UNIVERSITÀ
DEGLI STUDI
DI PADOVA

INTEGRAZIONE CLINICA TRA LE TECNICHE NELLO STUDIO DELLE VALVULOPATIE: LA RMC

Alberto Cipriani, MD, FESC
Associate Professor of Cardiology
University of Padua
alberto.cipriani@unipd.it

OUTLINE

- CMR in Guidelines recommendations
- Valve regurgitation
- Valve stenosis
- Combined valve disease

ESC European Society of Cardiology

European Heart Journal (2022) **43**, 561–632
https://doi.org/10.1093/eurheartj/ehab395

ESC/EACTS GUIDELINES

2021 ESC/EACTS Guidelines for the management of valvular heart disease

Dalle precedenti del 2017, emerse novità in merito a

1. Epidemiologia
2. Diagnostica non invasiva
3. Terapia anti-trombotica peri e post procedurale
4. Stratificazione del rischio per il timing ad intervento
5. Risultati e indicazioni all'intervento (chirurgia vs transcatetere)

ESC European Society of Cardiology

European Heart Journal (2022) **43**, 561–632
https://doi.org/10.1093/eurheartj/ehab395

ESC/EACTS GUIDELINES

2021 ESC/EACTS Guidelines for the management of valvular heart disease

Dalle precedenti del 2017, emerse novità in merito a

1. Epidemiologia
2. Diagnostica non invasiva (3D echo, CMR, CCT, biomarkers…)
3. Terapia anti-trombotica peri e post procedurale
4. Stratificazione del rischio per il timing ad intervento
5. Risultati e indicazioni all'intervento (chirurgia vs transcatetere)

ESC European Society of Cardiology

European Heart Journal (2022) **43**, 561–632
https://doi.org/10.1093/eurheartj/ehab395

ESC/EACTS GUIDELINES

2021 ESC
managen

Key points

- Precise evalua
as well as pro
sis and manag
- Echocardiogra
assess its sev
tions such a
markers are
preoperative
where non-in
- Risk stratifica
risk of interve
- Decision making in elderly patients requires special considerations, including life expectancy and expected quality of life, with regards to comorbidities and general condition (frailty).

repant
esions,
es, sys-
cardial
of right
cularly
on.[34] It
tic and

mitral regurgitation.

Ruolo aggiuntivo in:

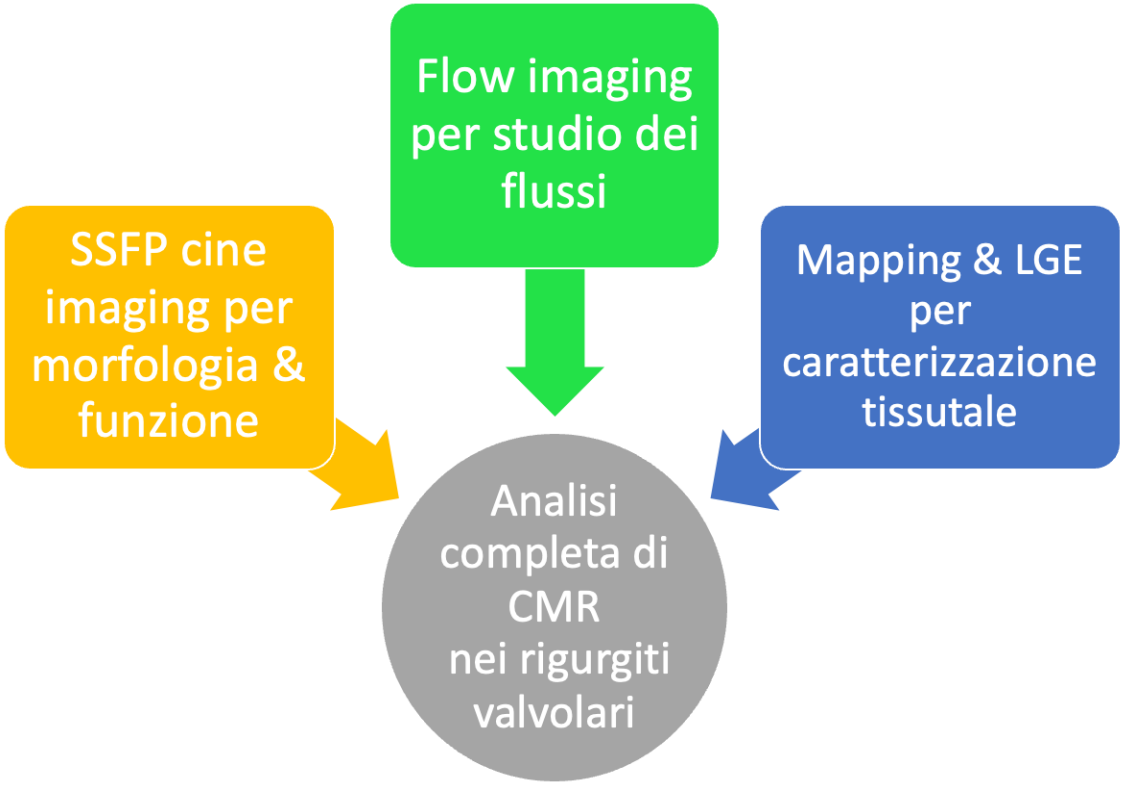
- Definizione volumi, funzione biventricolari
- Definizione calibri aortici
- Caratterizzazione tissutale (fibrosi)
- Definizione severità rigurgiti valvolari

1. MITRAL REGURGITATION
2. AORTIC REGURGITATION
3. AORTIC STENOSIS

Mitral Valve Regurgitation

1. MITRAL REGURGITATION
2. AORTIC REGURGITATION
3. AORTIC STENOSIS

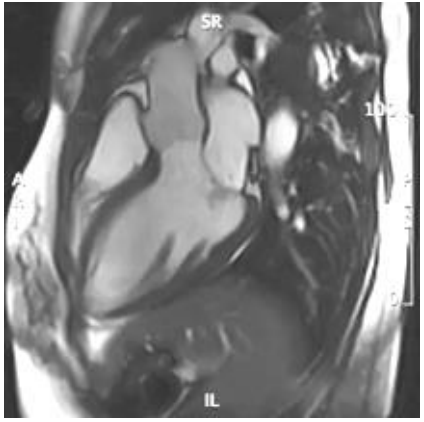
TOOLS


Flow imaging per studio dei flussi
SSFP cine imaging per morfologia & funzione
Mapping & LGE per caratterizzazione tissutale
Analisi completa di CMR nei rigurgiti valvolari

Valutazione del meccanismo del rigurgito mitralico

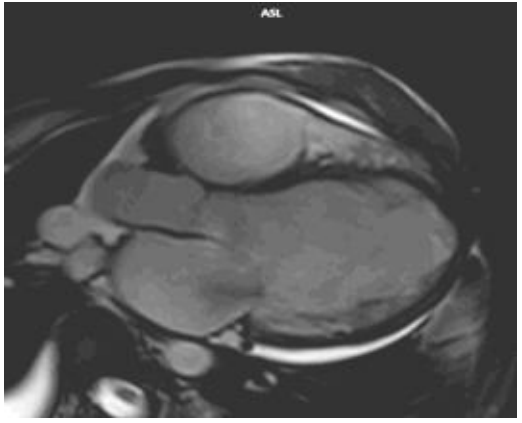
RIGURGITO MITRALICO

PRIMITIVO



Anomalia morfologica primitiva dell'apparato valvolare mitralico

SECONDARIO



Anomalia del miocardio ventricolare, ma NON dell'apparato valvolare mitralico

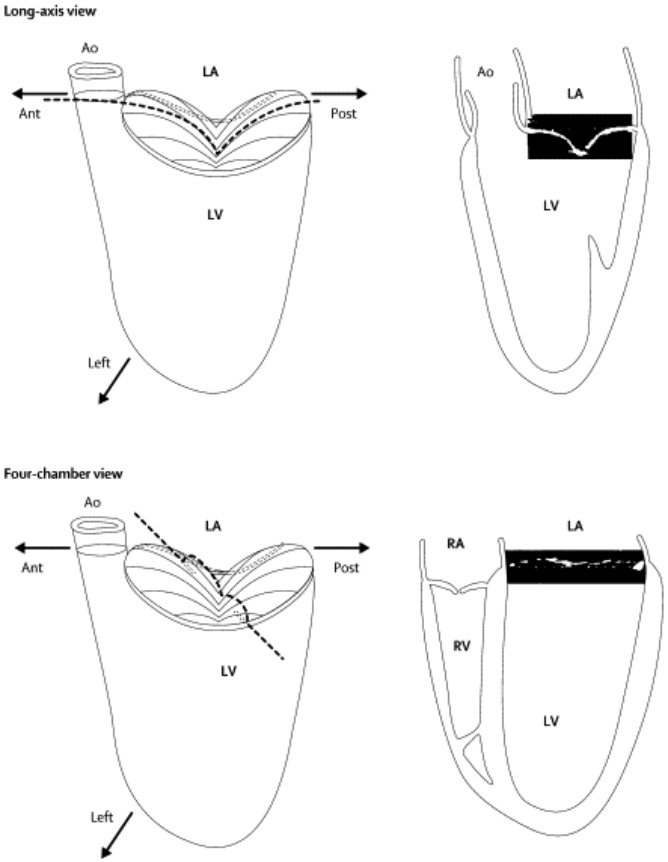
PROLASSO VALVOLARE MITRALICO

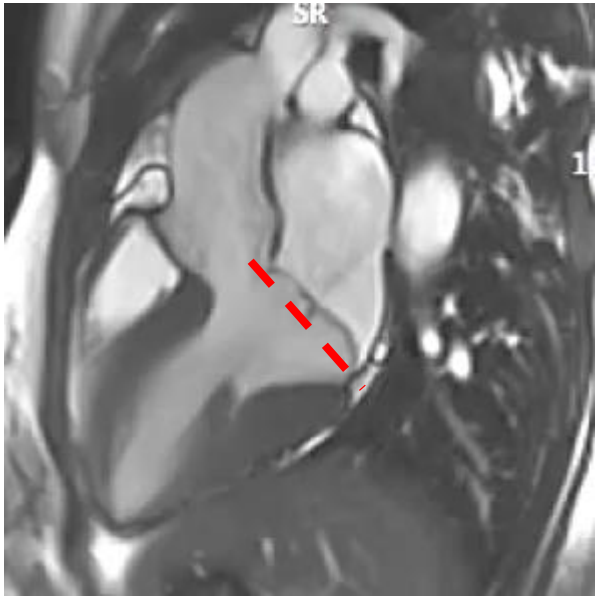
- Il prolasso valvolare mitralico (PVM) rappresenta un'anomalia valvolare comune diagnosticata mediante imaging cardiaco (a volte anche mediante ascoltazione cardiaca)
- La diagnosi di PVM è comunemente stabilita mediante ecocardiografia, in presenza di un tipico *ballooning* di uno o entrambi i lembi mitralici, con dislocazione sistolica **di almeno 2 mm** in atrio sinistro.
- Cause:
  - *Deficienza fibroelastica (>60y)*, caratterizzata da assottigliamento e allungamento cordale, con elevato rischio di rottura
  - *Degenerazione mixoide* (malattia di Barlow) (*40-60y*), caratterizzata da ispessimento cordale e dei lembi, dilatazione annulus, curling e fibrosi miocardica
- Sintomatologia varia: dolore toracico atipico, dispnea da sforzo, astenia, capogiri, cardiopalmo, sincope, ansia.
- Complicazioni varie: endocardite infettiva, stroke, flail di lembo, aritmie ventricolari e morte improvvisa.

CMR and Mitral Valve Prolapse

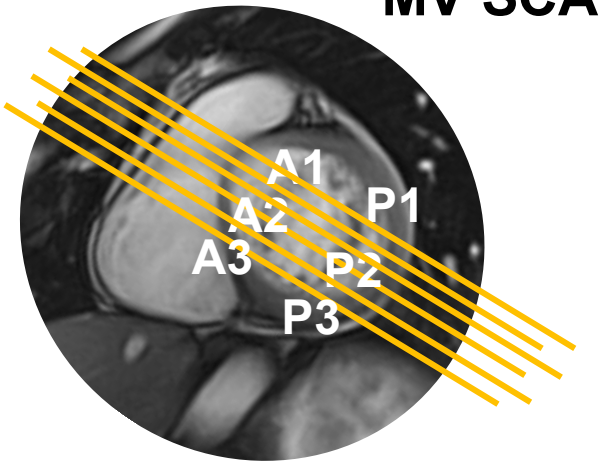
DIAGNOSI PVM:

- Cine asse lungo aorta
- Tele-sistole
- Individuare piano mitralico
- Misurare spessore lembi mitralici
- Misurare protrusione dei lembi mitralici in atrio sin
- Misurare eventuale MAD





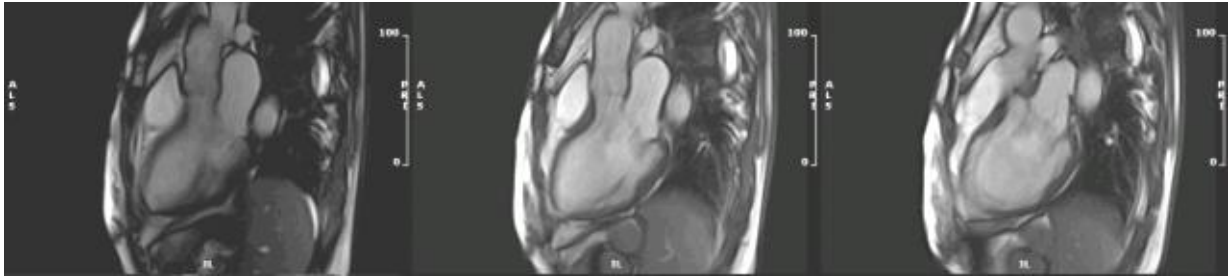
MV SCALLOPS USING SAX & LAX



Using the “en face” or short axis view of the MV, a stack of high resolution, small FOV 3C cine-CMR images interrogating the different scallops of the MV are created for analysis

(reconstructed in-plane spatial resolution of 0.6 x 0.6 mm, slice thickness of 4-5 mm, and temporal resolution of ~25 ms)

A3-P3 → A2-P2 → A1-P1



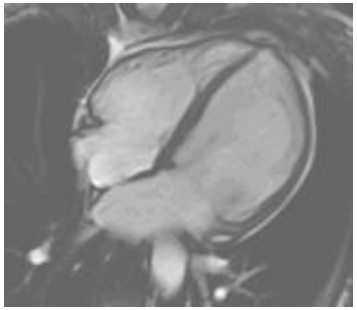
ALTRE CAUSE DI PRIMARY MR

- Malattia reumatica, radioterapia: lembi diffusamente ispessiti, lesioni commissurali
- Endocardite infettiva: lesioni valvolari (vegetazioni)

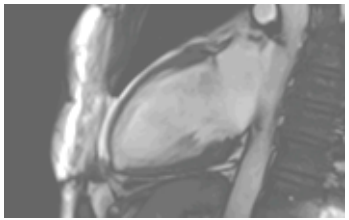
Quantificazione della severità del rigurgito mitralico

Visual assessment of MR severity

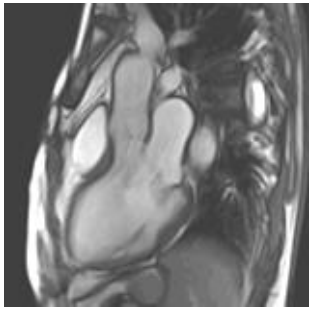
4c



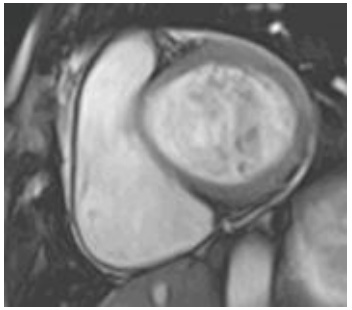
2c



3c



SAX



MR is present: YES
Mild-moderate-severe? NO, DON'T DO IT

VISUAL ASSESSMENT NOT RECOMMENDED

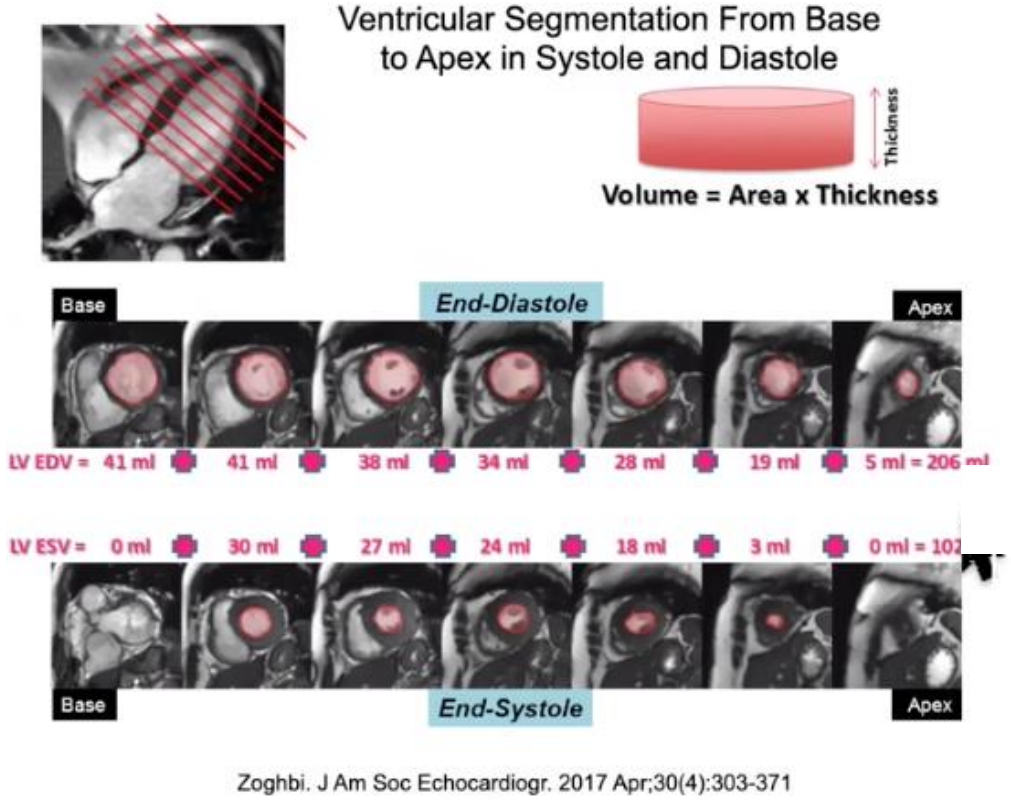
Severity assessment MR: step 1

LEFT VENTRICULAR VOLUMES

Sequential short-axis LV EDV and LV ESV are calculated by summation of disks (Simpson method)

(slice volume = area x thickness)

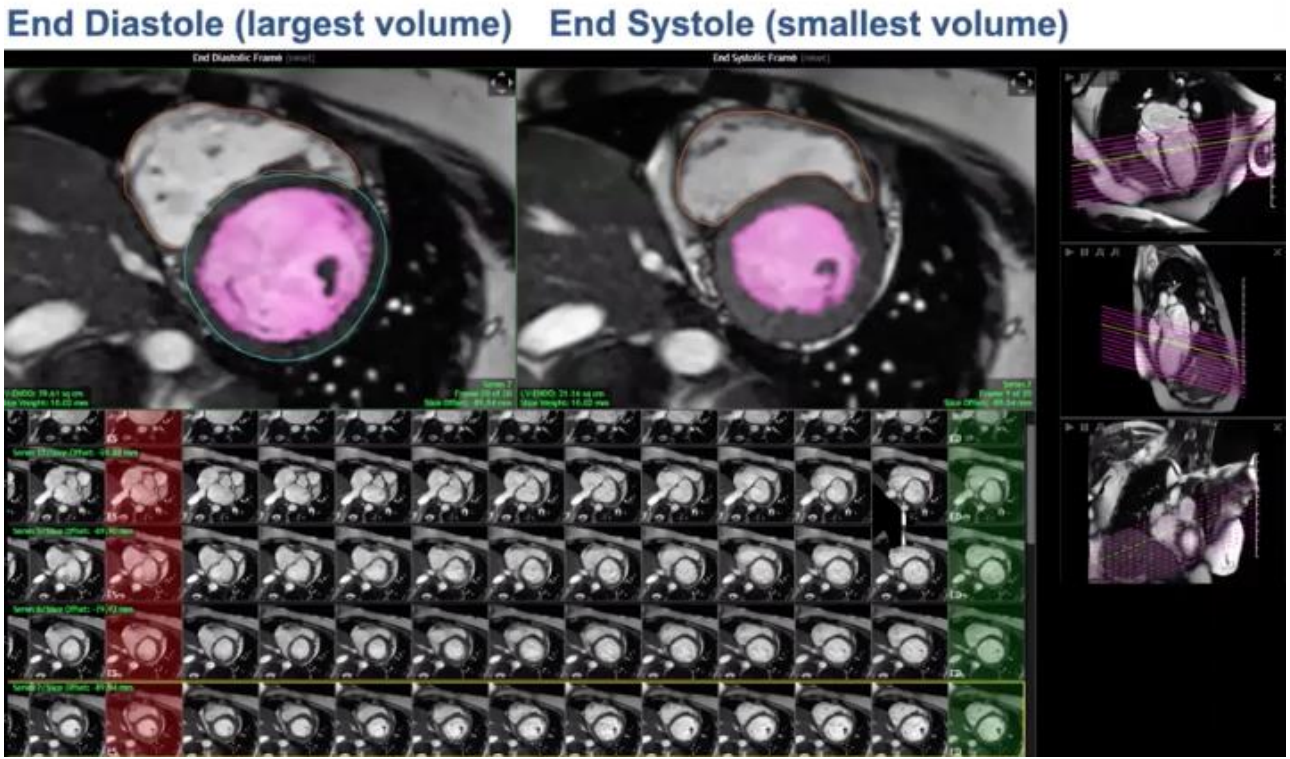
for each short-axis slice during diastole and systole



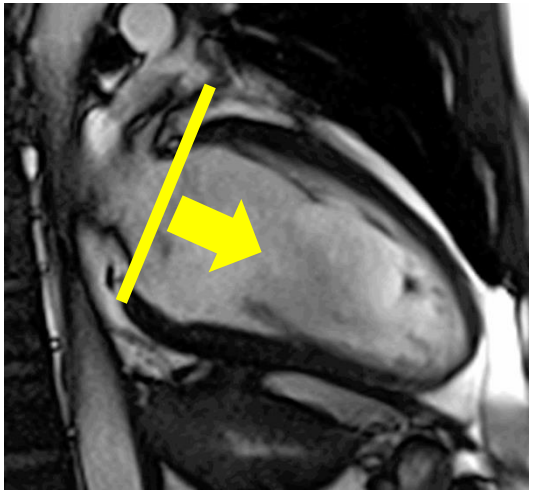
Zoghbi. J Am Soc Echocardiogr. 2017 Apr;30(4):303-371

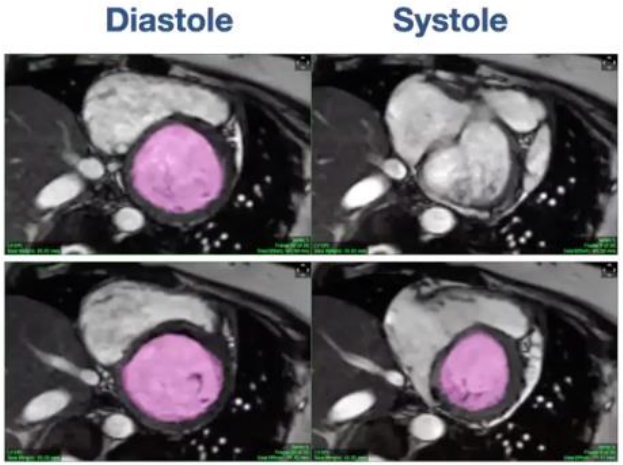
LV volume calculation: importance of accuracy

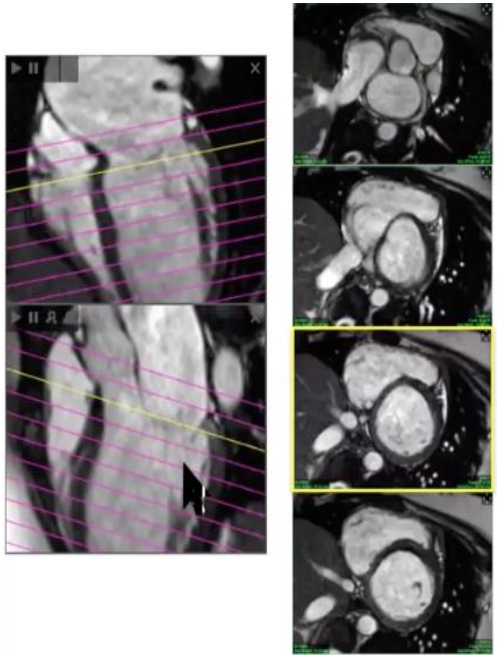
ACCURACY



LV volume calculation: importance of accuracy

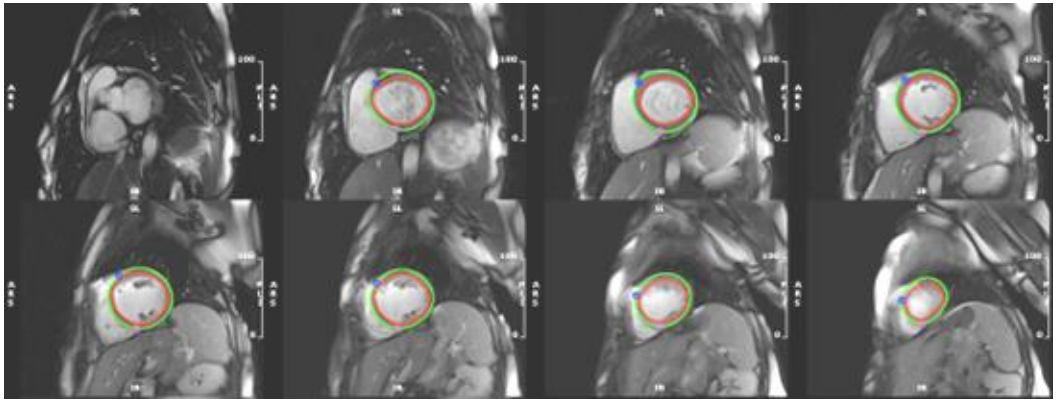






Basal plane typically descends during systole. A slice that contains blood volume at end-diastole may include only left atrium without LV blood volume at end-systole. Using cross-referencing from long-axis views to help correctly identify

Severity assessment MR: step 1



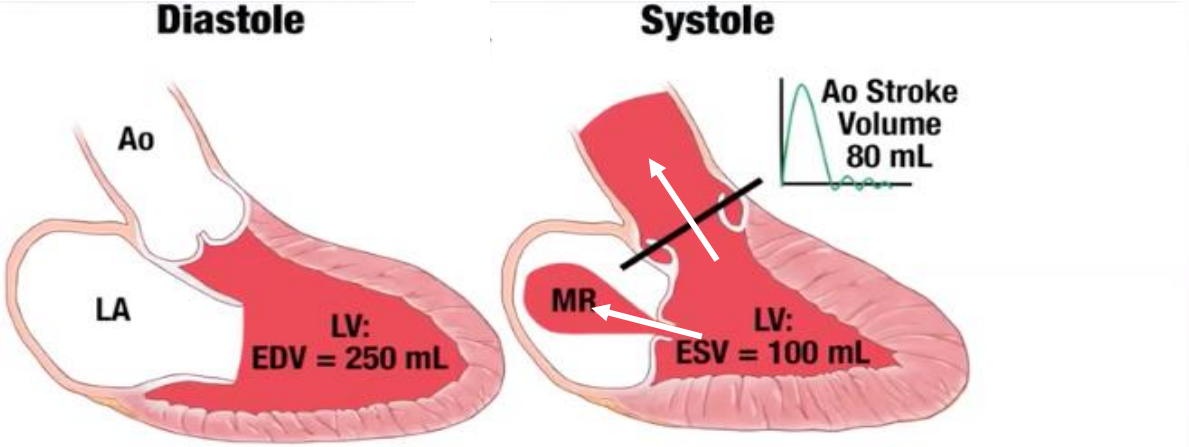
Prendere nota di:

Stroke Volume in mL (SV)

SV = EDV - ESV

Severity assessment MR: step 1

VOLUME DI RIGURGITO MITRALICO (VR) = STROKE VOLUME LV – VOLUME ANTEROGRADO AO



RVol and RF are calculated without any hemodynamic or shape assumptions and are not affected by the eccentricity of the MR jet or the orifice geometry

Zoghbi. J Am Soc Echocardiogr. 2017 Apr;30(4):303-371

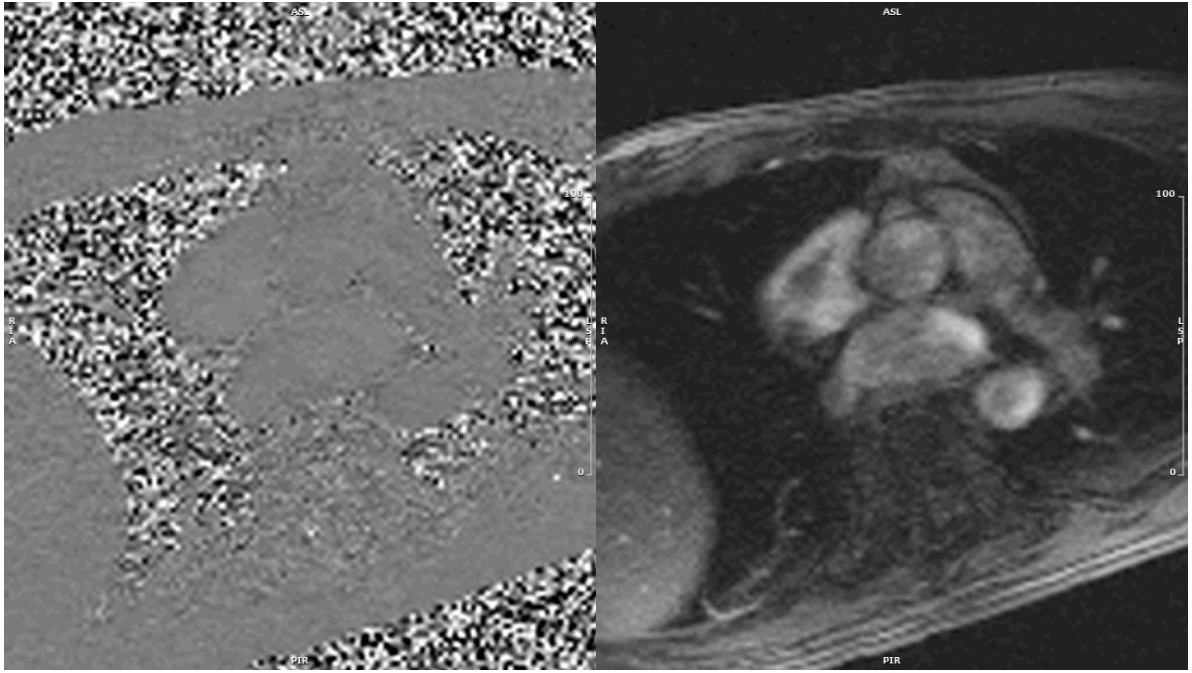
Severity assessment MR: step 2

Come si calcola il volume anterogrado aortico (o stroke volume aortico)?

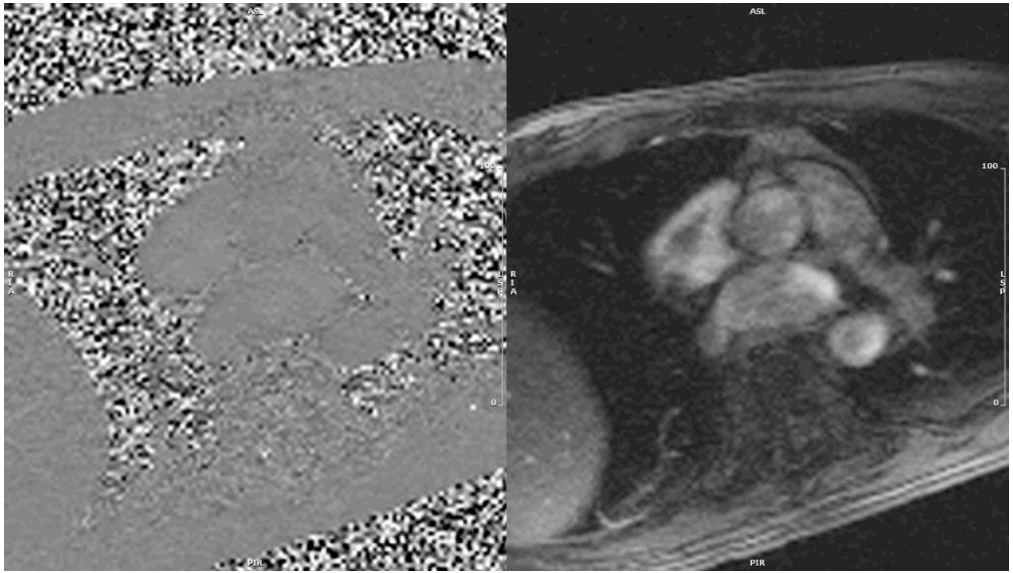
Phase Contrast CMR

Phase contrast CMR: description

PHASE **MAGNITUDE**



Live session 27_1_26

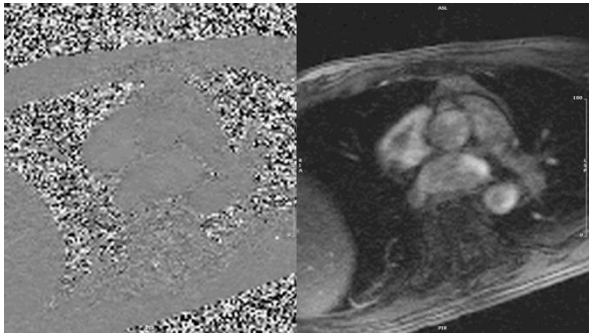


APPLICAZIONI IN CMR:

- Tutte le malattie valvolari
- Shunt
- Flusso in vasi extracardiaci
- Portata cardiaca

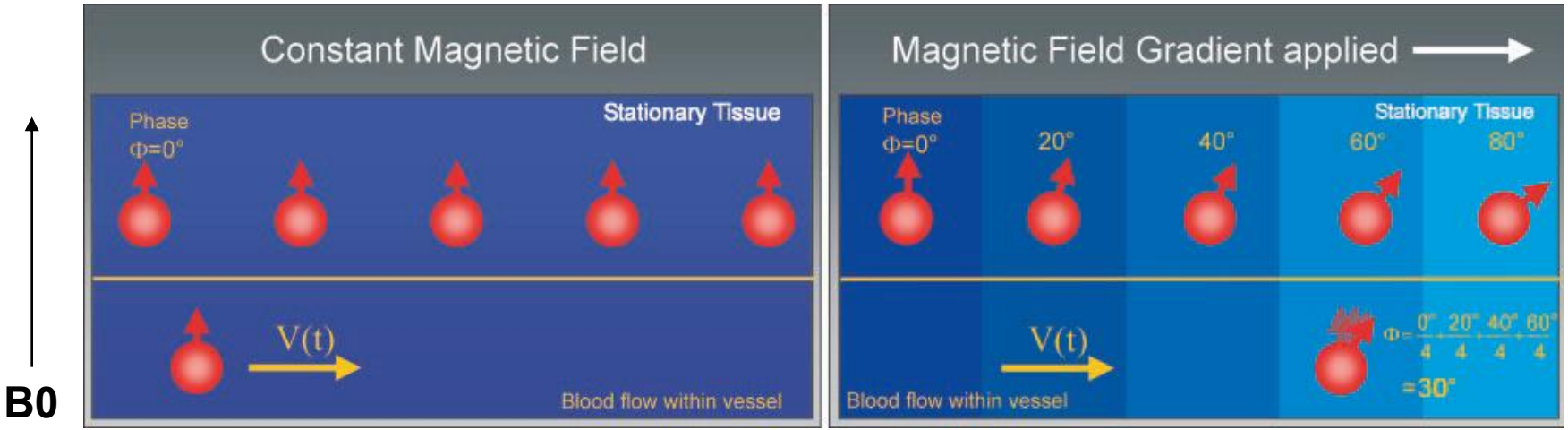
VANTAGGI:

- Non invasiva
- Quantitativa
- Flusso anterogrado e retrogrado
- Qualsiasi regione del corpo
- Multiplanarietà



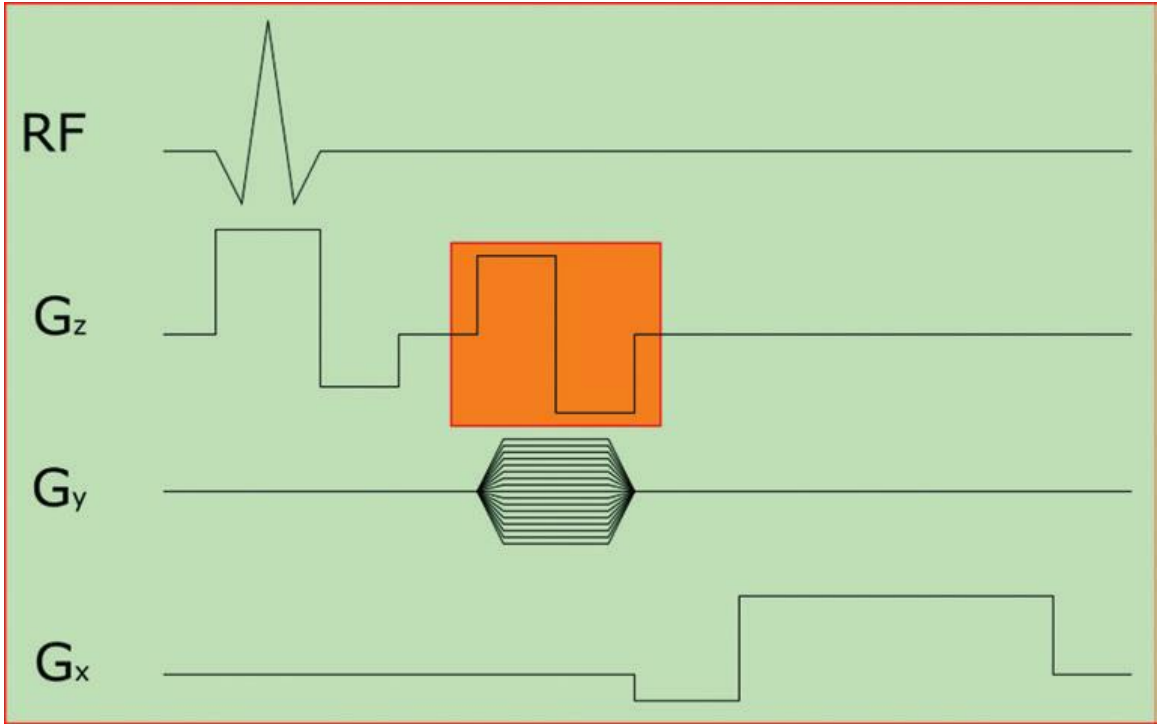
Live session 27_1_26

With phase-contrast imaging, the MRI signal is used to visualize and quantify velocity. This imaging modality relies on phase data, which are intrinsic to all MRI signals. With use of bipolar gradients, degrees of phase shift are encoded and in turn correlated directly with the velocity of protons.



- **Misuriamo differenze di fase (phase shift) tra i protoni dei tessuti fermi e i protoni dei tessuti in movimento**
- **Guadagno di fase proporzionale alla velocità dei protoni**

Live session 27_1_26



BIPOLAR GRADIENT

--> direction of image section selection

--> phase-encoding direction

--> frequency-encoding direction

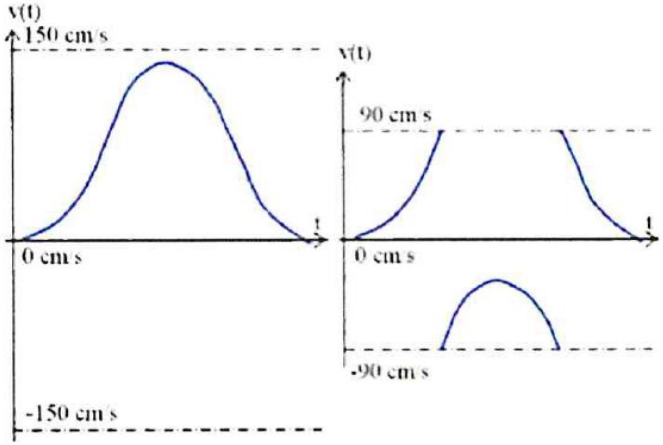
Live session 27_1_26

$$\Delta\Phi = \gamma \cdot \Delta m \cdot v$$

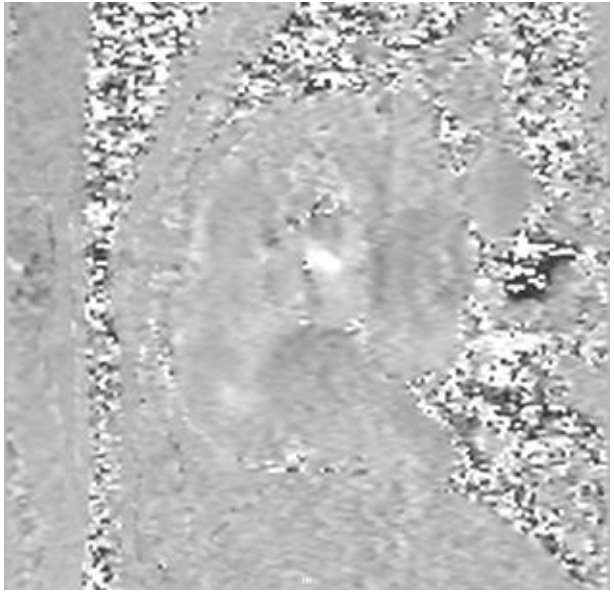
- $\Delta\Phi$: **Delta di fase**
- γ: **Costante giromagnetica**
- Δm: **gradiente**
- v: **Velocità (dipende da VENC)**

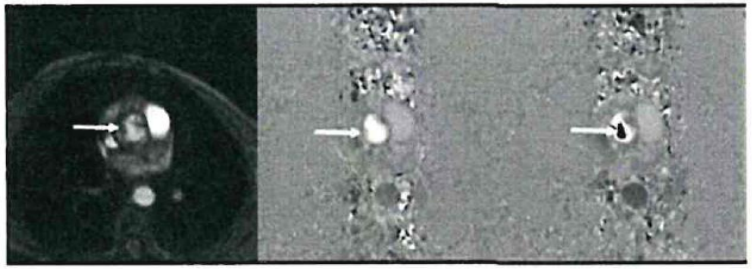
Live session 27_1_26

VENC TROPPO BASSA



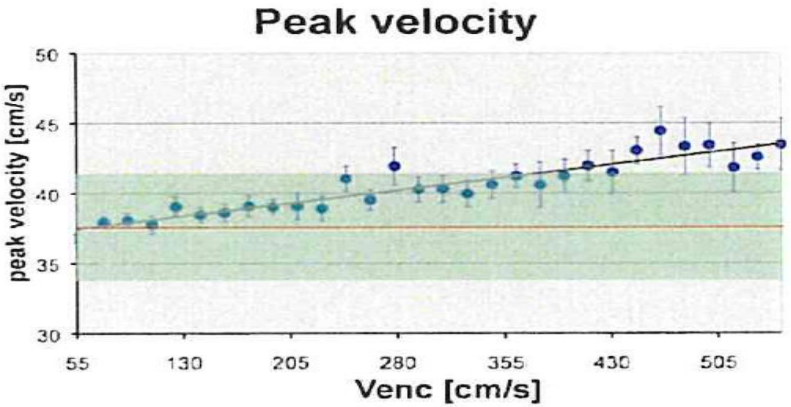
ALIASING

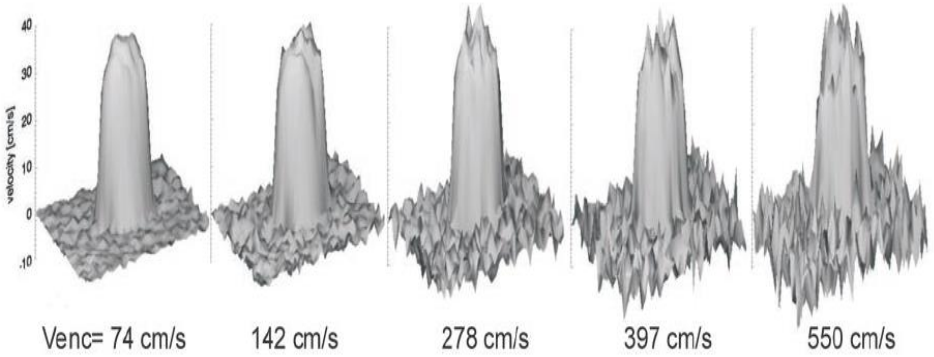




Lotz J, RadioGraphics 2002

VENC TROPPO ALTA





Lotz J, RadioGraphics 2002

Graphs show that, in an experimental setting, estimates of peak velocity demonstrate a deviation of more than 10% if V_{enc} increases by more than three times the velocity in the vessel

SCELTA DELLA CORRETTA VENC

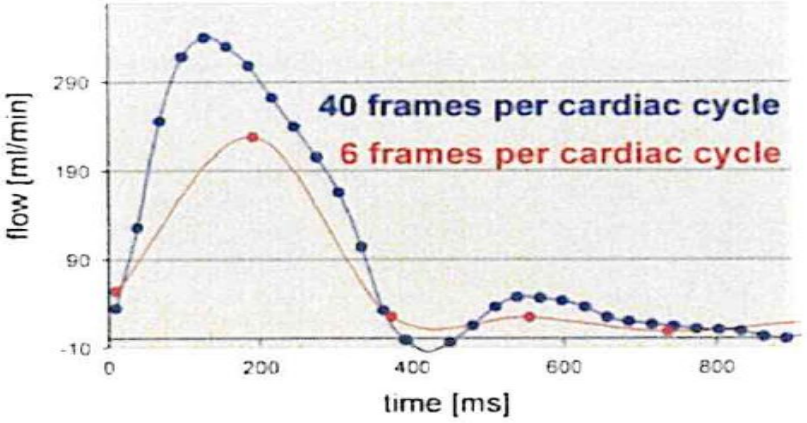
- AORTA 150 cm/s
- TRONCO POLMONARE 100 cm/s
- VENA POLMONARE 80 cm/s

- Da adattare se presenti stenosi valvolari…

POSSIBILI PROBLEMI

- Aliasing
- Artefatti: metalli, accelerazione, aritmie, turbolenze
- Inadeguata risoluzione temporale o spaziale
- Angolo di misurazione

RISOLUZIONE SPAZIALE E TEMPORALE

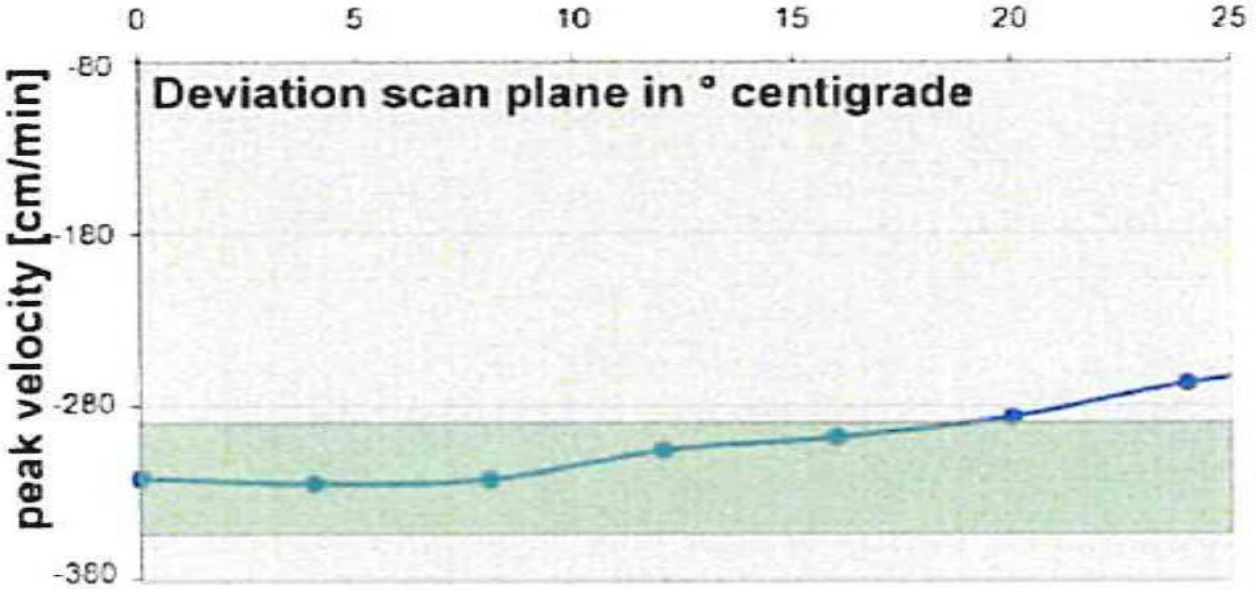


Almeno 11-16 frames per ciclo cardiaco

…With decreasing spatial resolution, partial volume effects cause under-estimation of the flow and peak velocity

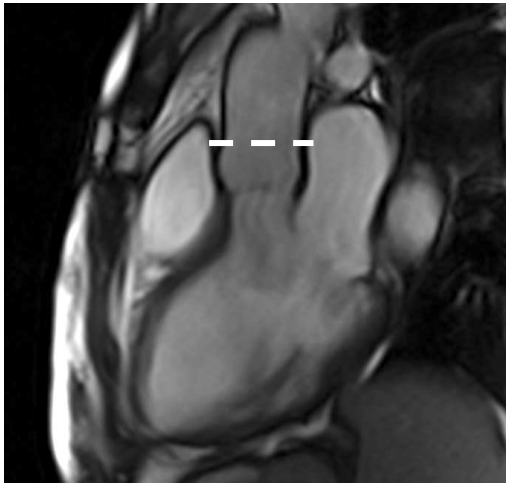
Almeno 8-11 pixels devono riempire il vaso d'interesse

ANGOLO DI MISURAZIONE

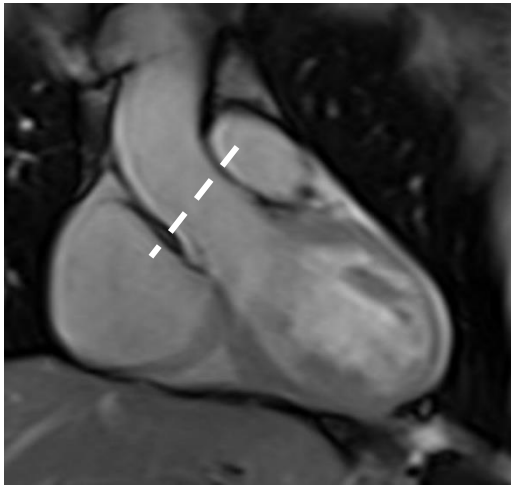


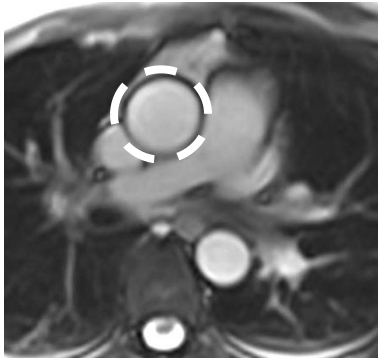
Phase contrast CMR: preparation

Asse lungo aortico



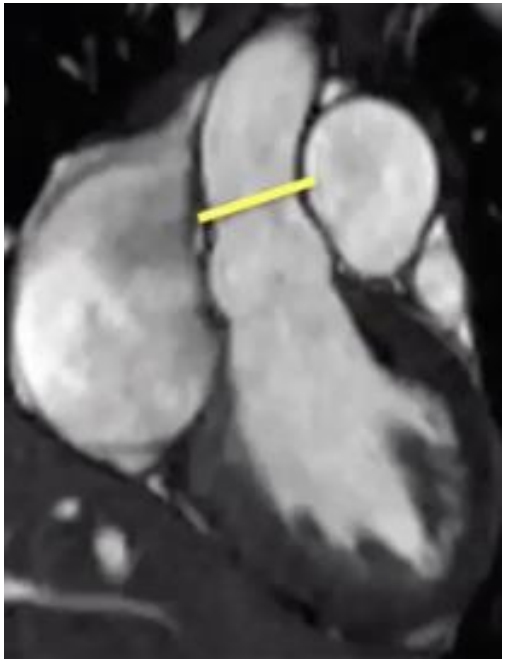
Coronale LVOT





Phase contrast CMR: Tips

- Slice ortogonale al flusso
- Slice sulla giunzione sino-tubulare, in diastole
- Timing indipendente dal mdc
- Se paziente ritmico e compliante: utilizzare sequenza corta in apnea
- Se paziente aritmico e poco compliante: utilizzare sequenza lunga a respiro libero



Ulteriori dettagli sulle PC possono essere trovati sul SCMR position statement: www.jcmr-online.com/content/15/1/35

Phase contrast CMR: VENC

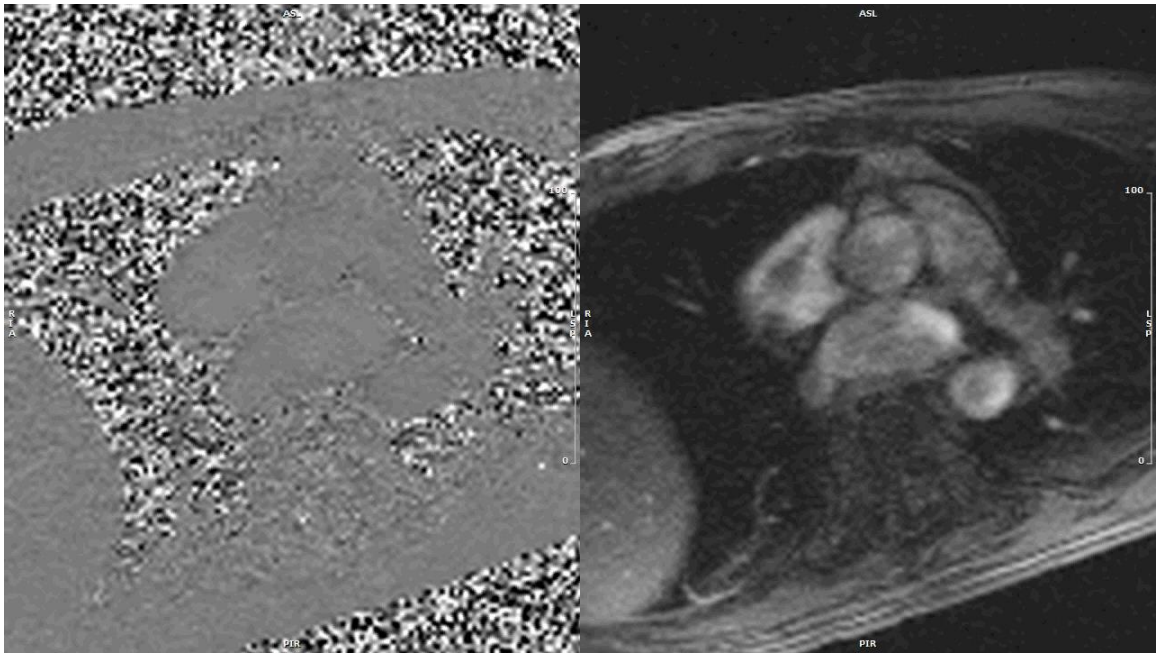
1. VENC = velocity encoding

- Accuratezza migliore con la VENC più bassa che non dà aliasing
- Per Aorta, partire da 150 -->200-->250 cm/s
  Per Polmonare partire da 100-->125--> 150 cm/s
- La VENC si alza in presenza di alti flussi (stenosi) (utile Vmax all'eco)

2. Plane

- Through-Plane: contrasto di fase calcolato lungo l'asse z
- In-Plane: contrasto di fase calcolato nel piano xy

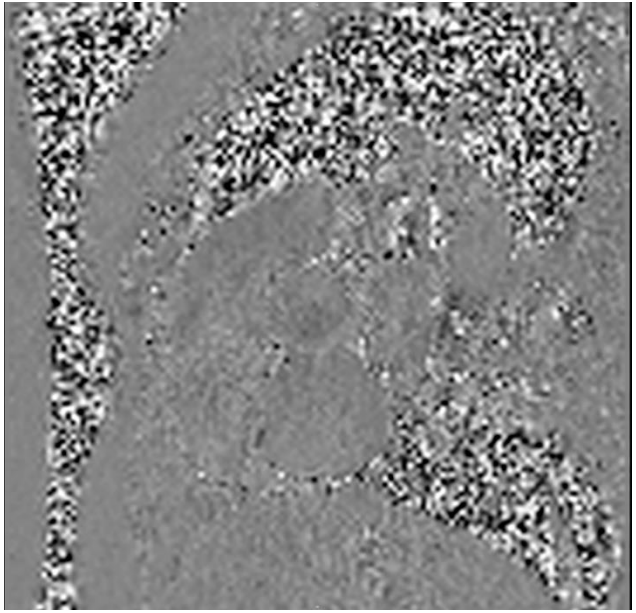
Phase contrast CMR: VENC

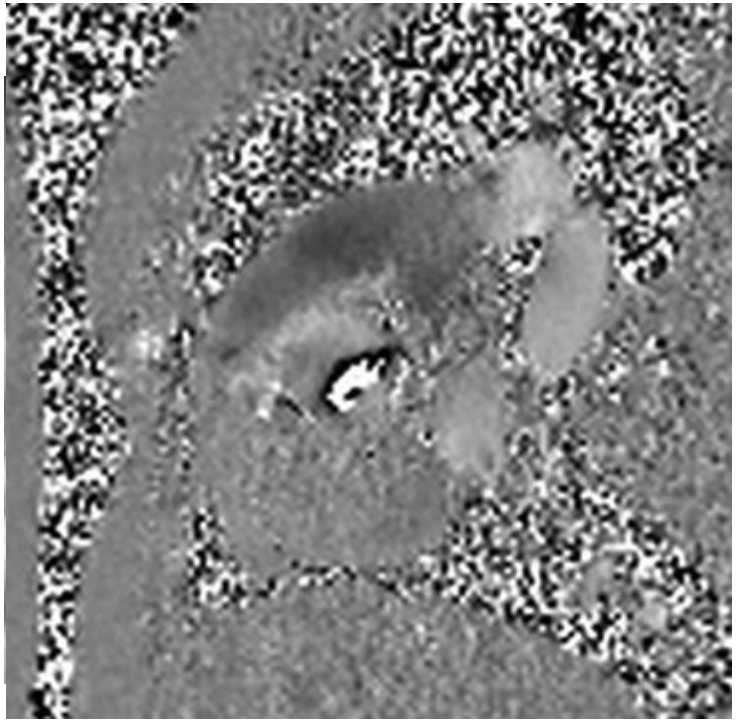


VENC 150

Phase contrast CMR: VENC

ALIASING



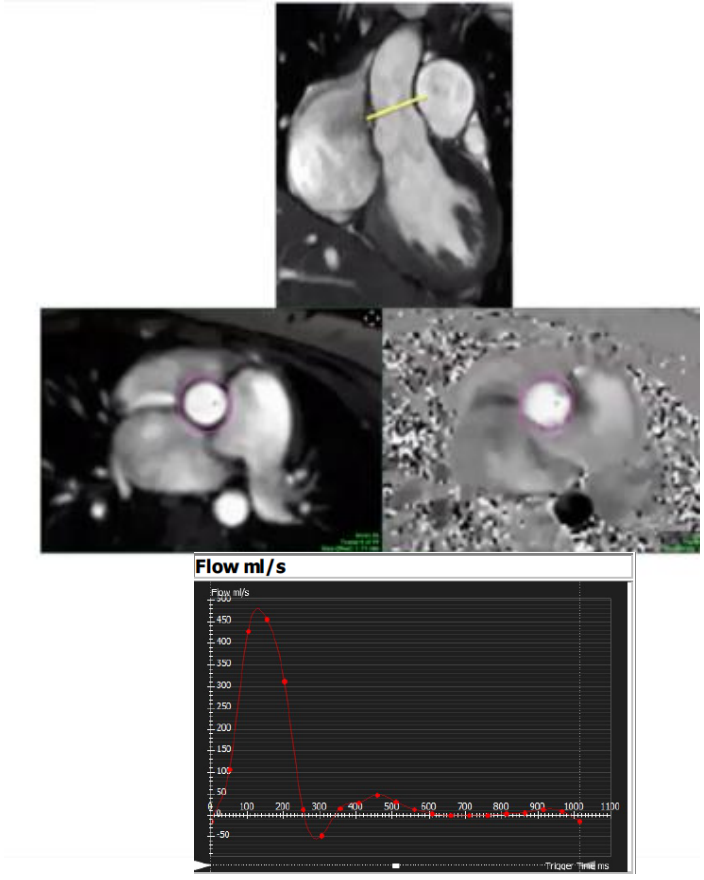


VENC 150

Severity assessment MR: step 2

- Per misurare la portata anterograda aortica, deve essere disegnata una ROI attorno alla sezione aortica (leggermente fuori dalla parete) nell'immagine in magnitude.

- Il flusso è quindi calcolato dal software integrando la velocità protonica di ogni pixel all'interno della ROI (vaso d'interesse) durante tutto il ciclo cardiaco.



Severity assessment MR: step 3

VOLUME DI RIGURGITO MITRALICO (VR) = STROKE VOLUME LV – VOLUME ANTEROGRADO AO

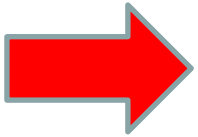
VR MITRALICO = 143 ml – 75 ml = 68 ml

$$\text{FRAZIONE DI RIGURGITO MITRALICO} = \frac{\text{VR x 100}}{\text{LV SV}} = \frac{\text{68 ml x 100}}{\text{143 ml}} = 48\%$$

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

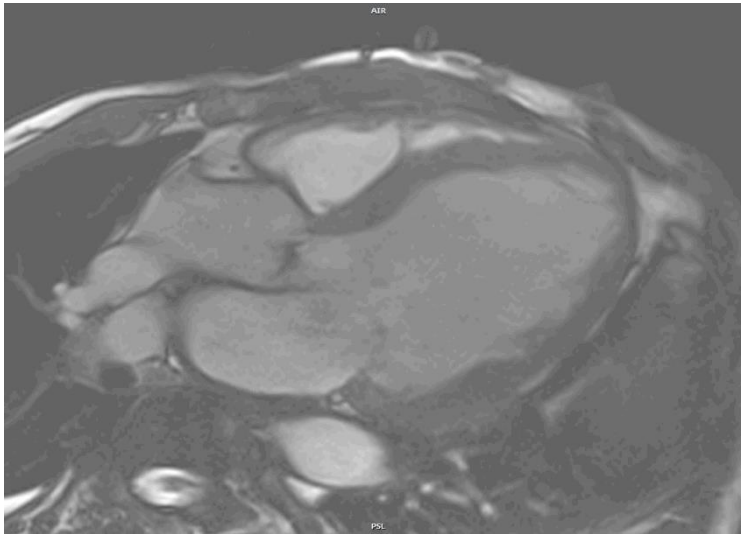
Severity assessment MR: other methods

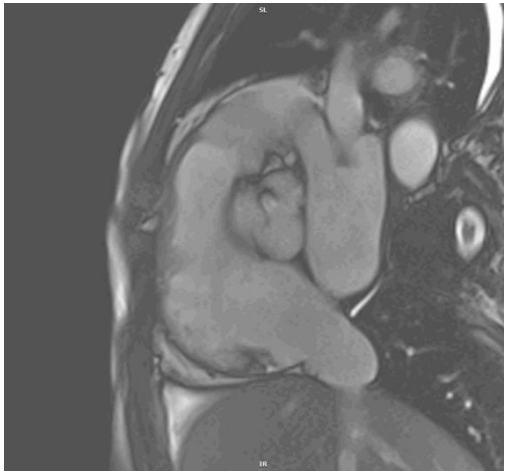


- **Mitral Regurgitant Volume** =
  1) LV SV– Aortic SV
     - *Applies even in presence of AI
     - more practical and reproducible
       - Kon MW. J Heart Valve Dis 2004;13:600–7.
  2) LV SV– Pulmonary SV
     - AoSV is within 5% of PA SV (in absence of intra-cardiac shunt)
     - *Useful in patients with AS, where asc aortic flow may have aliasing
  3) LV SV – RV SV
     - RVSV less reproducible due to extensive trabeculation of RV
     - *Significant concomitant regurgitant lesions invalidates use
  4) Mitral inflow – Aortic SV
- **Regurgitant Fraction (%)** = MR regurg vol / LVSV → **In assenza di Ao Reg**

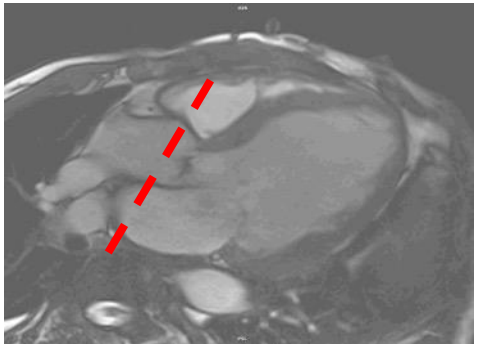
1. MITRAL REGURGITATION
2. AORTIC REGURGITATION
3. AORTIC STENOSIS

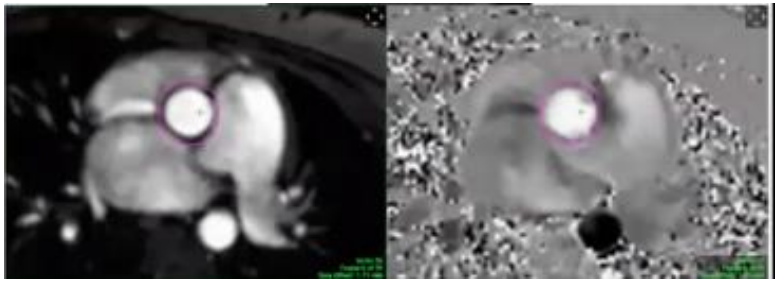
Aortic Valve Regurgitation

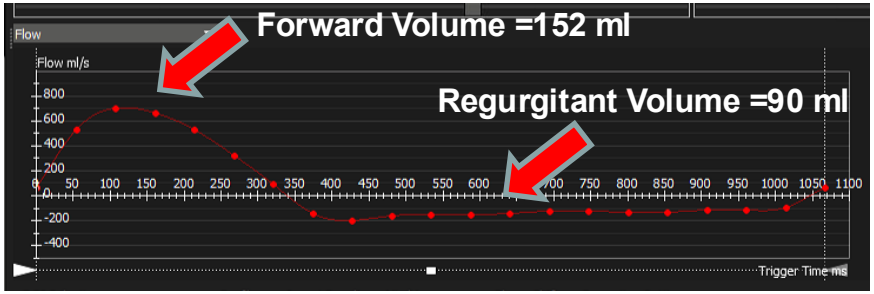




Aortic Valve Regurgitation: Direct method

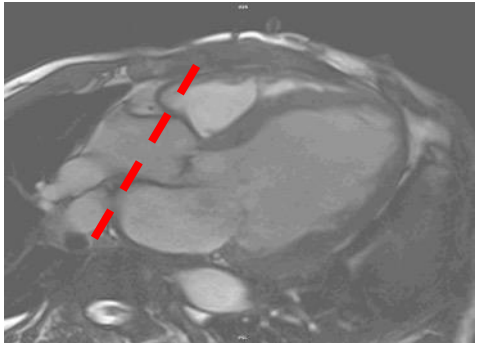


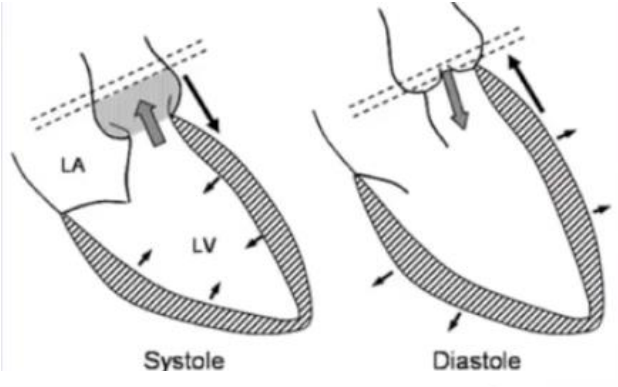




$$\text{Ao Regurgitant Fraction} = \frac{\text{Ao Reg Vol} \times 100}{\text{Ao Forward Vol}} = \frac{90\ \text{ml} \times 100}{152\ \text{ml}} = 59\%$$

Aortic Valve Regurgitation: Direct method





Final Echocardiography Grade 107 pts	RV (ml/s)			p Value*
	Sinotubular Junction	Mid-Ascending Aorta	Distal Ascending Aorta	
0+	4.0 ± 3.3	3.4 ± 2.9	2.0 ± 2.0	<0.001
I+	6.3 ± 3.1	4.3 ± 2.4	2.6 ± 1.7	<0.001
II+	15.4 ± 11.8	11.1 ± 11	7.2 ± 7.3	<0.001
III+	32.3 ± 24.3	28.6 ± 20.9	21.7 ± 16.7	<0.001
IV+	55.6 ± 23.7	50.9 ± 25.2	44.9 ± 22.3	0.05

Lost Volume
Jet turbolence

Gabriel. Am J Cardiol 2011;108:1014 –1020

Aortic Valve Regurgitation: Direct method

Imaging

Aortic Regurgitation Quantification Using Cardiovascular Magnetic Resonance

Association With Clinical Outcome

Saul G. Myerson, MBChB, MD, MRCP, FESC; Joanna d'Arcy, MBChB, MRCP; Raad Mohiaddin, PhD, FRCR, FRCP, FESC; John P. Greenwood, MBChB, PhD; Theodoros D. Karamitsos, MD, PhD; Jane M. Francis, DCR(R), DNM; Adrian P. Banning, MBBS, MD, FRCP, FESC; Jonathan P. Christiansen, MBChB, MD, FRACP, FACC, FCSANZ; Stefan Neubauer, MD, FRCP, FACC, FMedSci

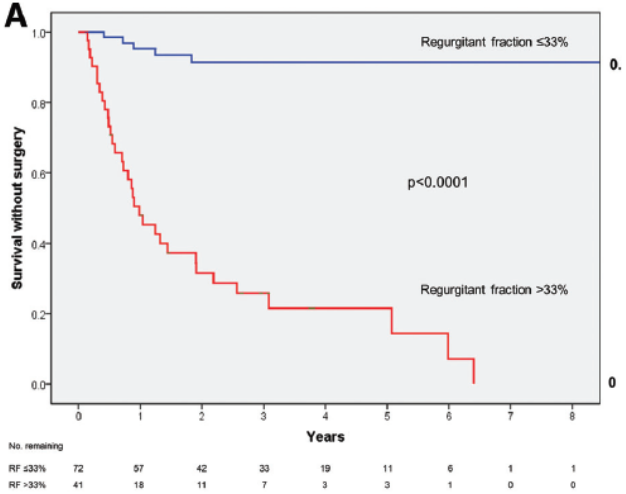


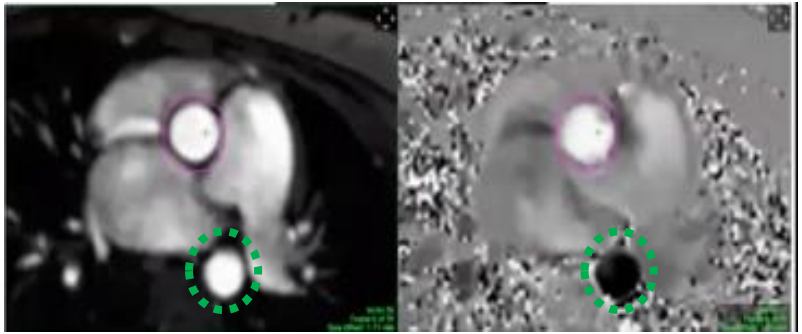
Table 1. Receiver Operating Characteristic (ROC) Data. Comparison of the Ability of Each CMR Parameter to Identify the Initially Asymptomatic Patients Who Would Develop Indications for Surgery, Using Receiver Operating Characteristic (ROC) Analysis

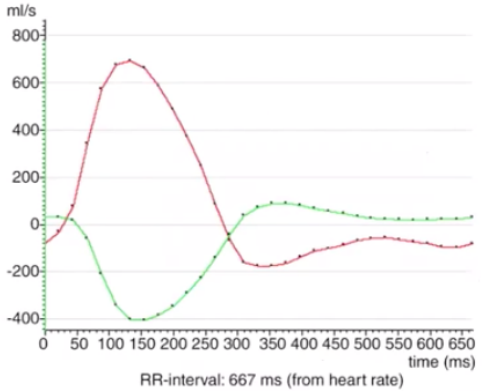
	AUC	Threshold	*p*	Sens (%)	Spec (%)
Regurgitant fraction (%)	0.93 (0.87 to 0.97)	>33	<0.0001	85	92

Myerson SG et al. Circulation. 2012;126(12):1452-1460.

Aortic Valve Regurgitation: Flow Reversal

DESCENDING AORTA HOLODIASTOLIC FLOW REVERSAL





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

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

Bolen L, Radiology 2011

Aortic Valve Regurgitation: Flow Reversal

ORIGINAL RESEARCH

Diagnostic and Prognostic Utility of Cardiac Magnetic Resonance Imaging in Aortic Regurgitation

Andreas A. Kammerlander, MD, PhD,[a] Matthias Wiesinger, MD,[a] Franz Duca, MD,[a] Stefan Aschauer, MD,[a] Christina Binder, MD,[a] Caroline Zotter Tufaro, MSc, PhD,[a] Christian Nitsche, MD,[a] Roza Badre-Eslam, MD,[a] Robert Schönbauer, MD,[b] Philipp Bartko, MD, PhD,[a] Dietrich Beitzke, MD,[c] Christian Loewe, MD,[c] Christian Hengstenberg, MD,[a] Diana Bonderman, MD,[a] Julia Mascherbauer, MD[a]

FIGURE 5 Discrepancies in Grading of Aortic Regurgitation Between Echocardiography and Cardiovascular Magnetic Resonance Imaging

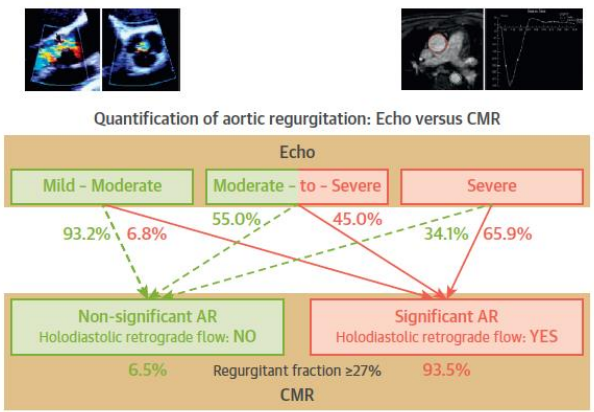
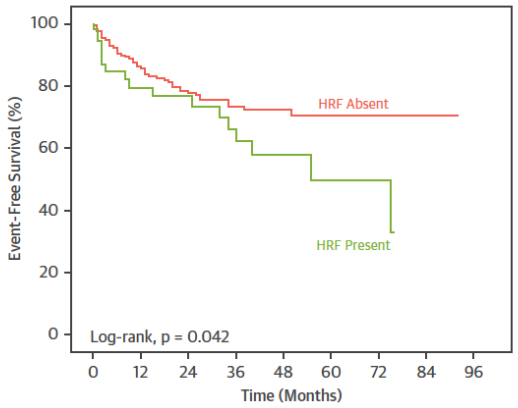


FIGURE 6 Kaplan-Meier Plot for Event-Free Survival



Kammerlander AA et al JACC Cardiovasc Imaging. 2019;12(8 Pt 1):1474-1483.

1. MITRAL REGURGITATION
2. AORTIC REGURGITATION
3. AORTIC STENOSIS

Valvular Heart Disease: Changing Concepts in Disease Management

Cardiovascular Magnetic Resonance Imaging for Valvular Heart Disease

Technique and Validation

Peter J. Cawley, MD; Jeffrey H. Maki, MD, PhD; Catherine M. Otto, MD

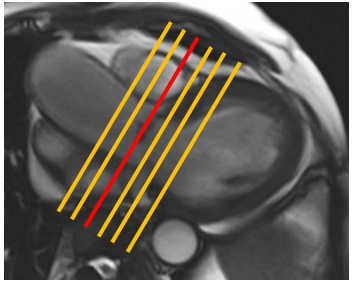
Table 2. Select Studies Validating Indices of Aortic Stenosis by CMR

First Author (Year)	Principle	Reference Standard	n	*r*	Mean Difference±1 SD (CMR−Echo)	CMR Reproducibility*: Mean Difference±1 SD
Velocity/gradients						
Kilner[23] (1993)	$\dot{V}_{max}$	TTE	26†	...	−0.10±0.46 m/s	0.11±0.29 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	
Sondergaard[25] (1993)	$\dot{V}_{max}$	TTE	12	...	−0.88±0.91 m/s	...
Caruthers[26] (2003)	peak ΔP	TTE	24	0.82	...	*r*=0.94§
	mean ΔP			0.87		
Physiological valve area						
Caruthers[26] (2003)	continuity equation	TTE	24	0.83	...	*r*=0.94§
Anatomic valve area						
John[27] (2003)	planimetry‖	TEE	40	0.96	0.02±0.08 cm^2¶	0.07±0.06 cm^2‡ 0.05±0.04 cm^2#
Kupfahl[28] (2004)	planimetry	TEE	32	...	0.02±0.21 cm^2	0.03±0.05 cm^2‡ −0.02±0.06 cm^2#
Debl[29] (2005)	planimetry	TEE	25	0.86	0.13±0.16 cm^2¶	...
Reant[30] (2006)	planimetry	TEE	39	0.58	0.01±0.14 cm^2 (Echo−CMR)	0.03±0.14 cm^2‡ 0.02±0.07 cm^2#
Schlosser[31] (2007)	planimetry	TEE	32	0.82	0.15±0.13 cm^2	0.75**‡

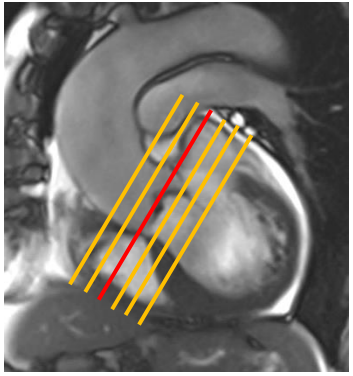
Cawley PJ et al. Circulation 2009;119:468-78

2D PLANIMETRY for Aortic Valve Area

3 CH (LVOT)

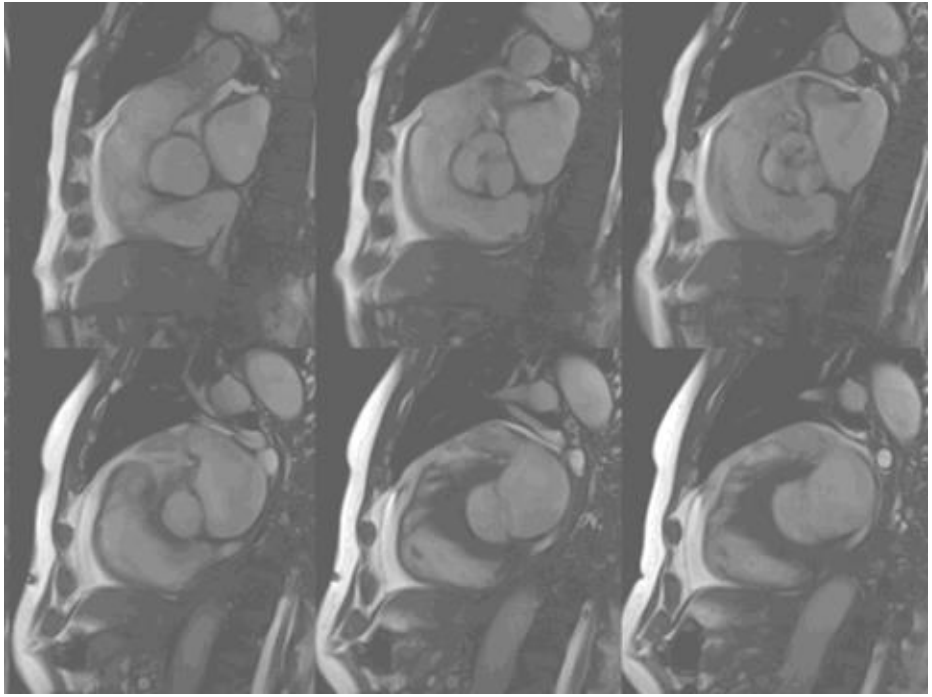


- Contiguous Stack
- NO GAP, slice 4-5 mm
- Aligned with the leaflets tips

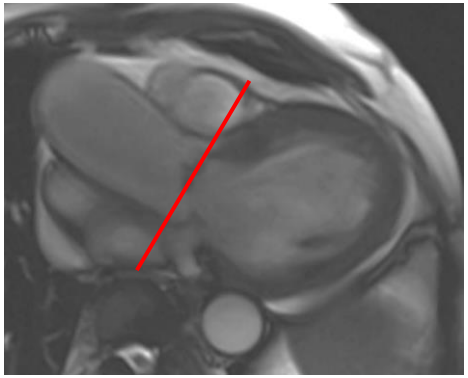


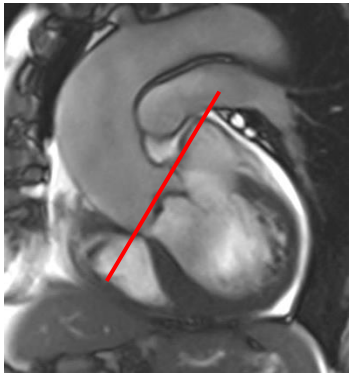
Coronal LVOT

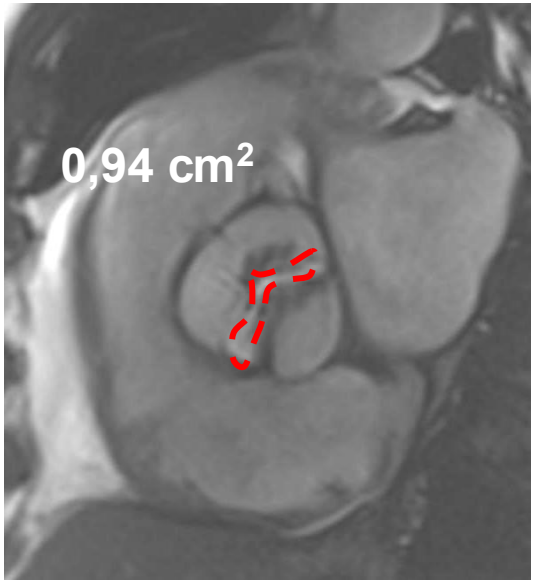
Short Axis Stack



2D PLANIMETRY for Aortic Valve Area

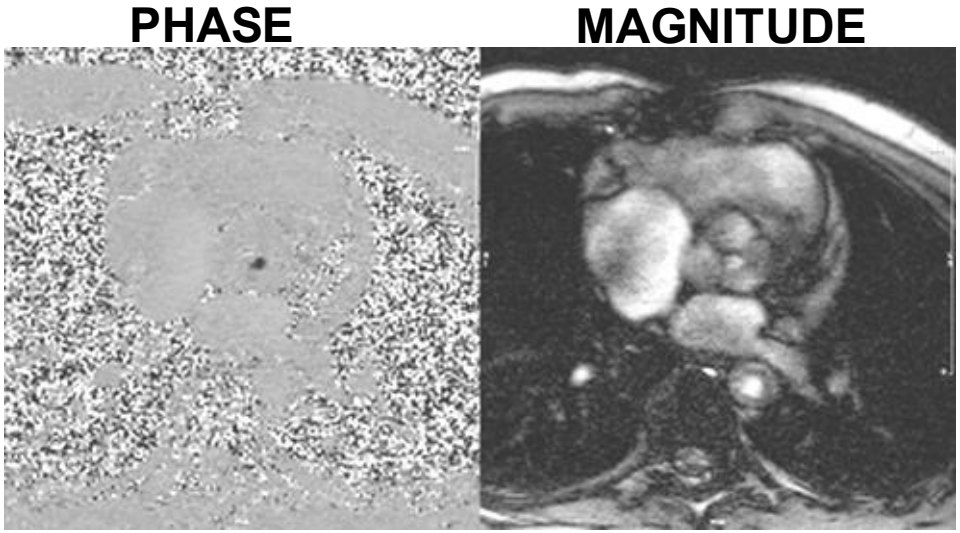






Planimetered AVA is the smallest systolic opening at the leaflet tips

PHASE CONTRAST for transaortic peak gradient



Peak gradient = 4 x (peak velocity)^2

CAVEAT:
Underestimation compared with CV Doppler due to signal loss (turbolence), lower temporal resolution, partial volume effects, intravoxel dephasing, background noise…

UNIVERSITÀ
DEGLI STUDI
DI PADOVA

INTEGRAZIONE CLINICA TRA LE TECNICHE NELLO STUDIO DELLE VALVULOPATIE: LA RMC

Alberto Cipriani, MD, FESC
Associate Professor of Cardiology
University of Padua
alberto.cipriani@unipd.it