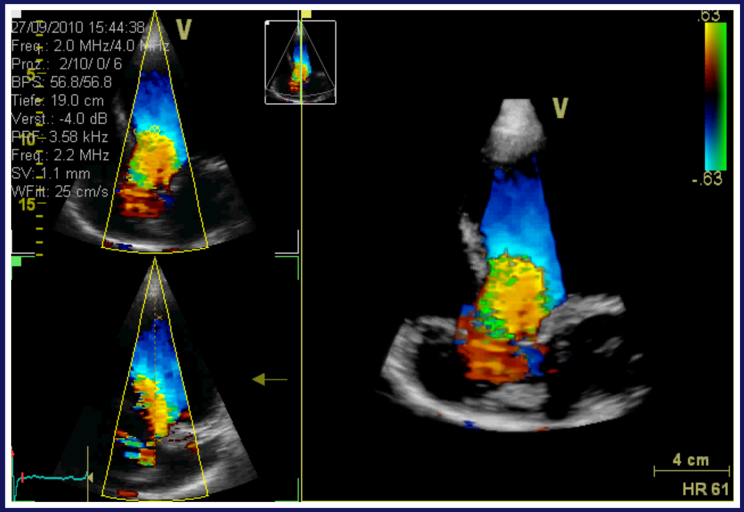
Automatic Tracking is crucial for the contours of the RV

Quantitative assessment confirms the diagnosis of severe aortic regurgitation.

Tracking after manual correction of the contours – calculation of RV volumes and RV stroke volume:
RVEDV 80ml; RVESV 20ml;
Effective SV about 60ml
LV-SV about 120ml; RV-SV about 60ml, thus regurgitatant fraction 50%

Echocardiographic Assessment of Aortic Regurgitation





Quantitative approach to estimate the regurgitant orifice area

$AV_{RV} = (SV_{LVOT} - SV_{RVOT}) =$ AR-regurgitant volume

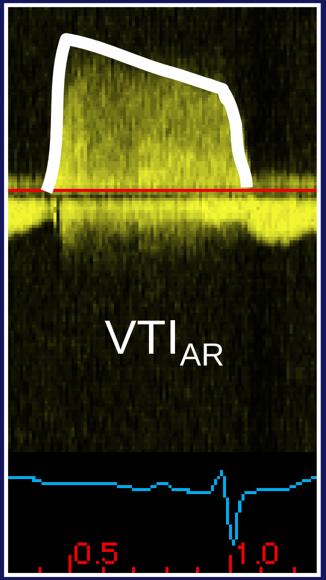
RV = regurgitant volume

$$\frac{AV_{RV}}{VTI_{AR}} = \; = EROA_{AV}$$

= effective regurgitant orifice area

AR = aortic regurgitation

> 30mm² = severe AR

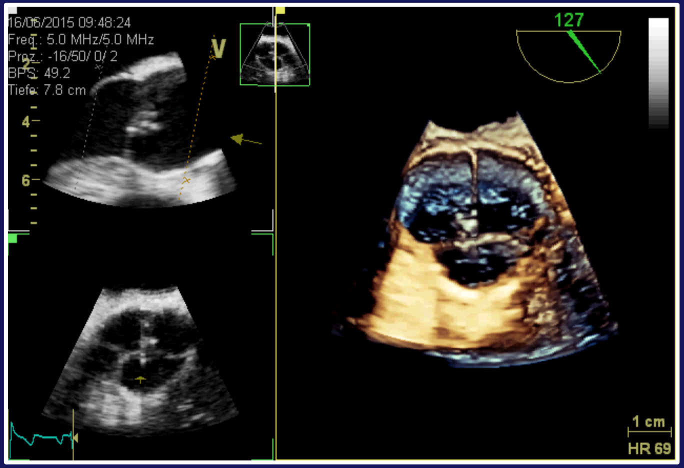


Transthoracic and transesophageal echocardiography: special practical aspects of 3D-imaging

- TTE is a more challenging task than TEE regarding the technical skill.
- In TTE frequencies are lower than TTE, thus spatial resolution is more limited.
- The higher the frequencies, the better the axial spatial resolution.
- The higher the frequencies, the less the penetration.
- Lateral resolution is affected by the frequency as well as by the band width of the transducer – normally in the higher regions of frequencies, but not at the highest – the lateral resolution is the best.

Why these informations?
– Of course to get the best image quality - and at least, to get the best rendering in postprocessing.

If contours are not excellent, no valid postprocession is possible.



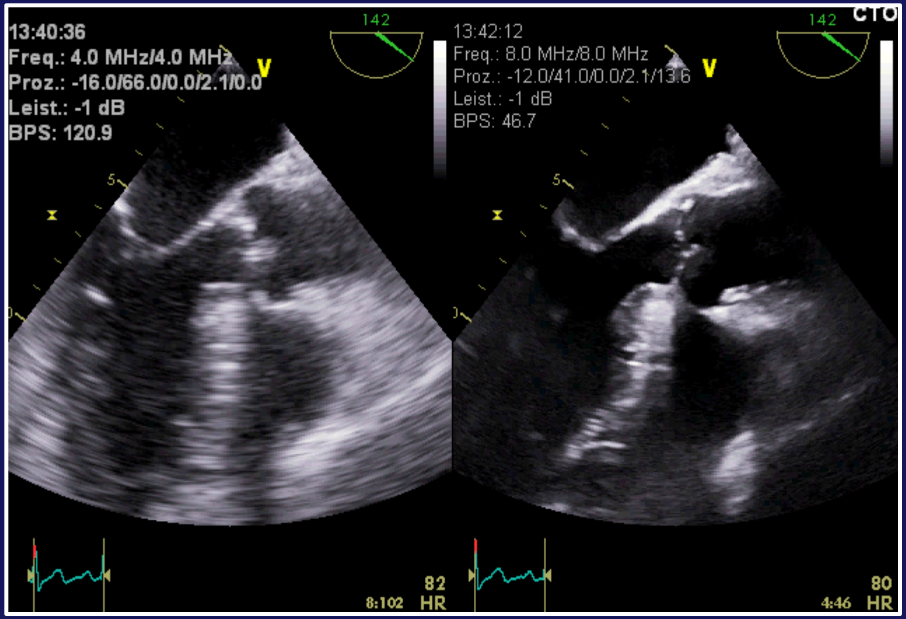
UNIVERSITÄT LEIPZIG
Medizinische Fakultät

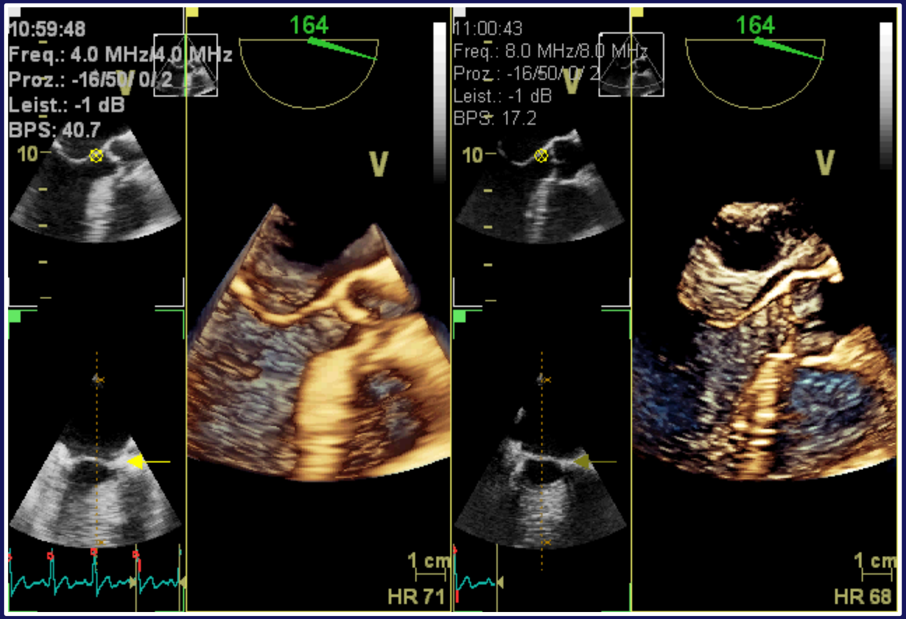
Echocardiographic Assessment of Aortic Regurgitation

Universitätsklinikum Leipzig
Anstalt öffentlichen Rechts

Prerquisite for excellent image quality
in 2D as well as 3D echocardiography:
knowledge about ultrasound physics and implementation of these aspects
into the workflow by just technical knowledge about the buttons.
and in case of interventions and surgery – training for a fast workflow.

Then, detailed information about aortic valve and aortic root morphology is possible.
The spatial and temporal resolution of 3D TEE is at least comparable to cardiac-CT.

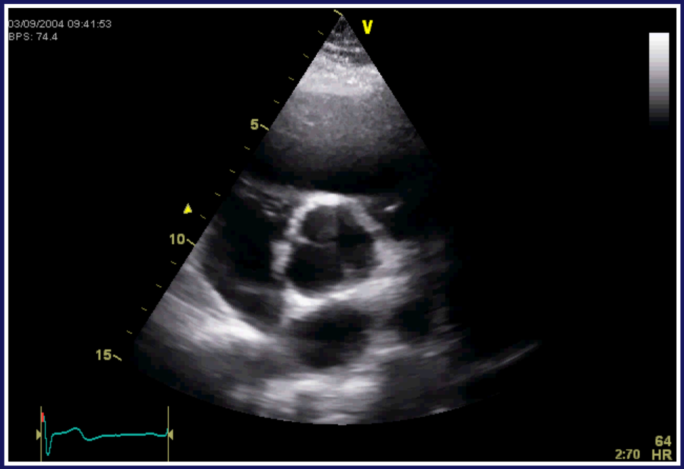


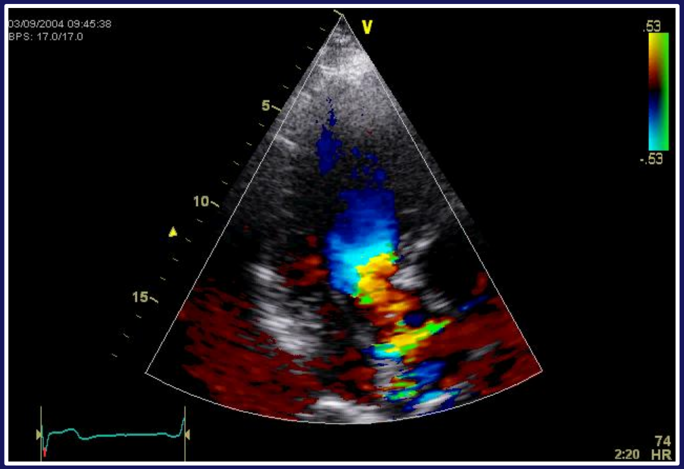


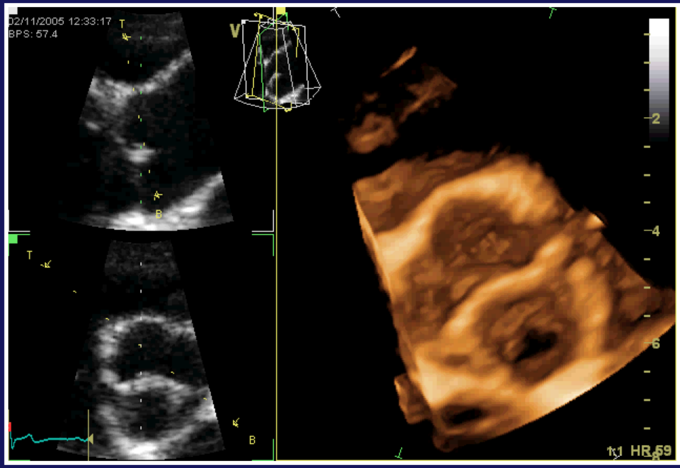
The same patients: „bad“ settings versus optimized settings in 2D and 3D-TEE.

Echocardiographic Assessment of Aortic Regurgitation

3D4D-TTE can be very helpful – and even sometimes better and sufficient in comparison to 3D TEE. „old examples of 2005 with old machines“

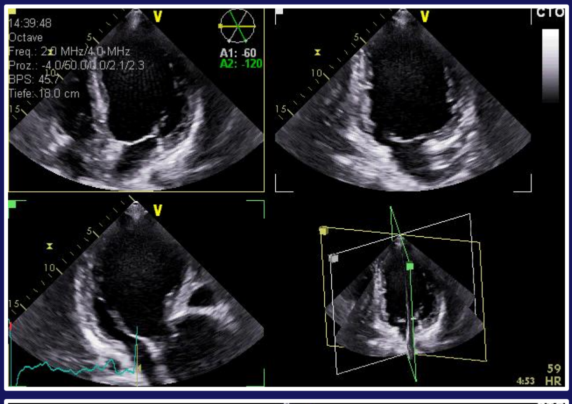






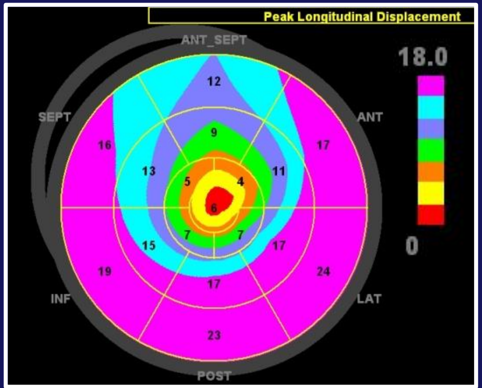
The additional value of information is obvious.
Surface imaging is a complete new modality than sectional scanning.

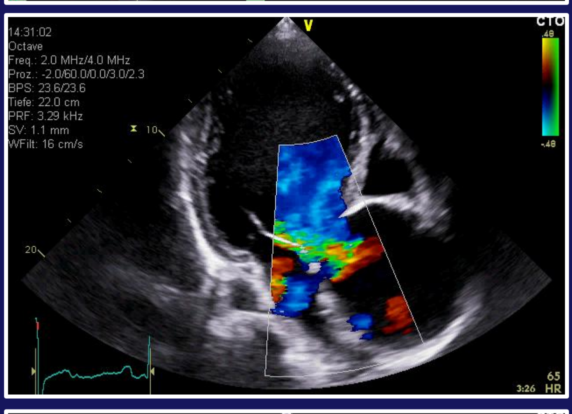
Echocardiographic Assessment of Aortic Regurgitation

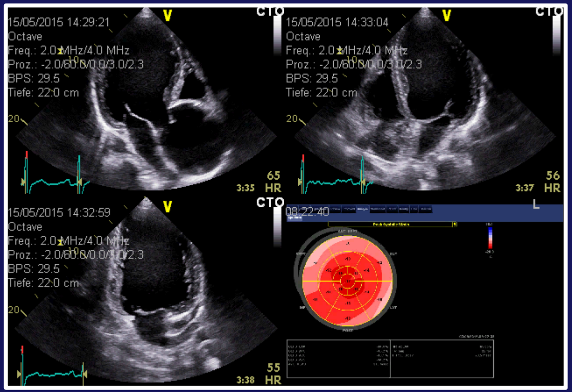


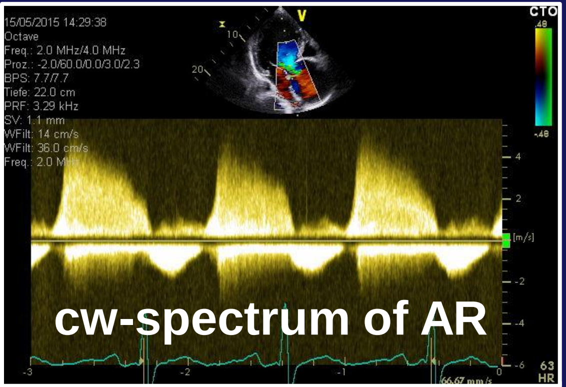
2D-TTE-imaging

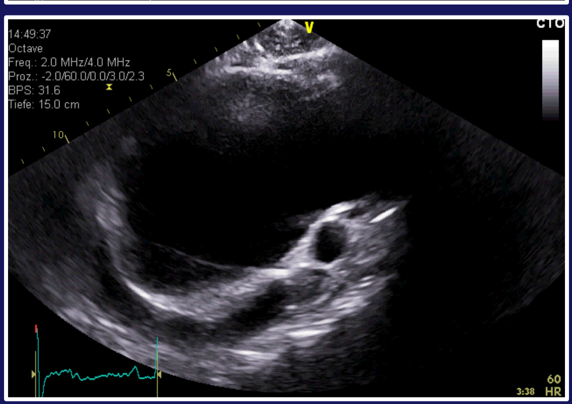
(triplane acquisition
and deformation imaging)
Visualisation of the aortic aneurysm
– funcional AR-anaylsis

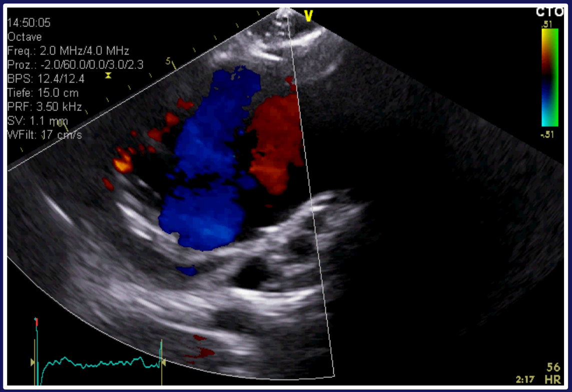


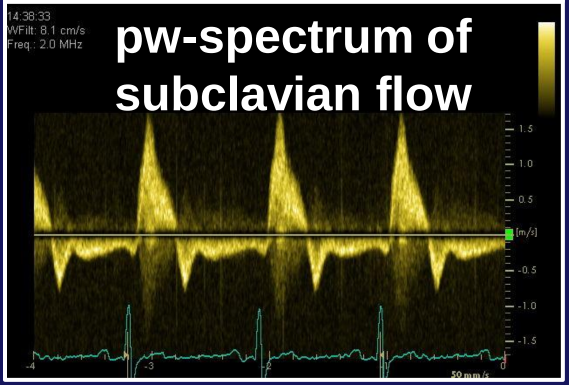






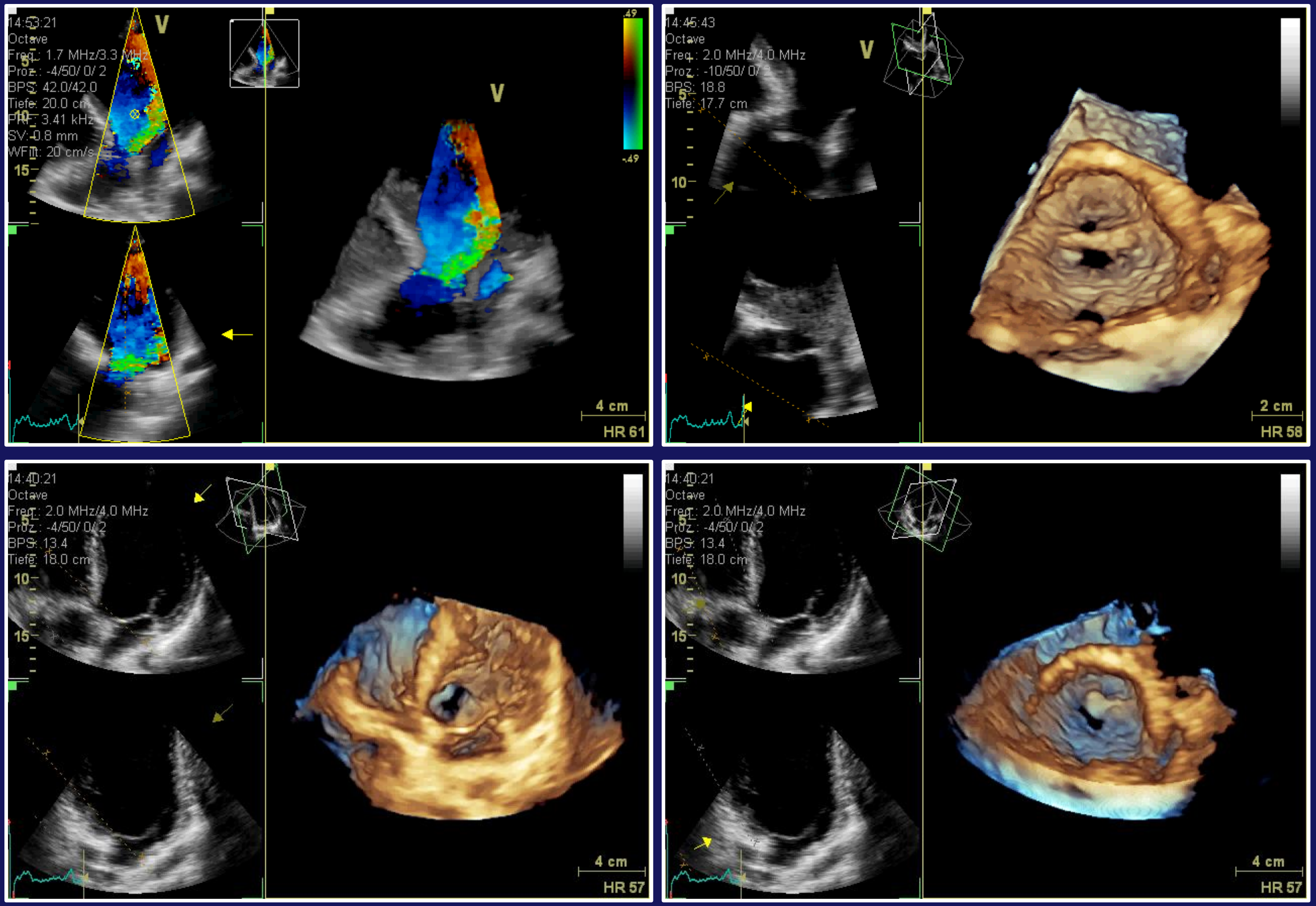






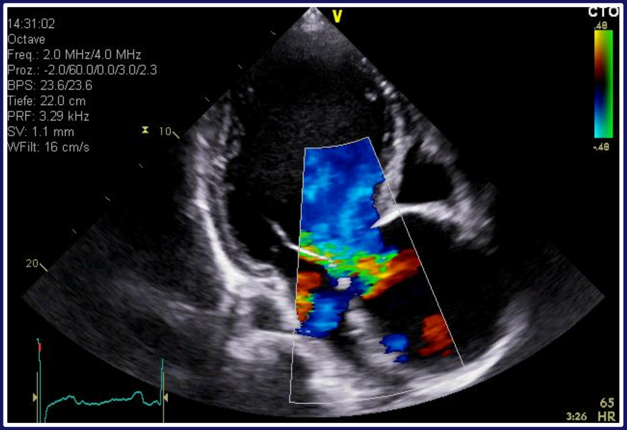
The added value of 3D-TTE-imaging

imaging of regurgitant flow; surface morphology of aortiv valve and root

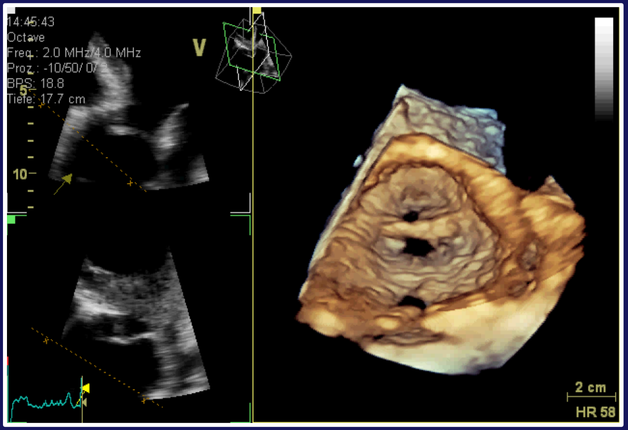


Echocardiographic Assessment of Aortic Regurgitation

pre



pre



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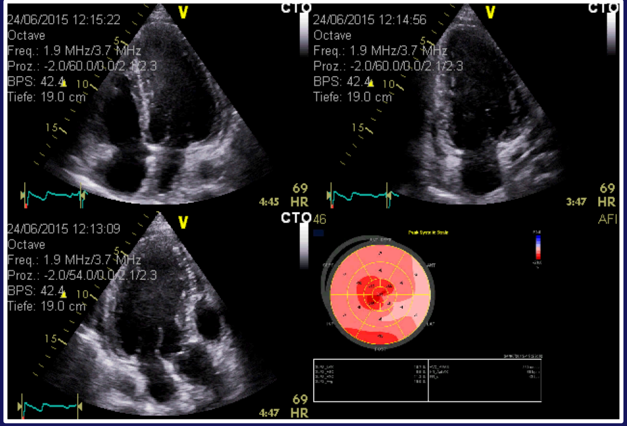
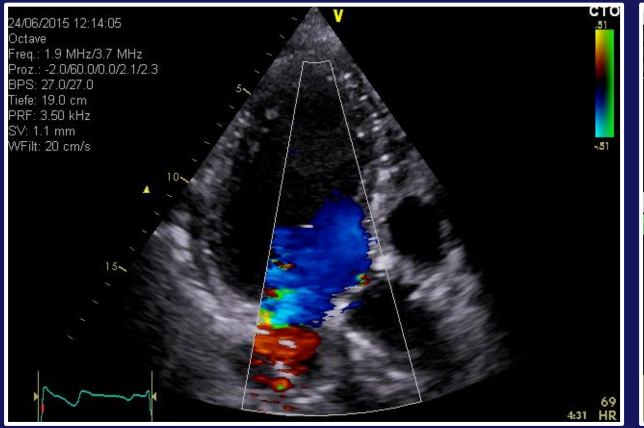


Comparison pre- and post-aortiv valve repair surgery

post



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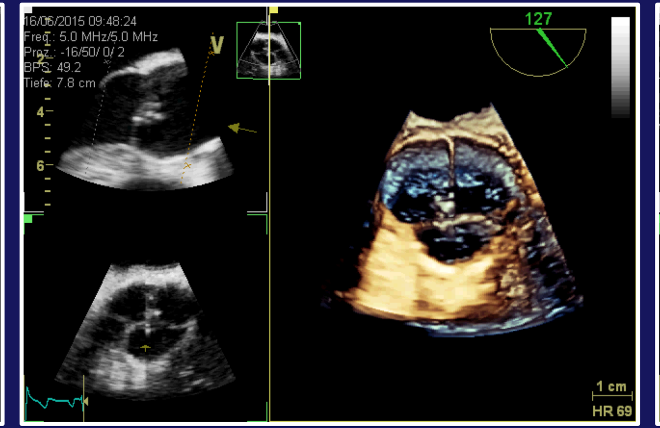

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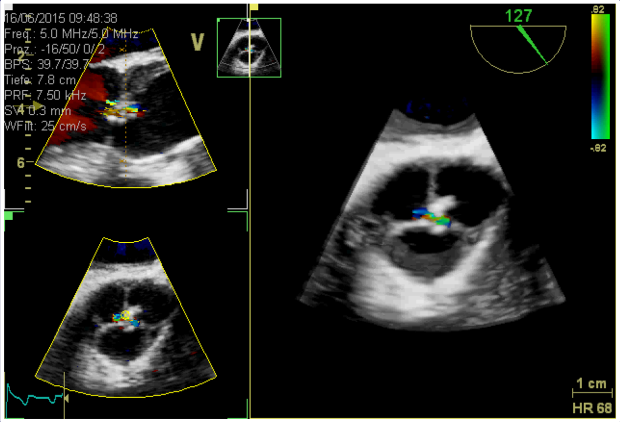
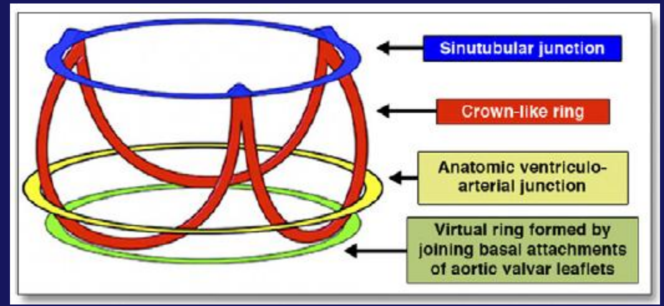
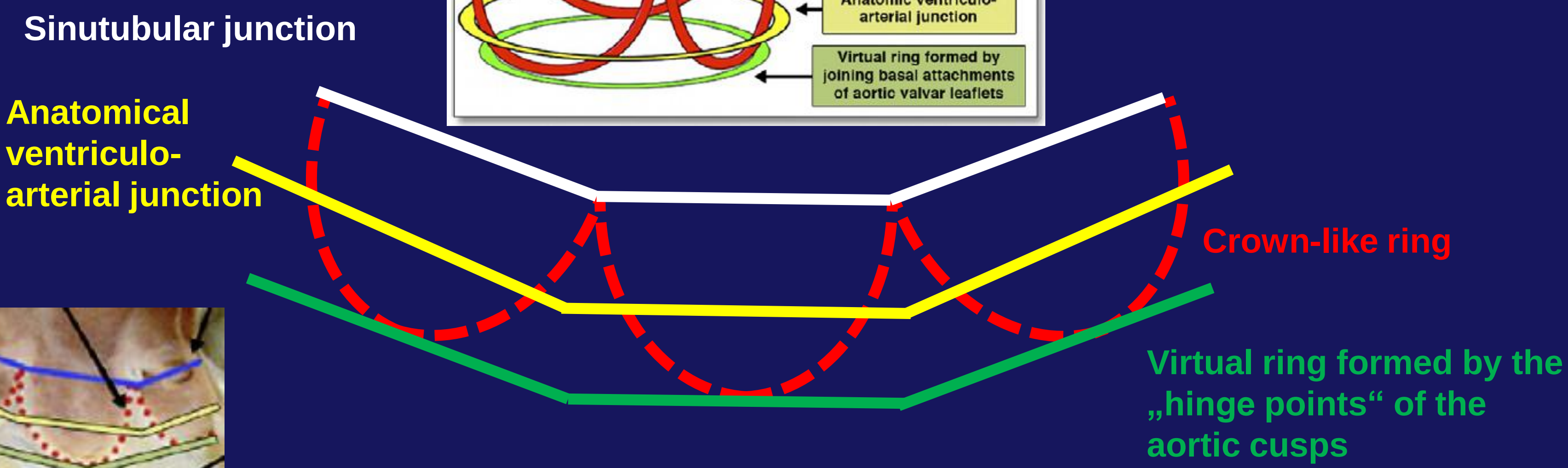
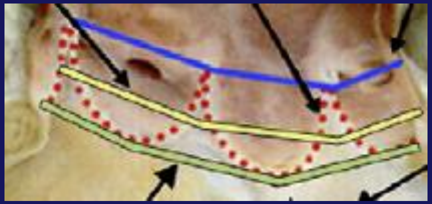
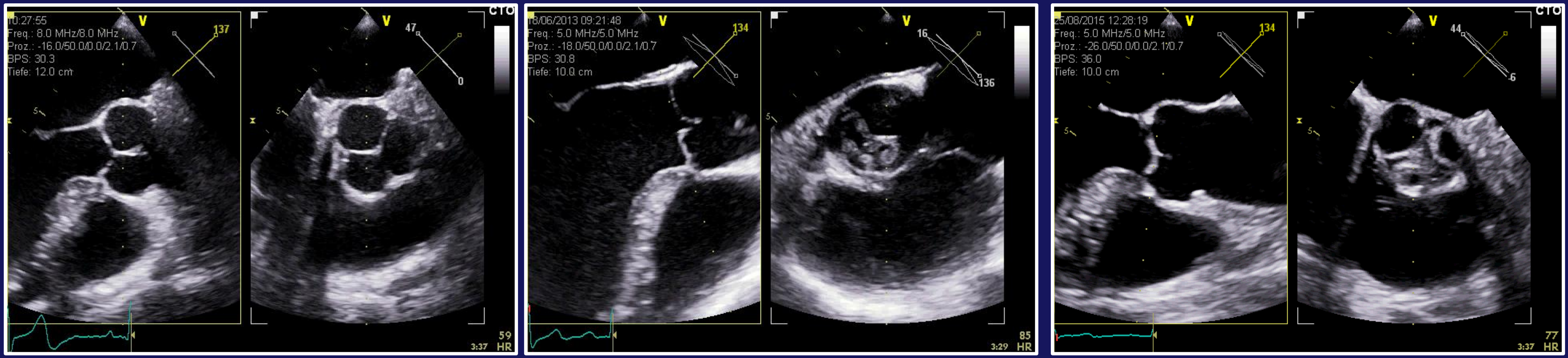


Echocardiographic Assessment of Aortic Regurgitation

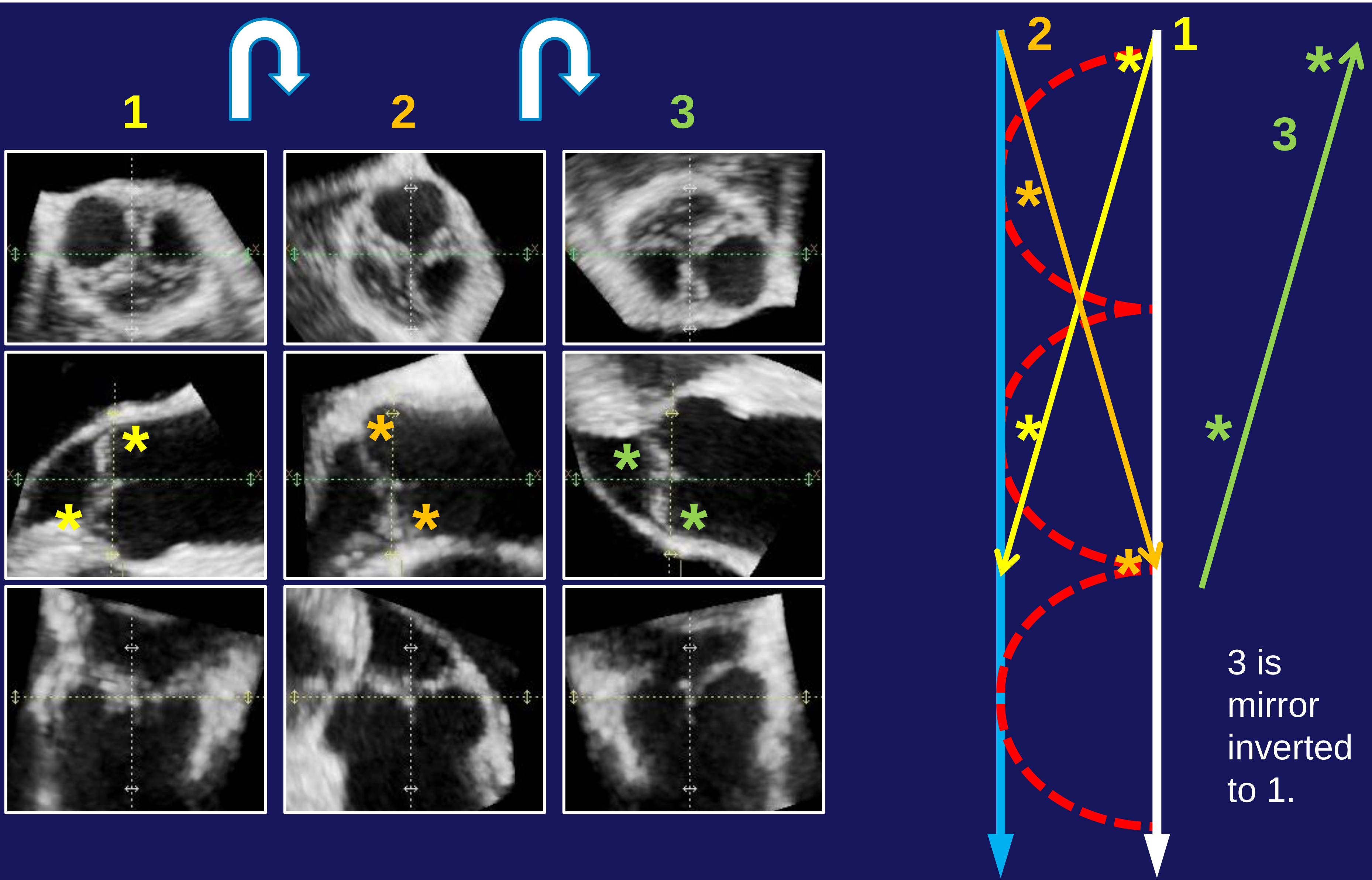




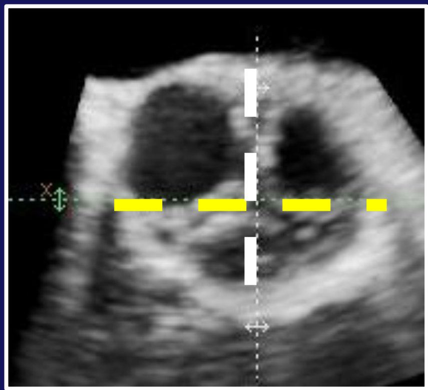


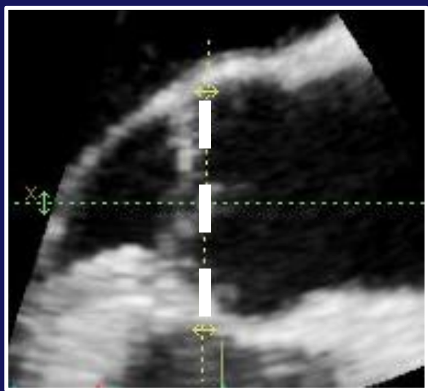


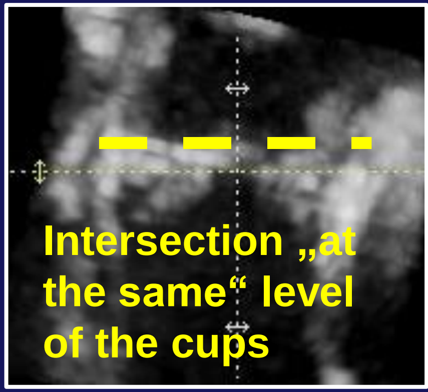
Echocardiographic Assessment of Aortic Regurgitation



Echocardiographic Assessment of Aortic Regurgitation

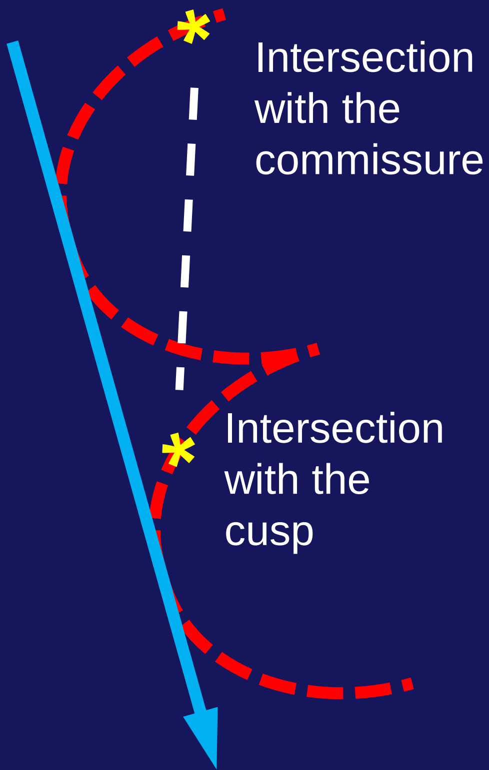




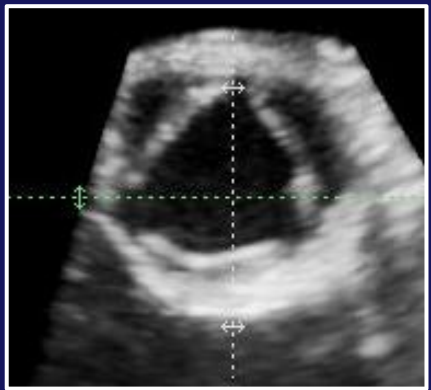


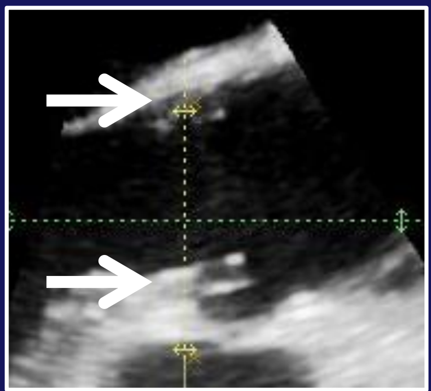
Diastole

Thus,
how to operate correctly?



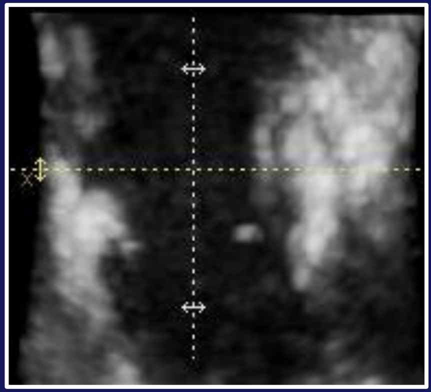
Systole



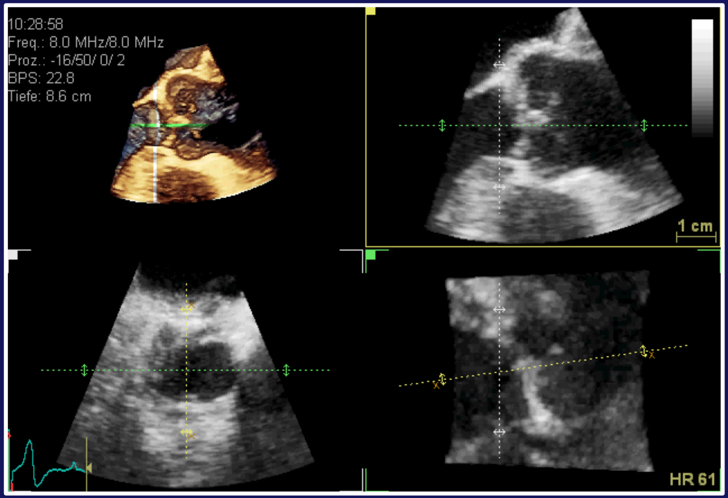


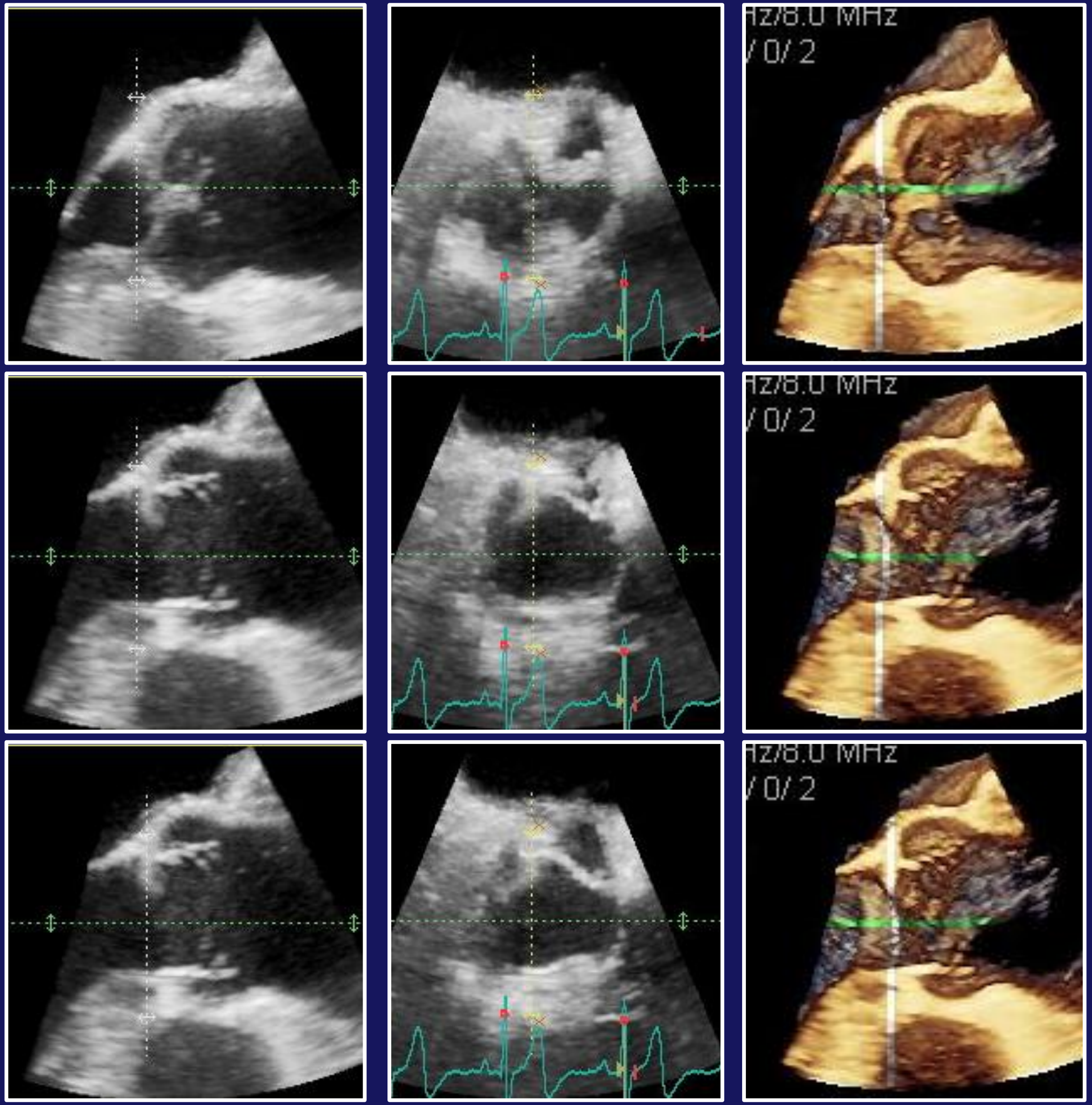
Intersection with the commissure

Intersection with the cusp



Echocardiographic Assessment of Aortic Regurgitation





1. step: adjust the central axis of AV during diastole to label the perpendicular plane through the hinge points
2. step: go to systole to measure the widest expansion of the LVOT
3. step: adjust the annulus plane in the LAX view

A Study of Functional Anatomy of Aortic-Mitral Valve Coupling Using 3D Matrix Transesophageal Echocardiography

Federico Veronesi, PhD; Cristiana Corsi, PhD; Lissa Sugeng, MD, MPH; Victor Mor-Avi, PhD; Enrico G. Caiani, PhD; Lynn Weinert, BS; Claudio Lamberti, MS; Roberto M. Lang, MD

Conclusions—This is the first study to report quantitative 3D assessment of the mitral and aortic valve dynamics from matrix array transesophageal images and describe the mitral-aortic coupling in a beating human heart. This ability may have impac on patient evaluation for valvular surgical interventions and prosthesis design. (*Circ Cardiovasc Imaging*. **2009;2:24-31.**)

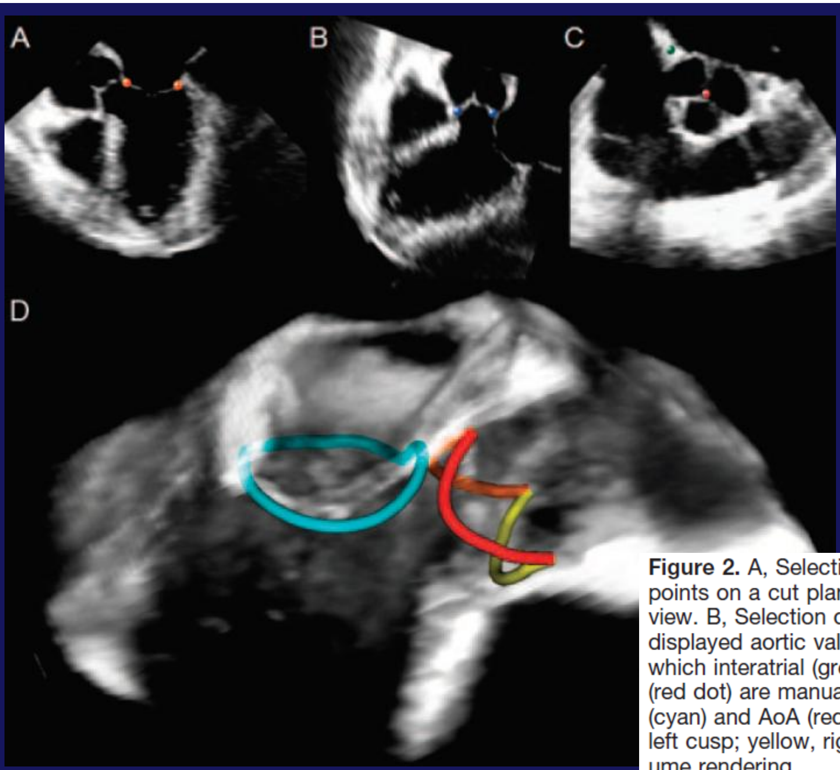


Figure 2. A, Selection of anterior and posterior MA points on a cut plane representing 3-chamber view. B, Selection of AoA points. C, Automatically displayed aortic valve short axis cut plane on which interatrial (green dot) and coaptation point (red dot) are manually identified. D, Computed MA (cyan) and AoA (red, noncoronary cusp; orange, left cusp; yellow, right cusp) splines on RT3DE volume rendering.

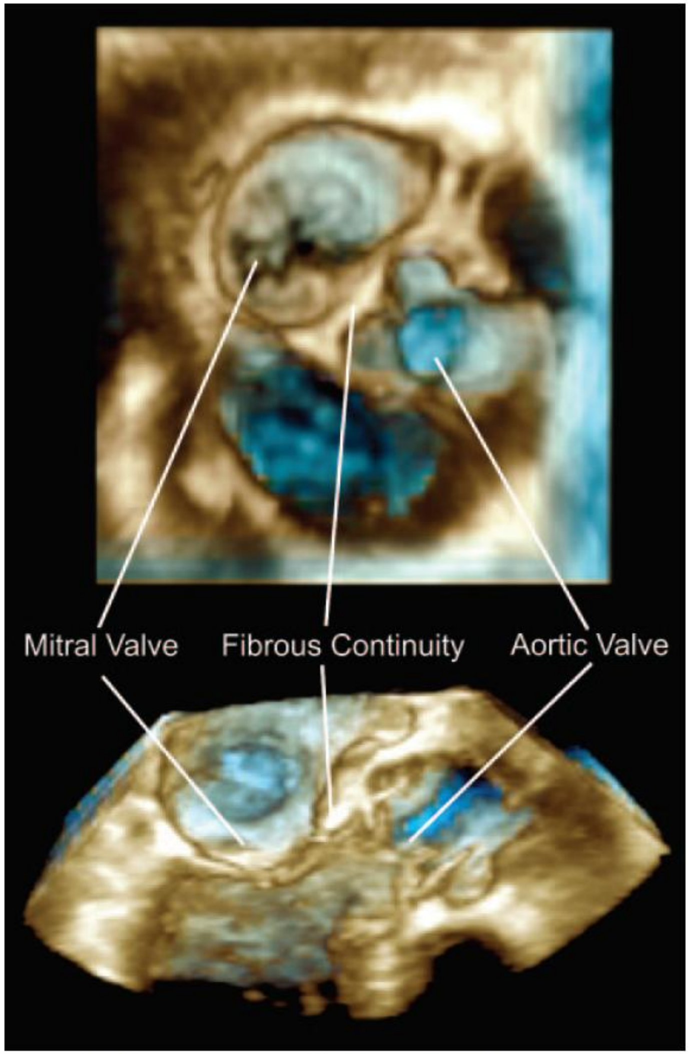


Figure 1. Volume rendering of RT3DE mTEE data visualized from atrium (top) and in a long axis view (bottom).

Echocardiographic Assessment of Aortic Regurgitation

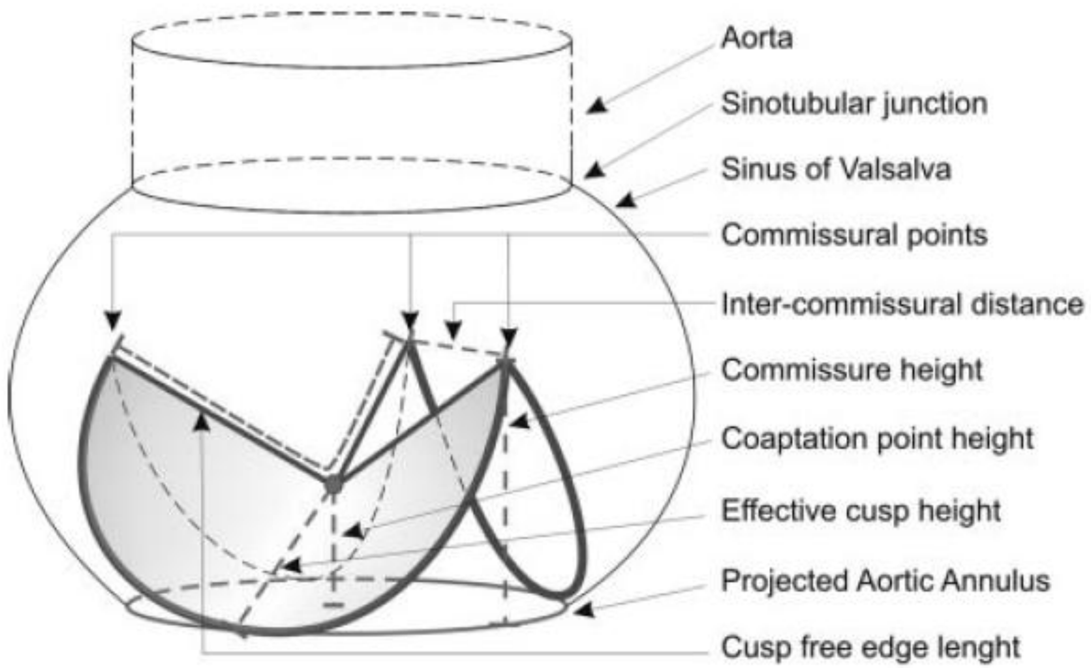


Figure 3. Schematic of automatically extracted AoA measurements.

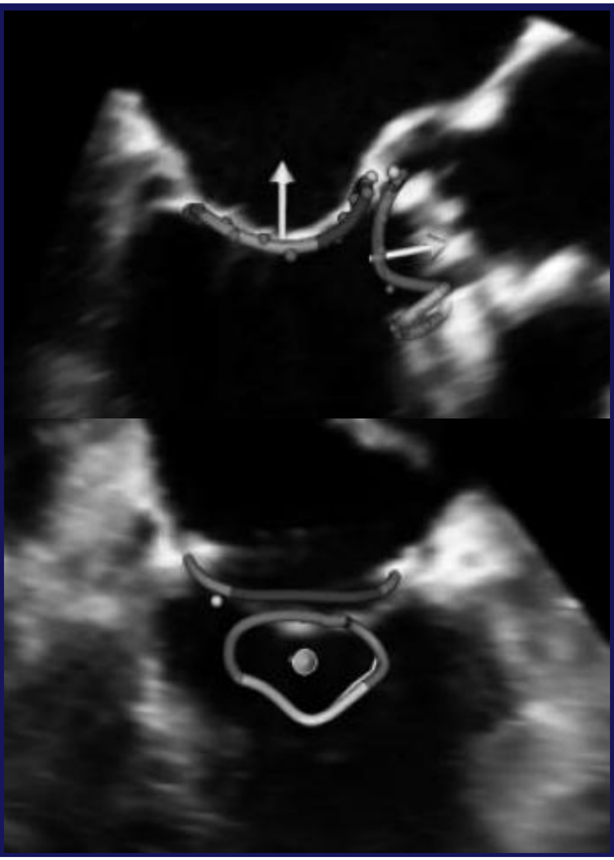


Figure 5. Left, Mitral and aortic annuli computed from a RT3DE data set obtained in a patient with severe sclerocalcific aortic stenosis, shown superimposed on a 3-chamber view. Note that the angle between the 2 valves is severely reduced (93°) compared with normal subjects and also the distance between the 2 valve was just 18 mm and did not changed during cardiac cycle. The aortic stenosis was most likely responsible for the reduced change in projected AoA area during the cardiac cycle, having a negative impact on the aortic-mitral coupling as reflected by a decrease in maximum diastolic area change to only 12%, compared with 25.4% of the ED area in normal subjects (Table 1). Right, Mitral and aortic annuli computed from a RT3DE data set obtained in a patient with implanted mitral ring, shown superimposed on a 2-chamber view. Note the deformation in the shape of the AoA. In this subject, reduced motion of the mitral valve (4.5 mm maximum at ES) and reduced MA height (4.3 mm) at ED was noted. In addition, the intercommissural distances where asymmetrical: the distance between the commissures of the left cusp was smaller (18 mm) compared with the noncoronary and right cusps (28 and 27 mm, respectively). Moreover, the saddle shape of the MA was not preserved because of the rigid ring.

Echocardiographic Assessment of Aortic Regurgitation

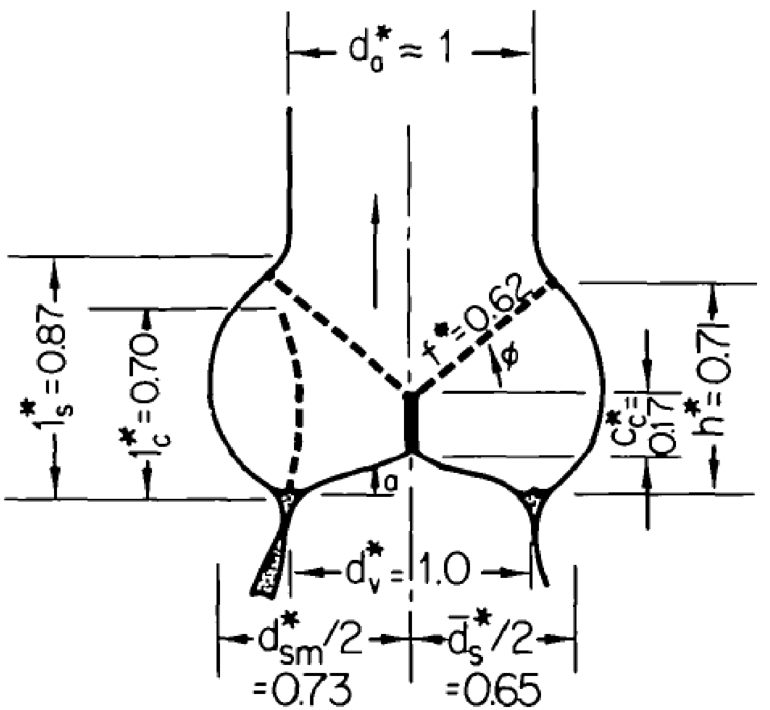
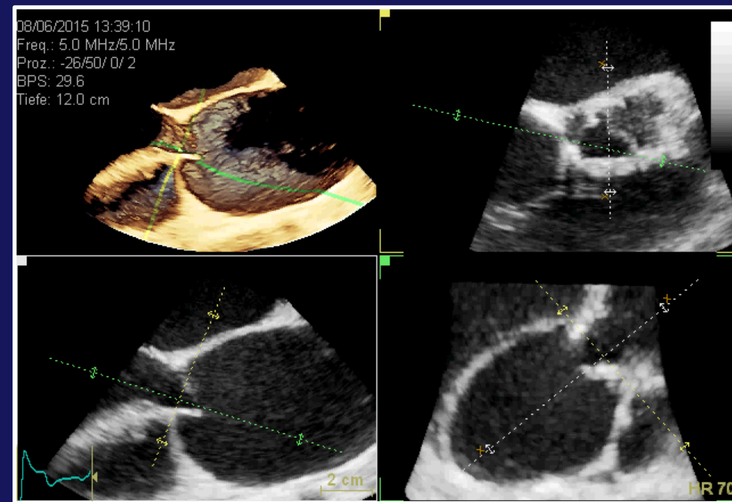
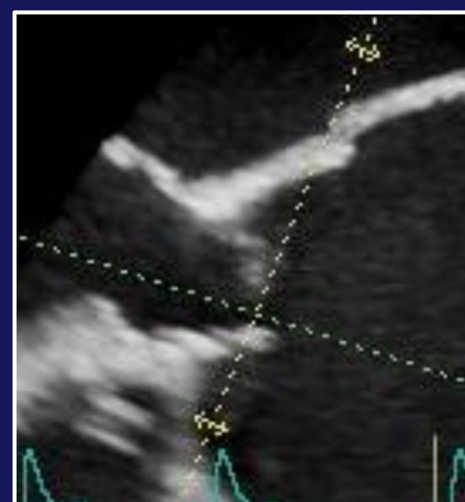


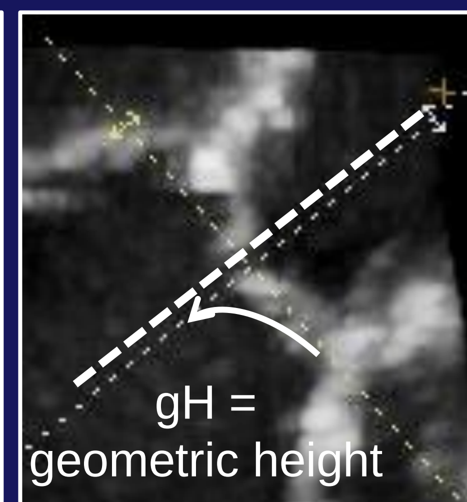
FIGURE 2

Geometry and relative dimensions of aortic valve region. See text for abbreviations.

Circulation Research, Vol. 35, December 1974



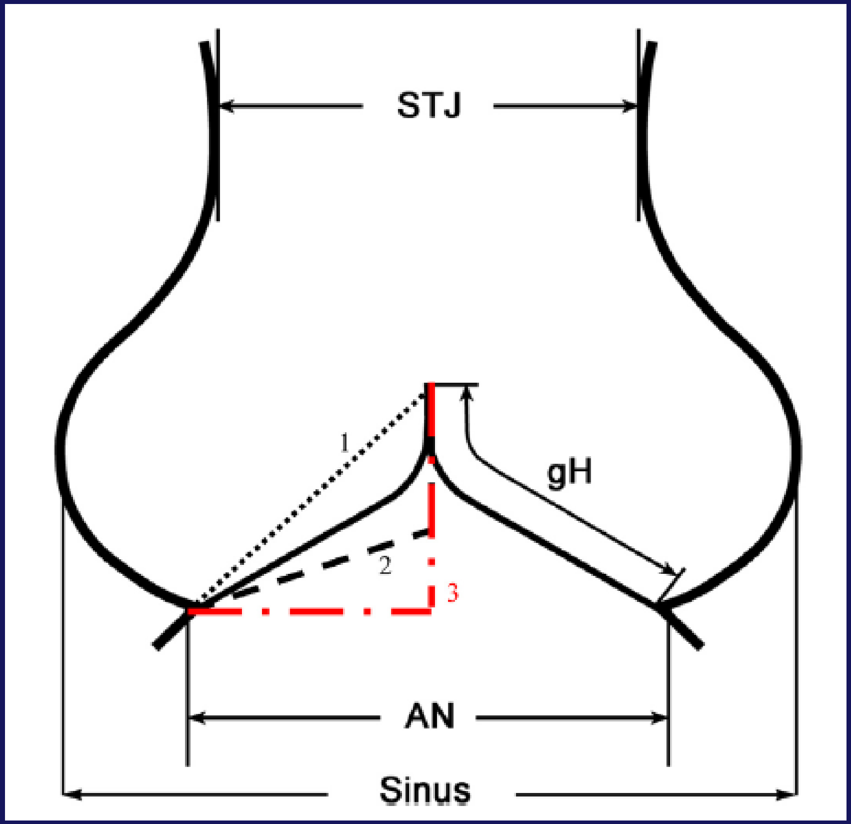


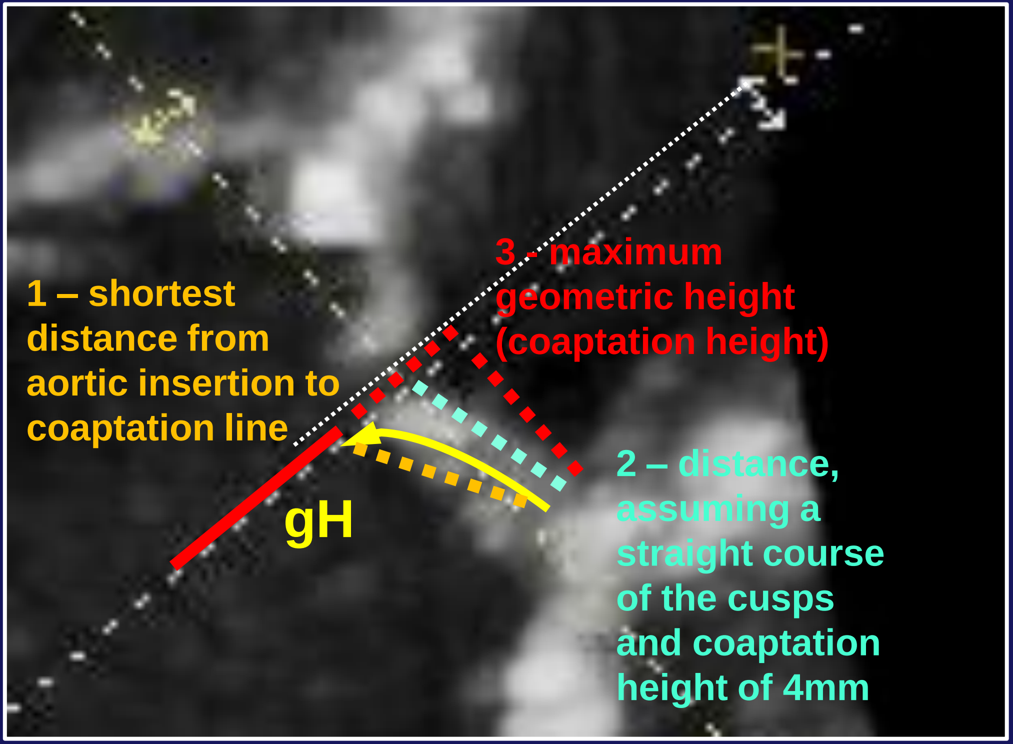


aus Swanson WM and Clark RE. Dimensions and Geometric Relationships of the Human Aortic Valve as a Function of Pressure. Circ Res 1974; 35: 871-882

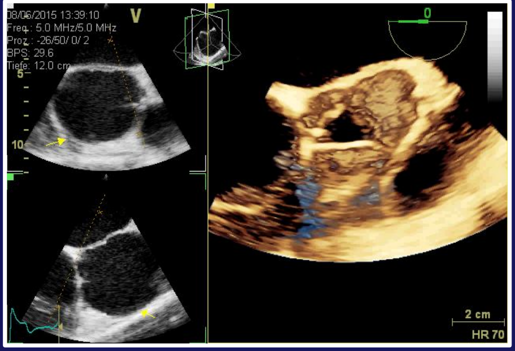
Echocardiographic Assessment of Aortic Regurgitation

The following measurements are possible (performed in special centers).

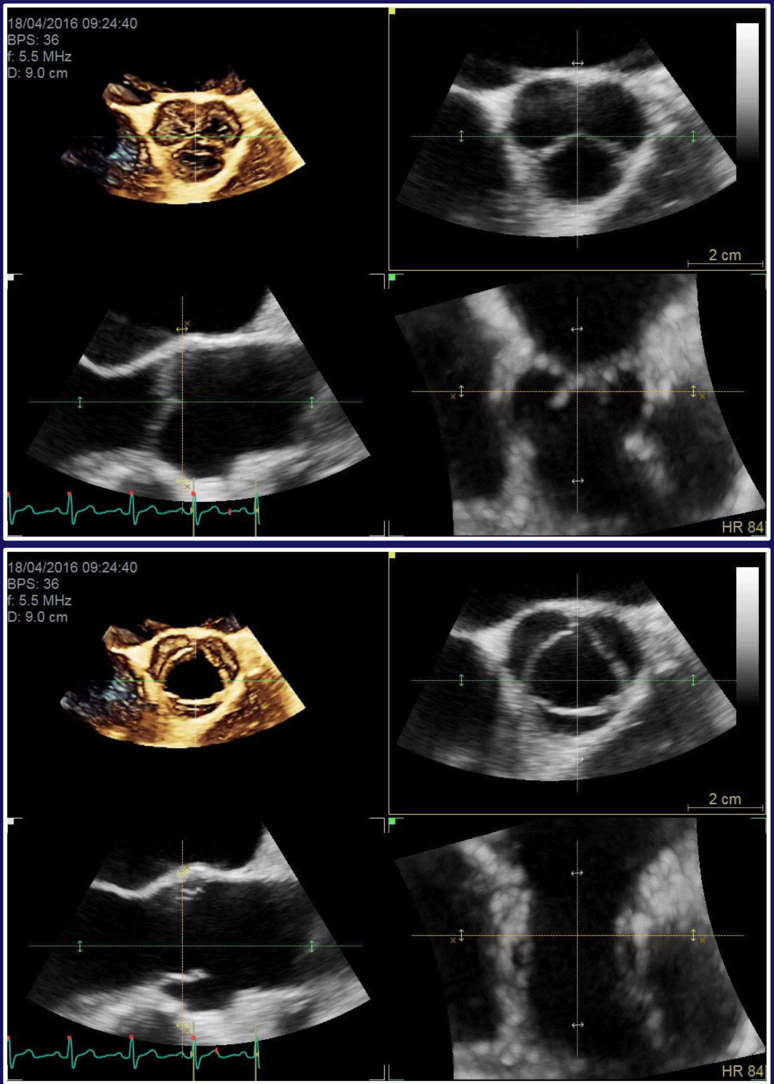




aus: Schäfers HJ, Schmied W, Marom G, Aicher D, Cusp height in aortic valves. The Journal of Thoracic and Cardiovascular Surgery 146; 2, 269-274 (2013

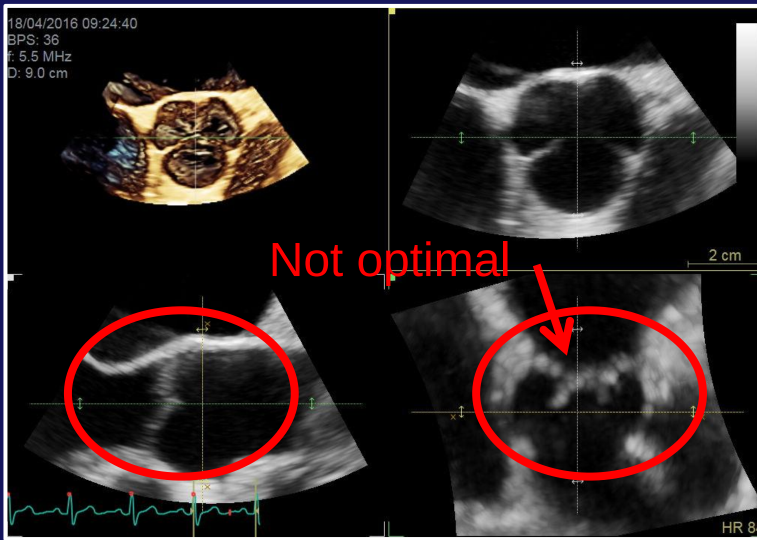


Assessment of Cusp Geometry: Effective and Geometric Height

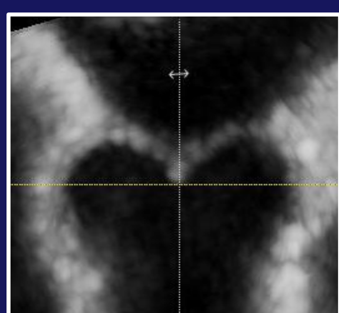


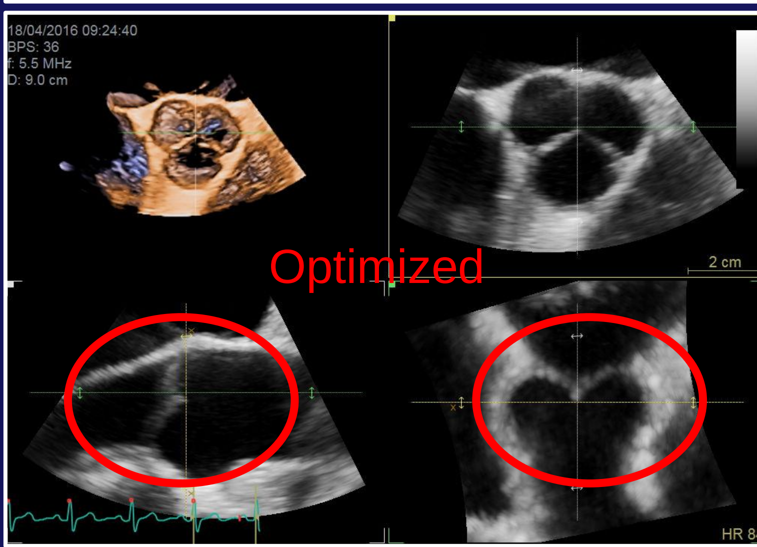
Step 1: Check alignements of the commissure between left and non coronary cusp to be perpendicular to the center of the right coronary cusp
In asymmetric aortic root geometry the corresponding opposite cusp has to be centered.

Assessment of Cusp Geometry: Effective and Geometric Height

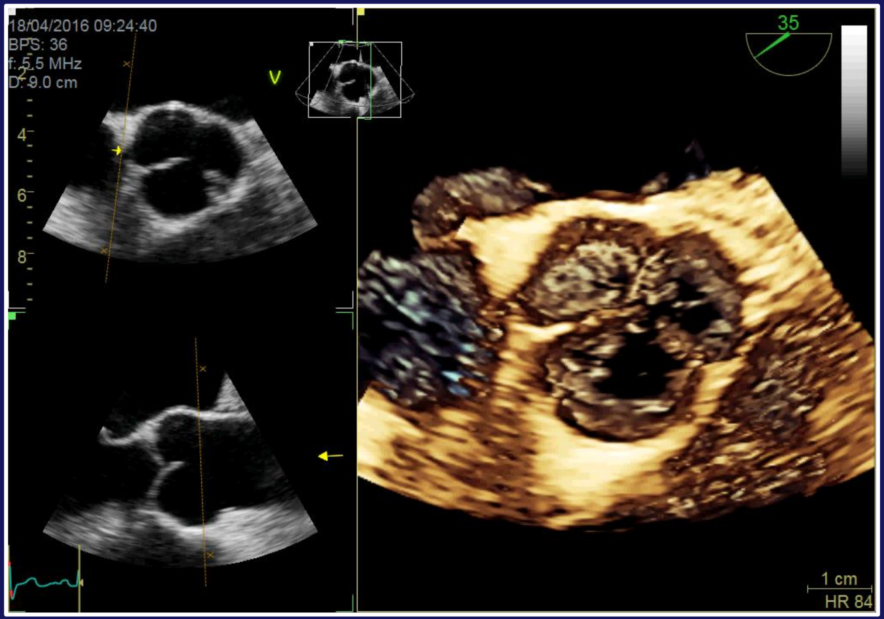


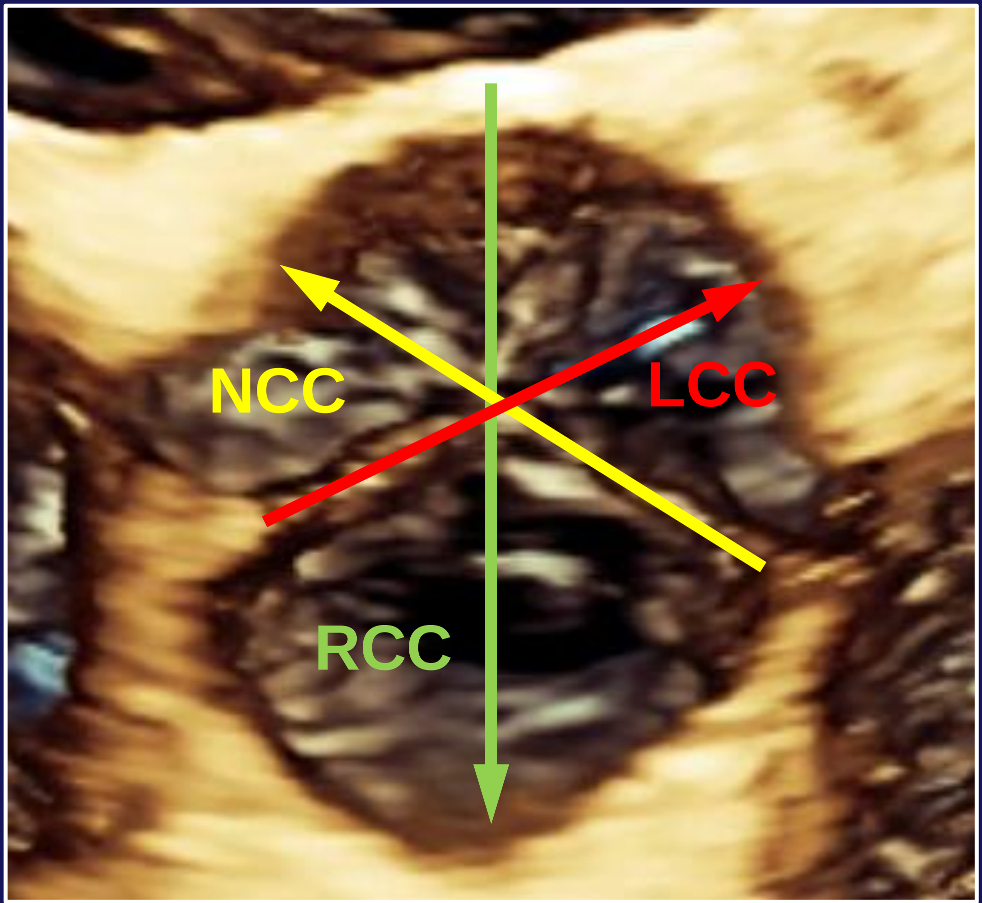
Step 2: Center in tricuspid valves the central point of all commissures





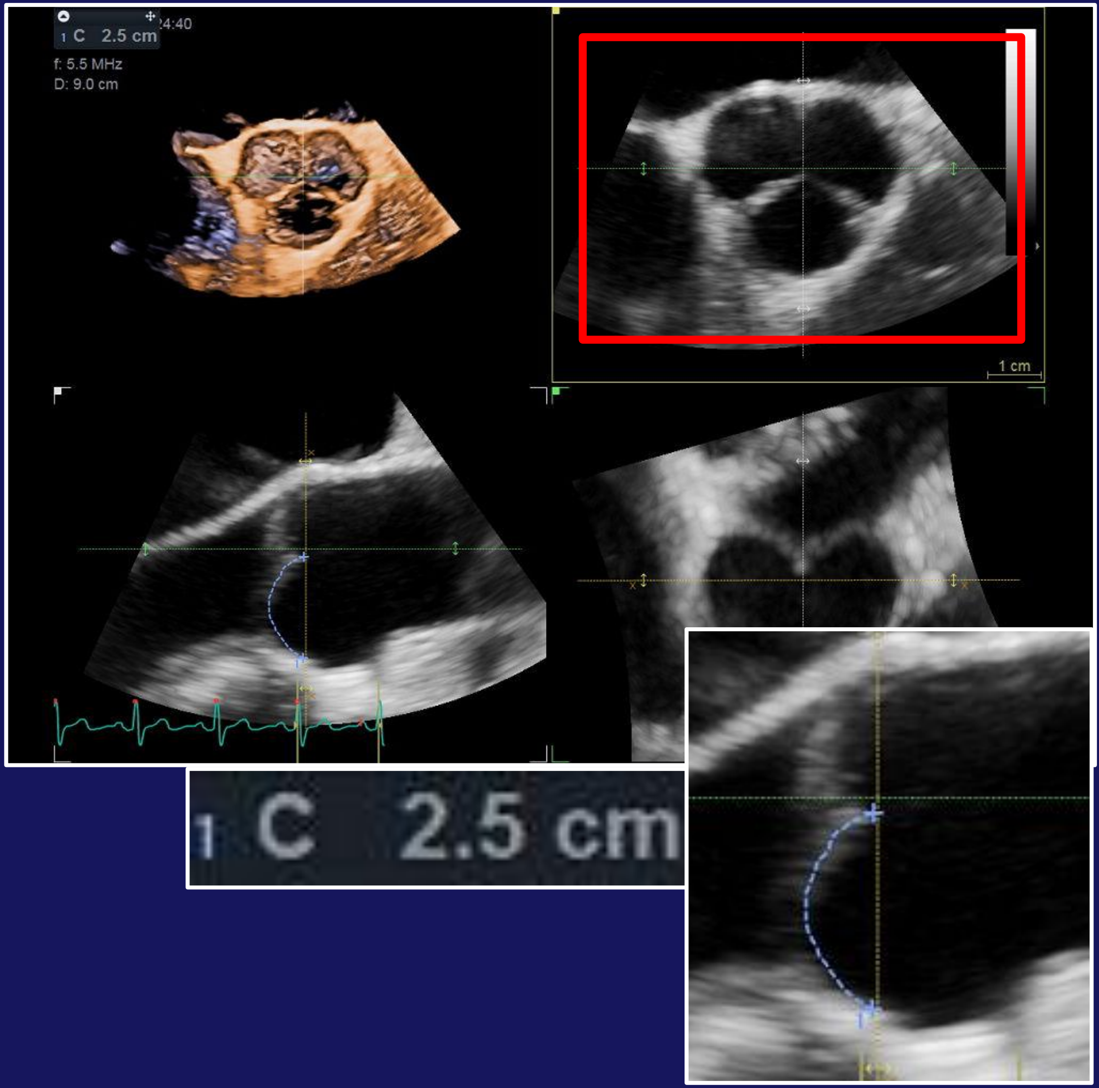
Cusp Geometry: Scheme of the Sectional Planes for Assessment of Geometric Height





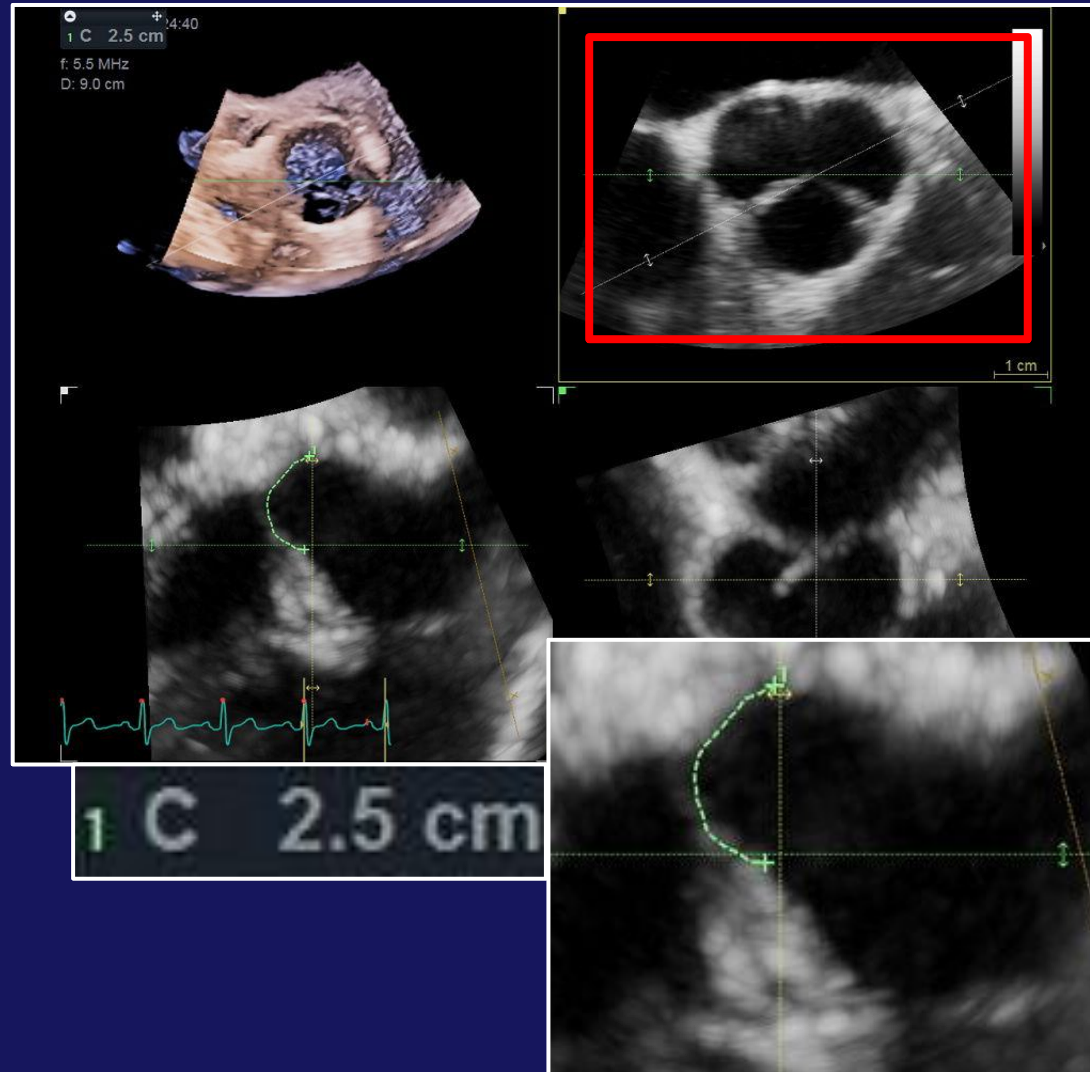
In 2D-TTE and TEE only the exact assessment of the right coronary cusp is possible. The left and non coronary cusp has to be analyzed in 3D data sets.

Assessment of Cusp Geometry: Effective and Geometric Height



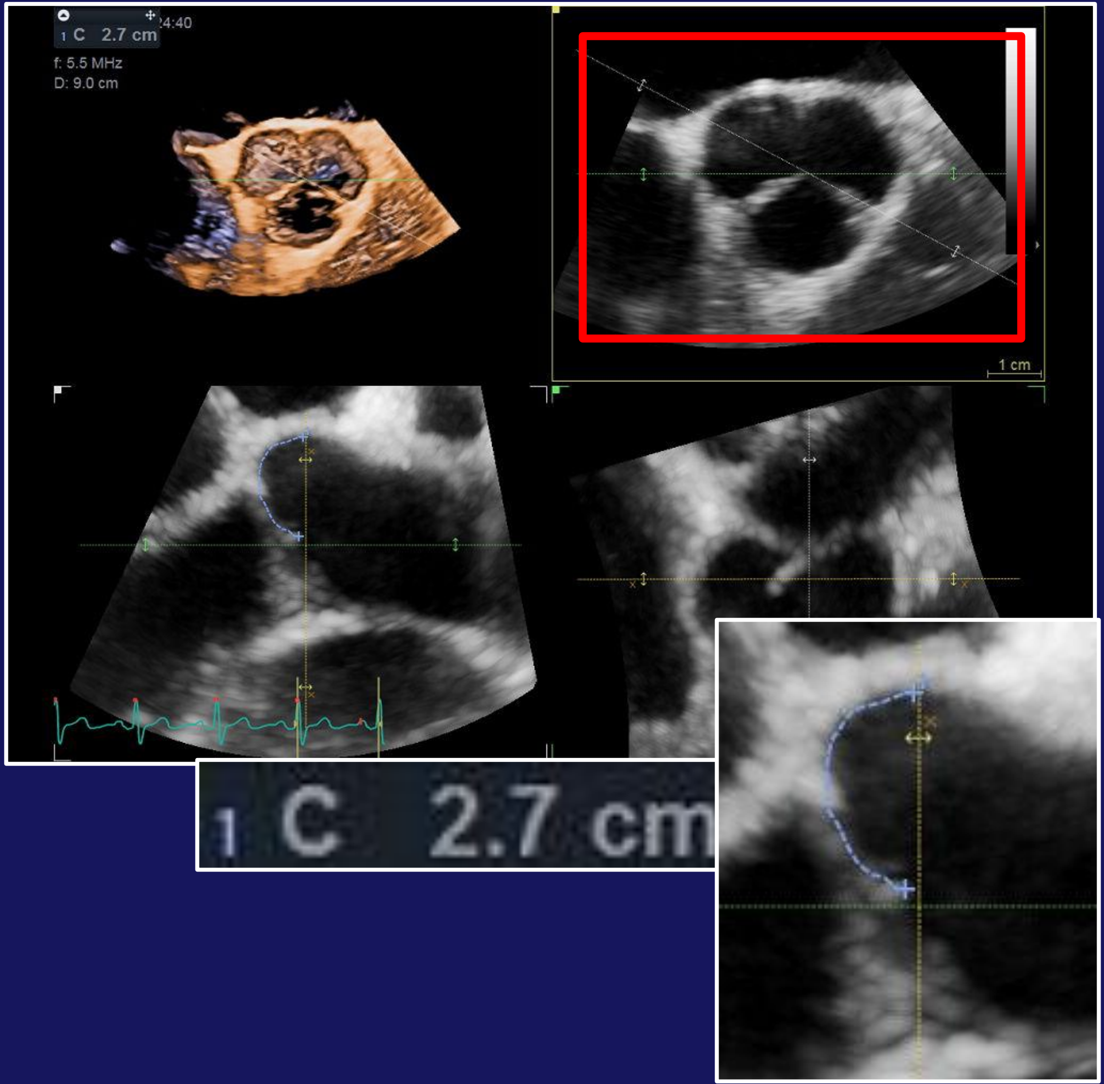
Assessment of the geometic height of the right coronary cusp

Assessment of Cusp Geometry: Effective and Geometric Height



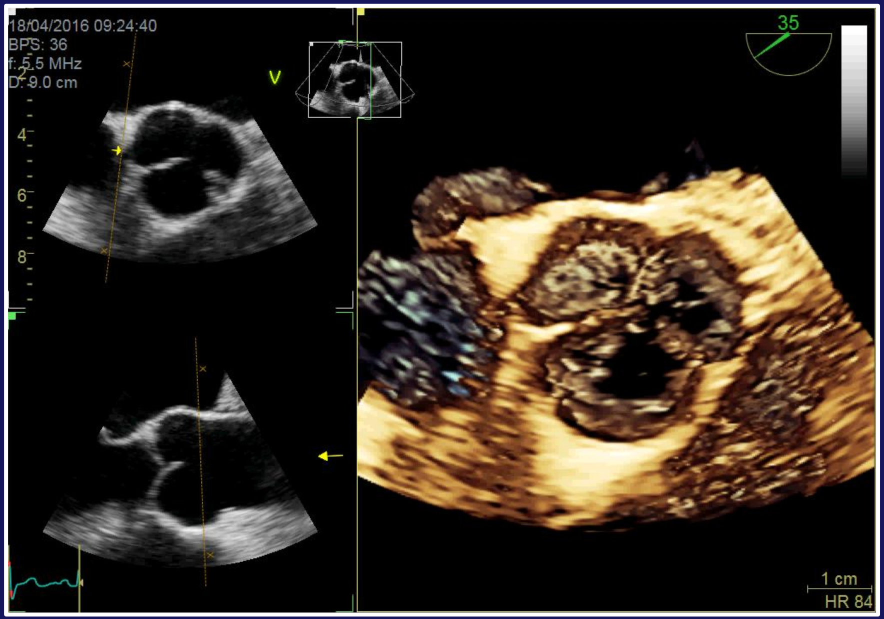
Assessment of the geometic height of the left coronary cusp

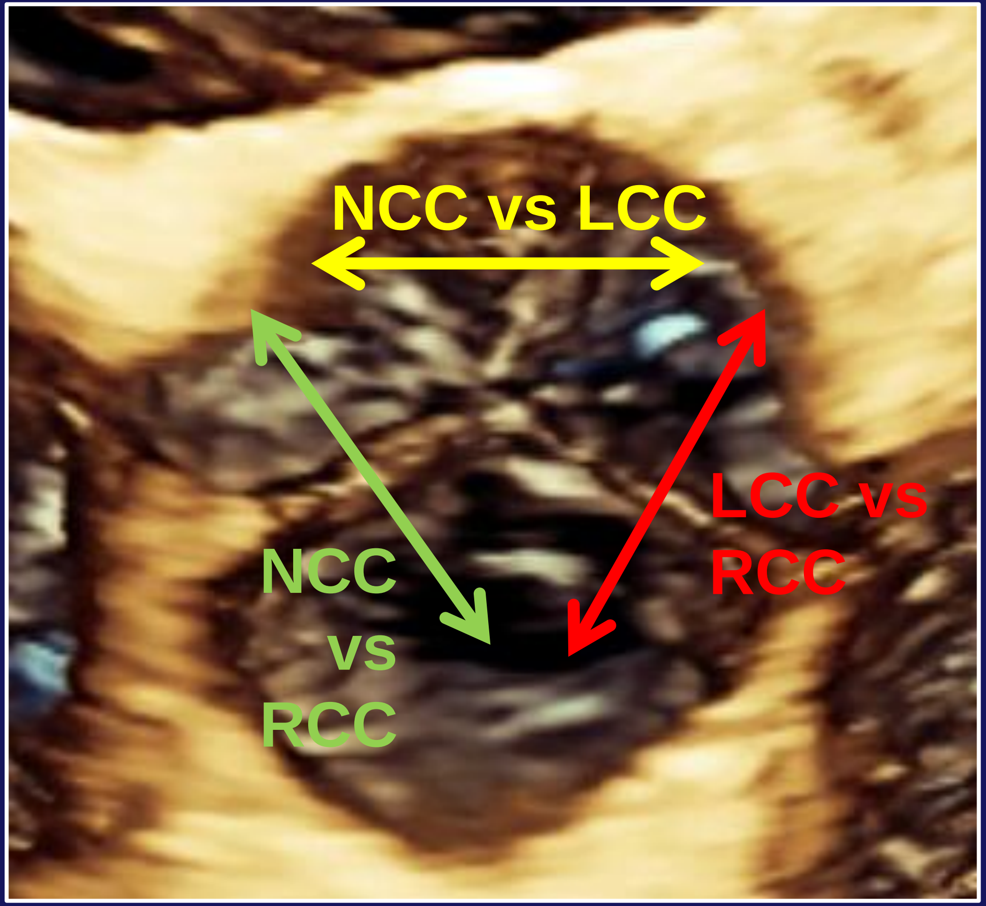
Assessment of Cusp Geometry: Effective and Geometric Height



Assessment of the geometic height of the non coronary cusp

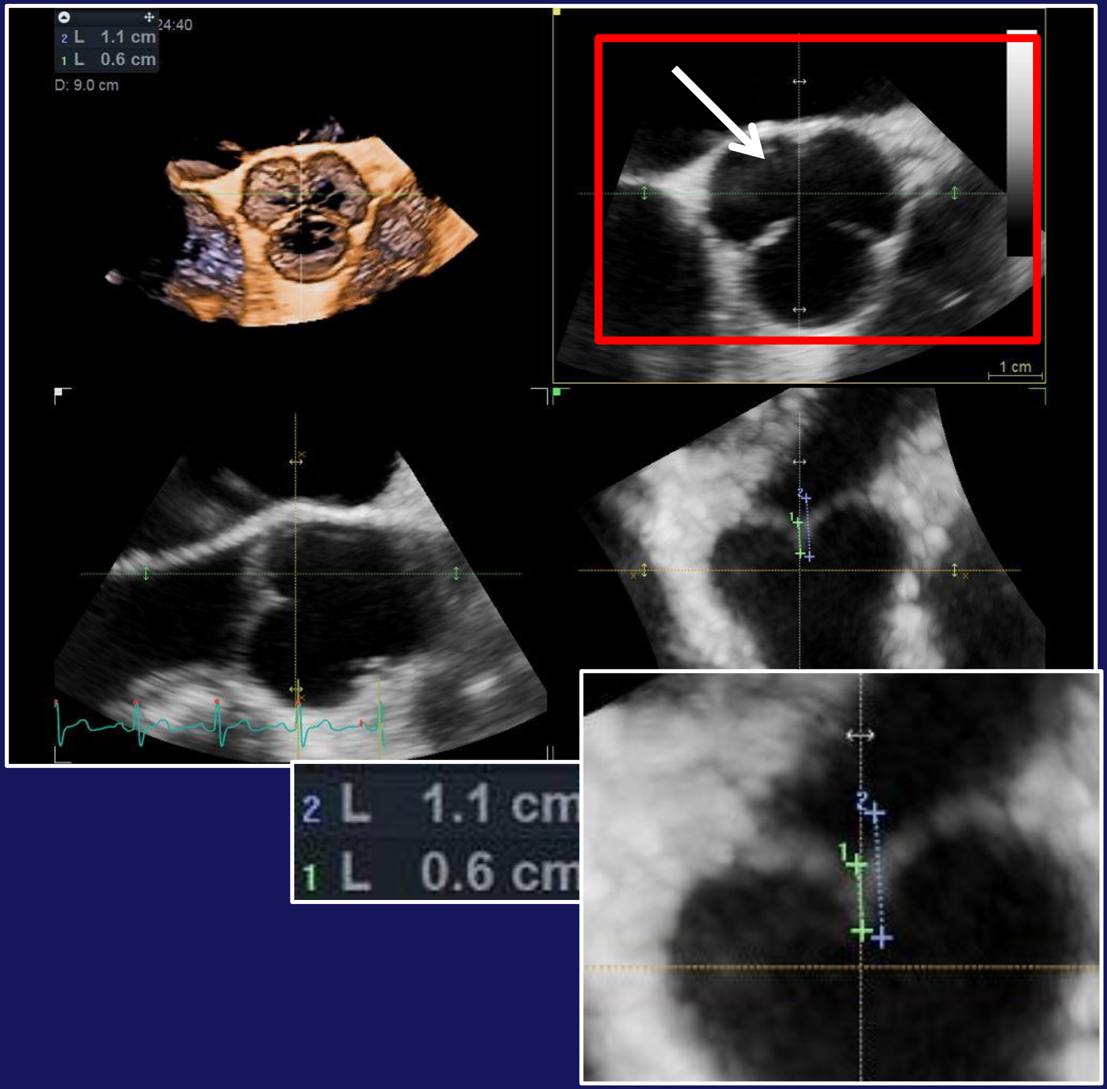
Cusp Geometry: Scheme of the Sectional Planes for Assessment of Effektive Height





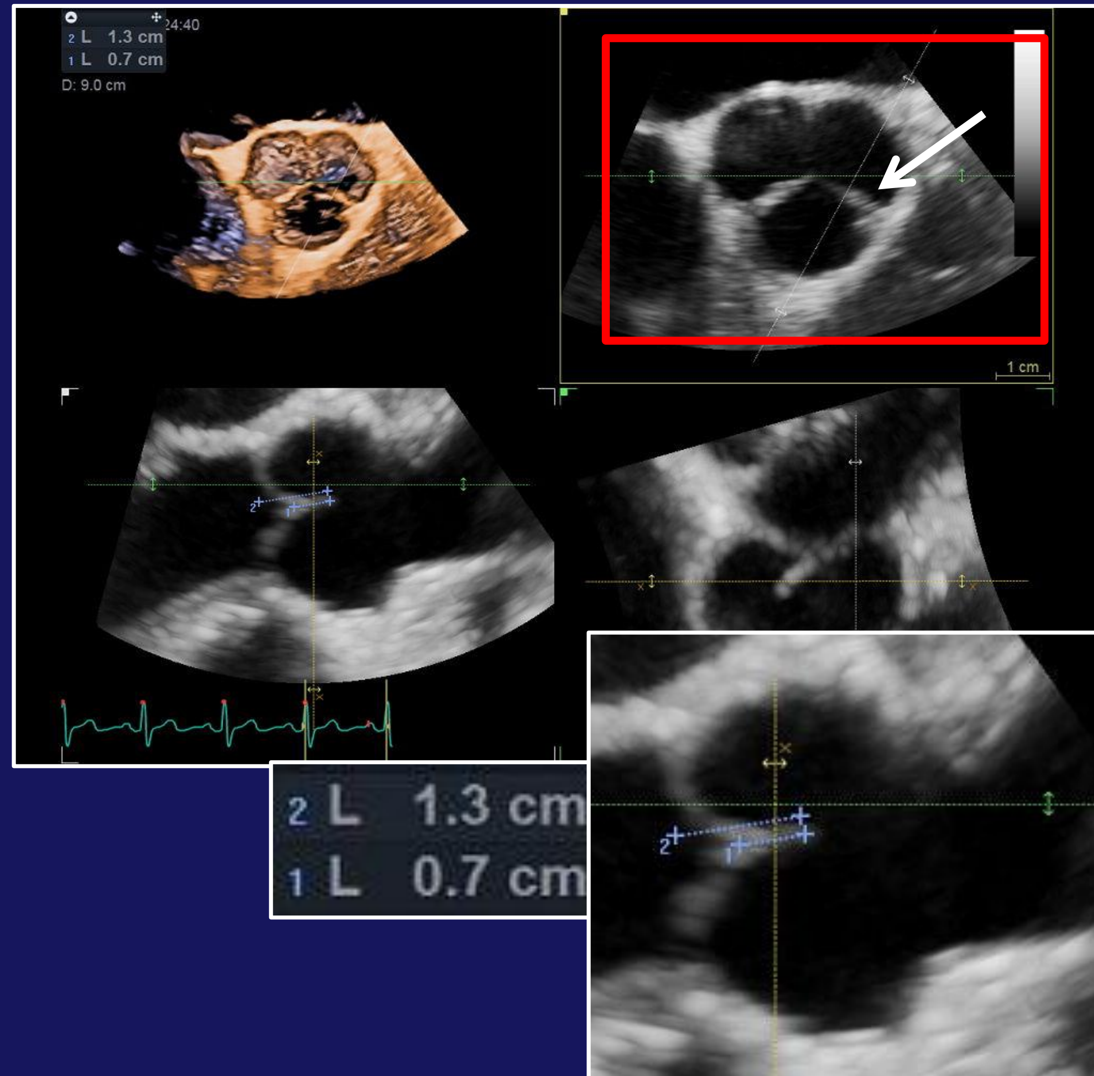
In 2D-TTE and TEE only the exact assessment of the right coronary cusp is possible. The left and non coronary cusp has to be analyzed in 3D data sets.

Assessment of Cusp Geometry: Effective and Geometric Height



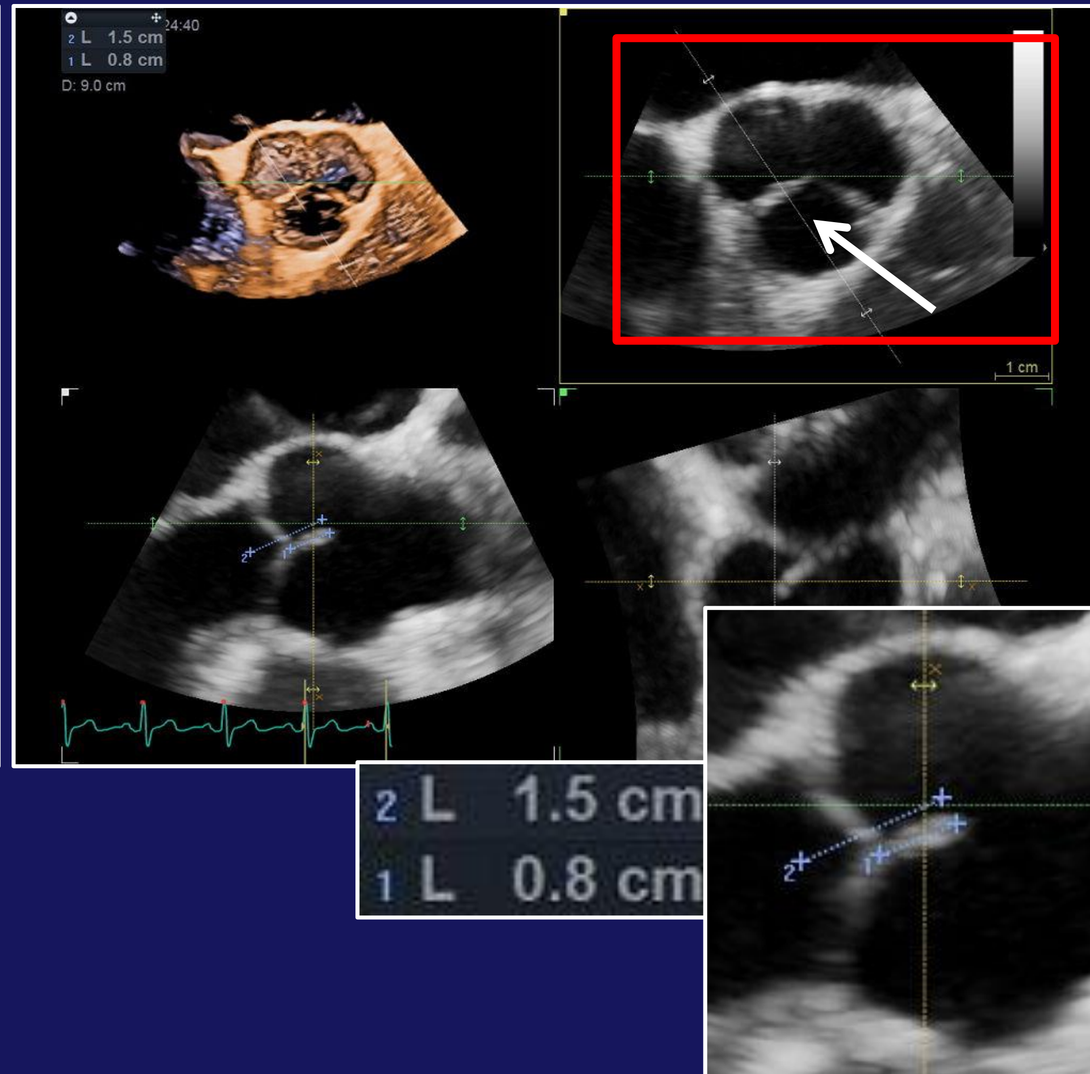
Assessment of the coaptation length and effective height between the left and non coronary cusp

Assessment of Cusp Geometry: Effective and Geometric Height



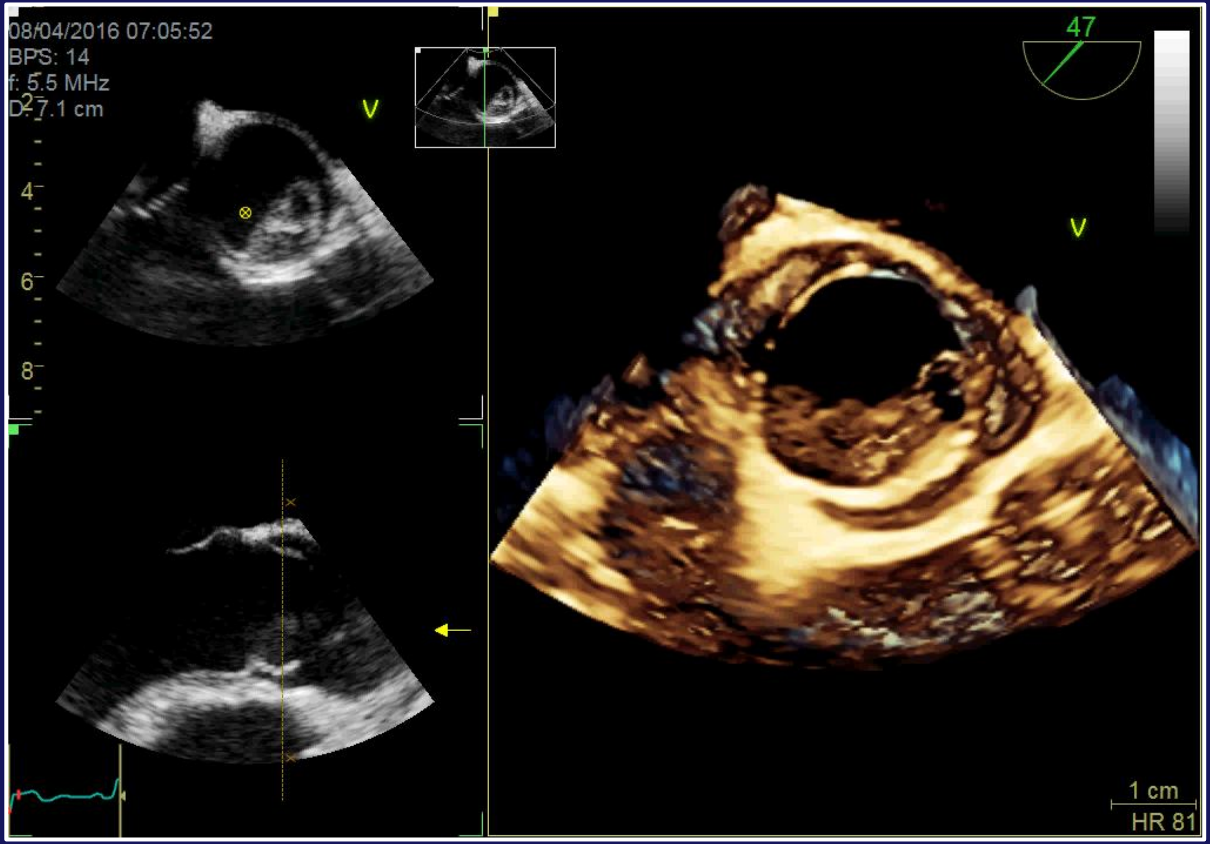
Assessment of the coaptation length and effective height between the left and right coronary cusp

Assessment of Cusp Geometry: Effective and Geometric Height

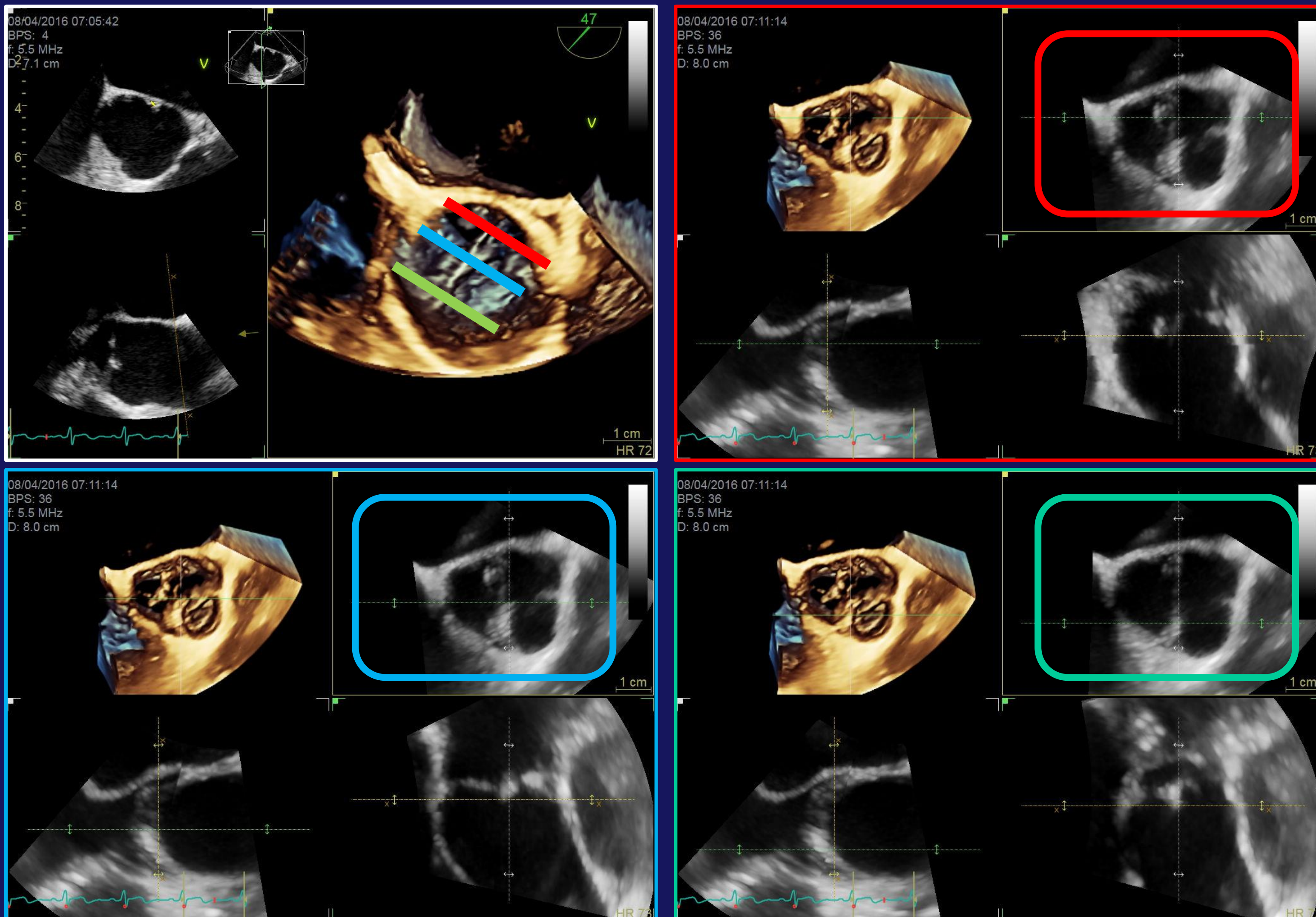


Assessment of the coaptation length and effective height between the right and non coronary cusp

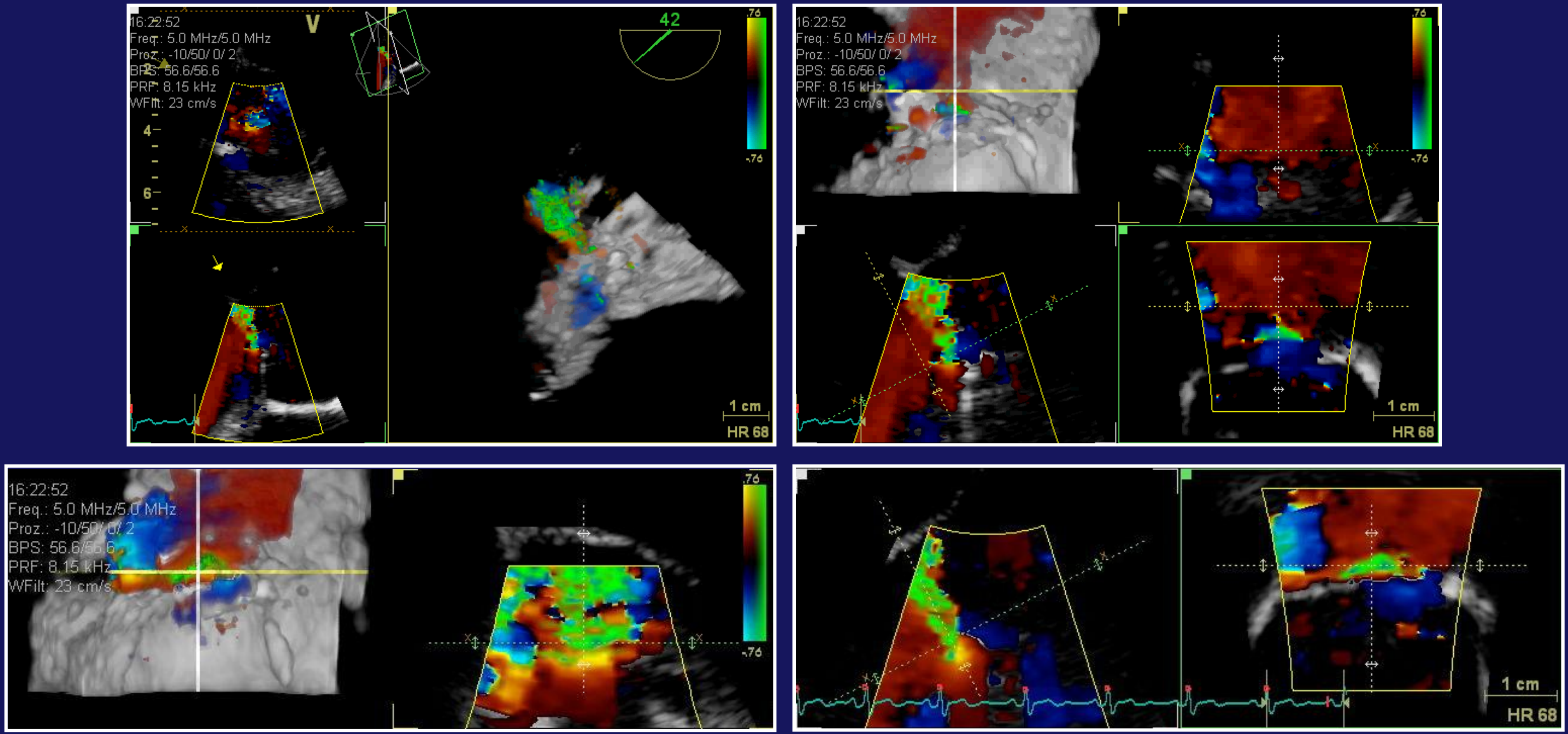
Assessment of Cusp Geometry: Effective and Geometric Height in BAV patients



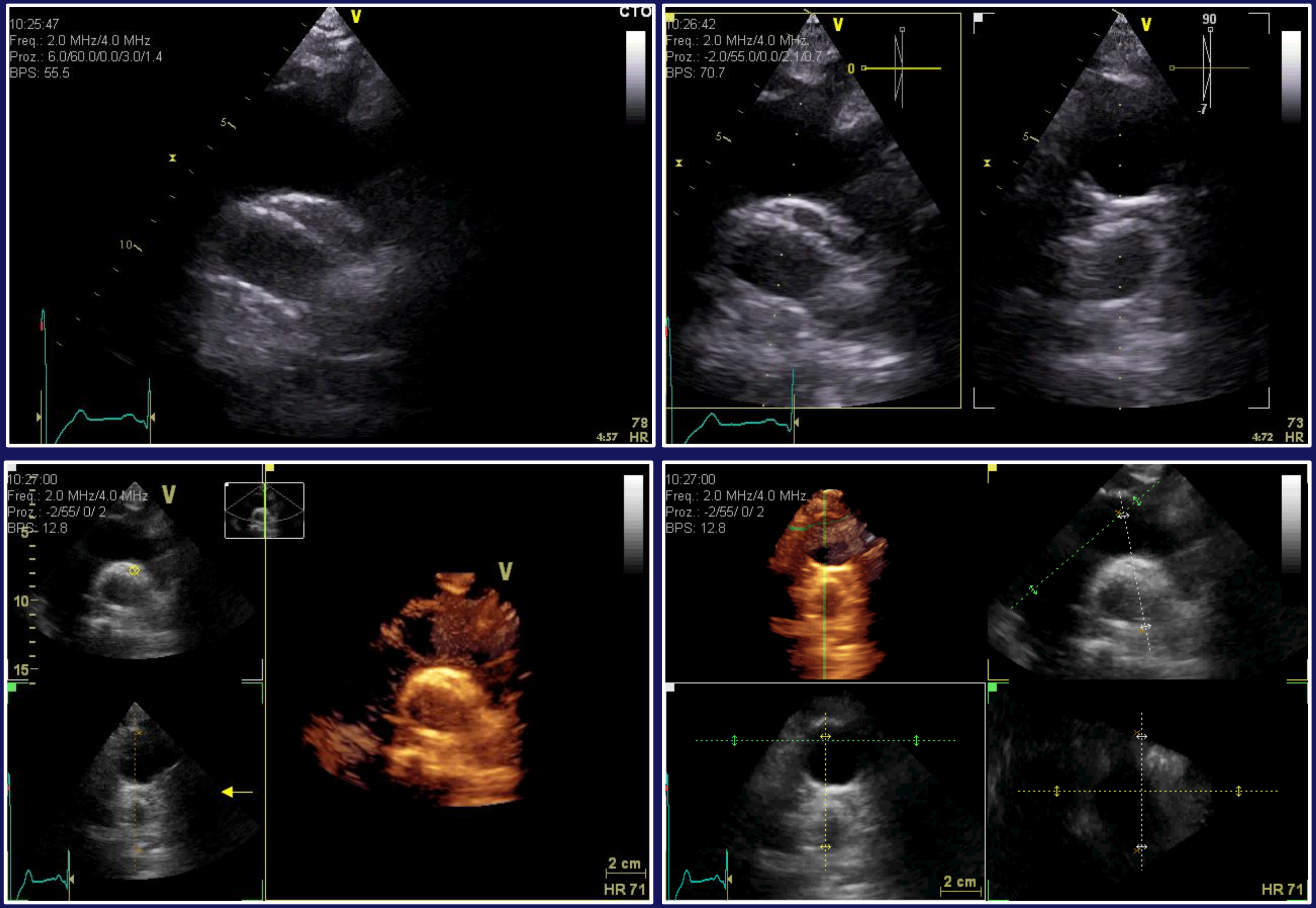
Assessment of Cusp Geometry: Effective and Geometric Height



Additional information and better diagnostic impact: Quantification of an excentric regurgitation in biscuspid aortic valve Case: ERO - 0.1-0.2 cm^2



Multidimensional analysis of aortic arch: Objective measurements of aortic dimensions

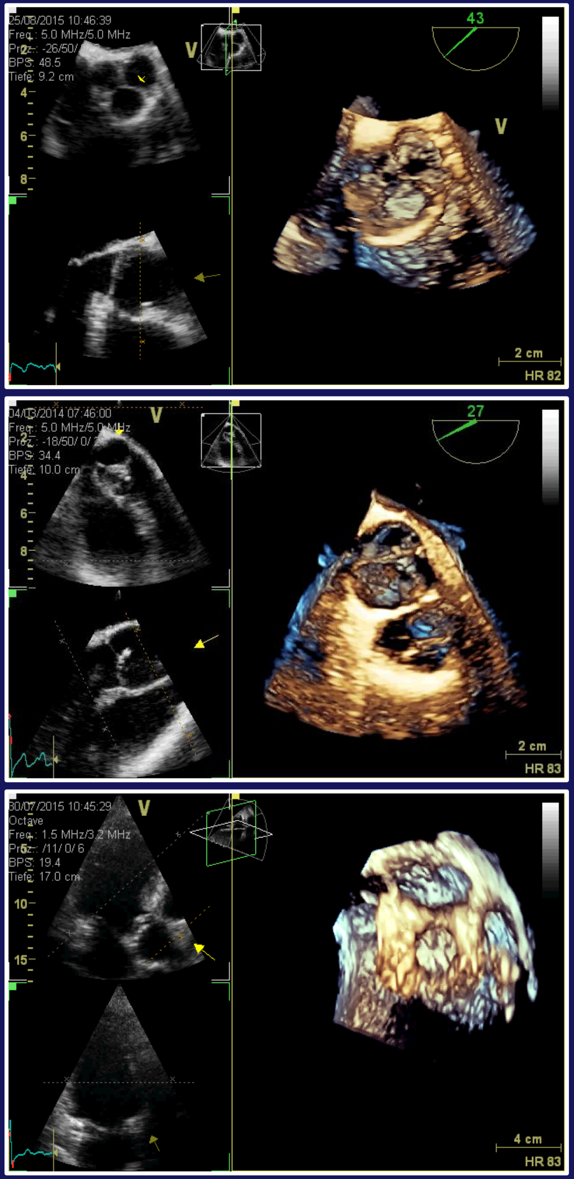


Grading of the severity of aortic regurgitation

- The color flow jet area for AR grading is always wrong.
- All semiquantitative methods have to be checked individually, because they have limitations in special AR scenarios.
- The PHT-method is often misleading and it is the „main producer“ of wrong severe aortic regurgitations due to methodological errors.
- The flow reversal in the subclavian artery is one of the best semiquantitative approaches, e.g. for paravalvular leackages in aortic prosthesis
- Measurements of the LV dimensions, LV volumes and LV ejection fraction are always mandatory inpatients with AR.
- The functional classification of aortic regurgitation should be performed.
- In patients with relevant AR always a quantitative approach of AR grading by determination of total and effective strioke volumes is mandatory.
- If echocardiography is not concise, use cardiac MR.

Summary:

1. 3D echocardiography enables a completely new modality of imaging in echocardiography – the visualization of surfaces (endocardium and the cusps).
2. Biplane and triplane simultaneous sectional planes enables a better and more acurate standardization of imaging with improvement of measurements of anatomical structures.
3. Postprocessing in 3D data sets offers the possibility of new views (e.g. en-face view of the coronary ostia, etc.)
4. Especially for the decicion making and the planning of the surgical strategy 3D echocardiography can provide important informations.
5. The higher the image quality, the better the information.
6. Thus, training and expertise in 3D echocardiography is a prerequisite for a better diagnosis.



Thank You for Your Attention