CMR for Regurgitant Valve Lesions

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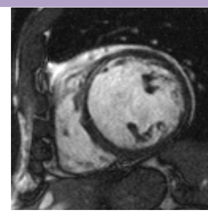
Sequences Needed:

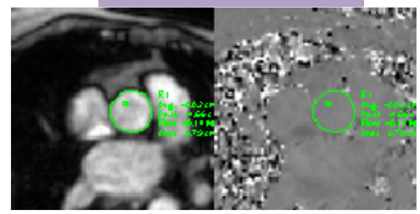
Houston Methodist DeBakey Heart & Vascular Center

CMR For Valve Assessment

Cine-CMR: LV/RV Stroke Volume

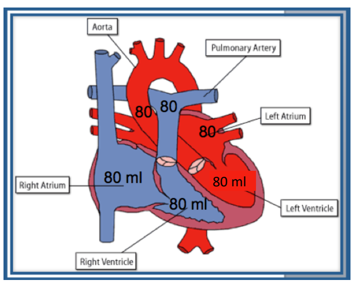


Phase Contrast CMR: Great Vessel Flow



Conservation of Flow Principle

Houston Methodist DeBakey Heart & Vascular Center



LVSV = RVSV = AO Flow = PA Flow

OUTLINE:

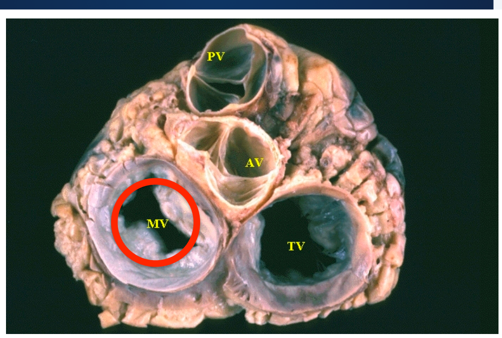
Houston Methodist DeBakey Heart & Vascular Center

- What are the goals of CMR in valve assessment ?
  - Severity of lesion
  - Mechanism of lesion
  - Consequences of lesion

- How does CMR compare to Echo
- When to use CMR for valve assessment

OUTLINE:

Houston Methodist DeBakey Heart & Vascular Center



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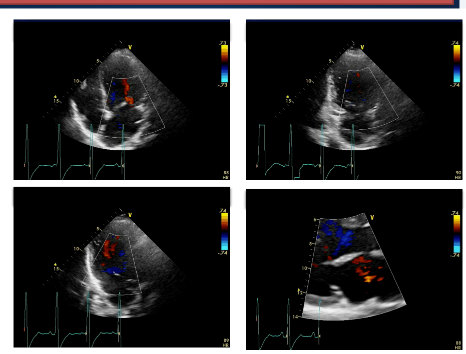
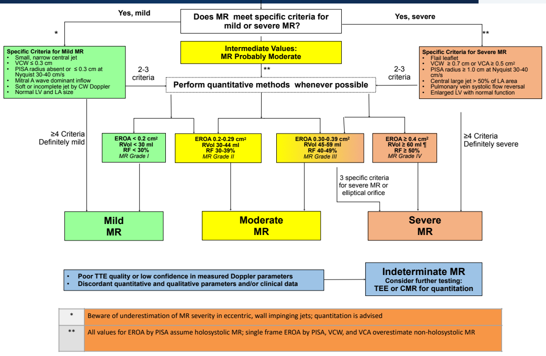
40 year old woman referred for evaluation of murmur.

Houston Methodist DeBakey Heart & Vascular Center



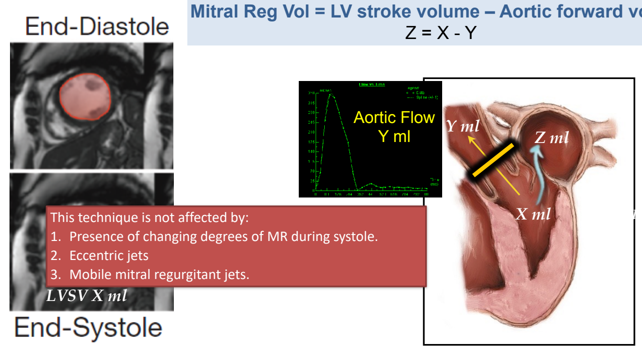
Chronic Mitral Regurgitation by Doppler Echocardiography



Zoghbi et al, JASE 2017

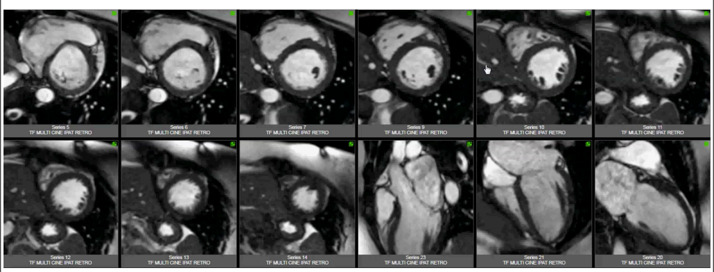
Quantification of Mitral Regurgitation Severity:

Mitral Reg Vol = LV stroke volume – Aortic forward volume
Z = X - Y



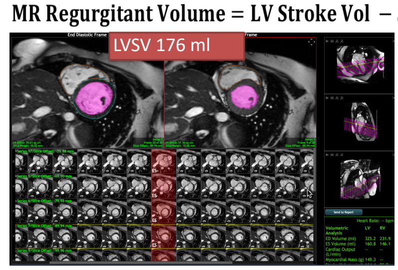
This technique is not affected by:
1. Presence of changing degrees of MR during systole.
2. Eccentric jets
3. Mobile mitral regurgitant jets.

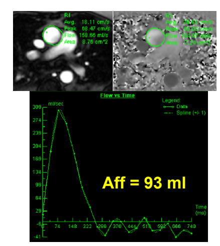
40 year old woman referred for evaluation of mitral regurgitation noted on echo.



MR Regurgitant Volume & Fraction

MR Regurgitant Volume = LV Stroke Vol – Systolic Aortic Forward Flow



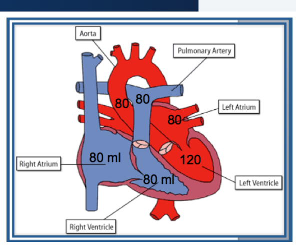


Mitral Reg Vol = LV SV – Aortic FF = 176 – 93 = 83 ml

Regurgitant Fraction (%) = MR regurg vol / MV Flow = 83/176 = 47%

Quantification of MR Severity

- **Mitral Regurgitant Volume** =
  1) LVSV – Aortic Forward Flow
     - Applies even in presence of AI
     - more practical and reproducible than the other methods
  2) LVSV – Net Pulmonary SV
     - AoSV is within 5% of PA SV (in absence of intra-cardiac shunt)
     - Useful in patients with AS, where asc aortic flow may have aliasing
  3) LVSV – RVSV*
     - RVSV less reproducible due to extensive trabeculation of RV
     - Significant concomitant regurgitant lesions invalidates use
     - Useful in setting of atrial fibrillation.
- **Regurg Fraction (%)** = MR Rvol / LVSV*

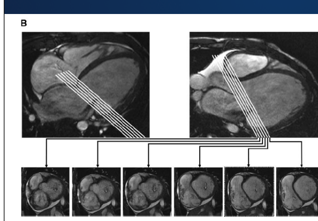


Quantitative Definitions of Severity of Mitral Regurgitation

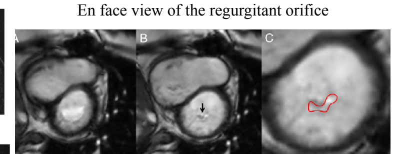
Degree of Regurgitation	Regurgitant Volume (mL/beat)	Regurgitant Fraction
Mild	<30	<30
Moderate	30–59	30–49
Severe	>60	>50

* in absence of concomitant left sided valve lesions

Direct Planimetry of the AROA Using CMR



En face view of the regurgitant orifice

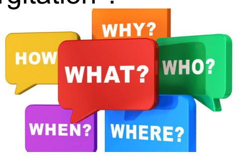


CMR-AROA>0.40cm2 had a 94% sensitivity and specificity for identification of Sellers angiographic grade 3 or 4 MR

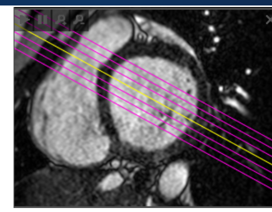
Buchner.Circ Cardiovasc Imaging 2008;1;148-155;

OUTLINE:

- How does CMR assess valve regurgitation ?
  - Severity of lesion
  - Mechanism of lesion
  - Consequences of lesion
- How does CMR compare to Echo for regurgitation assessment
- When to use CMR for valve regurgitation



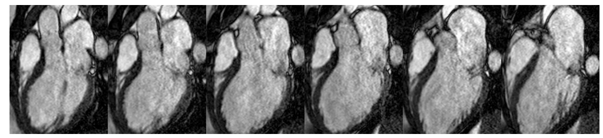
Mechanism of MR:



"En face" or short axis view of the MV

Long axis views of the MV

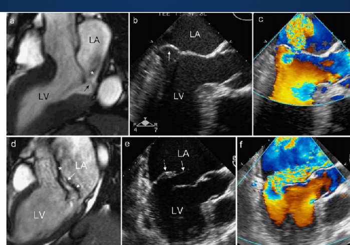
A1-P1 → A2-P2 → A3-P3



Mechanism of MR:

Prolapse

Flail



CMR is inferior to TEE in depicting torn chordae.

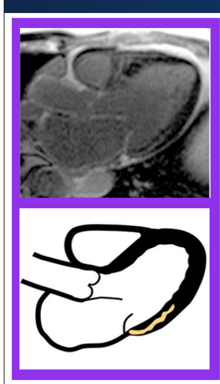
		Sensitivity	Specificity	Accuracy
AML	TEE (*n*=36)	75	96	92
	MRI (*n*=35)	71	96	91
PML	TEE (*n*=36)	86	93	89
	MRI (*n*=35)	86	100	91

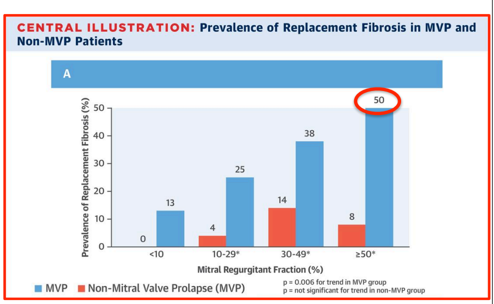
Stork A.Eur Radiol (2007) 17: 3189–3198

OUTLINE:

- How does CMR assess valve regurgitation ?
  - Severity of lesion
  - Mechanism of lesion
  - Consequences of lesion
    - LV Enlargement
    - LV Dysfunction
    - LA Enlargement
    - Myocardial Fibrosis

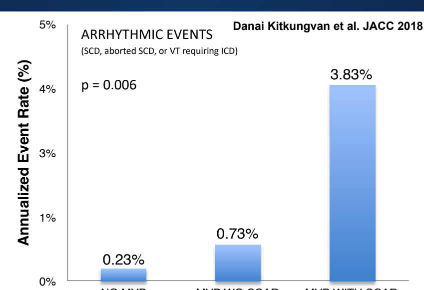
Fibrosis in Mitral Valve Prolapse





Danai Kitkungvan et al. JACC 2018;72:823-834

ARRHYTHMIC EVENTS AND MVP:

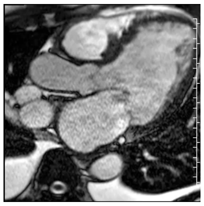


PATIENTS WITH MVP AND REPLACEMENT FIBROSIS HAD THE HIGHEST RATE OF ARRHYTHMIC EVENTS

TYPES OF MITRAL REGURGITATION

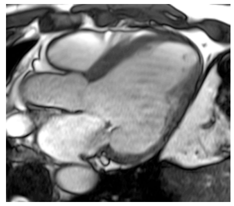
Mitral Regurgitation

Primary MR



Anatomic abnormality of the mitral valve

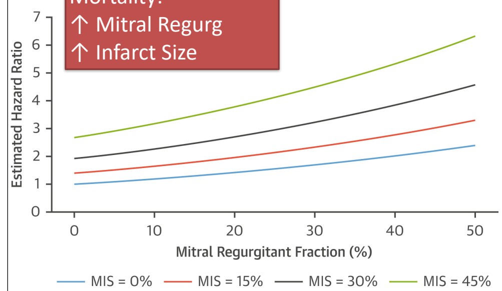
Secondary MR

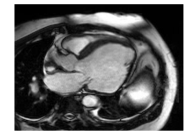


Abnormality of the myocardium NOT valve

Prognosis in Ischemic Secondary MR Is Influenced by MRF and Infarct Size

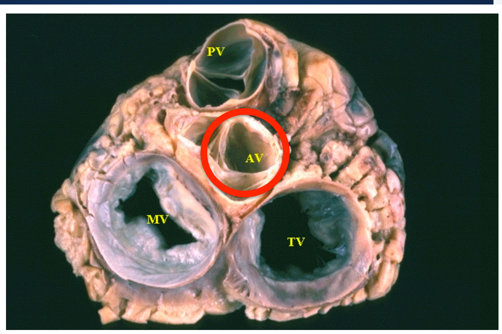
Mortality:
↑ Mitral Regurg
↑ Infarct Size





Cavalcante et al, JACC Cardiovascular Imaging 2019

OUTLINE:



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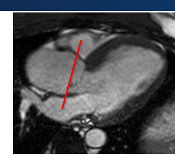
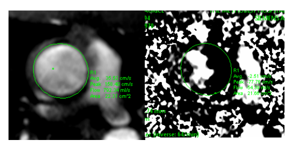
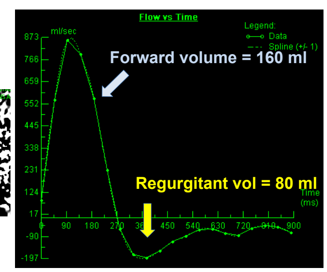
Quantification of AI Severity





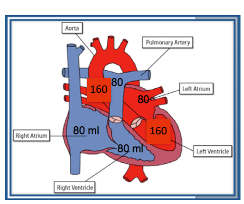


Lopez-Mattei.Methodist Debakey Cardiovasc J. 2013 Jul-Sep;9(3):142-8

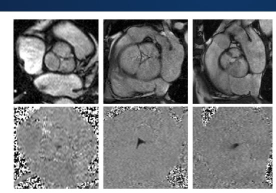
Quantification of AI Severity

Aortic Regurgitant Volume =

1. Direct measurement of regurgitant flow
2. Indirect methods:
   - ✦ LVOT FF - Pulmonic Net
   - ✦ LVSV - RVSV



Regurgitant Fraction (%) = $\frac{\text{AI Regurg Volume}}{\text{AV Flow}}$

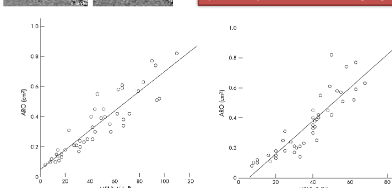


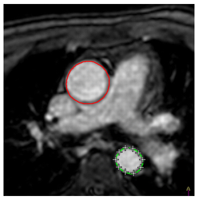
- Debl et al, Heart 2008

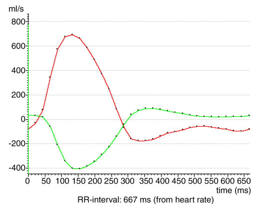
Table 3 MRI-planimetry of ARO, predictive values

	Cases/total (n)	ARO-cutoff (cm^2)	ROC-area (95% CI)	Sensitivity/ specificity (%)
MRI-AR ⩾III	26/45	0.28	0.99 (0.99 to 1.0)	96/95
CATH-AR ⩾III	21/32	0.28	0.95 (0.85 to 1.0)	90/91
MRI-AR IV	13/45	0.48	0.97 (0.90 to 1.0)	83/97

ARO > 0.28 had more than 90% sensitivity/ specificity for 3+ Aortic Regurgitation







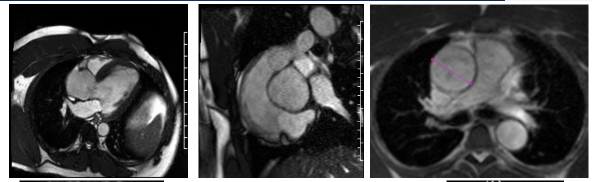
80 pts

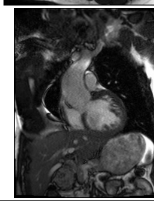
TTE Grade	Sensitivity (%)	Specificity (%)	Odds Ratio	P Value
4	100	93	164 (8)	<.001
3 or 4	61	100	192 (10)	<.001

Holodiastolic Flow Reversal: defined as flow reversal with a minimum flow of 10 mL/sec that persists through the entirety of diastole.

- Bolen et al, Radiology 2011

Bicuspid AI

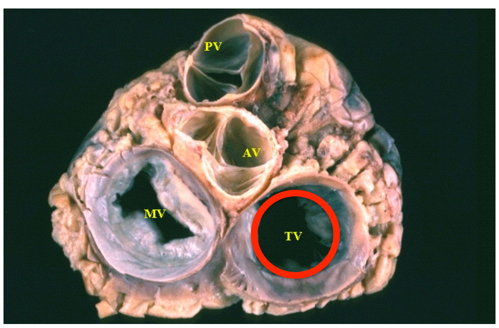




39 yr old with SOB:

- -Moderately enlarged LA and LV
- -Normal LV and RV systolic fxn
- -Bicuspid aortic valve with severe AI(RV 80 ml, RF 50%)
- -Severely dilated aortic root (5.3 cm at the sinus)
- - Moderately dilated ascending aorta (5.2 cm)

OUTLINE:



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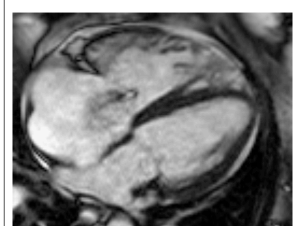
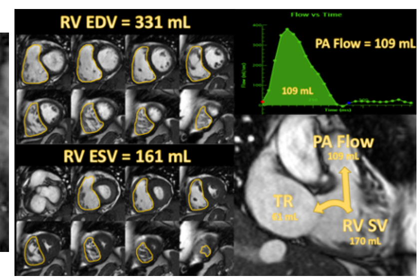
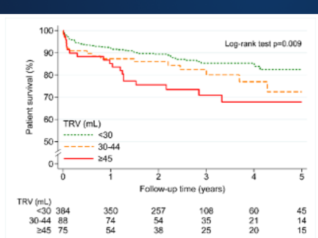
Functional Tricuspid Regurgitation

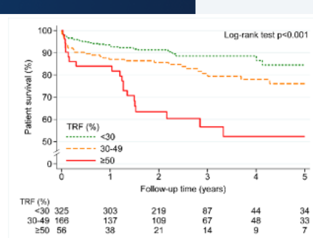




Zhan et al, Journal American College of Cardiology, 2020.

Functional Tricuspid Regurgitation



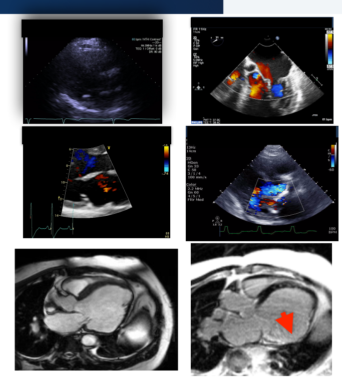


Tricuspid regurgitation severity quantified by CMR is independently associated with mortality even after adjusting for clinical and imaging covariates including RVEF, MR severity, and PA pressures

Zhan et al, Journal American College of Cardiology, 2020.

Conclusion:

- Technically difficult transthoracic echocardiography
- Discordance between Hx, PE, 2D, Doppler findings
- Eccentric Regurgitant Jets
- Non-holosystolic Regurgitant Jets
- Multiple Regurgitant Jets (i.e. MR and AR)
- Determine the consequences of the valve lesion
  - Quantification of LV volumes
  - Quantification of LVEF
  - Assessment of myocardial viability/scar



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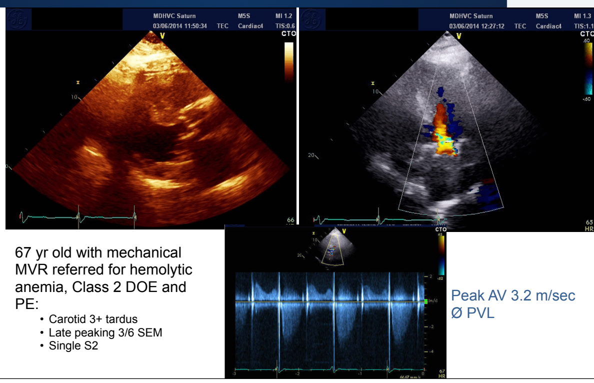
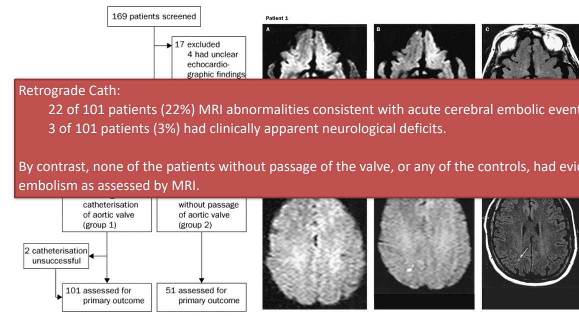


67 yr old with mechanical MVR referred for hemolytic anemia, Class 2 DOE and PE:

- Carotid 3+ tardus
- Late peaking 3/6 SEM
- Single S2

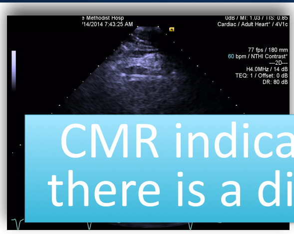
Peak AV 3.2 m/sec
Ø PVL



Retrograde Cath:
22 of 101 patients (22%) MRI abnormalities consistent with acute cerebral embolic events
3 of 101 patients (3%) had clinically apparent neurological deficits.

By contrast, none of the patients without passage of the valve, or any of the controls, had evidence of cere[l]
embolism as assessed by MRI.

Oman et al, Lancet 2003 .



- Suboptimal acoustic windows

se

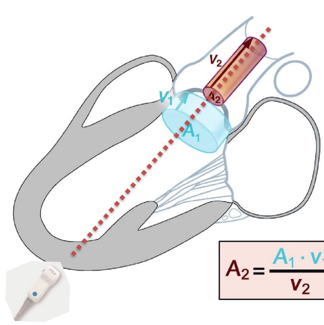
CMR indicated when there is a discordance

Clinical Hx and PE = AV Gradient = AV Area

	MILD	MODERATE	SEVERE
Aortic Jet Velocity (m/sec)	2.6 - 2.9	3.0 - 4.0	> 4.0
Mean Gradient (mm HG)	< 20	20 - 40	> 40
AVA (cm^2)	> 1.5	1.0 - 1.5	< 1.0
Indexed AVA (cm^2/m^2)	> 0.85	0.60 - 0.85	< 0.6
Velocity Ratio	> 0.50	0.25 - 0.50	< 0.25

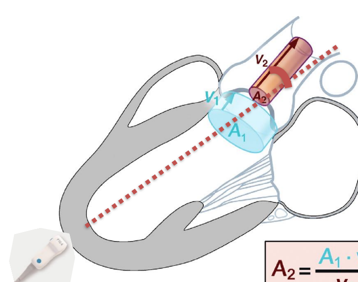
All measures of AS severity are derived from CW across the aortic valve

Baumgartner et al JASE 2009.



$$A_2 = \frac{A_1 \cdot v_1}{v_2}$$

Helmut Baumgartner et al. Eur J Echocardiogr 2009;10:1-25



$$A_2 = \frac{A_1 \cdot v_1}{v_2}$$

Helmut Baumgartner et al. Eur J Echocardiogr 2009;10:1-25

Goal of Imaging in Valvular Stenosis:

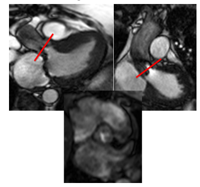
Severity
Velocity and Valve Area

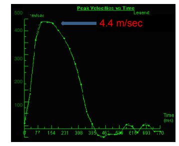
Mechanism
Bicuspid

Consequence
Volumes & function

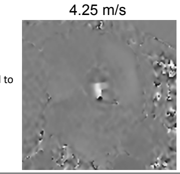
LV viability & Contractile Reserve

Magnitude

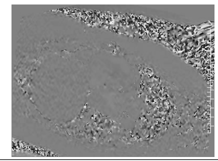




4.25 m/s

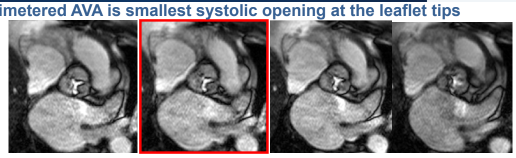


4.50 m/s

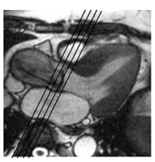


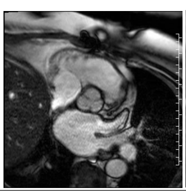
- Peak and Mean Velocity
- Continuity Equation can be used to derive EOA

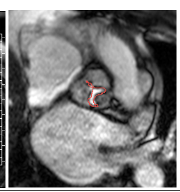
Planimetered AVA is smallest systolic opening at the leaflet tips



Thin (≤4mm) overlapping slices







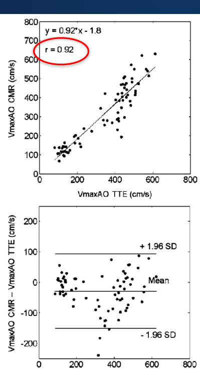
AVA 0.8 cm sq.

Clinical Hx and PE = AV Gradient = AV Area

CMR IS ABLE TO PROVIDE 2 INDEPENDENT MEASURES OF AS SEVERITY:

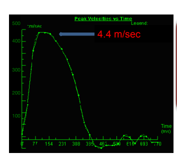
1. VELOCITY
2. ANATOMIC ORIFICE AREA

Concordance

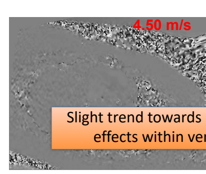


- Imaging plane NOT perpendicular to flow
- Partial volume averaging
- Signal loss in turbulent jets
- Phase shift errors due to fast acceleration
- Lower temporal resolution
- Irregular heart rhythm

Defrance. *Circ Cardiovasc Imaging.* 2012;5:604-612



First Author (Year)	Principle	Reference Standard	n	r	Mean Difference±1 SD (CMR−Echo)
Velocity/gradients					
Kilner[23] (1993)	$\dot{V}_{max}$	TTE	26†	...	−0.10±0.46 m/s
Eichenberger[24] (1993)	peak ΔP	TTE	15	...	2.6±13.3 mm Hg
	mean ΔP			0.96	−0.6±8.5 mm Hg
Caruthers[26] (2003)	peak ΔP	TTE	24	0.82	...
	mean ΔP			0.87	

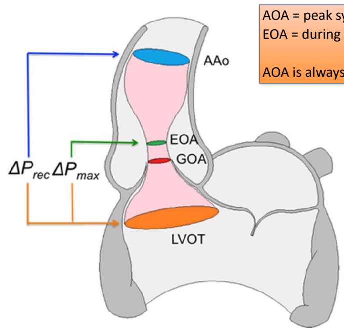


Slight trend towards underestimation by CMR due to partial volume effects within vena contracta and lower temporal resolution

Anatomic Orifice Area and Effective Orifice Area are not the same

AOA = peak systole
EOA = during entire systolic period

AOA is always ≥ EOA



Neelakantan Saikrishnan et al. Circulation. 2014;129:244-253

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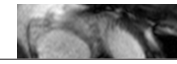
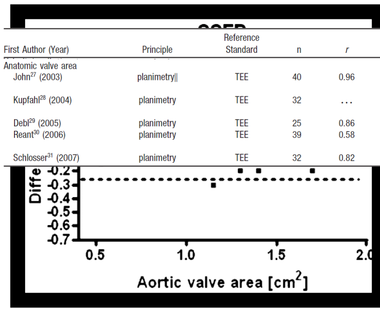
32 pts





First Author (Year)	Principle	Reference Standard	n	r	Mean Difference±1 SD (CMR−Echo)	CMR Reproducibility*: Mean Difference±1 SD
Anatomic valve area						
John[27] (2003)	planimetry‖	TEE	40	0.96	0.02±0.08 cm²¶	0.07±0.06 cm²‡ 0.05±0.04 cm²#
Kupfahl[28] (2004)	planimetry	TEE	32	…	0.02±0.21 cm²	0.03±0.05 cm²‡ −0.02±0.06 cm²#
Debl[29] (2005)	planimetry	TEE	25	0.86	0.13±0.16 cm²¶	…
Reant[30] (2006)	planimetry	TEE	39	0.58	0.01±0.14 cm² (Echo−CMR)	0.03±0.14 cm²‡ 0.02±0.07 cm²#
Schlosser[31] (2007)	planimetry	TEE	32	0.82	0.15±0.13 cm²	0.75**‡

Shlosser.Eur Radiol (2007) 17: 1284–1290

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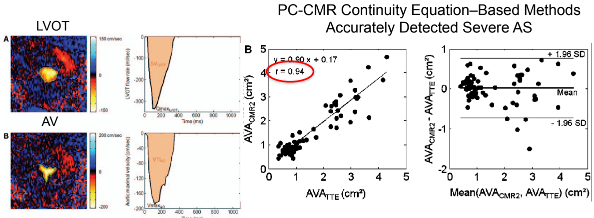
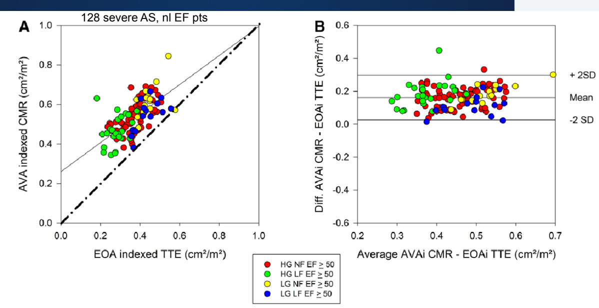
53 AS patients (AVA TTE=0.87±0.44 cm2) and 21 controls

PC-CMR Continuity Equation–Based Methods Accurately Detected Severe AS



$$(Continuity\ Equation)\ AVA = \frac{LVOT\ area\ x\ VTI\ LVOT}{VTI\ Ao} = \frac{SV\ LVOT}{VTI\ Ao}$$

Defrance.*Circ Cardiovasc Imaging*. 2012;5:604-612

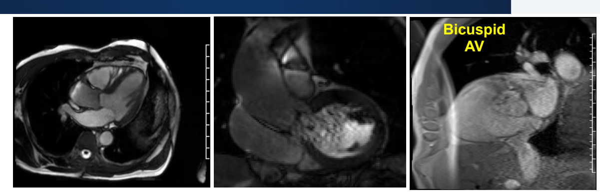


Continuity equation assesses the effective orifice area (EOA), which is always smaller than the actual anatomic orifice & correlates better with clinical outcome

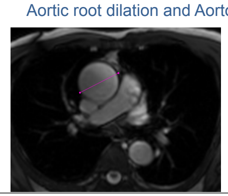
Barone-Rochette.*Circ Cardiovasc Imaging*. 2013;6:1009-1017

Goal of Imaging in Valvular Stenosis:

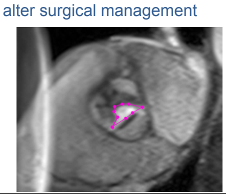
Severity	Mechanism	Consequence	LV viability & Contractile Reserve
Velocity and Valve Area	Bicuspid	Volumes & function	



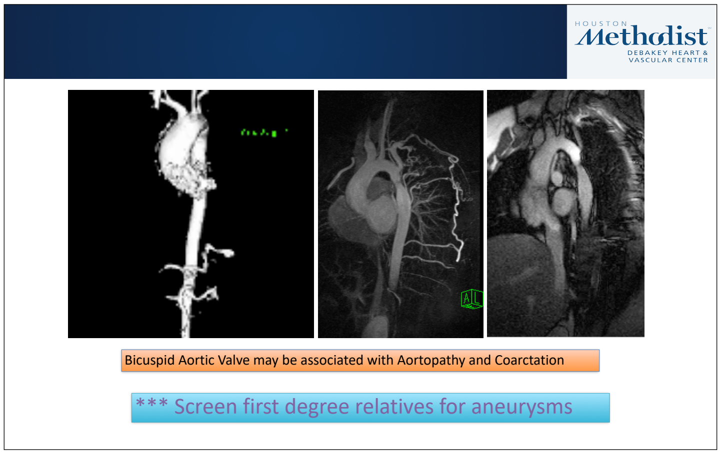
Aortic root dilation and Aortopathy alter surgical management

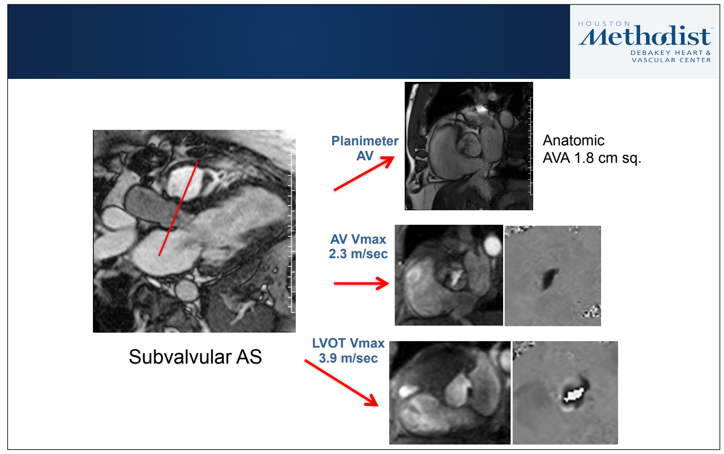


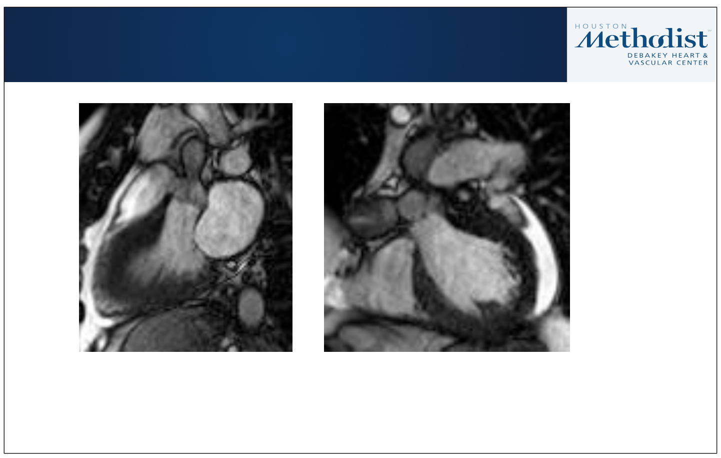
5.0cm
Asc
Aorta

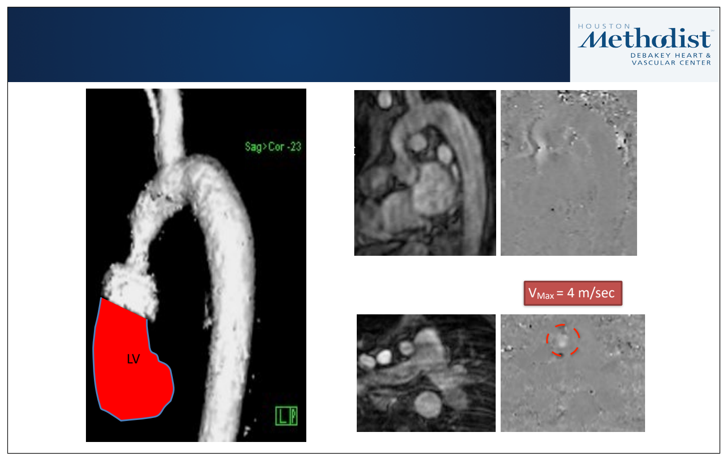


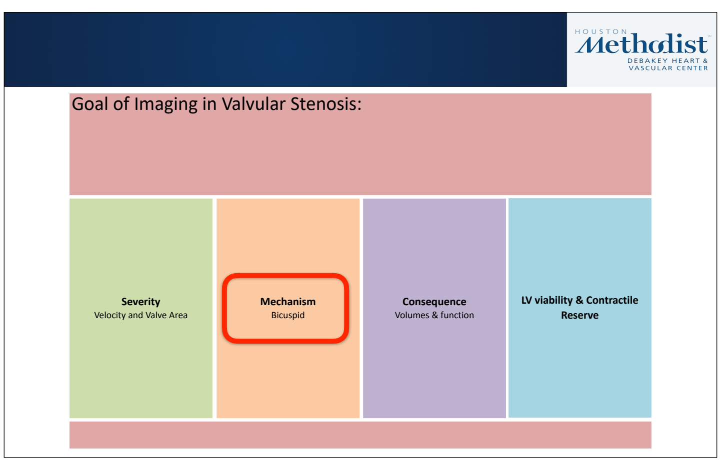
AVA
1.1
cm sq.

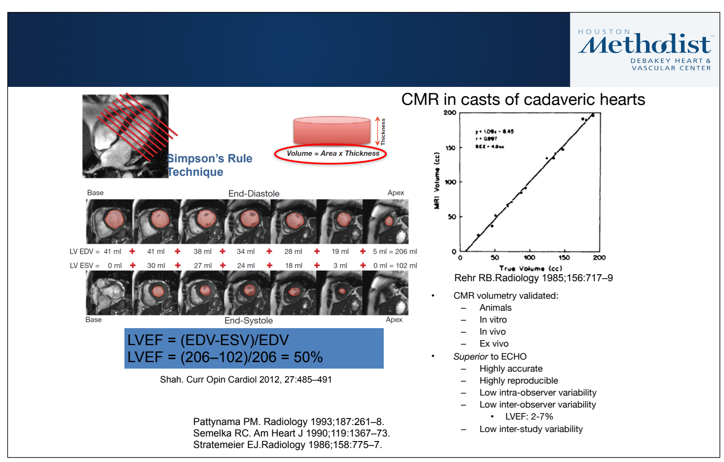

HOUSTON Methodist DEBAKEY HEART & VASCULAR CENTER
Bicuspid Aortic Valve may be associated with Aortopathy and Coarctation
*** Screen first degree relatives for aneurysms


HOUSTON Methodist DEBAKEY HEART & VASCULAR CENTER
Planimeter AV
Anatomic
AVA 1.8 cm sq.
AV Vmax
2.3 m/sec
Subvalvular AS
LVOT Vmax
3.9 m/sec

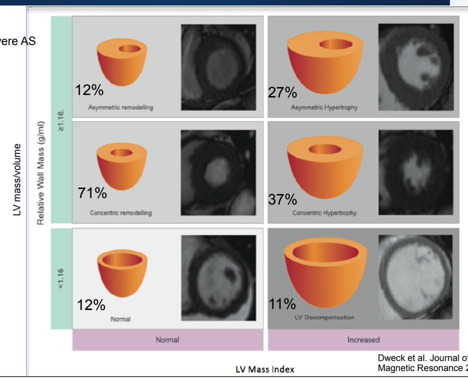

HOUSTON Methodist DEBAKEY HEART & VASCULAR CENTER


HOUSTON Methodist DEBAKEY HEART & VASCULAR CENTER
Sag>Cor -23
LV
VMax = 4 m/sec


HOUSTON Methodist DEBAKEY HEART & VASCULAR CENTER
Goal of Imaging in Valvular Stenosis:
Severity
Velocity and Valve Area
Mechanism
Bicuspid
Consequence
Volumes & function
LV viability & Contractile Reserve


HOUSTON Methodist DEBAKEY HEART & VASCULAR CENTER
Simpson's Rule Technique
Volume = Area x Thickness
Thickness
Base
End-Diastole
Apex
LV EDV = 41 ml + 41 ml + 38 ml + 34 ml + 28 ml + 19 ml + 5 ml = 206 ml
LV ESV = 0 ml + 30 ml + 27 ml + 24 ml + 18 ml + 3 ml + 0 ml = 102 ml
Base
End-Systole
Apex
LVEF = (EDV-ESV)/EDV
LVEF = (206–102)/206 = 50%
Shah. Curr Opin Cardiol 2012, 27:485–491
Pattynama PM. Radiology 1993;187:261–8.
Semelka RC. Am Heart J 1990;119:1367–73.
Stratemeier EJ.Radiology 1986;158:775–7.
CMR in casts of cadaveric hearts
MRI Volume (cc)
True Volume (cc)
Rehr RB.Radiology 1985;156:717–9
• CMR volumetry validated:
– Animals
– In vitro
– In vivo
– Ex vivo
• Superior to ECHO
– Highly accurate
– Highly reproducible
– Low intra-observer variability
– Low inter-observer variability
• LVEF: 2-7%
– Low inter-study variability

91 pts
mod-severe AS



Dweck et al. Journal of Cardiovascular Magnetic Resonance 2012, 14:50

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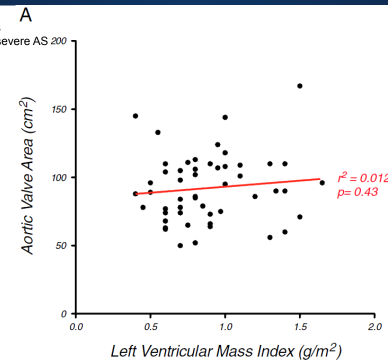
91 pts
mod-severe AS



Might explain the marked heterogeneity between the severity of valve stenosis and symptom onset

Dweck et al. Journal of Cardiovascular Magnetic Resonance 2012, 14:50

TABLE 3. CMR Data

	Stented (n=23)		Stentless (n=15)	
	Preoperative	6 Months	Preoperative	6 Months
LVMI, g/m²	129±46	104±45	134±41	100±28
LV mass, g	244±94	195±87	244±76	183±53
Ejection fraction, %	68±15	71±11	69±19	76±12
LV end-diastolic volume, median (interquartile range), mL	129 (100, 197)	109 (88, 149)	134 (95, 194)	99 (82, 123)
LV end-systolic volume, median (interquartile range), mL	35 (23, 69)	31 (21, 49)	29 (15, 113)	22 (11, 32)

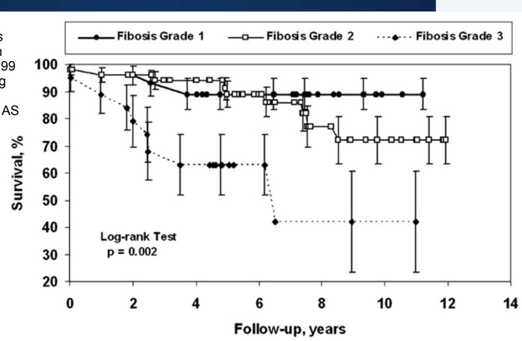
Values are mean±SD unless indicated otherwise.

Perez de Arenaza D et al. Circulation 2005;112:2696-2702

Goal of Imaging in Valvular Stenosis:

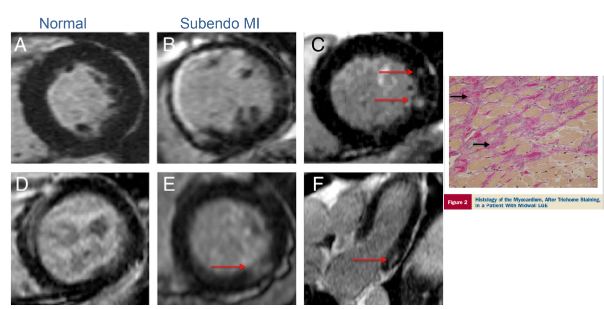
Severity	Mechanism	Consequence	LV viability & Contractile Reserve
Velocity and Valve Area	Bicuspid	Volumes & function	

Biopsy specimens taken from septum in 99 undergoing AVR for severe AS



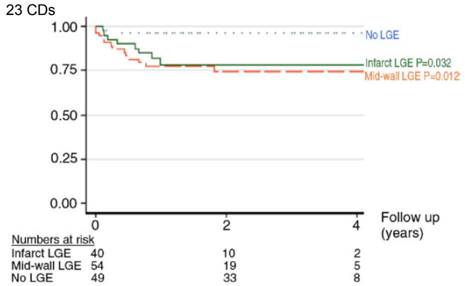
Patients with severe myocardial fibrosis had a dilated left ventricle and lower EFs

Milano.J Thorac Cardiovasc Surg 2012;144:830-7



Midwall fibrosis

Dweck. J Am Coll Cardiol 2011;58:1271–9



Midwall fibrosis (n =54) had an *6-fold increase* in cardiac mortality despite similar AS severity and CAD burden

Figure 4 **Kaplan-Meier Survival Estimates by Pattern of LGE for Cardiac Mortality in 143 Patients With Moderate or Severe Aortic Stenosis**

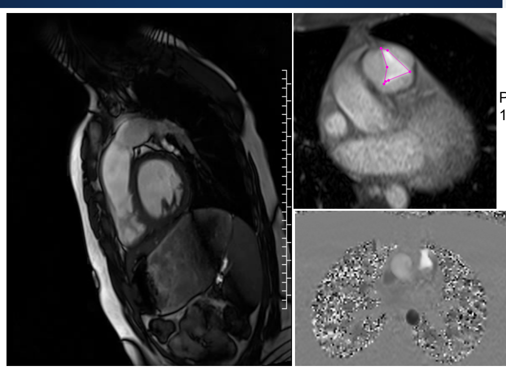
Dweck. J Am Coll Cardiol 2011;58:1271–9

Table 4 **Cox Regression Multivariate Analysis for All-Cause Mortality**

Variable	Hazard Ratio	95% Confidence Interval	p Value
Ejection fraction	0.96	0.94–0.99	0.01
Indexed LVEDV	0.68	0.18–2.61	0.57
Midwall LGE	5.35	1.16–24.56	0.03
Infarct LGE	2.56	0.48–13.64	0.27
Subsequent AVR	0.32	0.13–0.76	0.01

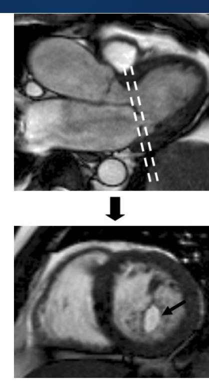
LGE potential to provide additional prognostic information for risk stratification in severe AS patients

Dweck. J Am Coll Cardiol 2011;58:1271–9



Pulmonic VA 1.8 cm sq.

Peak Velocity 2.25 m/sec



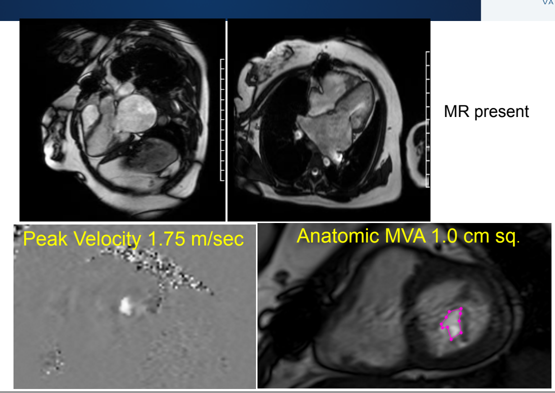
Multiple parallel thin slices helpful to position the plane at the leaflet tips

Myerson Journal of Cardiovascular Magnetic Resonance 2012, 14:7

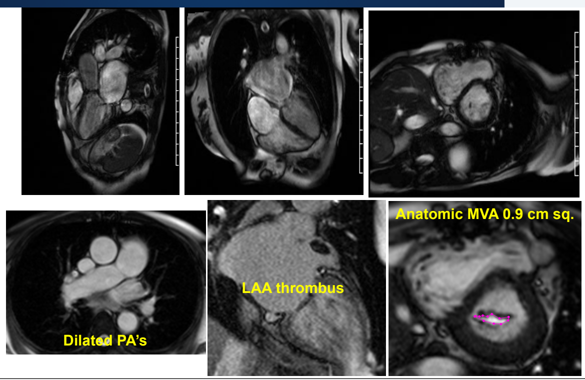
First Author (Year)	CMR Method	Reference Standard: Method	n	r	Mean Difference±1 SD (CMR−Other Modality)	CMR Reproducibility*: Mean Difference±1 SD
Velocity/gradients						
Mohiaddin[32] (1991)	$\dot{V}_{max}$	TTE: $\dot{V}_{max}$	5	…	−0.12±0.27 m/s	…
Kilner[23] (1993)	$\dot{V}_{max}$	TTE: $\dot{V}_{max}$	26†	…	0.10±0.46 m/s	0.11+0.29 m/s‡
Hartiala[33] (1993)	E velocity	TTE: E velocity	10§	0.68	…	0.16%‡§
	A velocity	TTE: A velocity		0.83		0.68%‡§
Heidenreich[34] (1995)	peak ΔP	TTE: peak ΔP	14	0.89	Vmax: 0.38±0.2 m/s	0.001 m/s‡
	mean ΔP	TTE: mean ΔP		0.95	(Echo−CMR)	
Valve areas						
Lin[35] (2004)	T½, T2	TTE: T½	17	0.86	0.5±0.59 cm^2	r=0.96‡
Djavidani[36] (2005)	planimetry	TTE: T½	22	0.81	0.13±0.24 cm^2‖	0.03±0.01 cm^2‡¶
		catheterization: Gorlin	17	0.89	0.08±0.22 cm^2‖	0.04±0.02 cm^2#¶
Djavidani[37] (2006)	planimetry**	TTE: T½	13	0.98	0.03±0.09 cm^2‖	…
		catheterization: Gorlin	13	0.95	0.13±0.15 cm^2‖	

Atrial fibrillation reduces accuracy of the flow measurements

Cawley. *Circulation*. 2009;119:468-478



MR present



VALVUL

Thank You For Your Attention

SIS

- Paravalvular Regurgitation
- Eccentric Regurgitant Jets
- Multiple Regurgitant Jets
- Serial Assessments of RVol

- Discrepancy Btw PE, 2D, Doppler
- Suboptimal Echo Windows
- Multiple Valvular Lesions
- Assessment of LV volumes & EF
- Valve Morphology (Bicuspid)

- Suboptimal Doppler Alignment
- Discrepancy Between Velocity and Area
- Thoracic Aorta
- Subvalvular or Supravalvular Obstruction