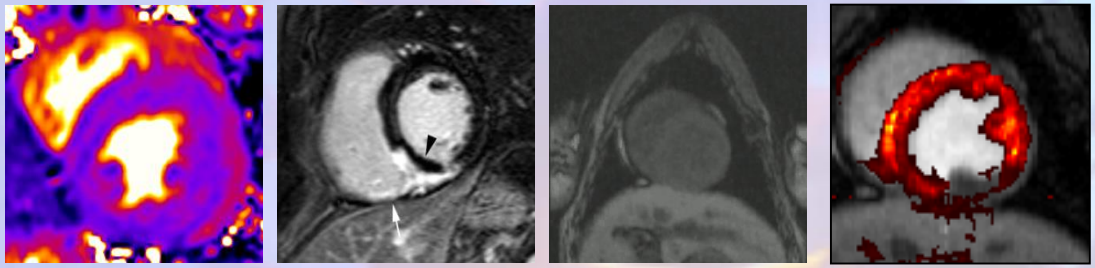
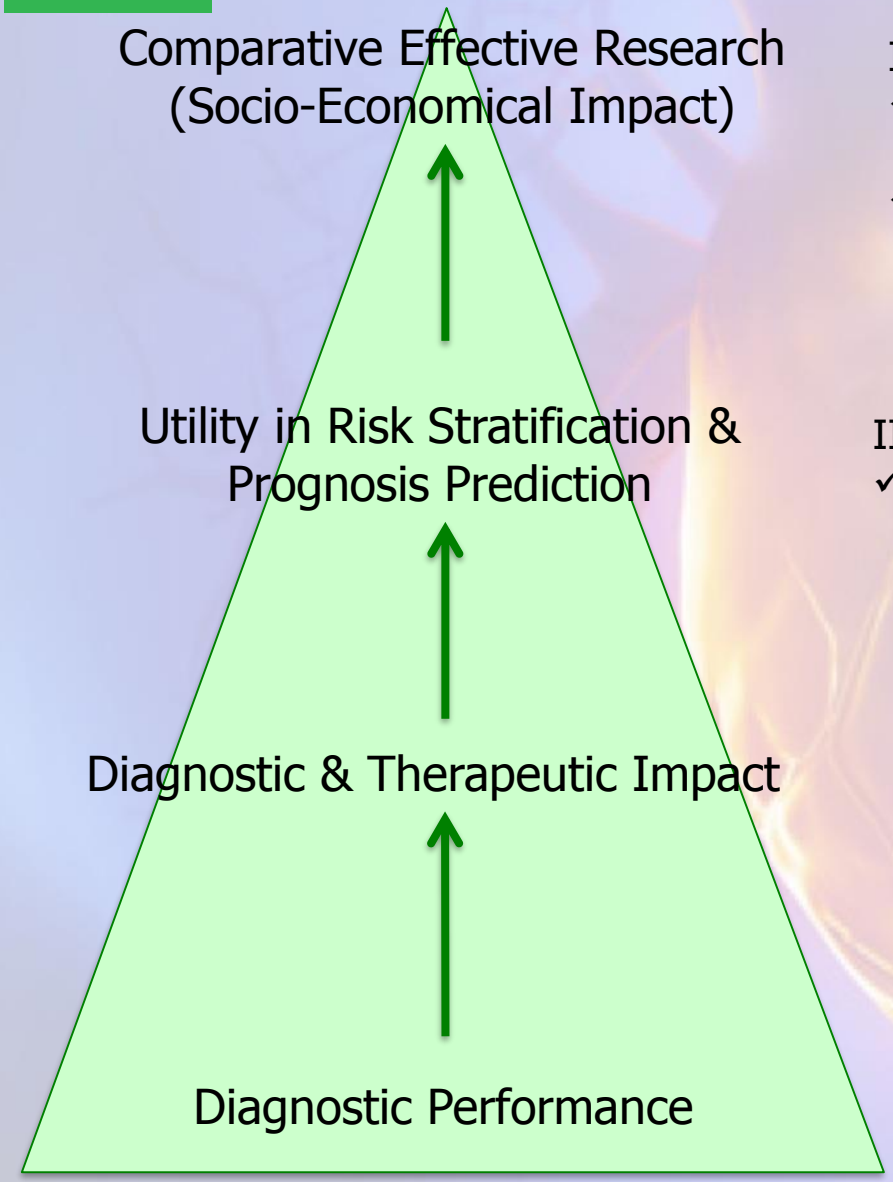
Pier Giorgio Masci, M.D., Ph.D

Cardiology Division
CMR Center of the CHUV
University Hospital Lausanne - CHUV
Switzerland

Centre de
RM Cardiaque



Valore Incrementale della RMN cardiaca nei pazienti con cardiopatia ischemica



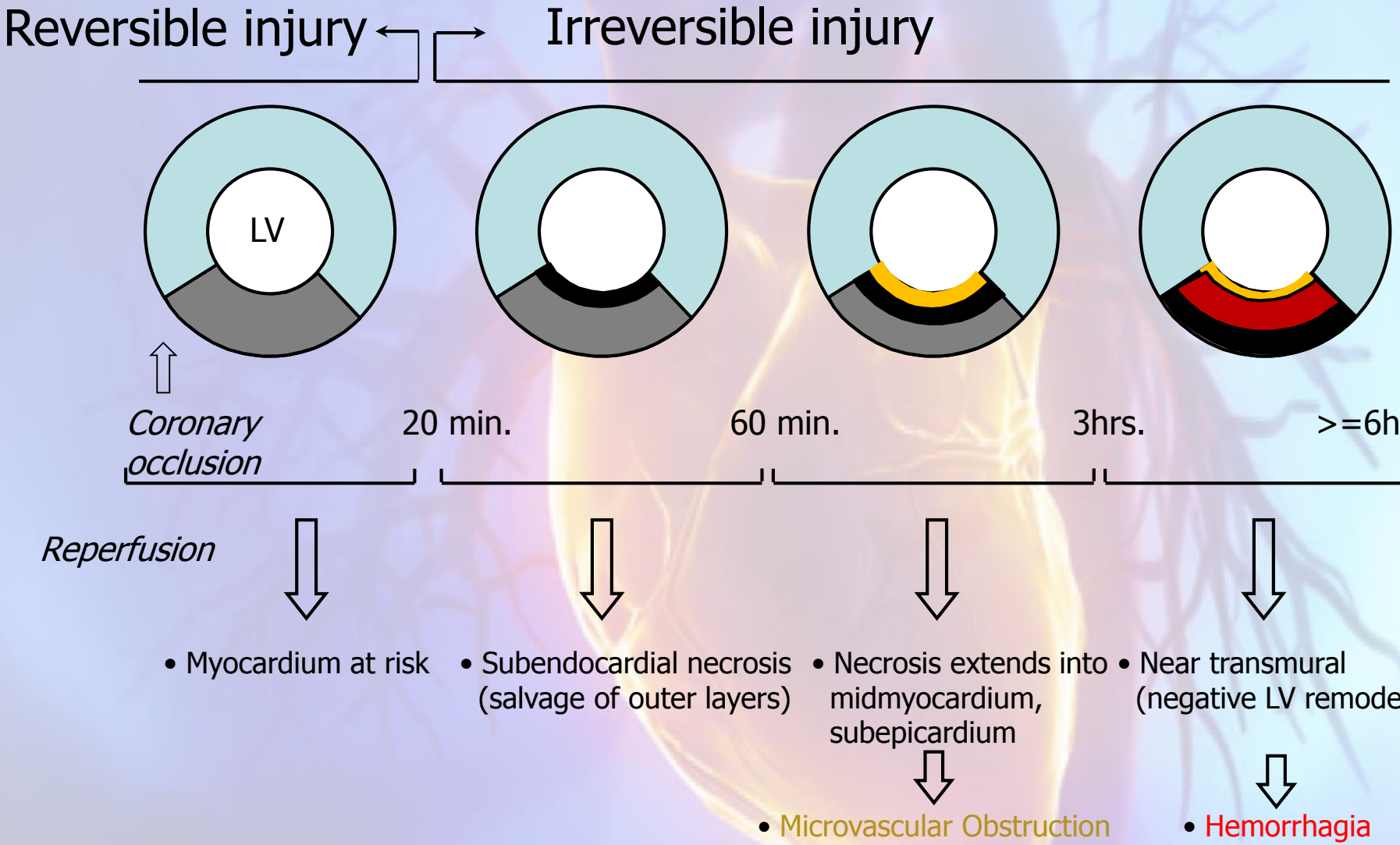
IV. Optimized Test Effectiveness Strategy
- ✓ Compare Effectiveness of 2 or more imaging driven strategies with a RCT
- ✓ Cost-Effectiveness

III. Prognostic Utility
- ✓ Accuracy of imaging marker in detecting hard clinical end-points with ADDITIVE/INDEPENDENT value respect clinical/other risk algorytms

II. Diagnostic & Therapeutic Impact
- ✓ Relationship between imaging markers of ischemia & MD decision making / therapeutic interventions

I. Diagnostic Performance
- ✓ Technical Aspects
- ✓ Accuracy in detecting obstructive CAD

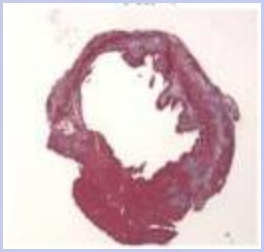
Acute Myocardial Infarction & CMR



Centre de RM Cardiaque

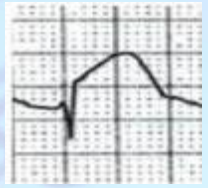
CHUV

Acute Myocardial Infarction & CMR



-Protocol imaging –

- CMR @ (sub)acute MI-

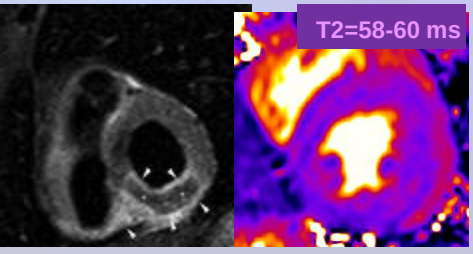


Gd-chelate* (optional)

Gd-chelate

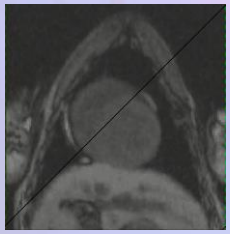
Morphological/ Mapping Imaging

- T2w-STIR
- T2* GRE
- T2-mapping



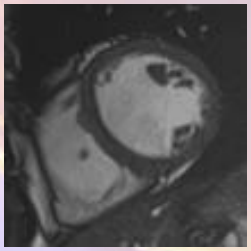
Area-at risk Haemorrhagia

First-pass perfusion* (optional)



Early MO

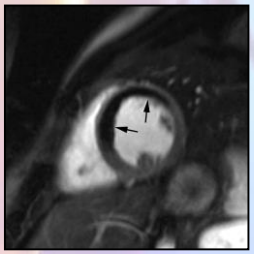
Cine-SSFP



Regional & Global Remodeling/Function

Post-contrast T1w Imaging

- Early (1-4 min)
- Late (12-20 min)

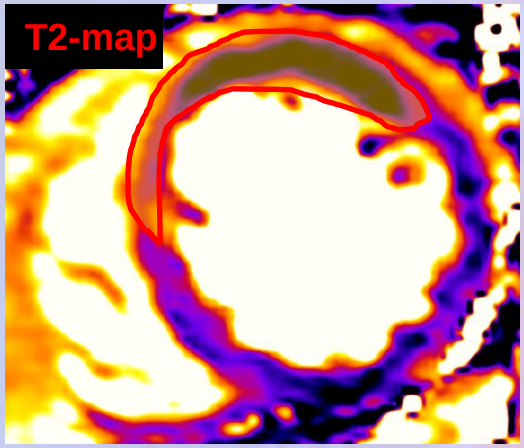


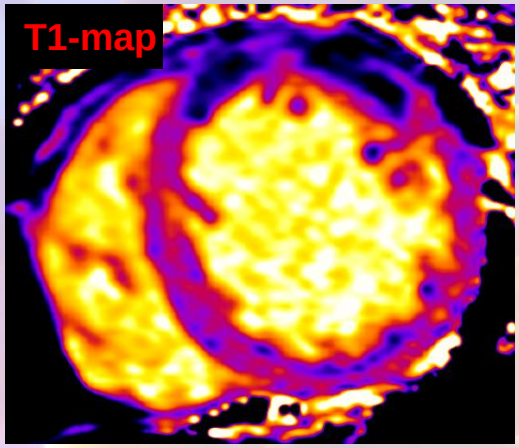
Early MO

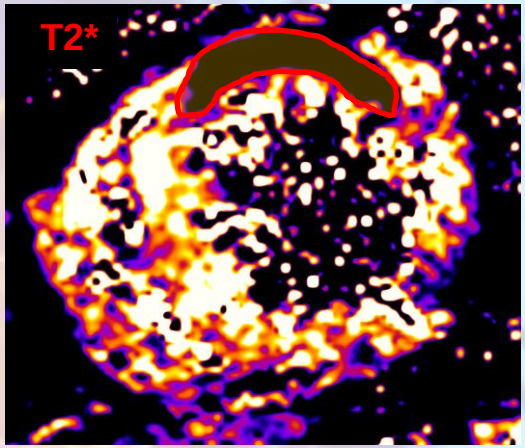
Late MO Necrosis Scarring

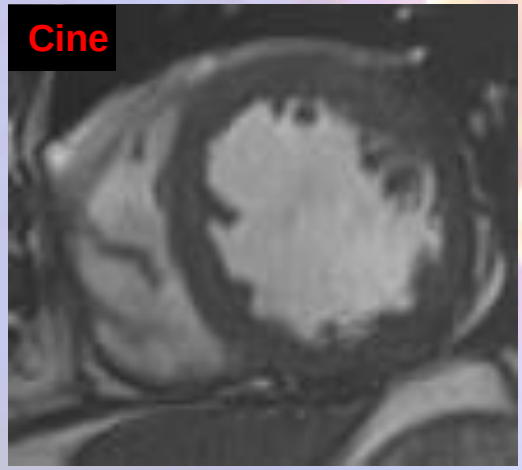
Acute Myocardial Infarction & CMR

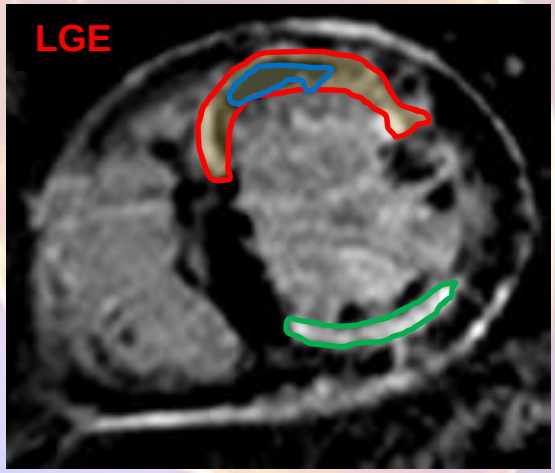
-PostInfarction Remodeling –
- The value of CMR -





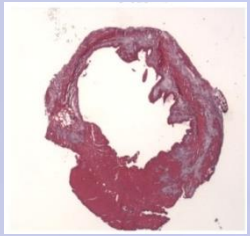




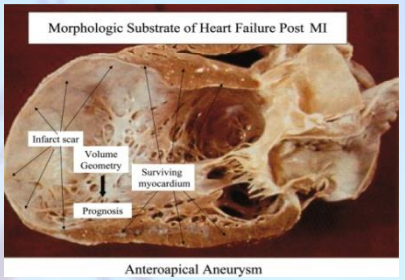


1. Edema => area-at-risk
2. Hemorrhage
3. LGE=>Infarct size
4. MVO
5. Myocardial salvage

Acute Myocardial Infarction & CMR

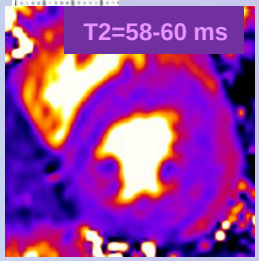


-PostInfarction Remodeling –
- The value of CMR -



Acute Phase

Chronic Phase



T2/T1/T2(*)mapping

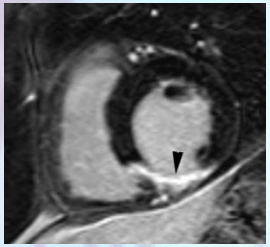
1. Area at risk
2. Haemorrhagia

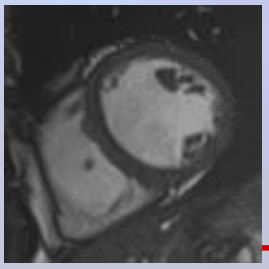
Post-Gd Img

1. MO [early&late]
2. Infarct burden [late] (IS / transmurality)

Post-Gd Img

1. Infarct burden (IS / transmurality)
2. Viability





Cine Img

1. Regional structural & Functional Remodeling
2. Ventricular Geometrical & Functional Remodeling

Cine Img

1. Regional structural & Functional Remodeling
2. Ventricular Geometrical & Functional Remodeling

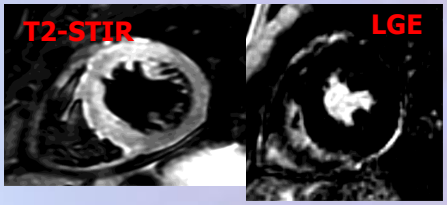
Acute Myocardial Infarction & CMR

ACS & Unobstructed Coronaries

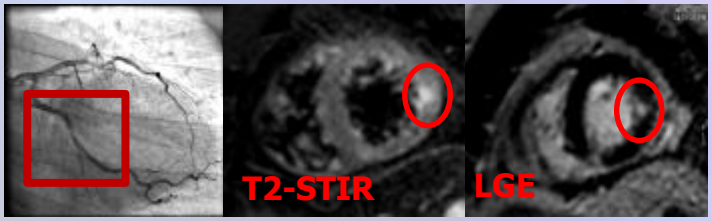
Ischemic Causes

- 'Concealed' Plaque Destabilization
- Coronary Vasospasm
- Distal Embolization

Coronary Vasospasm



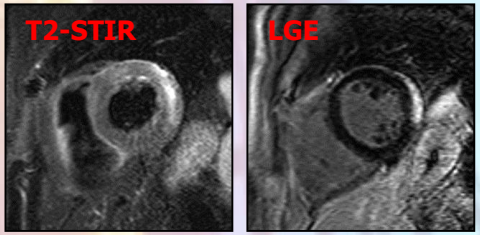
Plaque destabilization/embolization



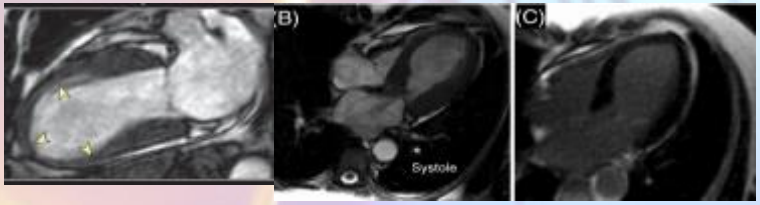
Non-Ischemic Causes

- Peri(myo)carditis
- Tako-Tsubo (stress) CM
- Cardiomuopathy/Heart Failure

Acute Myocarditis



Tako-Tsubo (Stress) CM



Centre de RM Cardiaque

CHUV

Acute Myocardial Infarction & CMR

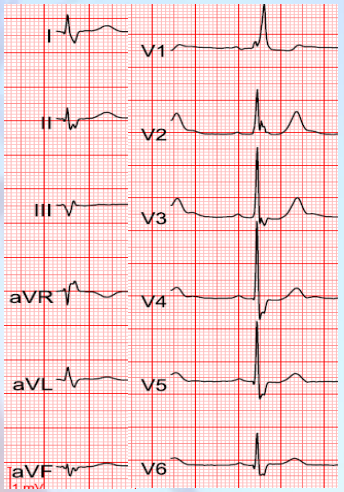
Differential Diagnosis
- Clinical Case #1-

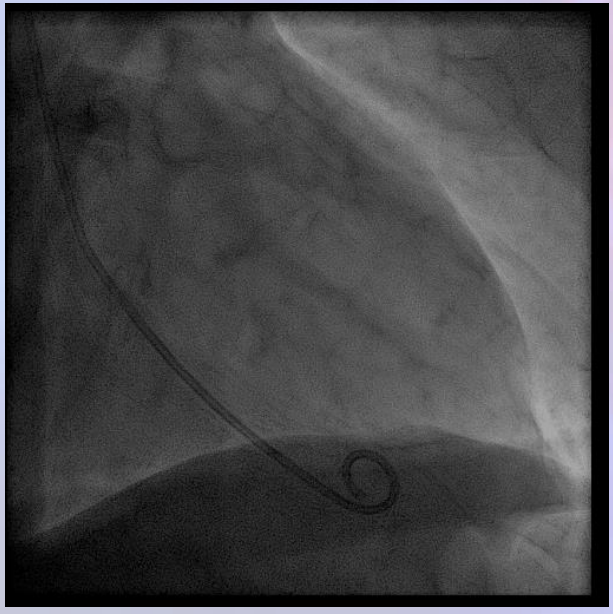
CH

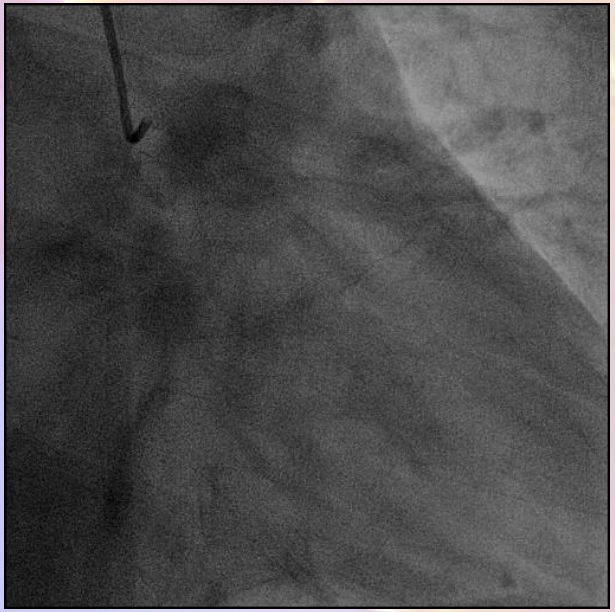
Man 71 y.o. HTA, Hypercholesterolemia
during physical activity→ typical CP (8/10→2/10 after nitrate)

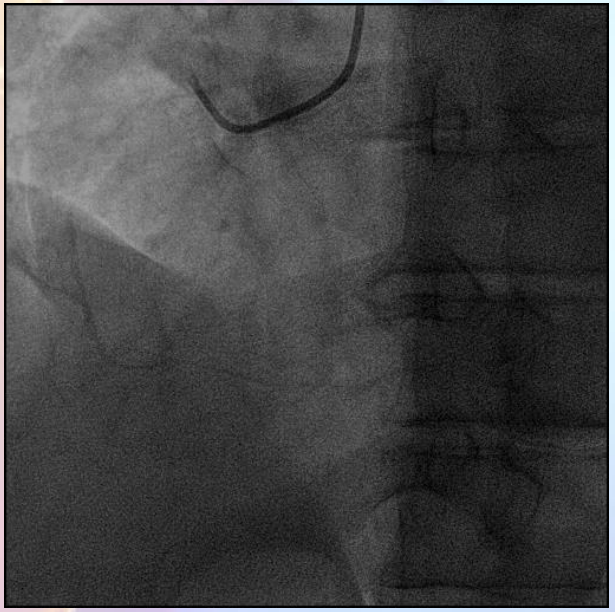
Labo

CK pic 566 U/L (UNL: 190 U/L); HsTnT pic 569 ng/L (UNL: 14 ng/l)









Centre de RM Cardiaque

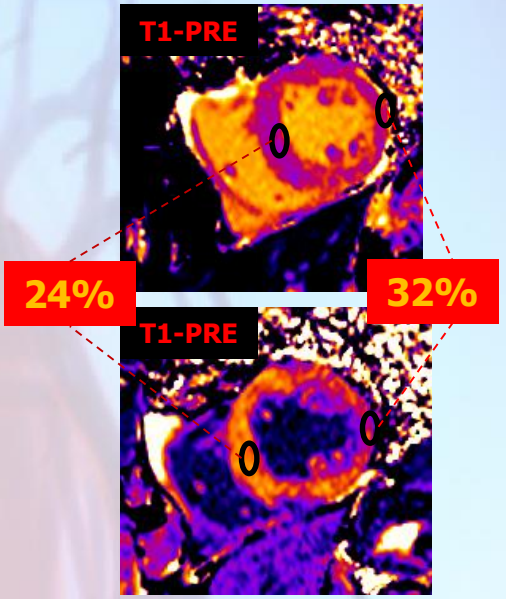
CHUV

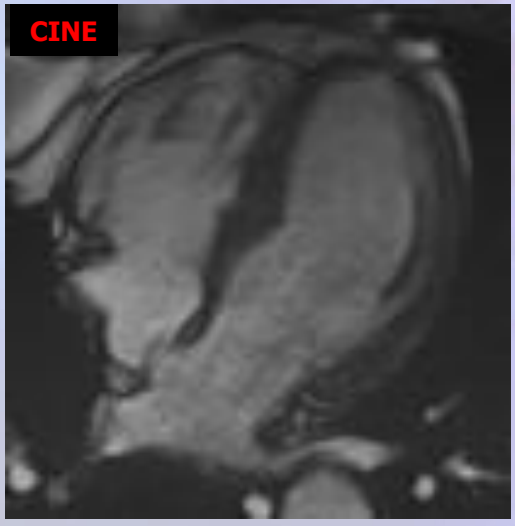
Acute Myocardial Infarction & CMR

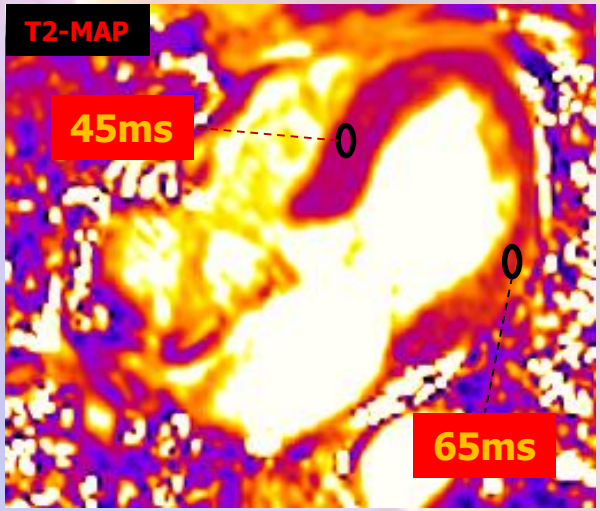
Differential Diagnosis
- Clinical Case #1-

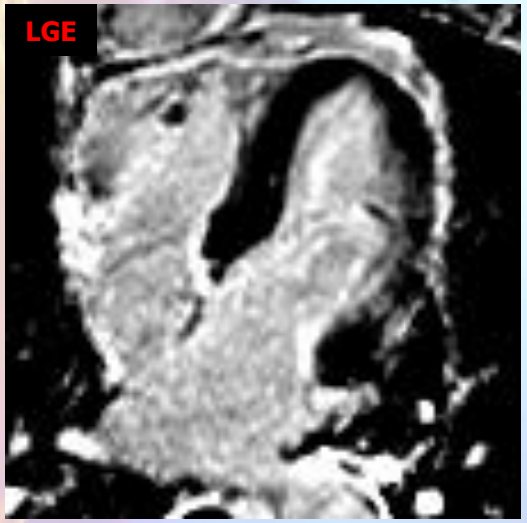
Acute ischemic insult of the LV lateral wall likely as a result of vasospasm

About 4-8% of about cardiomyocytes of the lateral wall underwent necrosis (→ CK peak 566 UI)









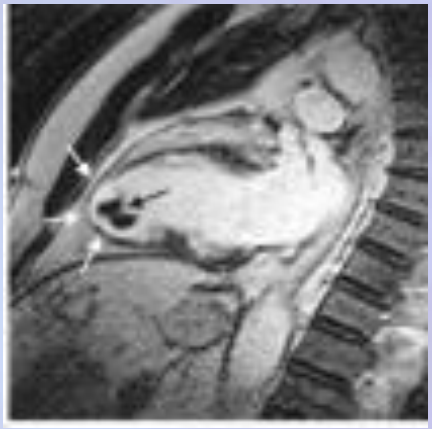
Centre de RM Cardiaque

CHUV

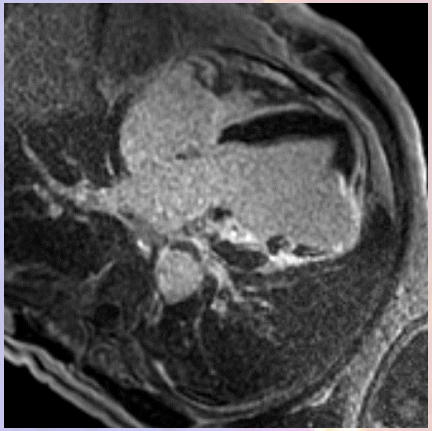
Acute Myocardial Infarction & CMR

- Comprehensive CMR @ acute MI –
- PostInfarction Evaluation-

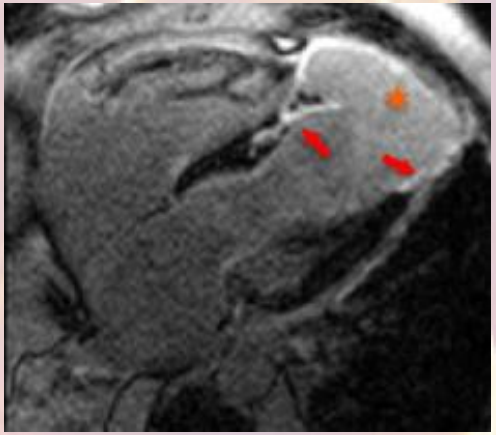
Post-MI Sequelae



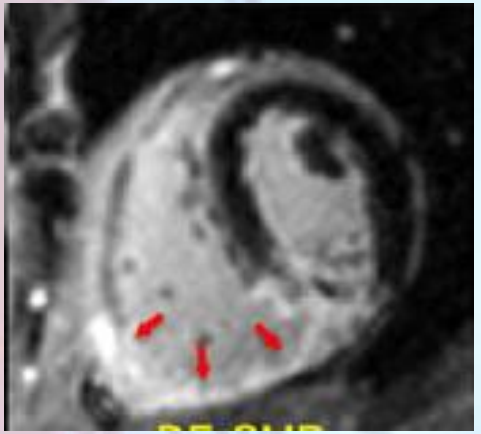
Thrombosis



Pseudoaneurysm

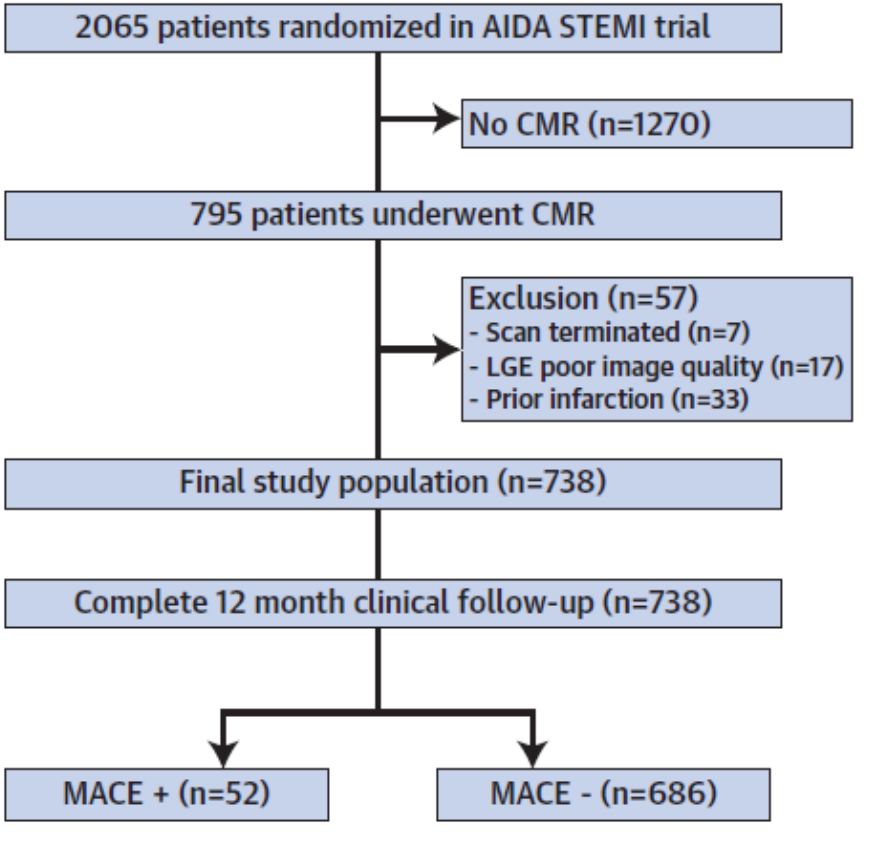


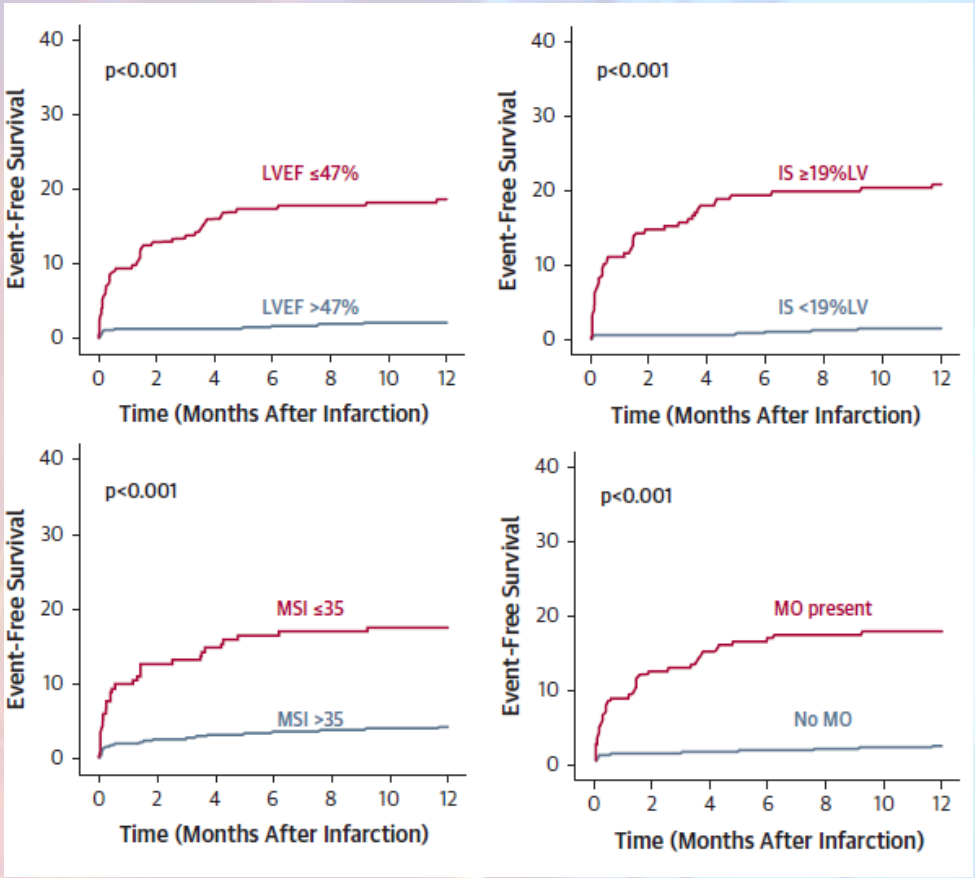
Septal Defect



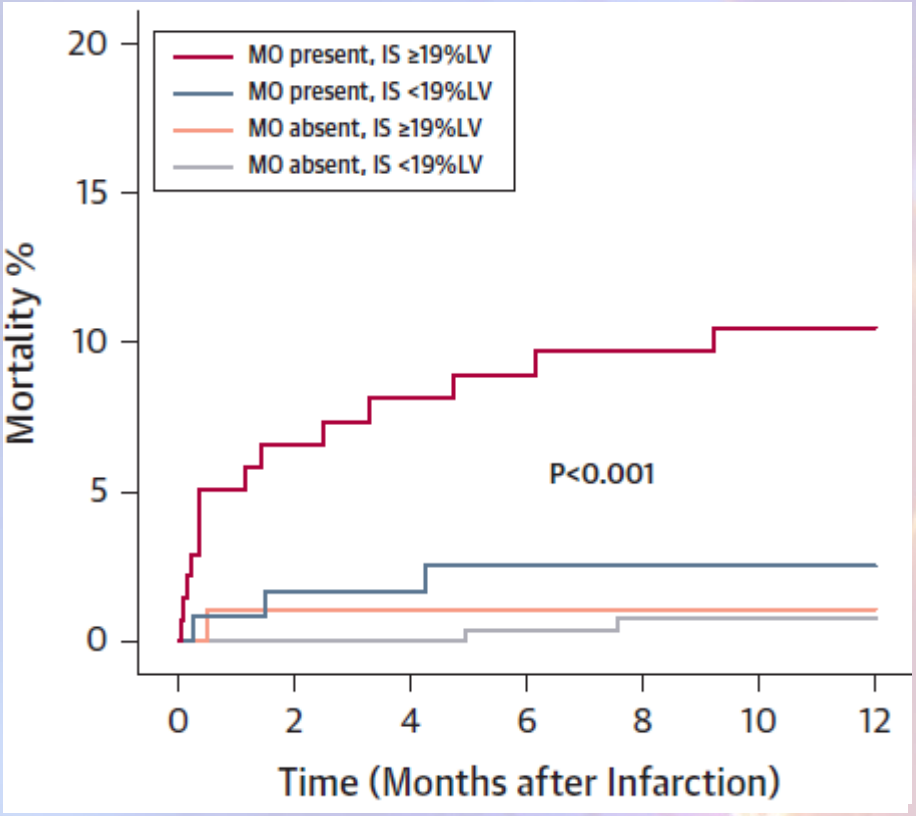
RV infarction

Acute Myocardial Infarction & CMR





Acute Myocardial Infarction & CMR



	C-Statistic	p Value
Model 1: TIMI risk score	0.705	–
Model 2: TIMI risk score + LVEF ≤47%	0.761	0.042 (Model 1 vs. Model 2)
Model 3: TIMI risk score + LVEF ≤47% + Infarct size ≥19%LV	0.786	0.110 (Model 2 vs. Model 3)
Model 4: TIMI risk score + LVEF ≤47% + Infarct size ≥19%LV + MO ≥1.4%LV	0.801	0.036 (Model 2 vs. Model 4) 0.172 (Model 3 vs. Model 4)

	Univariate Analysis		Stepwise Multivariate Analysis	
	Hazard Ratio (CI)	p Value	Hazard Ratio (CI)	p Value
Smoker	2.14 (1.12-4.1)	0.021	–	–
Number of diseased vessels	1.42 (1.07-1.89)	0.017	–	–
Peak CK	1.01 (1.00-1.02)	0.022	–	–
TIMI risk score	1.41 (1.27-1.58)	<0.001	1.24 (1.08-1.44)	0.03
LV ejection fraction ≤47%	4.38 (2.49-7.71)	<0.001	–	–
Infarct size ≥19% LV	5.41 (2.78-10.53)	<0.001	–	–
MO ≥1.4% LV	5.62 (3.12-10.12)	<0.001	3.63 (1.35-7.90)	0.004

- 13 of 20 deaths occurred in patients with MO(+) & IS≥19% of LV mass
- 1 cardiac death in the group MO(-) & IS<19% of LV mass

Centre de RM Cardiaque

CHUV

Acute Myocardial Infarction & CMR

967 patients of CoReCMR-In-STEMI assessed for eligibility

Patients excluded:
1. 29 (3.0%) time-to-reperfusion >12 hours
2. 30 (3.1%) previous MI or coronary revascularization
3. 29 (3.0) claustrophobia or refuse to perform CMR
4. 25 (2.8%) insufficient image quality

854 patients underwent clinical follow-up

Primary End-point: combined all-death & HF hospitalization

Follow-up: 1 to 13 years (median 5.5 years)

Patients excluded:
44 (5.1%) patients lost to follow-up

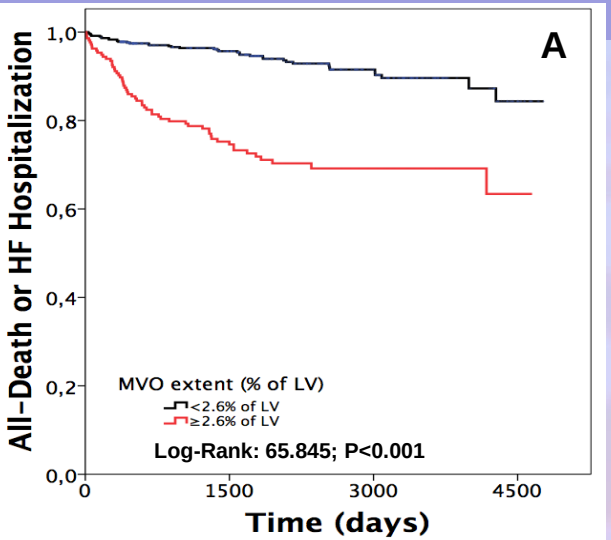
810 acute STEMI patients finally included
In the pre-specified study
(clinical outcome analysis)

Symons et al. Submitted

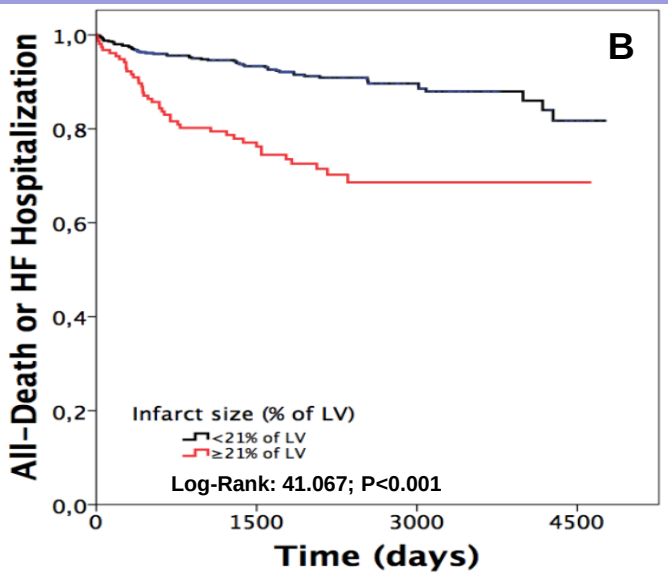
Centre de RM Cardiaque

CHUV

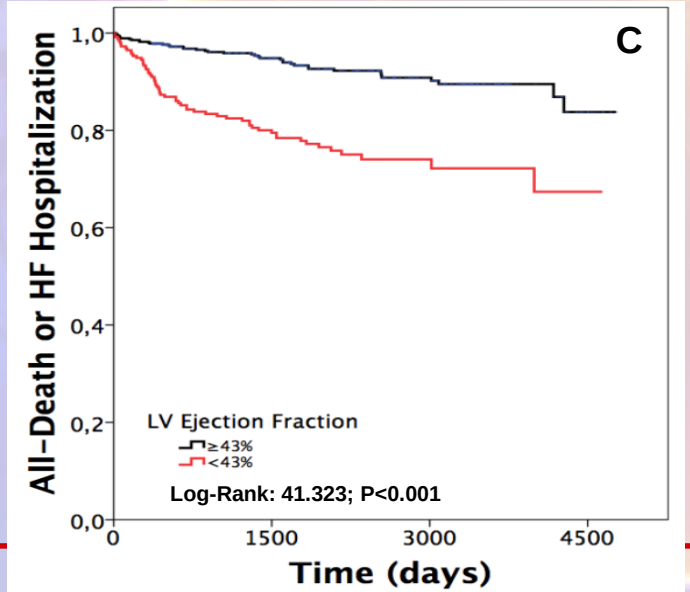
Acute Myocardial Infarction & CMR



MVO<2.6% 595	378	149	4
MVO≥2.6% 215	69	117	35



IS<21% 655	406	163	1
IS≥21% 155	89	20	0



EF≥ 43% 555	342	144	16
EF<43% 255	153	40	7

Centre de RM Cardiaque

CHUV

Acute Myocardial Infarction & CMR

Table 3. Multivariate Cox-Regression Analysis for the prediction of the primary end-point

Baseline Characteristics	Model-1		Model-2	
	HR (95% CI)	P-Value	HR (95% CI)	P-Value
Model c				
Age≥67years	1.977 (1.272-3.074)	0.002	2.142 (1.381-3.324)	0.001
Active Smoking	0.628 (0.400-0.985)	0.043	0.659 (0.419-1.037)	0.072
Killip Class 2,3 vs 1	1.575 (0.882-2.812)	0.125	1.636 (0.922-2.902)	0.092
CK-MB ≥42*	1.683 (1.084-2.612)	0.020	1.701 (1.099-2.635)	0.017
MAP<95 mmHg	2.011 (1.281-3.156)	0.002	1.997 (1.271-3.138)	0.003
Heart rate≥76 bpm	1.141 (0.742-1.756)	0.548	1.191 (0.774-1.833)	0.426
TIMI flow post PCI	0.714 (0.458-1.114)	0.138	0.713 (0.461-1.103)	0.128
Rentrop grade 01,s vs 2,3	2.623 (0.639-10.773)	0.181	2.690 (0.658-11.001)	0.168
LV-EDVi≥81 ml/m2	1.274 (0.824-1.970)	0.275		
LV-ESVi≥39 ml/m2			1.875 (1.137-3.093)	0.014
LV-EF<43%	1.765 (1.074-2.903)	0.025		
Infarct size≥21% of LV	0.957 (0.546-1.677)	0.877	1.086 (0.644-1.830)	0.758
MVO extent ≥2.6% of LV	3.185 (1.892-5.362)	<0.001	3.199 (1.915-5.343)	<0.001
Model d				
Active Smoking	0.667 (0.432-1.029)	0.067	0.675 (0.439-1.040)	0.074
CK-MB≥42	1.804 (1.175-2.769)	0.007	1.836 (1.197-2.815)	0.005
TIMI flow post PCI	0.799 (0.509-1.255)	0.329	0.790 (0.505-1.234)	0.300
Rentrop Grade 0,1 vs 2,3	2.592 (0.633-10.610)	0.185	2.700 (0.661-11.036)	0.167
LV-EDVi≥81 ml/m^2	1.239 (0.809-1.898)	0.324		
LV-ESVi≥39 ml/m2			1.870 (1.144-3.057)	0.013
LV-EF<43%	1.859 (1.155-2.991)	0.001		
Infarct size≥21% of LV	0.981 (0.577-1.668)	0.943	1.122 (0.684-1.842)	0.648
MVO extent ≥2.6% of LV	2.896 (1.761-4.761)	<0.001	2.898 (1.779-4.720)	<0.001
TIMI Risk Score≥4	2.653 (1.725-4.081)	<0.001	2.851 (1.865-4.358)	<0.001

Acute Myocardial Infarction & CMR

Table 4. Multivariate Cox-Regression Analysis for the primary end-point and chi-squared improvement obtained by the stepwise inclusion of each covariate.

Baseline Characteristics			χ^2		
	HR (95% CI)	P-Value	Δ from Previous Step	P-value	Overall
Model a-1					
MVO extent ≥2.6% of LV	3.411 (2.184-5.328)	<0.001	52.883	<0.001	52.883
Age≥67years	2.022 (1.305-3.134)	0.002	19.914	<0.001	72.797
MAP <95 mmHg	1.986 (1.283-3.074)	0.002	10.837	0.001	83.634
LV-EF<43%	1.884 (1.212-2.928)	0.005	8.014	0.005	91.648
CK-MB≥42	1.668(1.083-2.568)	0.020	5.138	0.023	96.786
Active Smoking	0.637 (0.407-0.995)	0.048	3.994	0.046	100.780
Model a-2					
MVO extent≥2.6% of LV	3.505 (2.269-5.415)	<0.001	52.883	<0.001	52.883
Age≥67years	2.612 (1.746-3.909)	<0.001	19.914	<0.001	72.797
MAP <95 mmHg	1.971 (1.275-3.046)	0.002	10.837	0.001	83.634
LV-ESVi≥39ml/m^2	1.924 (1.189-3.112)	0.008	7.729	0.005	91.363
CK-MB≥42	1.642(1.066-2.528)	0.024	5.239	0.022	96.601
Model b-1					
MVO extent≥2.6% of LV	3.098 (2.007-4.782)	<0.001	54.730	<0.001	54.730
TIMI Risk Score≥4	3.033 (2.015-4.566)	<0.001	32.480	<0.001	87.210
LV-EF<43%	1.929 (1.251-2.975)	0.003	8.948	0.002	96.158
CK-MB≥42	1.743(1.141-2.662)	0.010	6.900	0.009	103.058
Model b-2					
MVO extent ≥2.6% of LV	3.219 (2.101-4.933)	<0.001	57.730	<0.001	54.730
TIMI Risk Score≥4	3.280 (2.186-4.921)	<0.001	32.480	<0.001	87.210
LV-ESVi≥39ml/m^2	1.902 (1.186-3.051)	0.008	7.235	0.007	94.445
CK-MB≥42	1.771 (1.159-2.705)	0.008	7.285	0.007	101.730

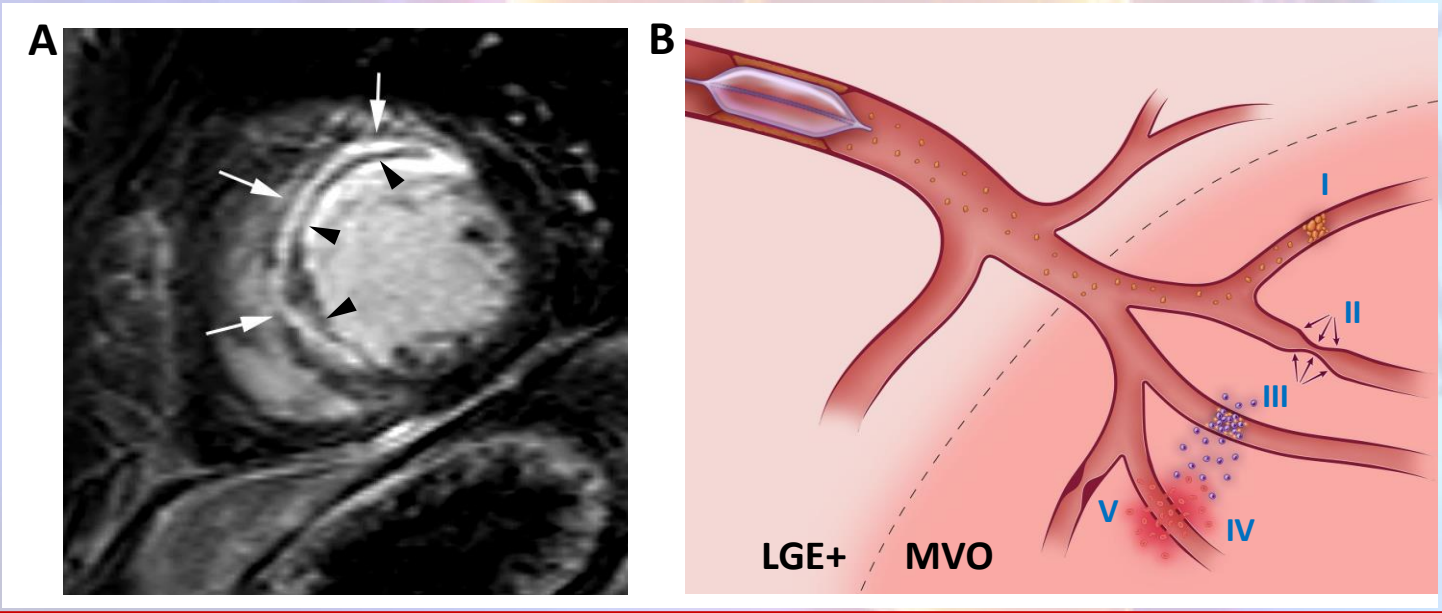
MAP: mean arterial pressure; other abbreviations as in previous tables.

Acute Myocardial Infarction & CMR

Table 5. Multivariate analyses for the secondary end-points end-point based on MVO extent<2.6% or ≥2.6 % of LV

Adverse Events	MVO exten≥2.6% of LV (n=215)	MVO extent<2.6% of LV (n=595)	HR (95 CI)	P-value
All-Death	15 (7.0%)	24 (4.0%)	2.055 (1.076-3.925)*	0.029
HF Hospitalization	44 (20.5%)	16 (2.7%)	5.999 (3.251-11.069)*	<0.001

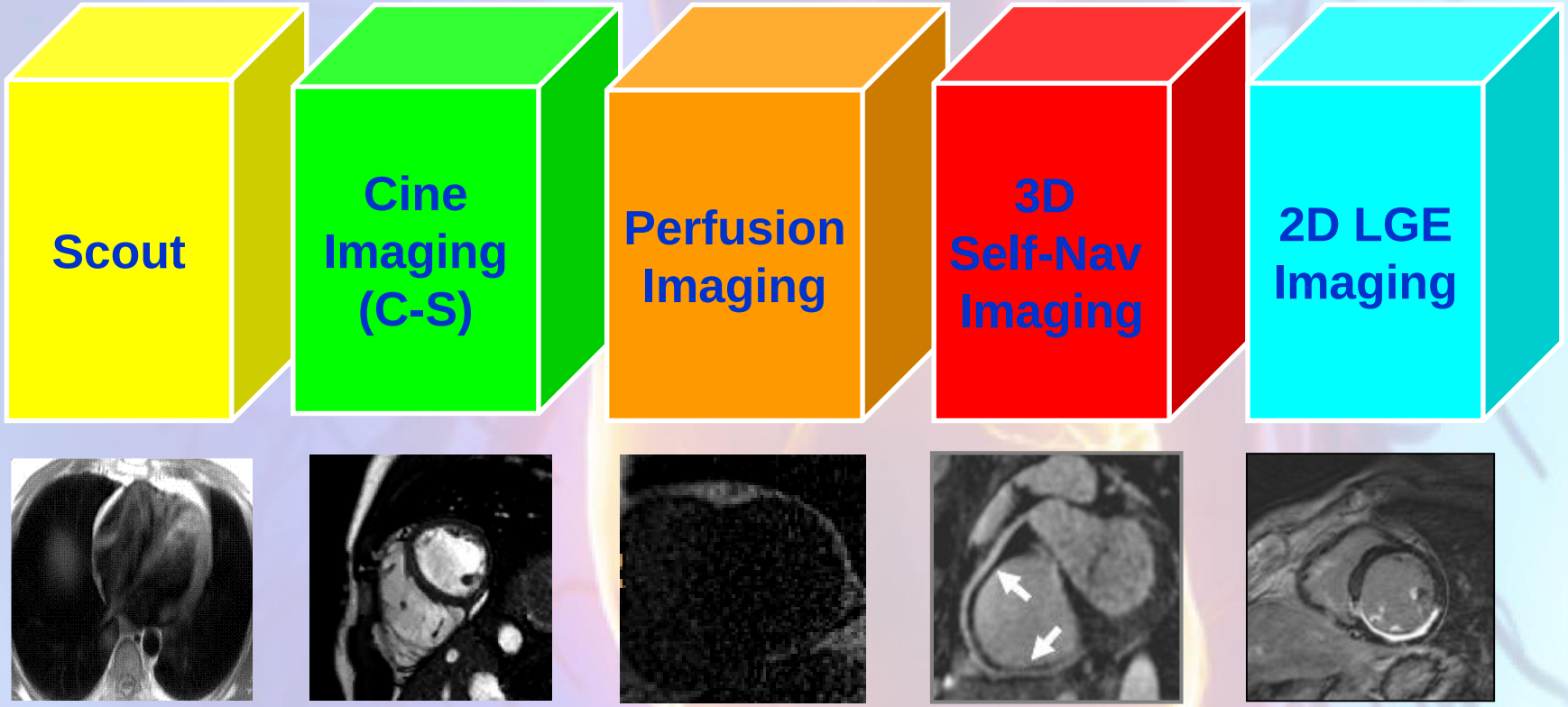
*After correction Age≥67 years; Mean Arterial blood pressure <95 mmHg, LV-EF<43%.; HF: heart failure.



Centre de RM Cardiaque

CHUV

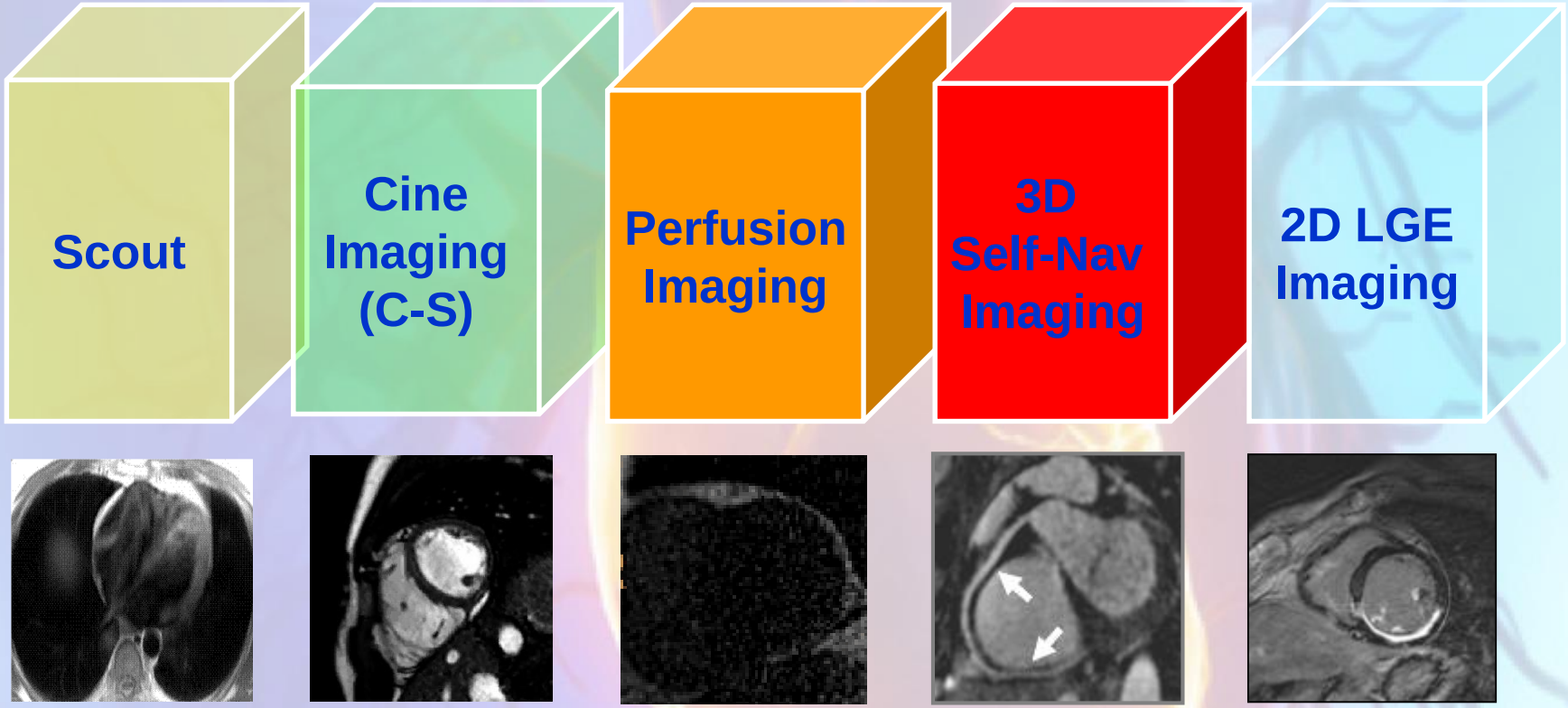
Chronic Ischemic Heart Disease & CMR



Centre de RM Cardiaque

CHUV

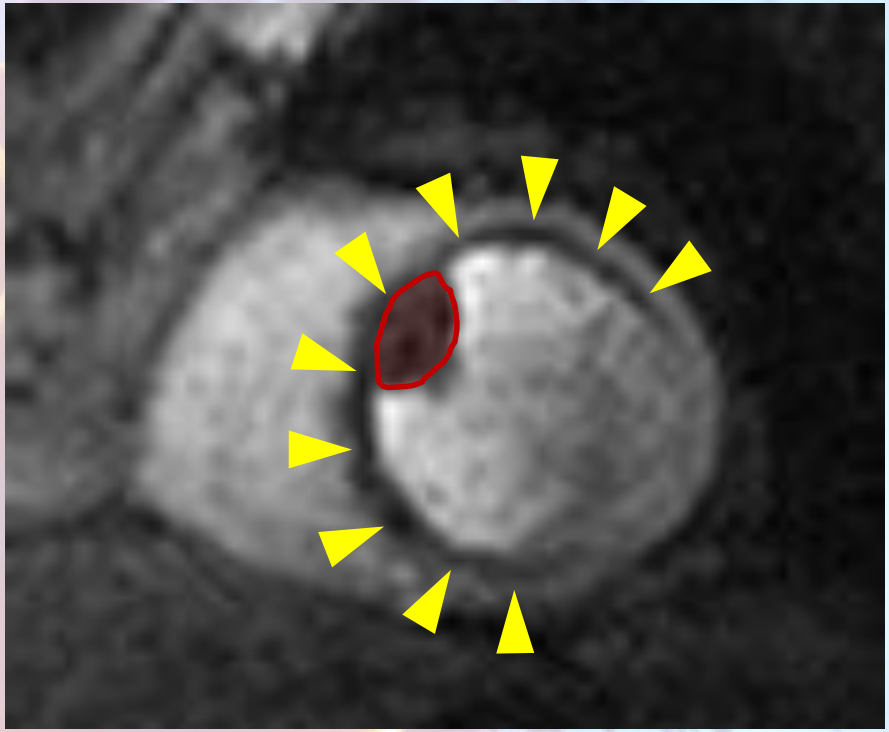
Chronic Ischemic Heart Disease & CMR



Centre de RM Cardiaque

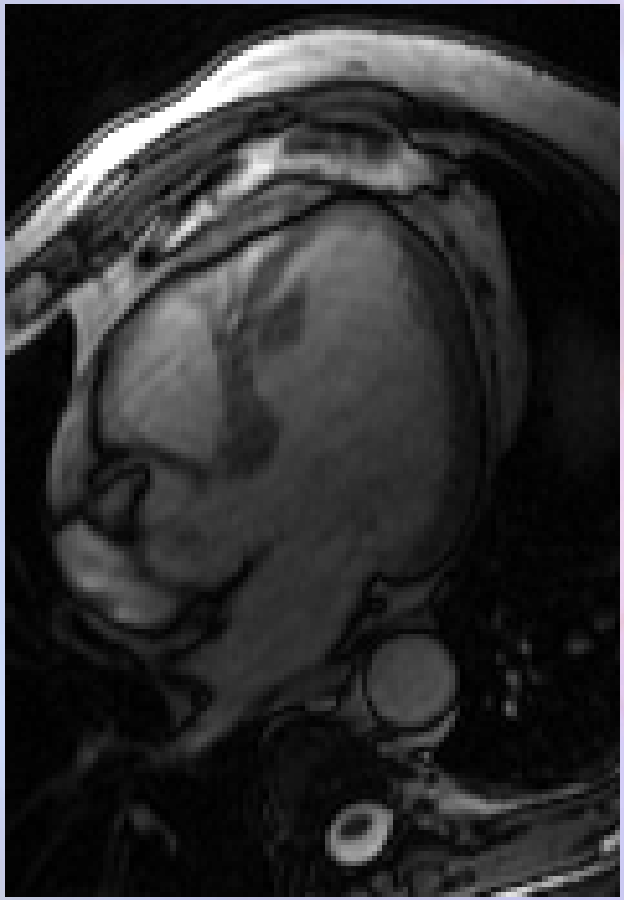
CHUV

Chronic Ischemic Heart Disease & CMR



Courtesy of Juerg Schwitter

Chronic Ischemic Heart Disease & CMR

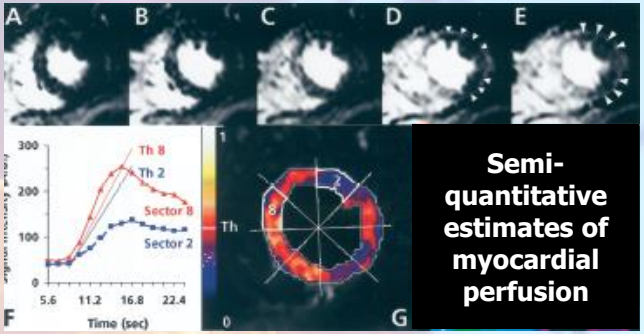


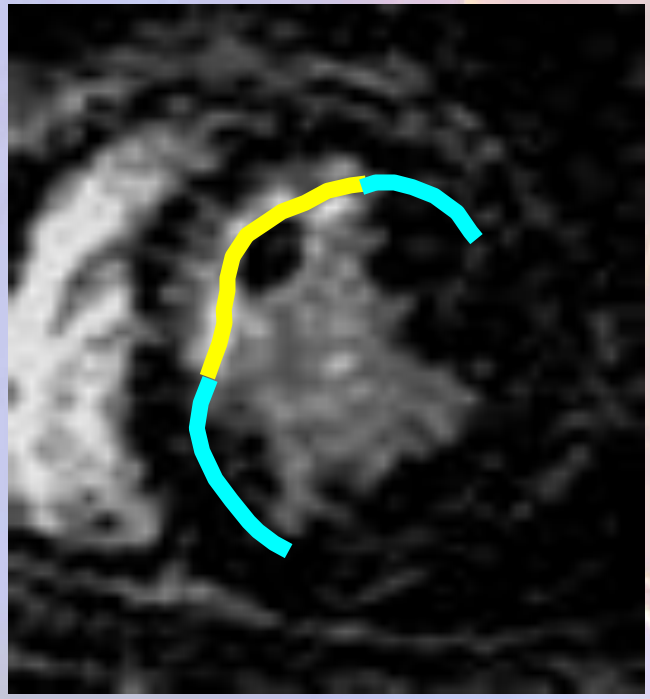
Centre de RM Cardiaque

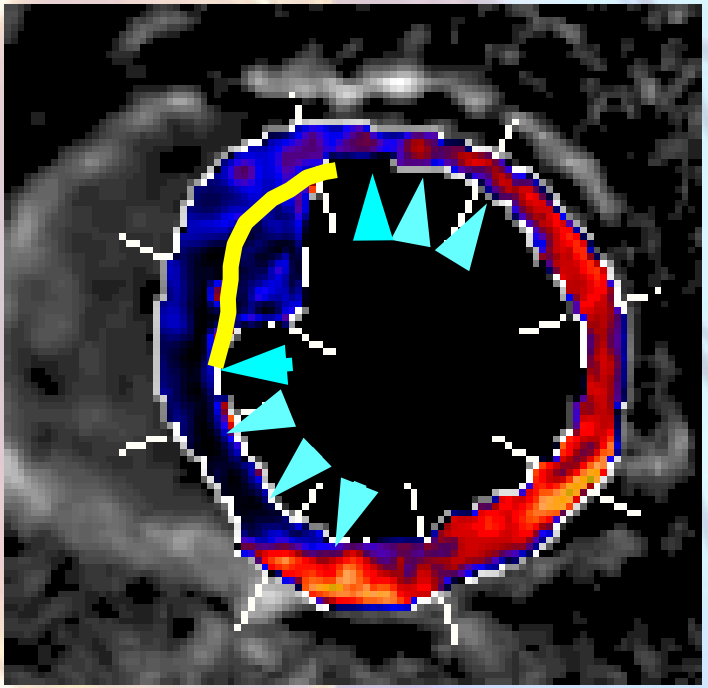
CHUV

Chronic Ischemic Heart Disease & CMR

Comprehensive Assessment of Ischemic Heart Disease



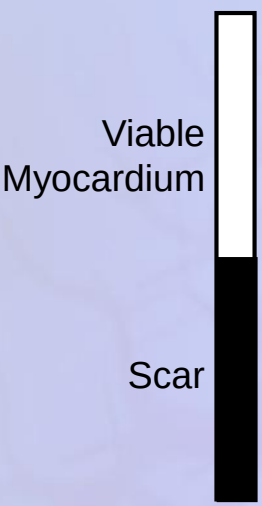


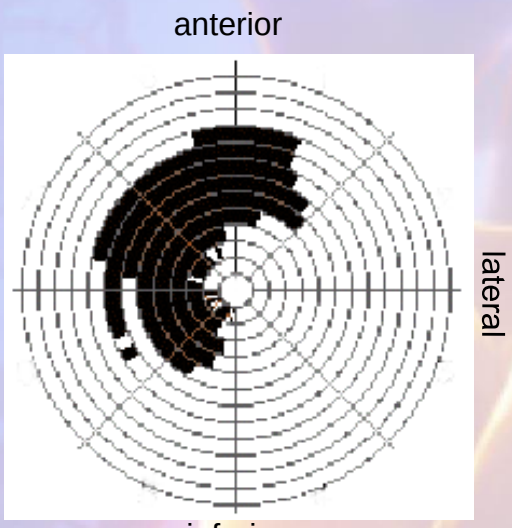


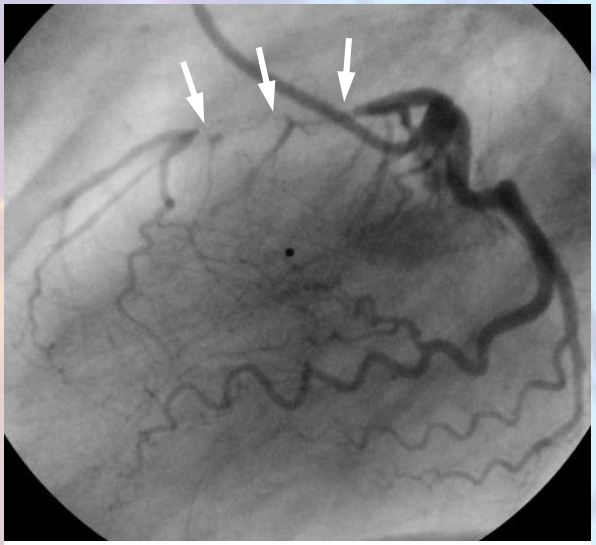
Centre de RM Cardiaque

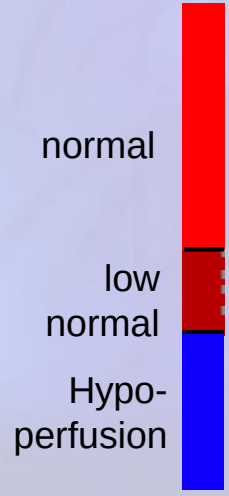
CHUV

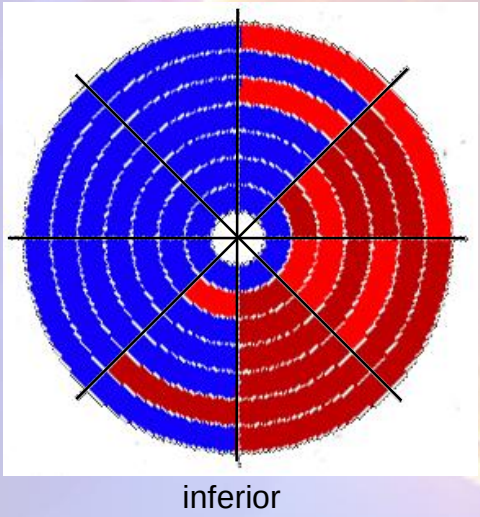
Chronic Ischemic Heart Disease & CMR

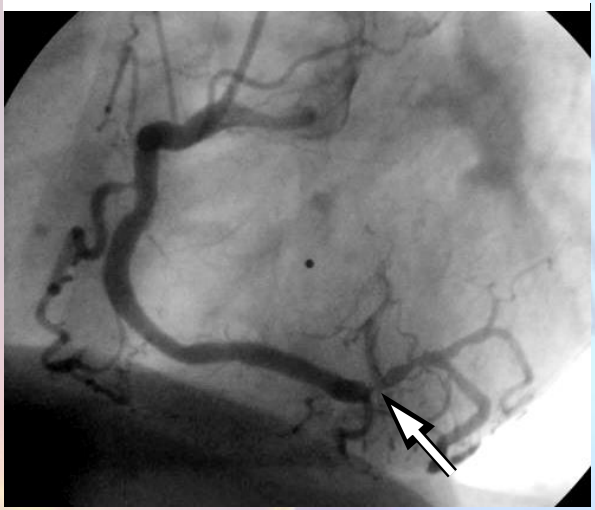








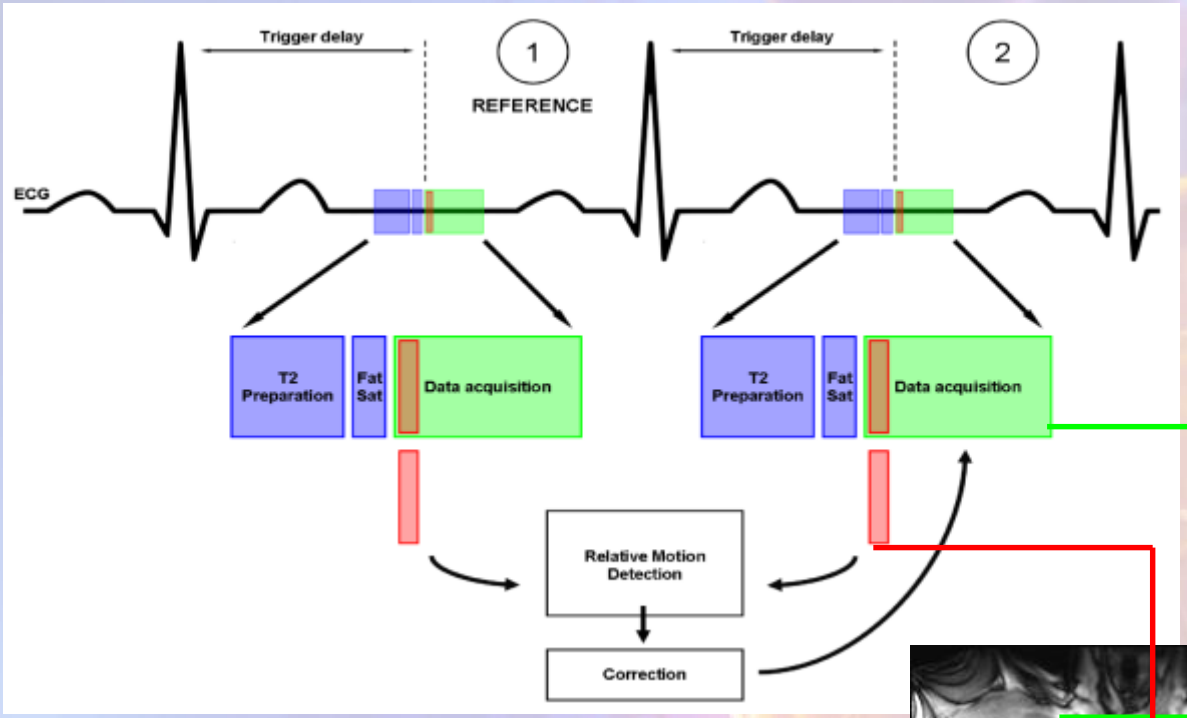




Centre de RM Cardiaque

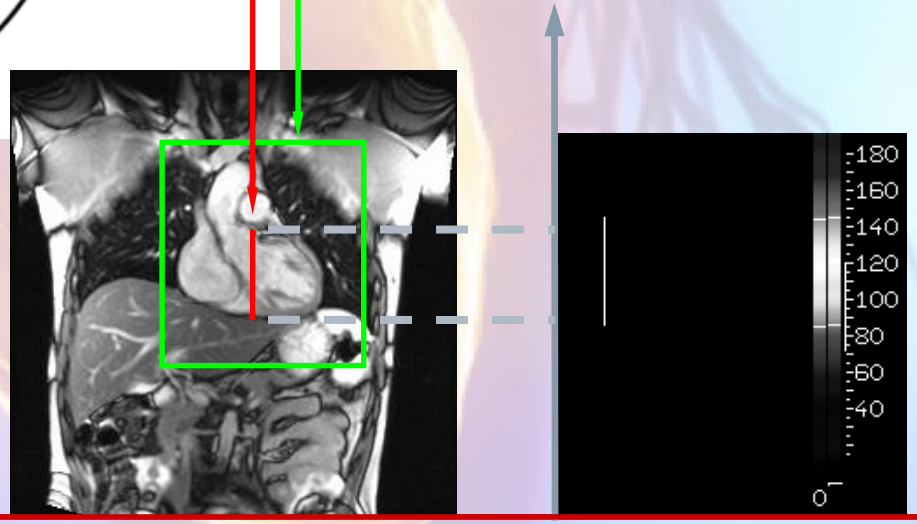
CHUV

Chronic Ischemic Heart Disease & CMR



Self-navigation enables

1. 100% scan efficiency: the duration of the acquisition is known a priori.
2. No temporal delays and hysteretic effects.
3. No navigator placement and feasibility of whole-heart acquisition: minimal planning effort.
4. Isotropic spatial resolution is enabled.



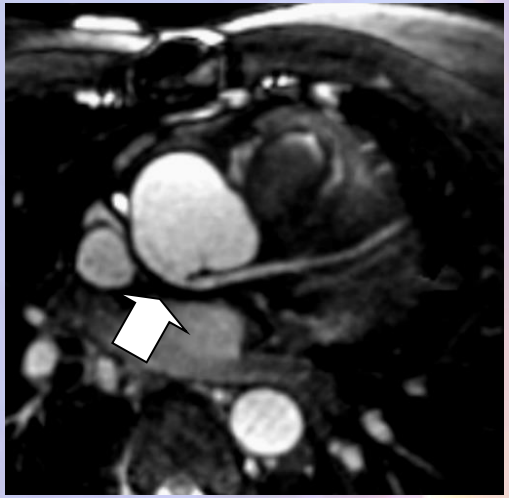
- Fat Saturated, T2-prepared 3D bSSFP sequence
- FOV (220 mm)³ - Base resolution (192 px) ³
- Voxel size (0.9 mm)³ isotropic
- TA = 377 - 610 Heart Beats = ~ 6 -10 min during free breathing 100% scan efficiency

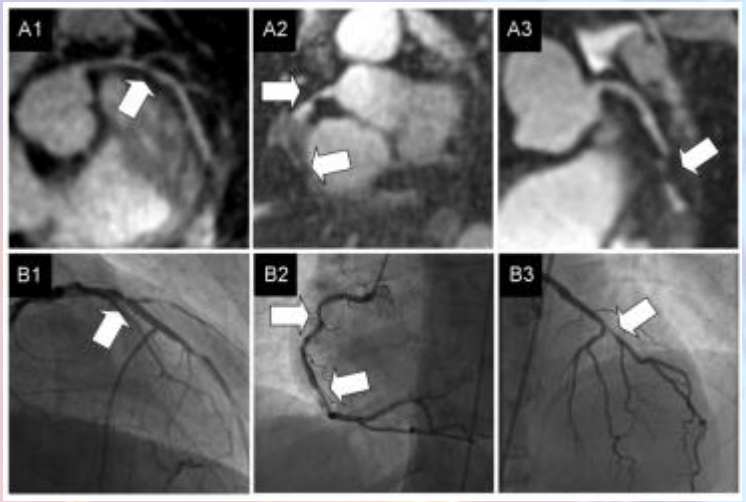
Courtesy of D. Piccini & Pr Stuber

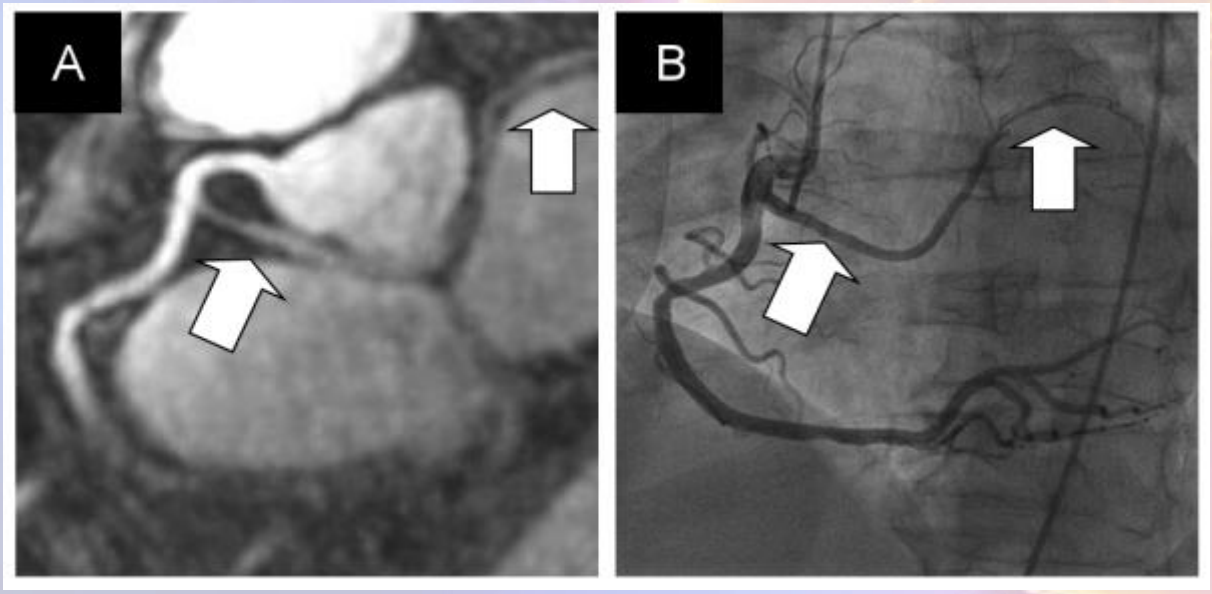
Centre de RM Cardiaque

CHUV

Chronic Ischemic Heart Disease & CMR







Courtesy of D. Piccini & Pr Stuber

Centre de RM Cardiaque

CHUV

Chronic Ischemic Heart Disease & CMR

Cardiovascular magnetic resonance and single-photon emission computed tomography for diagnosis of coronary heart disease (CE-MARC): a prospective trial

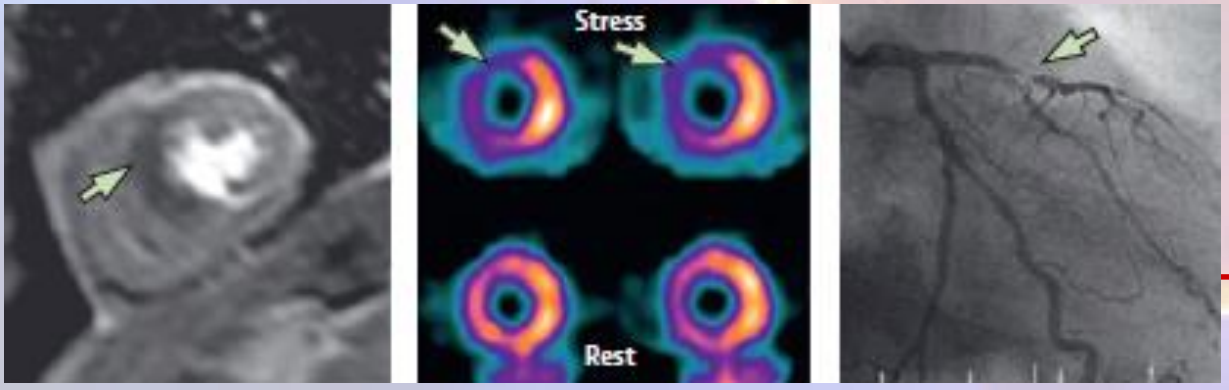
John P Greenwood, Neil Maredia, John F Younger, Julia M Brown, Jane Nixon, Colin C Everett, Petra Bijsterveld, John P Ridgway, Aleksandra Radjenovic, Catherine J Dickinson, Stephen G Ball, Sven Plein

Study Characteristics

- 752 consecutive patients with ≥1 RF and stable angina (obstructive CAD prevalence 39%)
- Head-to head comparison of CMR and ^{99m}Tc-gated SPECT (3 weeks apart; identical stress protocol)
- All patients underwent ICA irrespective of CMR / SPECT imaging results (avoidance of referral bias)

End-Points

- Diagnostic accuracy of multiparametric CMR for detection of CAD (primary EP)
- Comparison of multiparametric CMR with ^{99m}Tc-gated SPECT for detection of CAD
- Comparison of only the equivalent components of CMR with ^{99m}Tc-gated SPECT

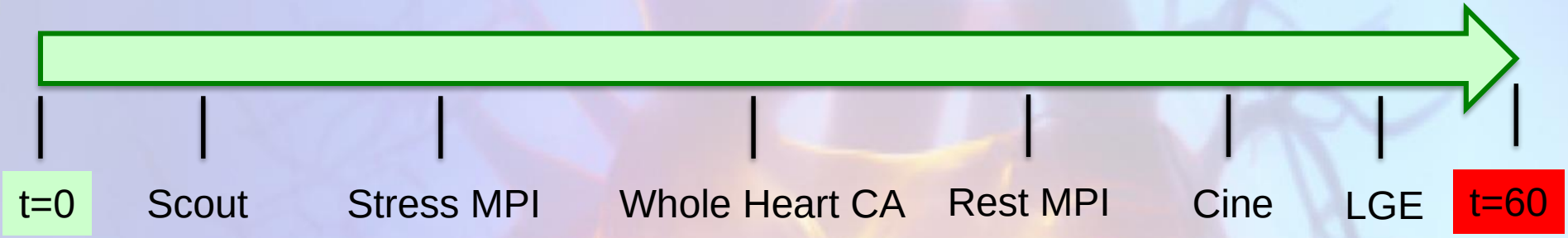


Lancet 2012

Centre de RM Cardiaque

CHUV

Chronic Ischemic Heart Disease & CMR

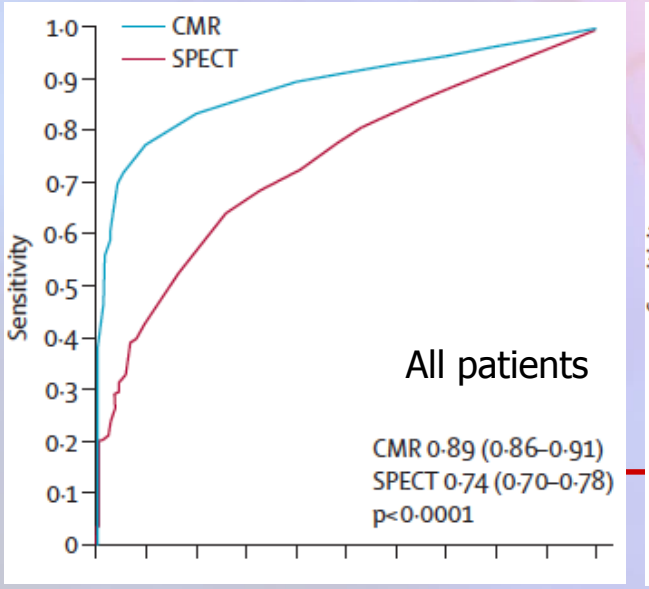


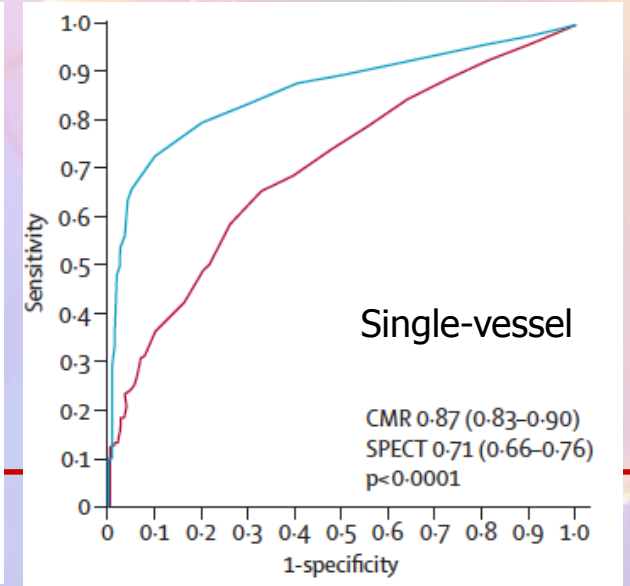
Criteria for Positive CMR

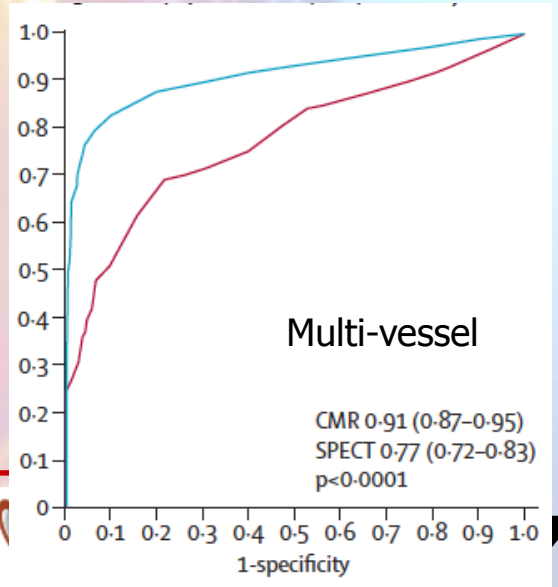
- Any evidence of regional WMA
- Inducible ischemia (MPI-CMR)
- CA stenosis @ MR angiography
- Ischemic Scar on LGE

Modality	Se/Sp	PPV/NPV
CMR	86[82]*/83[86]	77[79]/90[88]§
SPECT	66*/83	71/77§

*, § P<0.05







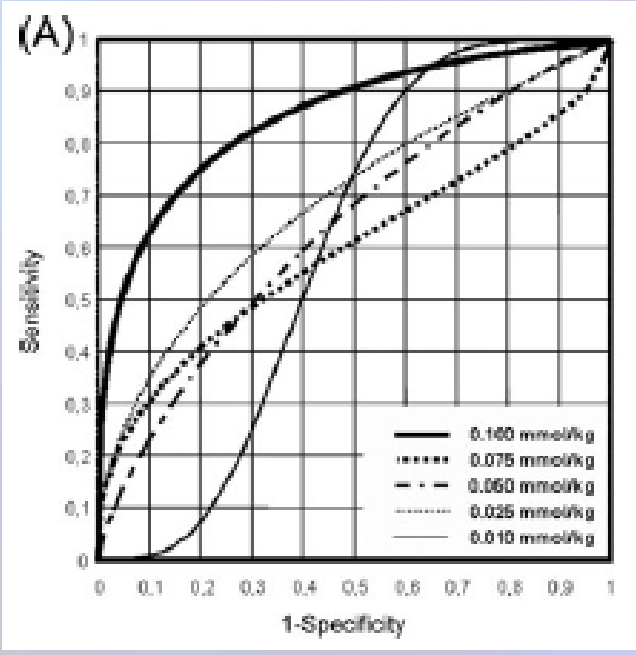
Chronic Ischemic Heart Disease & CMR

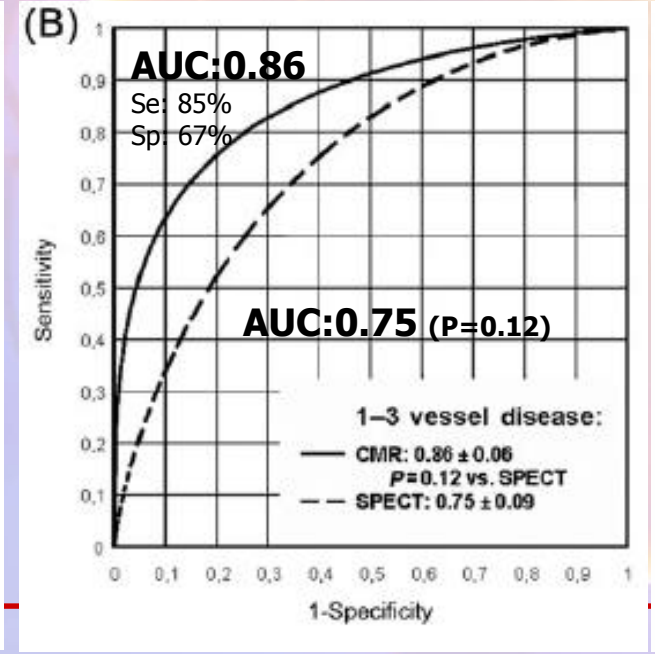
MR-IMPACT: comparison of perfusion-cardiac magnetic resonance with single-photon emission computed tomography for the detection of coronary artery disease in a multicentre, multivendor, randomized trial

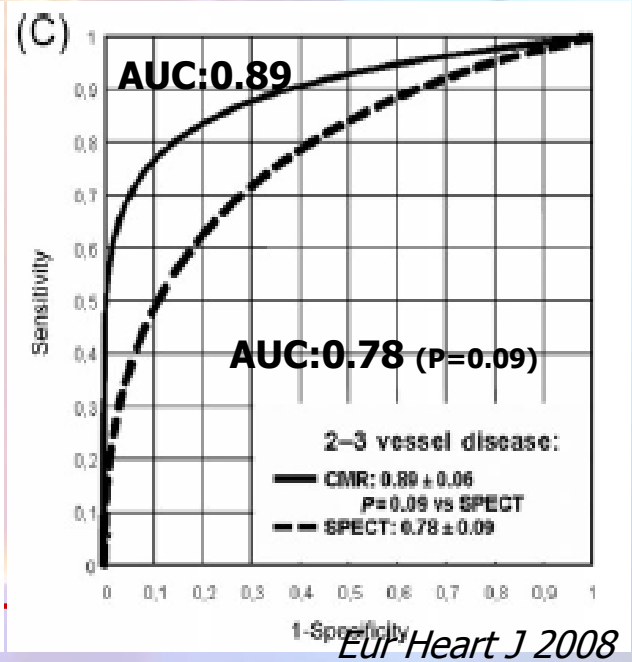
Juerg Schwitter[1]*, Christian M. Wacker[2], Albert C. van Rossum[3], Massimo Lombardi[4], Nidal Al-Saadi[5], Hakan Ahlstrom[6], Thorsten Dill[7], Henrik B.W. Larsson[8], Scott D. Flamm[9], Moritz Marquardt[10], and Lars Johansson[6]

Study Characteristics

- Double-blinded, randomised trial – multivendor (GE & Siemens & Philips)
- 234 pts in 18 centers referred to ICA for clinical reasons (CAD prev 77%)
- MPI-CMR vs MPI-SPECT
- QCA stenosis ≥50% (in vessels> 2mm)







Eur Heart J 2008

Chronic Ischemic Heart Disease & CMR

MR-IMPACT II: Magnetic Resonance Imaging for Myocardial Perfusion Assessment in Coronary artery disease Trial: perfusion-cardiac magnetic

Juerg Schwitter[1]*, Christian M. Wacker[2], Norbert Wilke[3], Nidal Al-Saadi[4], Ekkehart Sauer[5], Kalman Huettle[6], Stefan O. Schönberg[7], Andreas Luchner[8], Oliver Strohm[9], Hakan Ahlstrom[10], Thorsten Dill[11], Nadja Hoebel[12], and Tamas Simor[13], for the MR-IMPACT Investigators

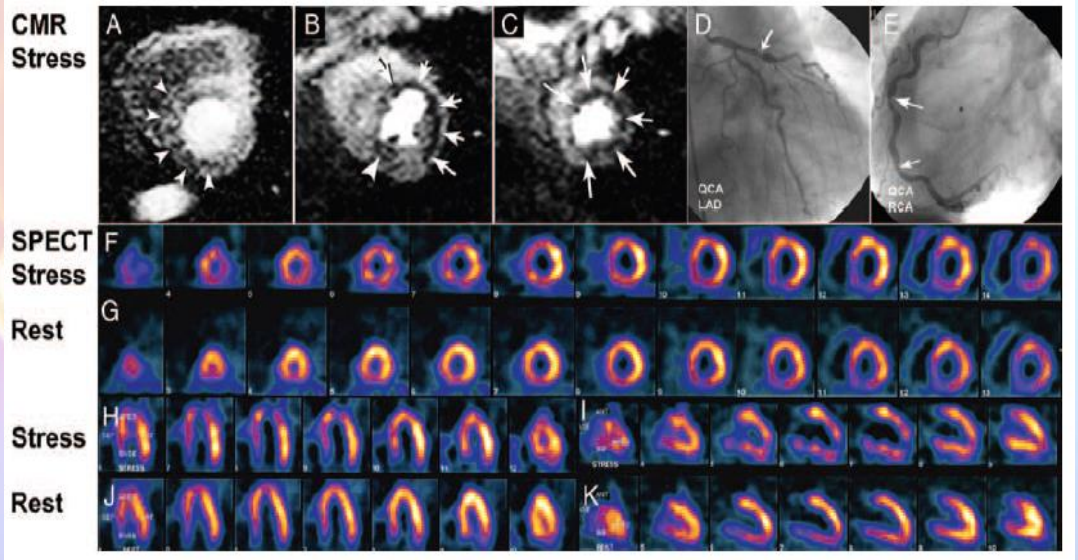
Study Characteristics

- Multivendor trial
  533 pts in 33 centers (US & EU)
  (CAD prev 49%)
- ICA, MPI-CMR and SPECT
- QCA stenosis ≥50%
  (in vessels> 2mm)

*0.075 mmol/kg Gd-based CA for perfusion

Modality	Se	Sp
CMR	75*	61 §
SPECT	61*	72 §

*, § P<0.05



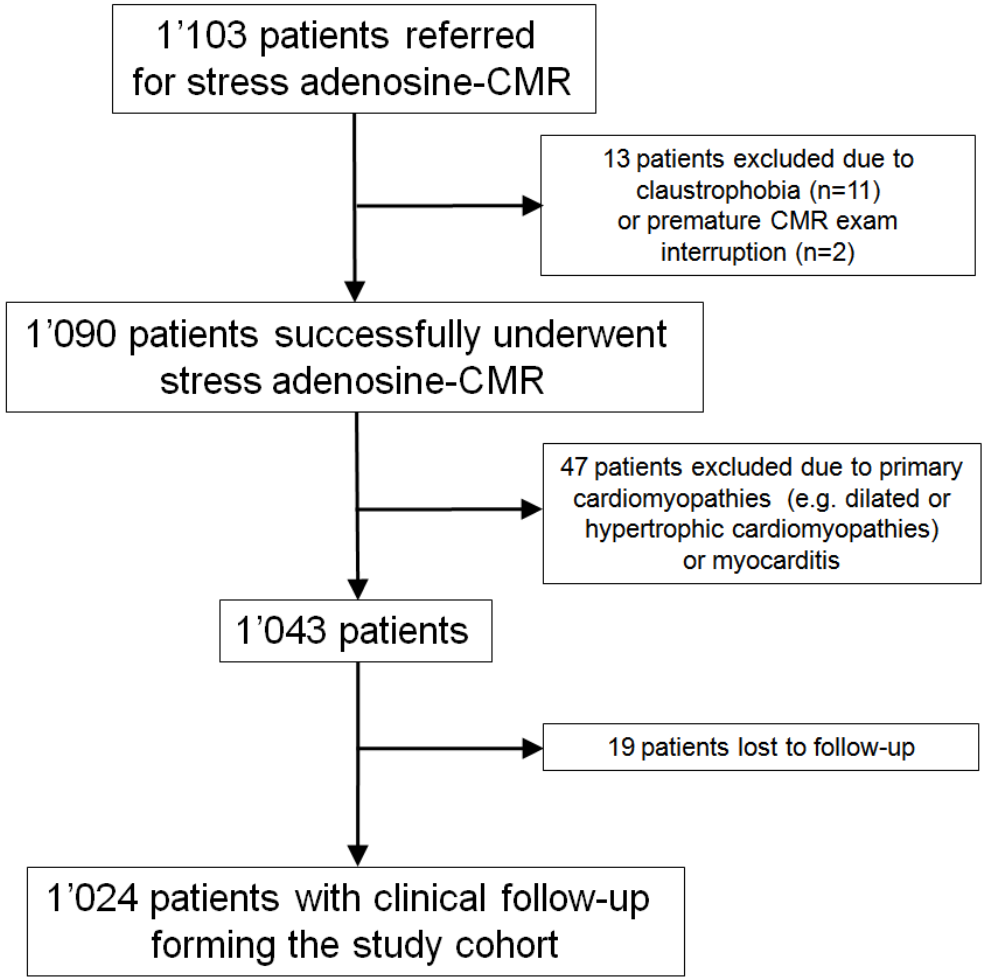
1. Lower CA dose (0.1-0.15 mmol/Kg)
2. 33 centers (small centers)
3. Lack of quality controls across centers

Centre de RM Cardiaque

CHUV

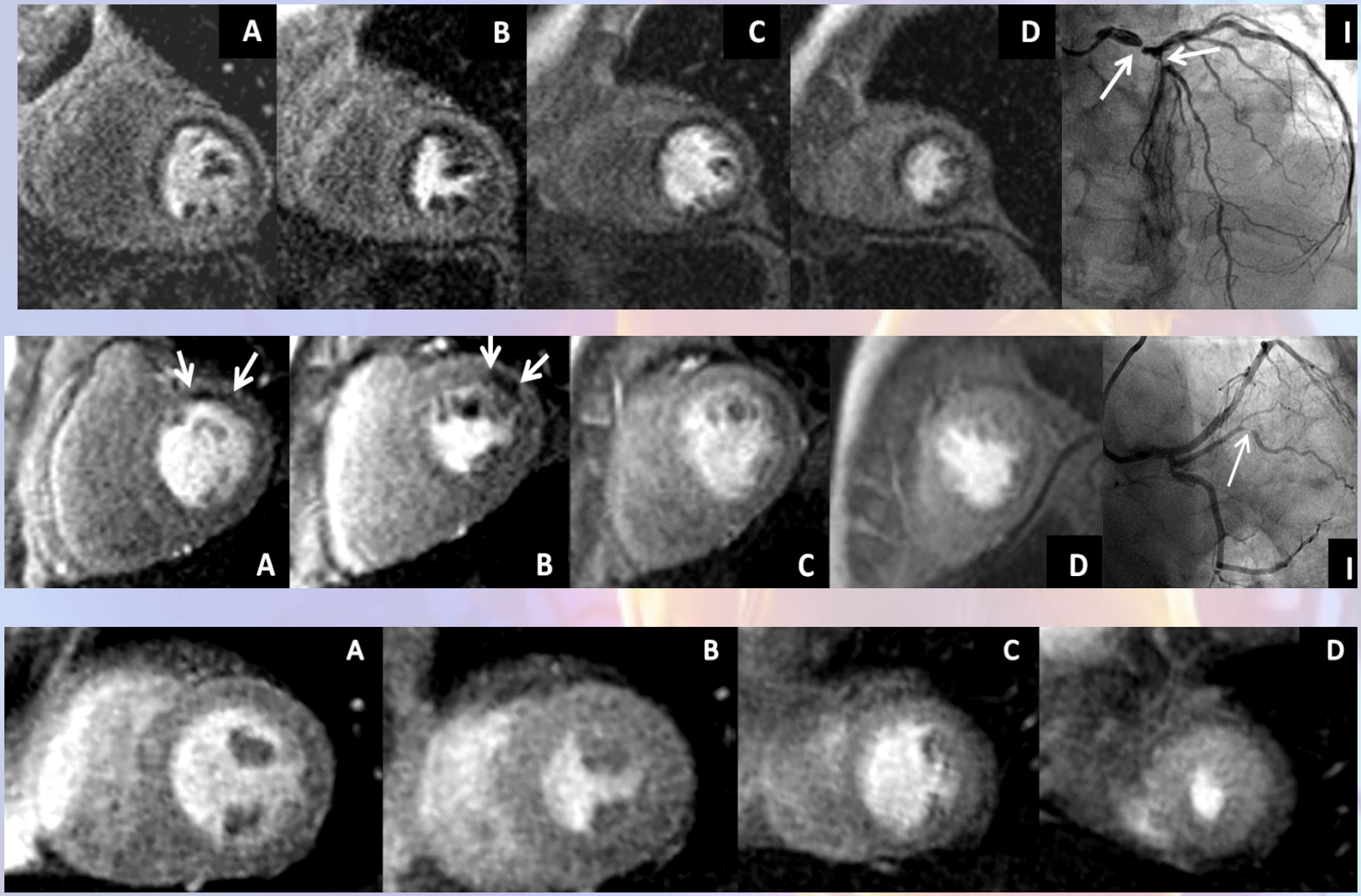
Chronic Ischemic Heart Disease & CMR

Fig. 1



Masci et al in press JACC-CVI

Chronic Ischemic Heart Disease & CMR

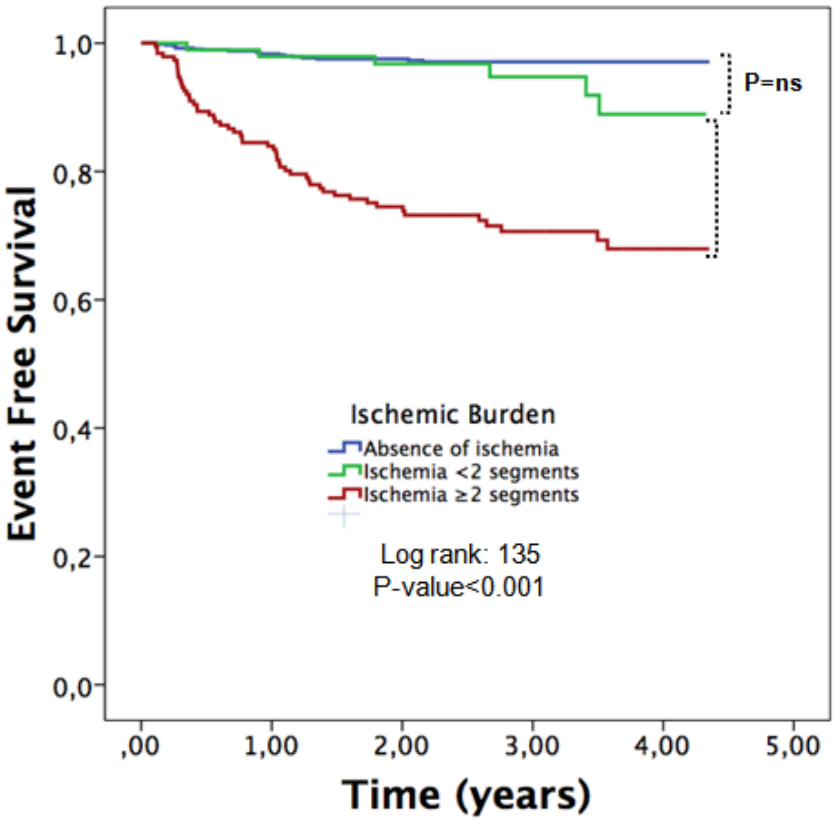


Ischemic Burden

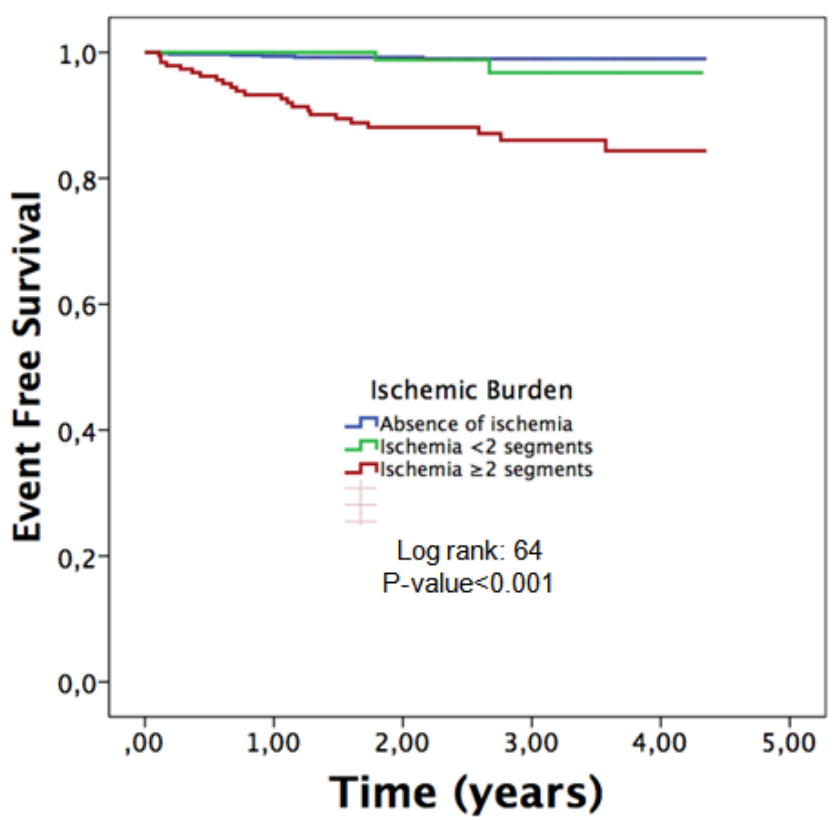
Centre de RM Cardiaque

CHUV

Chronic Ischemic Heart Disease & CMR



Cardiac Death, non-fatal MI,
late revascularization (>90 days); [n=86]



Cardiac Death, non-fatal MI
[n=32]

Centre de RM Cardiaque

CHUV

Chronic Ischemic Heart Disease & CMR

Table 4. Multivariate Cox regression analysis for the primary end-point

Baseline Variables	HR (95 CI)	P-Value
Multivariate-analysis-1		
Model a*		
Age (years)	1.038 (1.018-1.058)	<0.001
Presence of LGE	1.892 (1.118-3.014)	0.007
Presence of ischemia	6.855 (4.139-11.354)	<0.001
Model b**		
Age (years)	1.035 (1.015-1.055)	0.001
Presence of LGE	1.894 (1.189-3.017)	0.007
Presence of ischemia	6.841 (4.130-11.331)	<0.001
Model c***		
Age (years)	1.035 (1.015-1.056)	0.001
Presence of LGE	1.894 (1.189-3.017)	0.007
Presence of ischemia	6.855 (4.139-11.354)	<0.001
Multivariate-analysis-2		
Model d°		
Age ≥67 years	2.321 (1.466-3.676)	<0.001
LV-EF ≤40%	1.752 (1.040-2.950)	0.035
Ischemic burden ≥1.5 segments	8.347 (5.267-13.229)	<0.001
LGE score ≥0.03	1.655 (1.006-2.723)	0.047
Model e°°		
Age ≥67 years	2.418 (1.535-3.808)	<0.001
LV-ESVi ≥46 ml/m^2	2.195 (1.380-3.491)	0.001
Ischemic burden ≥1.5 segments	8.722 (5.515-13.794)	<0.001
Model f°°°		
Age ≥67 years	2.423 (1.542-3.808)	<0.001
LV-EDVi ≥71 ml/m^2	1.631 (1.043-2.549)	0.032
Ischemic burden ≥1.5 segments	8.376 (5.286-13.273)	<0.001
LGE score ≥0.03	1.764 (1.098-2.836)	0.019

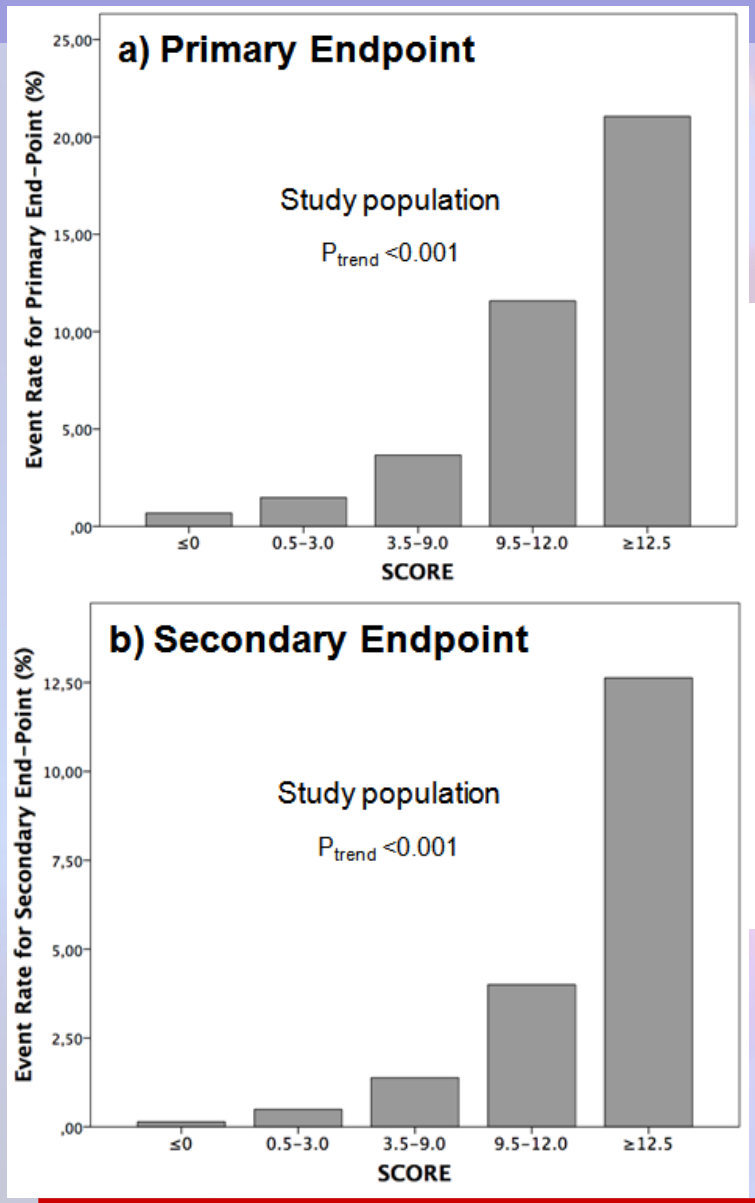
Chronic Ischemic Heart Disease & CMR

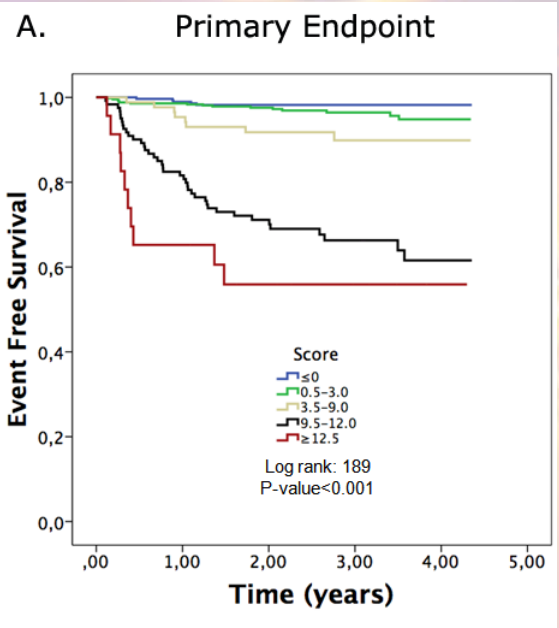
Table 6. Stepwise inclusion procedure for the multivariate-Analysis-2 (model d)

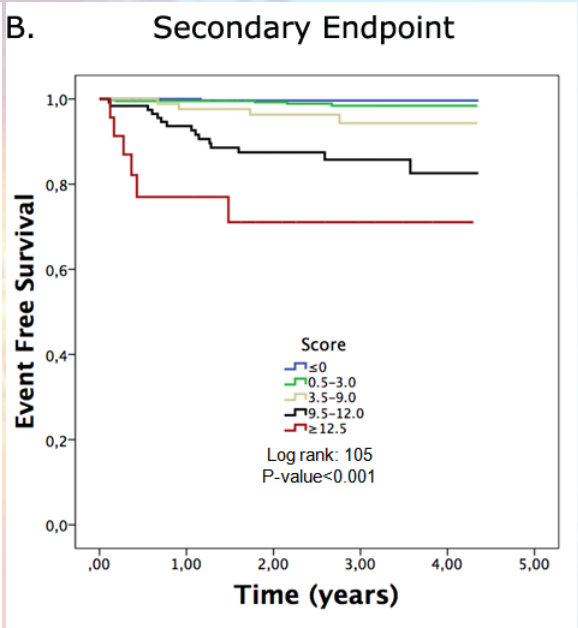
Baseline Variables	HR (95% CI)	P-Value	χ^2 Step	χ^2 Global Model	P-Value
Step 1					
Ischemic burden ≥1.5	9.003 (5.692-14.240)	<0.001	95.425	95.425	<0.001
Step 2					
Ischemic burden ≥1.5	8.644 (5.468-13.665)	<0.001			
Age ≥67 years	2.701 (1.722-4.235)	<0.001	19.511	114.936	<0.001
Step 3					
Ischemic burden ≥1.5	8.733 (5.521-13.814)	<0.001			
Age ≥67 years	2.557 (1.488-3.735)	<0.001			
LV-EF ≤40%	2.155 (1.320-3.515)	0.002	8.485	123.421	0.004
Step 4					
Ischemic burden ≥1.5	8.347 (5.267-13.229)	<0.001			
Age ≥67 years	2.321 (1.466-3.676)	<0.001			
LV-EF ≤40%	1.752 (1.040-2.950)	0.035			
LGE score ≥0.03	1.655 (1.006-2.723)	0.047	4.042	127.463	0.044

Covariates in the model: age ≥67 years; previous coronary revascularization; prior myocardial infarction; history of hypertension; LV-EDVi ≥71ml/m^2; LV-EF ≤40%; Ischemic burden ≥1.5 segments; LGE score ≥0.03.

Chronic Ischemic Heart Disease & CMR







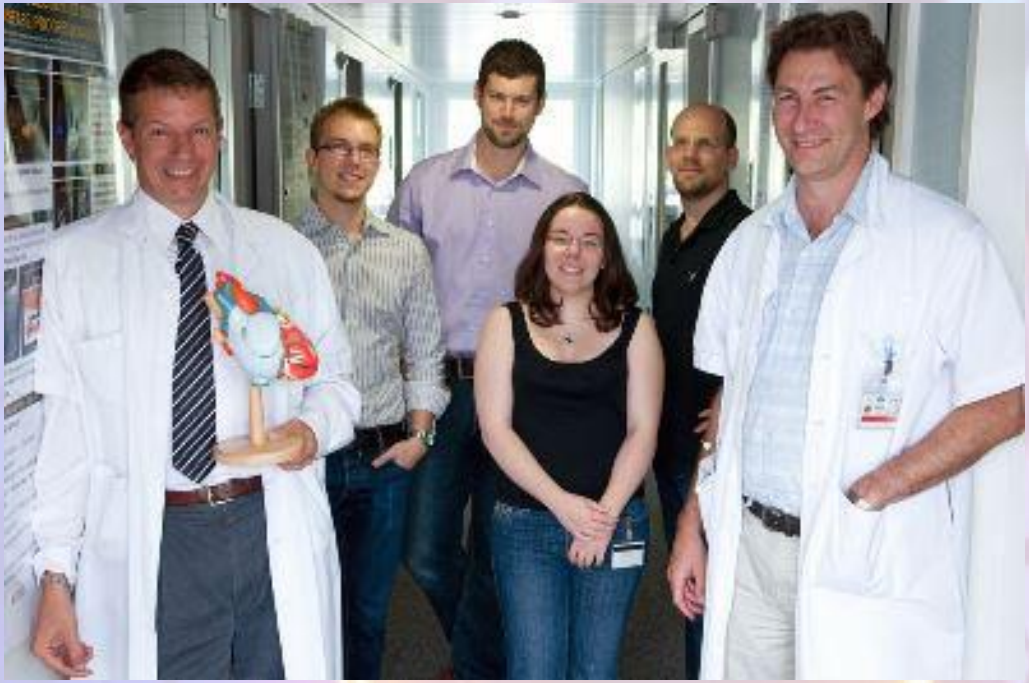
Centre de RM Cardiaque

CHUV

CIBM

Director
Prof. M. Stuber

- Ruud van Heeswijk
- Davide Piccini
- Jérôme Yerly
- Jessica Bastiaansen
- Gabriele Bonanno
- Simone Coppo
- Andrew Coristine
- Hélène Feliciano
- Jérôme Chaptinel
- Giulia Ginami
- Jean Delacoste
- Roberto Colotti
- Emeline Lugand



CRMC

Director
Prof. J. Schwitter

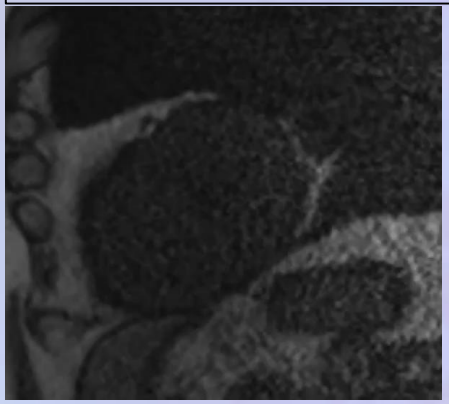
- PG Masci
- G. Vincenti
- P. Monney
- T. Rutz

- Laurent Nathaline (research ass)

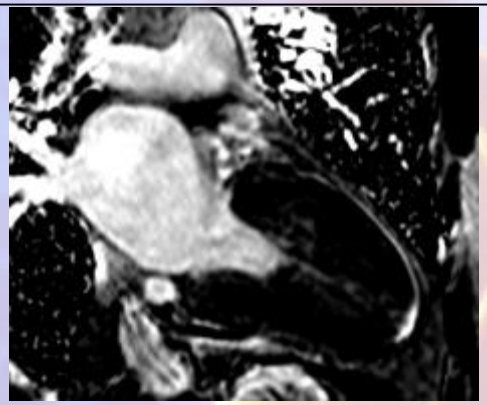
pgmasci@gmail.com / pier-giorgio.masci@chuv.ch

Chronic Ischemic Heart Disease & CMR

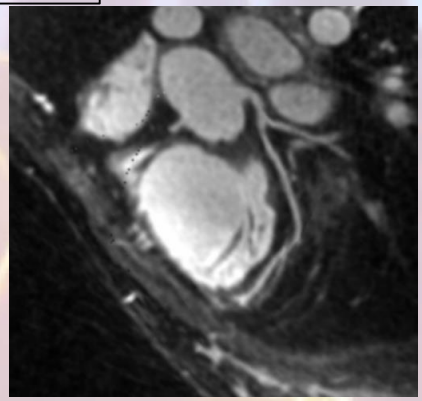
Case #1
Patient 52 y.o, male, HTA & hypercholesteremia
Typical chest pain during effort (CCS-II)



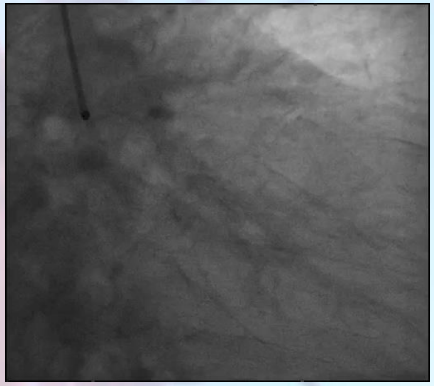
Stress-Perfusion



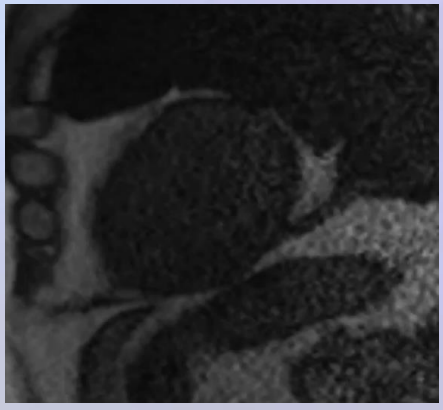
LGE

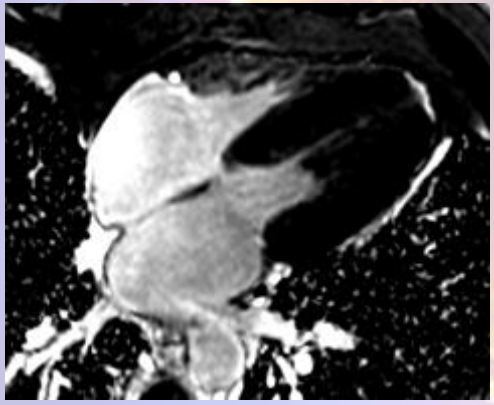


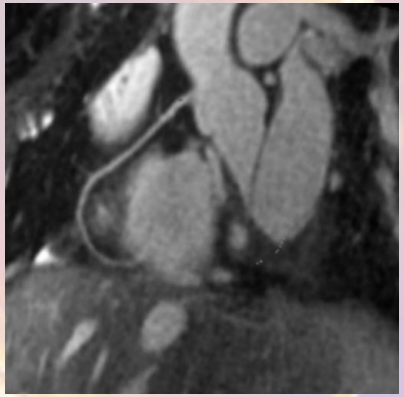
Whole Heart-CA

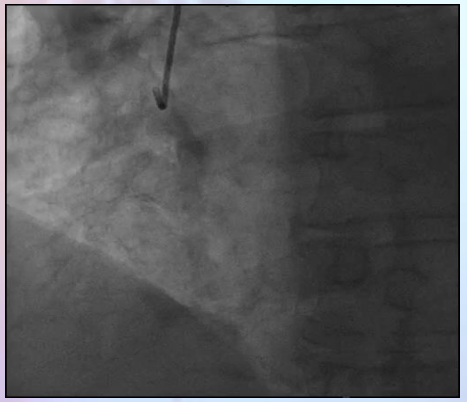


Invasive CA





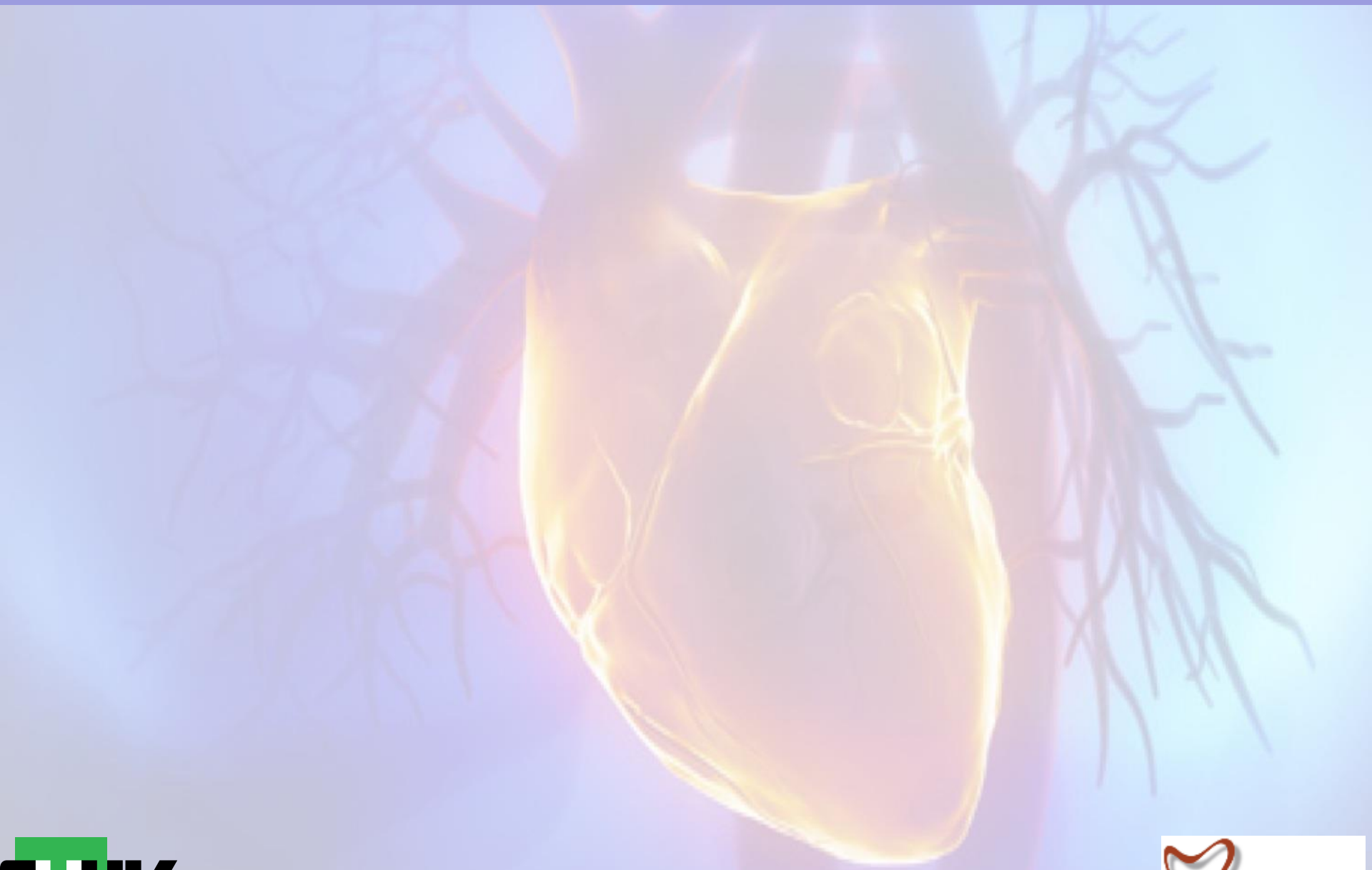




Centre de RM Cardiaque

CHUV

CMR in Acute Ischemic Heart Disease



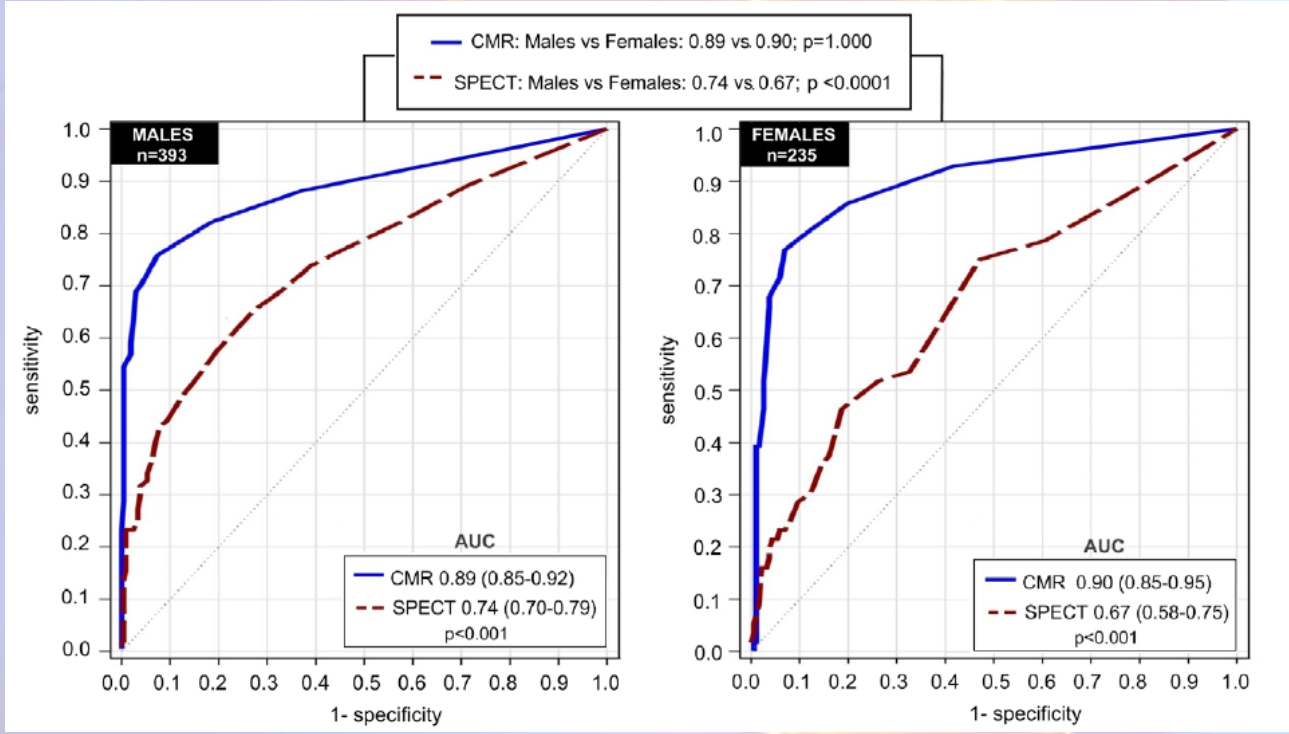
CHUV

Centre de RM Cardiaque

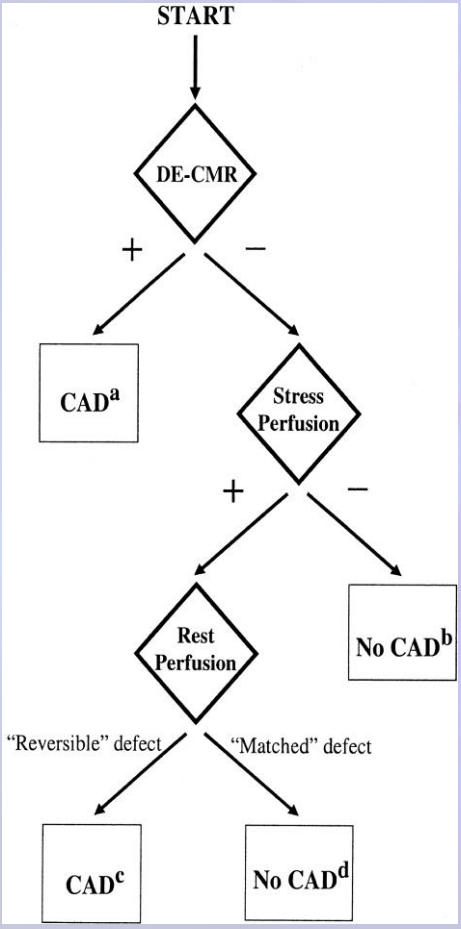
Chronic Ischemic Heart Disease & CMR

Comparison of Cardiovascular Magnetic Resonance and Single-Photon Emission Computed Tomography in Women With Suspected Coronary Artery Disease From the Clinical Evaluation of Magnetic Resonance Imaging in Coronary Heart Disease (CE-MARC) Trial

John P. Greenwood, PhD; Manish Motwani, MB, ChB; Neil Maredia, MD; Julia M. Brown, MSc; Colin C. Everett, MSc; Jane Nixon, PhD; Petra Bijsterveld, MA; Catherine J. Dickinson, PhD; Stephen G. Ball, PhD; Sven Plein, PhD



Myocardial Perfusion Imaging By Cardiovascular MR



100 pts with intermediate pretest probability for CAD
in part for post-test referral bias

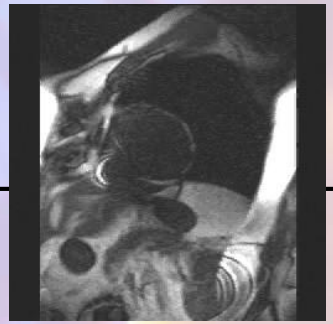
	Sensitivity	Specificity	Accuracy
Interpretation Algorithm	89%	87%	88%
Perfusion (rest/stress)	84%	54%	68%
Cine (rest)	49%	73%	63%
DE-CMR	49%	98%	78%

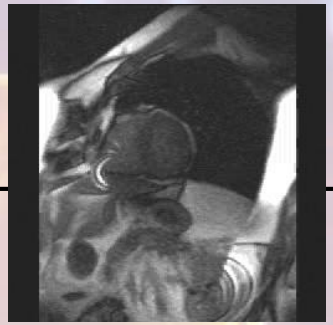
Coronary Stenosis ≥ 70% or LMS ≥ 50%
(obstructive CAD: 40%)

SPECT **->** Se/Sp=65-82%/59-67%

Klem et al. J Am Coll Cardiol 2006

Myocardial Perfusion Imaging By Cardiovascular MR





Adenosine

Start Localizers

Stress MPI

Rest MPI

± 3’

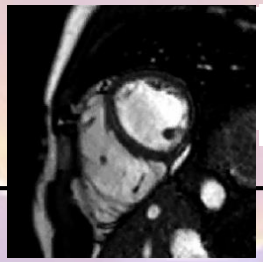
± 15’

± 10’

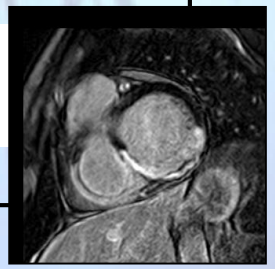
*

*

Cardiac Function



Delayed Enhancement

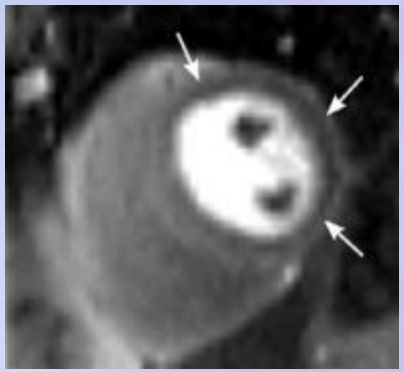


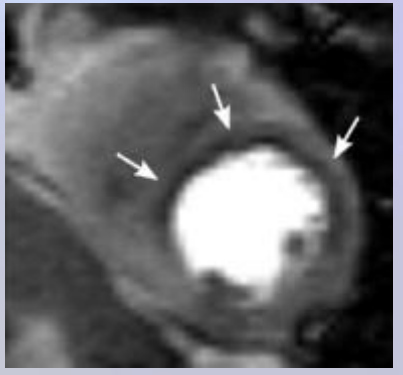
*Gd-chelate (0.5M) 0.1 mmol/kg at 3-8 ml/min

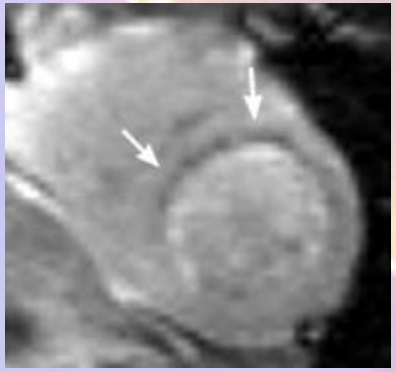
Improve Acquisition Protocol and Analysis

1) Adequate patient preparation
2) Selection of adenosine dose (up to 210 mg/kg/min)
3) Acquisition protocol (mistrigerring / respiration artifacts / Valsalva maneuver)

Time





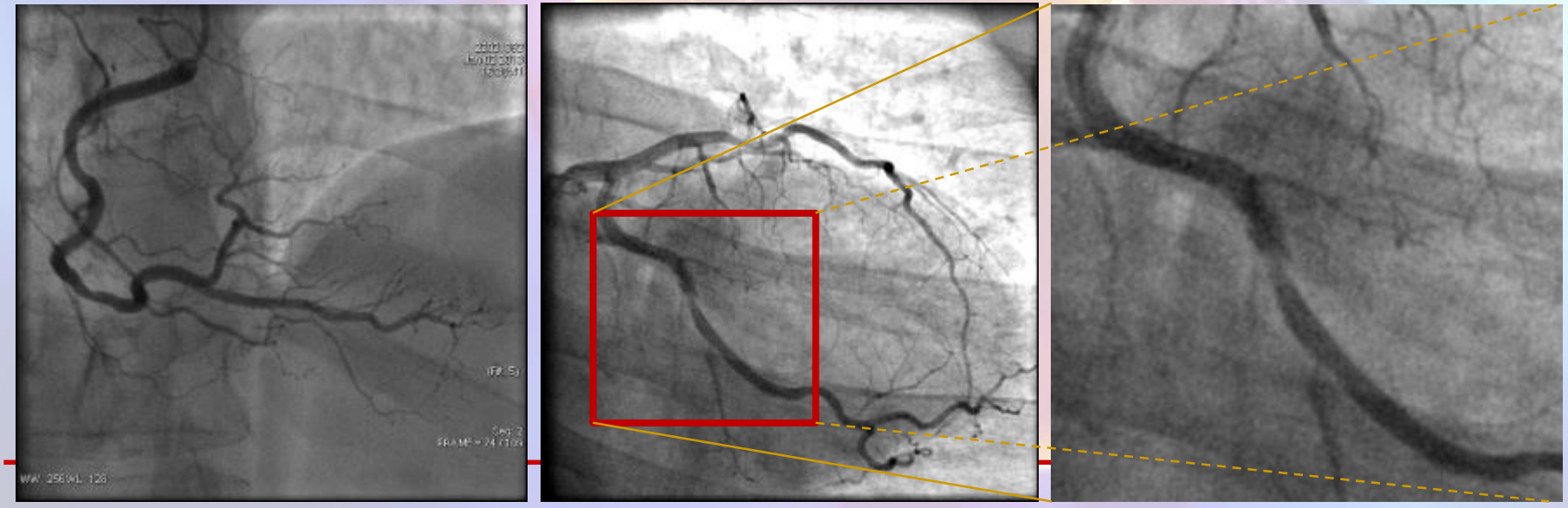


Dark-rim	**Perfusion-Defect**
Short-lasting (second-pass)	Persisting
Starts CM arrives in LV cavity	Starts when CM arrives myocardium
» Hyperemia	» Hyperemia
SI <baseline SI	SI> baseline SI
may superimpose to true perfusion defect	

Acute Myocardial Infarction & CMR

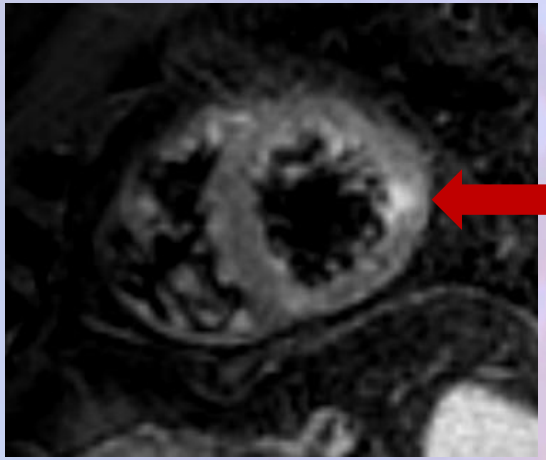
Differential Diagnosis
- Clinical Case #1-

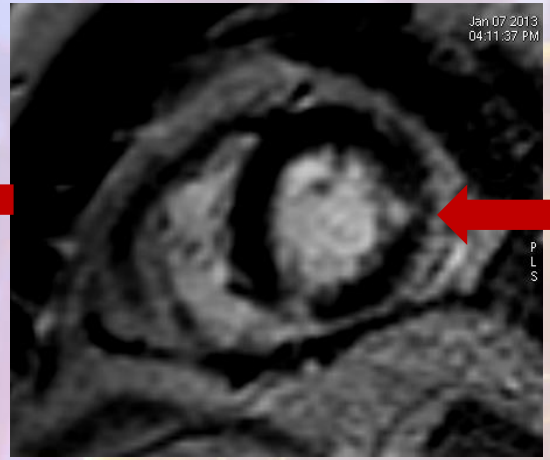
43 y.o man smoker, typical long-lasting CP,
cTnI 3.41 ng/ml, no WM abnormalities at echo



Acute Myocardial Infarction & CMR

Differential Diagnosis
- Ischemic Causes -

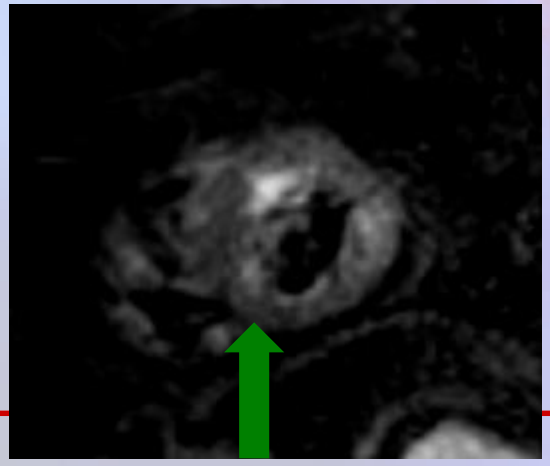


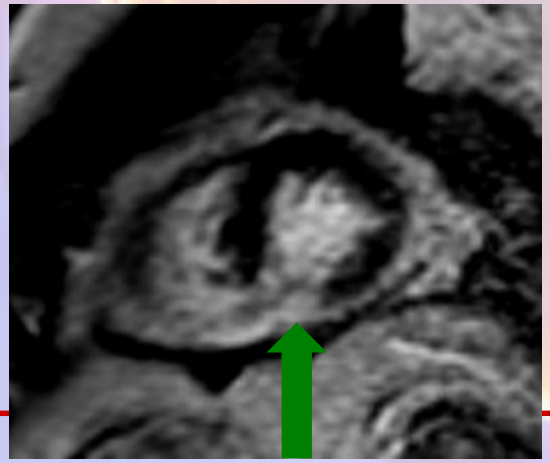


T2w-STIR

Late GE

Plaque disruption and
distal embolization



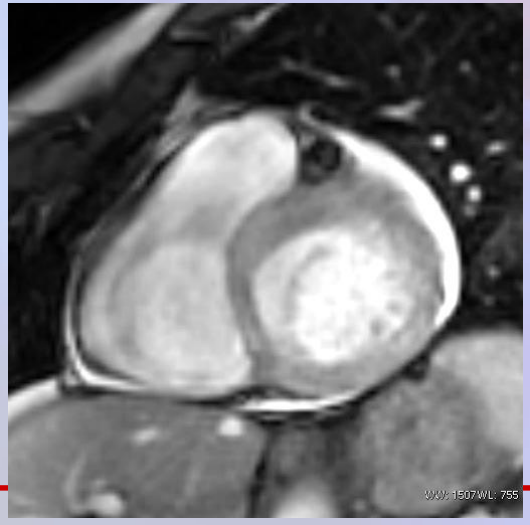


Previous irreversible
Ischemic damage

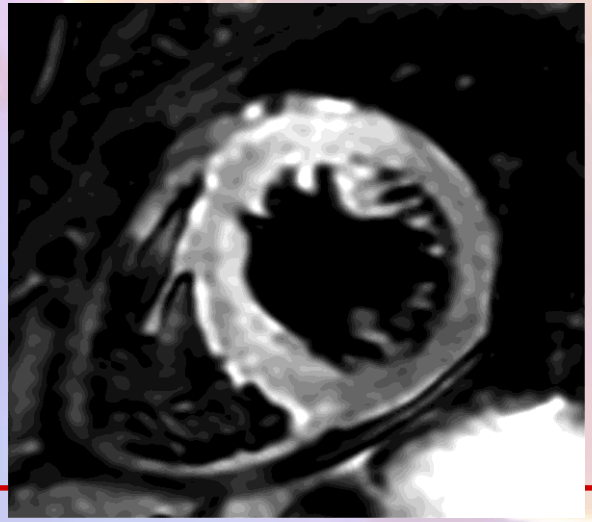
Acute Myocardial Infarction & CMR

63-year old woman with typical chest pain, minimal increment of cTnI, negative T wave in DI & from V2-V5, normal coronary angiograms. Five days after the clinical presentation, the patient was referred to CMR.

Coronary Vasospasm ?



Cine Imaging



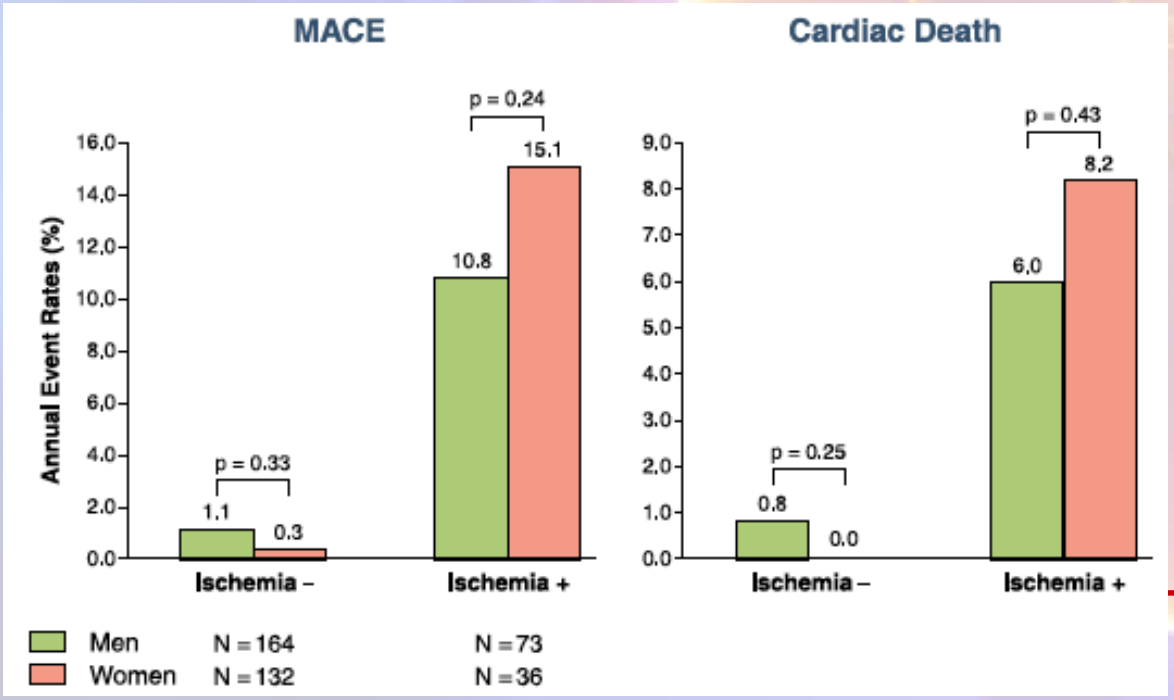
T2-w imaging

Late Gd Enhancement

Stress Myocardial Perfusion Imaging by CMR Provides Strong Prognostic Value to Cardiac Events Regardless of Patient's Sex

Otavio R. Coelho-Filho, MD,* Luciana F. Seabra, MD,* François-Pierre Mongeon, MD,* Shuaib M. Abdullah, MD,* Sanjeev A. Francis, MD,* Ron Blankstein, MD,*† Marcelo F. Di Carli, MD,† Michael Jerosch-Herold, PHD,† Raymond Y. Kwong, MD, MPH*

Boston, Massachusetts



Study Characteristics

- 405 pts (168 women)
- Cine-CMR, MPI-CMR, LGE
- Median FU 30 months (21 cardiac-death, 15 MI)
- Major Adverse Cardiac Events

HR 6.18 (2.07-18.51), P=0.001
For MPI-CMR (+) at multivariate Cox-Regression Analysis

JACC CVI 2011

Intermediate-Term Prognostic Value of Reversible Perfusion Deficit Diagnosed by Adenosine CMR

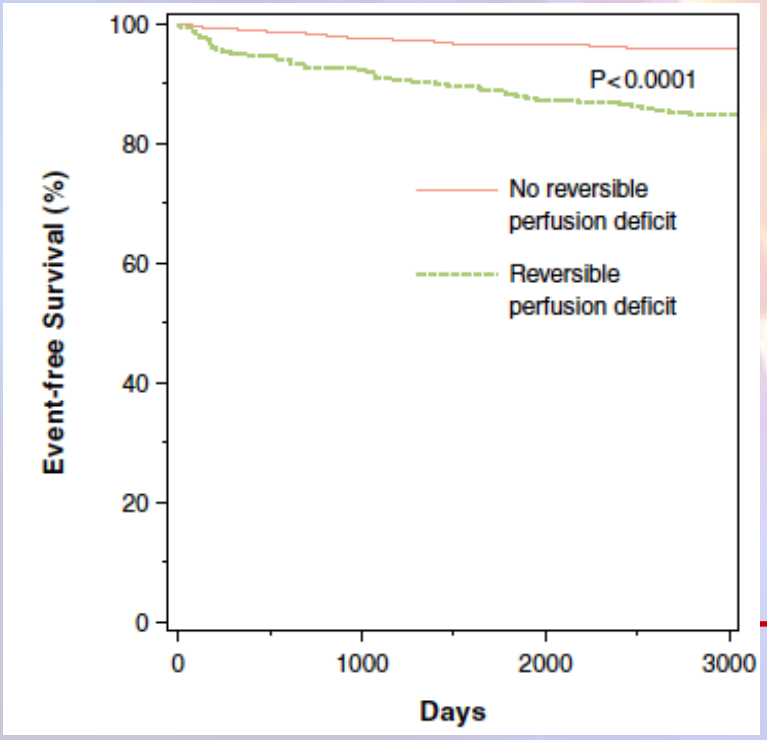
A Prospective Follow-Up Study in a Consecutive Patient Population

Dominik Buckert, MD, Patricia Dewes, Thomas Walcher, MD, Wolfgang Rottbauer, MD, Peter Bernhardt, MD

Ulm, Germany

Study Characteristics

- 1229 pts
- Cine-CMR, MPI-CMR, LGE
- Median FU 4.2 years
- Major Adverse Cardiac Events



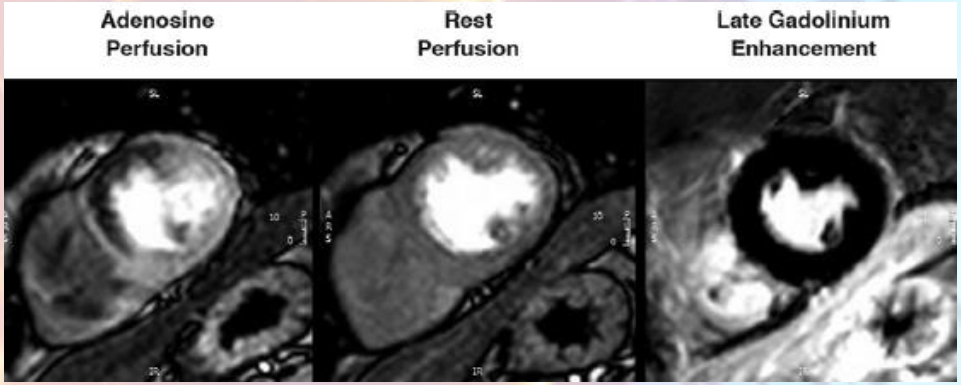


Table 4. Multivariate Analysis of Predictors of the Primary Endpoint

Variable	HR	95% CI	p Value
Age	1.02	1.00–1.05	0.0385
Diabetes mellitus	1.34	1.06–1.67	0.0127
Wall motion score	1.07	0.98–1.09	<0.0001
Reversible perfusion deficit	3.21	2.06–5.00	<0.0001

JACC CVI 2013

obrigado a todos
pela vossa atenção

pgmasci@gmail.com / pier-giorgio.masci@chuv.ch

Centre de RM Cardiaque

Practice Guideline

2012 ACCF/AHA/ACP/AATS/PCNA/SCAI/STS Guideline for the Diagnosis and Management of Patients With Stable Ischemic Heart Disease

Table 11. Stress Testing and Advanced Imaging for Initial Diagnosis in Patients With Suspected SIHD Who Require Noninvasive Testing

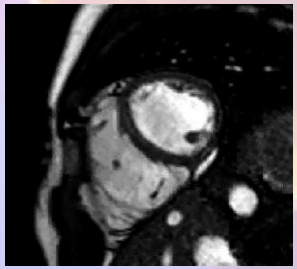
	Exercise Status		ECG Interpretable		Pretest Probability of IHD					
Test	Able	Unable	Yes	No	Low	Intermediate	High	COR	LOE	References
Patients able to exercise*										
Exercise ECG	X		X			X		I	A	(114, 145–147)
Exercise with nuclear MPI or Echo	X			X		X	X	I	B	(91, 132, 148–156)
Exercise ECG	X		X		X			IIa	C	N/A
Exercise with nuclear MPI or Echo	X		X			X	X	IIa	B	(91, 132, 148–156)
Pharmacological stress CMR	X			X		X	X	IIa	B	(153, 157, 158)
CCTA	X		Any			X		IIb	B	(158–166)
Exercise Echo	X		X			X		IIb	C	N/A
Pharmacological stress with nuclear MPI, Echo, or CMR	X		X			Any		III: No Benefit	C	(155, 167, 168)
Exercise stress with nuclear MPI	X		X		X			III: No Benefit	C	N/A
Patients unable to exercise										
Pharmacological stress with nuclear MPI or Echo		X	Any			X	X	I	B	(148–150, 152–156)
Pharmacological stress Echo		X	Any		X			IIa	C	N/A
CCTA		X	Any		X	X		IIa	B	(158–166)
Pharmacological stress CMR		X	Any			X	X	IIa	B	(153, 157, 158, 169–172)
Exercise ECG		X		X		Any		III: No Benefit	C	(91, 132, 148–156, 161)

Circulation 2012

Stress CMR

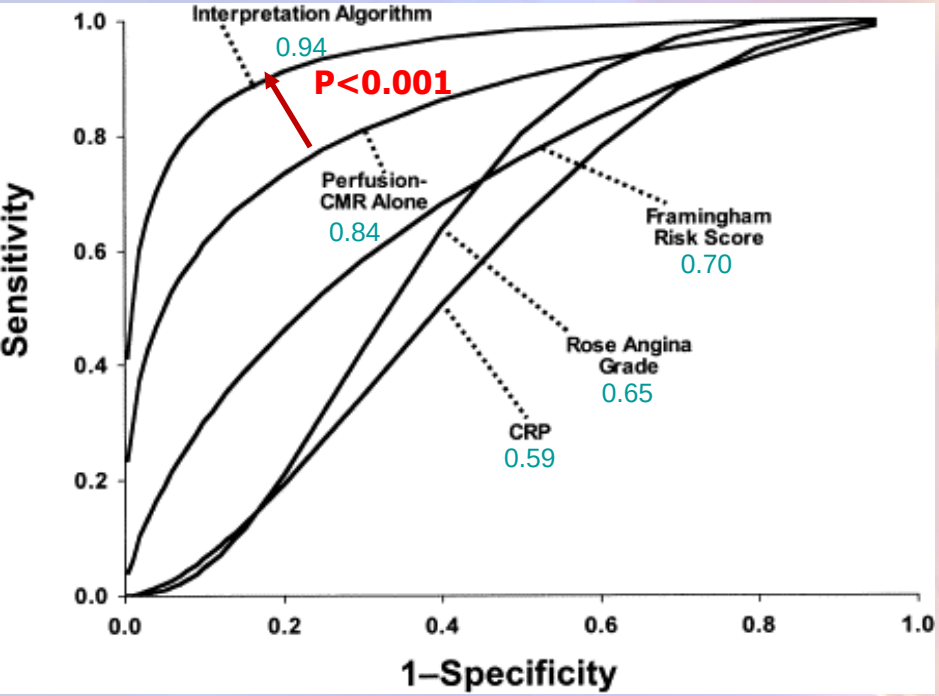
- Myocardial Perfusion Imaging

- Dobutamine Stress CMR

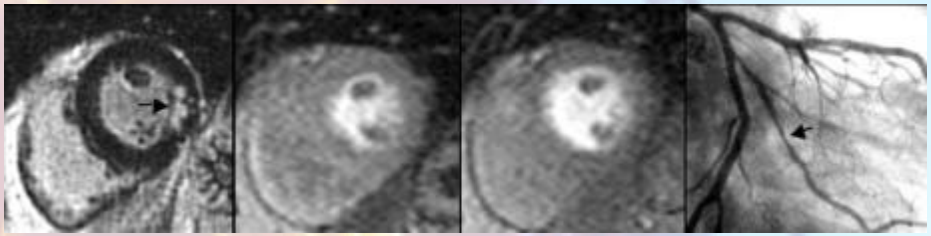


- Exercise Stress CMRI

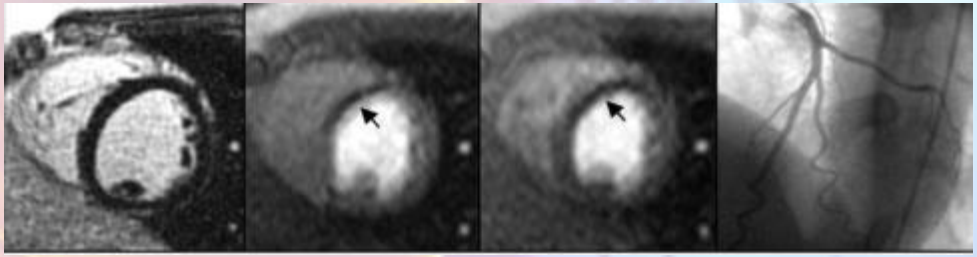
Myocardial Perfusion Imaging By Cardiovascular MR



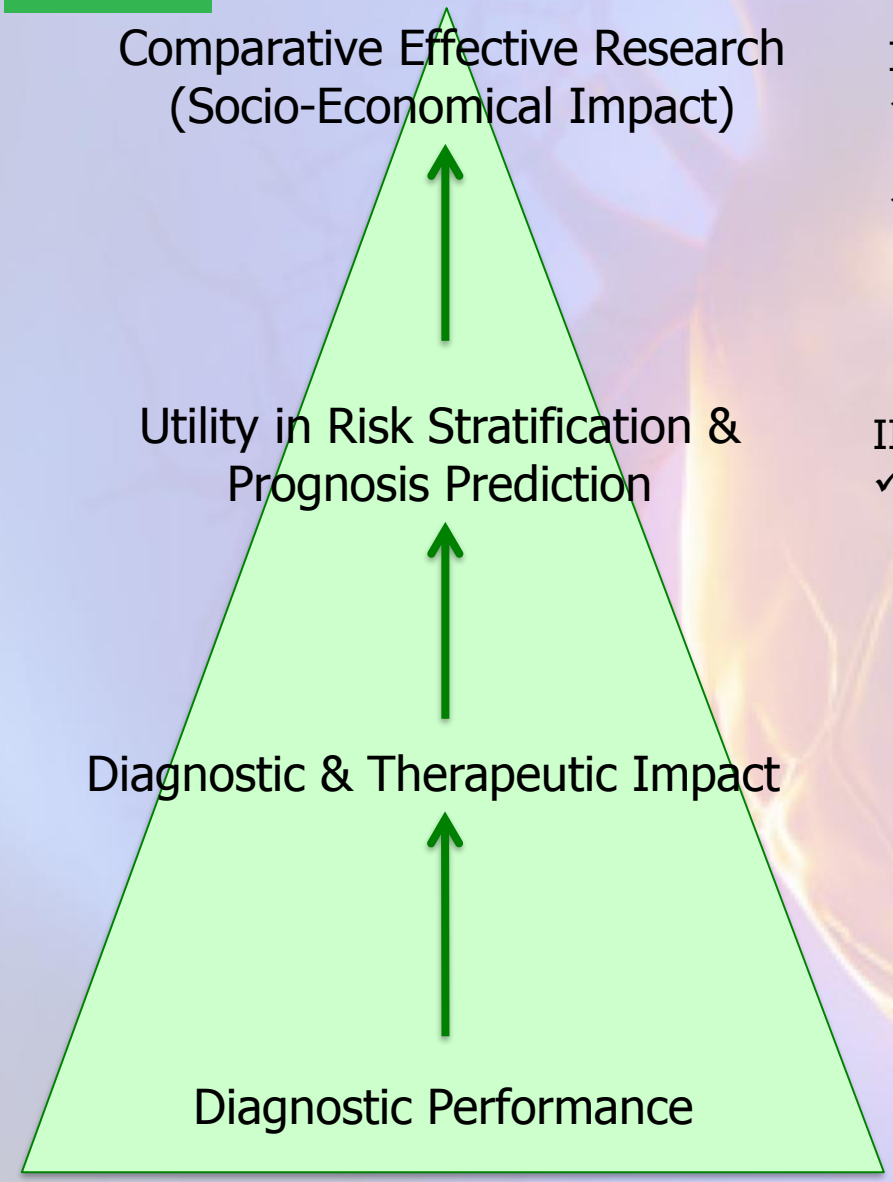
(Se 84% vs 89%)



(Sp 58% vs 87%)



Klem et al. J Am Coll Cardiol 2006



IV. Optimized Test Effectiveness Strategy
- ✓ Compare Effectiveness of 2 or more imaging driven strategies with a RCT
- ✓ Cost-Effectiveness

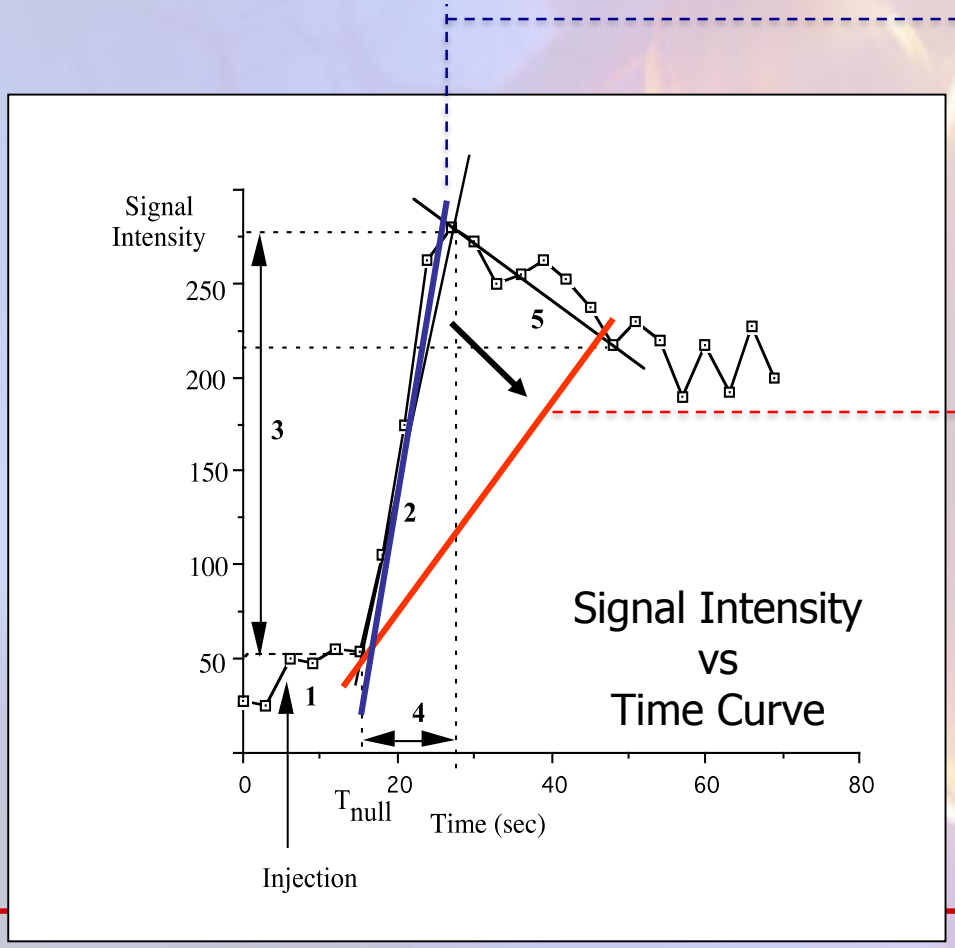
III. Prognostic Utility
- ✓ Accuracy of imaging marker in detecting hard clinical end-points with ADDITIVE/INDEPENDENT value respect clinical/other risk algorytms

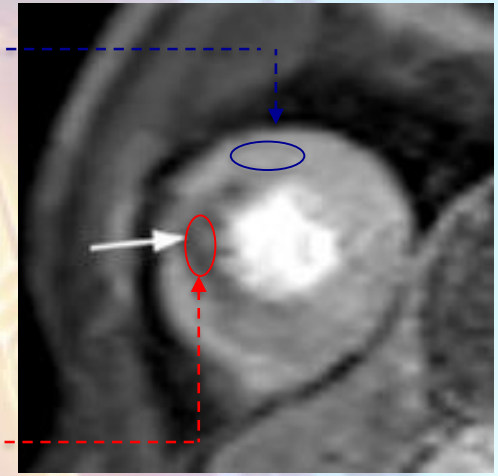
II. Diagnostic & Therapeutic Impact
- ✓ Relationship between imaging markers of ischemia & MD decision making / therapeutic interventions

I. Diagnostic Performance
- ✓ Technical Aspects
- ✓ Accuracy in detecting obstructive CAD

Myocardial Perfusion Imaging By Cardiovascular MR

Semiquantitive Analysis



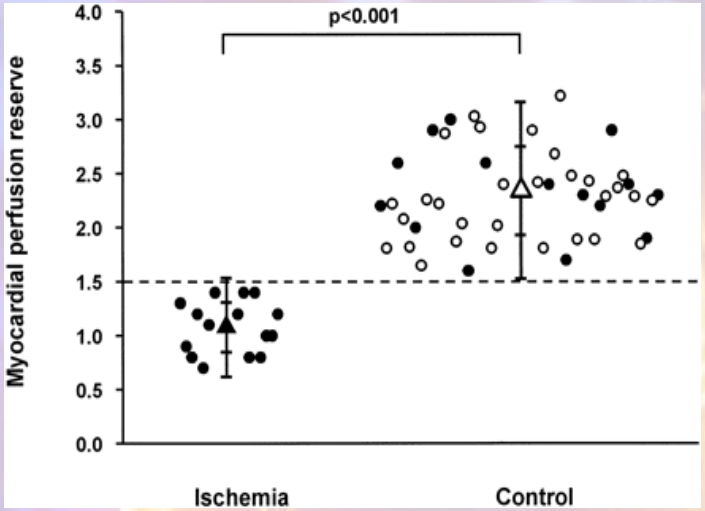


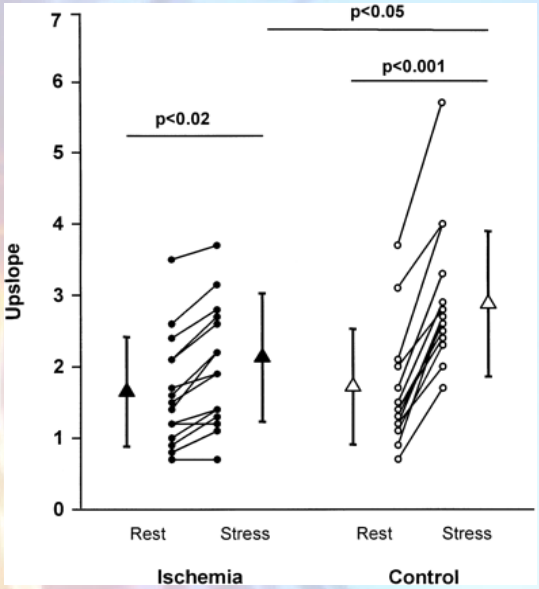
1 - Time to start
2 - Upslope (linear-fit≠γ-fit)
3 - Signal Intensity Increase
4 - Time to peak
5 - Downslope

Myocardial Perfusion Imaging By Cardiovascular MR

Myocardial Perfusion Reserve (MPR)

$$\frac{\text{Upslope}_{(corr)}\ \text{stress}}{\text{Upslope}_{(corr)}\ \text{rest}}$$





MPR: cut off value:1.5

- Nl segments: 2.33 ± 0.41
- Ischemic segments: 1.08 ± 0.23

Se: 90 % / Sp: 83% / Acc: 87% (CA stenosis ≥ 75%)

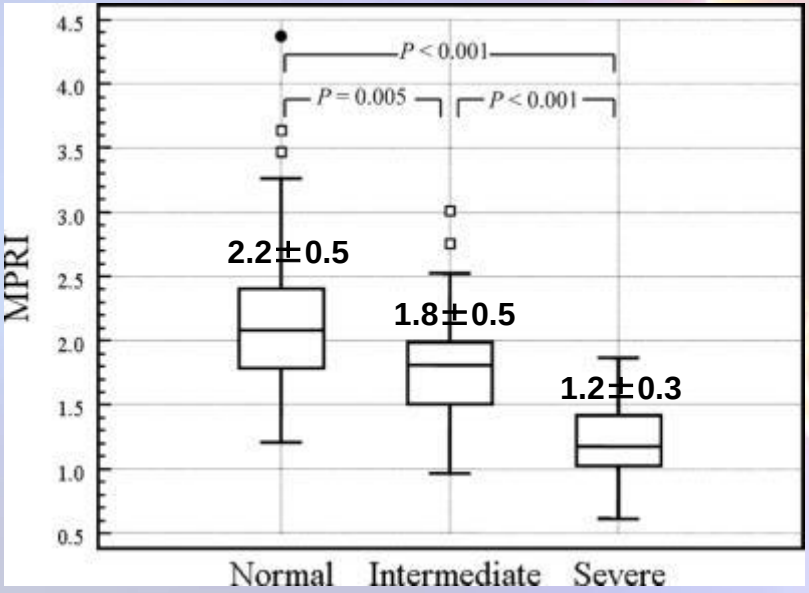
Al-Saadi et al. Circulation 2000

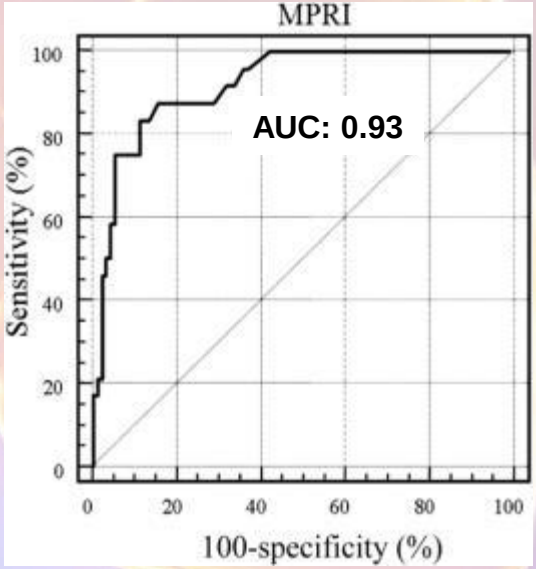
Myocardial Perfusion Imaging By Cardiovascular MR

Normal (coronary stenosis < 50%)
Intermediate (stenosis > 50% & FFR >0.75)
Severe (stenosis > 50% & FFR ≤0.75)

→ non-relevant

→ relevant (severe)





Cut-Off MPRI 1.5

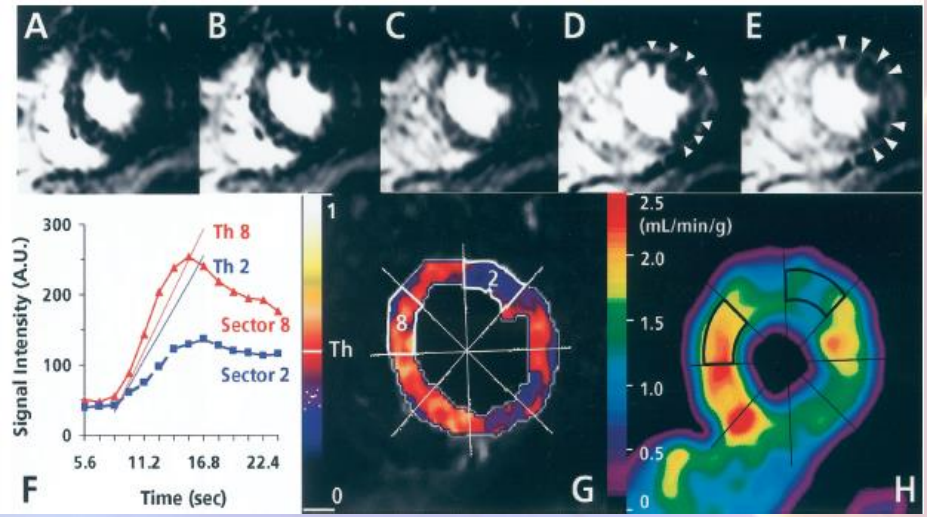
Sensitivity 88%
Specificity 90%

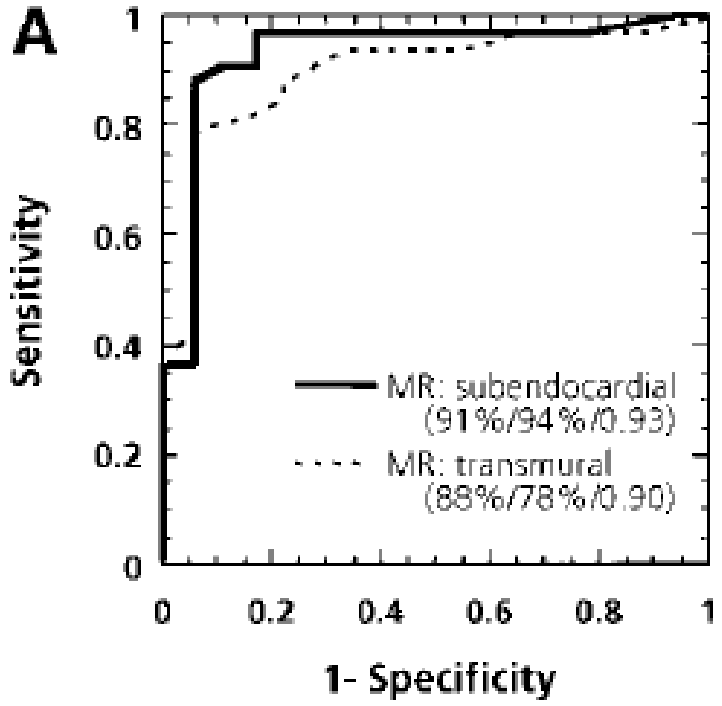
Rieber et al. Eur Heart J 2006

Assessment of Myocardial Perfusion in Coronary Artery Disease by Magnetic Resonance

A Comparison With Positron Emission Tomography and Coronary Angiography

J. Schwitter, MD; D. Nanz, PhD; S. Kneifel, MD; K. Bertschinger, MD; M. Büchi, MD; P.R. Knüsel, MD; B. Marincek, MD; T.F. Lüscher, MD; G.K. von Schulthess, MD, PhD





Modality	Se	Sp
Subendocardial	91	94
Transmural	88	78

*, § P<0.05

Circulation 2001

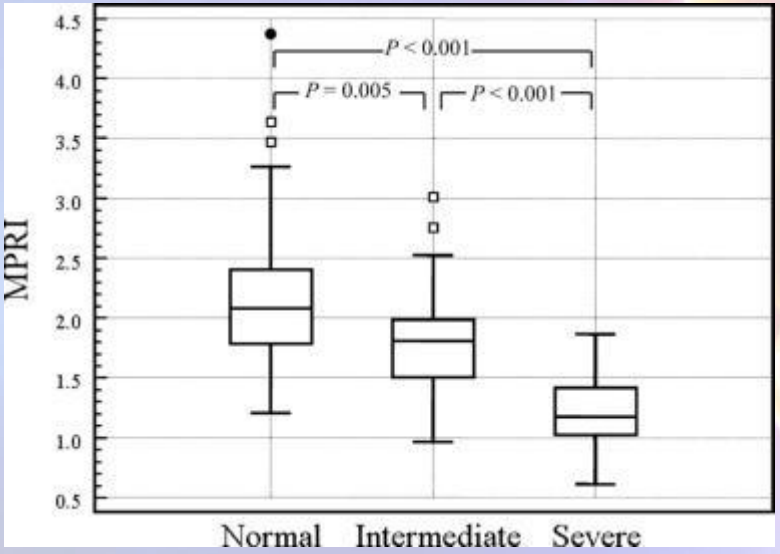
Myocardial Perfusion Imaging

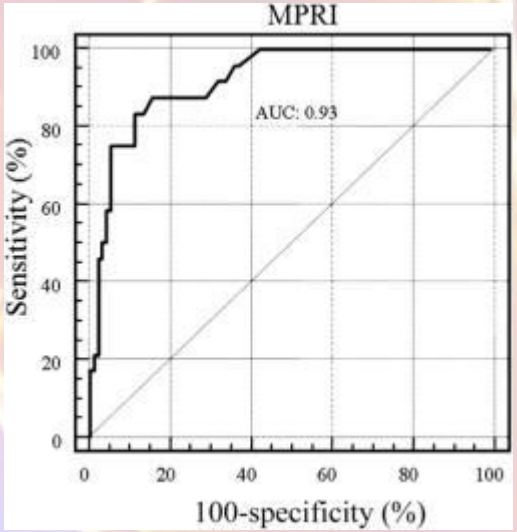
MR-MPI vs CXA + FFR

Normal (coronary stenosis < 50%)
Intermediate (stenosis > 50% - FFR > 0.75)
Severe (stenosis > 50% - FFR ≤ 0.75 or TO)

→ non-relevant

→ relevant (severe)





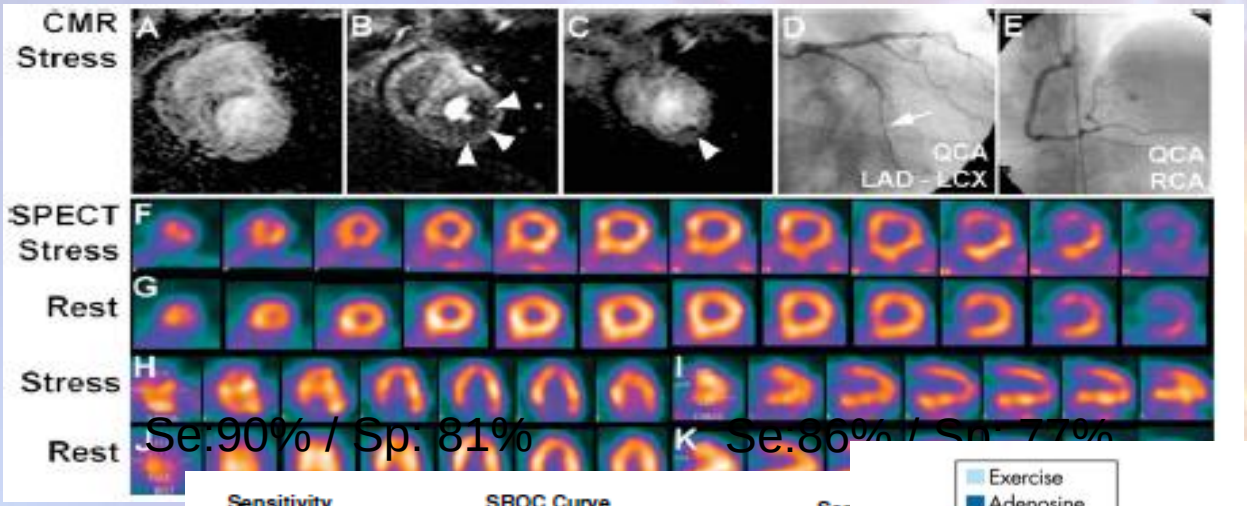
Cut-Off MPR 1.5

Sensitivity 88%
Specificity 90%

Rieber et al. Eur Heart J 2006; 27:1465-1471

-First Pass Perfusion Cardiac MRI-
-Diagnostic Performance -

Myocardial Perfusion Imaging



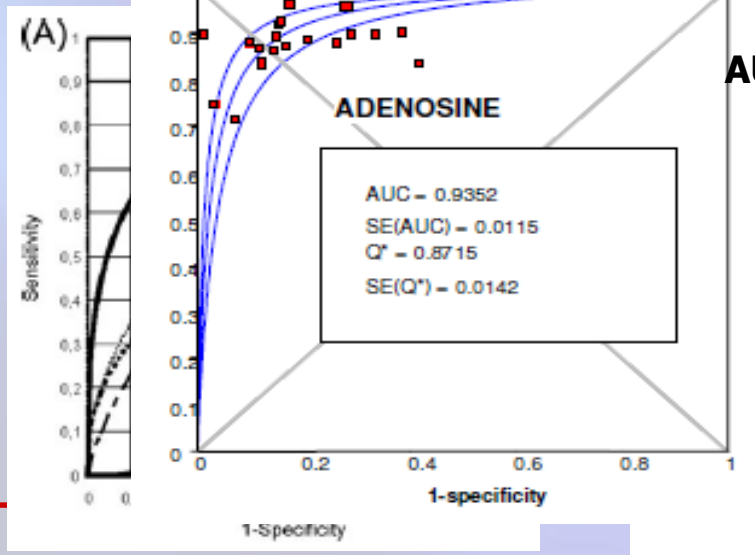
MR-IMPACT trial

234 pts in 18 centers referred to CA for clinical reason

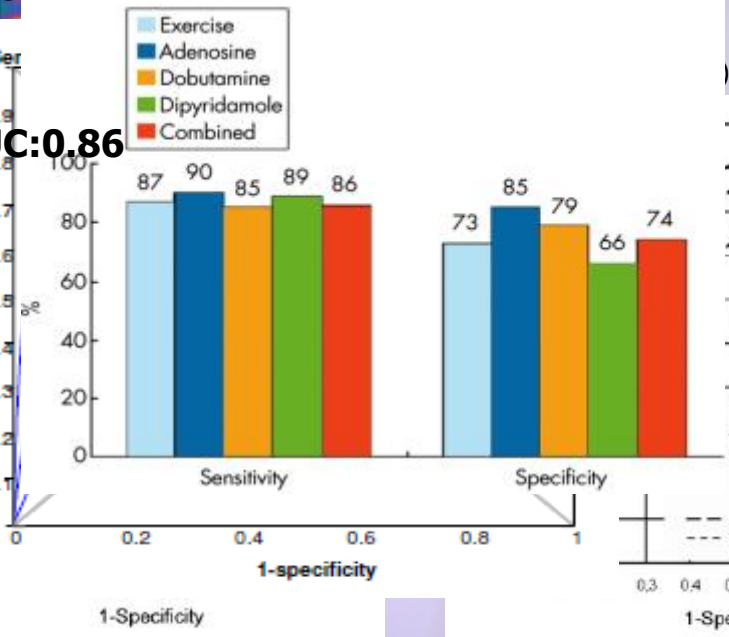
(Cardiac MRI vs SPECT)

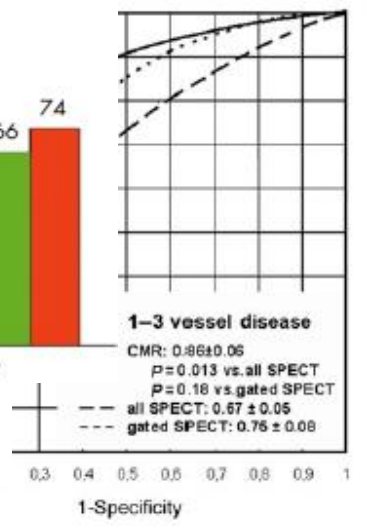
(CA stenosis ≥50% in Vessel > 2mm)

vs SPECT$_{(all)}$

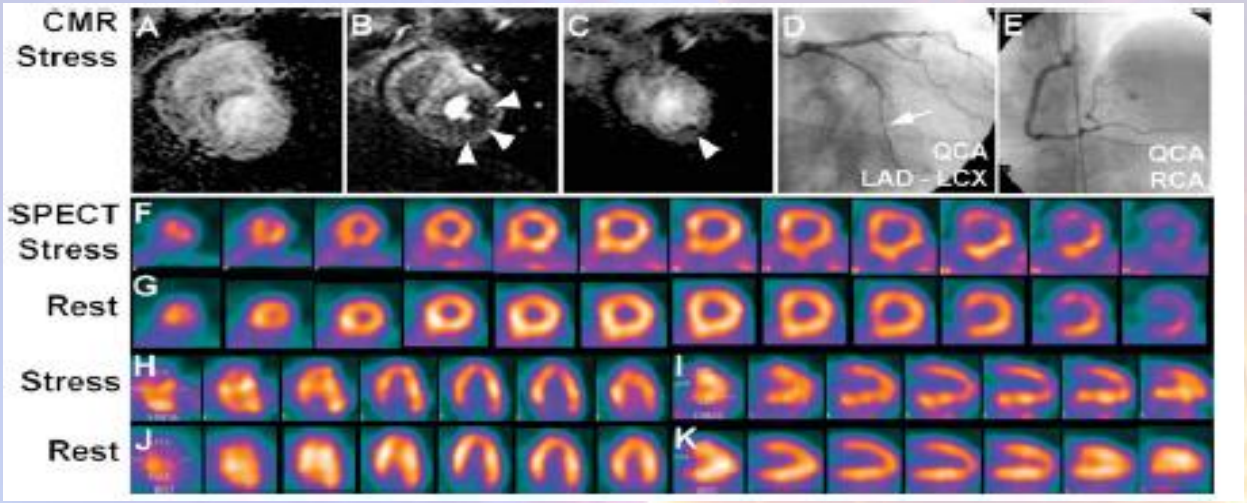


AUC:0.86





Diagnostic Performance



MR-IMPACT trial

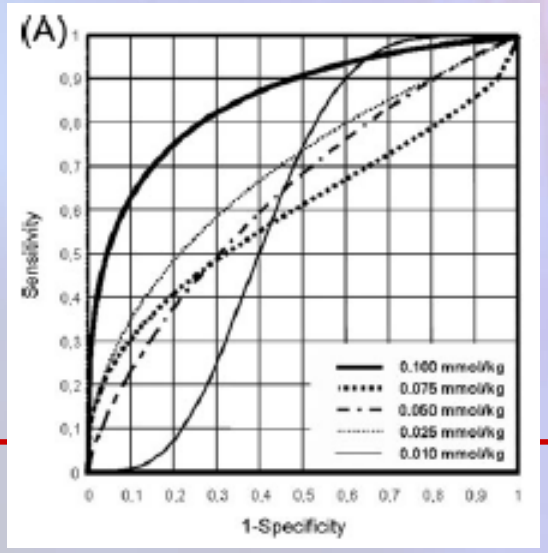
234 pts in 18 centers referred to CA for clinical reason

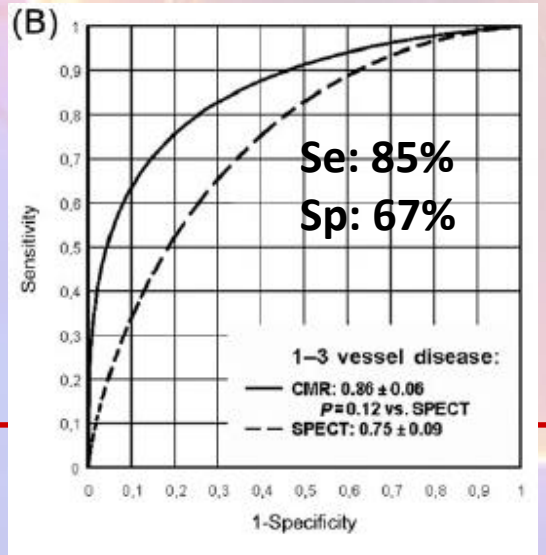
(CMR vs SPECT)

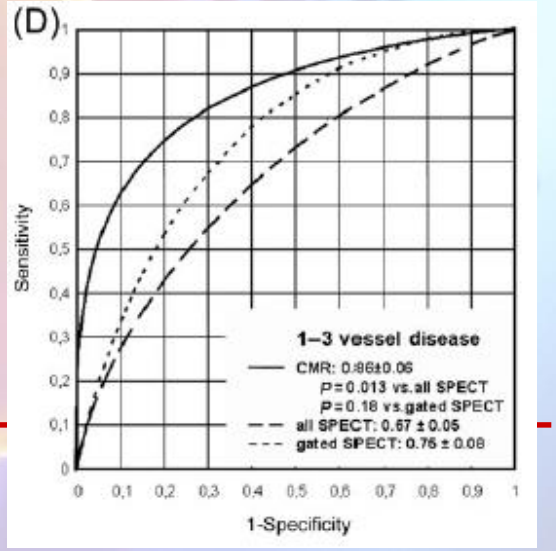
(CA stenosis ≥50% in Vessel > 2mm)

MRI $_{(0.1\ mmol/kg)}$ vs SPECT $_{(all)}$

Head-to-head $_{(n=42)}$

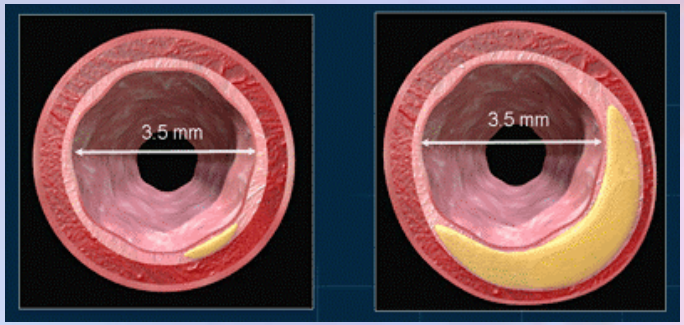






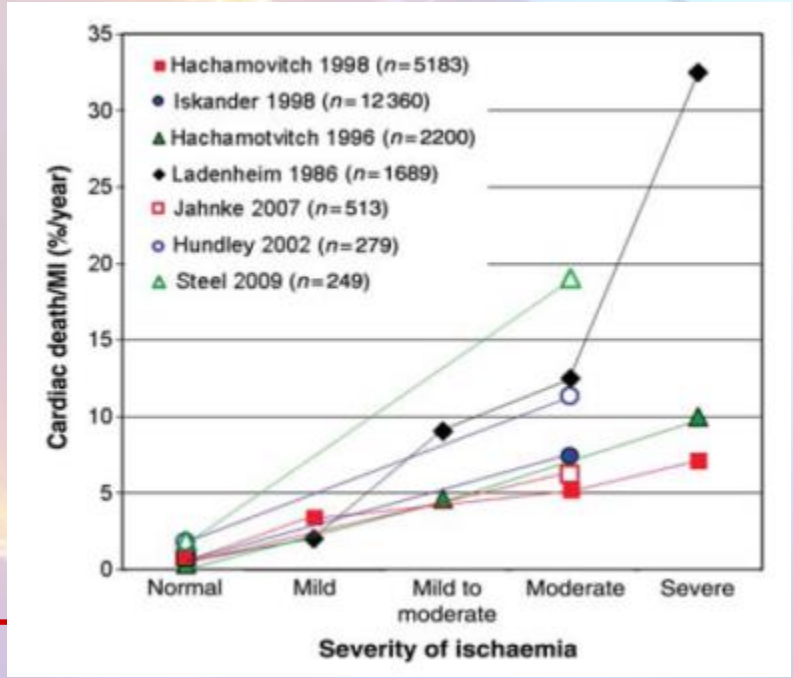
Myocardial Perfusion Imaging

Coronary Angiography CANNOT provide information about the functional consequences of coronary stenosis



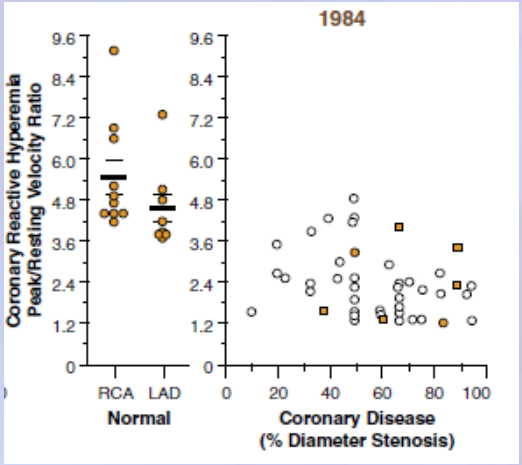
Only luminography ('silhouette image')

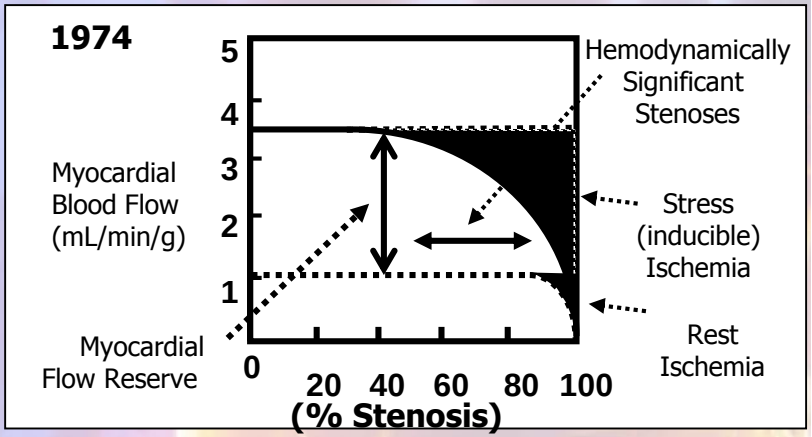
The degree of ischemia rather than 'anatomical' stenosis herald adverse cardiac events

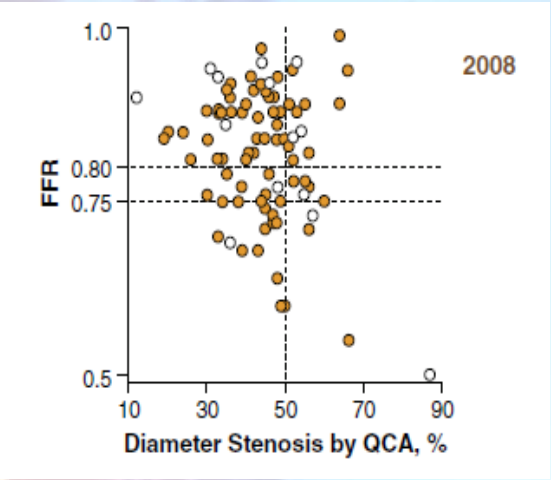


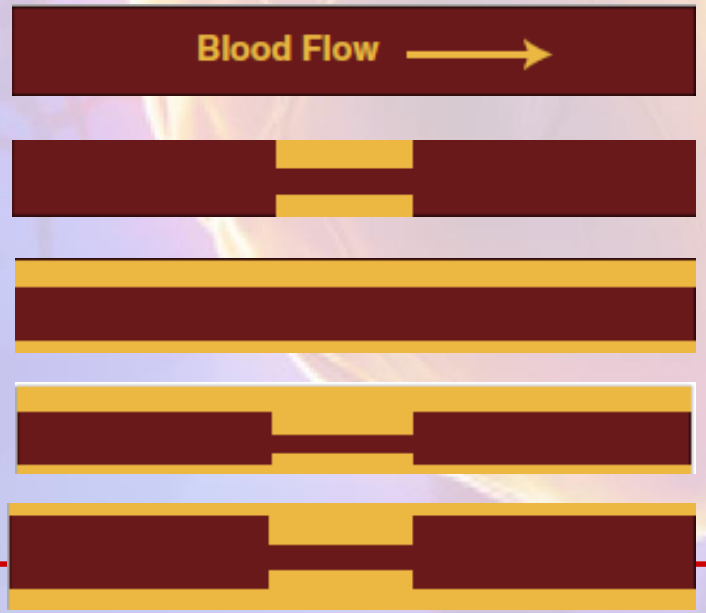
Myocardial Perfusion Imaging

-Coronary Function vs Anatomy –
- Flow vs Stenosis-









QCA: 0/CFR=4.0

QCA: 60%/CFR=3.4

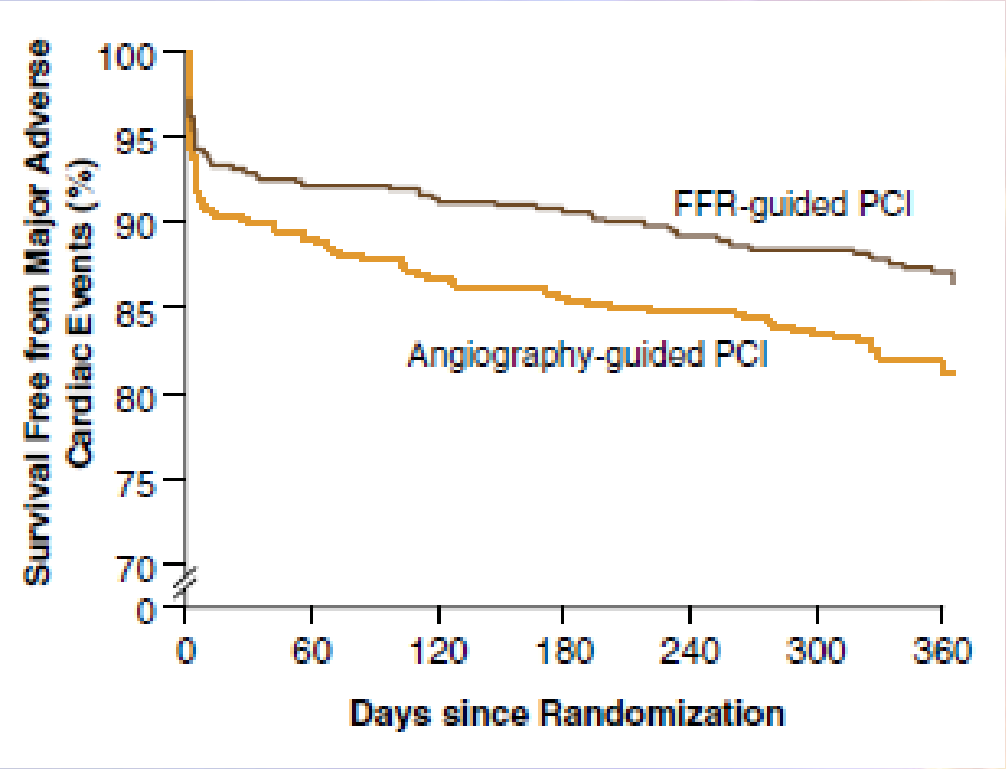
QCA: 0%/CFR=1.4

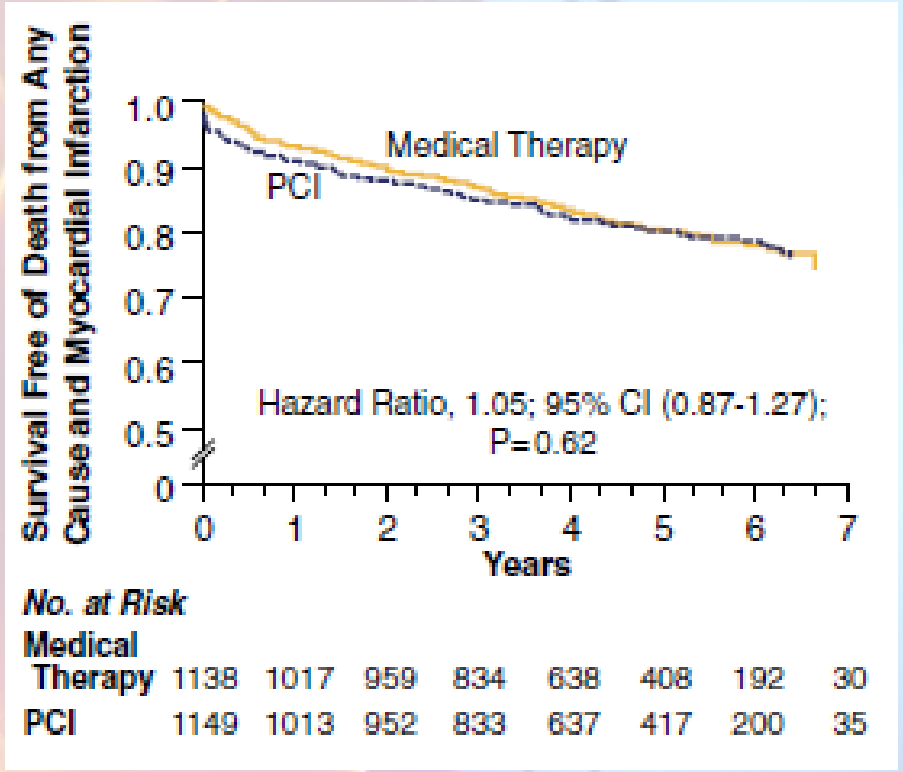
QCA: 60%/CFR=1.0

QCA: 60%/CFR=3.5

Myocardial Perfusion Imaging

-Coronary Function vs Anatomy –
- Flow vs Stenosis-





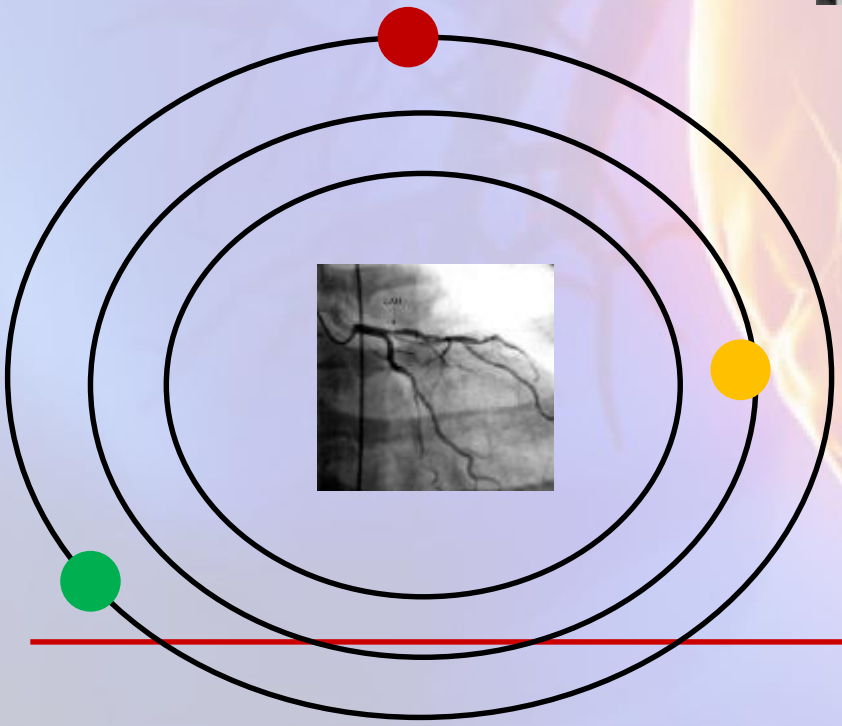
Tonino et al NEJM 2009

Boden et al NEJM 2007

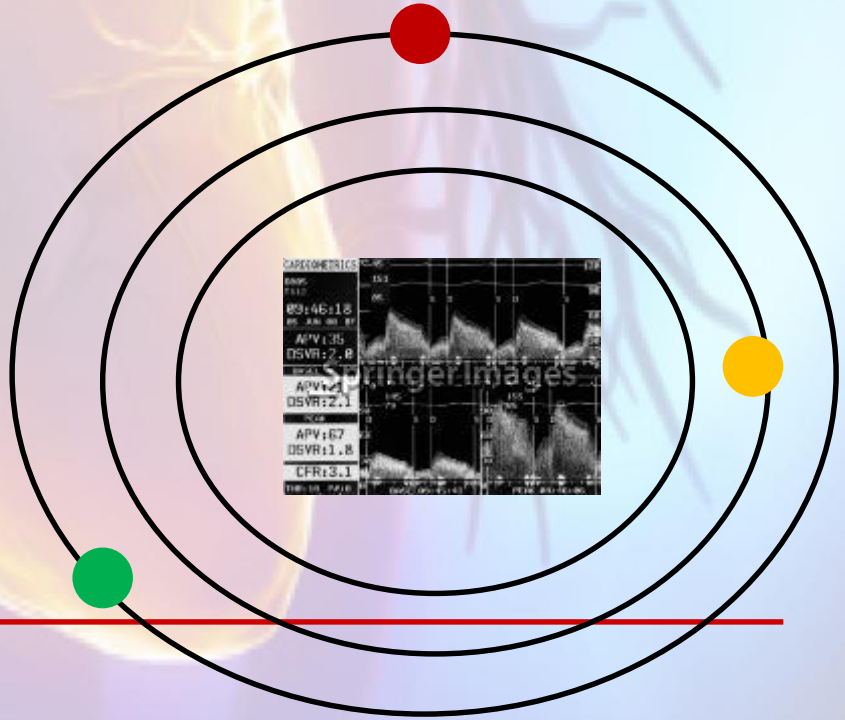
Myocardial Perfusion Imaging

-Coronary Function vs Anatomy –
- Flow vs Stenosis -

Anatomically-driven revascularization

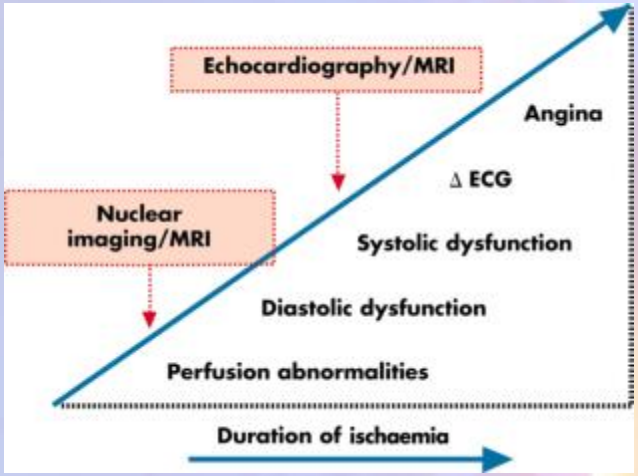


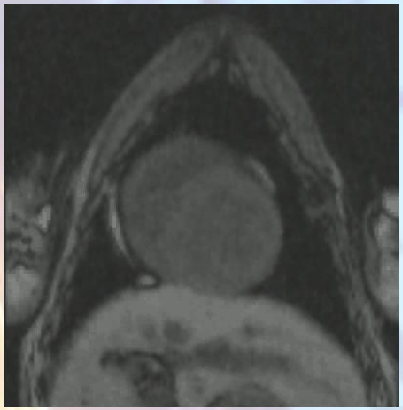
Physiologically-driven revascularization



Myocardial Perfusion Imaging

-First Pass Perfusion Cardiac MRI-

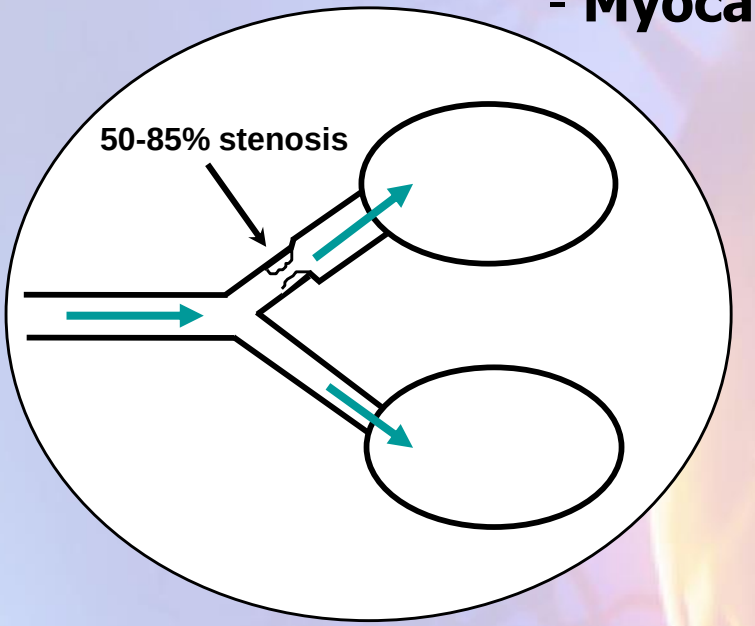




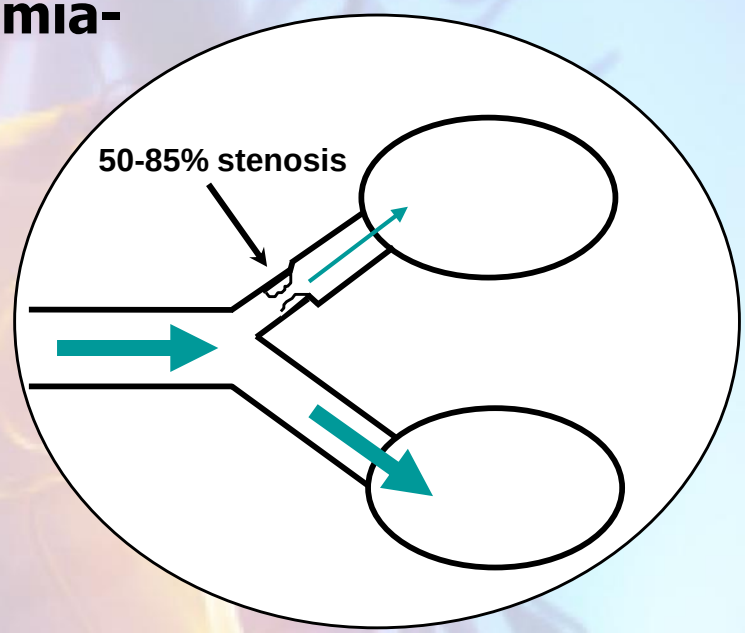
1. **Myocardial hyperemia**
2. **Pulse Sequence**
3. **Protocol**
4. **Image Analysis**
5. **Diagnostic Performance**

Myocardial Perfusion Imaging

-First Pass Perfusion Cardiac MRI-
- Myocardial Hyperemia-



Rest



Vasodilating Agent

Adenosine i.v. (140 µg/kg/minute for 6 min)

Adenosine induces vasodilatation A2 receptors on smooth muscle

Maximal vasodilation of normal vessels

No dilation of stenotic vessels => steal-effect

Inducible Myocardial Ischemia

Mechanisms

- **DIRECT** effect inducing maximal hyperemia at 3-4 min of iv infusion 140 mg/kg/min (protocol 6 min)
- **Coronary Steal**
- Half-life **(< 10 sec)**. No need of antidote
- Modest increase of workload (blood pressure product)

Side-Effects

- Facial flushing (35%), chest pain (33%), headache (21%) and dyspnea (19%)
- Transient AV block (III degree in 0.8%)
- Severe bronchospasm (0.08%)
- Myocardial infarction (0.01%)
- Death (0.009%)

Contraindication II-III degree AV block, sick-sinus syndrome & asthma

Myocardial Perfusion Imaging

-First Pass Perfusion Cardiac MRI-
- Pulse Sequence -

High Spatial Resolution
(extent of perfusion defect)

High Temporal Resolution
(SI vs Time curve/motion artficacts)

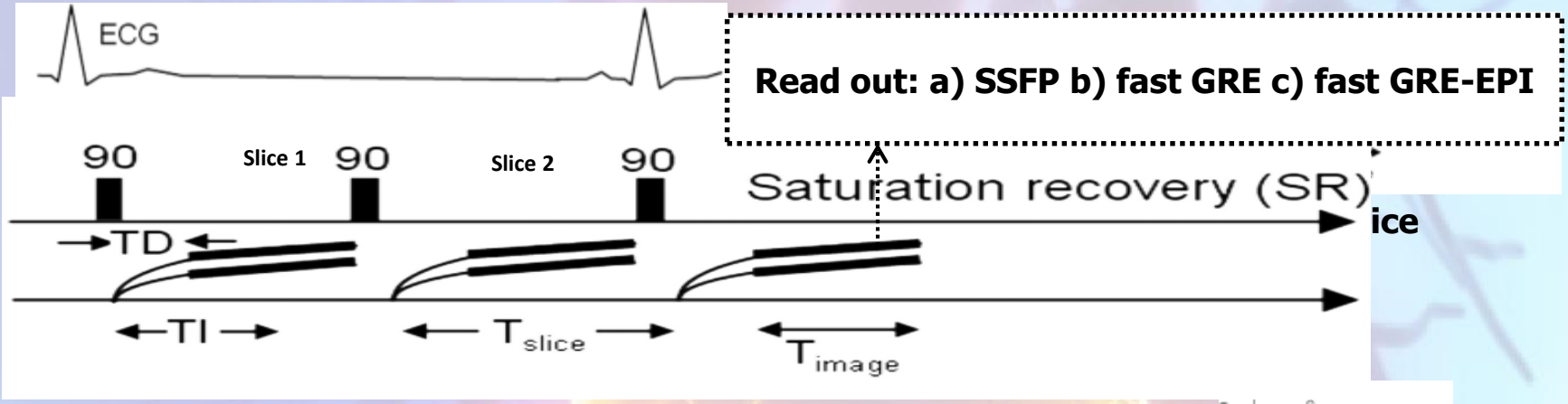
Accuracy & Reproducibility
↕
High Image Quality

Good coverage of LV

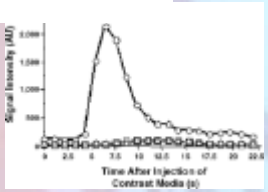
High SNR & CNR
(perfusion defect visualization)

Myocardial Perfusion Imaging

-First Pass Perfusion Cardiac MRI-
- Pulse Sequence-



1.The time between the frames of the same slice ⟷



2. Time per slice acquisition (T_{slice}) ⟷ LV coverage

3. The time per readout ($T_{imaging}$) ⟷ Motion artifacts

4.Spatial resolution (< 3mm in plane)

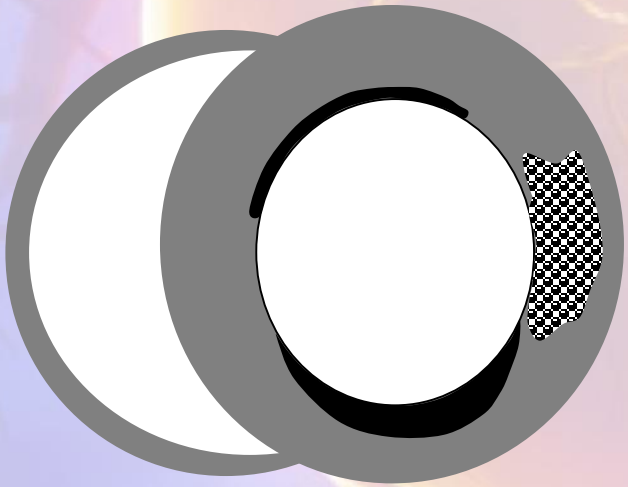
5. LV coverage (at least 3 short-axis slices for 16-segment AHA model)

Myocardial Perfusion Imaging

-First Pass Perfusion Cardiac MRI-
- Dark-rim Artifacts -

1. Cardiac motion during T_{image} (matrix size, SENSE, cardiac phase)
2. Gibb's ringing at sub-endocardium (CM dose/infusion rate/spatial res/SSFP)
3. Partial Volume effects (blood and myocardium off-resonance)
4. Magnetic Susceptibility (» SSFP) & T2* effect (at high CM dose)

LAD: stripe-like



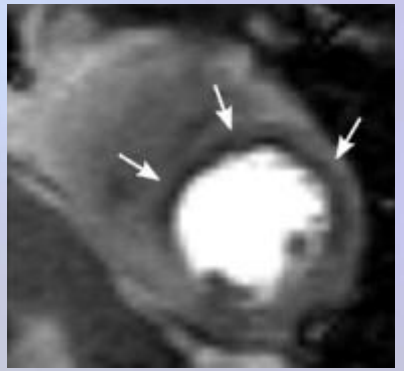
LCx: speckled (salt & pepper)

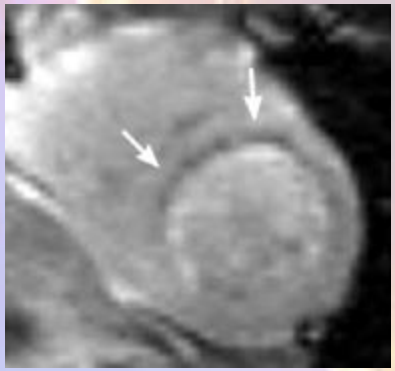
RCA: crescent-like

Myocardial Perfusion Imaging

-First Pass Perfusion Cardiac MRI-
- Dark-rim Artifacts -

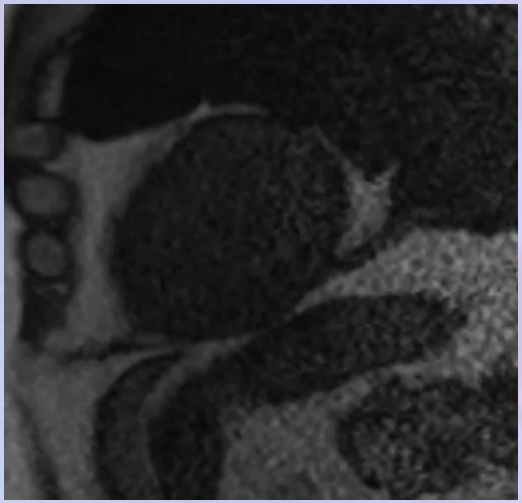
Time

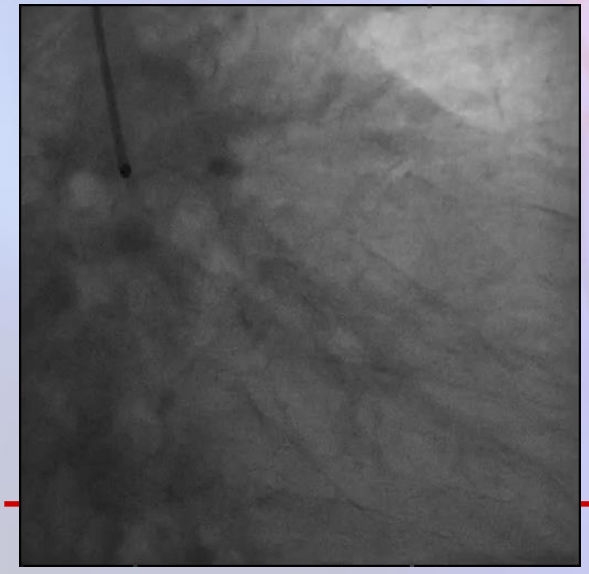


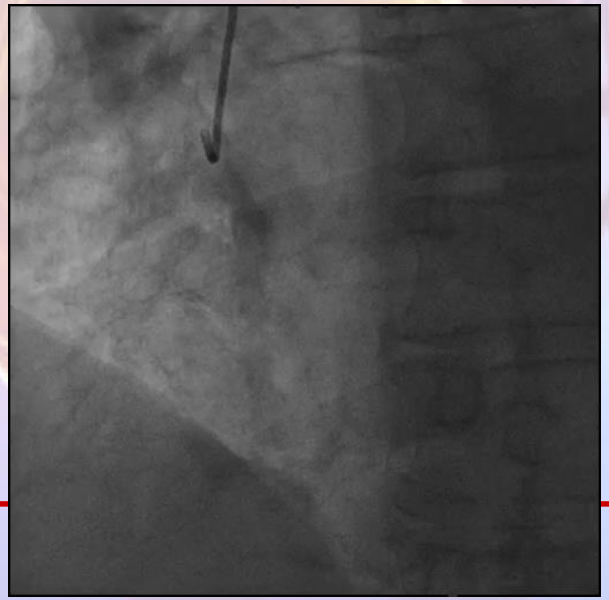


Dark-rim	**Perfusion-Defect**
Short-lasting (second-pass)	Persisting
Starts CM arrives in LV cavity	Starts when CM arrives myocardium
» Hyperemia	» Hyperemia
SI <baseline SI	SI> baseline SI
may superimpose to true perfusion defect	

Myocardial Perfusion Imaging

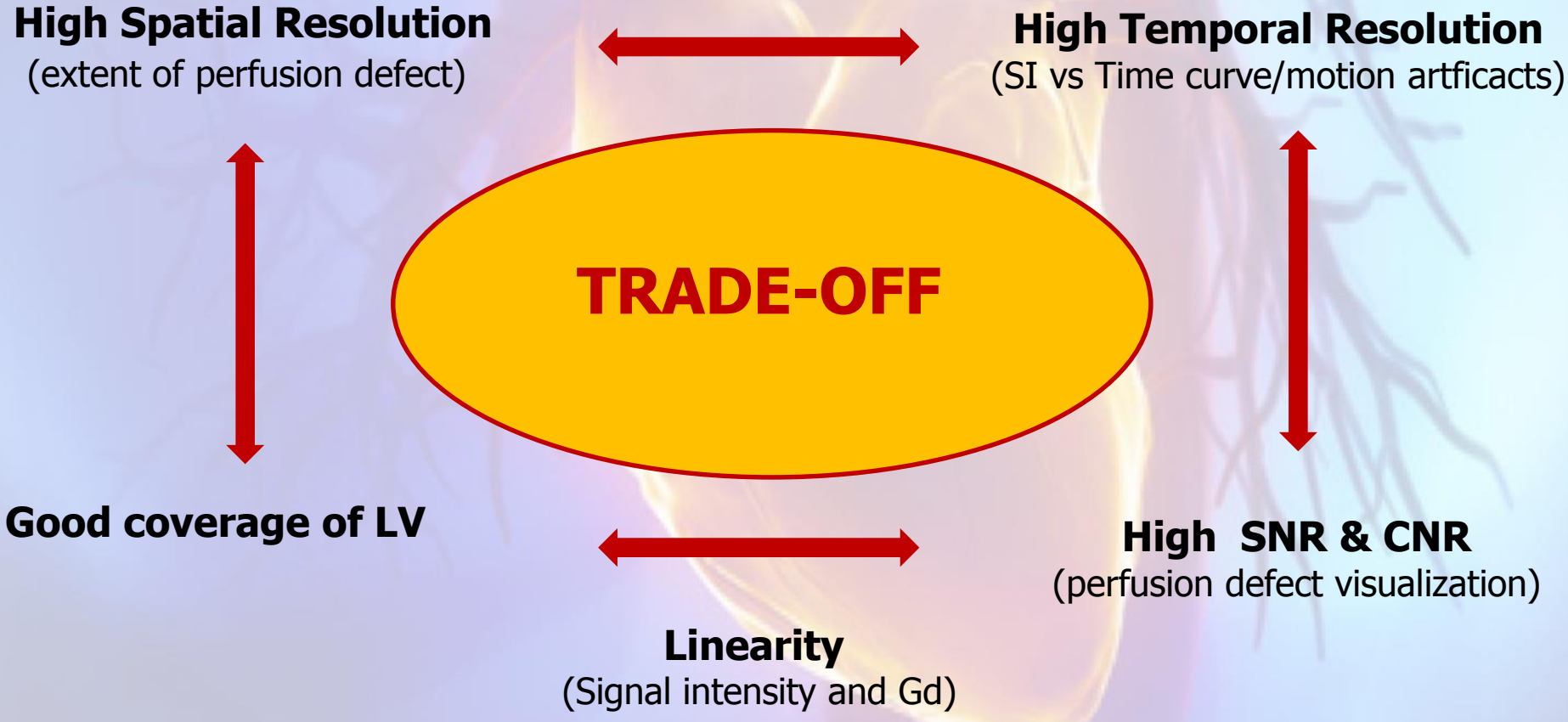






Myocardial Perfusion Imaging

-First Pass Perfusion Cardiac MRI-
- Pulse Sequence -



Myocardial Perfusion Imaging

-First Pass Perfusion Cardiac MRI-
- Pulse Sequences -

T1-weighted sequence

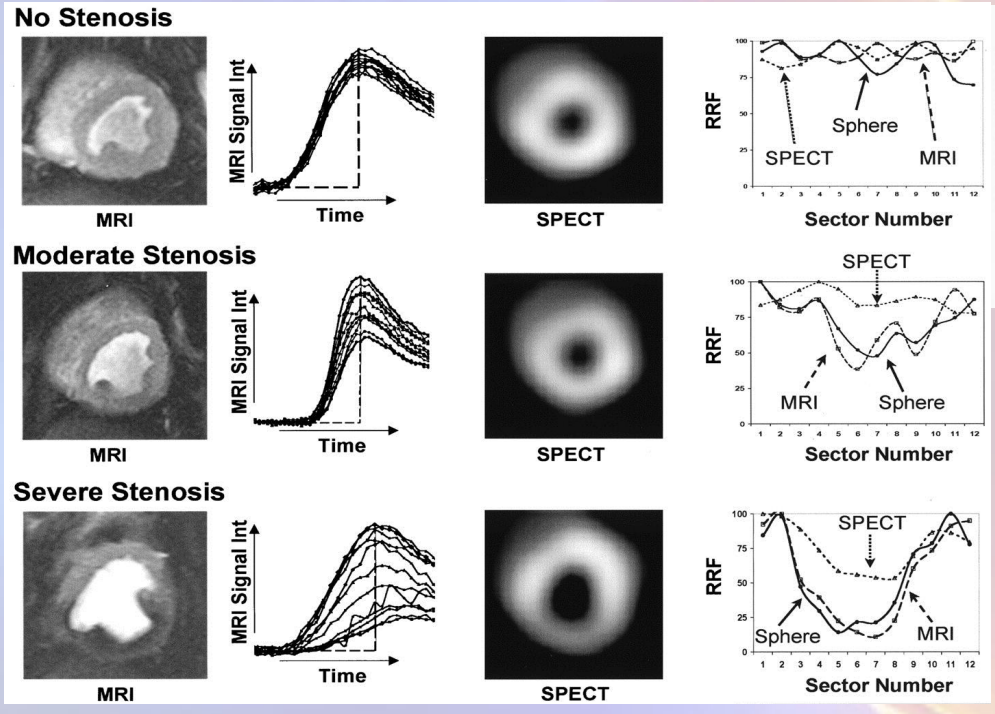
Method	SR-SSFP	SR-FLASH	SR-GRE-EPI
TE (ms)	1.1	1.3	1.1 (TE1)
TR (ms)	2.3	2.2	6.1
BW (Hz/pixel)	1400	780	1630
Echotrain length	1	1	4
Readout Flip Angle	50	12	25
Matrix	128 × 80	128 × 80	128 × 80
Parallel Imaging	R = 2	R = 2	R = 2
TD (ms) (to 1st line)	39	41	54
TI (ms) (to center)	85	85	85
$T_{imaging}$ (ms)	92	88	61
T_{slice} (ms) (total)	132	130	117
Slices per RR @ 60/90/120 bpm	7/5/3	7/5/3	8/5/4

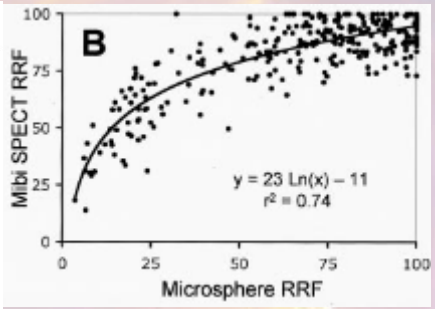
Trade-off spatial/temporal resolution, SNR&CNR and LV coverage (N° slices)

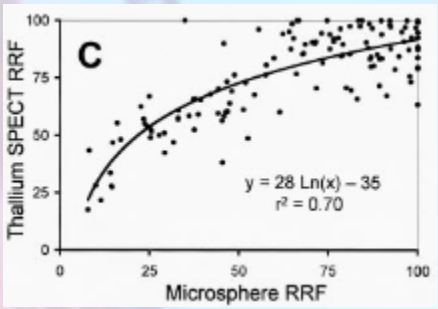
Myocardial Perfusion Imaging

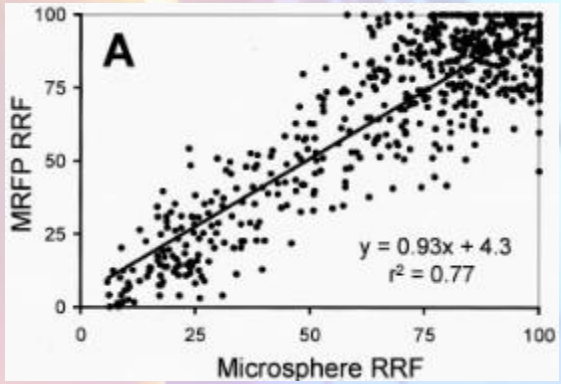
-First Pass Perfusion Cardiac MRI-
- Diagnostic Performance -

Cardiac MRI versus ^{99}Tc- and ^{201}Tl SPECT





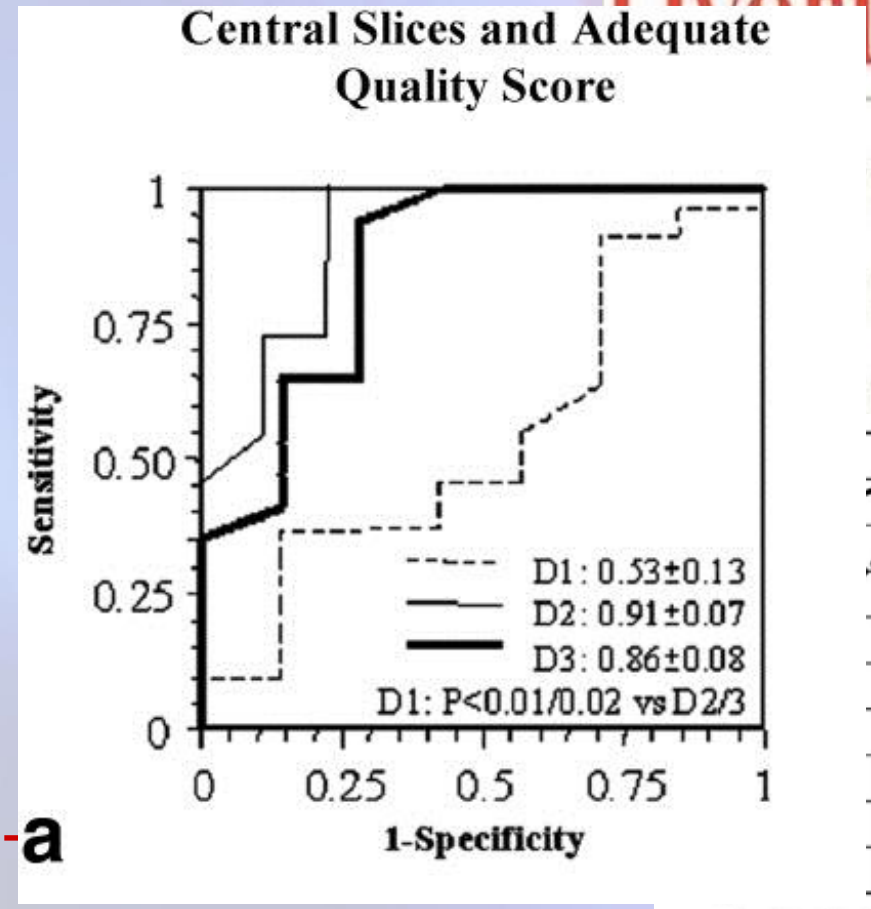


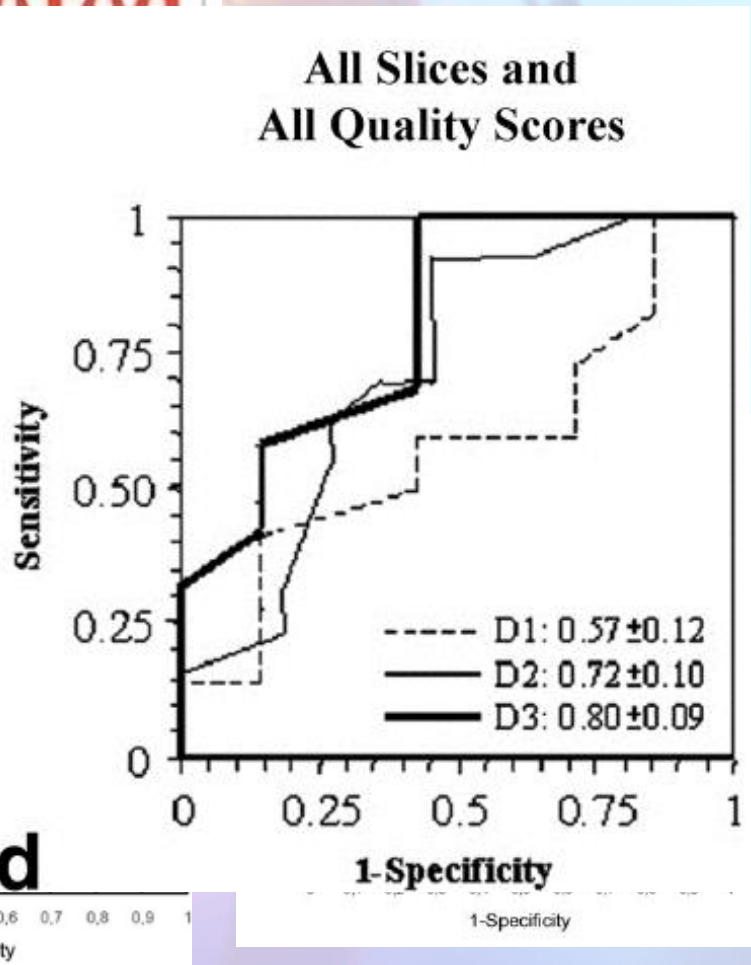


Lee et al. Circulation 2004

Myocardial Perfusion Imaging

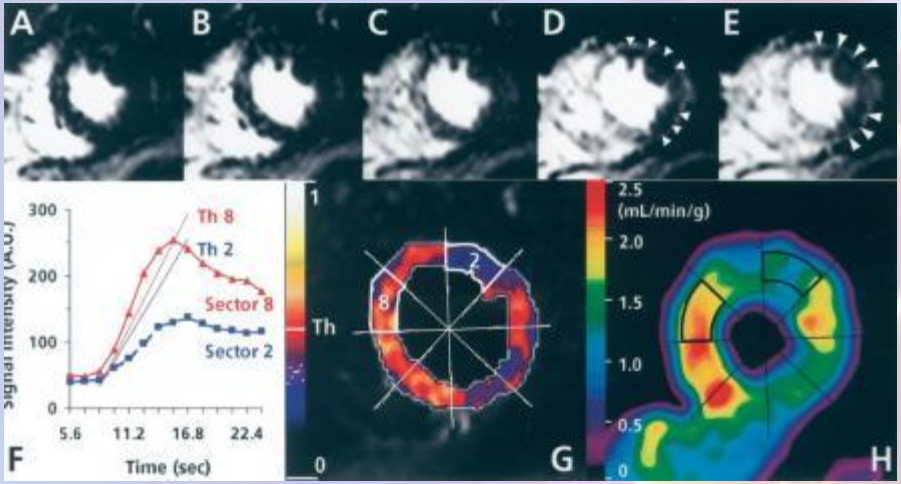
-Coronary Function vs Anatomy –
- Flow vs Stenosis -

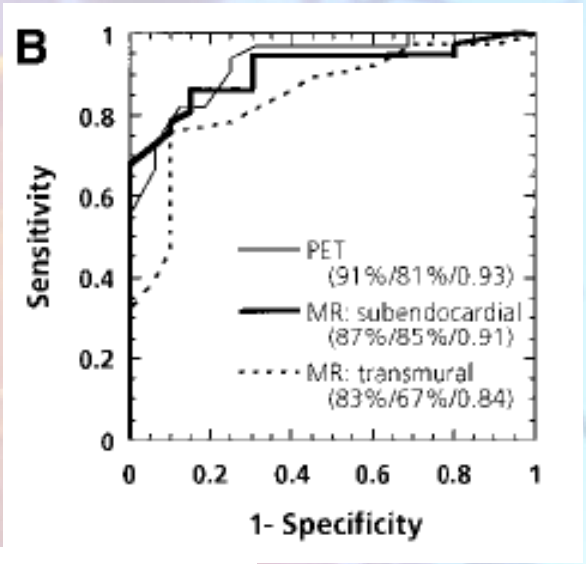


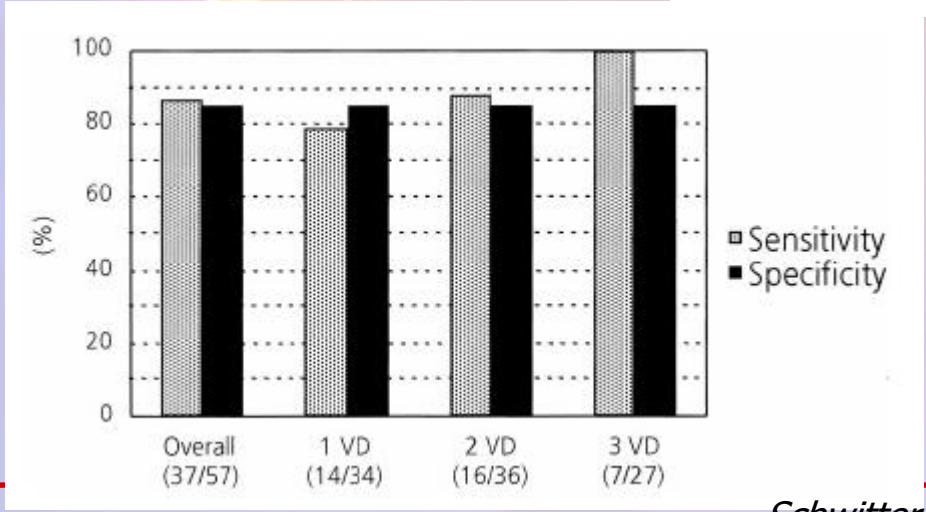


Myocardial Perfusion Imaging

-First Pass Perfusion Cardiac MRI-
- Diagnostic Performance -







Schwitter et al. Circulation 2001

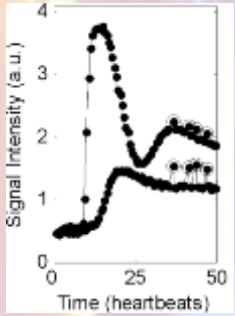
Myocardial Perfusion Imaging

-First Pass Perfusion Cardiac MRI-
- Image Analysis -

Qualitative visual

Semi-quantitative

Signal-intensity versus time curves



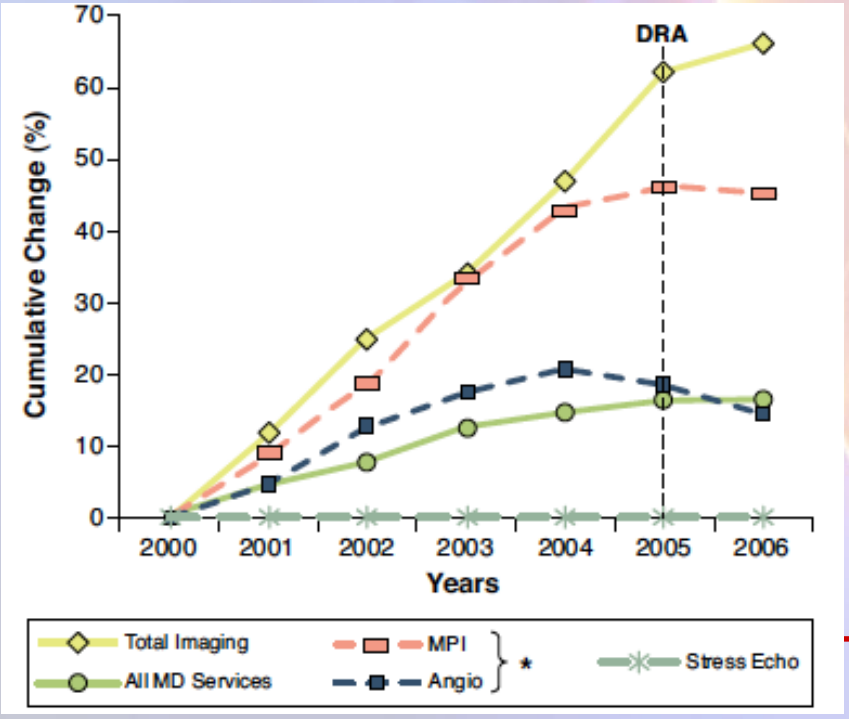
Quantitative => absolute myocardial blood flow (ml/g/min)

BUSINESS AND ADVOCACY

Cardiovascular Imaging Research at the Crossroads

Leslee J. Shaw, PHD,* James K. Min, MD,† Rory Hachamovitch, MD, MS,‡ Eric D. Peterson, MD, MPH,§ Robert C. Hendel, MD,‖ Pamela K. Woodard, MD,¶ Daniel S. Berman, MD,‡ Pamela S. Douglas, MD§

Atlanta, Georgia; New York, New York; Los Angeles, California; Durham, North Carolina; Riverwoods, Illinois; and St. Louis, Missouri



Comparative Effective Research (CER)

- ✓ Net improvement in health outcomes by comparing 2 imaging modality (imaging vs no-imaging ?)
- ✓ Randomized controlled studies
- ✓ Choice of hard end-points independently assigned (quantitative & rigorously collected)
- ✓ Generalizability of results
- ✓ Costs containment

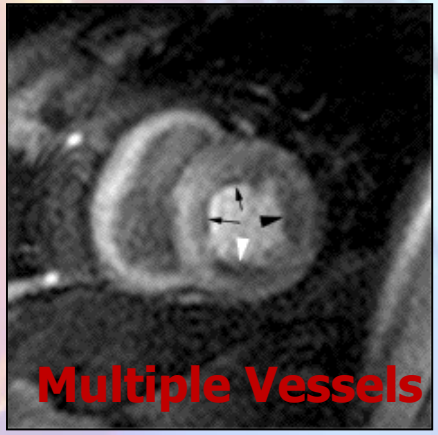
Myocardial Perfusion Imaging

-First Pass Perfusion Cardiac MRI-
- Image Analysis -

Qualitative visual

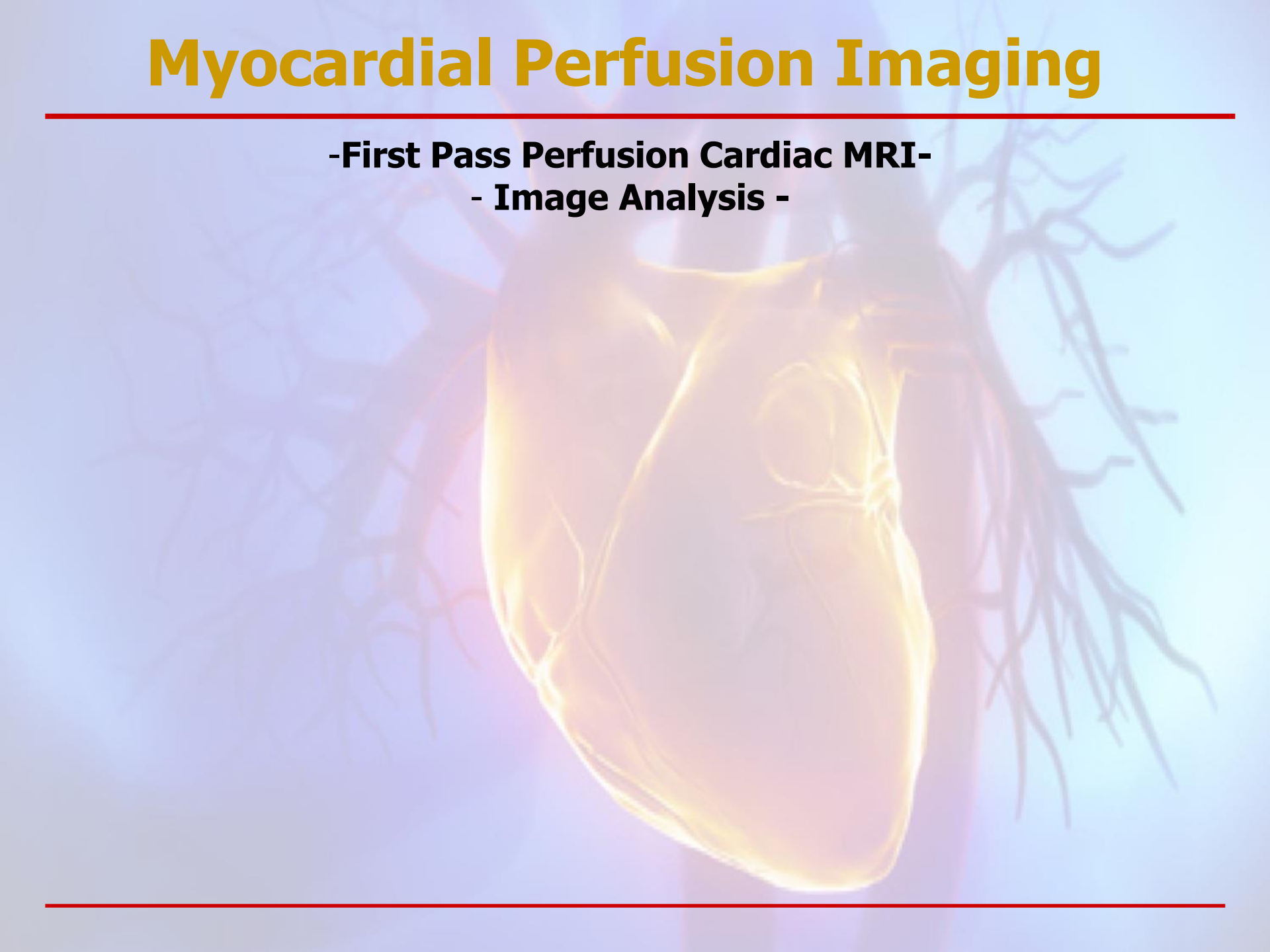
1. Differentiation between dark-rim artifact vs true perfusion defect

2. Severity of Perfusion defect
   - subendocardial
   - transmural
   - number of territory involved



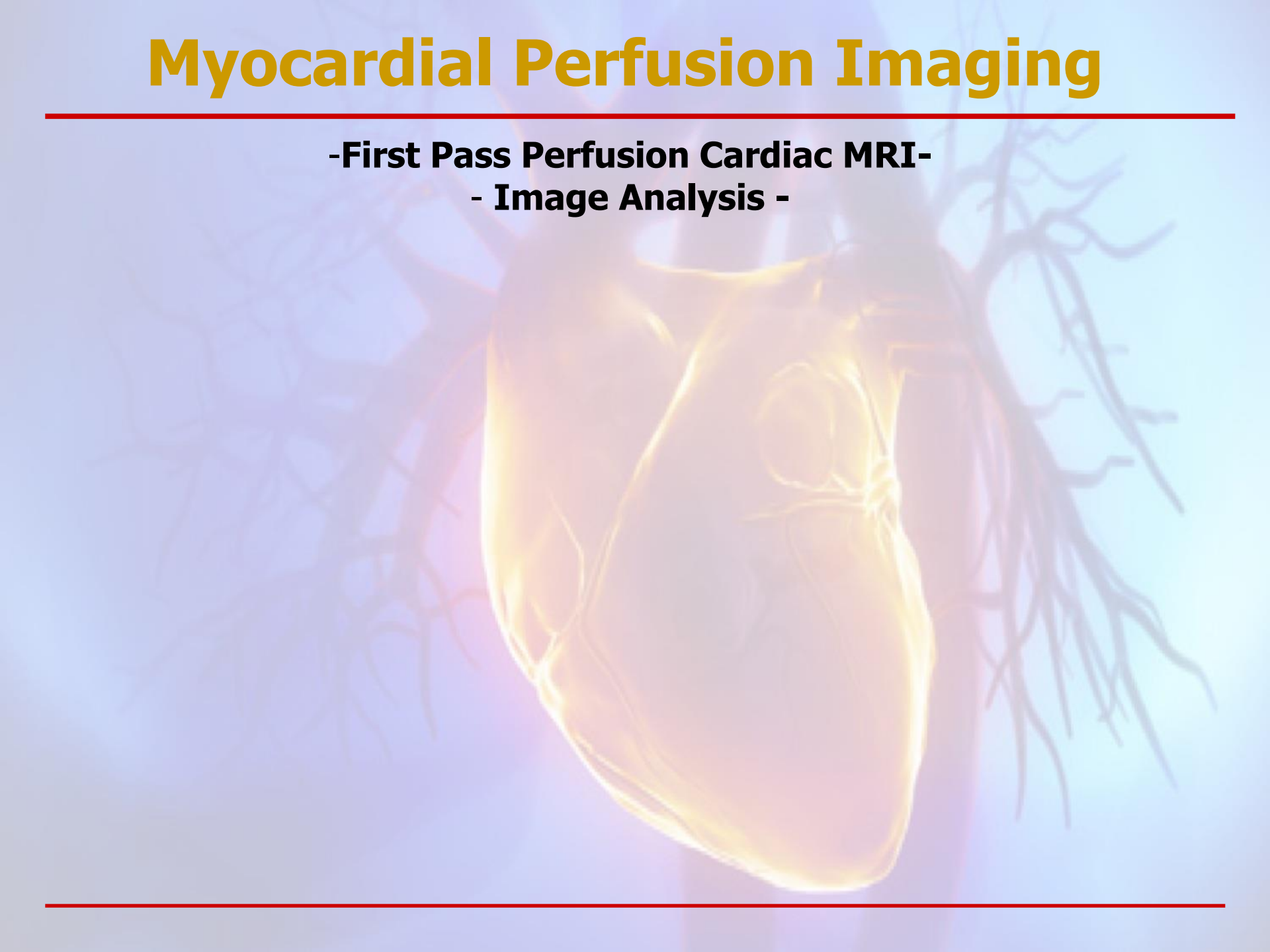
Myocardial Perfusion Imaging

-First Pass Perfusion Cardiac MRI-
- Image Analysis -

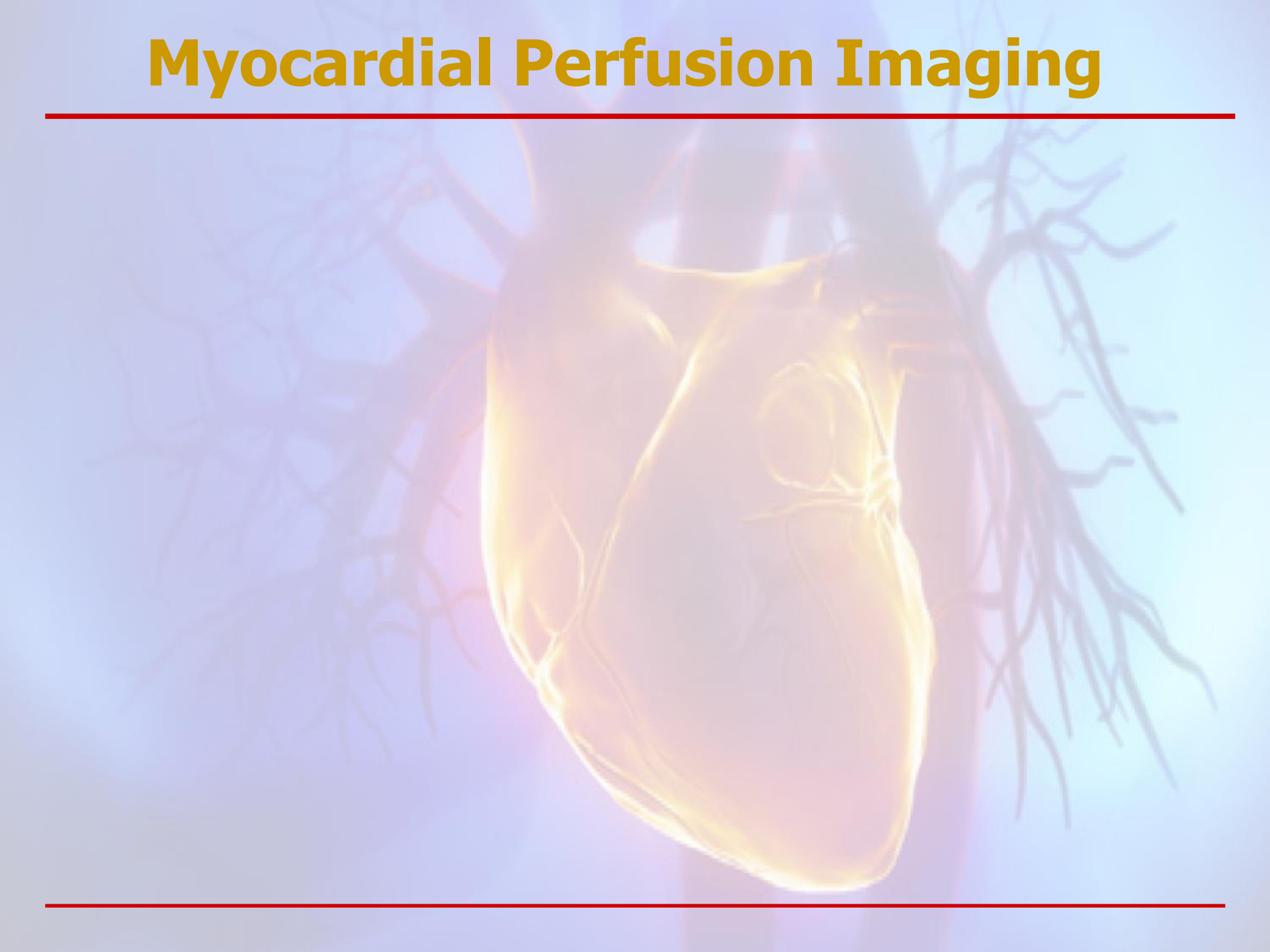


Myocardial Perfusion Imaging

-First Pass Perfusion Cardiac MRI-
- Image Analysis -



Myocardial Perfusion Imaging



Myocardial Perfusion Imaging

Fast gradient-echo

- *K*-lines are acquired after RF pulse with prolonged read-out duration (350-450 ms according to phase-encoding steps)
- Long acquisition times
- Suboptimal spatial resolution

EPI or Hybrid Echo-Planar Pulse Sequence

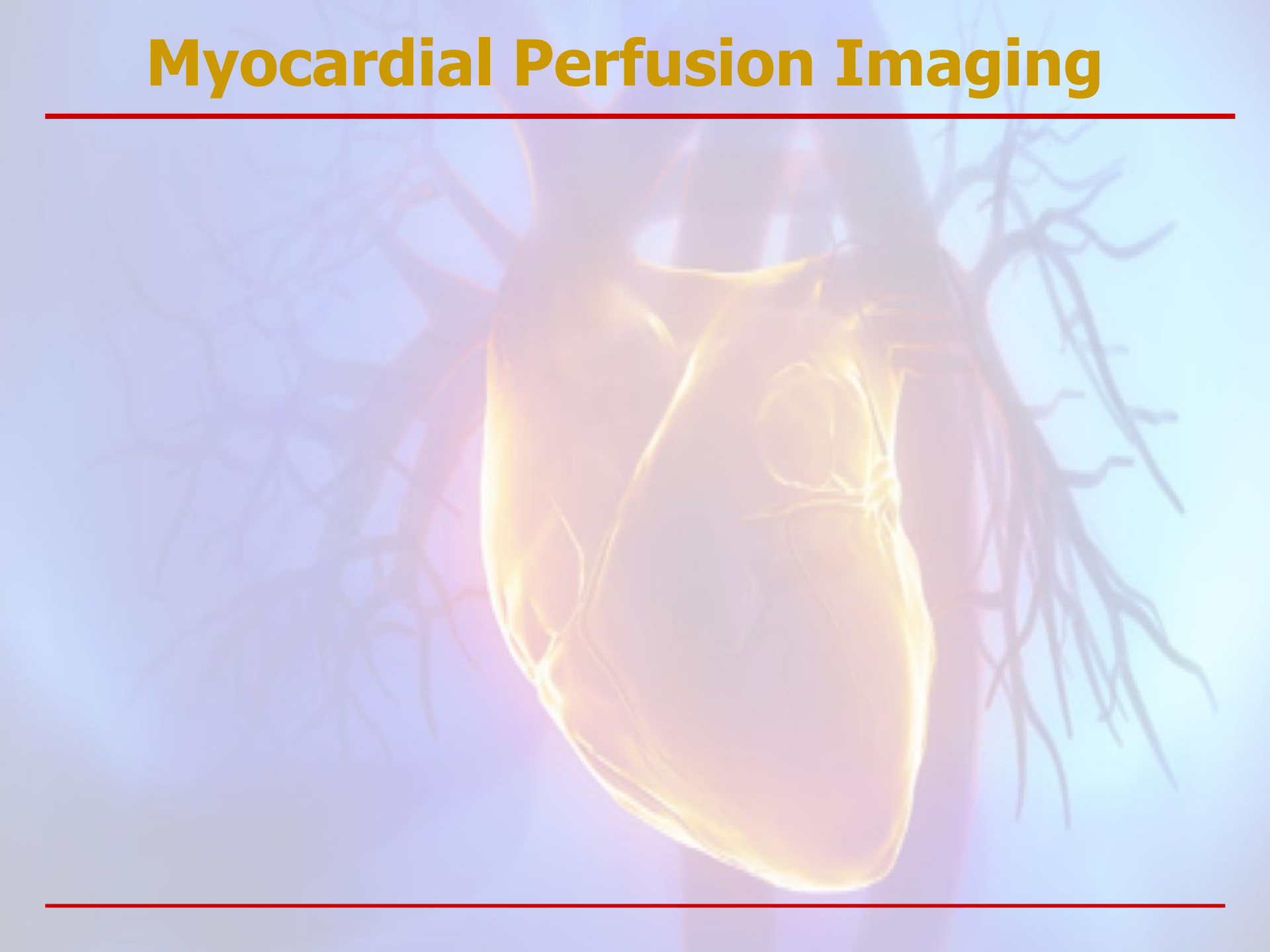
- Single excitation (30-70 msec)
- Susceptibility artifacts / relationship CA concentration - SI not linear
- Off-resonance - T2* relaxation

Steady state free precession (SSFP)

- Reducing ETL to 8
- Multiple RF excitation
- Improved image quality and image contrast

Parallel imaging

Myocardial Perfusion Imaging



Search for Ideal Technique

Exercise ECG — Se 68% — Sp 77%

SPECT — Se 86% — Sp 74%

- Radiation dose (8-20 mSv)
- Photon scatter / Attenuation artifacts

PET

- Availibility / Tracer / Expensive

Stress echocardiography = ± SPECT

- No radiation
- Limited : inadequate imaging window

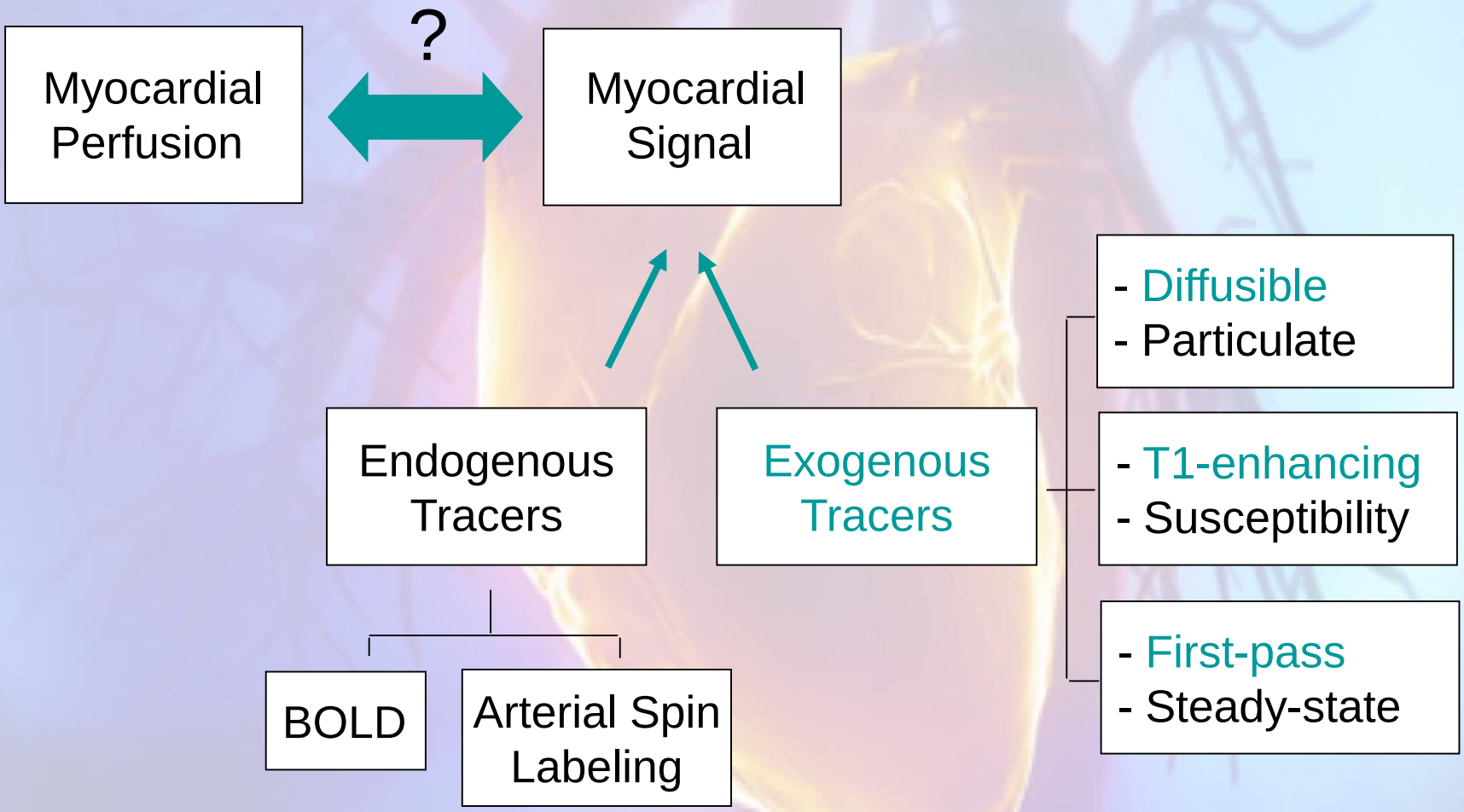
MDCT

- Radiation
- Only anatomical, no functional information

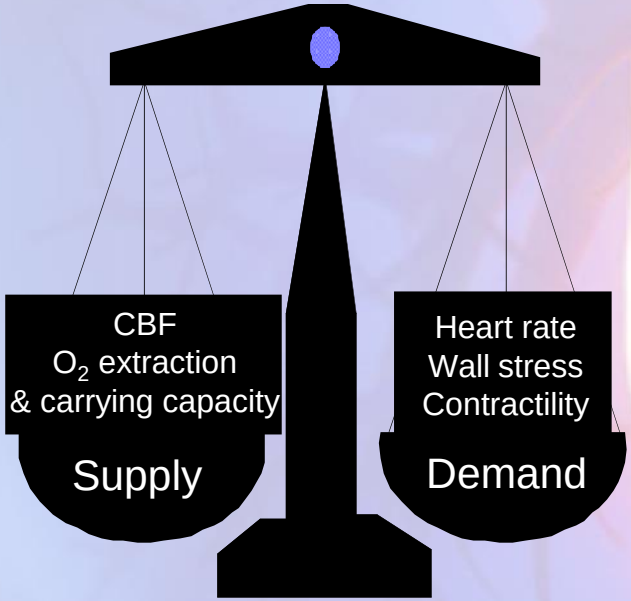
MRI

- MR Myocardial Perfusion Imaging (MPI)
- Stress Function MRI

Myocardial Perfusion Imaging



Myocardial Metabolism



Oxygen extraction already high in basal circumstances

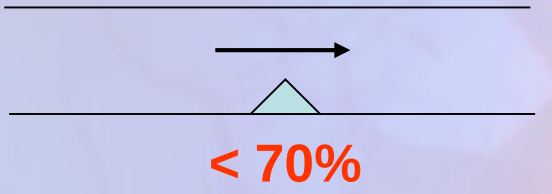
Thus, changes in myocardial oxygen supply result from changes in coronary flow

Primarily caused by coronary atheromatosis

Microvascular disease

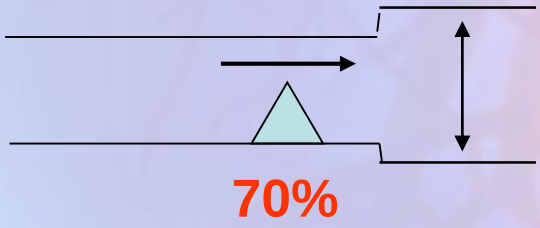
Flow Profile across a Stenosis

Basal Conditions



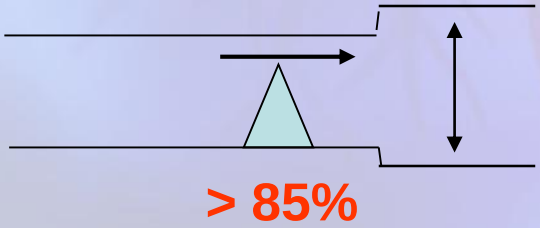
< 70%

R = 0 => Flow = normal



70%

R= ++ / P = -- / Cor ++ => Flow = normal
(coronary vasodilatory reserve)

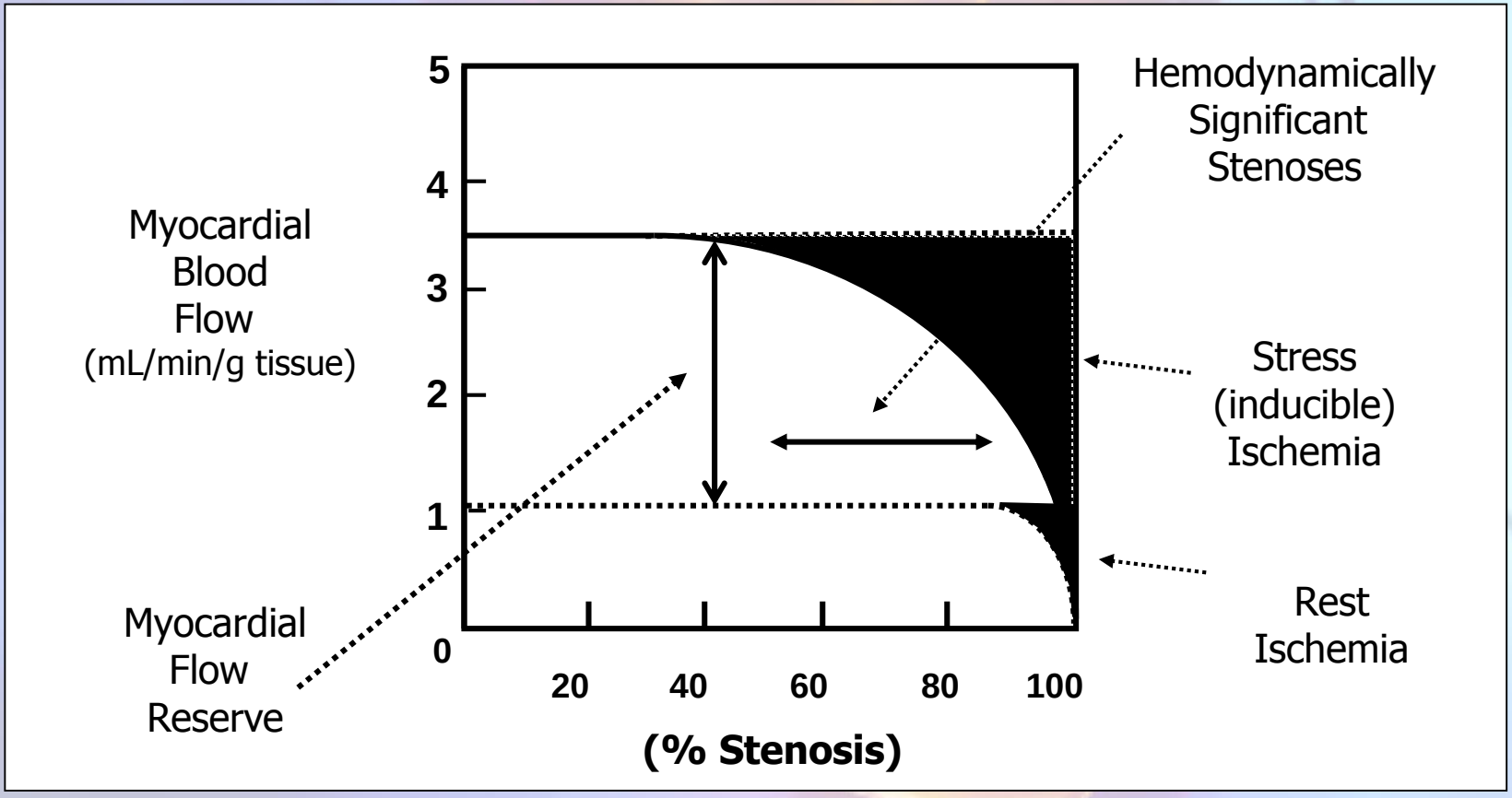


> 85%

R=+++ / P = --- / Cor ++ => Flow --

Myocardial Perfusion Imaging

MBF (max stress) = 4 - 6 x MBF (baseline)
0.5 - 1.1 mL/min/g => 3.7 - 6.7 mL/min/g



Gould, 1974

Mechanisms

Adenosine

- **DIRECT** effect : hyperemia
- IV dose of 140 μg/kg/min
- Half-life **(< 10 sec)**
- 6-min infusion, injection perfusion agent after 3 minutes
- Moderate increase of blood pressure product

Dipyridamole

- **Indirect** by increasing interstitial levels of adenosine
- IV: 0.56 mg/kg during 4 min (0.84 mg/kg during 6 min for myocardial perfusion imaging + WM abnormalities
- Half-life 30 min => prolonged side-effects and ischemia
- Injection of perfusion agent 2 minutes after the end of the 4-min infusion
- Antidotum: aminophylline

Mechanisms

Adenosine

- Facial flushing 35%
- Slight chest pain 33%

  Headache 21% dyspnea 19%

  Nausea / dizziness / sour pain - pain in jaw and shoulders
- Important side-effects restricted to heart & lungs
- AV conduction inhibition => AV block
- Severe bronchospasm (0.08%)
- Myocardial infarction (0.01%)
- Death (0.009%)

Dipyridamole

- Less intense than adenosine
- Chest pain 20%
- Headache 12%
- Dizziness 12%
- Nausea 5%
- Minor dysrhythmias: premature ventricular beats (5-20%)
- Symptomatic bradycardia, AF, VT, VF (very rare)
- Non-fatal MI (0.02%) / Cardiac death (0.01%) / Bronchospasm in asthma patients !!

Contraindications: asthma, AV block II-III

Myocardial Perfusion Imaging

Temporal resolution

Spatial resolution

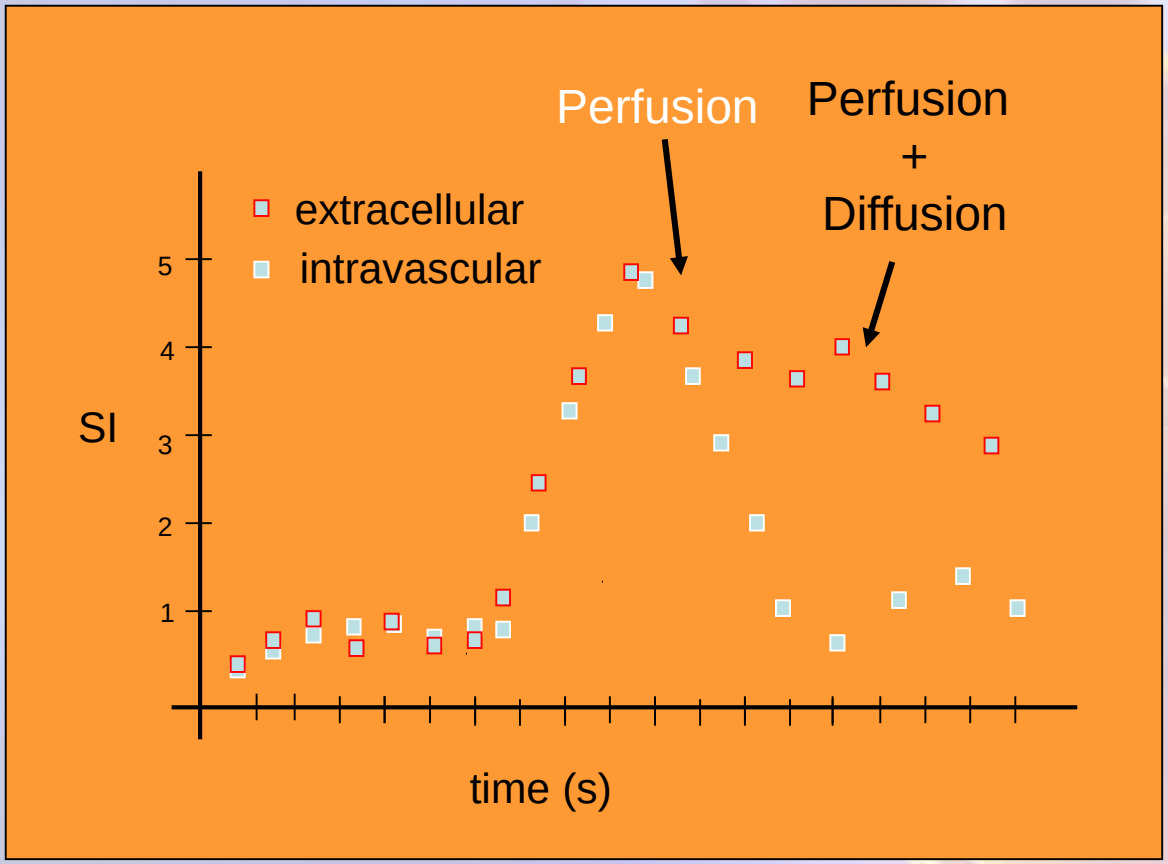
- **transmural discrimination**
- **LV coverage (apex-base)**

High CNR / SNR to discriminate normal from ischemic myocardium

Linear relation signal intensity to contrast dose (ie, input function) for quantification

Correction for respiration

MRI Perfusion (“First-Pass”)



1) **Gadolinium-DTPA small particle**

2) **Diffuse rapidly across into Interstitial space**

3) **SI ≈ [Gadolinio-DTPA]**

Lee et al. Circulation 2004;110:58-65

Myocardial Perfusion Imaging

FAST MR Techniques

Goal: 1 image per 1-2 RR per slice location, with a sufficient spatial resolution, free of artifacts:

Fast gradient-echo
- Long acquisition times (500-700 msec/image)
- Artifacts (cardiac motion - edge blurring)

EPI
- Single excitation (30-70 msec)
- Susceptibility artifacts / relationship CA concentration - SI not linear
- Off-resonance - T2* relaxation

Hybrid EPI-fast gradient-echo
- Reducing ETL to 8
- Multiple RF excitation
- Improved image quality and image contrast

Steady state free precession (SSFP)

Parallel imaging

Myocardial Perfusion Imaging

Contrast Dose and Injection Protocol

Small homogeneous bolus needed to track first pass of contrast (central venous line)

4 to 5 ml/s followed by 15 ml saline flush (power-injector)

Dose: choice between SNR and relationship linearity CA - SI (input function)

- **Low CA dose: lower SNR but linear relation**
- **High CA dose: higher SNR but nonlinear relation**
- **Optimal CA dose dependent on type of MR sequence used**

2 IV lines (one for contrast / one for vasodilator)

Myocardial Perfusion Imaging

First European Multicenter Experience

3 centers

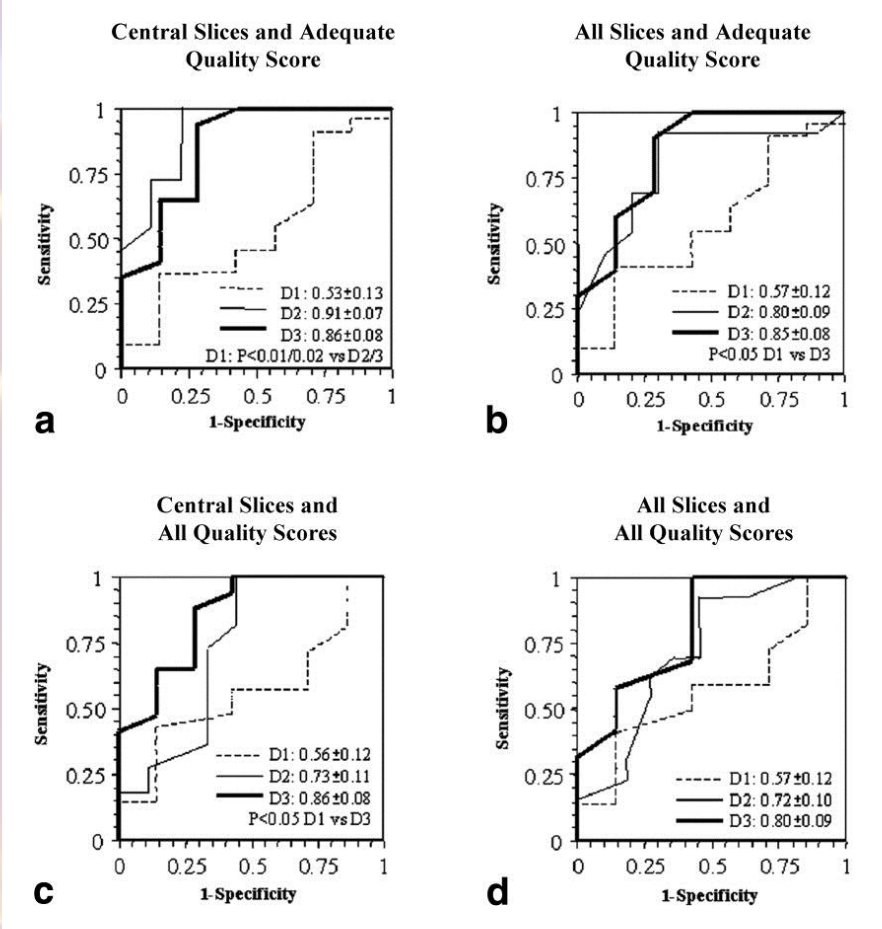
0.05-0.1-0.15 mmol/kg Gd-DTPA

SI increase : 100-200-280%

AUC (ROC): 0.53-0.91-0.86

Pooled (0.1-0.15)

- **Sensitivity: 93%**
- **Specificity: 75%**



MR-Impact Trial (18 centers)

0.01 to 0.1 mmol/kg Gd-DTPA-BMA

0.1 the best AUC (ROC): 0.85

0.1 mmol/kg Gd is the ideal dose

Schwitter et al. ESC 2005

Myocardial Perfusion Imaging

Coverage of Ventricles - Spatial Resolution

Optimal compromise between in-plane resolution / LV coverage and temporal resolution

LV coverage at least 3 slices

basal / mid / apical => 16 segment

In plane resolution: 2.7 x 2.7mm (or better)

Subendocardial defect detection

Artifact reduction

Myocardial Perfusion Imaging

Compensation for Respiratory Motion

Breath-hold strategies

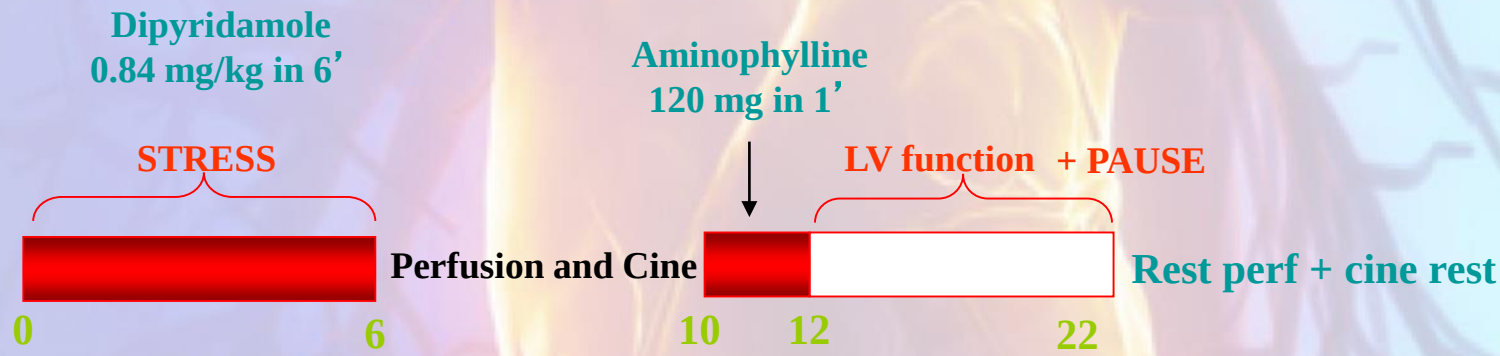
1: deep breath-in and breath outs just before myocardial perfusion study / breath-hold as long as possible / shallow breathing afterwards till end of measurement

2: shallow breathing

oxygen mask

Elastic matching for respiratory motion correction

Myocardial Perfusion Imaging



"two birds (perfusion and function) with a stone (dipyridamole)"

Myocardial Perfusion Imaging

MPI analysis

Qualitative visual

Semi-quantitative

- **Signal-intensity versus time curves**
- **Parametric perfusion maps, factor analysis**
- **Calculation of MPR (myocardial perfusion reserve)**

Quantitative => absolute myocardial blood flow (ml blood /g tissue/min)

Myocardial Perfusion Imaging

Analysis - Visual

Clinically most often used

Perfusion deficit:

- **Severity / Duration**
- **Transmural extent**
- **Segmental approach (e.g. 16/17 segments) - CA perfusion territory**
- **Perfusion defect:**
  - **Stress: yes / rest: no => CAD**
  - **Stress: yes / rest: yes => artifact (matched defect)**
- **Relation perfusion defect - late enhancement**
  - **Match**
  - **Mismatch**

Myocardial Perfusion Imaging

Visible as nonenhancing part of myocardium during first pass of contrast!!

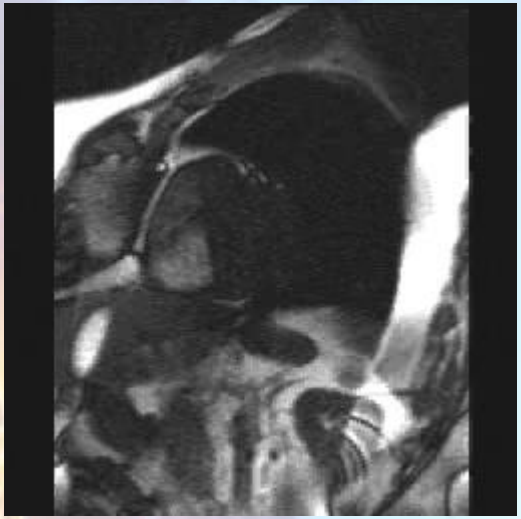
Obeys anatomical borders and respects course of blood supply by coronary arteries

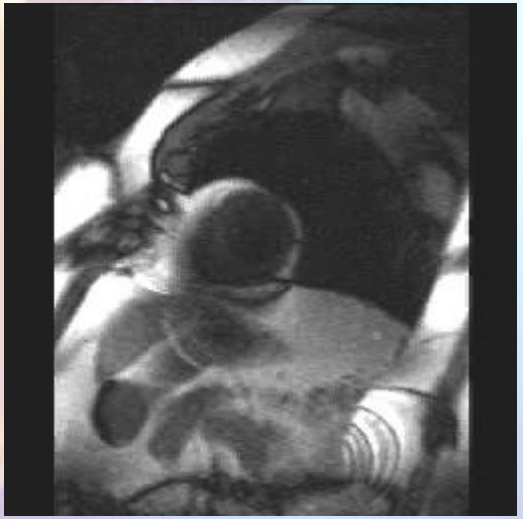
Most pronounced in subendocardium with variable transmural spread

Duration of defect ranges from brief to prolonged

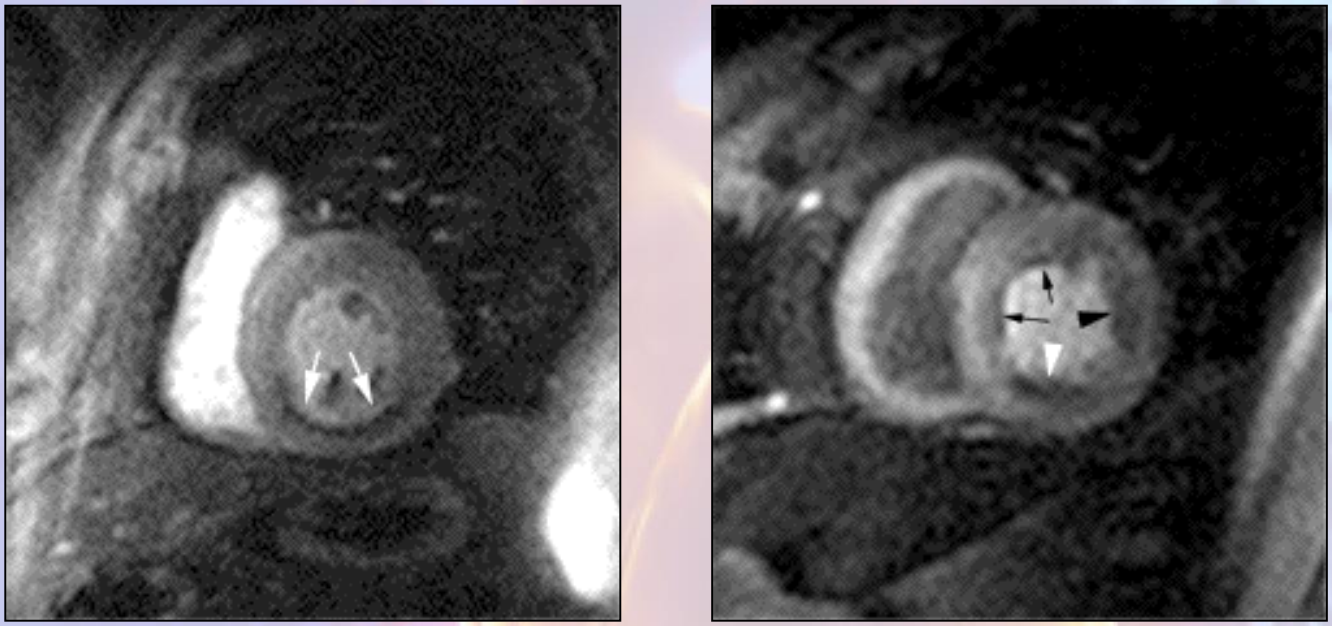
Size of perfusion defect is determined by position coronary artery stenosis

Abnormalities are always more pronounced during stress than at rest



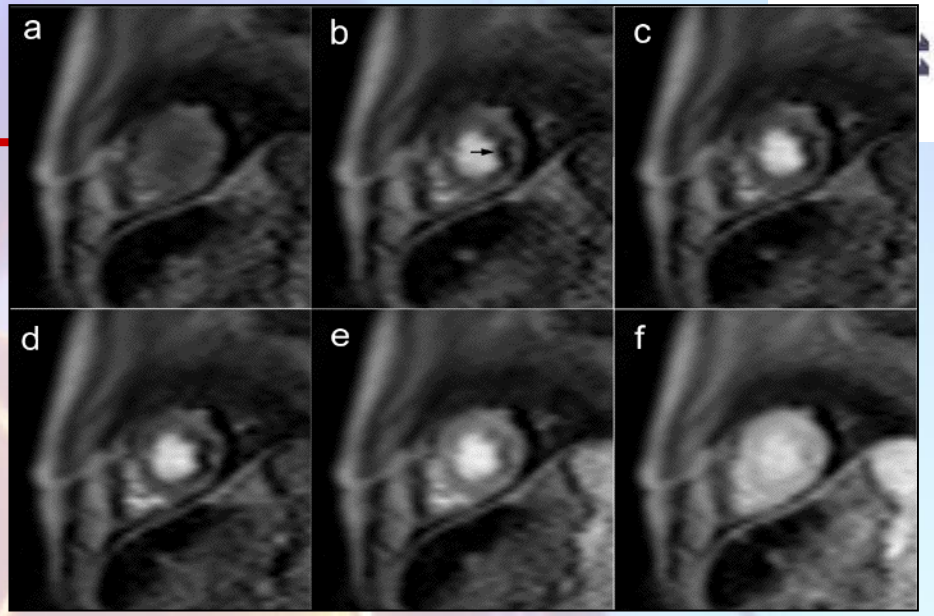


Myocardial Perfusion Imaging



Multiple CA lesions: separate perfusion defects

Dark-Rim Artifacts



Very often present, sequence related
Contrast arrival in LV cavity
- Difference in relaxivity
- Susceptibility
- Edges bloodpool / myocardium

During hyperemia ++ => yielding impression of true defect

Usually darker than nonenhanced myocardium

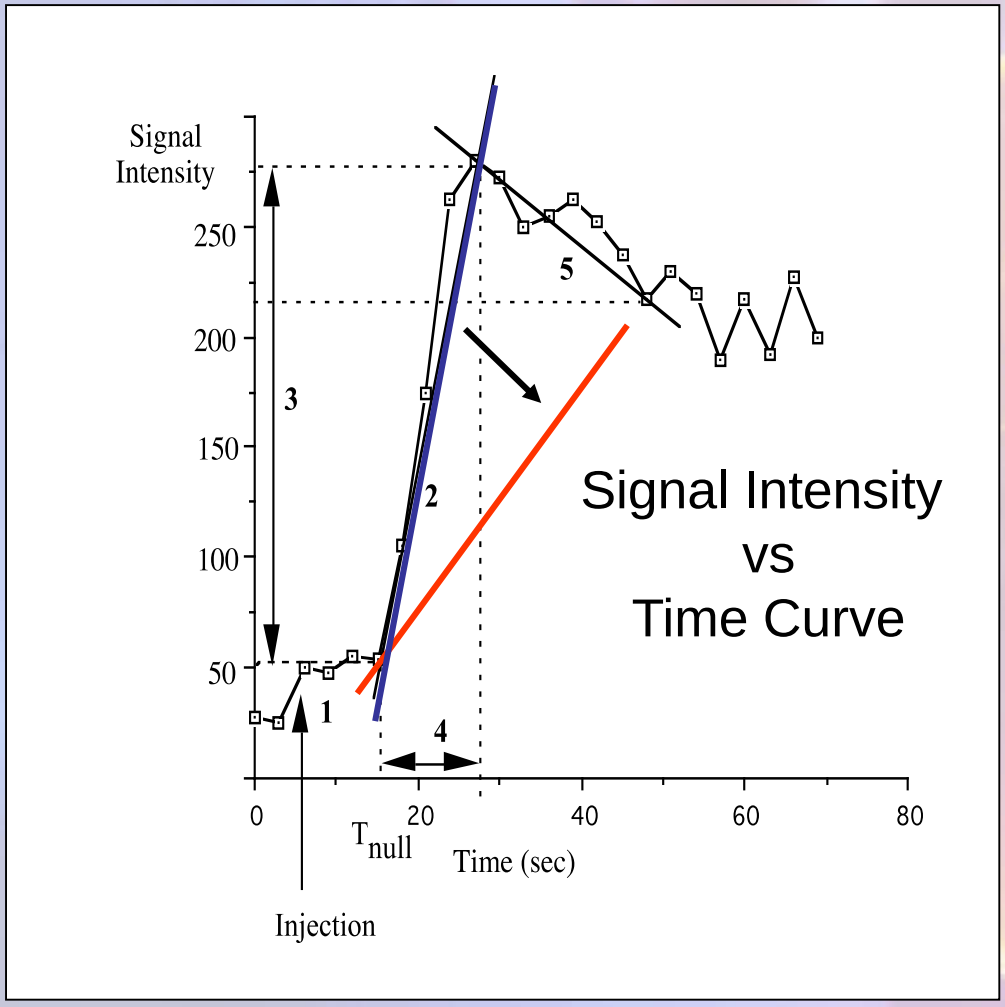
Rapid decrease in severity / disappear during contrast washout in ventricular cavity / may reappear during second pass

Most pronounced in basal part / septum / papillary muscles

May be superimposed on true defect !!

Myocardial Perfusion Imaging

Analysis - Semi-Quantitive

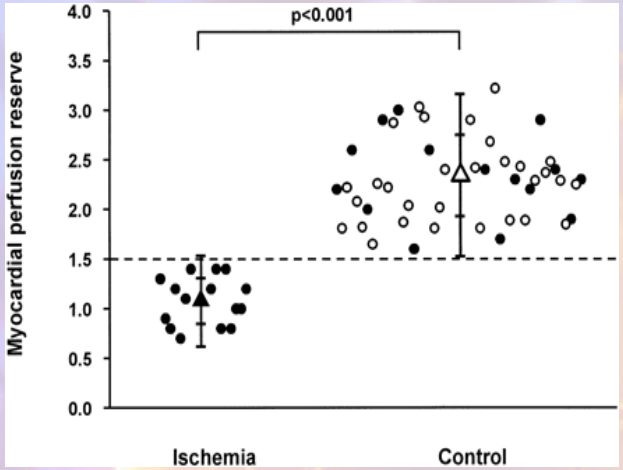


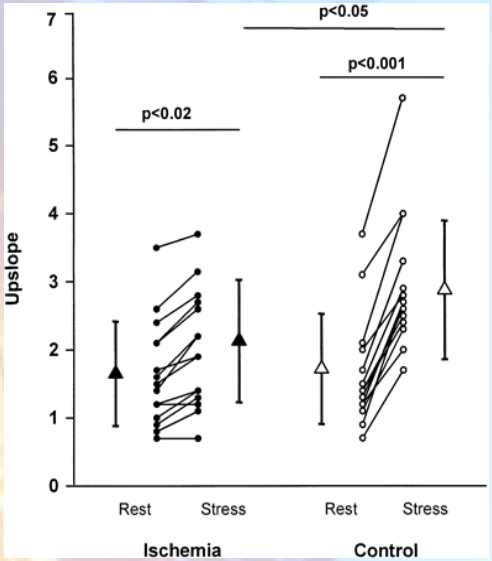
1 - Time to start
2 - Upslope
3 - Signal increase
4 - Time to peak
5 - Downslope

- Linear fit
- Gamma variate fit

Myocardial Perfusion Imaging

$$\frac{\text{Upslope}_{(corr)}\ \text{stress}}{\text{Upslope}_{(corr)}\ \text{rest}}$$





Upslope (Linear Fit): cut off value: 1.5

- Nl segments: 2.33 ± 0.41
- Ischemic segments: 1.08 ± 0.23

Se: 90 % / Sp: 83% / Acc: 87% (CA stenosis ≥ 75%)

Al-Saadi et al. Circulation 2000

Myocardial Perfusion Imaging

Difficult

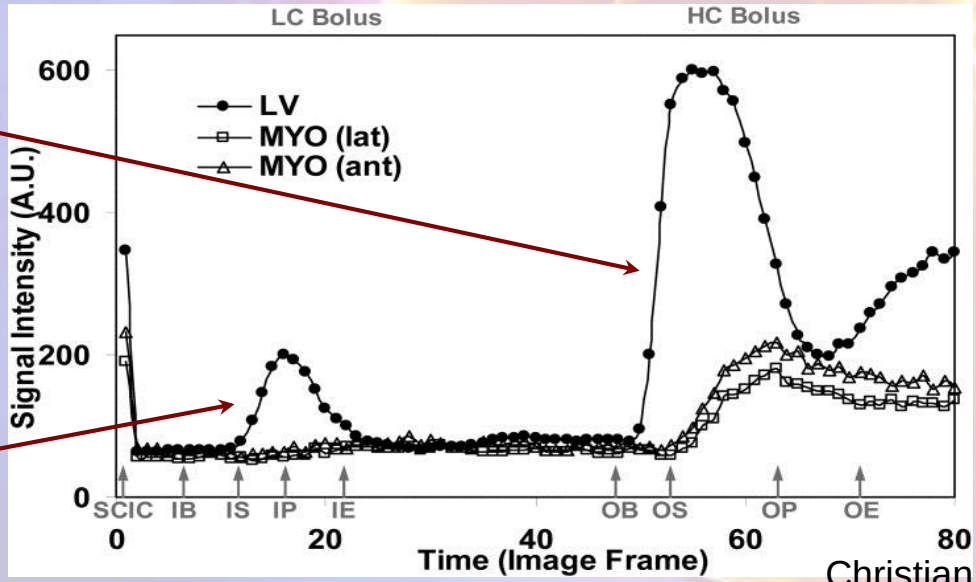
Requires deconvolution of the measured myocardial SI curve with the arterial input function SI curve

Dual-bolus approach, promising

Tracer-kinetics models based on compartmental analysis of Gd-uptake

0.1 mmol

0.005 mmol

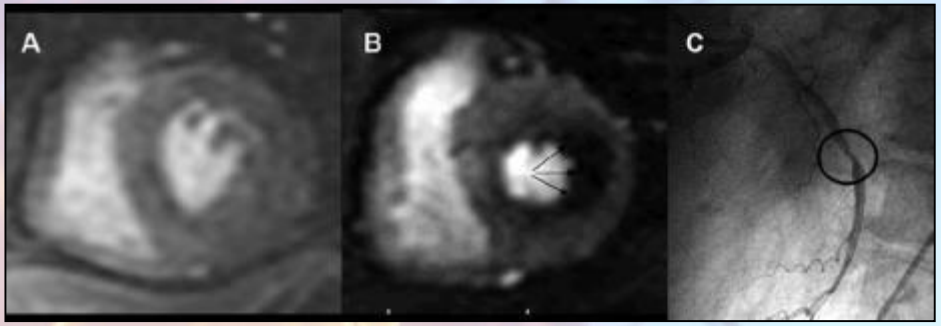


MBF (mL/min/g)
(10 humans):
- Rest: 1.02 ± 0.22
- Stress: 3.39 ± 0.59

Christian et al. Radiology 2004;232:677-684
Hsu et al. JMRI 2006;23:315-322

Myocardial Perfusion Imaging

Clinical implication of adenosine-stress cardiac magnetic resonance imaging as potential gatekeeper prior to invasive examination in patients with AHA/ACC class II indication for coronary angiography



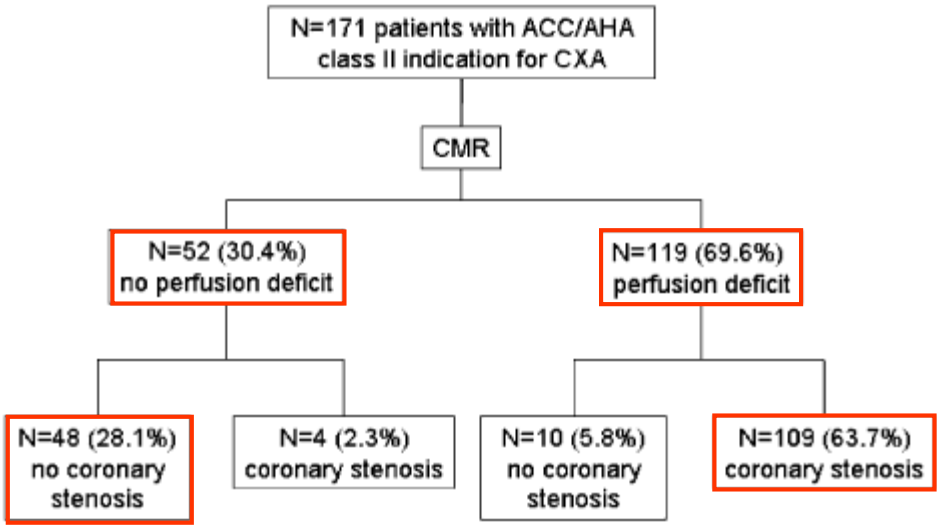
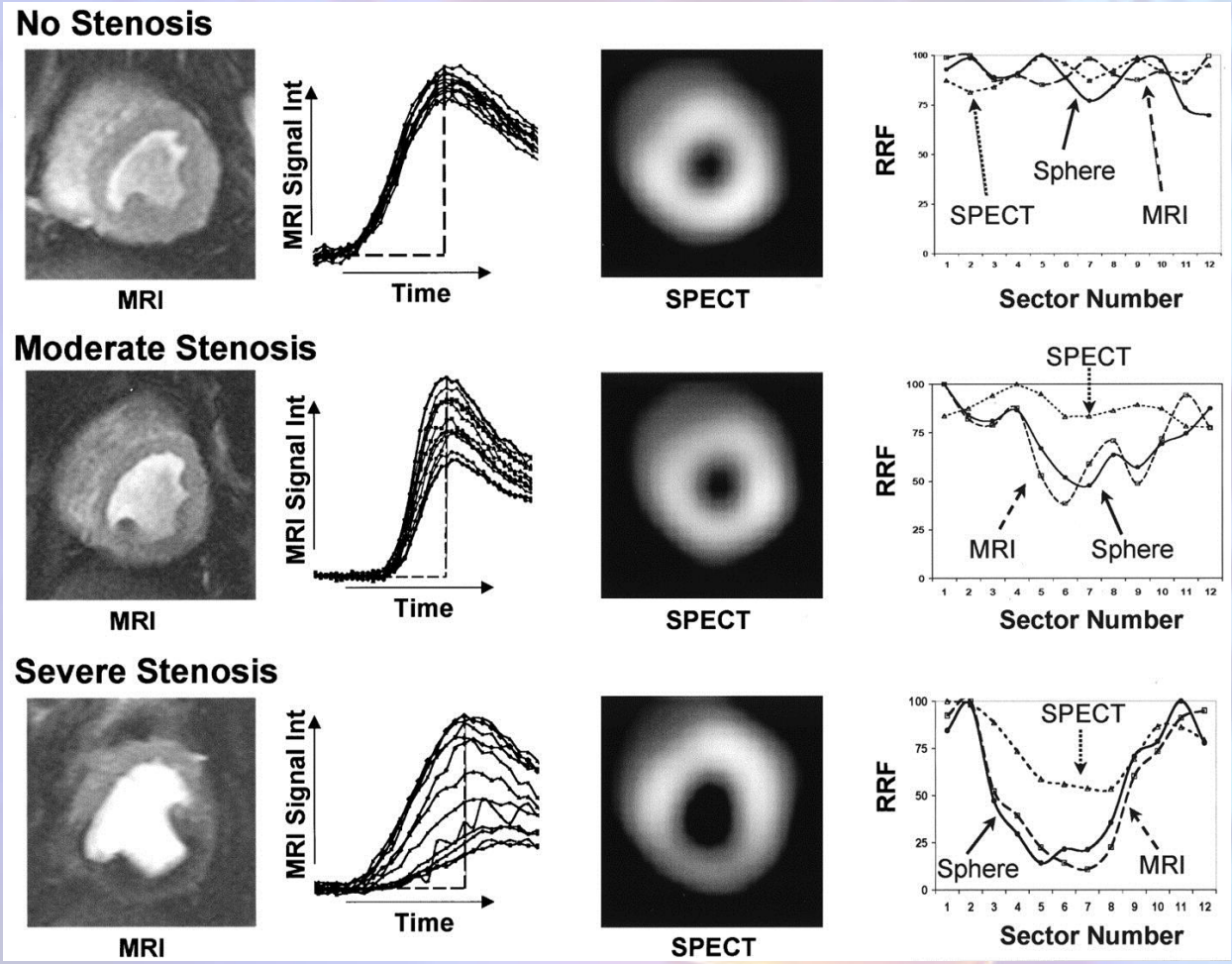


Fig. 2 CMR stress perfusion and CXA findings in our patients (chi square for CMR and stenosis >70%: 113.7, $p < 0.0001$)

false positive results. Sensitivity of CMR to detect relevant CAD (>70% luminal narrowing) was 0.96, specificity 0.83, positive predictive value 0.92 and negative predictive value 0.92. Of the CMR components, perfusion deficit was the strongest independent predictor (odds ratio 132.3, $p < 0.0001$).

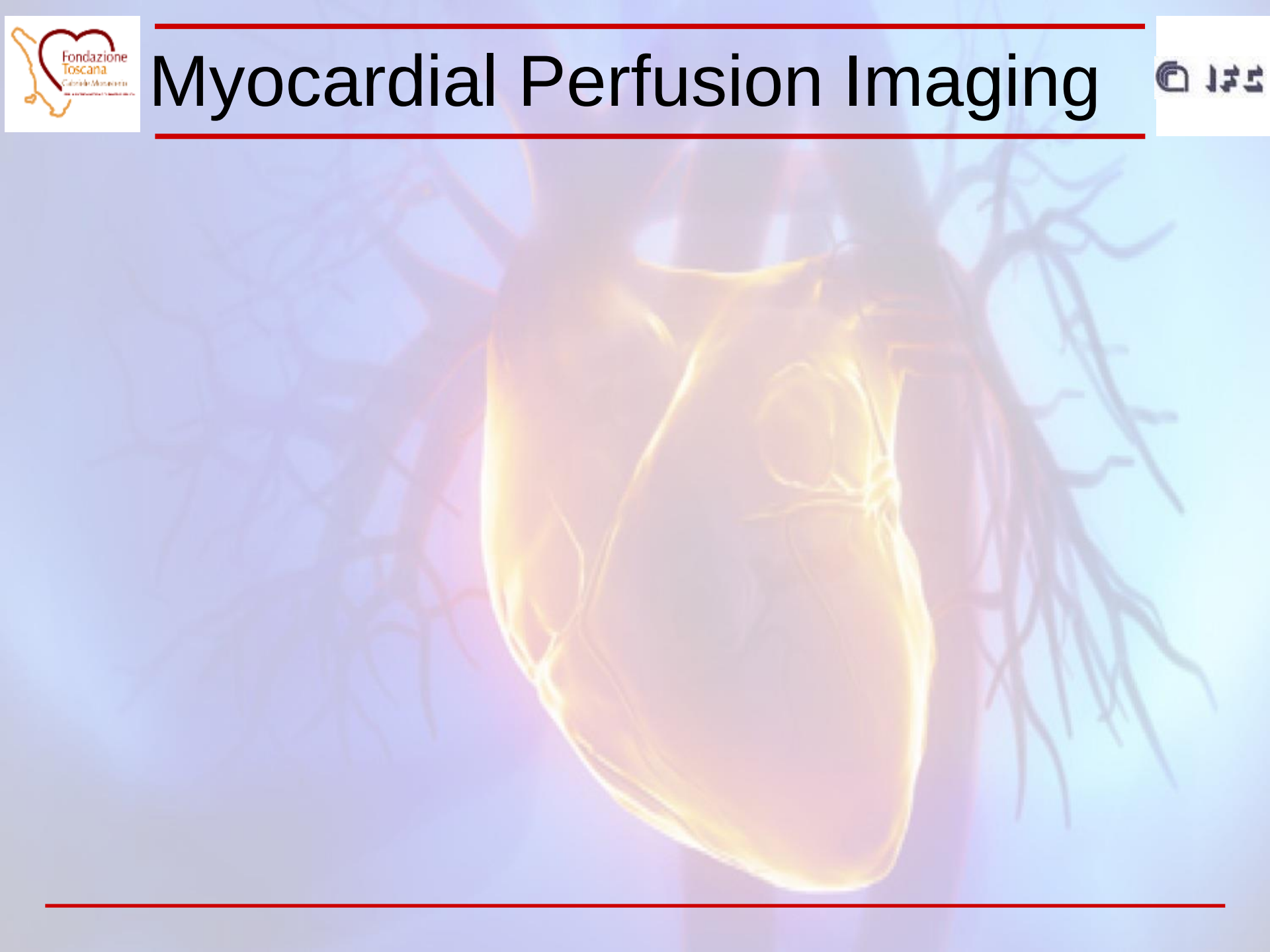
Myocardial Perfusion Imaging

MR-MPI versus SPECT



Lee et al. Circulation 2004;110:58-65

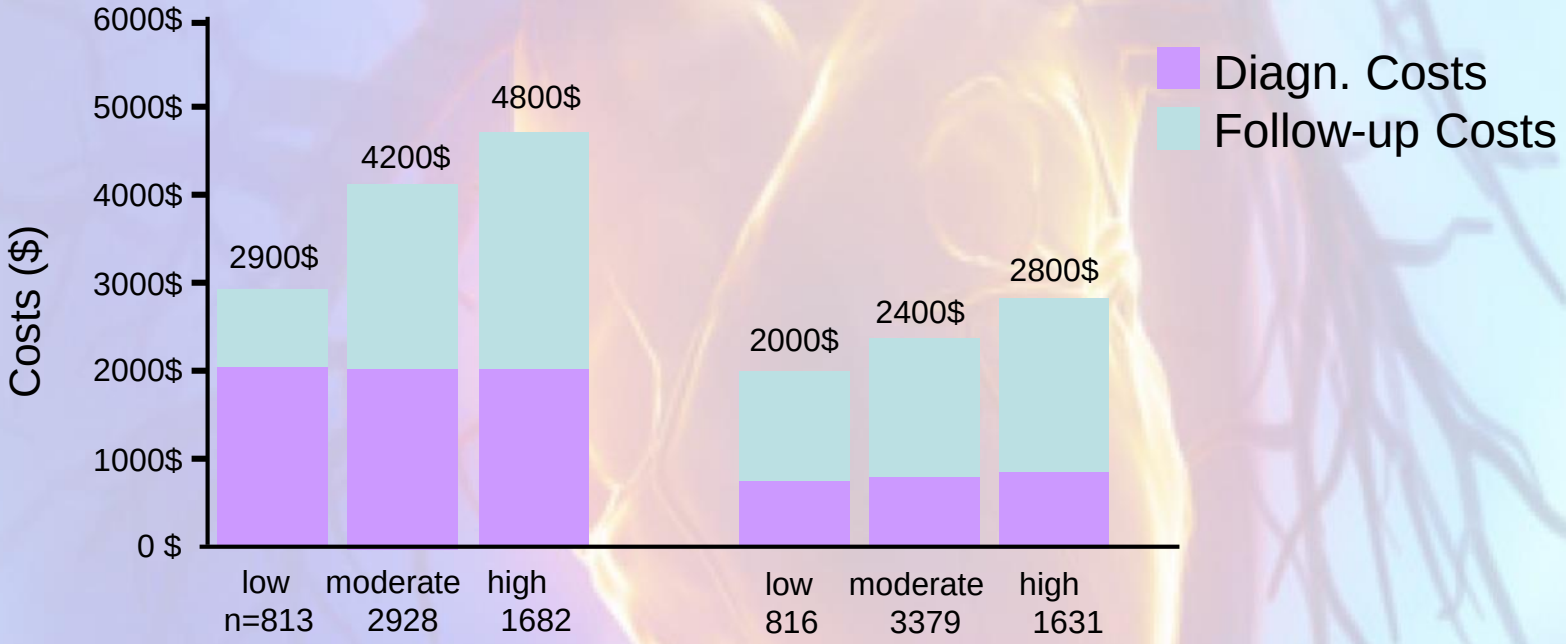
Myocardial Perfusion Imaging



Myocardial Perfusion Imaging

Costs

Invasive vs. Noninvasive approach (11.249 Pts)



Shaw et al, JACC, 1999

Myocardial Perfusion Imaging

Conclusions

Growing scientific evidence that MR-MPI is highly valuable to depict hemodynamically significant coronary stenoses

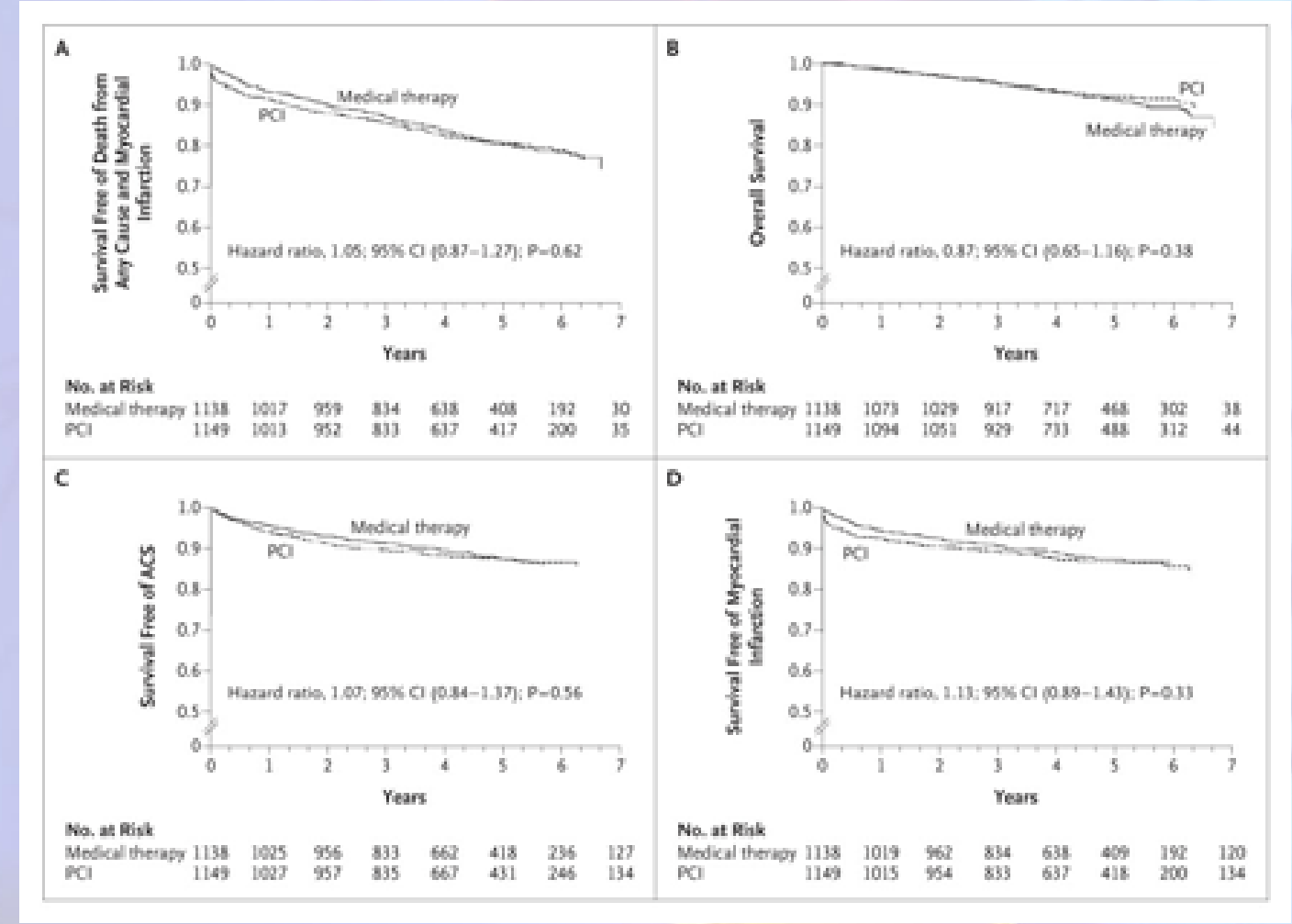
STRENGTHS

- Easy-to-perform
- Safe, fast
- No radiation
- Spatial resolution
- Part of comprehensive exam
- CAD + MVD
- Efficient gate-keeper =>
  - risk stratification
  - reduction of medical cost
- Prognostic value in predicting CAD-related events

LIMITATIONS

- Sequence design
- Compromise between imaging parameters
- Artifact-free images
- Interpretation
- Quantification of absolute MBF

CURE



Boden NE et al NEJM 07