
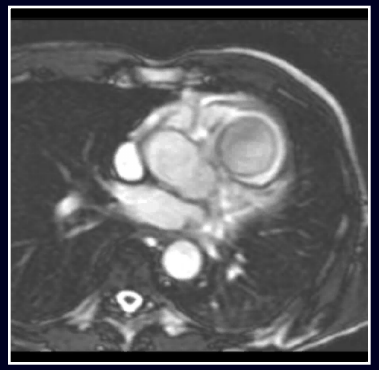
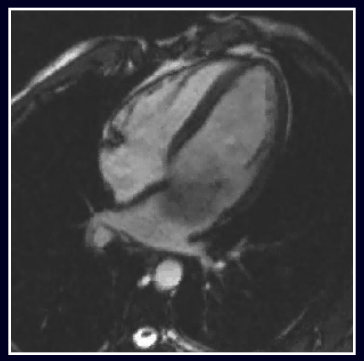


Cardio-RM: requisiti tecnologici, protocolli di esame, tecnica di esecuzione e ricostruzione

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AGENDA

- REQUISITI TECNOLOGICI
- TECNICA DI ESECUZIONE E RICOSTRUZIONE
- PROTOCOLLI D'ESAME

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NUCLEAR MAGNETIC RESONANCE

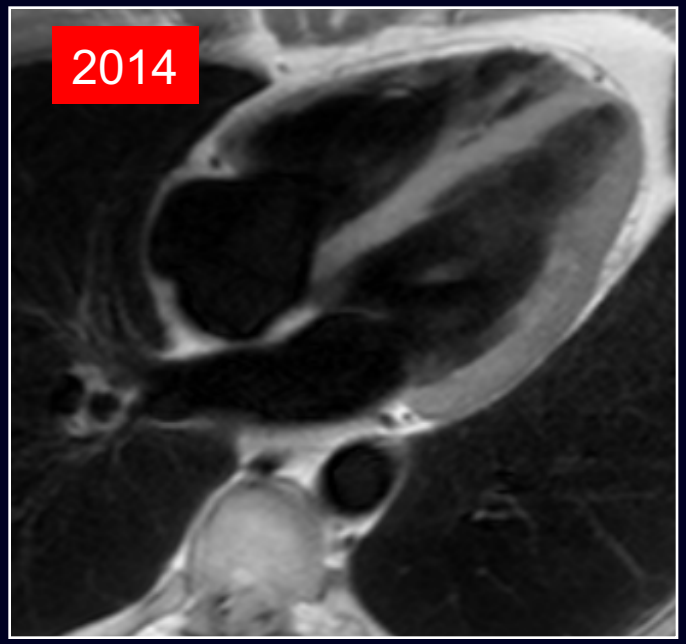
Robert J. Herfkens, M.D.
Charles B. Higgins, M.D.
Hedvig Hricak, M.D.
Martin J. Lipton, M.D.
Lawrence E. Crooks, Ph.D.
Peter Lanzer, M.D.
Elias Botvinick, M.D.
Bruce Brundage, M.D.
Phillip E. Sheldon, M.D.
Leon Kaufman, Ph.D.

Nuclear Magnetic Resonance Imaging of the Cardiovascular System: Normal and Pathologic Findings[1]

SPECIAL REVIEW: CLINICIAN UPDATE

Clinical Use of Cardiovascular Magnetic Resonance

Gerald M. Pohost, MD; Lynne Hung, MD; Mark Doyle, PhD



RM Cuore: Peculiarità Anatomiche

- Complessità dei movimenti cardio-respiratori
- Orientamento anatomico del cuore
- Flusso nelle camere cardiache
- Vasi a decorso toruoso e di piccolo calibro (coronarie)
- Ampie dimensioni della gabbia toracica
- Elevata intensità del segnale del tessuto adiposo epicardico
- Interazione con studio grossi vasi

RM Cuore: requisiti Tecnici e "culturali"

- Alta intensità di campo: 1.0 - 3.0 Tesla
- Elevata velocità di risalita dei gradienti
- Bobine di superificie multicanale (SNR - imaging parallelo)
- ECG triggering
- Sequenze specifiche
- Monitoraggio cardio-respiratorio
- Software cardiaco dedicato
- Competenze cardiologiche...

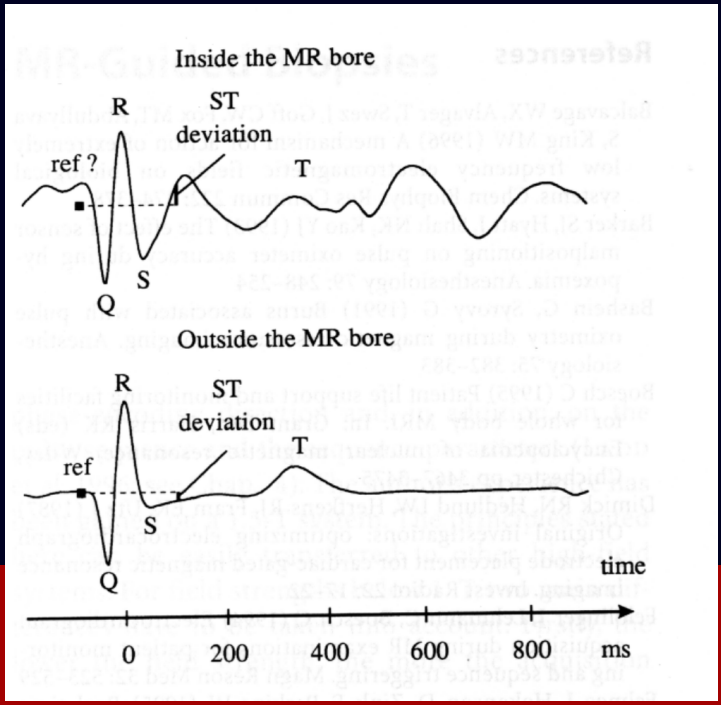
Demographic, clinical and acquisition data.

Study population (n)	3376 (100%)
Geographic distribution of participating centers and % of patient's enrolled	- 21 North (46.3%) - 14 Center (36.8%) - 5 South and Islands (16.9%)
Gender	Male: 2254 (67.0%); Female: 1122 (33.0%)
Mean age (years)	47.2 ± 19.3 (1–92)
Body mass index (kg/m^2)	24.8 ± 2.2 (21.6–27.4)
Patient's source	Outpatients: 2070 (61.0%) Day hospital: 232 (7.0%) Hospitalized: 1050 (31.0%) Non-specified: 23 (1.0%)
Clinical priority	Urgent: 6.5%; elective (91.6%)
Scanner type (patient's enrolled and %)	1.0 T: 25 (0.7%) 1.5 T: 3257 (96.5%) 3.0 T: 92 (2.8%)

Francone M, et al. Italian registry of cardiac magnetic resonance. Eur J Radiol (2013)

Static magnetic field

- **Known reversible effect : T-wave elevation in ECG : movement of blood (=conductive) causes magnetohydrodynamic effect.**
- **Highest potential ever induced : 64 mV in 10T-field*.**



No evidence of hazardous phenomena at 1.5T

*Budinger, Workshop ISMRM 1998

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Come eseguire e ricostruire un esame?

Cardiosincronizzazione ottimale

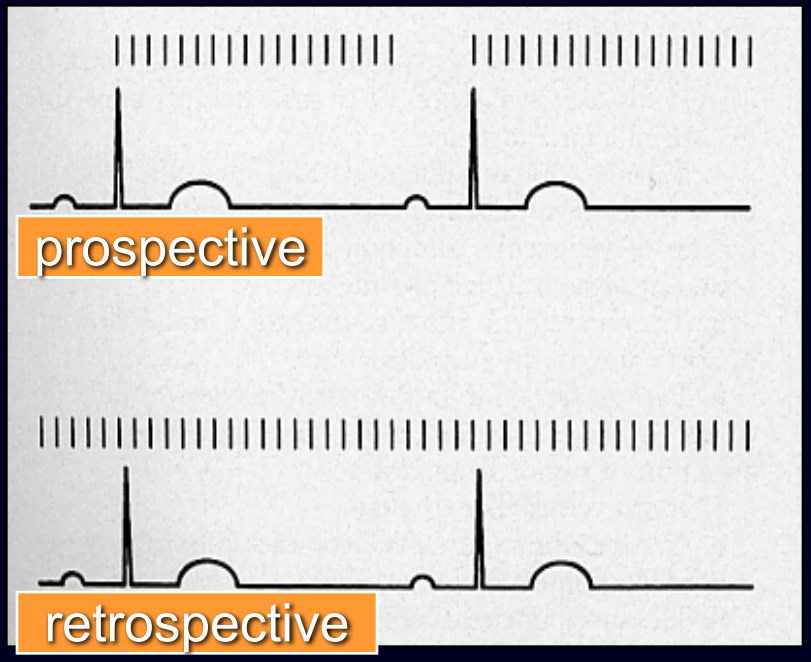
Costruzione di piani anatomici mirati al quesito clinico

Workstation dedicate (volumi, funzione massa + LGE Edema?)

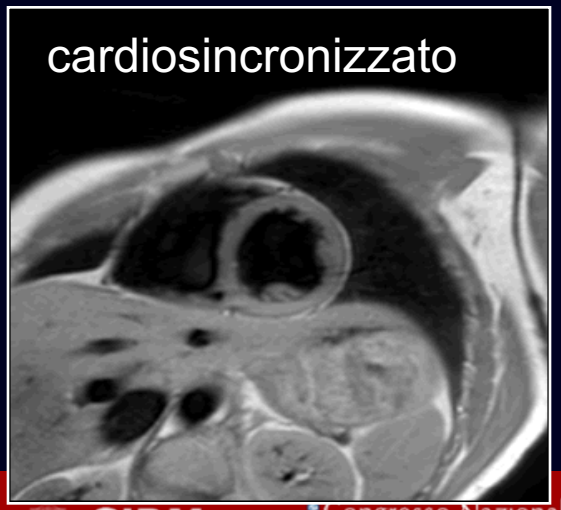
Correlazione con i dati clinici e strumentali del paziente (volumi, FE, massa ventricolare etc...)

Cardiosincronizzazione

Gating cardiaco retrospettivo o prospettico



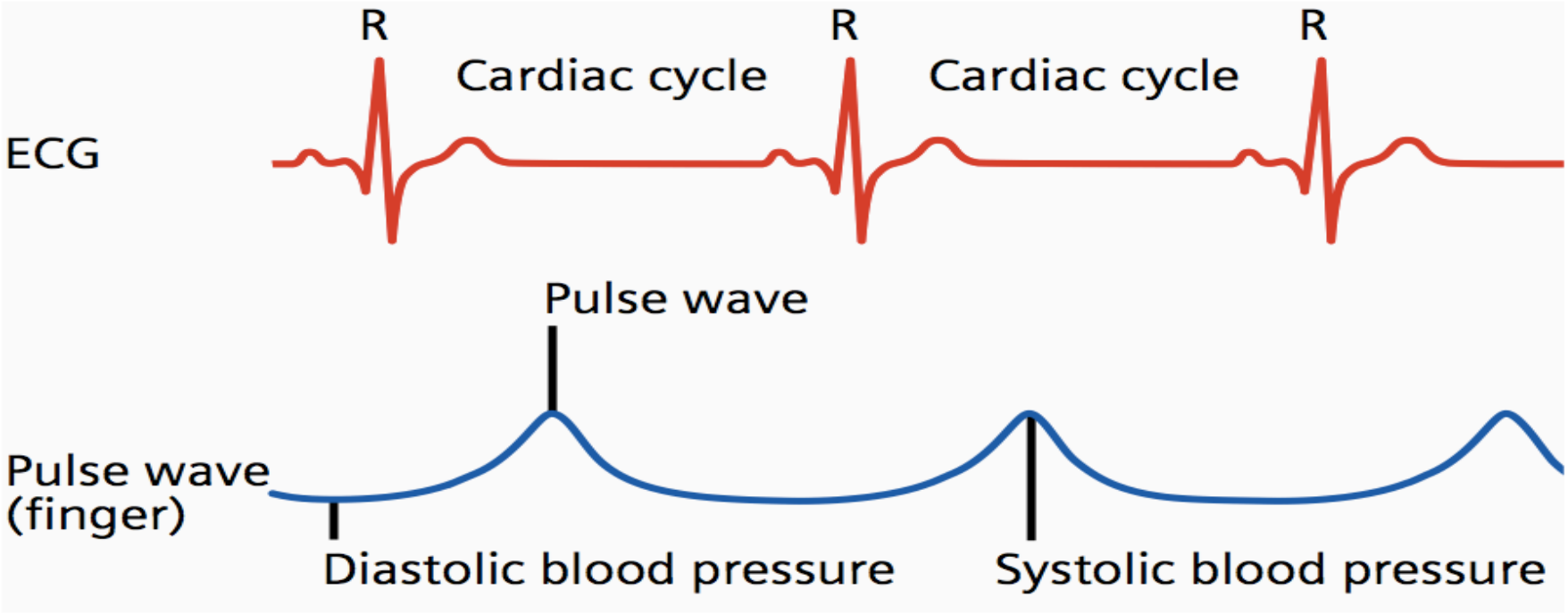
Lanzer et al. Radiology 1984

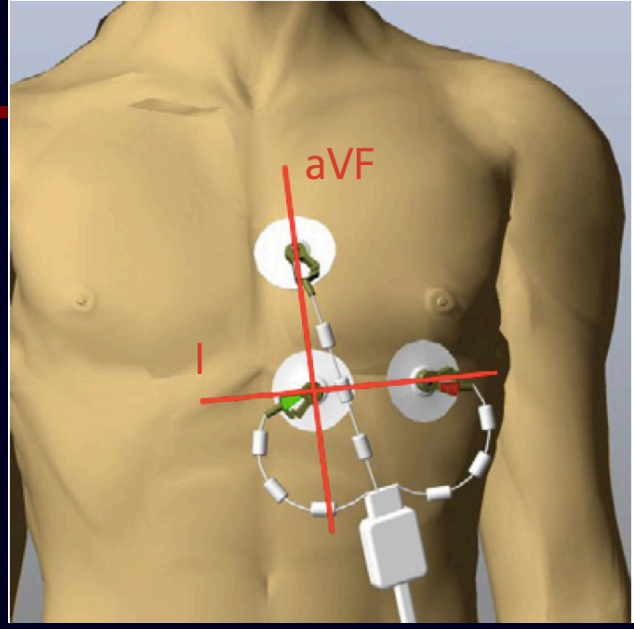


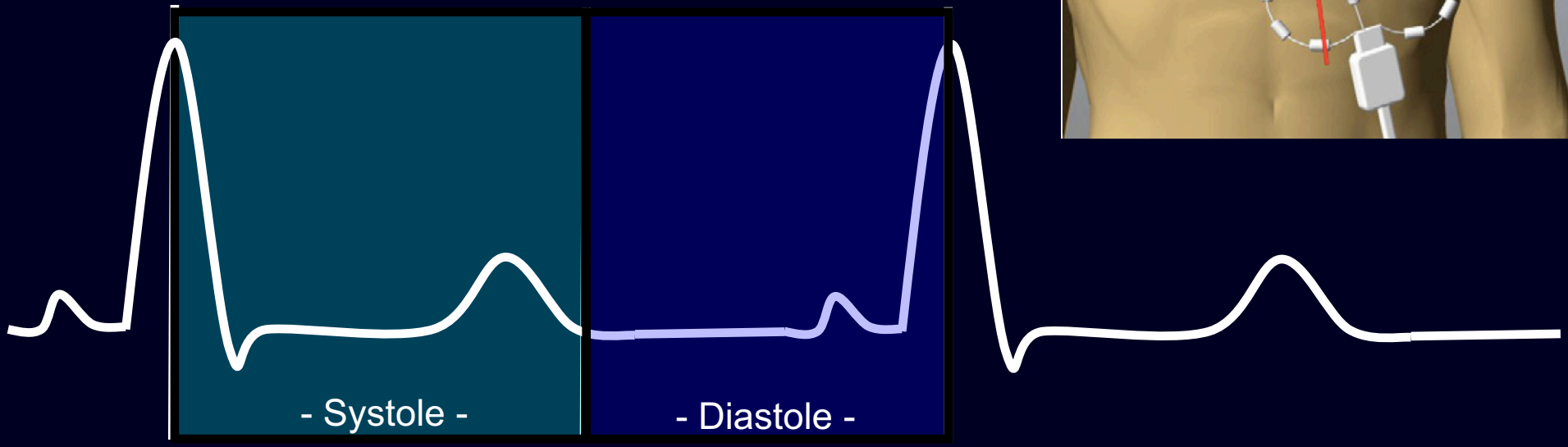
Cardiosincronizzazione

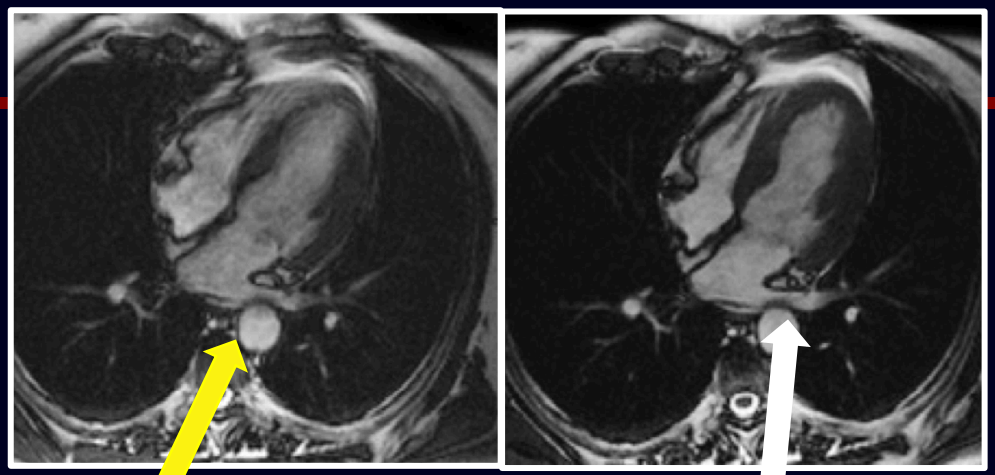
Trigger ECG → ECG

Trigger ECG → Pulsiossimetro

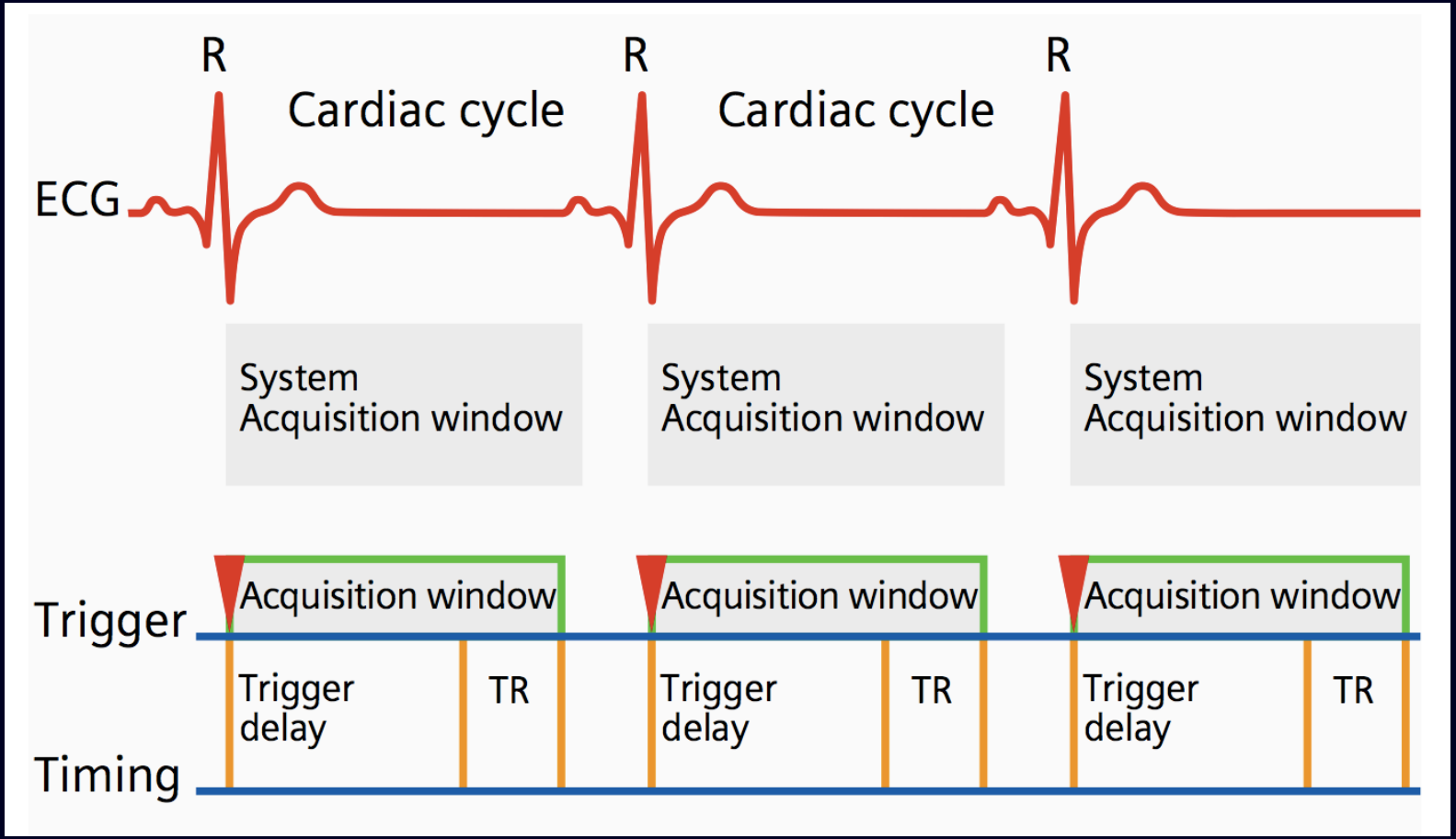



aVF
I

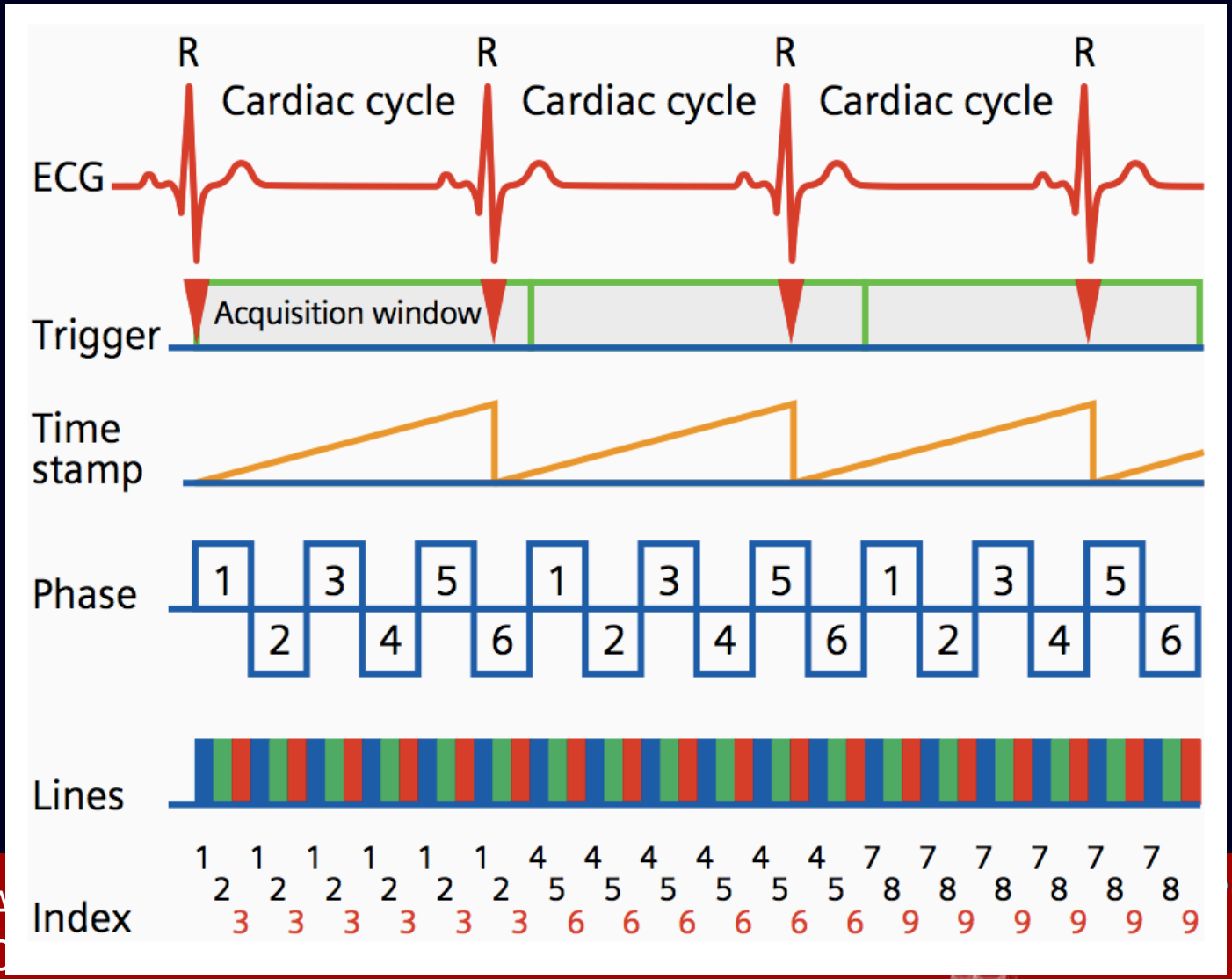

- Systole -
- Diastole -



Trigger prospettico

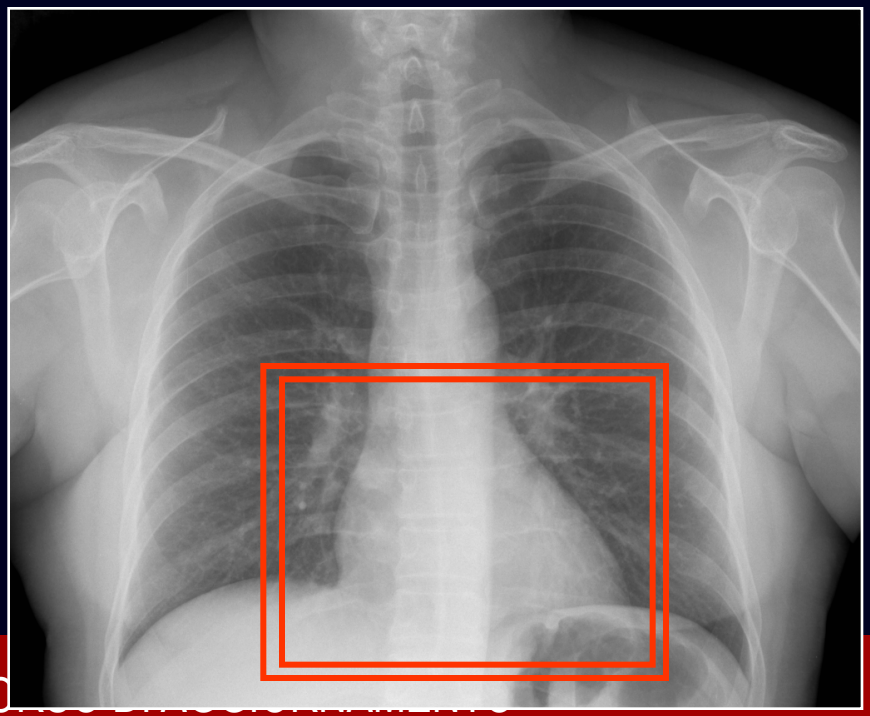


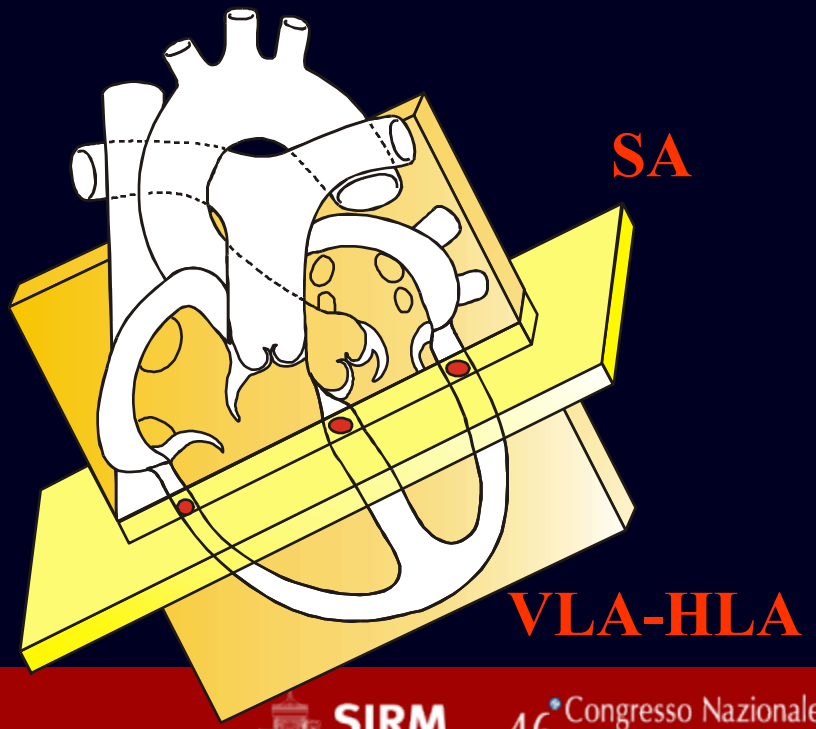
Trigger retrospettivo



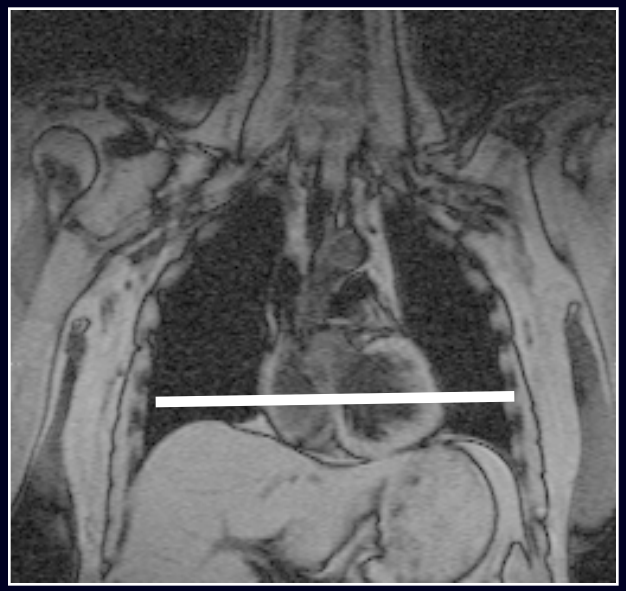
RM Cuore: Peculiarità Anatomiche

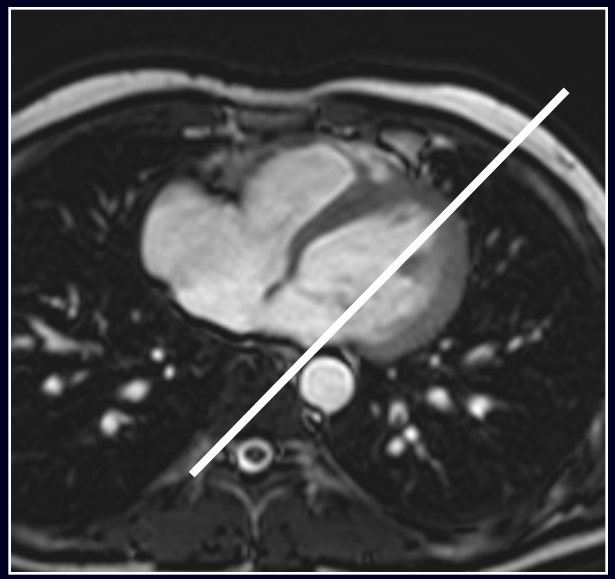
- **Il cuore non è orientato secondo assi anatomici ortogonali!!!**
- **Necessità di costruire piani di scansione specifici**

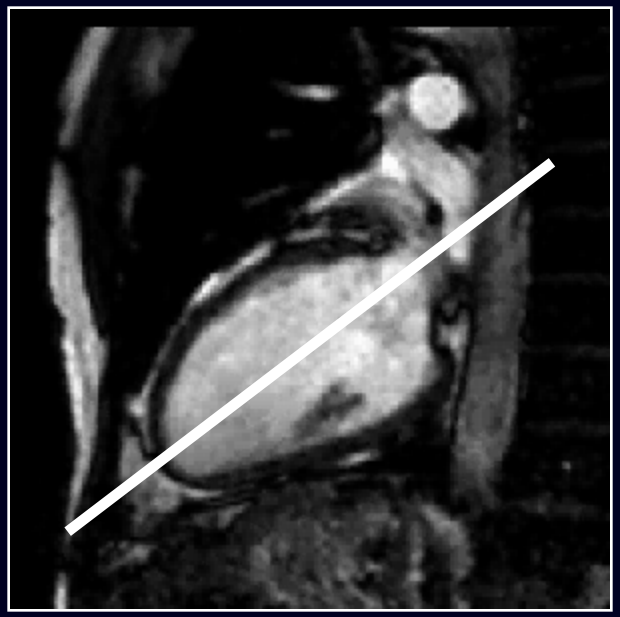


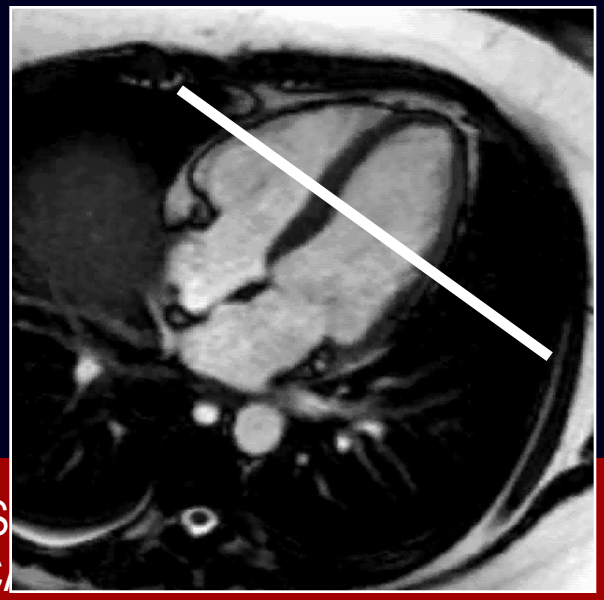


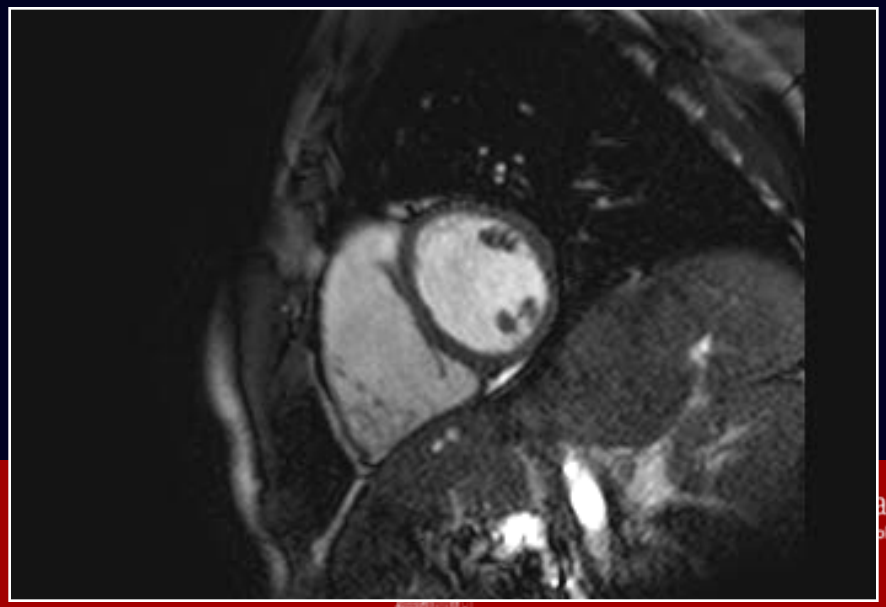
Principali piani di scansione in Cardio-RM

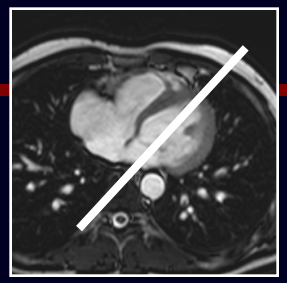




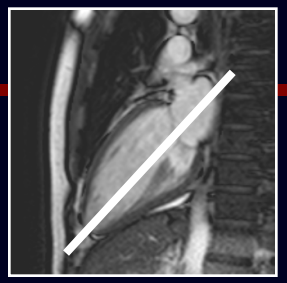




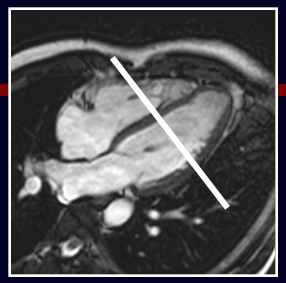




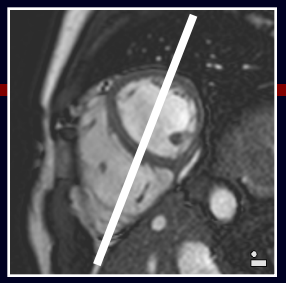
Assiale



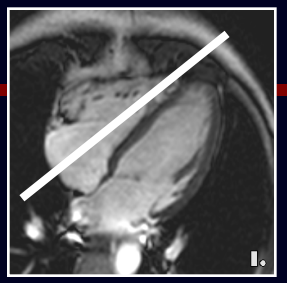
Asse lungo verticale



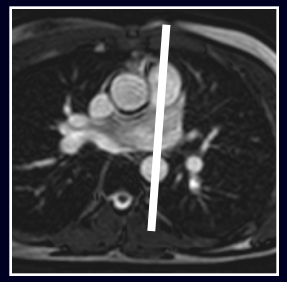
Asse lungo orizzontale



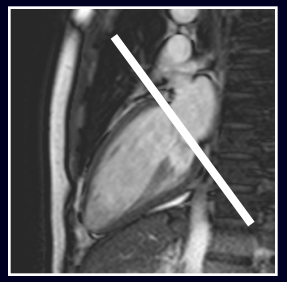
Asse corto



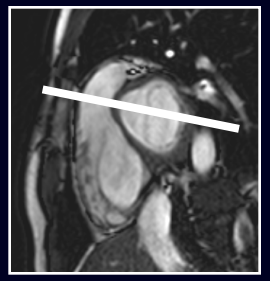
Asse lungo orizzontale ver



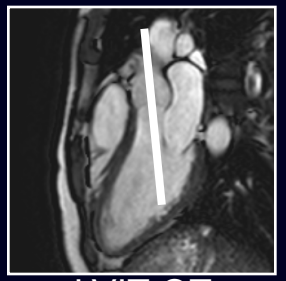
Assiale



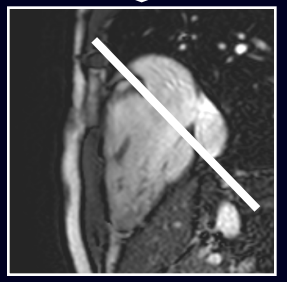
Asse lungo verticale



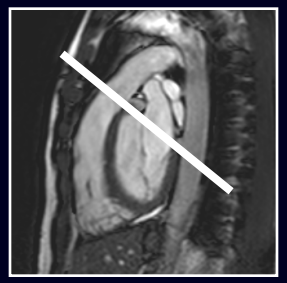
Asse corto basale



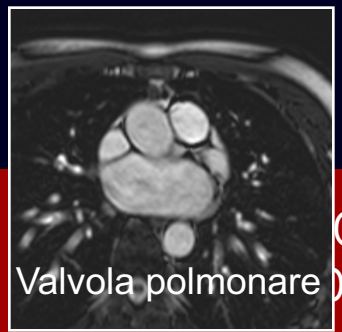
LVIT-OT



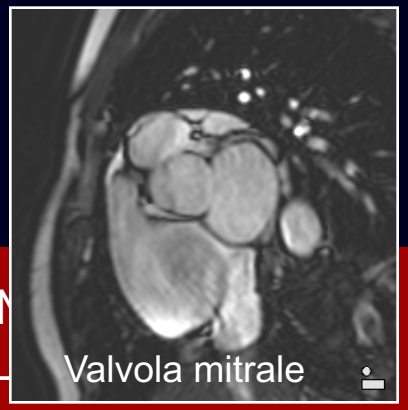
2 Camere Ventricolo Destro



RVOT



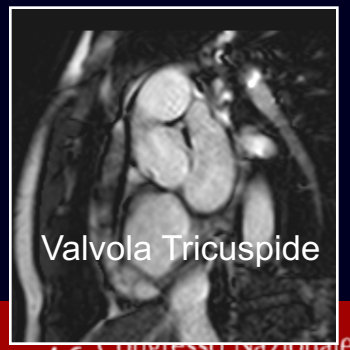
Valvola polmonare



Valvola mitrale

LVOT

Valvola Aortica



Valvola Tricuspide

Piani di scansione ideali per visualizzazione di camere cardiache e principali strutture anatomiche*

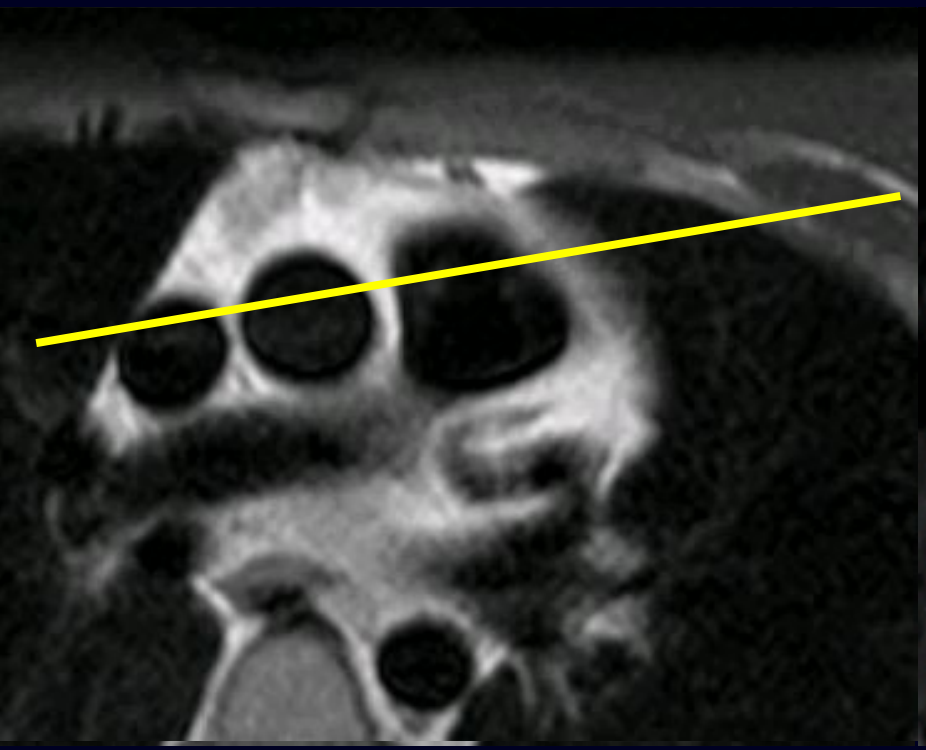
Struttura anatomica o camera	Piano di scansione
Ventricolo sinistro	*4 camere, asse corto, LVOT°*
Ventricolo destro	*4 camere, asse corto, RVOT^*
Atrio sinistro	*4 camere, LVOT e asse lungo verticale*
Atrio destro	*4 camere, assiale e coronale*
Aorta	*Sagittale obliquo tra a. ascendente e discendente*
Arteria polmonare principale	*Assiale, sagittale obliquo orientato dalla RVOT*
Arterie coronarie	*Protocollo "whole body" a 3 punti*
Valvola aortica	*Coronale obliqua, assiale obliqua trans-aortica*

** modificato da Ginat GT et al: AJR 2011:808–815*

° Left ventricular outflow tract

^ Right ventricular outflow tract

Asse lungo ventricolo destro ed RVOT



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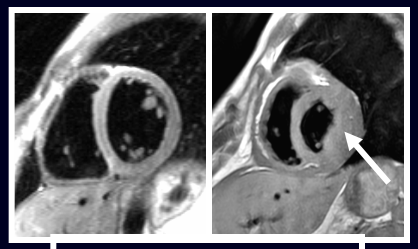
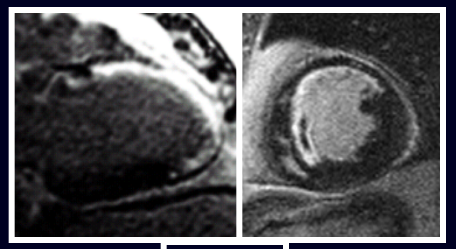
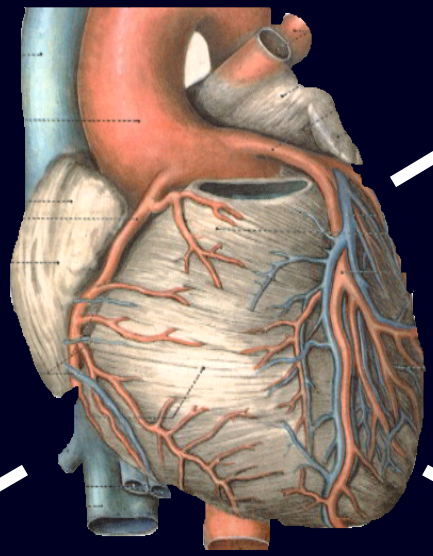
Cardiac MR Toolbox



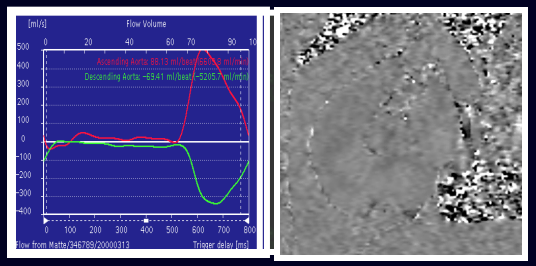
Morphology



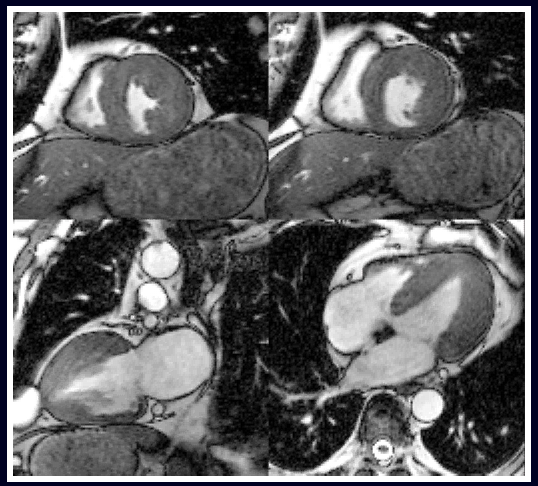
LGE



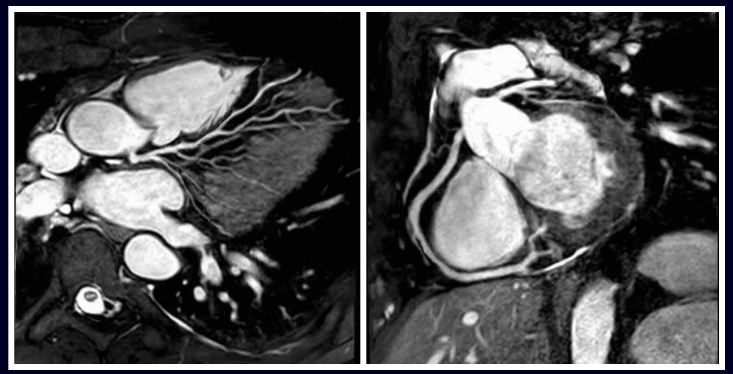
Great vessels



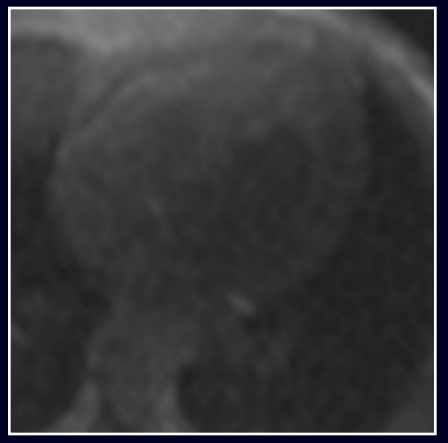
Flow Quantification



Function



Coronary Artery Imaging



Perfusion Assessment

Marc Kouwenhoven, Philips Medical Systems

Morfologia

- Piani dedicati
- Caratterizzazione tissutale

Funzione

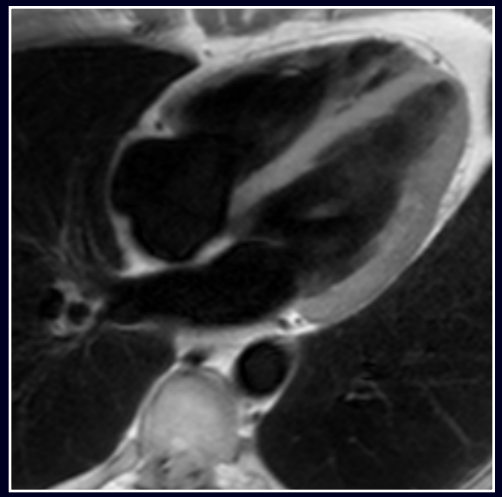
- Funzione ventricolare
- Perfusione
- Quantificazione flussi

RM Cuore: Protocolli di studio

Real Time
(RT)-b-SSFP

Perfusione
SR/IR spoiled-GE/b-SSFP

Morfologia
T1w-FSE
b-SSFP

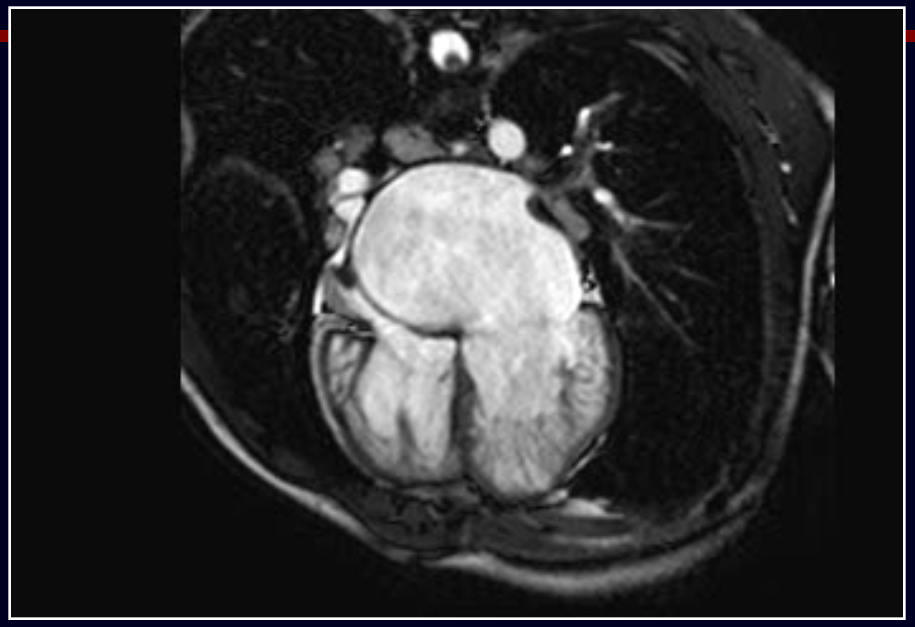


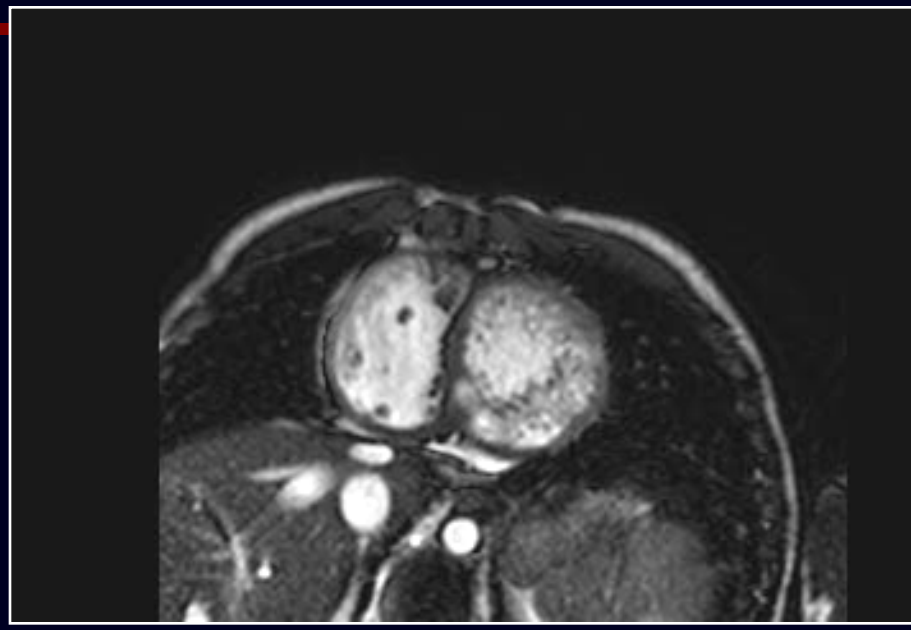
Caratterizzazione tissutale
T1w-FSE (- / + CA)
T2w-STIR-FSE
CE-IR MRI

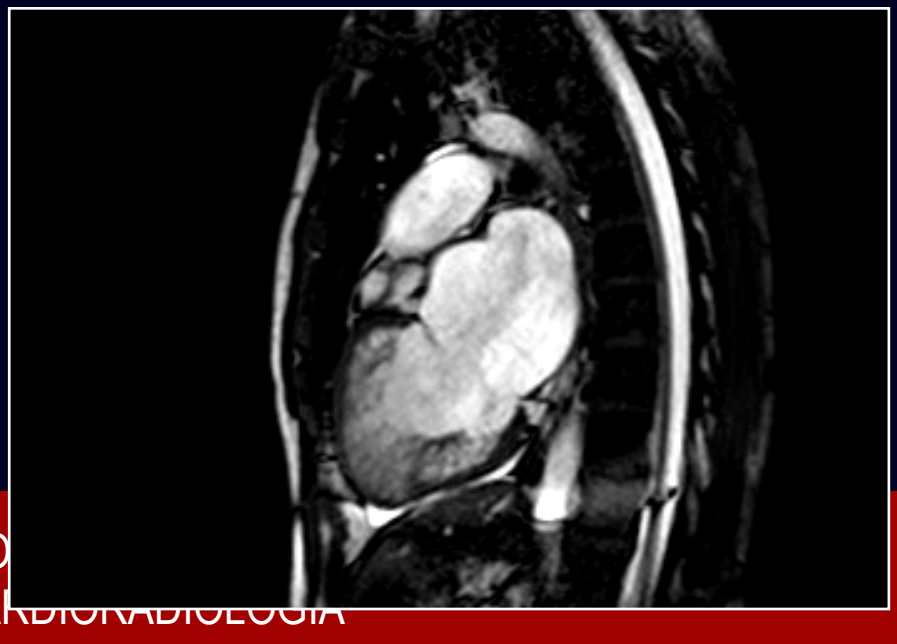
Funzione
b-SSFP cine MRI

Flusso
b-SSFP cine MRI
VENC cine MRI

Arterie Coronarie
b-SSFP



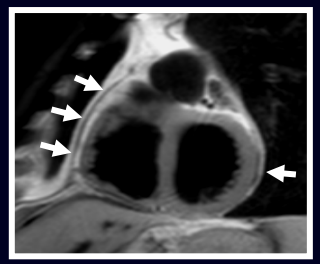




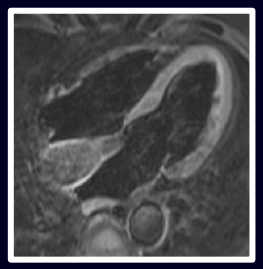
Funzionale o morfologica?

Come approcciare la scelta delle sequenze??

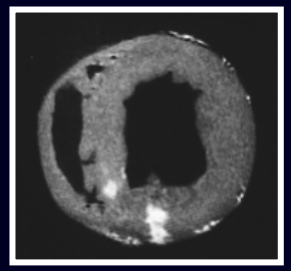
IR Turbo spin-echo e derivate: "black or dark blood"



T1wTSE o double-IR



T1wTSE fat sat

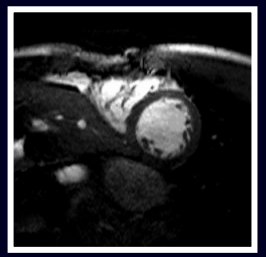


T1wTSE post-Gd

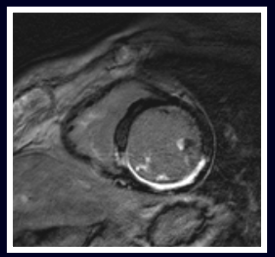
HASTE

T2w STIR o triple-IR

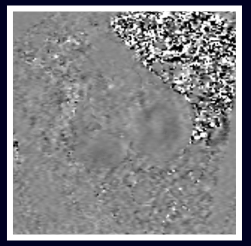
Gradient echo e derivate: "Dark o Bright-Blood"



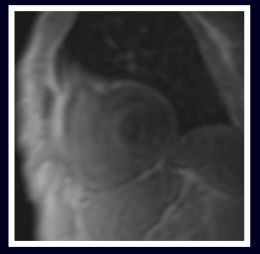
b-SSFP



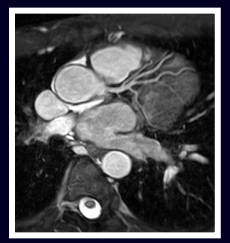
GRE-IR



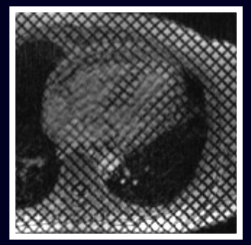
VENC



Perfusione

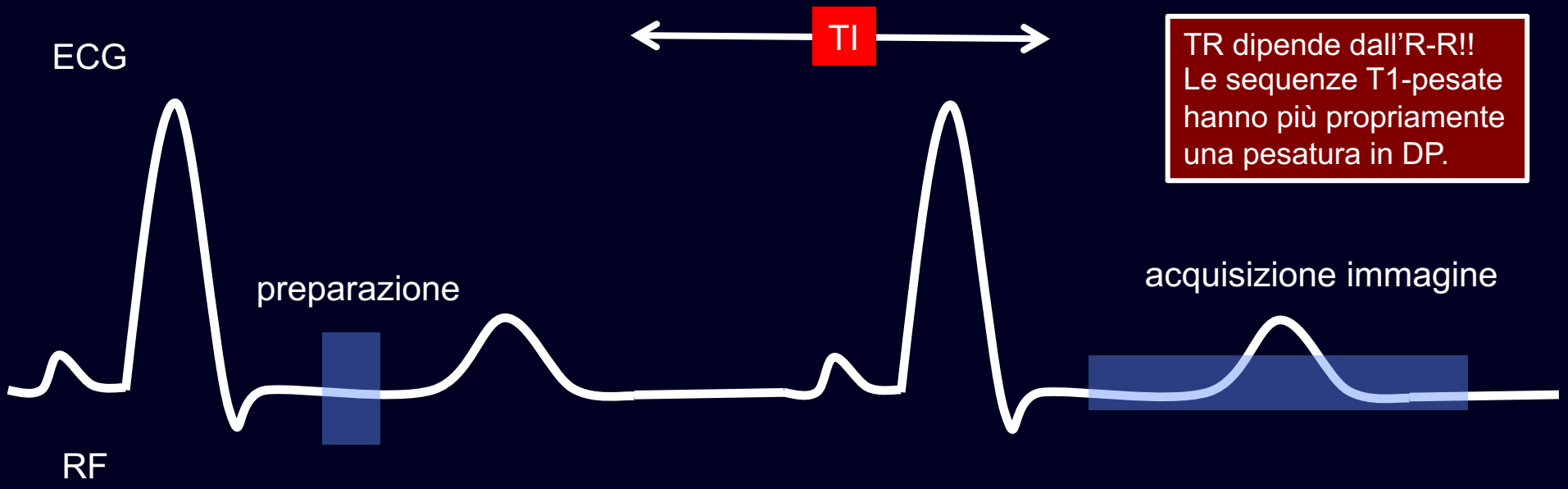


3D bSSFP



Tagging

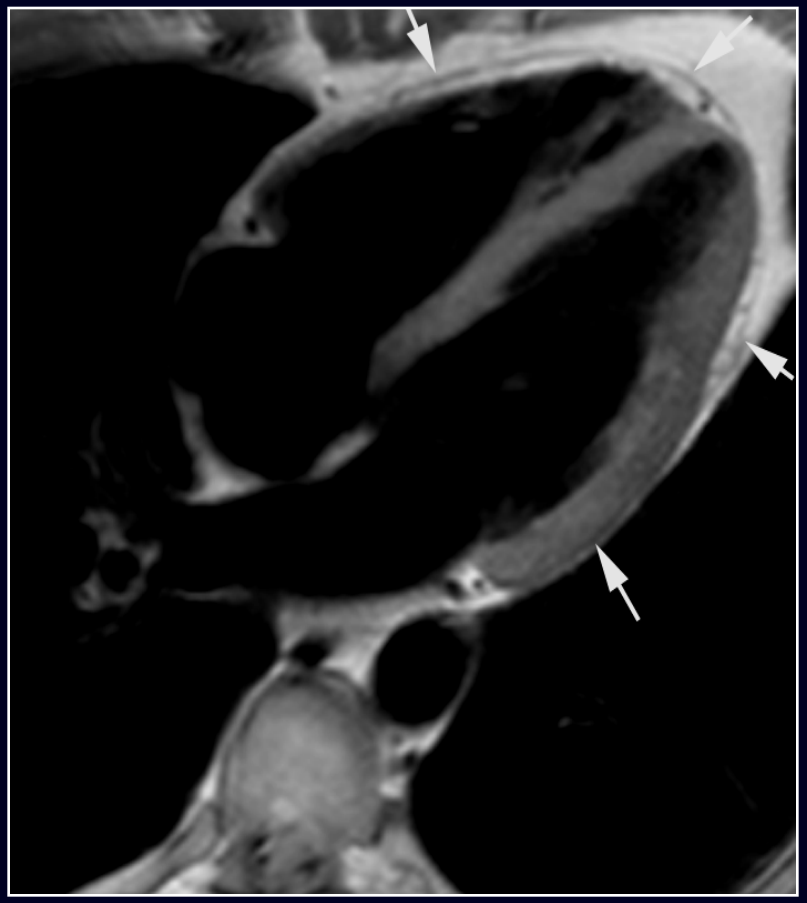
Spin-Echo MRI: “Black or Dark-Blood MRI”



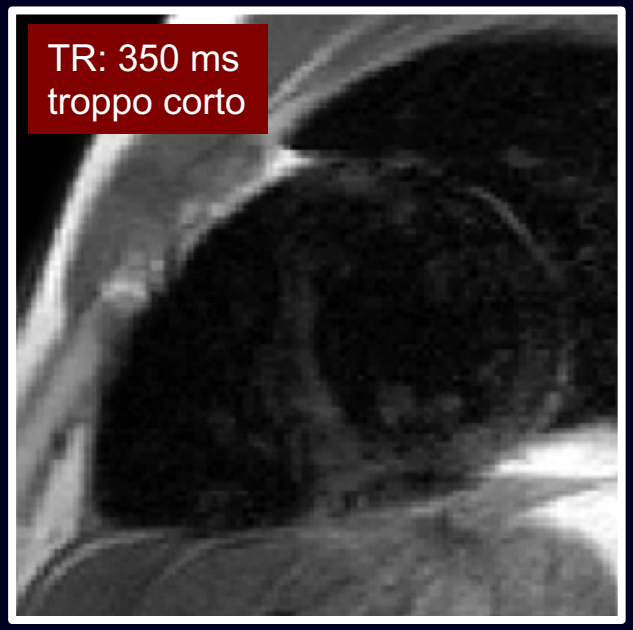
Il cuore deve trovarsi esattamente nella stessa fase del ciclo tra i due successivi impulsi a 180°

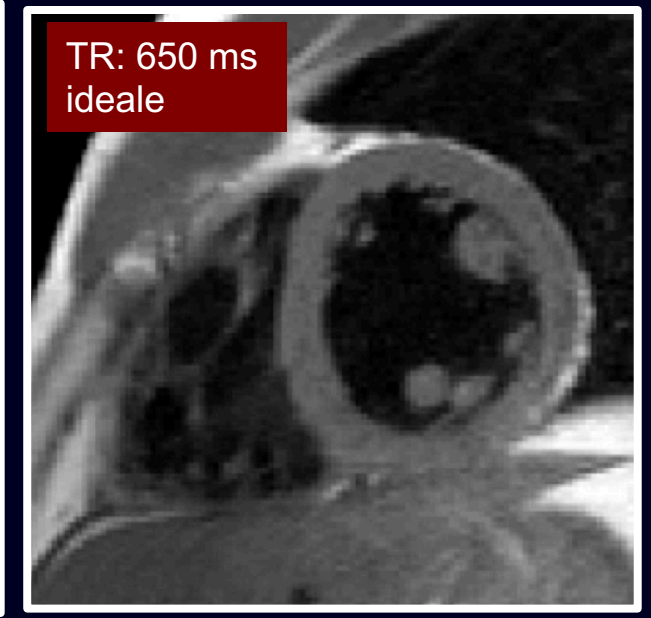
L’acquisizione dei dati deve avvenire in diastole, per la maggior durata e possibilità di ottenere omogenea soppressione del segnale del sangue!!!

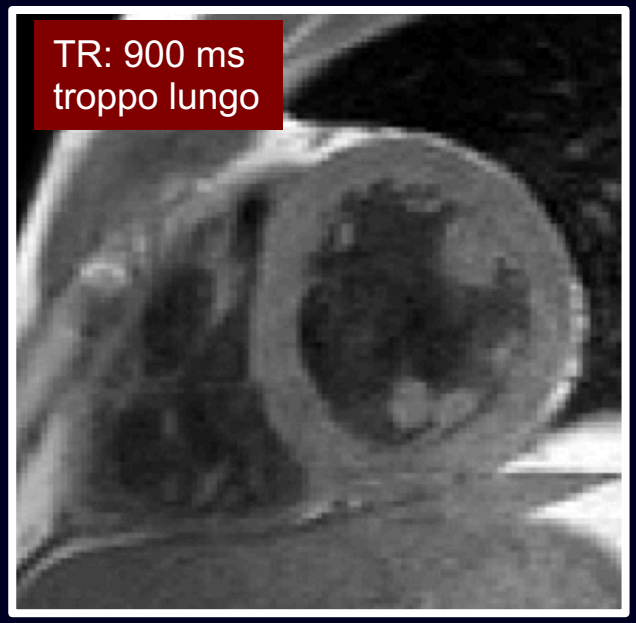
Spin-Echo MRI: "Black or Dark-Blood MRI"



Spin-Echo MRI: "Black or Dark-Blood MRI"

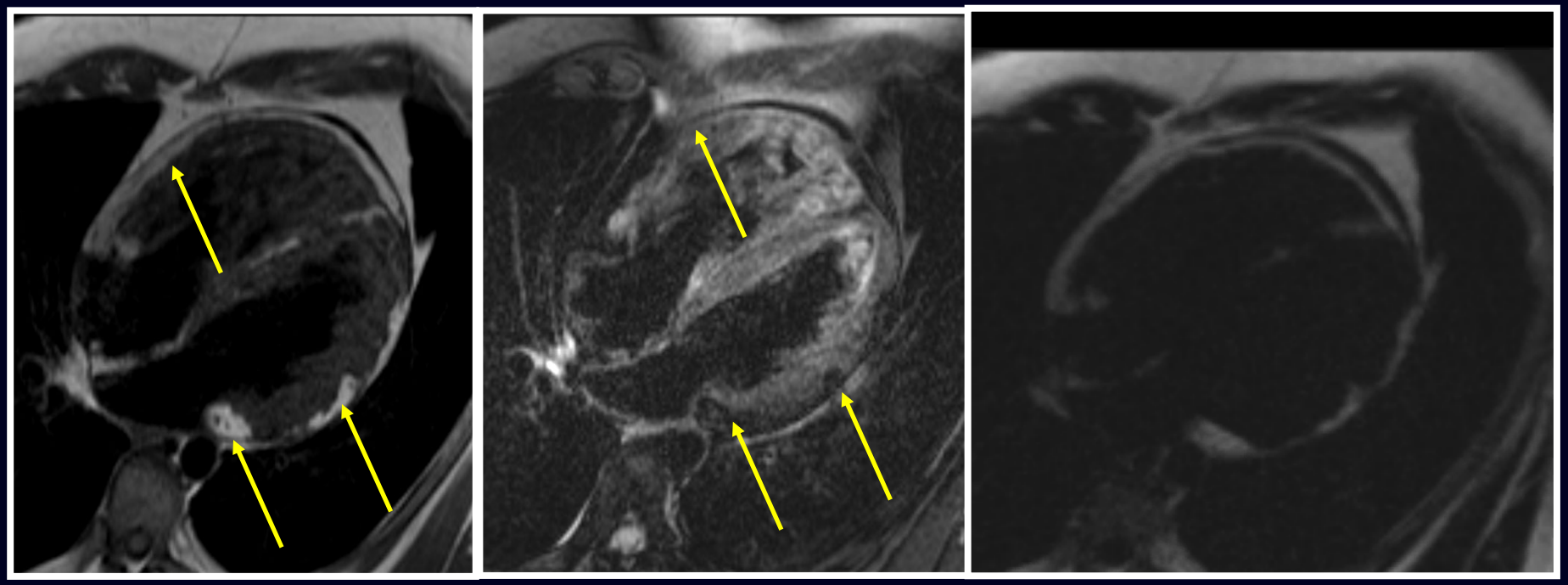






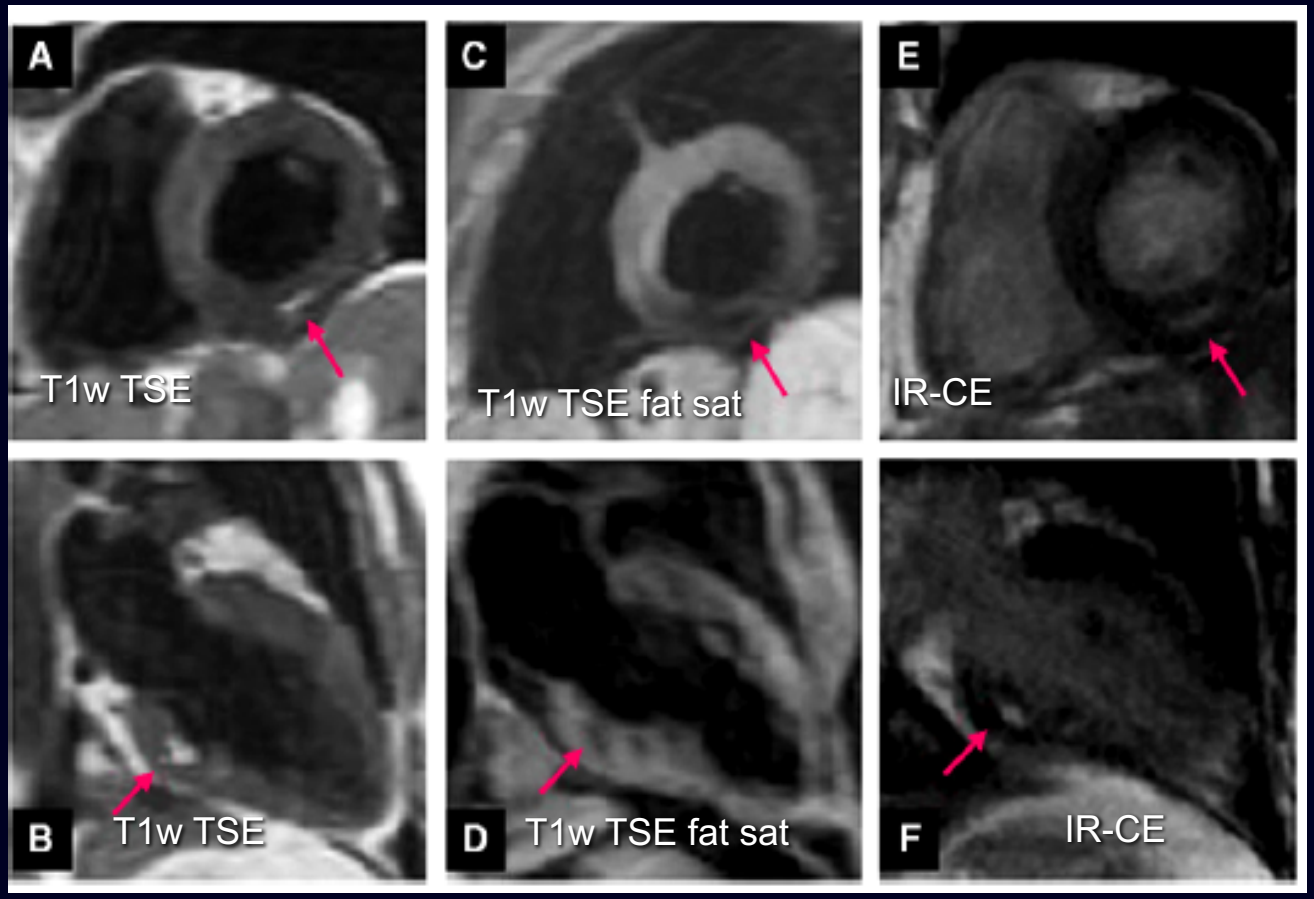
TR ottimale: 600 – 800 ms

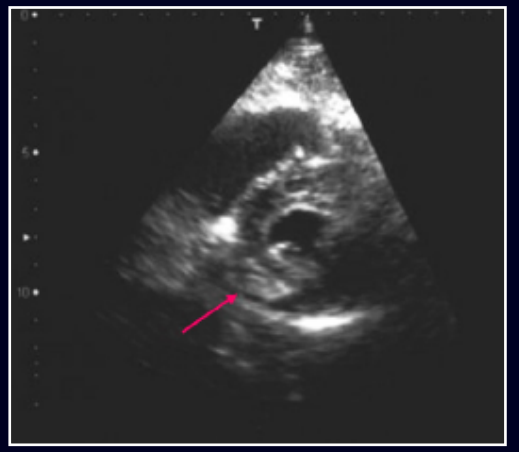
ARVC



Infiltrazione fibroadiposa (?) + discinesia parete libera

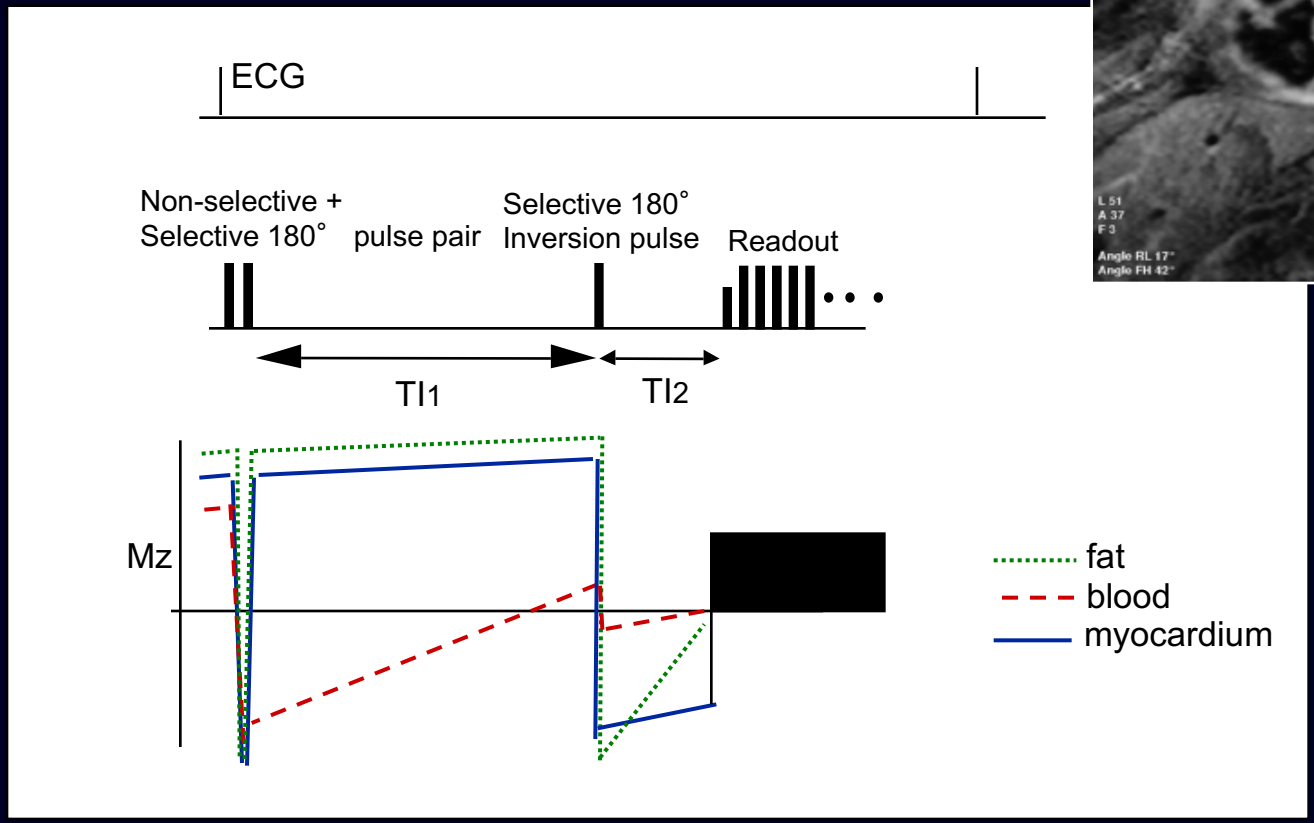
✓ 62 aa donna, rilievo TTE di formazione iperecogena intramiocardica





Bucciarelli Ducci C, Francone M Int Journ of Cardiol 2006

ECG triggered Black-Blood T2w-STIR FSE Technique

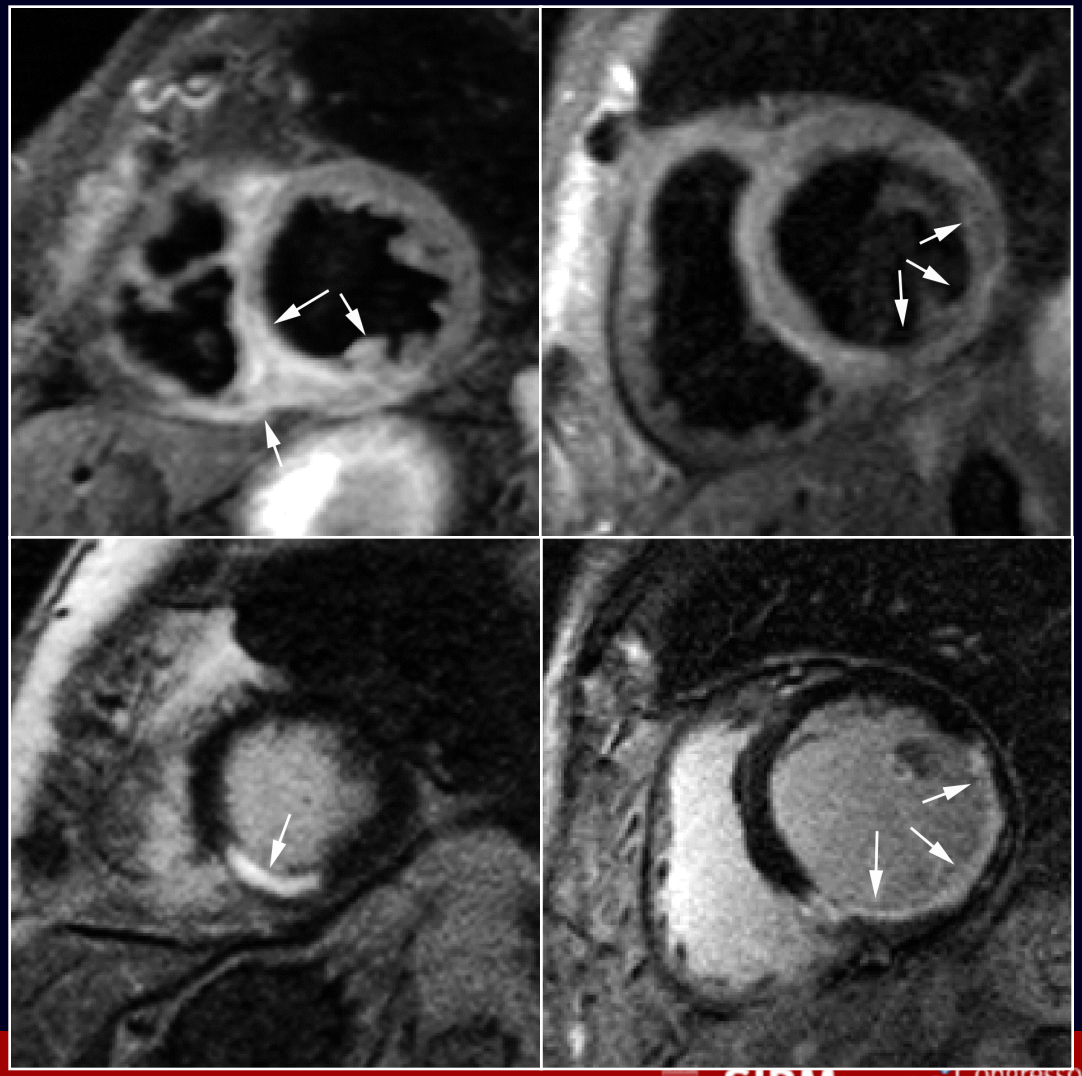


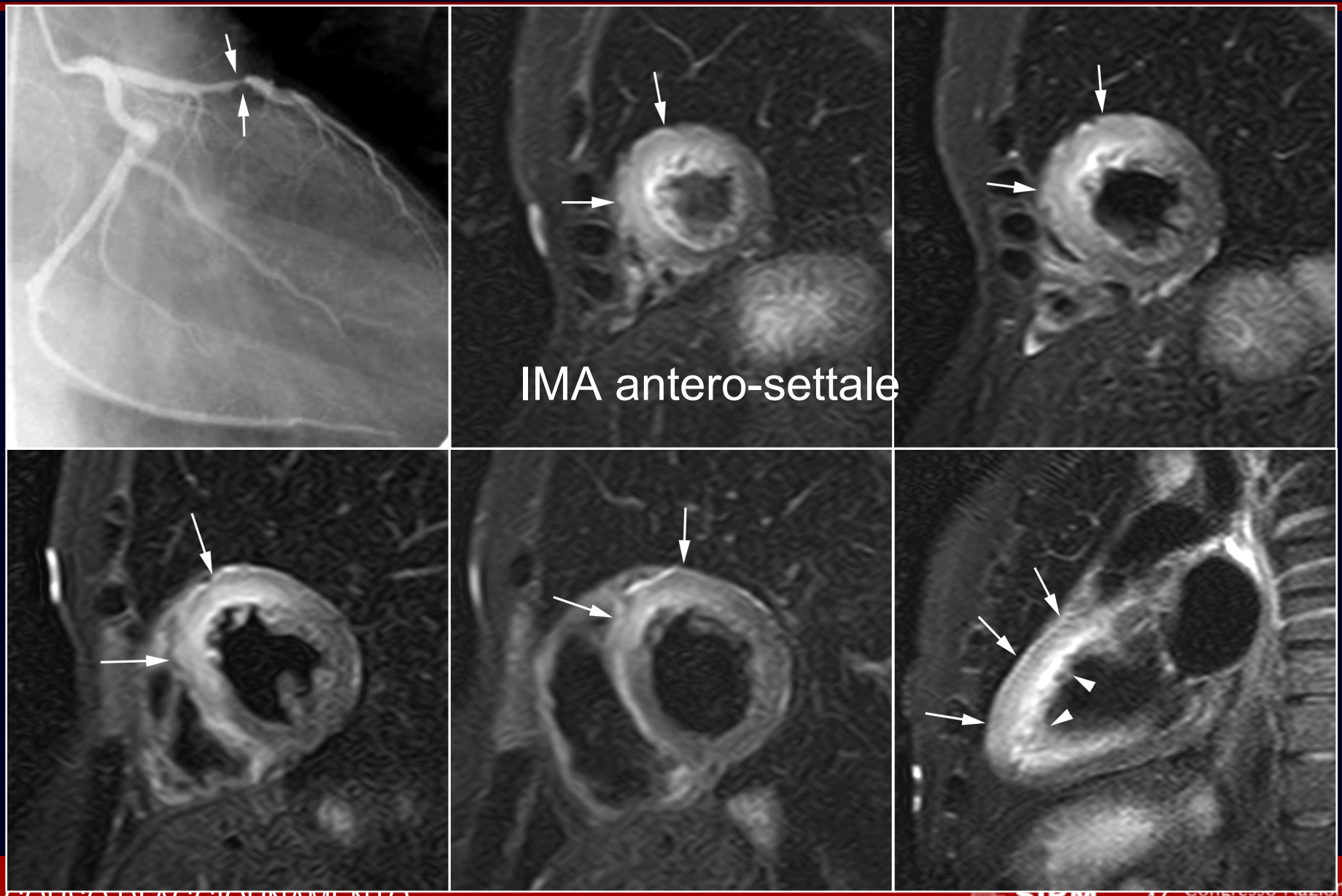
M. Francone et al Radiol Med 2010

Differenziazione tra Infarto Auto e Cronico

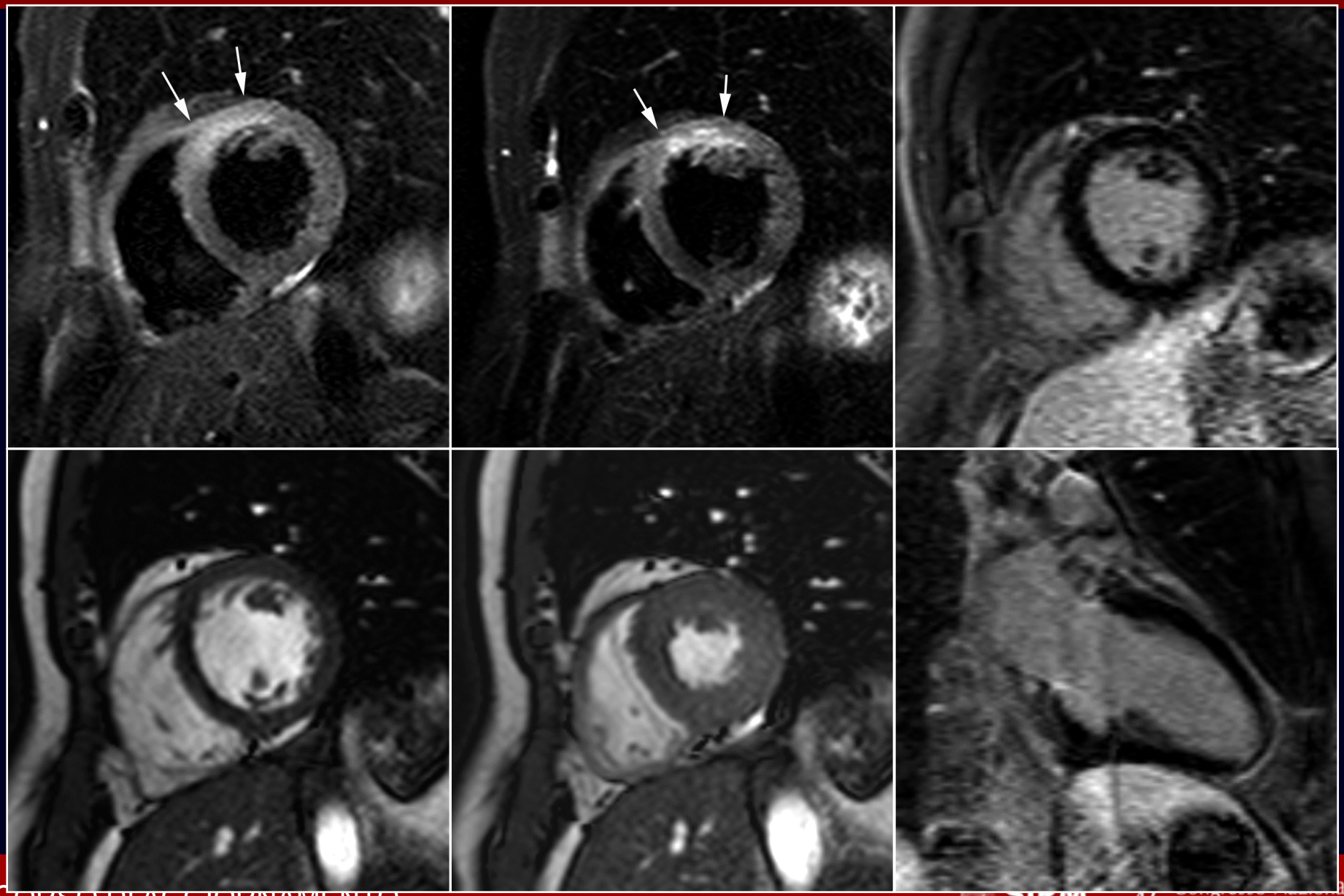
Edema-weighted Imaging

Delayed enhancement




IMA antero-settale

Insulto ischemico senza necrosi



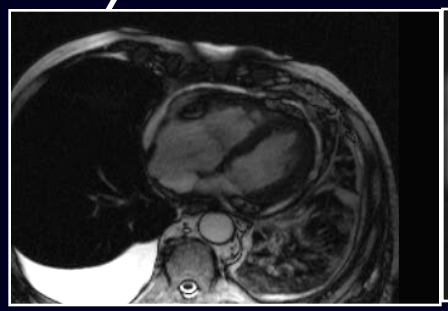
Sequenze black blood: punti chiave

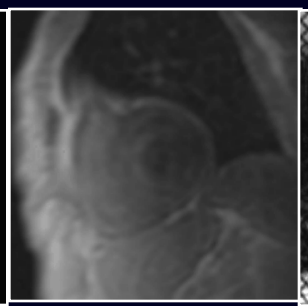
- Doppio o triplo impulso di pre-saturazione (IR)
- Elevato dettaglio morfologico
- Modulo di saturazione spettrale del tessuto adiposo (infiltrazione fibro-adiposa, lipomi etc)
- Caratterizzazione tissutale (masse) + “edema-weighted imaging”

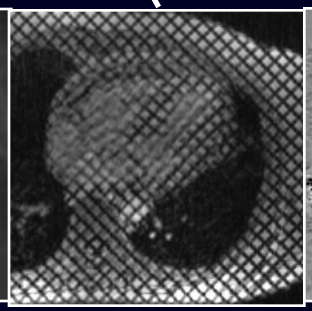
Gradient-Echo (Bright Blood MRI)

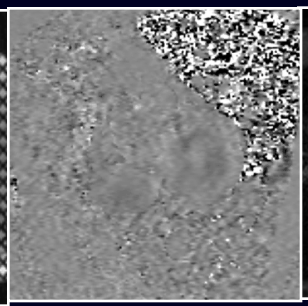
Cinesi regionale e globale

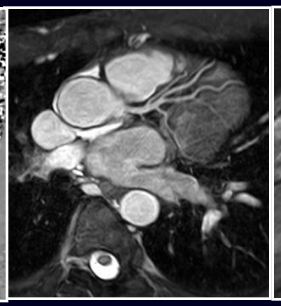
Danno miocardico da necrosi/flogosi etc

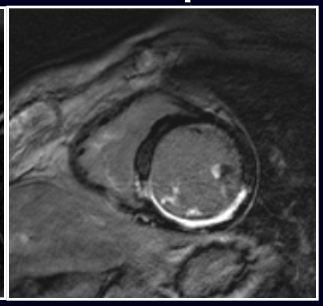








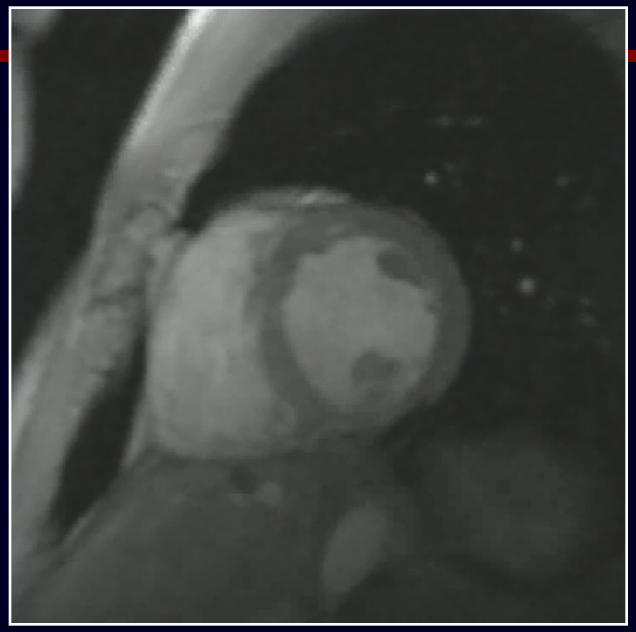




b-SSFP *Perfusione* *Tagging* *VENC* *3D bSSFP* *GRE-IR*

Funzione valvolare e pattern di riempimento

Coronaro-RM



Spoiled gradient-echo

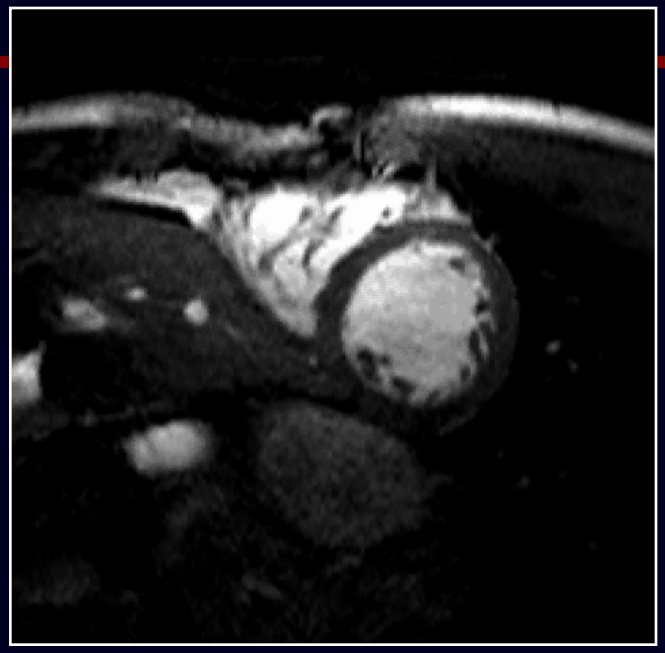
Contrasto miocardio/sangue

- flusso ematico intracavitario
- saturazione dei protoni statici

Dettaglio anatomico: basso a livello subendocardico per flusso lento

15-20 frames/ciclo cardiaco

Cinesi Regionale: ±



Balanced SSFP

Contrasto

- rapporto T2/T1

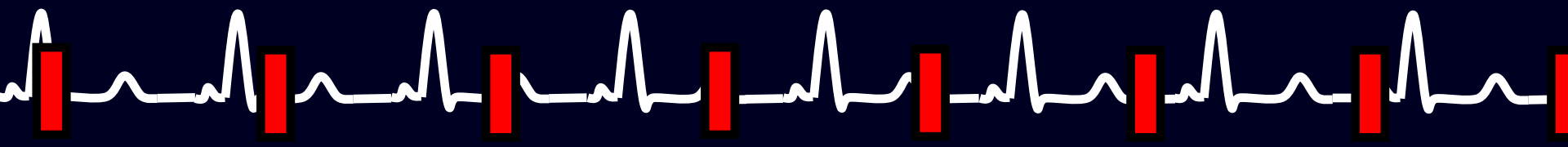
Dettaglio anatomico: elevato

Delineation / interface

- epicardio - miocardio ++
- miocardio – camere cardiache
- Imaging parallelo (Real-Time Cine MRI)

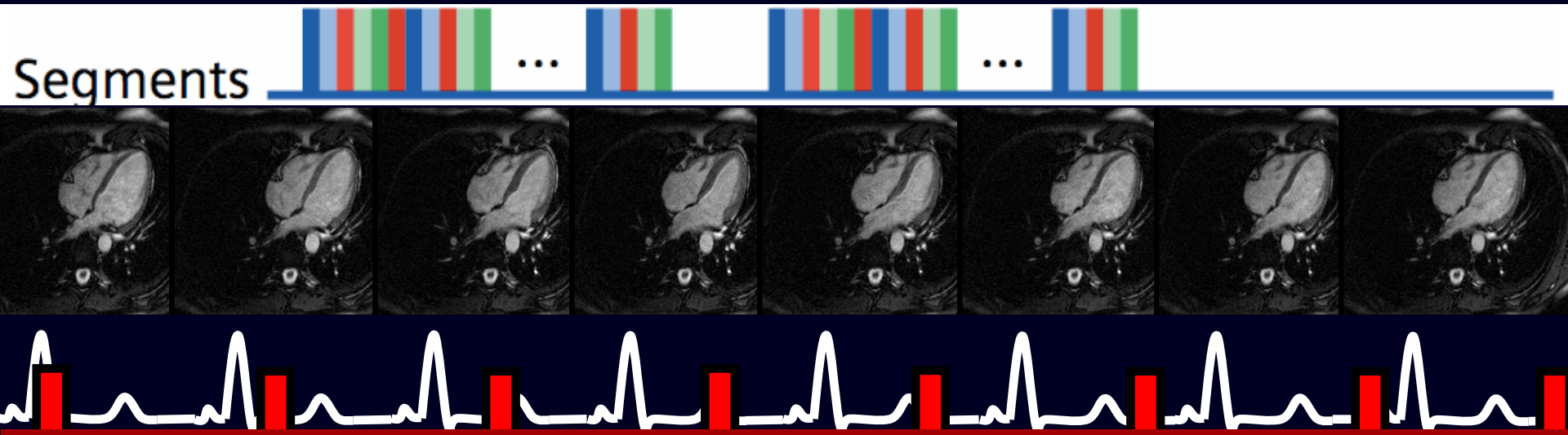
Cinesi Regionale: ++

Dynamic/ CINE GRE-Images Acquisition using several heartbeats from different cardiac phases in breath hold!



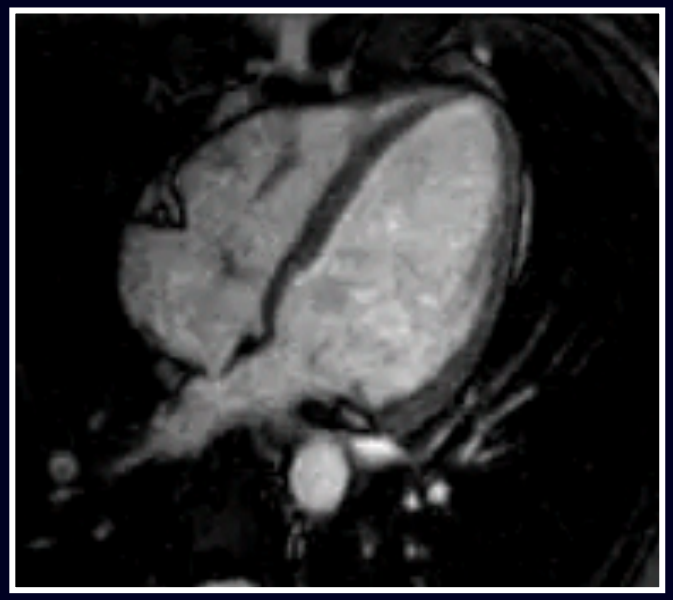
e.g. 1 slice in 8 heart beats per breath hold

Dynamic/ CINE GRE-Images Acquisition using several heartbeats from different cardiac phases in breath hold!



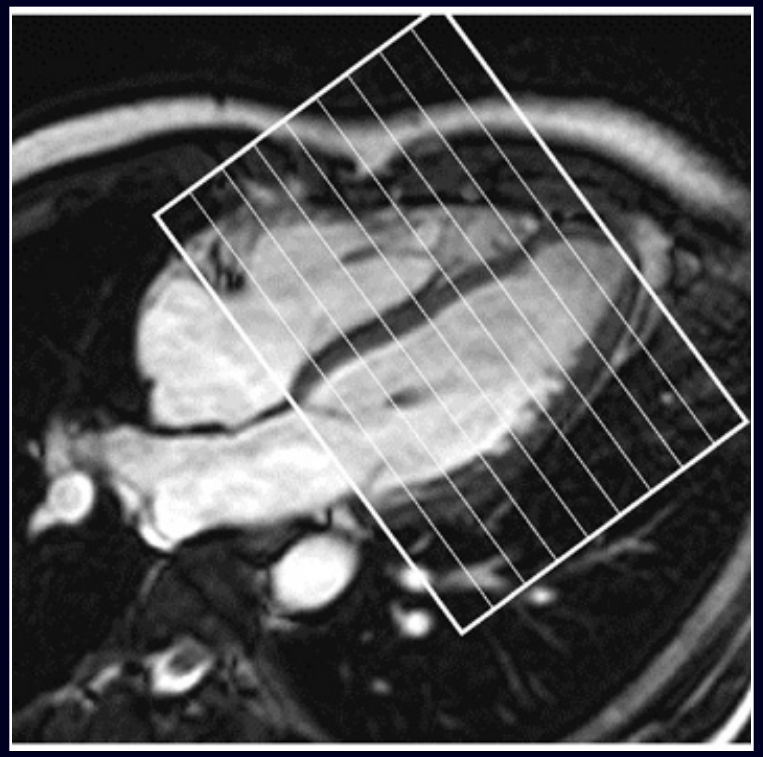
„steady state free precession“ (SSFP)

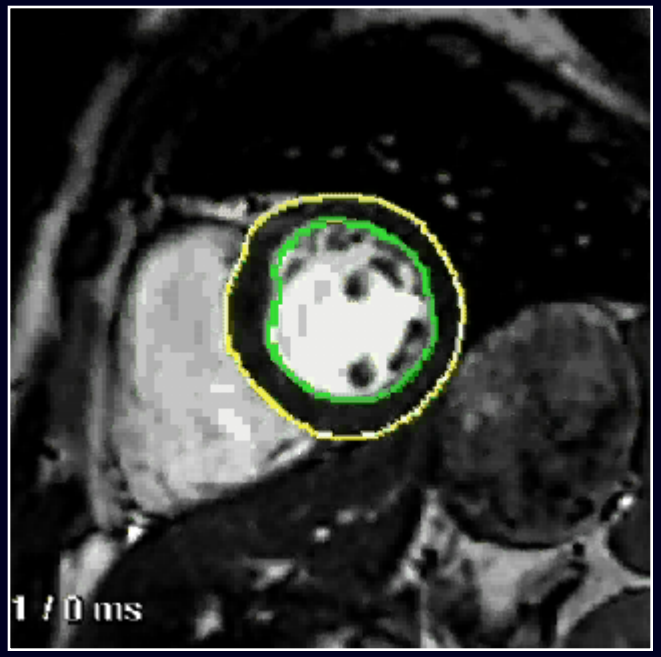
trueFISP-sequence (Siemens)
balanced TFE / FFE (Philips)
FIESTA (GE)



e.g. 1 slice in 8 heart beats per breath hold

Funzione Ventricolare sinistra





Stress RM con dobutamina: aumento progressivo del dosaggio

rest
55bpm

10 grammi
75bpm

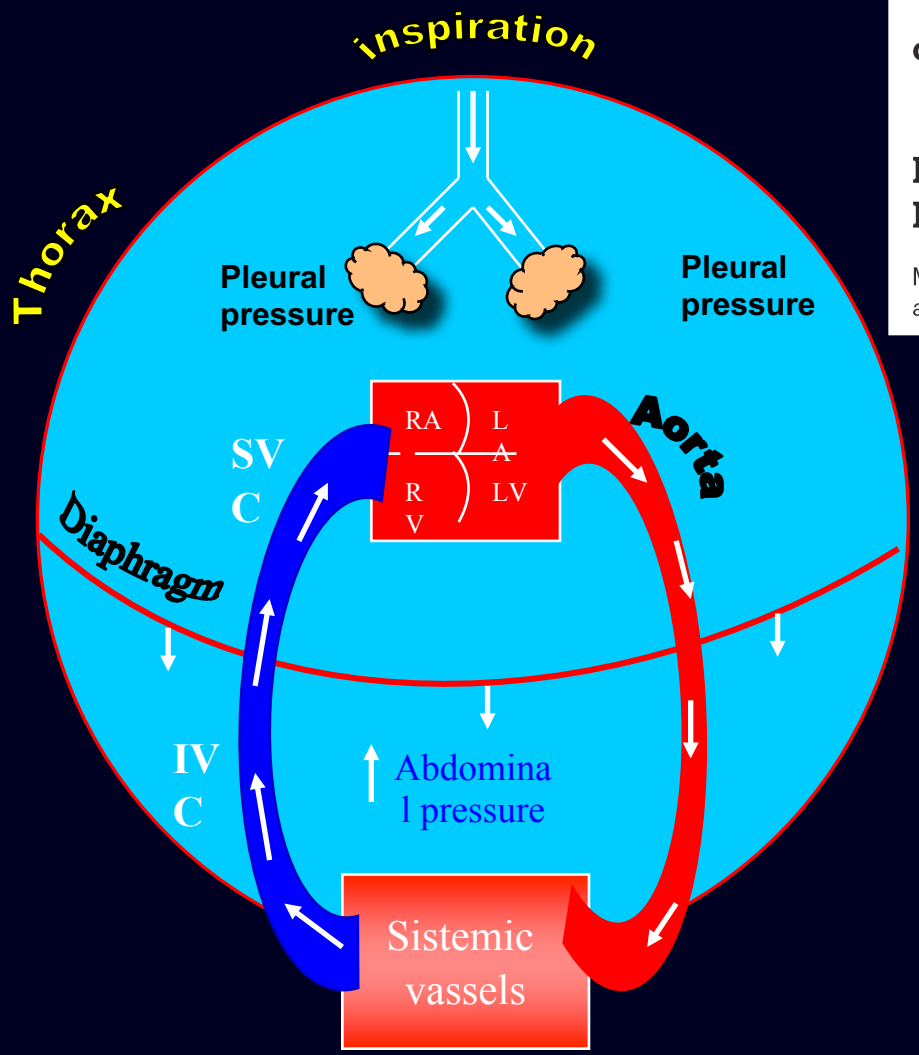
20 grammi
85bpm

30 grammi
110bpm

40 grammi
150bpm

Cortesia (e miocardio) Prof. J. Bogaert KU Leuven

Real-Time MRI

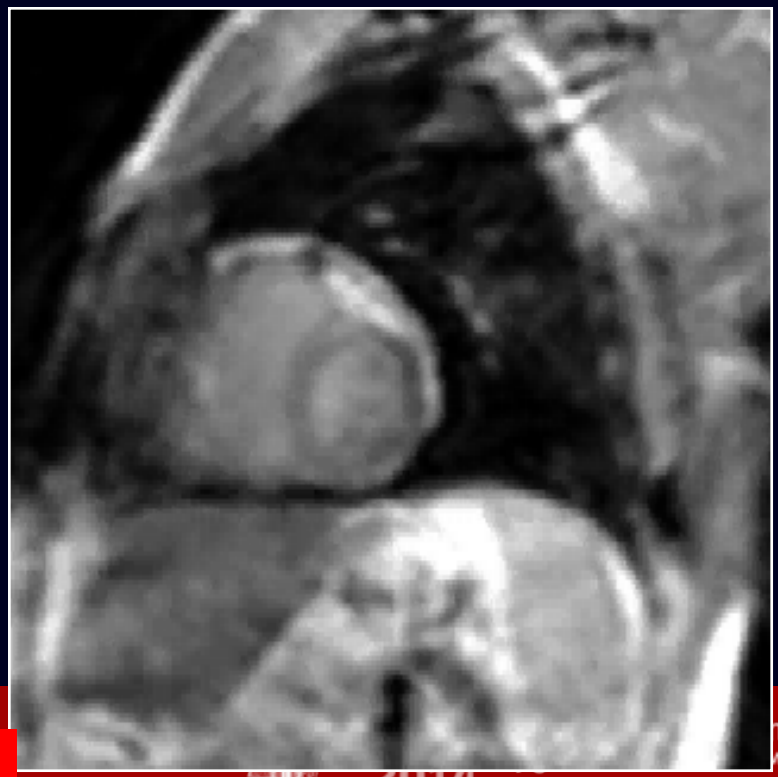


JOURNAL OF MAGNETIC RESONANCE IMAGING 21:305–309 (2005)

Clinical Note

Real-Time Cine MRI of Ventricular Septal Motion: A Novel Approach to Assess Ventricular Coupling

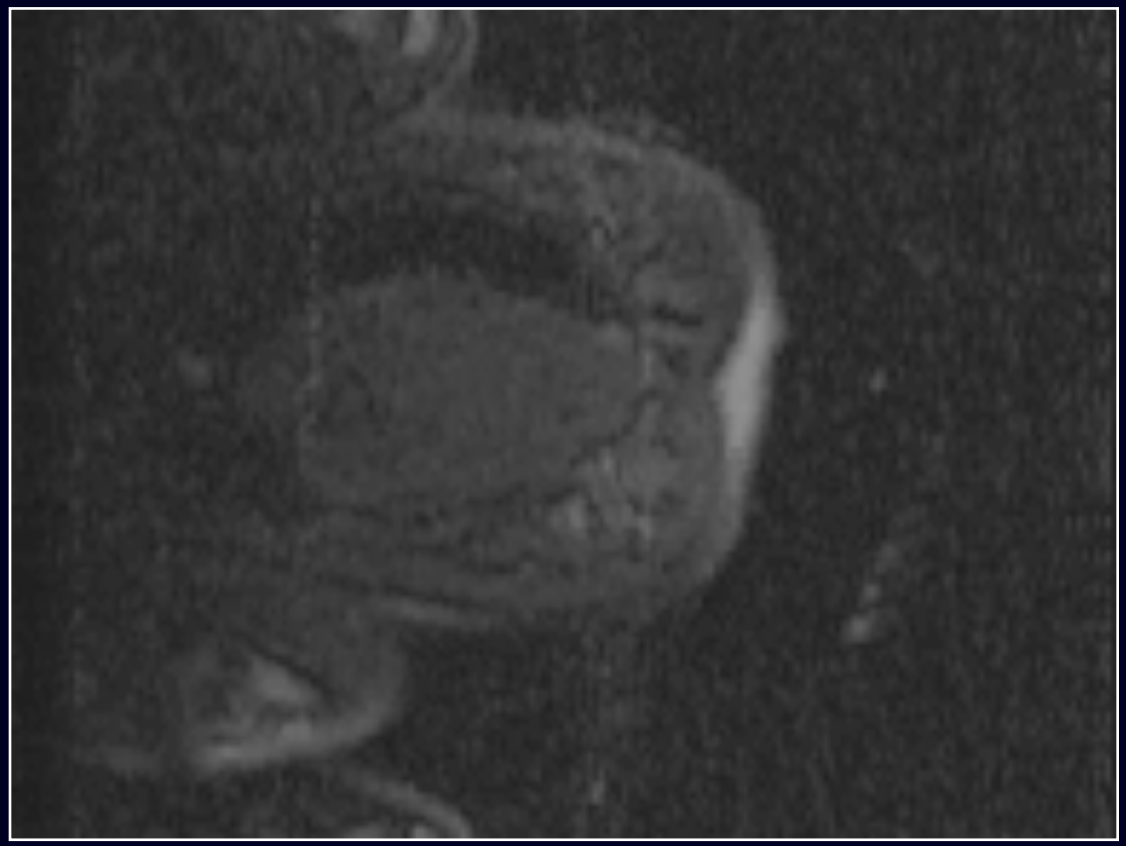
Marco Francone, MD, Steven Dymarkowski, MD, PhD, Maria Kalantzi, MD, and Jan Bogaert, MD, PhD*



Tecnica no ECG-triggering and no breath-hold!!!

Stem Cells Myocardial Injection

Visualizzazione del catetere



Courtesy E. McVeigh, Johns Hopkins University, Baltimore MD

Cine MRI: punti chiave

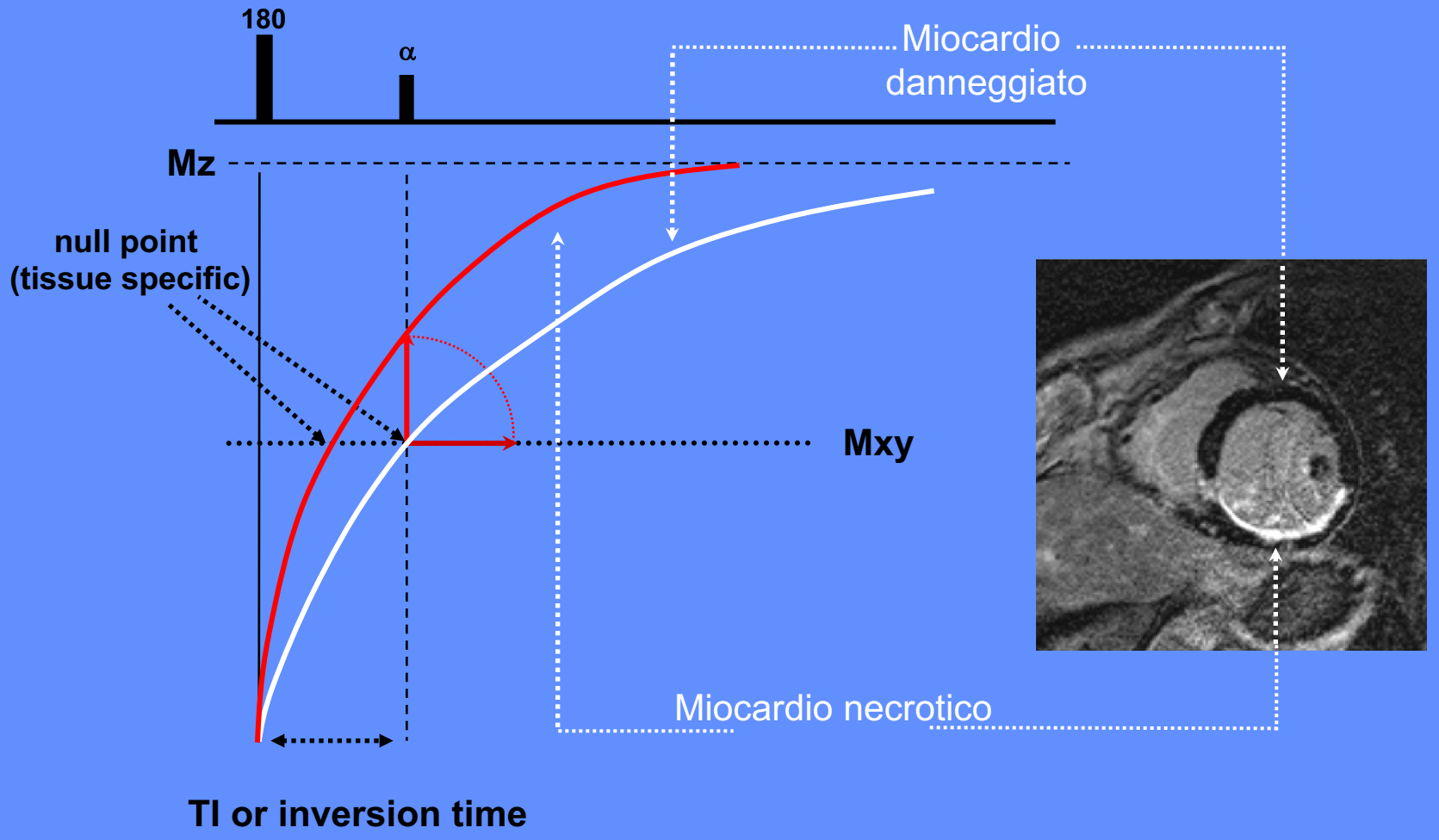
- Le sequenze B-SSFP (*true-FISP/FIESTA/b-FFE*) rappresentano le sequenze di scelta per lo studio di volumi e funzione ventricolare sinistra

- Approccio breath hold- Real Time

- Elevata risoluzione temporale (fino a 10 msec)

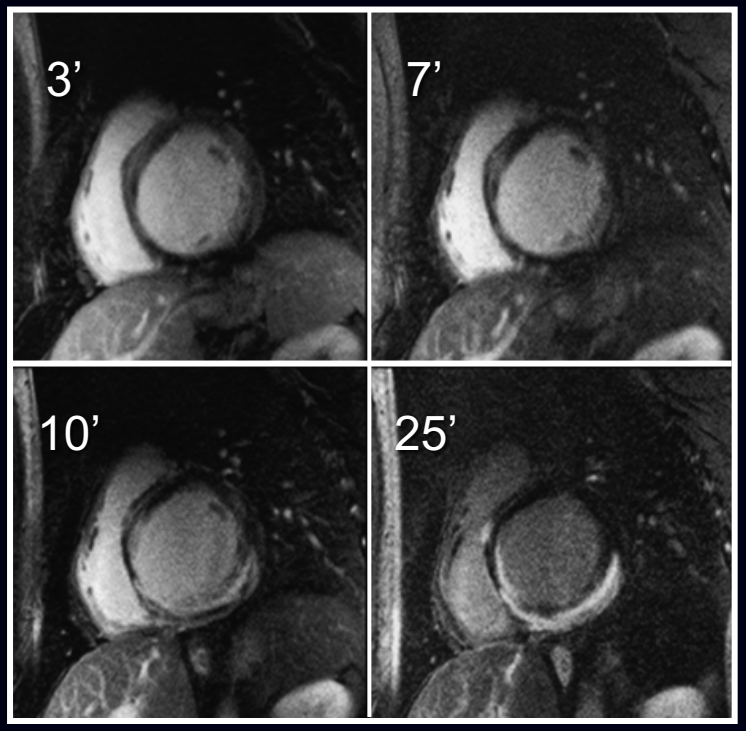
- Elevato dettaglio morfologico

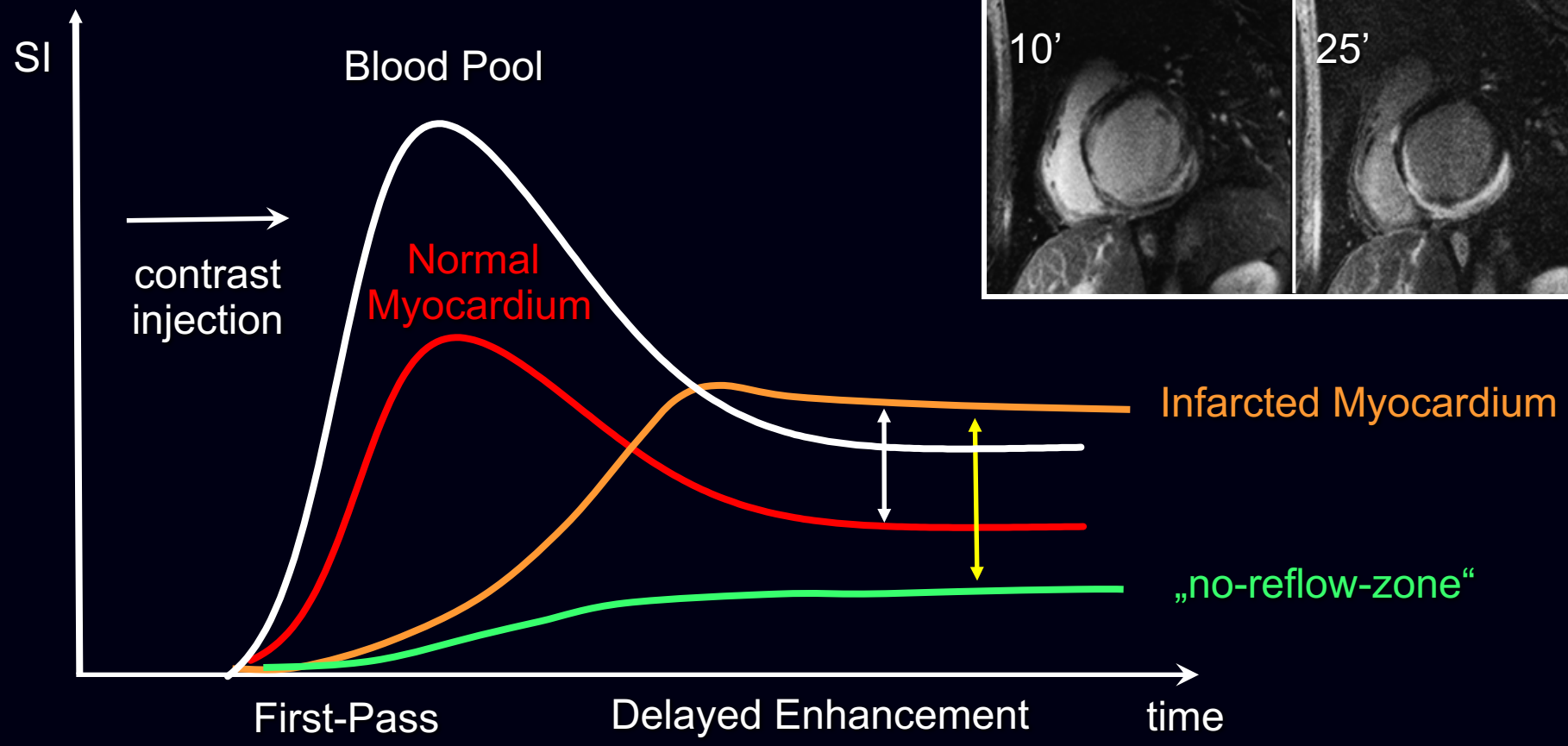
Late enhancement



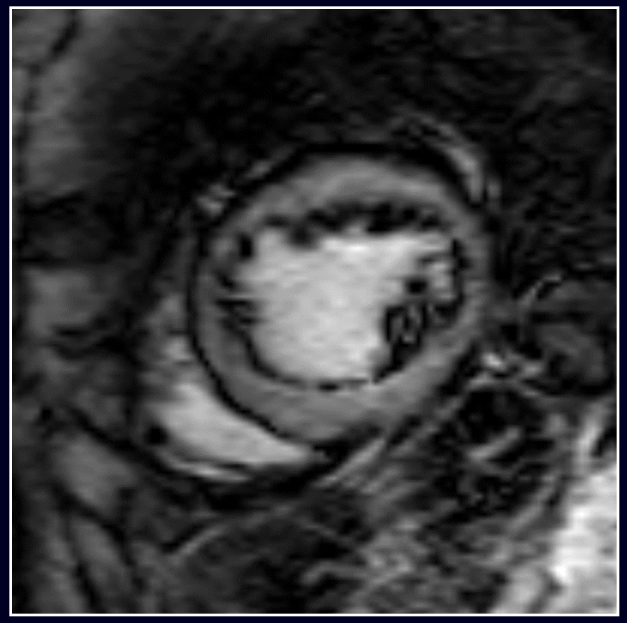
Concetto di late enhancement:

Curva cinetica del Gd



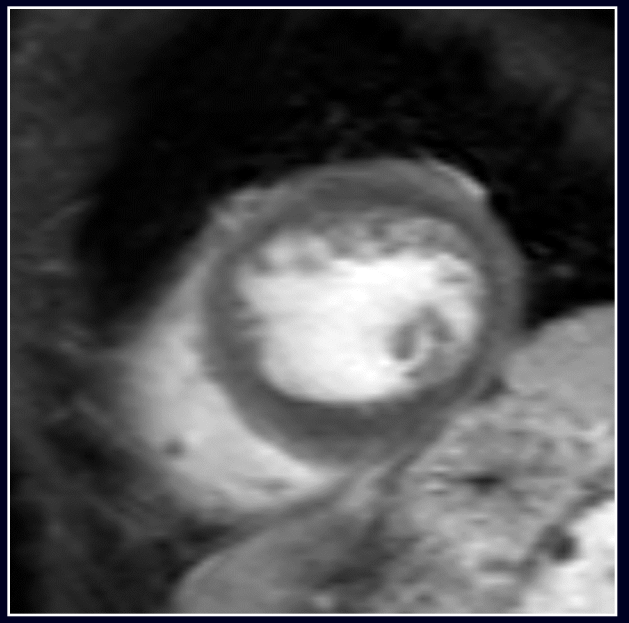


Scelta del T.I.



210 msec

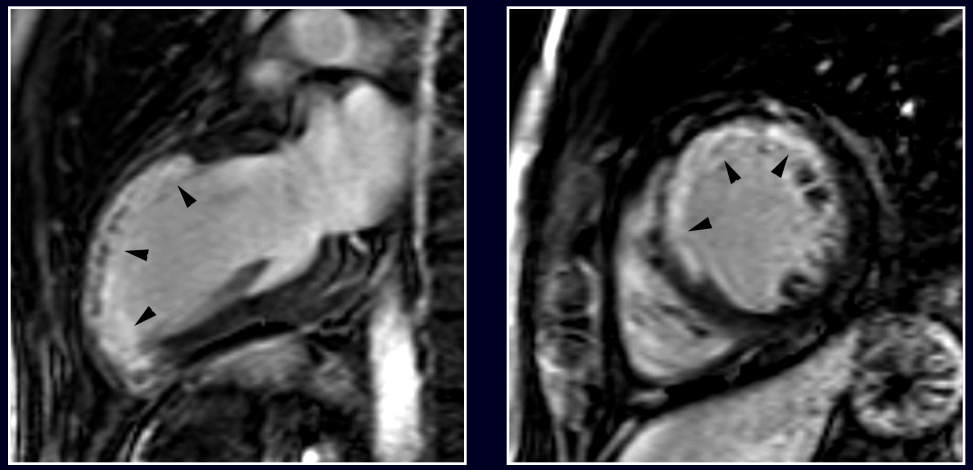
250 msec



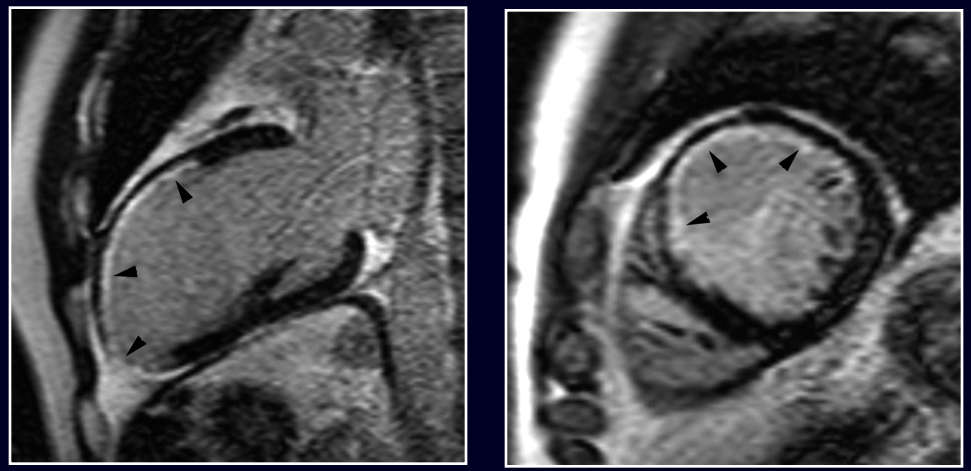
300 msec

Infarto Discendente Anteriore

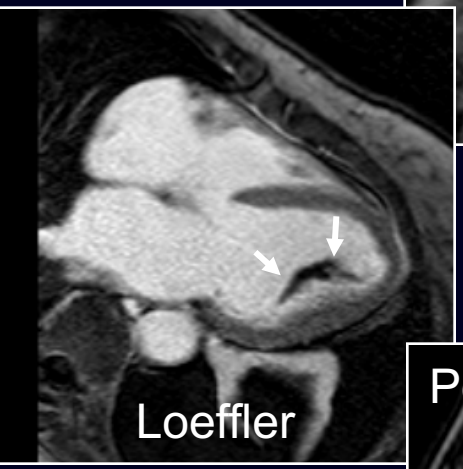
4 giorni

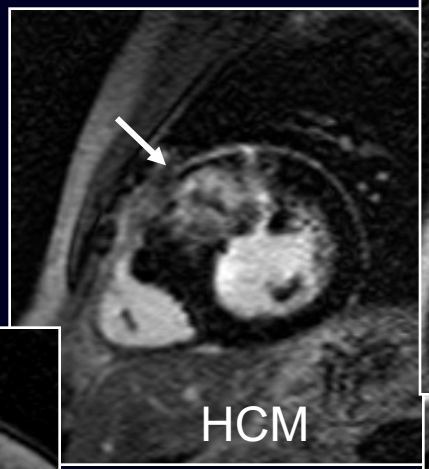


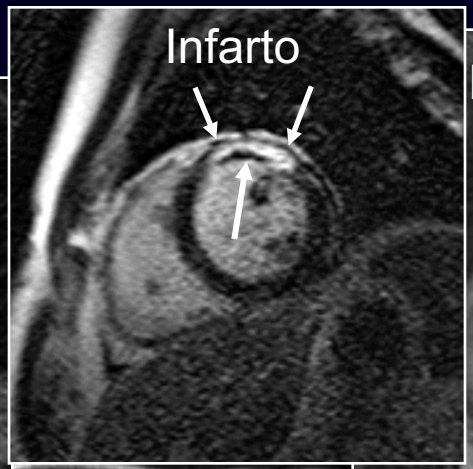
4 mesi

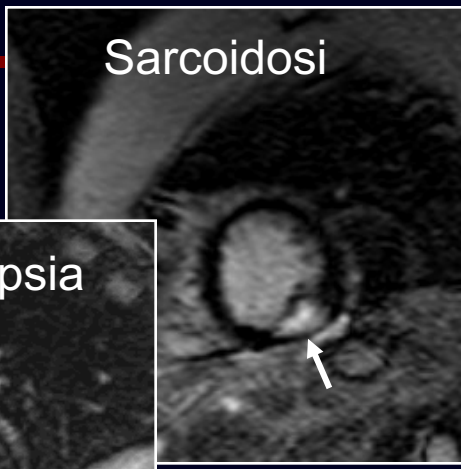


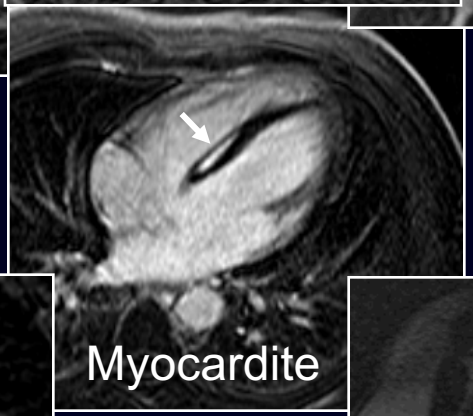
Delayed enhancement in cardio-RM…

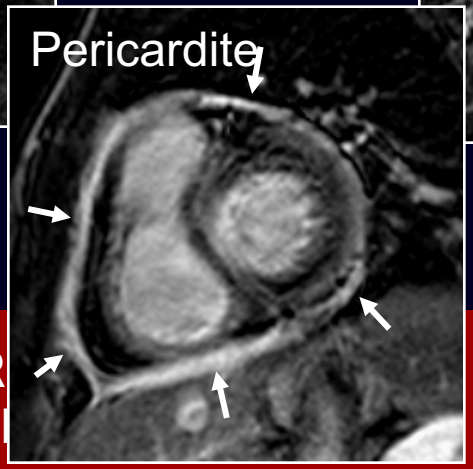


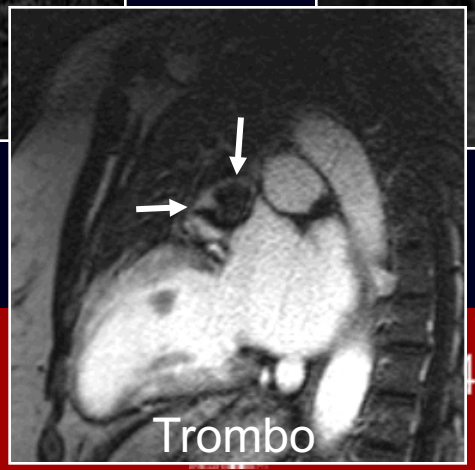




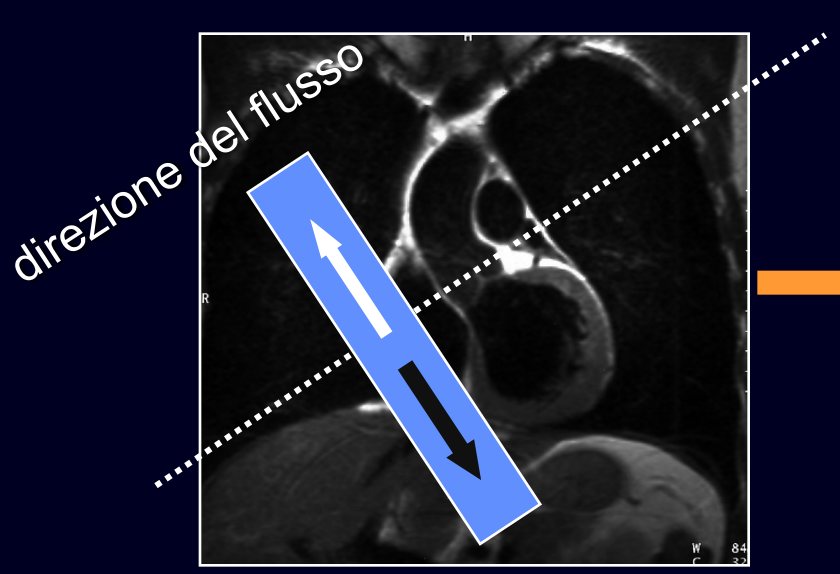


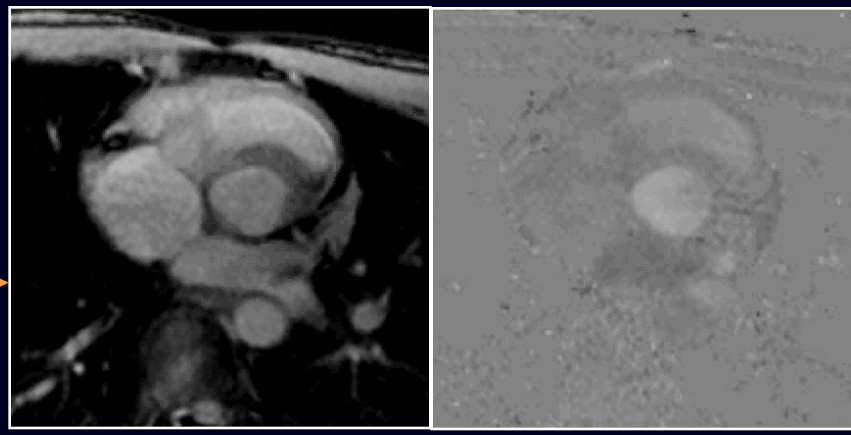


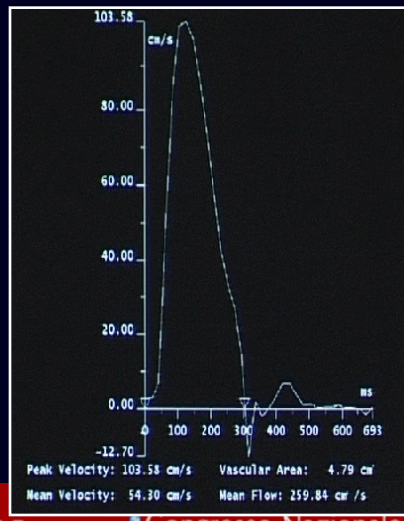




Velocity-Encoded MRI

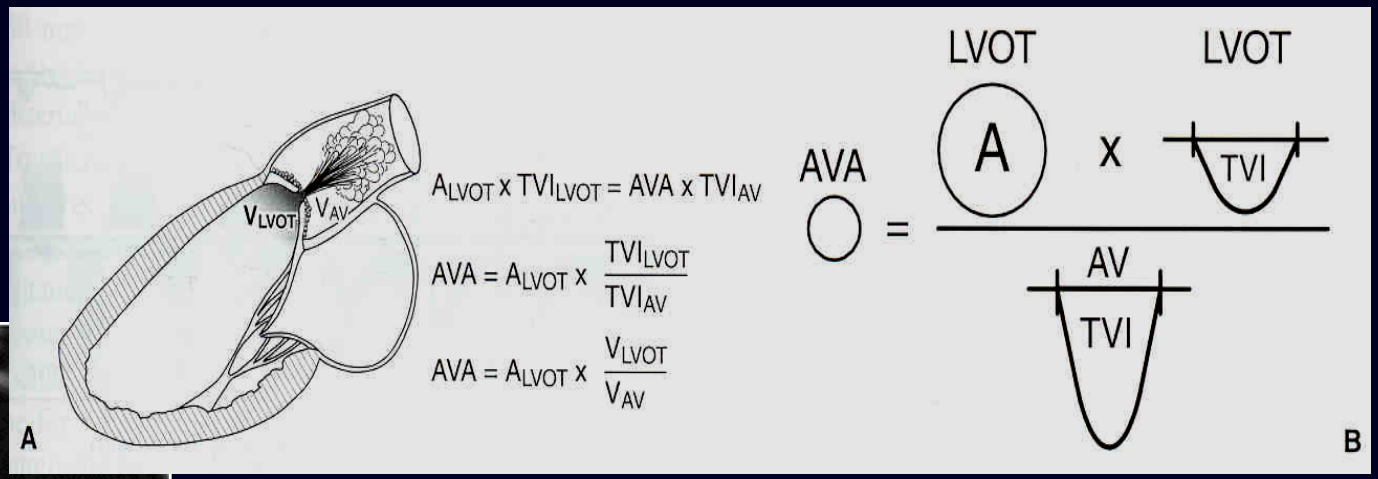


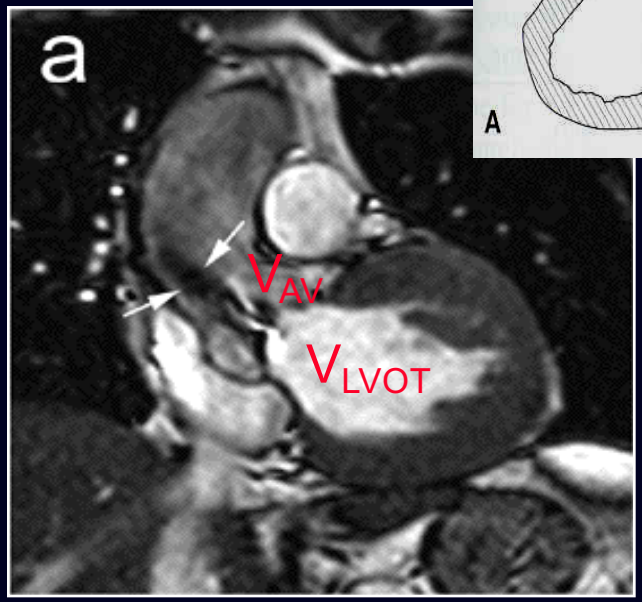




- *Livello di grigio funzione di velocità e direzione del flusso*
- protoni stazionari: *grigi*
- Flusso di protoni perpendicolari al piano nero o bianco

Stenosi Aortica





AVA <1.0 cm^2 /(0.6 cm^2/m^2) = severa SA

AVA = aortic valve area
TVI = time-velocity integral

Equazione modificata di Bernoulli $\Delta = 4V^2$

Velocity-Encoded Cine-MRI

Applicazioni cliniche

- Flusso
  - intravascolare
  - transvalvolare (velocità/volumi/gradienti pressori)
  - intraventricolare

- Funzione ventricolare
- Fibrosi miocardica

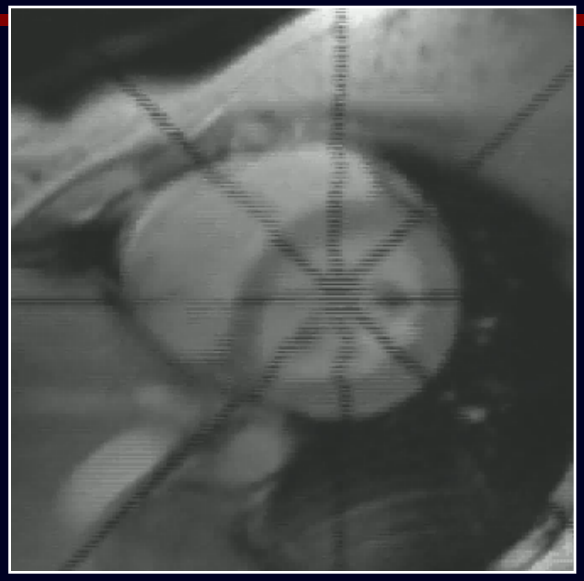
Limiti

- Ruolo marginale (ecocardiografia- doppler)
- Poco accurata nella valutazione dei lembi valvolari
- Scelta terapeutica?

Tagging miocardico

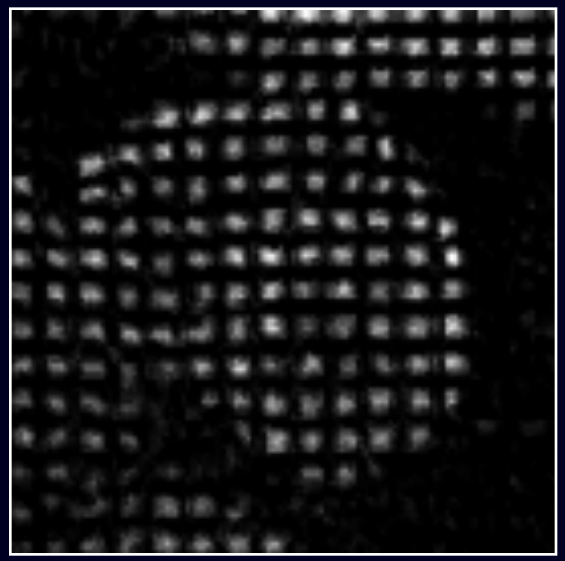
Tagging of the human heart with MRI a new method for noninvasive assessment of myocardial motion (Tagging Radiale)

E. Zerhouni, Radiology 1988; 169: 59



Heart wall motion: Improved method for spatial modulation of magnetization for MRI (SPAMM)

L.Axel, Radiology, 1989; 172: 349



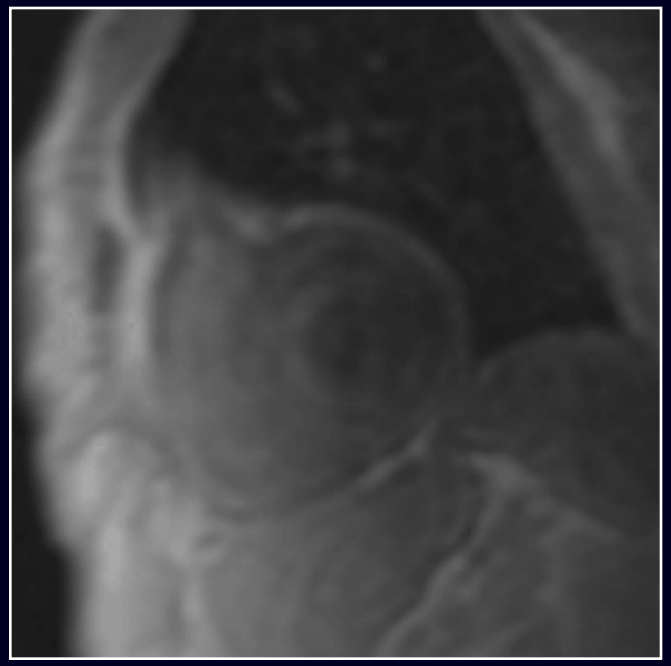
Tagging at 3.0 T

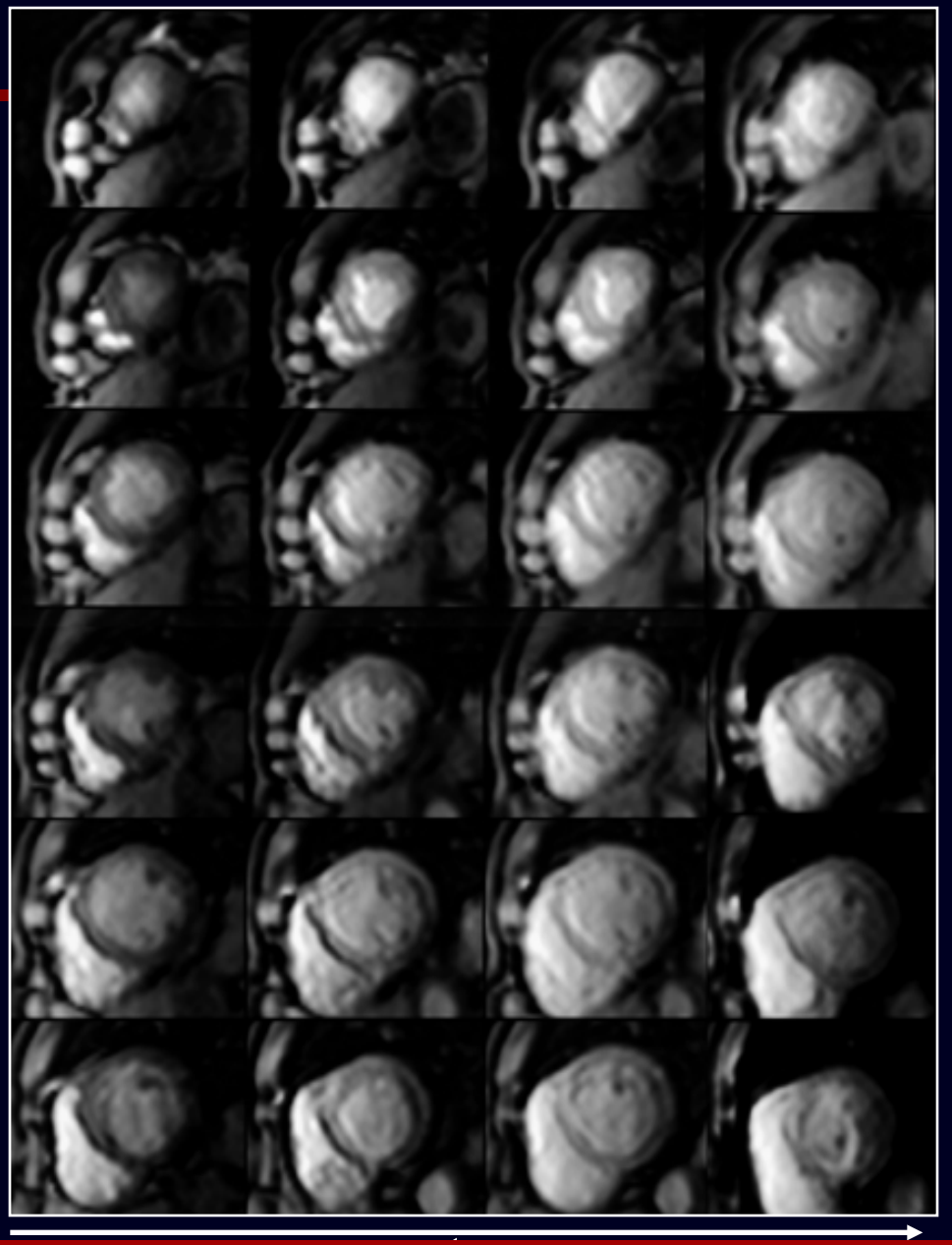
HOCM and normal LV-EF 70%

HOCM and Tagging

Perfusione Miocardica o first pass imaging

livello





Perfusione Miocardica

- *Sequenze Ultrafast - Fast GRE / EPI / fast GRE + EPI/ FLASH*

- Risoluzione temporale (3 immagini => ogni battito cardiaco)
- Impulso di presaturazione per abbattere il segnale miocardico
- Risoluzione spaziale adeguata
- T1w
- Studio del ventricolo sinistro (SA, LA, o combinazione SA - LA)
- Piccolo bolo di mdc ad elevato flusso (4 ml/s)
- Dose mdc (0.05 - 0.1 mmol/kg - 0.2 ?)

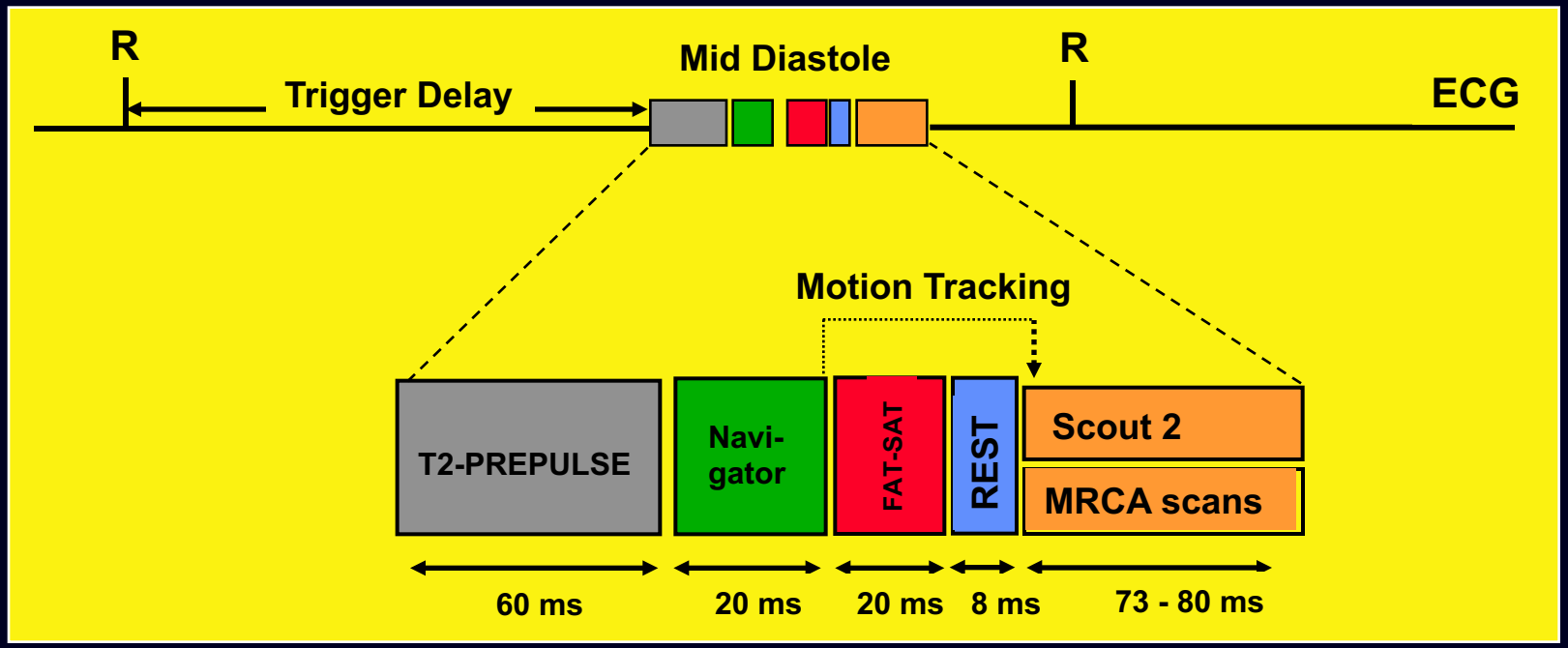
Coronaro-RM
Difficoltà diagnostiche

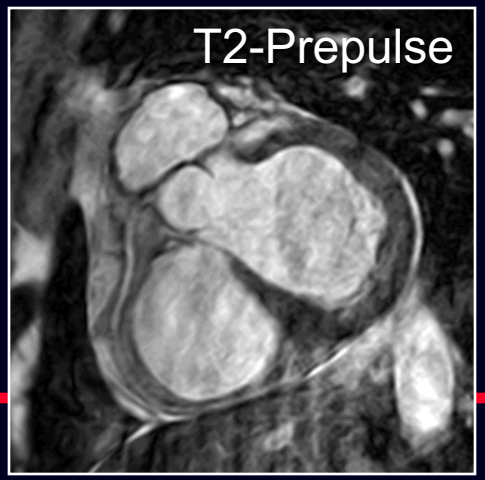
- Vasi di piccolo calibro (2-5mm)
- Decorso lungo e tortuoso
- Fisopatologia pecualiare
  - Pattern di flusso / velocità / flusso di collaterali
- Motilità cardiaca variabile nei tre vasi coronarici
- Artefatti da respirazione
- Tessuto adiposo epicardico
- Risoluzione spaziale
- Copertura volumetrica di tutti i vasi

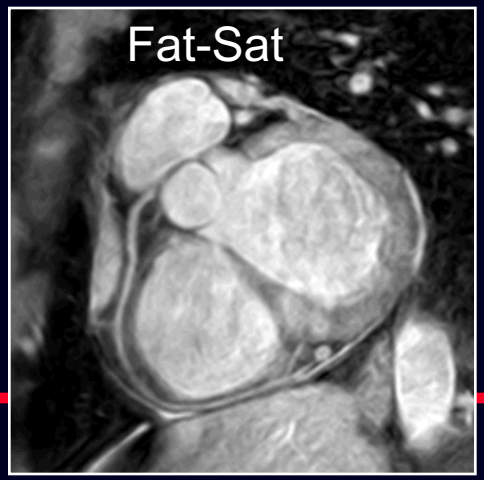
MRCA: Tecniche di acquisizione

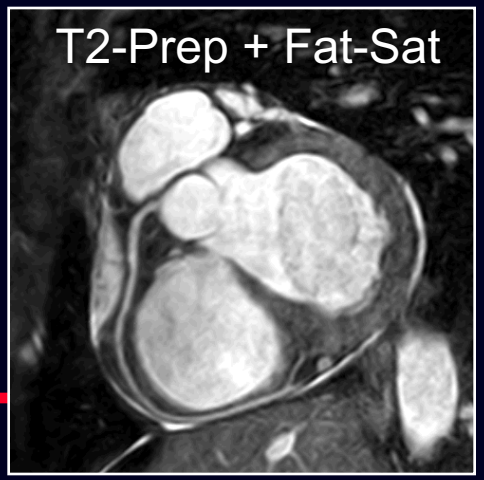
Breathing Motion Compensation	- Navigators
	- Breath-hold
	- Self-gating
Contrast Enhancement Techniques	- Magnetization Transfer Contrast (MTC)
	- T2-preparation pulse
	- Steady-state imaging
	- Intravascular contrast agents
	- Fat suppression techniques
	- Arterial spin labeling
Fast Imaging Techniques	- Echo-planar imaging (EPI)
	- Parallel Imaging
High-Spatial Resolution Techniques	- 3D turbo field-echo (TFE) - FLASH
	- 3D b-SSFP - (true-FISP)
	- 3D turbo spin-echo (TSE)
K-space Filling Techniques	- 3D cartesian
	- 3D radial
	- 3D spiral
	- key-hole imaging
Volume Coverage Techniques	- coronary artery targetted approach
	- whole-heart coronary MRA
Black-blood Imaging	- 3D turbo spin-echo (TSE)
	- 3D SSFP

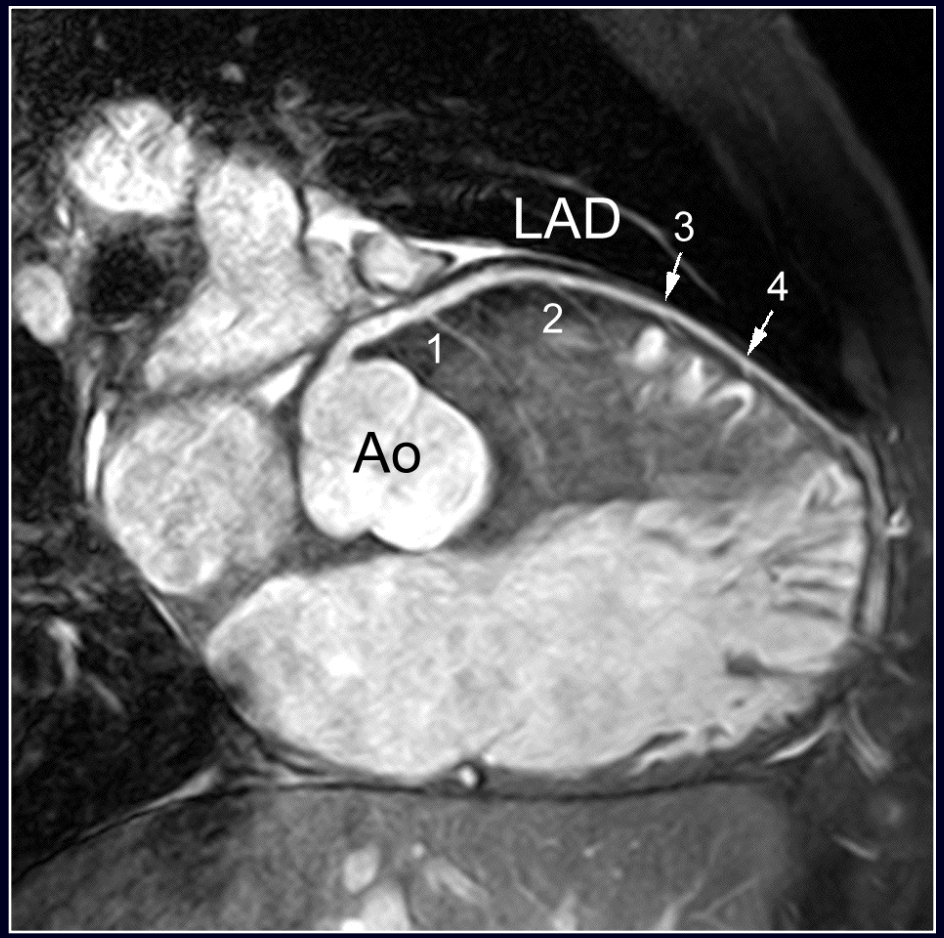
MRCA Sequence design

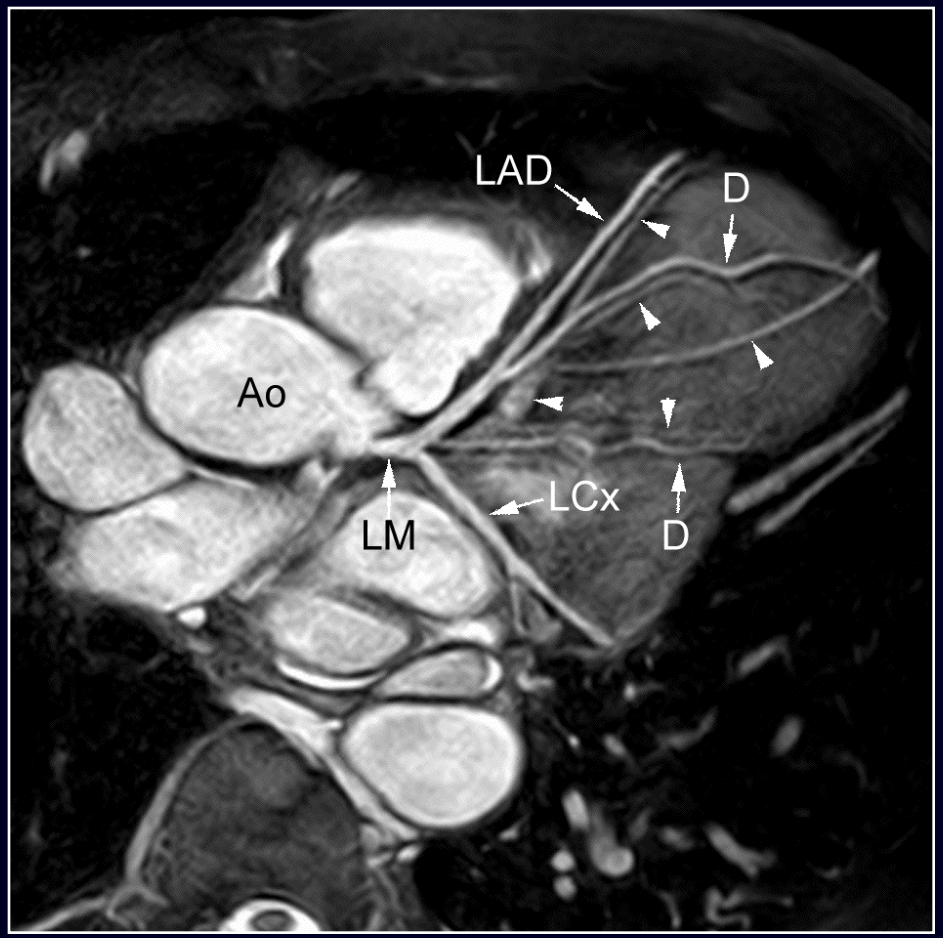








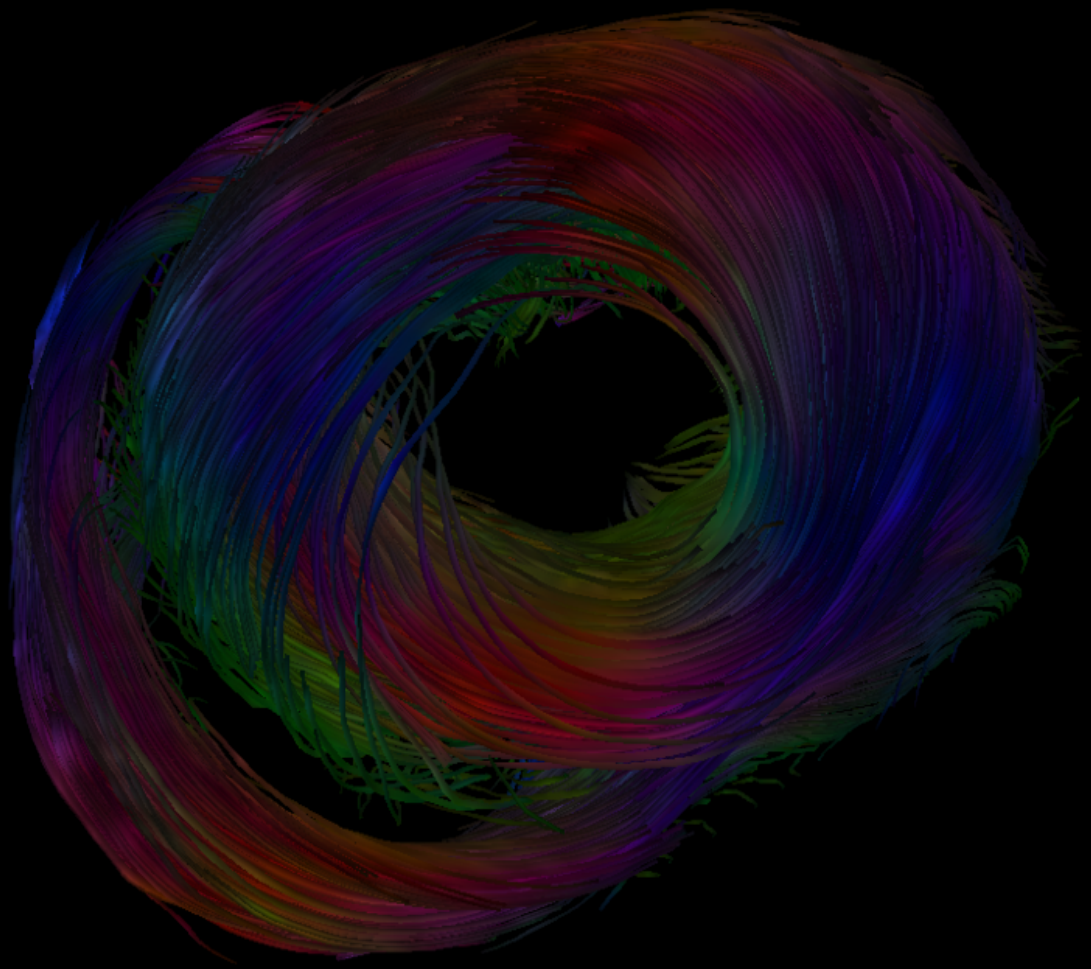


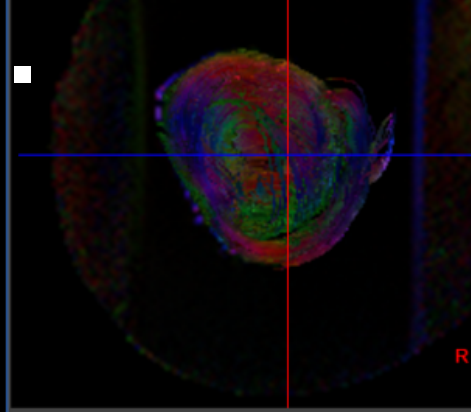


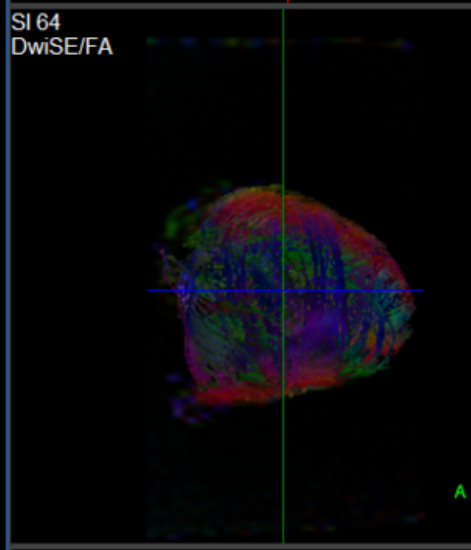
Cortesia: Prof. J. Bogaert KU Leuven

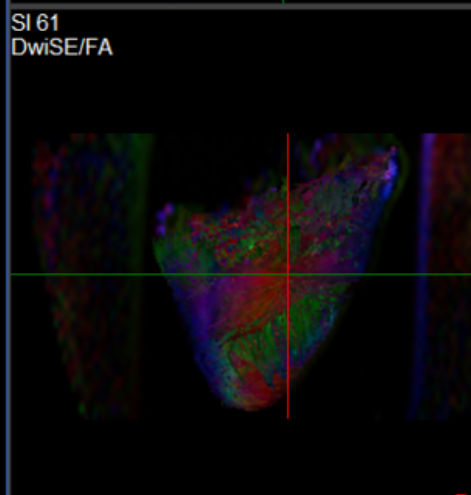
Uno sguardo al futuro...

Diffusion-Tensor MRI

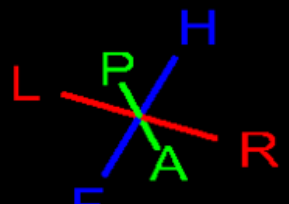




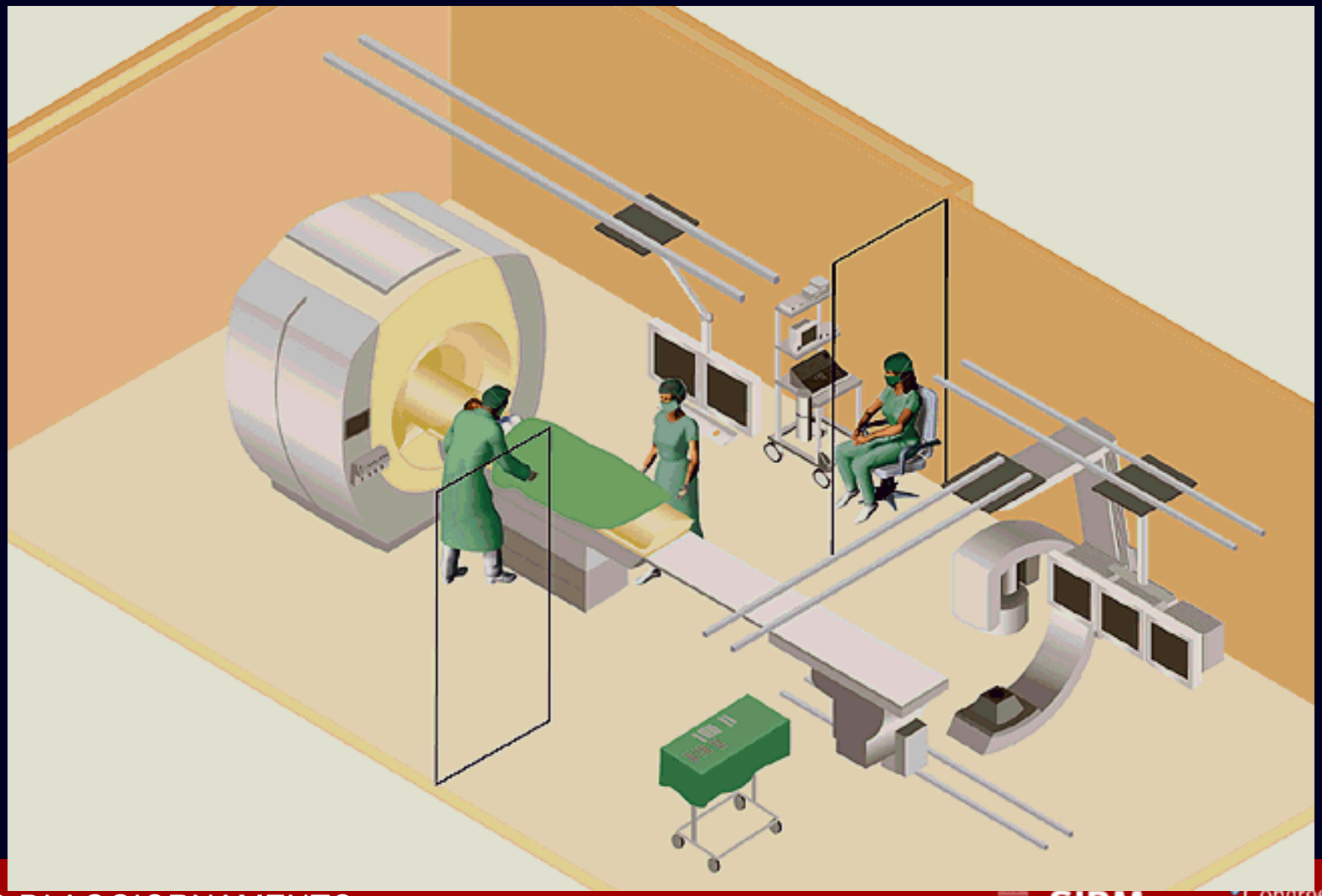




Courtesy: R. Peeters / C. Sage / S. Sunaert



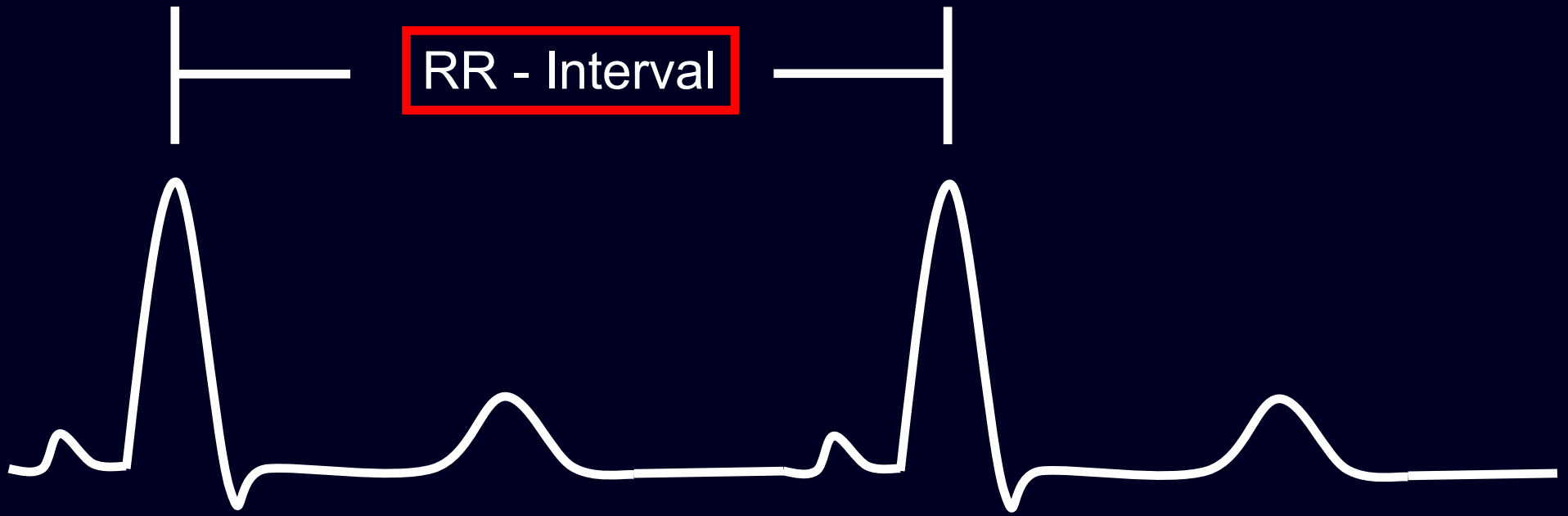
Interventional Suite: System Concept



Grazie per l'attenzione!!!

What do we need for CMR?

1-heartbeat or RR-Interval



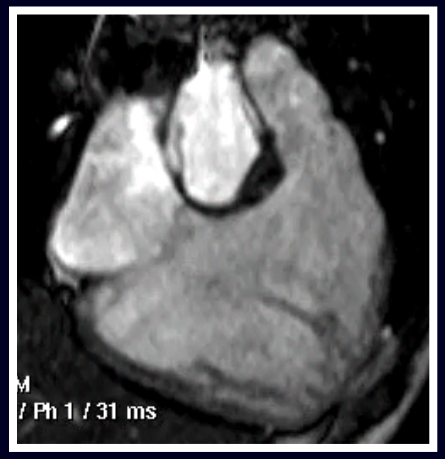
Funzione ventricolare destra influenzata da 3 compartimenti:

inflow tract

porzione trabecolata

outflow tract

setto interventricolare



Interdipendenza ventricolare

Loeffler-s endomyocardial disease:

thrombosis + fibrosis + eosinophilic infiltrate