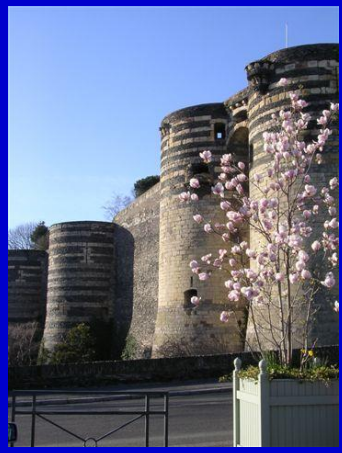
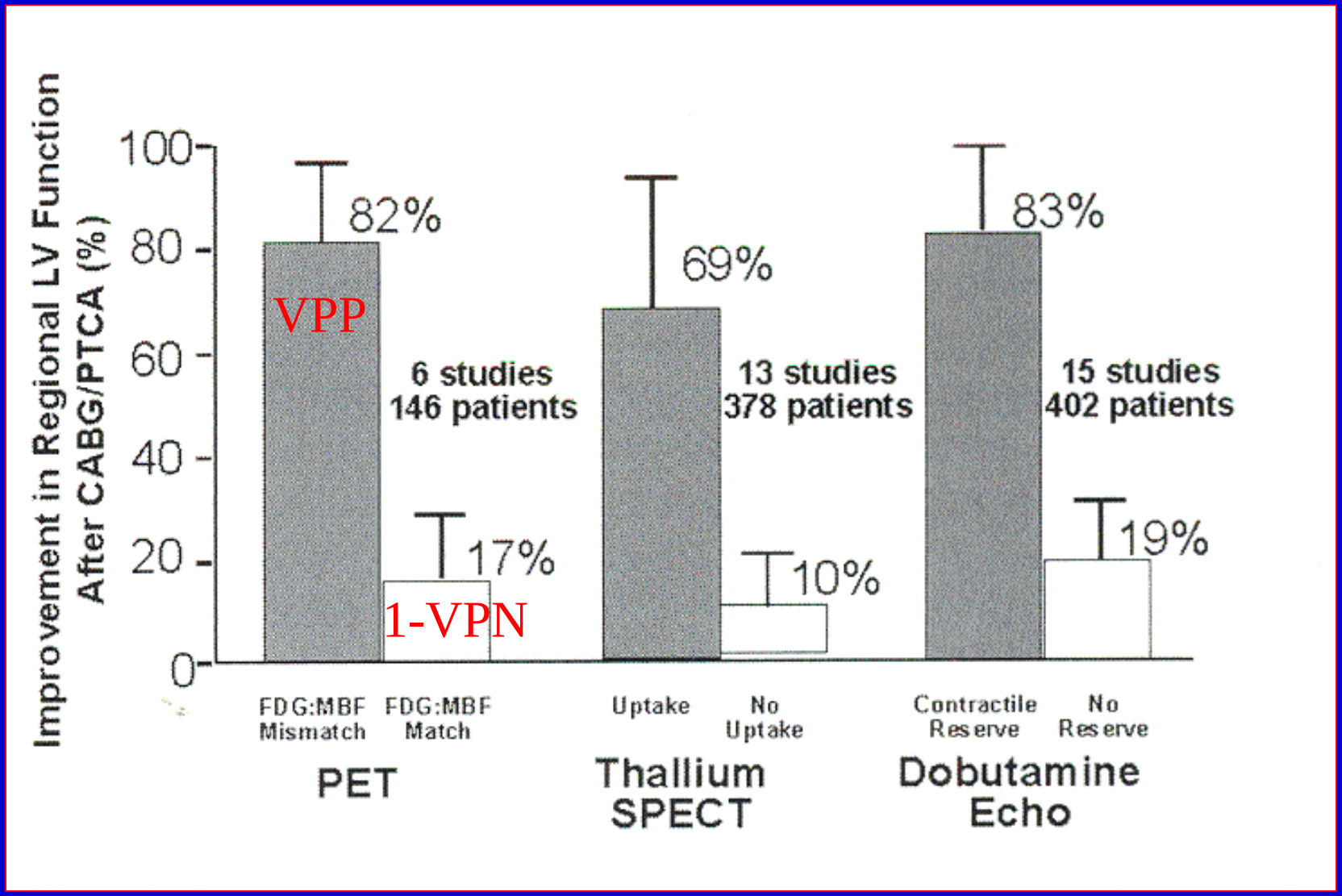
Viabilité myocardique
Apports de l'IRM



Pr Alain FURBER
UPRES EA 3860 et Service de Cardiologie
CHU et Université d'Angers

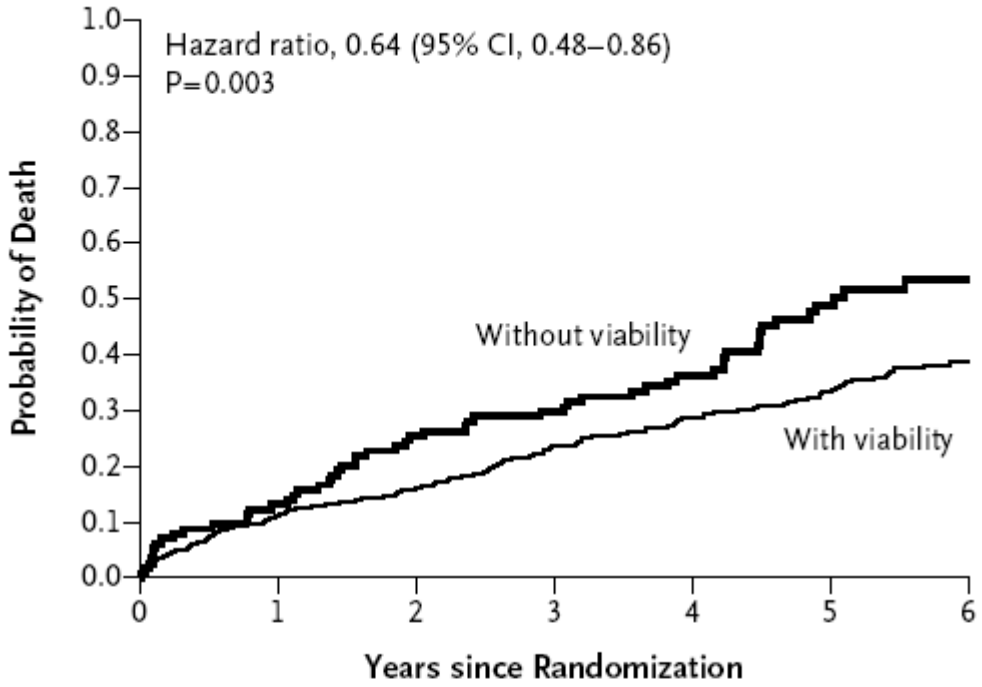
Les méthodes d'étude de la viabilité

- Echographie dobutamine
  - Réserve contractile
- Scintigraphie Thallium 201
  - Diminution de perfusion avec intégrité membranaire
- Scintigraphie Sestamibi
  - Fonction mitochondriale préservée
- Scintigraphie FDG et TEP
  - Diminution de perfusion avec activité métabolique



Bonow RO Circulation 1996

STICH Trial



No. at Risk							
Without viability	114	99	85	80	63	36	16
With viability	487	432	409	371	294	188	102

Figure 1. Kaplan–Meier Analysis of the Probability of Death, According to Myocardial Viability Status.

The comparison that is shown has not been adjusted for other prognostic baseline variables. After adjustment for such variables on multivariable analysis, the between-group difference was not significant (P=0.21).

Bonow RO *NEJM 2011*

STICH Trial

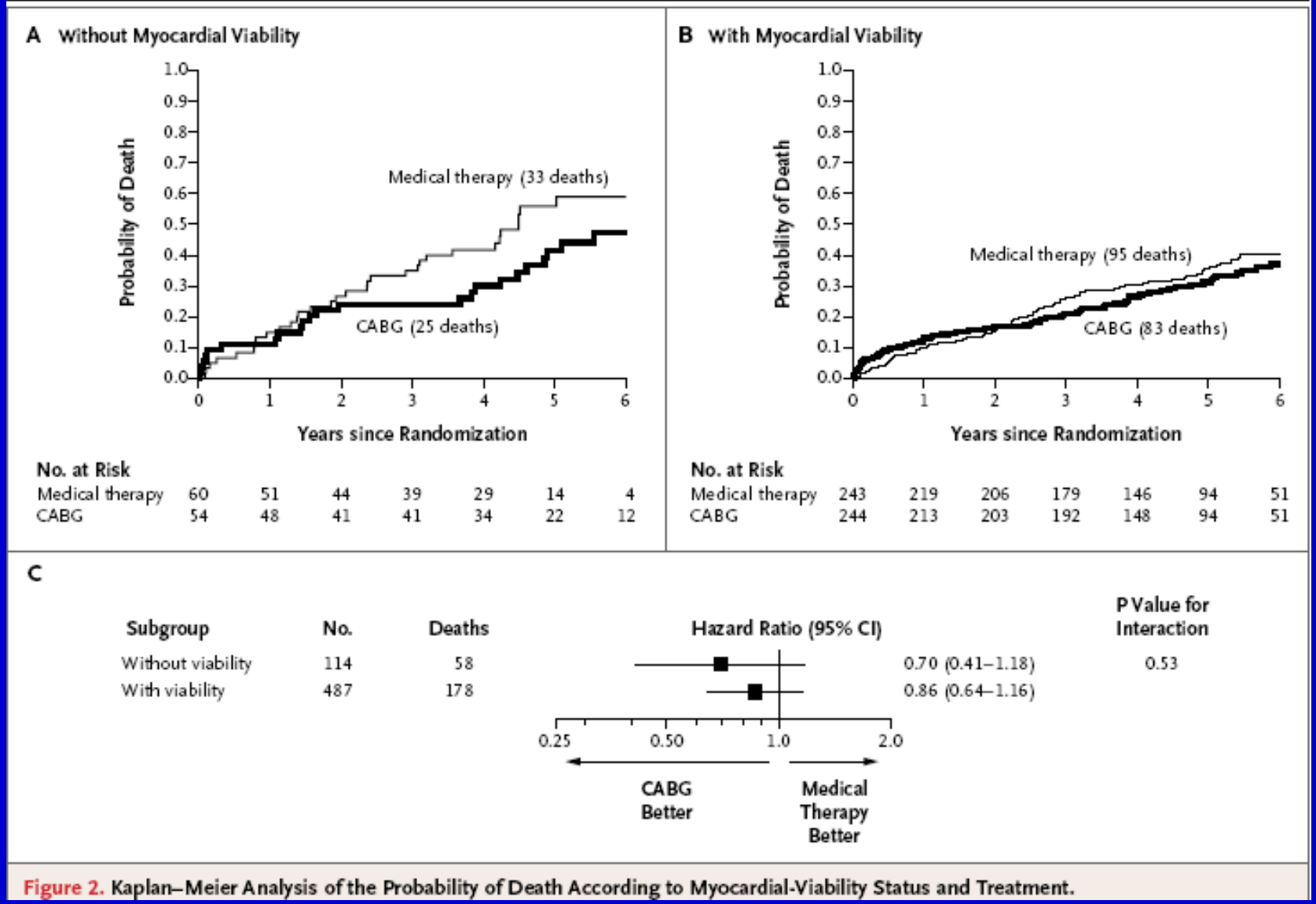


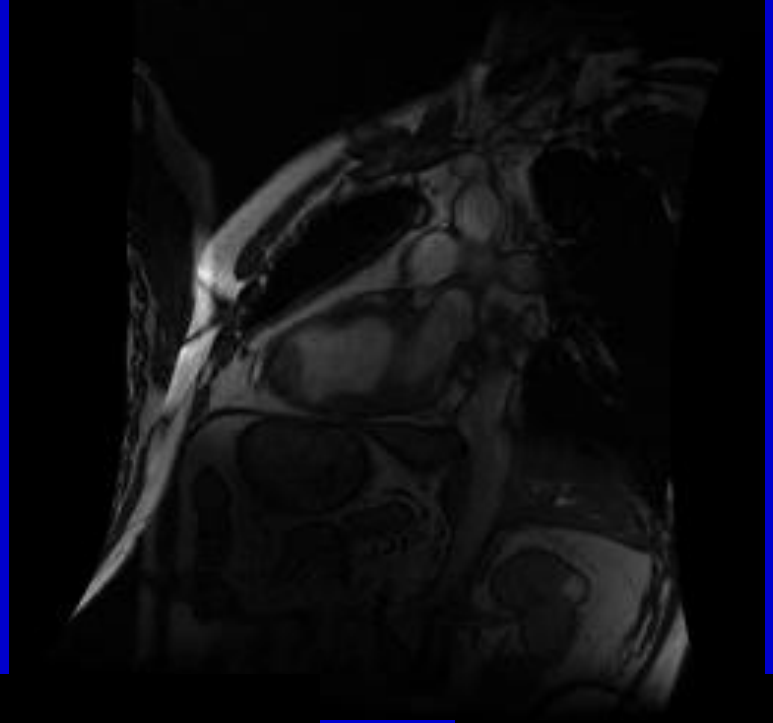
Figure 2. Kaplan–Meier Analysis of the Probability of Death According to Myocardial-Viability Status and Treatment.

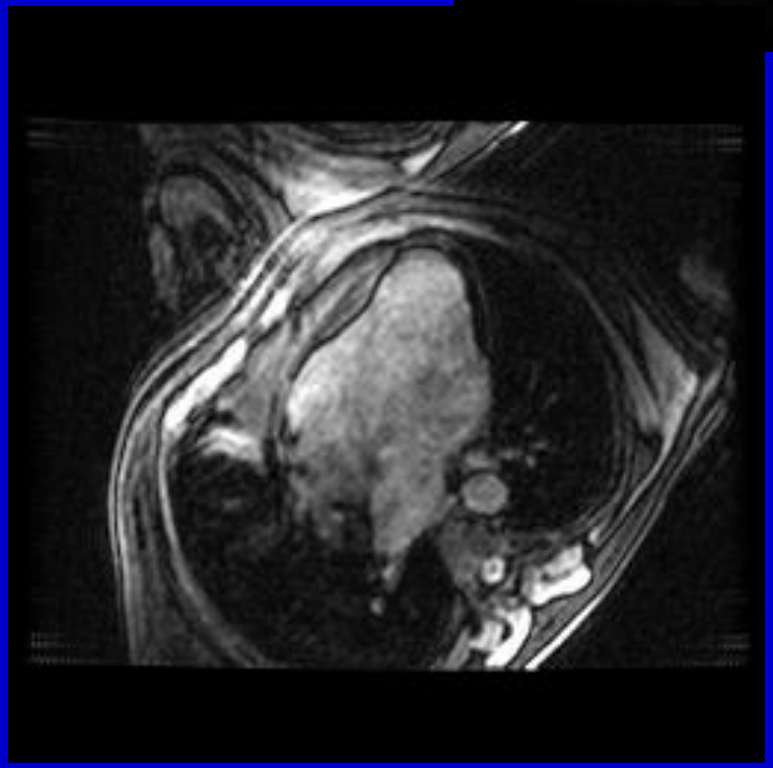
≥ 2 of 3 VD, EF, ESV

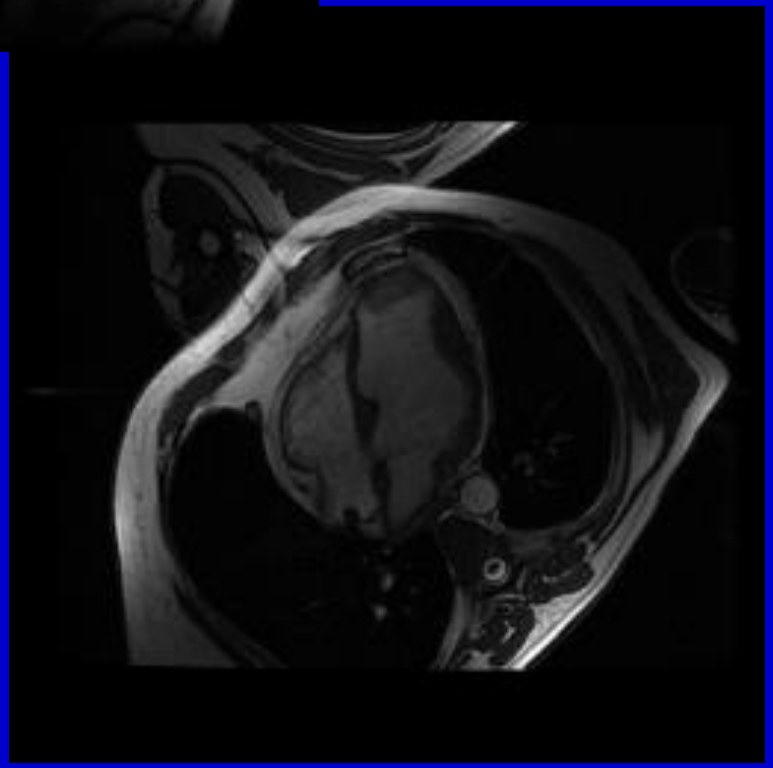
Bonow RO *NEJM 2011*

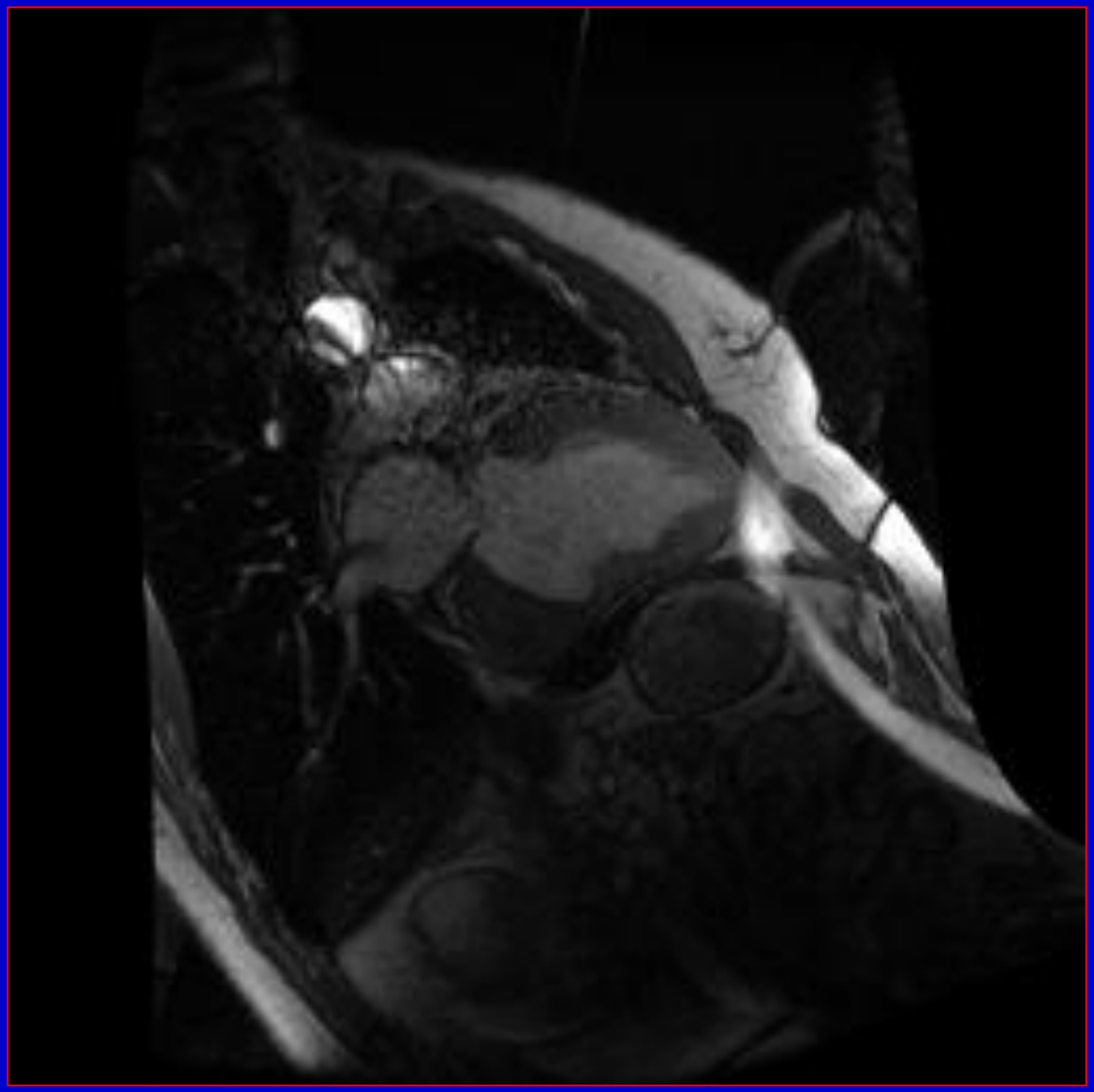
Infarctus et IRM

- Dans le post-infarctus
  - Fonction VG globale et régionale
  - Diagnostic des complications
  - Perméabilité de l'artère responsable
  - **Viabilité myocardique**
  - Ischémie résiduelle
    - Fonction VG régionale sous dobutamine
    - Perfusion myocardique régionale sous dipyridamole
    - Réserve coronaire sous adénosine









Viabilité et IRM

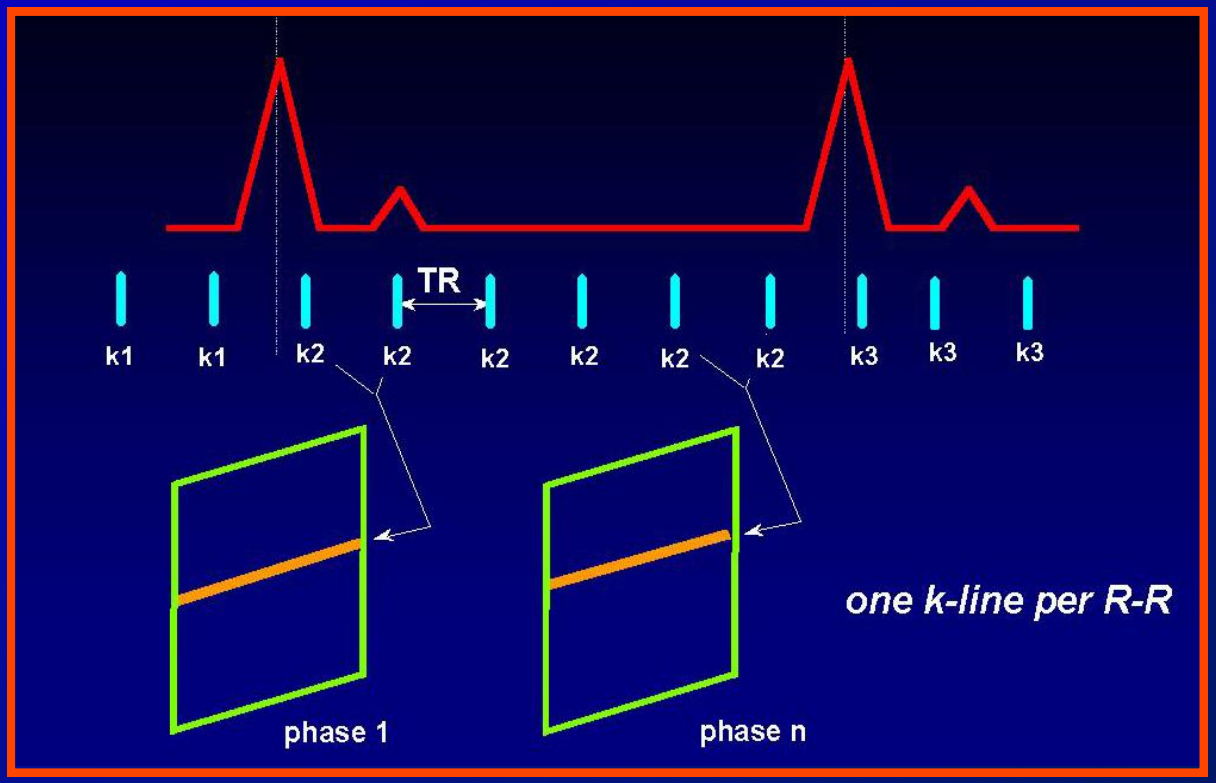
- Fonction VG régionale de repos
  - Epaisseur pariétale
  - Epaississement systolique
- Réserve contractile
  - IRM sous dobutamine
- Réhaussement tardif après gadolinium
- Spectroscopie RMN
  - Phosphore 31 (ATP, PCr)
  - Proton ^{1}H, Sodium-23, Potassium-39

Fonction VG et IRM
Les séquences d'acquisition

- Séquences Sang Blanc
  - Echo de gradient (GRE)
  - Echo de gradient rapide (fast GRE)
  - Echo de gradient rapide avec segmentation de l'espace k

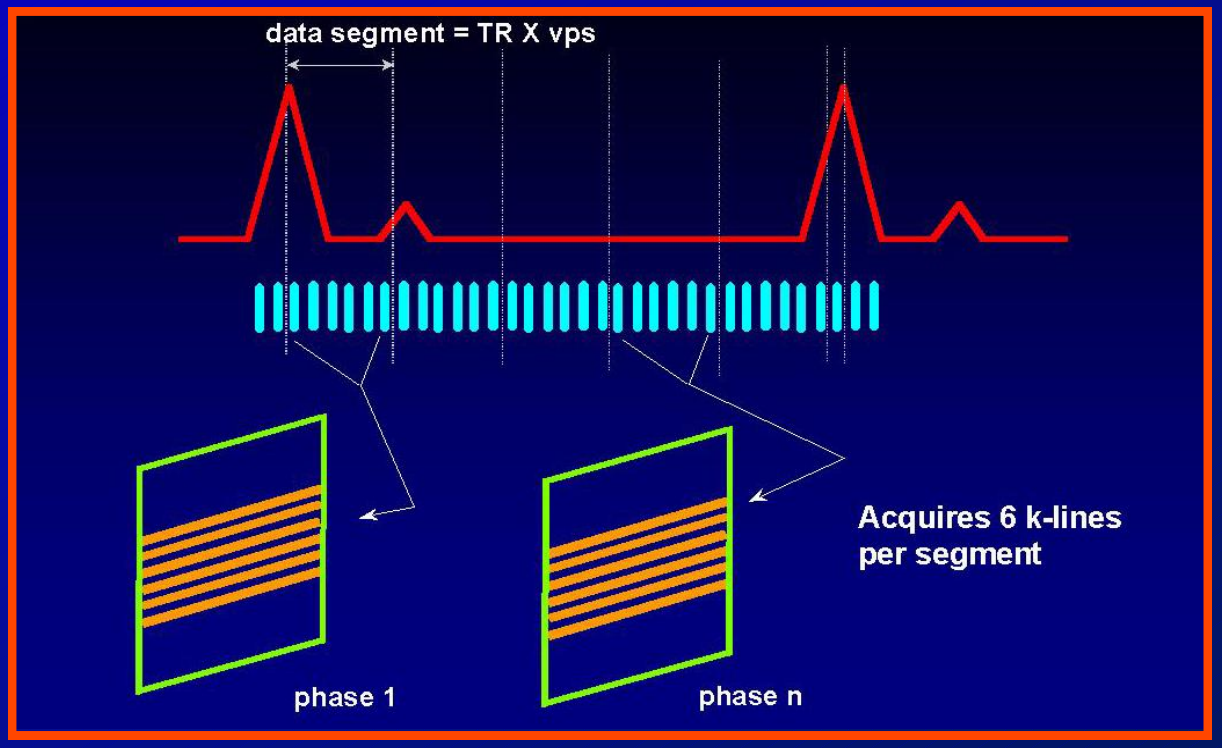
MAGNETIC RESONANCE IMAGING

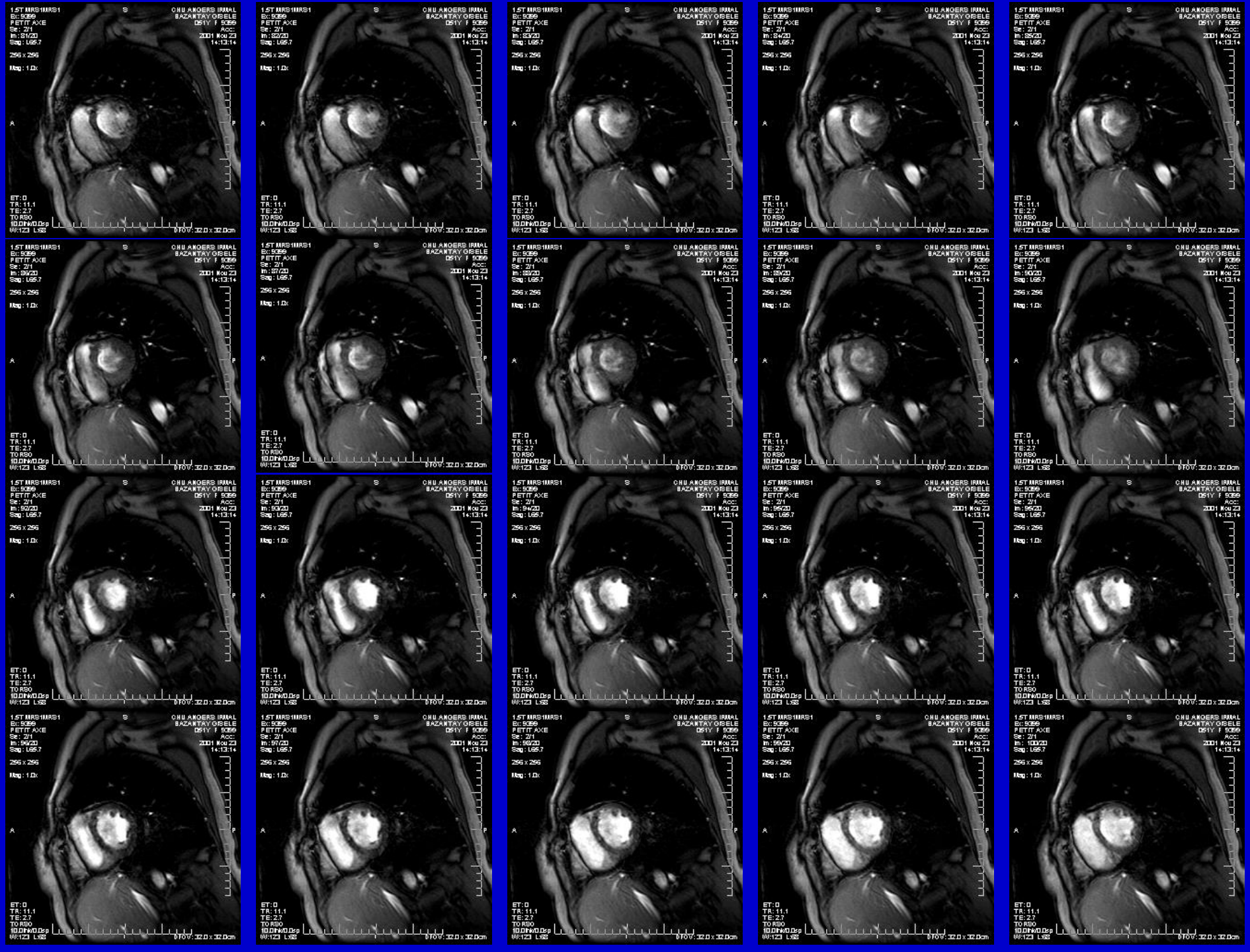
Conventional gradient echo cine



MAGNETIC RESONANCE IMAGING

Fast gradient echo cine segmented k-space




1.5T MRS1MRS1
CHU ANGERS IRMAL
BAZANTAY GISELE
PETIT AXE
2001 Nov 23
14:13:14
256 x 256
Mag : 1.0x
ET:0
TR: 11.1
TE: 2.7
T0 RS0
10.0HW0.0sp
W\123 LS8
DFOV: 32.0 x 32.0cm

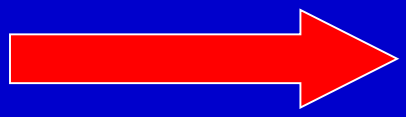
Fonction VG et IRM

- Limites de l'écho de gradient rapide
  - Flux sanguin lent :
    - Muscles papillaires
    - Anomalies sévères de la contractilité
  - Diminution sensible du contraste entre myocarde et sang circulant
  - Echec des logiciels de détection automatique des contours endocardiques

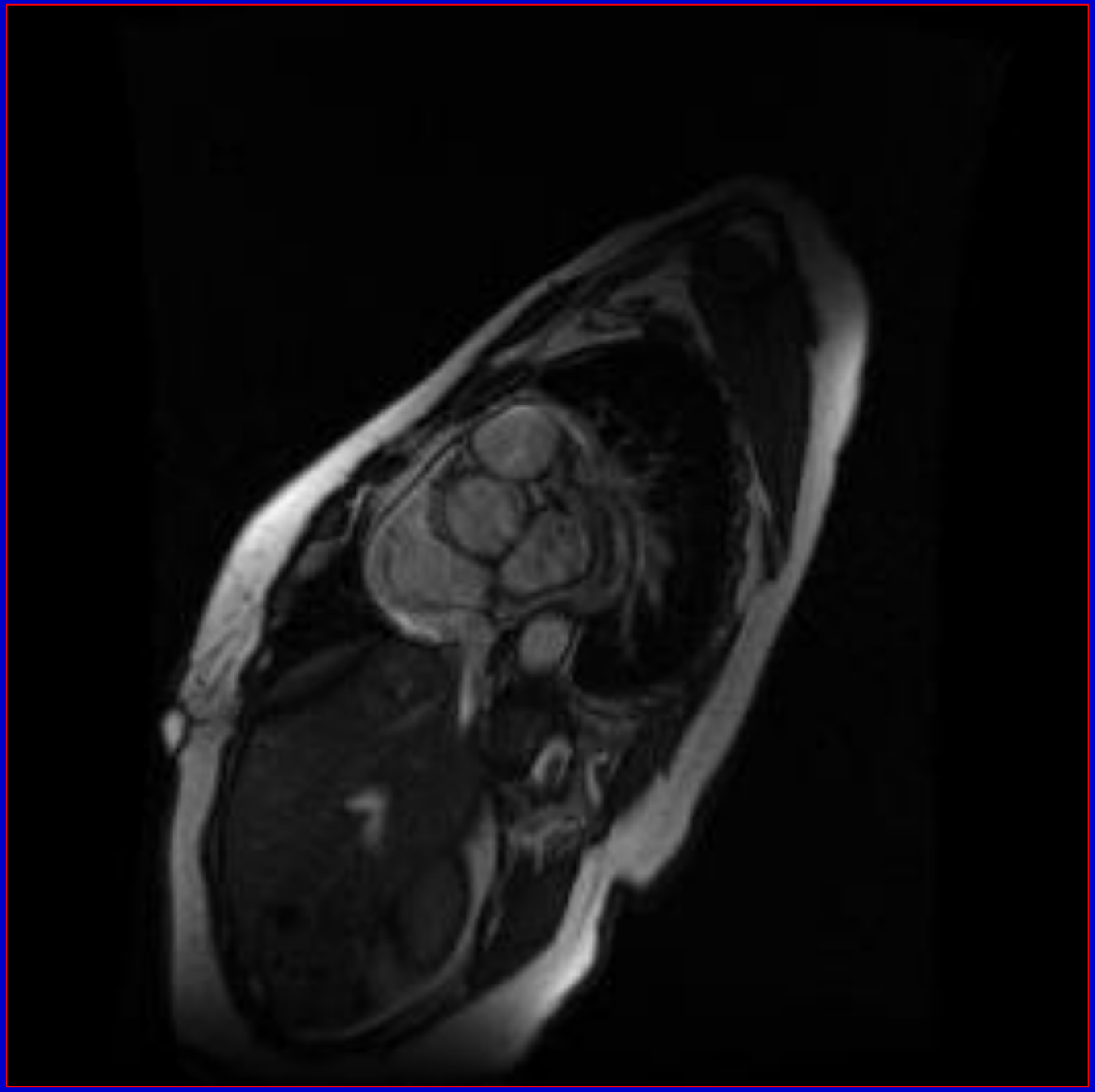
Fonction VG et IRM

Les séquences Précession à l'équilibre

- SSFP Steady-State Free Precession
  - FIESTA, FISP, True FISP, BFFE, …
- Dépend de T1/T2 tissulaire et peu du flux
- Nécessite un TR très court (sensible aux inhomogénéités du champs magnétique)

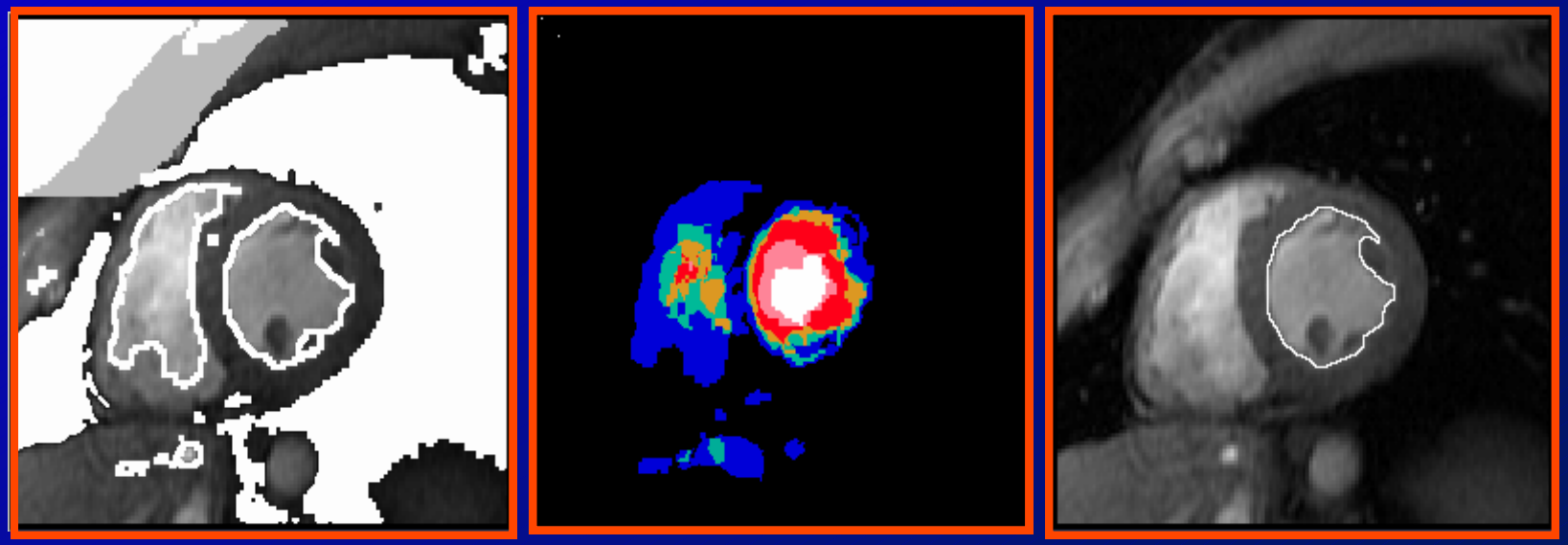


Augmentation SNR et CNR
Augmentation résolution temporelle
Diminution temps d'acquisition X 3
Pour une même résolution spatiale



Description of the detection algorithm

Location of the human left ventricle

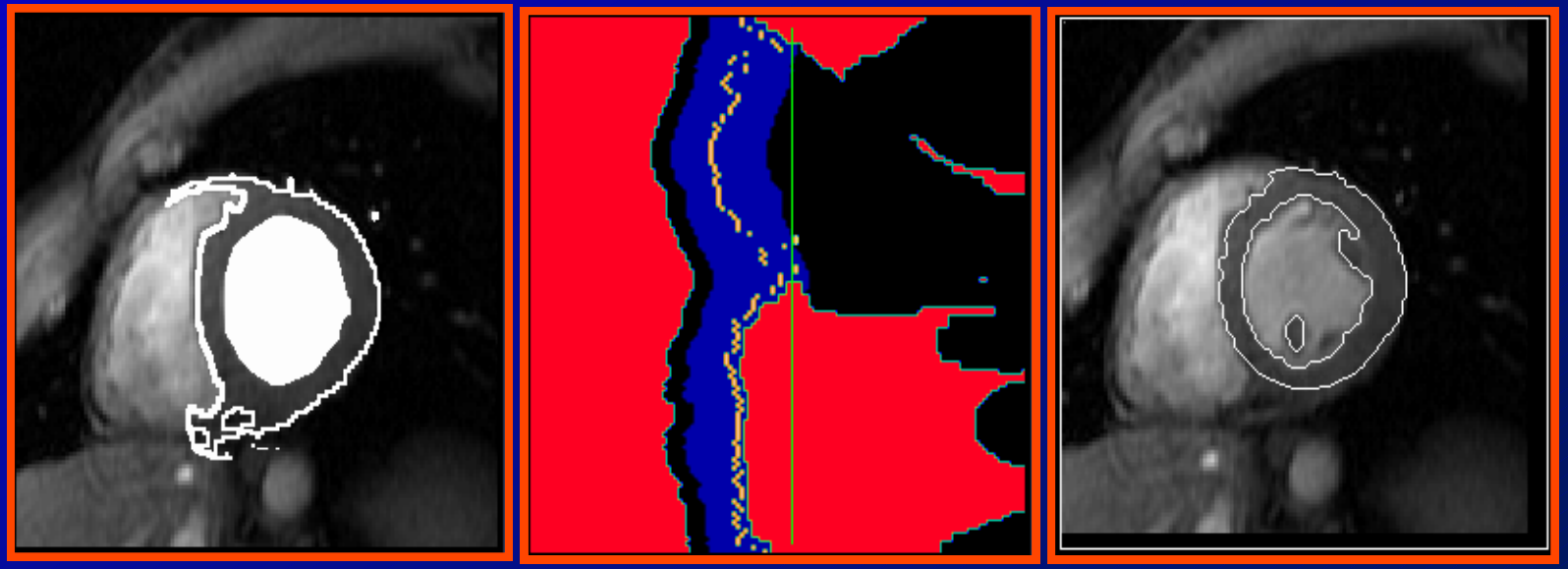


(a) (b) (c)

A. Furber et al. J.M.R.I. 1998

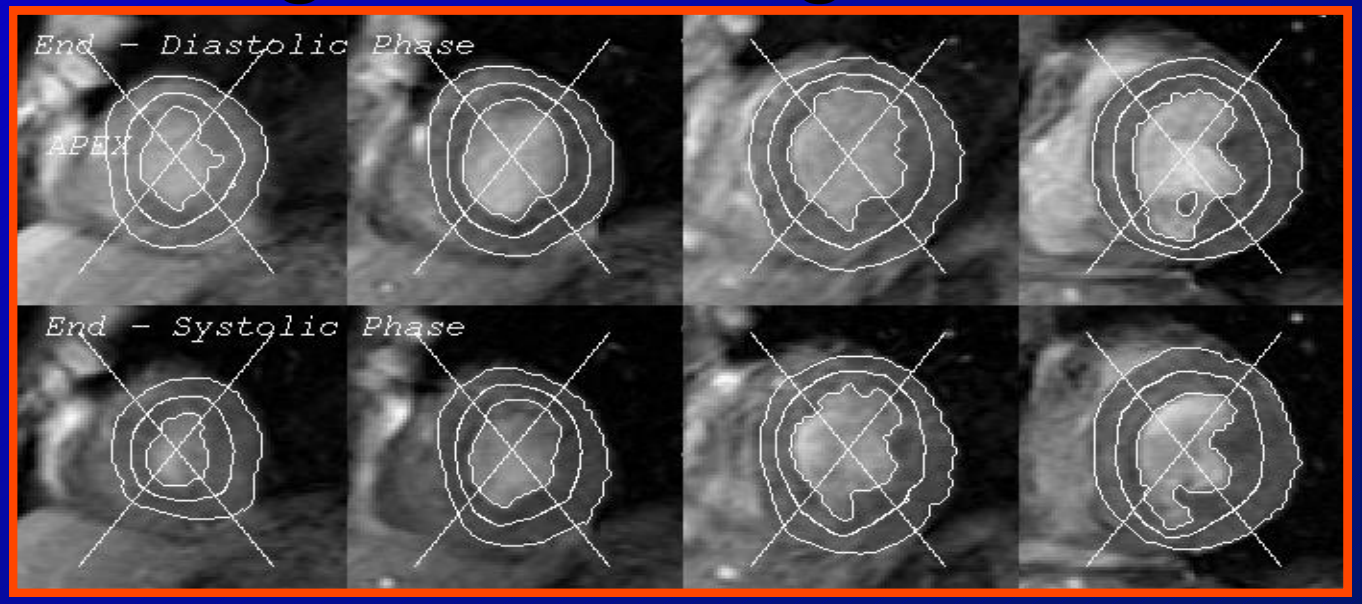
Description of the detection algorithm

Definition of a search zone for the detection of the epicardium and construction of the myocardial borders in normal volunteer



A. Furber et al. J.M.R.I. 1998

Fonction ventriculaire gauche globale et régionale



FE, VTD, VTS
masse VG

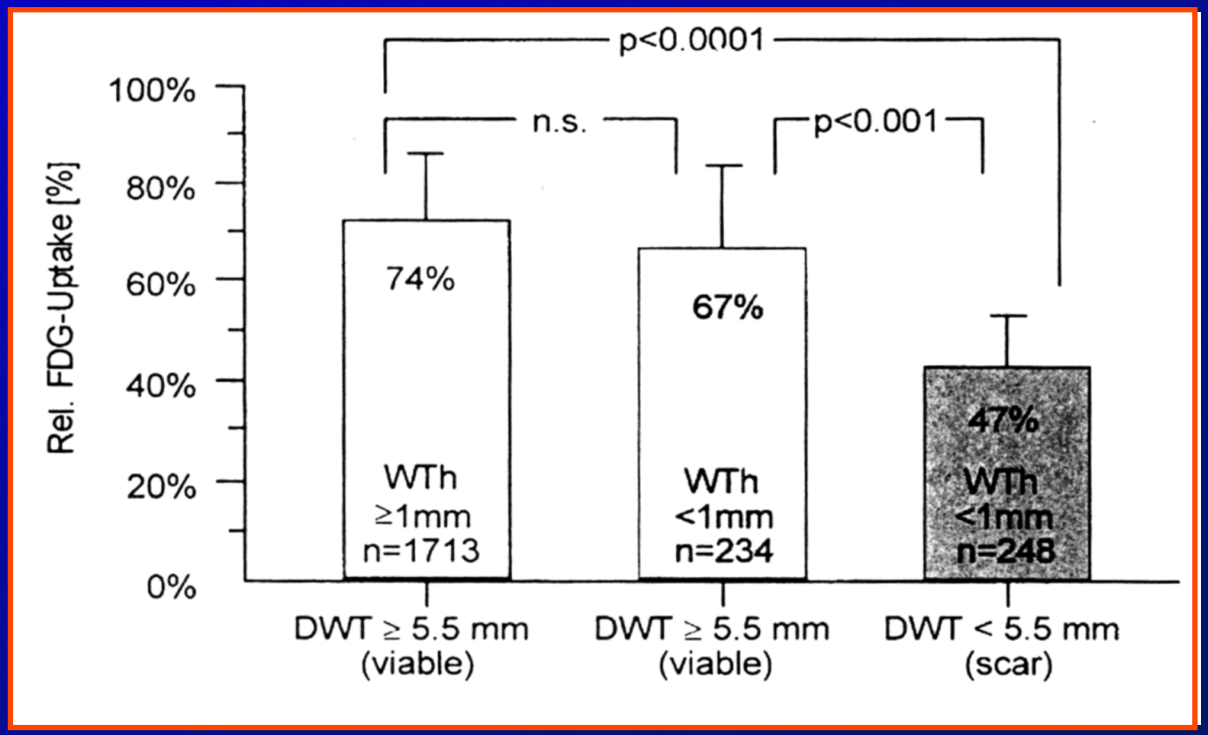
FE sectorielles,
Mvt endocardique
épaississement systolique

Viabilité et IRM
Infarctus chronique

- Epaississement systolique ≥ 2 mm : Viabilité
- Absence d'épaississement systolique
  - Epaisseur pariétale télédiastolique
  - Epaisseur pariétale télésystolique

Viabilité et IRM

Epaisseur pariétale télédiastolique



Baer et al. Circulation 1995

5,5 mm = moyenne des normaux – 2,5 DS

Viabilité et ciné-IRM

Valeur prédictive de récupération fonctionnelle après revascularisation

Dobutamine 10 µg/kg/mn	Stress SWT≥2mm	DWT ≥ 5.5mm
Sensitivity	89%	92%
Specificity	94%	56%
Positive predictive accuracy	96%	78%
Negative predictive accuracy	83%	82%
Diagnostic accuracy	91%	79%

Baer et al. JACC 1998

DWT < 5,5 mm : 12/125 segments récupèrent

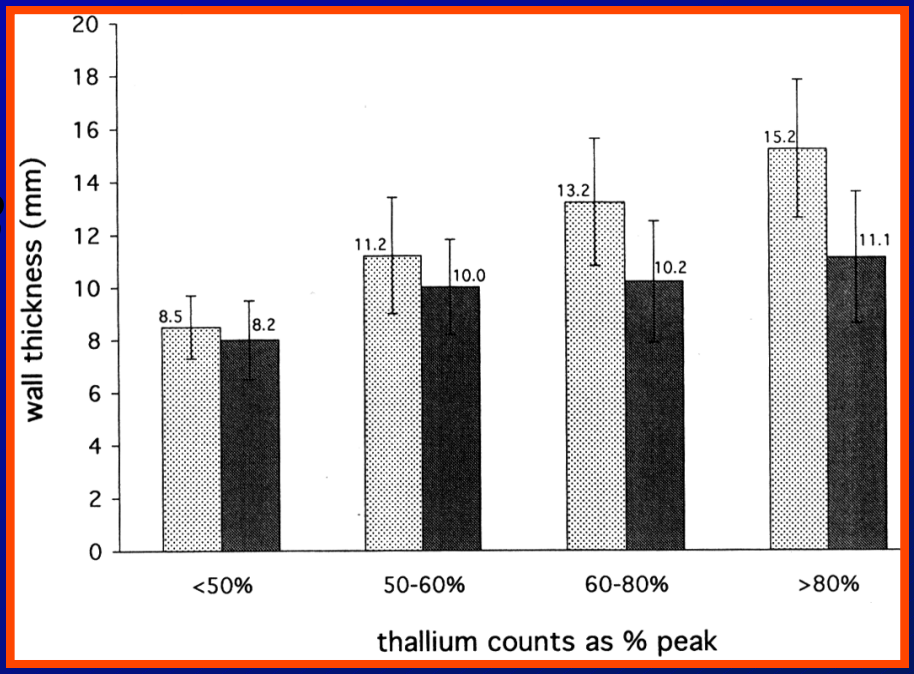
Negative predictive accuracy 90 %

Viabilité myocardique et Ciné-IRM

Corrélation IRM Th-201 sur 18 secteurs

Epaisseur
systolique 14/18
diastolique 4/18

Epaississement
systolique 3/18



Lawson et al. Am J Cardiol 1997

Epaisseur télésystolique ≥ 9,8 mm
Sensibilité 90 %, Spécificité 94 %
Fixation Thallium > 50 %

Viabilité et IRM
Infarctus aigu

- IDM reperfusé épaisseur pariétale identique dans l'infarctus transmural et sous-endocardique
- Amincissement existe même en l'absence de nécrose transmurale : phénomène d'expansion
- Augmentation de l'épaisseur pariétale secondaire à l'œdème péri-infarctus
- Absence de corrélation entre pourcentage d'épaississement et étendue de l'infarctus (stunning)

MR viability imaging / FDG PET

Dobutamine stress MRI : Contractile reserve
Myocardial infarction ≥ 4 months

Dobutamine 10μg / kg / min	TEE	MRI
MRI 89 % agreement		
Sensitivity	77%	81%
Specificity	94%	100%
PP accuracy	95%	100%
NP accuracy	73%	77%
Diagnostic accuracy	84%	88%

Baer et al. Am J Cardiol 1996

91 % agreement between DES and MRI
in the detection of myocardial viability

Zamorano et al. Am J Cardiol 2002

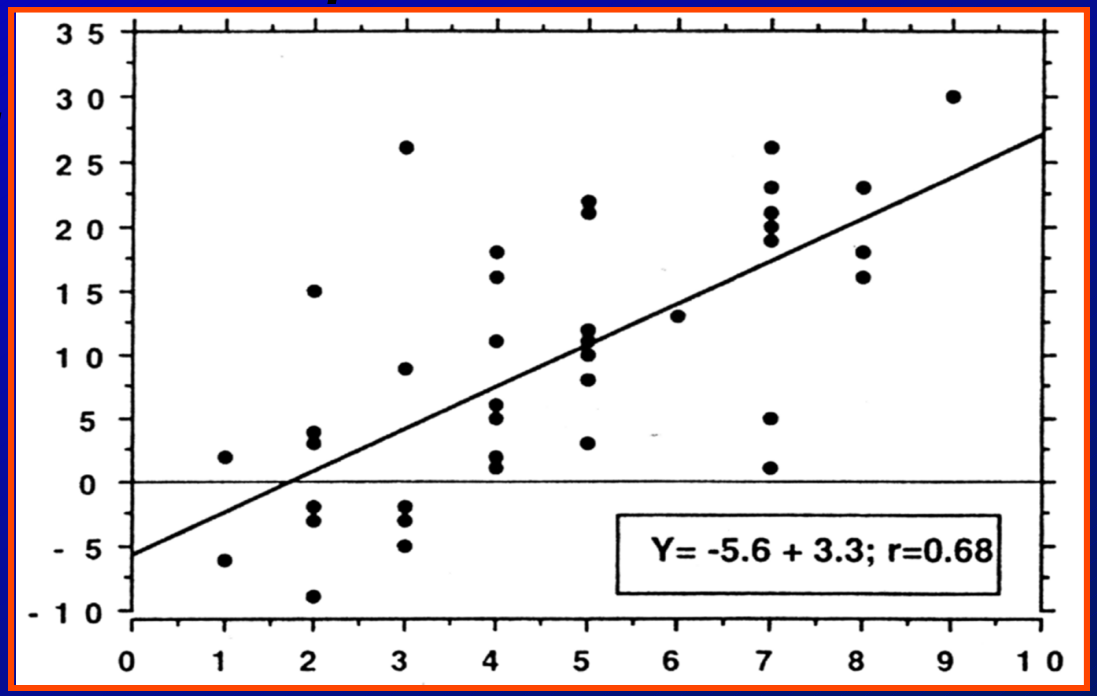
Viabilité myocardique et Ciné-IRM

Réserve contractile sous dobutamine

	Sensibilité	Spécificité	Référence
Baer 1995	81 %	95 %	FDG TEP
Baer 1996	81 %	100 %	FDG TEP
Dendale 1995 (IDM aigu)	91 %	69 %	Récup fonct
Baer 1998	89 %	94 %	Récup fonct
Sayad 1998	89 %	93 %	Récup fonct

Viabilité et ciné-IRM de stress

Corrélation entre réponse à la Dobutamine et récupération fonctionnelle



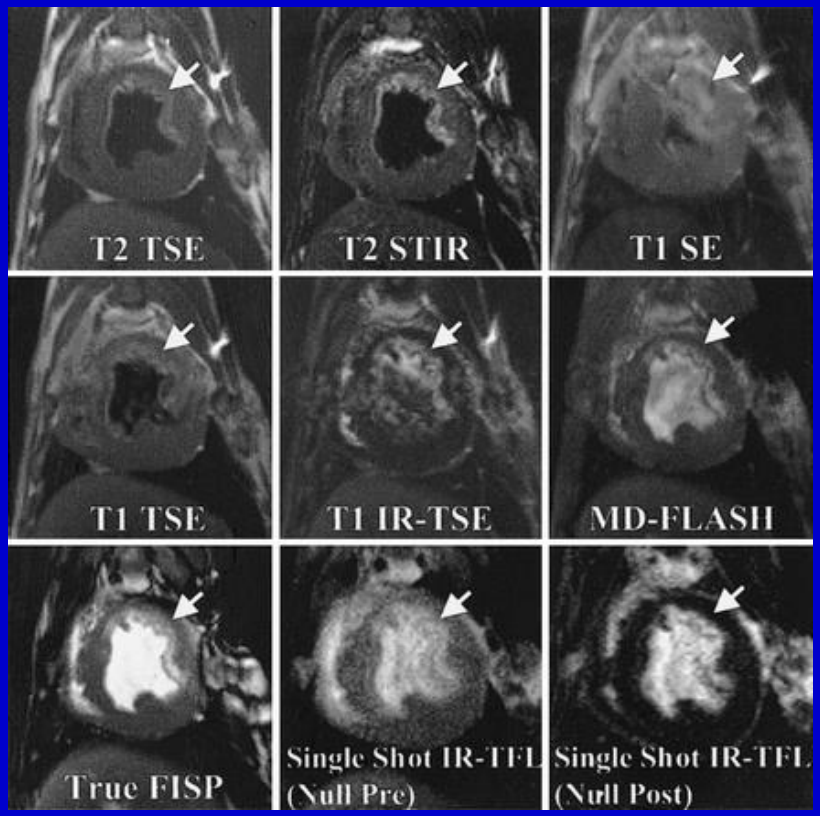
Avantages et limites de l'IRM

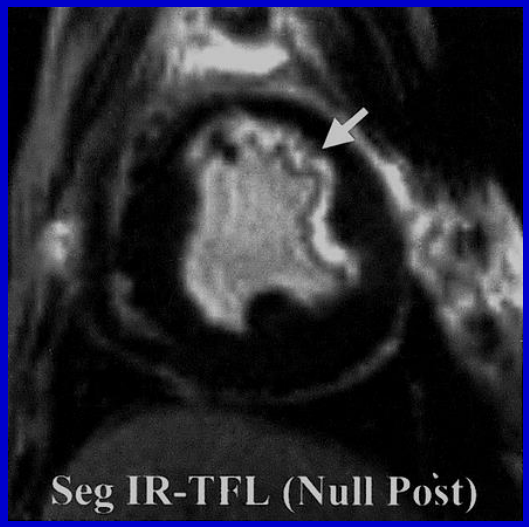
- Visualisation de l'ensemble du VG
- Résolution spatiale et temporelle
  - Analyse qualitative et quantitative
  - Même quand la FC augmente (2D FIESTA, …)
- Les limites de l'aimant
  - Surveillance du patient (il faut rester dans l'aimant)
  - Qualité de l'ECG dans l'aimant (nb de dérivations)
  - Complications de la dobutamine rare à 10 µg/kg/min mais 7,4% à fortes doses :
    - TV 0,07 %, FV 0,07 %
    - Hypertension 0,4 %, Hypotension 0,7 %

Réhaussement tardif après gadolinium

Viabilité

Influence de la séquence





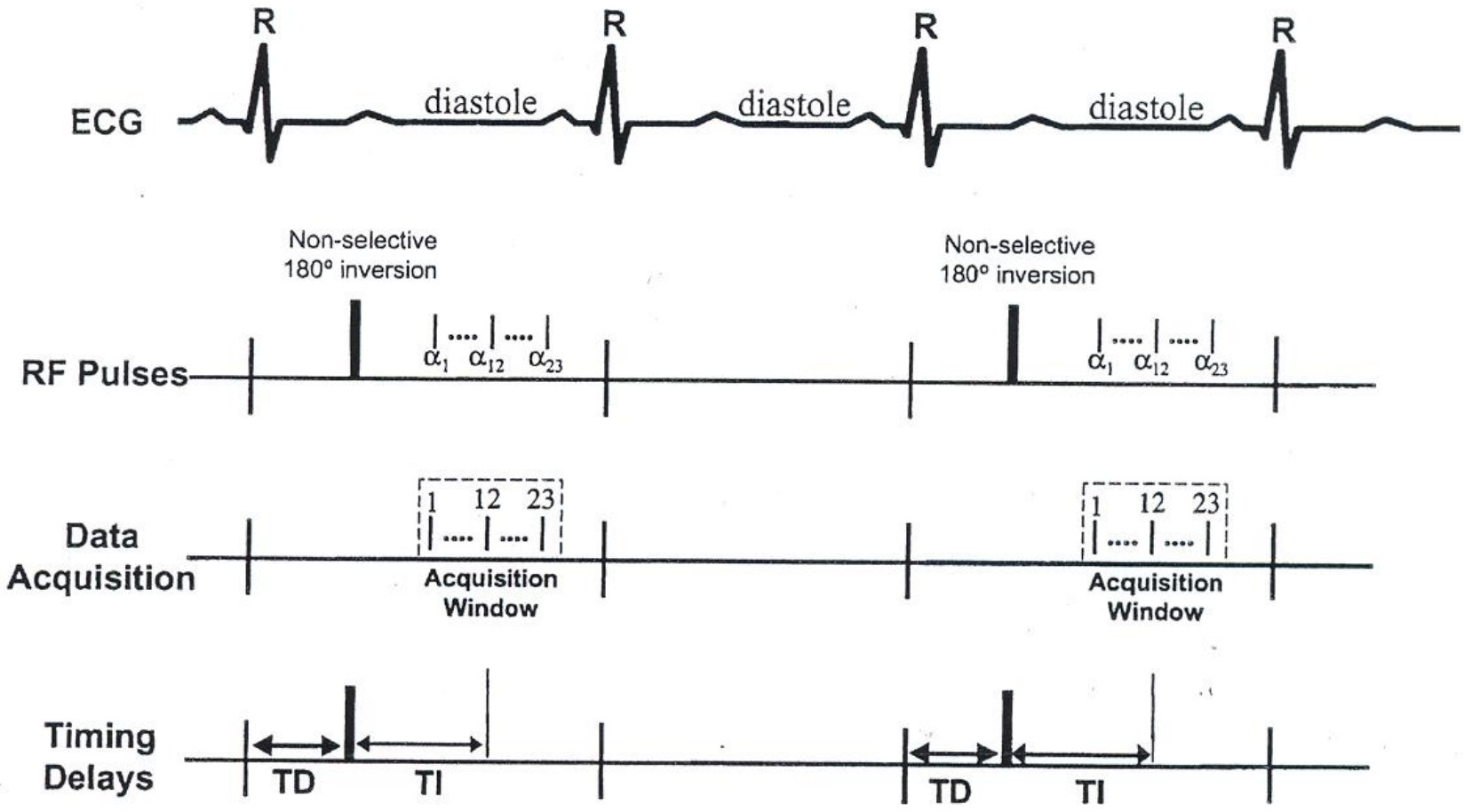
The segmented inversion-recovery turboFLASH (*Seg IR-TFL*) (or IR prep Fast GRE) image demonstrates the highest contrast-to-noise ratio between the infarcted and normal myocardium.

Simonetti et all. An improved MR imaging technique for the visualization of myocardial infarction. Radiology 2001.

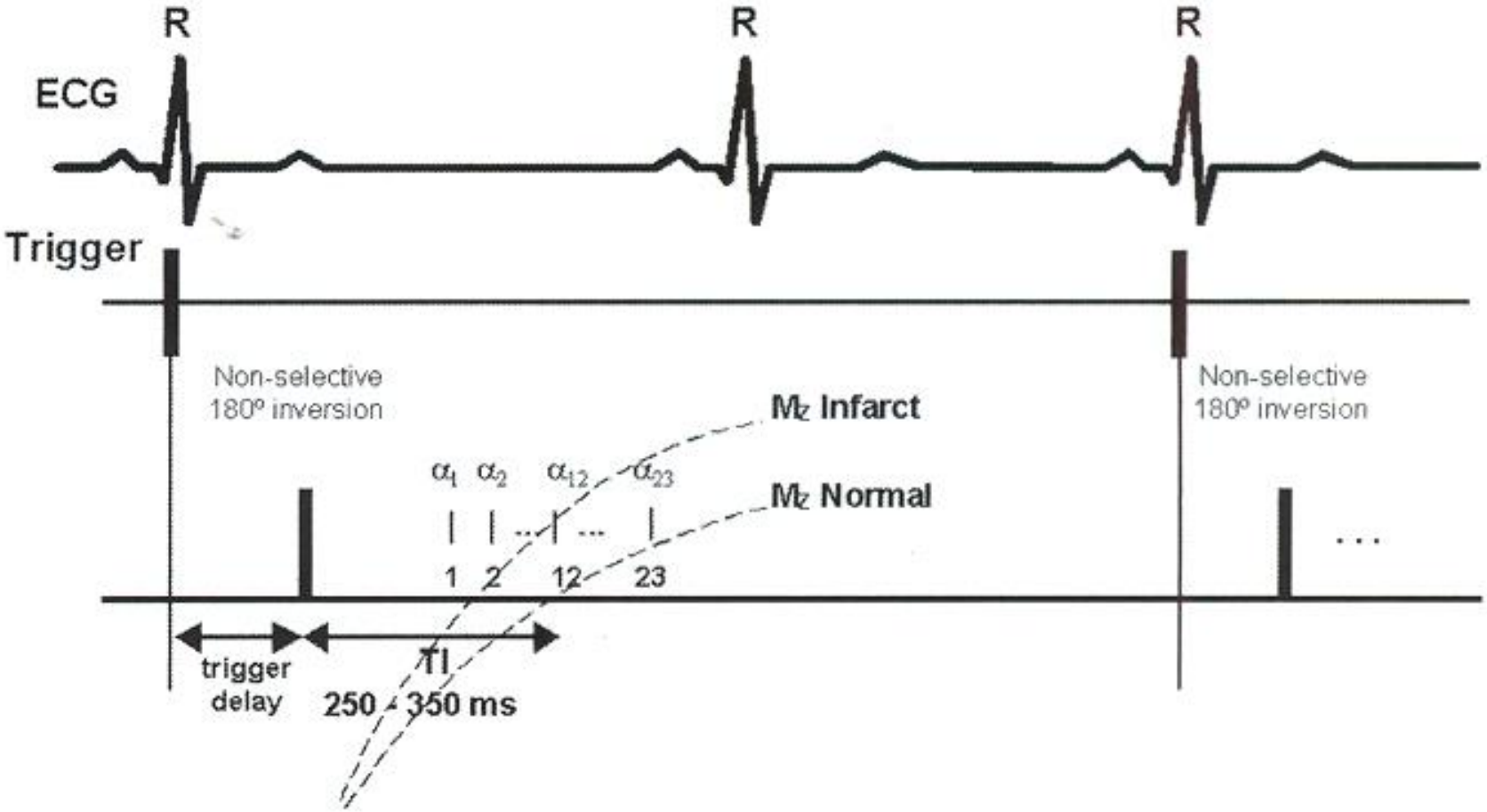
Principe du réhaussement tardif

- Gadolinium 0,1-0,2 mmol/kg
  - Raccourcissement T1
  - Accroissement du signal des images pondérées T1
- Séquences pondérées T1
  - Basées sur une inversion-récupération
  - Segmentées Acquisition pendant une apnée
  - Impulsion initiale d'inversion
    - Temps d'inversion Ti

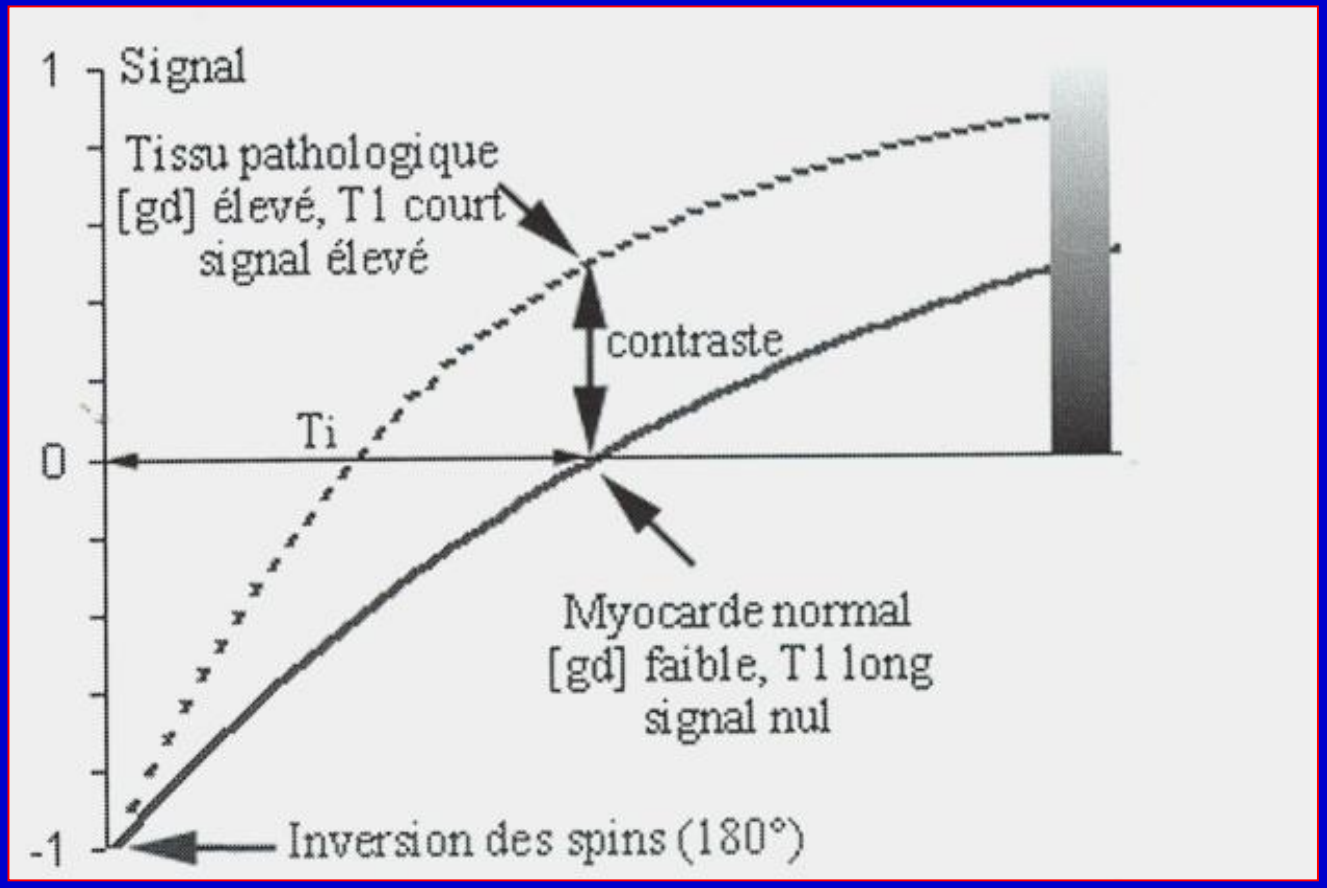
Principe du réhaussement tardif

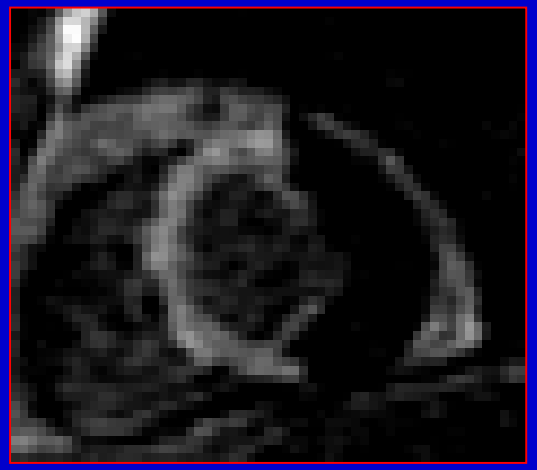


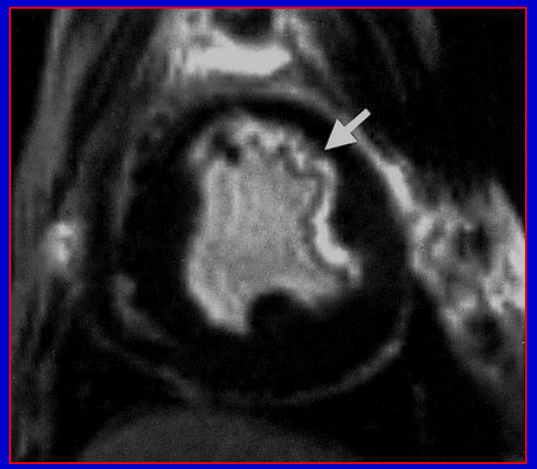
Principe du réhaussement tardif



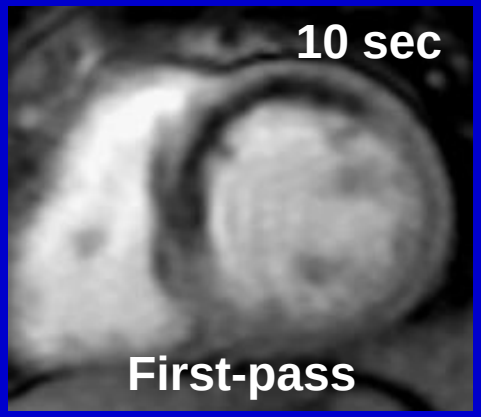
Delayed hyperenhancement



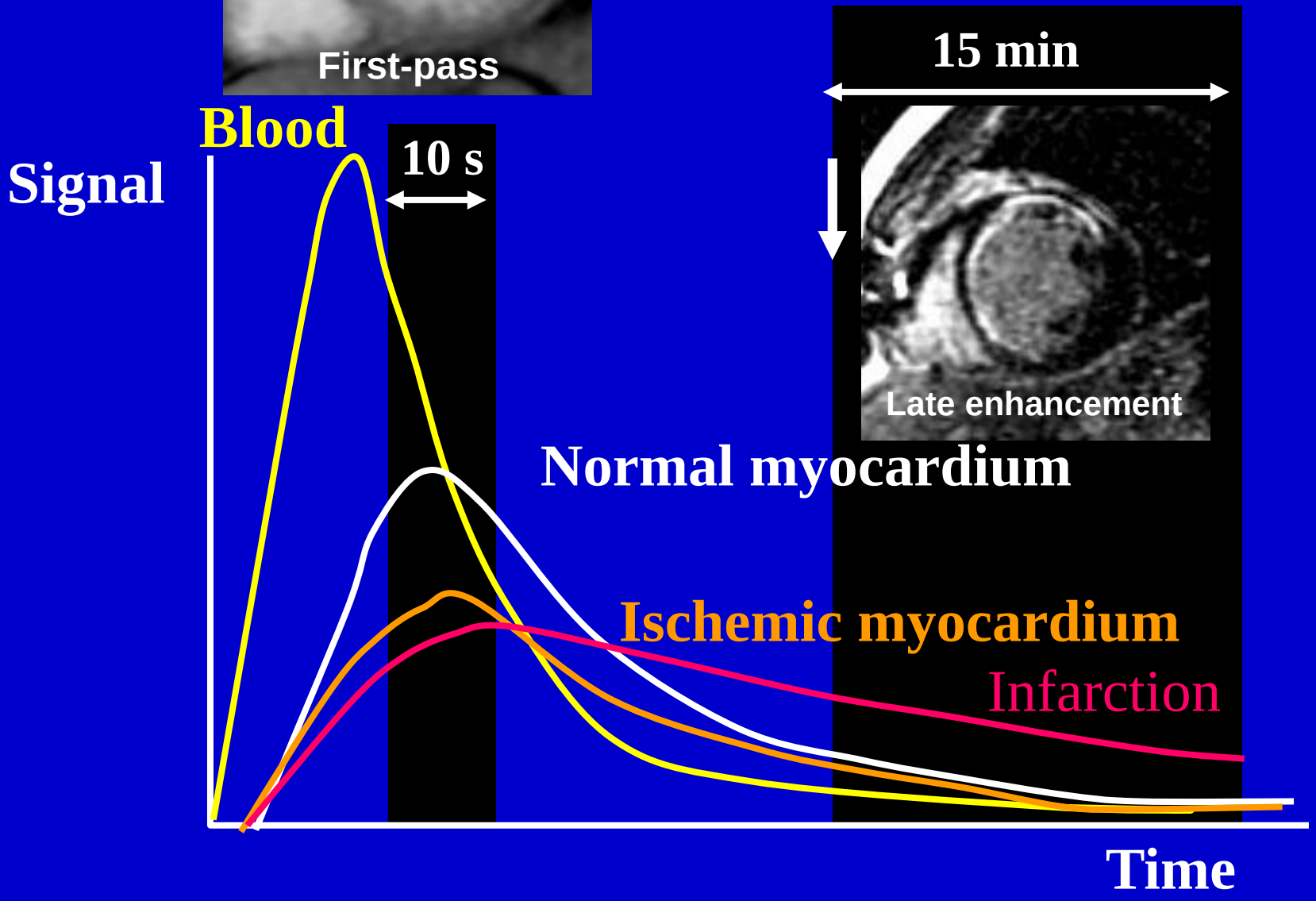




500 to 1000 % increase in the signal intensity
of infarcted compared to remote regions



Wolff et al. Circulation 2004
Sensitivity 93%, Specificity 75%

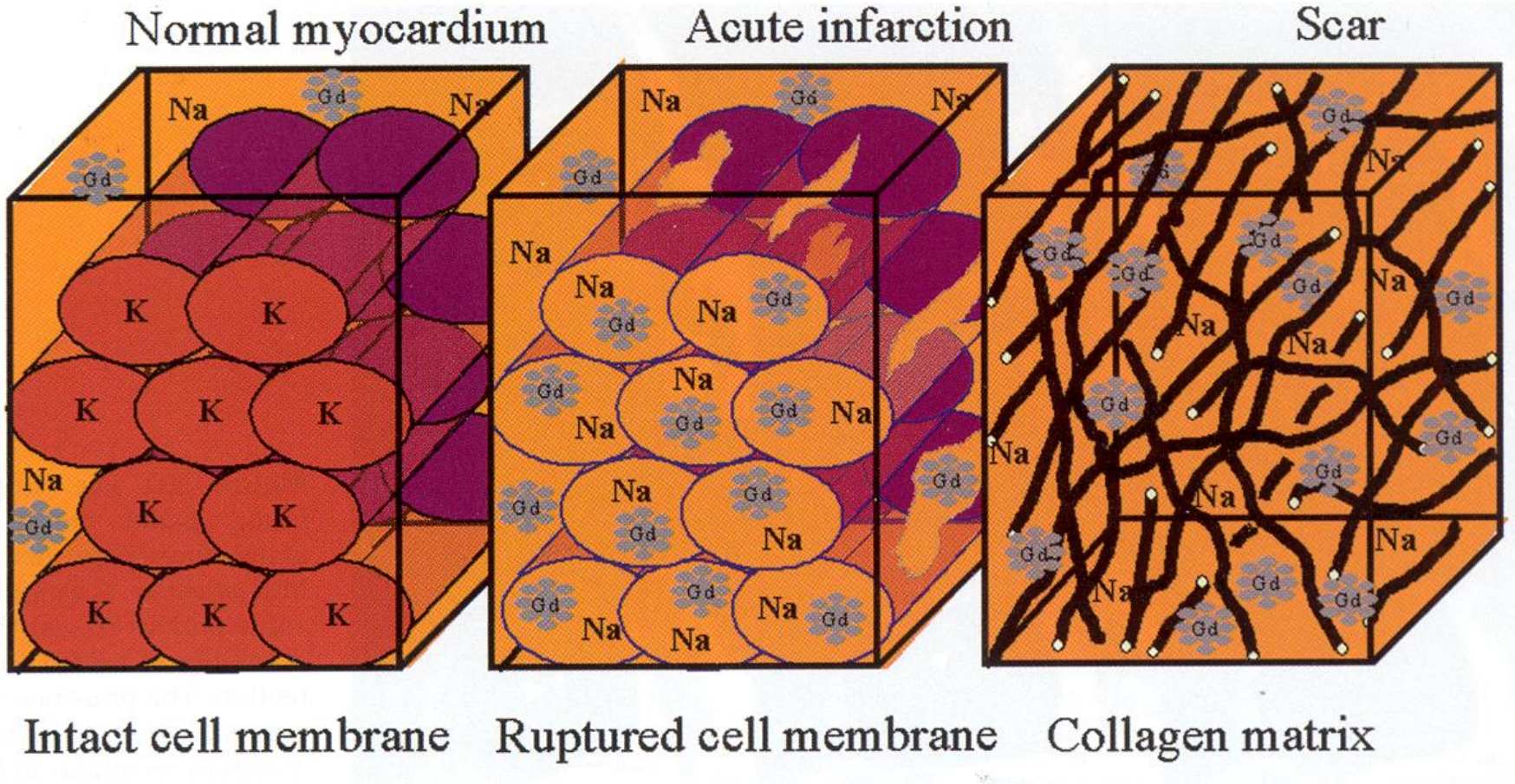


Rétention du gadolinium

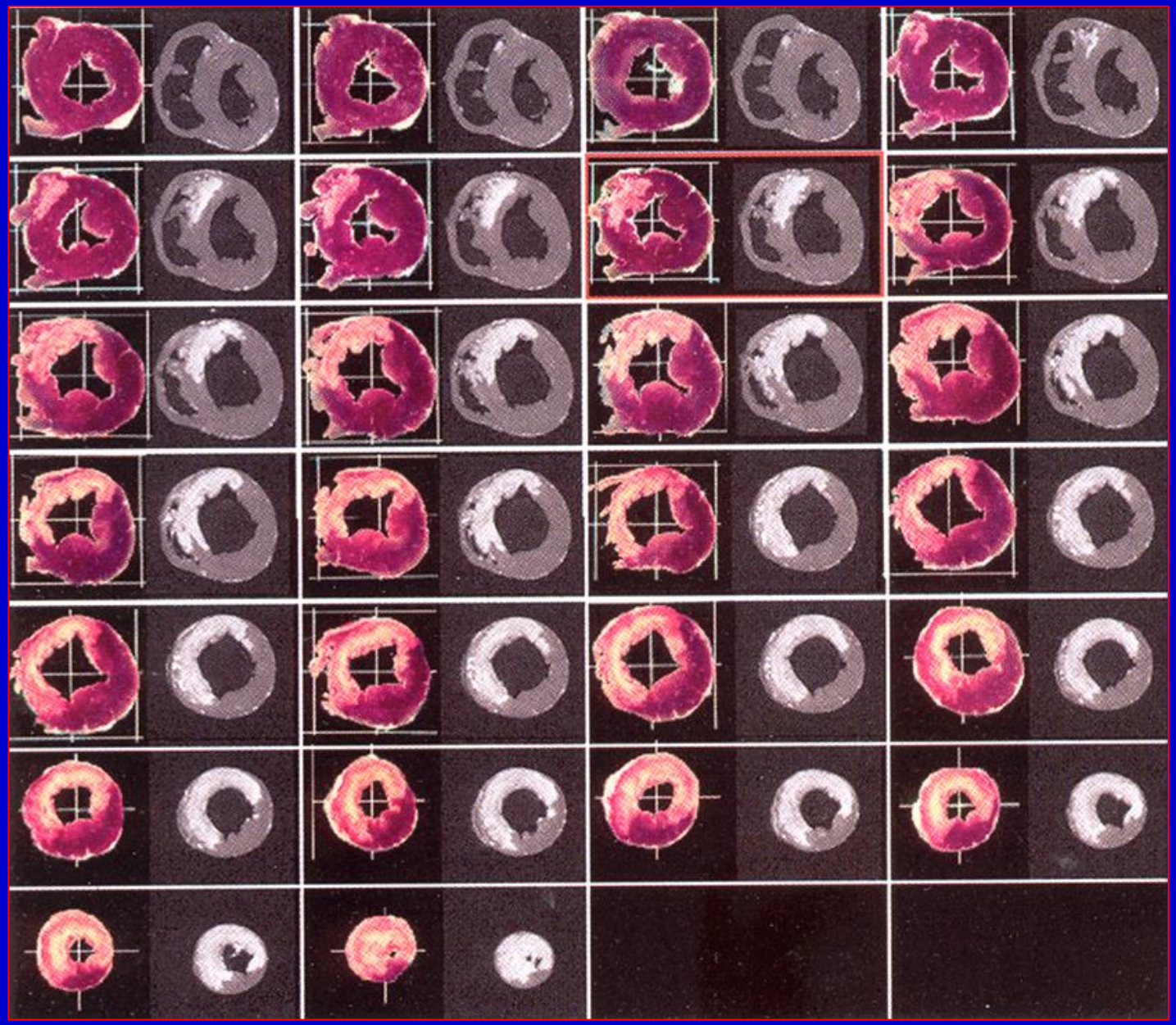
- Distribution dans le compartiment extracellulaire
- Infarctus aigu
  - Diminution du wash-out dans les tissus inflammatoires et oedématiés de la zône infarcie
  - Accroissement du volume de distribution
    - Compartiment intracellulaire détruit

Infarctus chronique

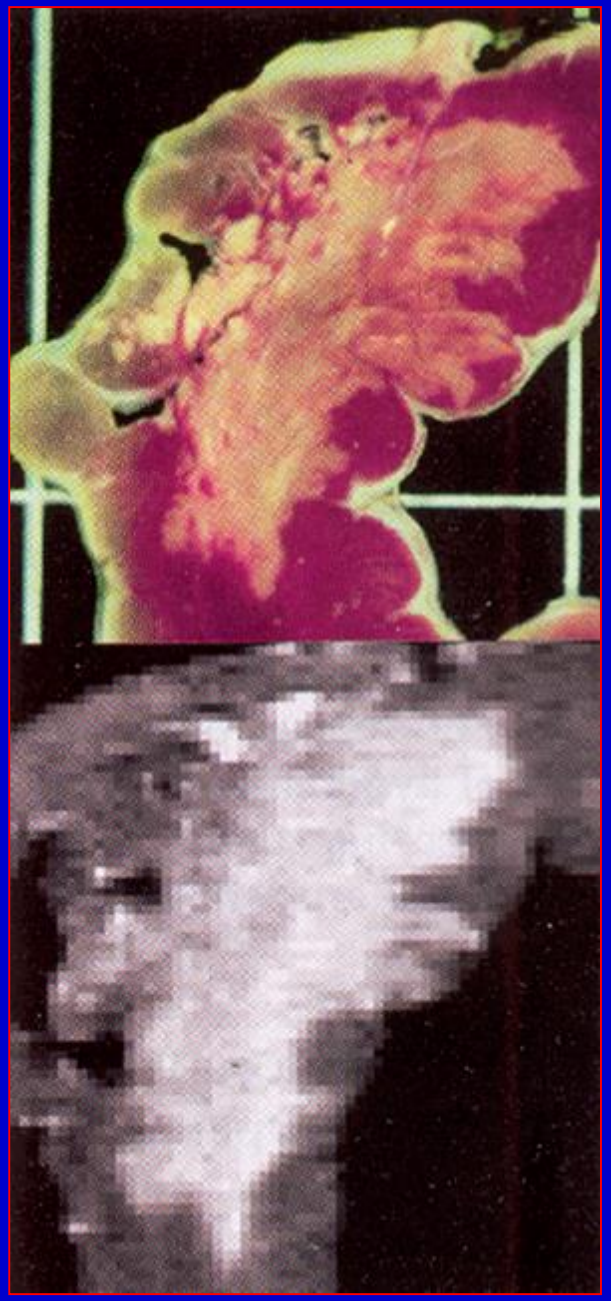
- Augmentation du volume de distribution extracellulaire par accroissement de l'espace interstitiel (cicatrice fibreuse)



Réhaussement tardif
Infarctus aigu

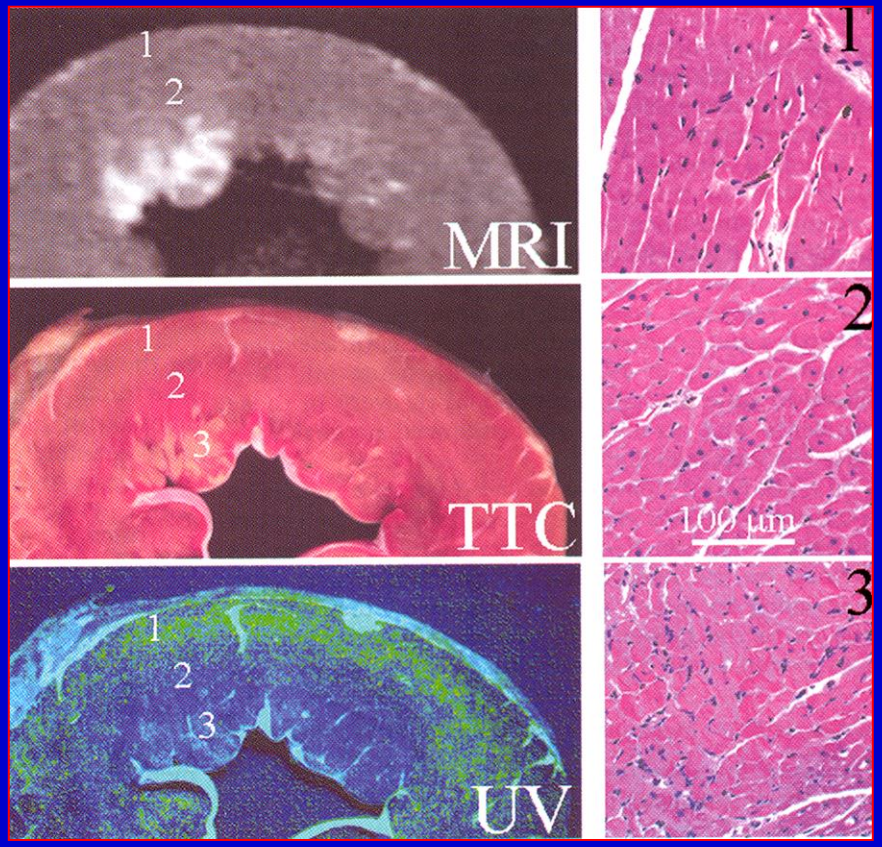


Kim et al. Circulation 1999



Infarctus reperfusé et non reperfusé
18 chiens
IRM ex vivo à J3 de l'infarctus
Hypersignal = nécrose (TTC)

Kim et al. Circulation 1999



Nécrose

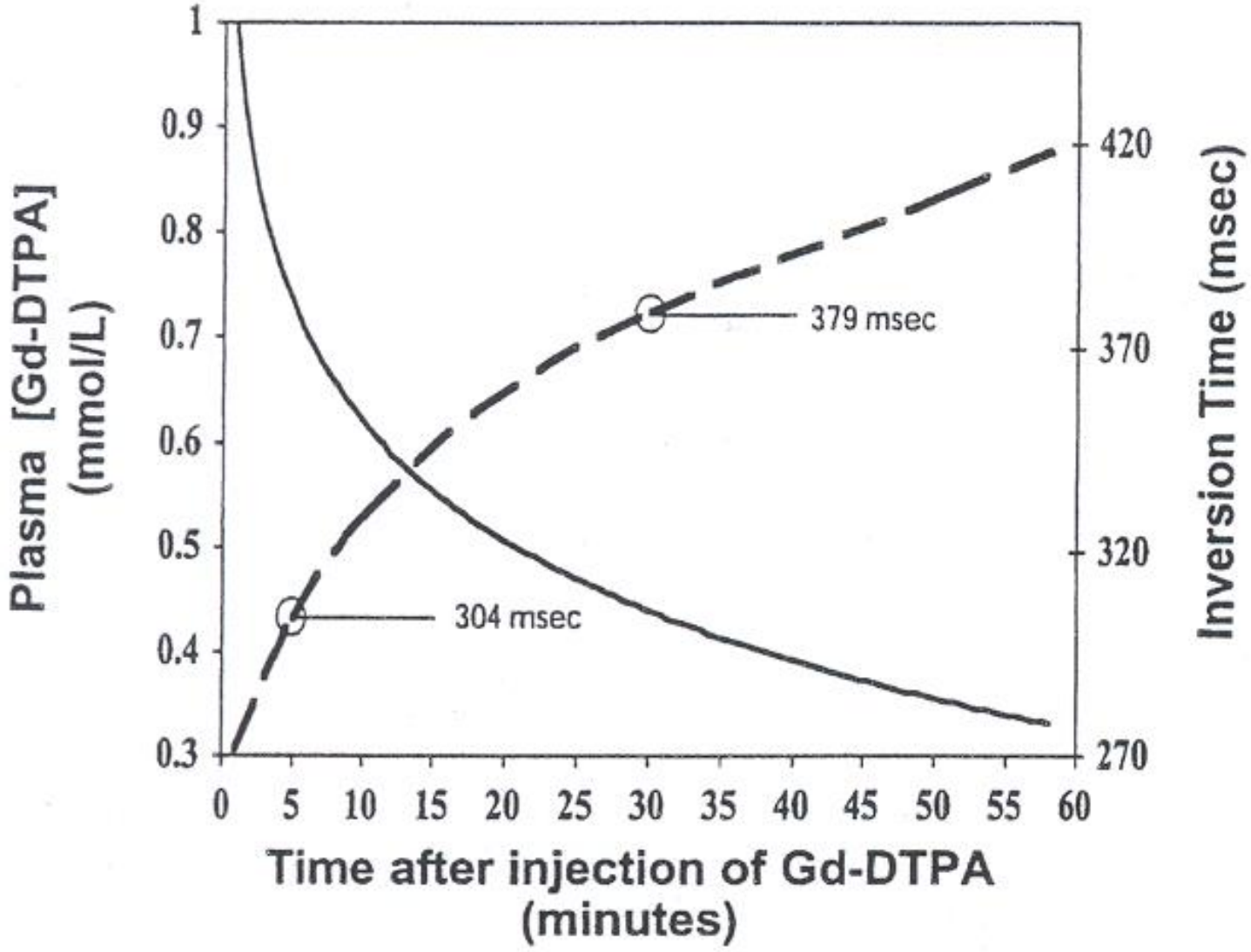
Zône à risque

Microparticules fluorescentes

Fieno et al. JACC 2000

Taille de la zône d'hypersignal

- Délai entre injection de gadolinium et acquisition (disparition en 1h)



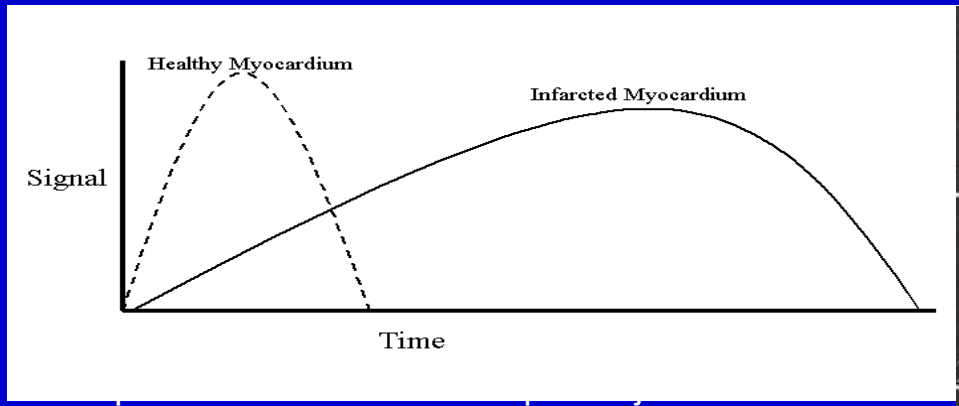
- Lorsque Ti est ajusté, la taille de l'infarctus reste constante

Les conséquences d'un mauvais Ti

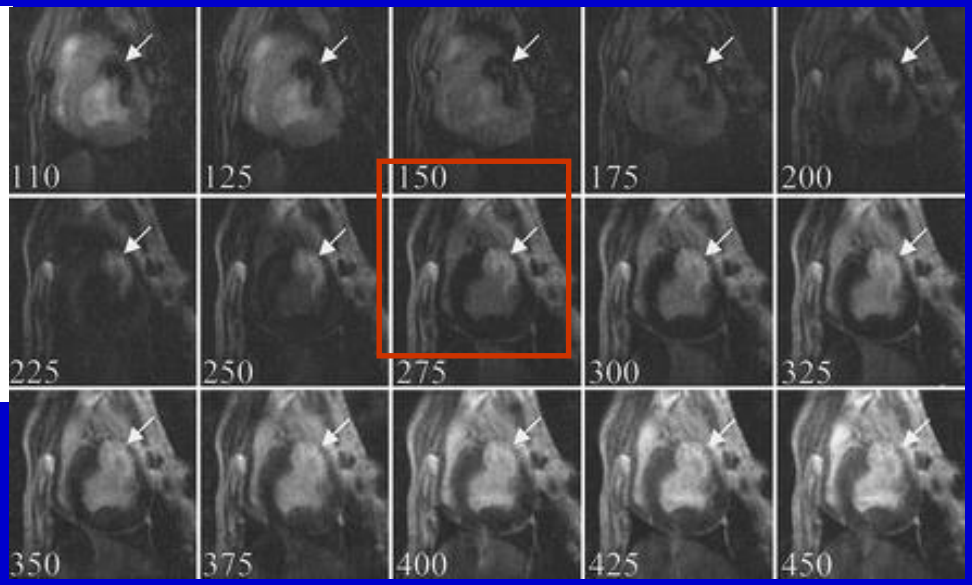
- si le Ti est trop court
  - Sous-estimation de l'hypersignal
- si le Ti est trop long
  - Diminution du contraste

Viabilité

Influence du temps TI



Gadolinium 0.1mmol/kg)



Typical zero-crossing times:

- Tizero (infarct. myocarde): ca. 80 ms
- Tizero (sang): ca. 150 ms
- Tizero (myocarde normal): 250 ms

Transition de bas à haut signal dans la région infarcie lorsque TI augmente. Dans ce cas, le contraste optimal est atteint à 275 ms de TI, valeur pour laquelle le signal du myocarde normal est nul.

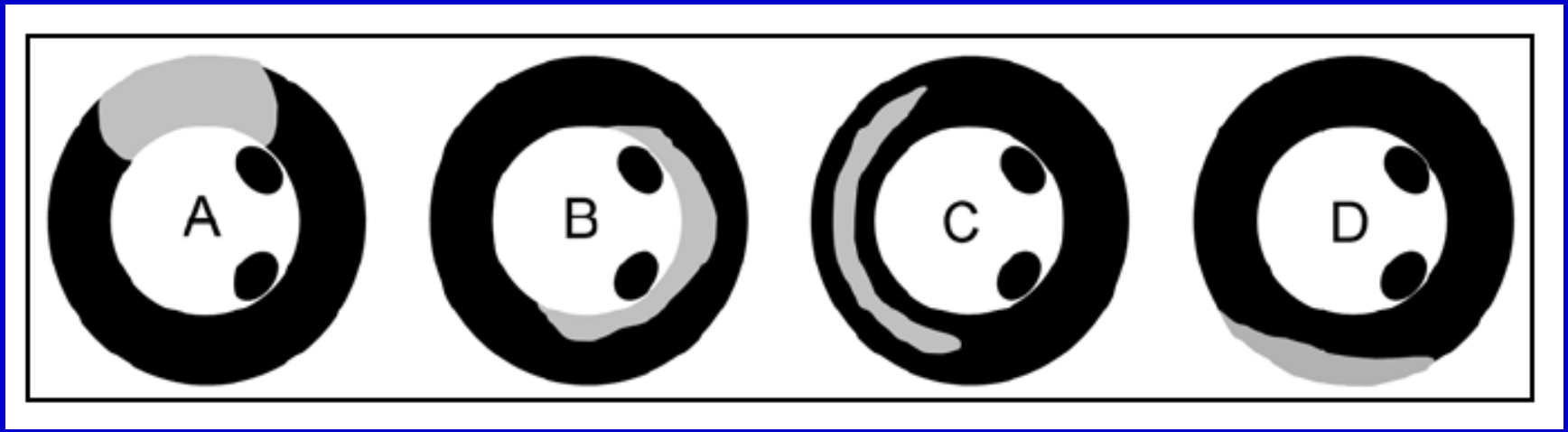
Simonetti et all. An improved MR imaging technique for the visualization of myocardial infarction. Radiology 2001.

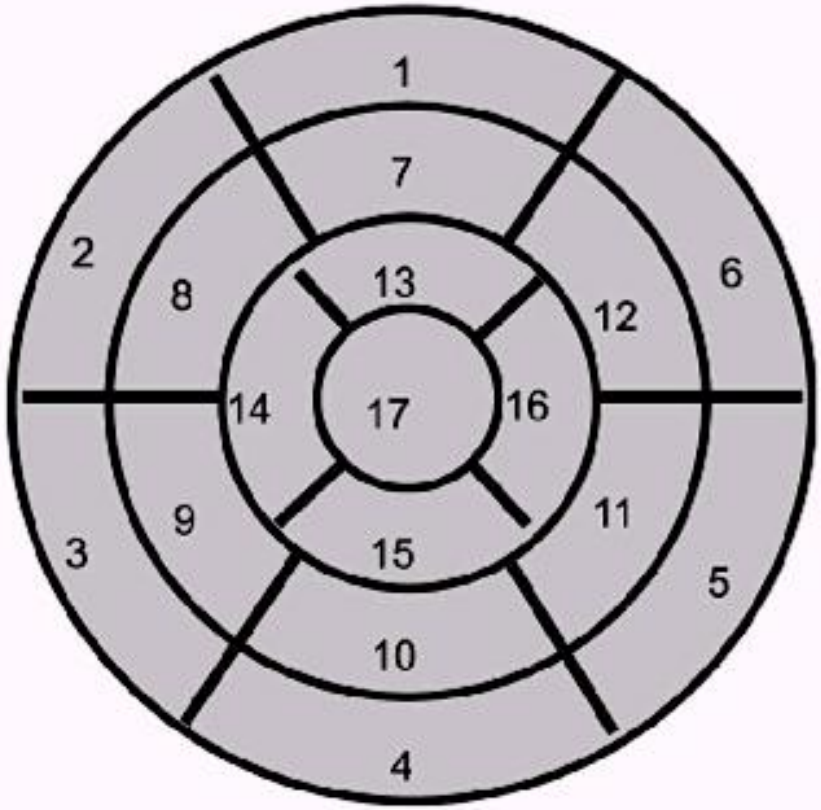
Taille de la zône d'hypersignal

- Age de l'infarctus
  - Diminution des phénomènes inflammatoires
  - Transformation fibreuse
  - La plage d'hypersignal est moins étendue qu'à la phase aiguë (diminution de l'œdème, la cicatrice fibreuse occupe moins de place)

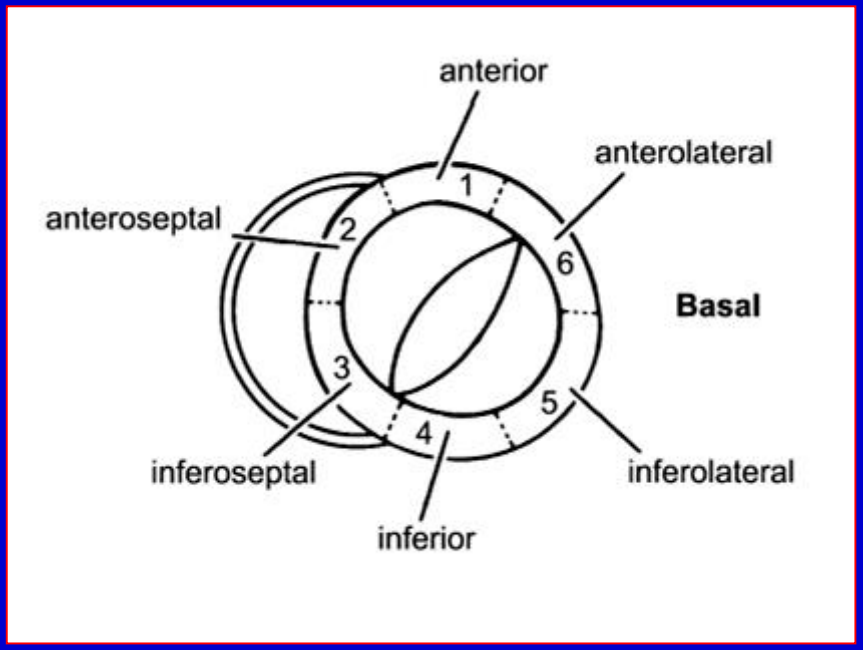
Analyse de l'hypersignal

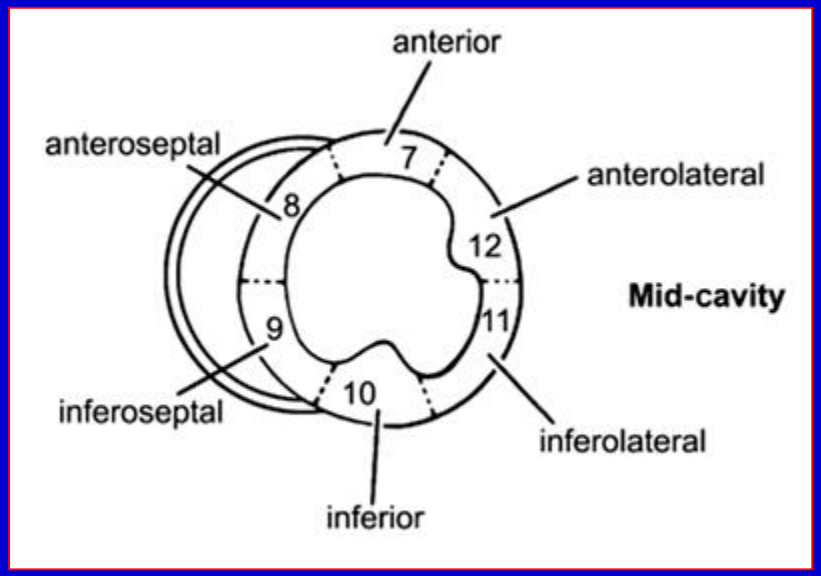
- Localisation
  - Transmural, Sous-endocardique
  - Médio-ventriculaire, Sous-épicardique

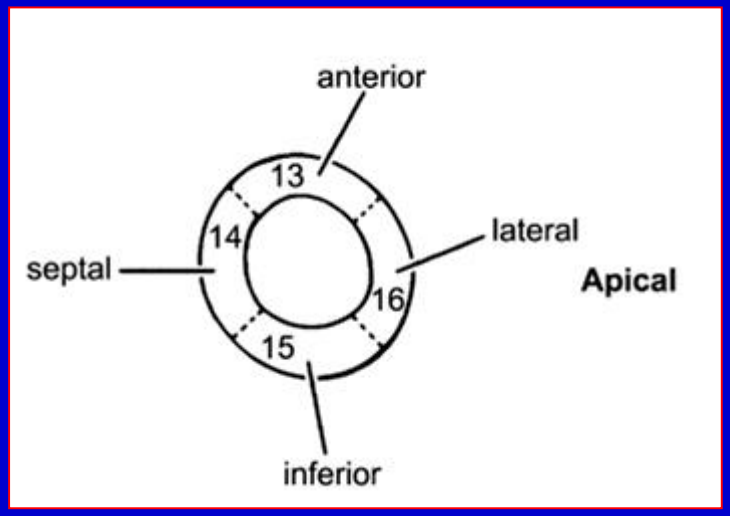


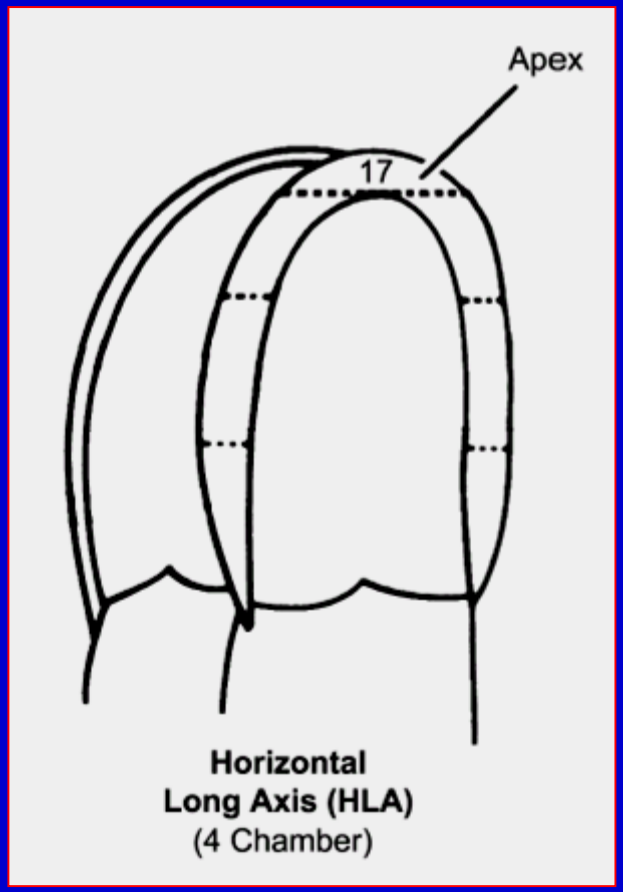


1. basal anterior
2. basal anteroseptal
3. basal inferoseptal
4. basal inferior
5. basal inferolateral
6. basal anterolateral
7. mid anterior
8. mid anteroseptal
9. mid inferoseptal
10. mid inferior
11. mid inferolateral
12. mid anterolateral
13. apical anterior
14. apical septal
15. apical inferior
16. apical lateral
17. apex

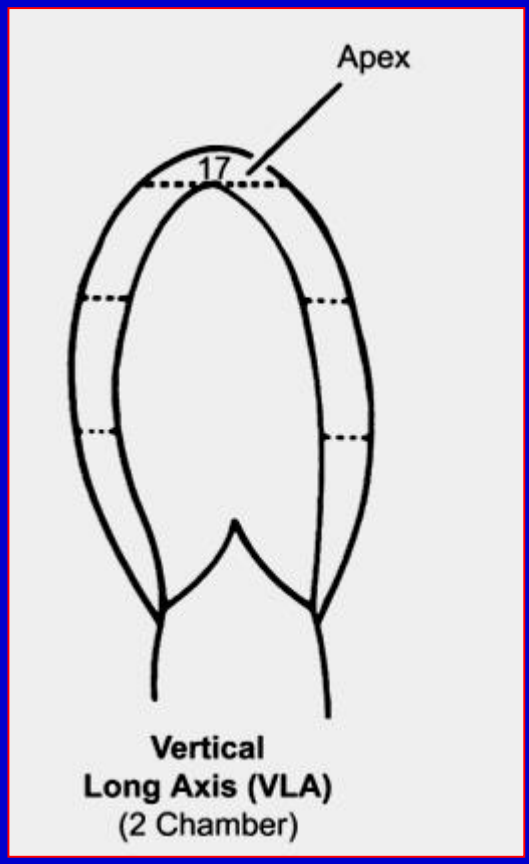

anterior
anterolateral
anteroseptal
1
2
6
Basal
3
5
4
inferoseptal
inferolateral
inferior


anterior
anteroseptal
7
anterolateral
8
12
Mid-cavity
9
11
10
inferoseptal
inferolateral
inferior


anterior
13
lateral
14
septal
16
Apical
15
inferior

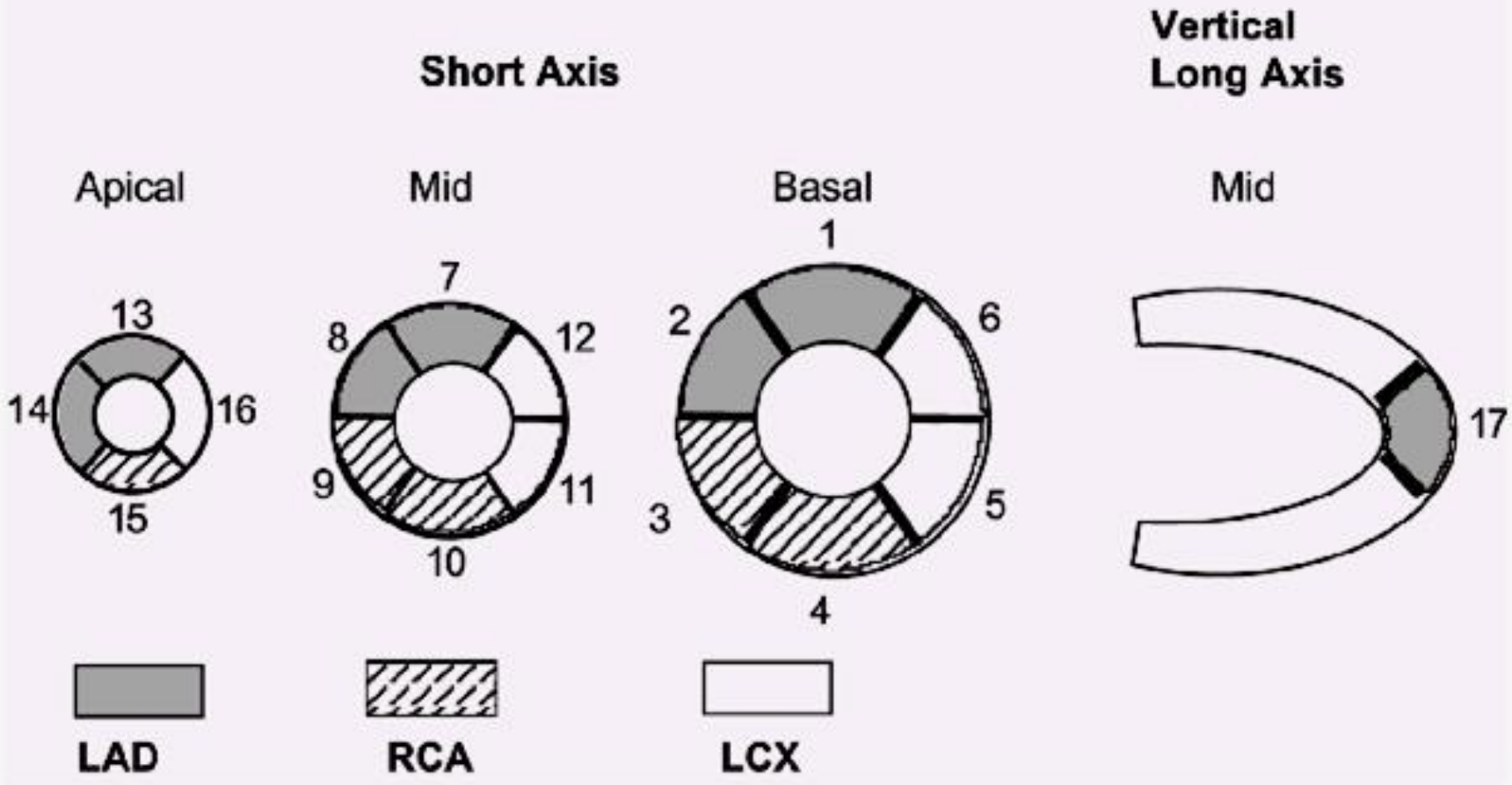


Horizontal
Long Axis (HLA)
(4 Chamber)

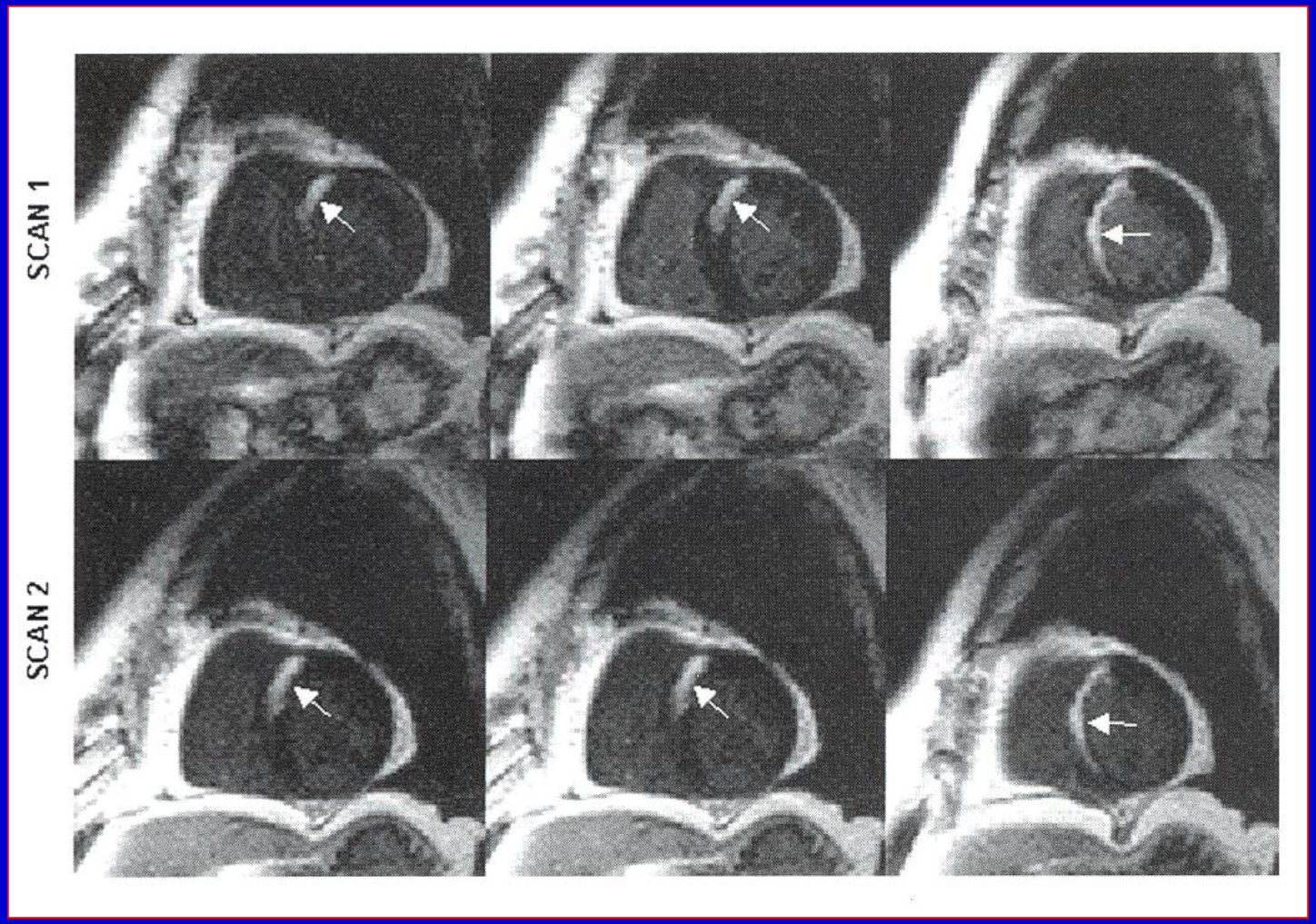


Vertical
Long Axis (VLA)
(2 Chamber)

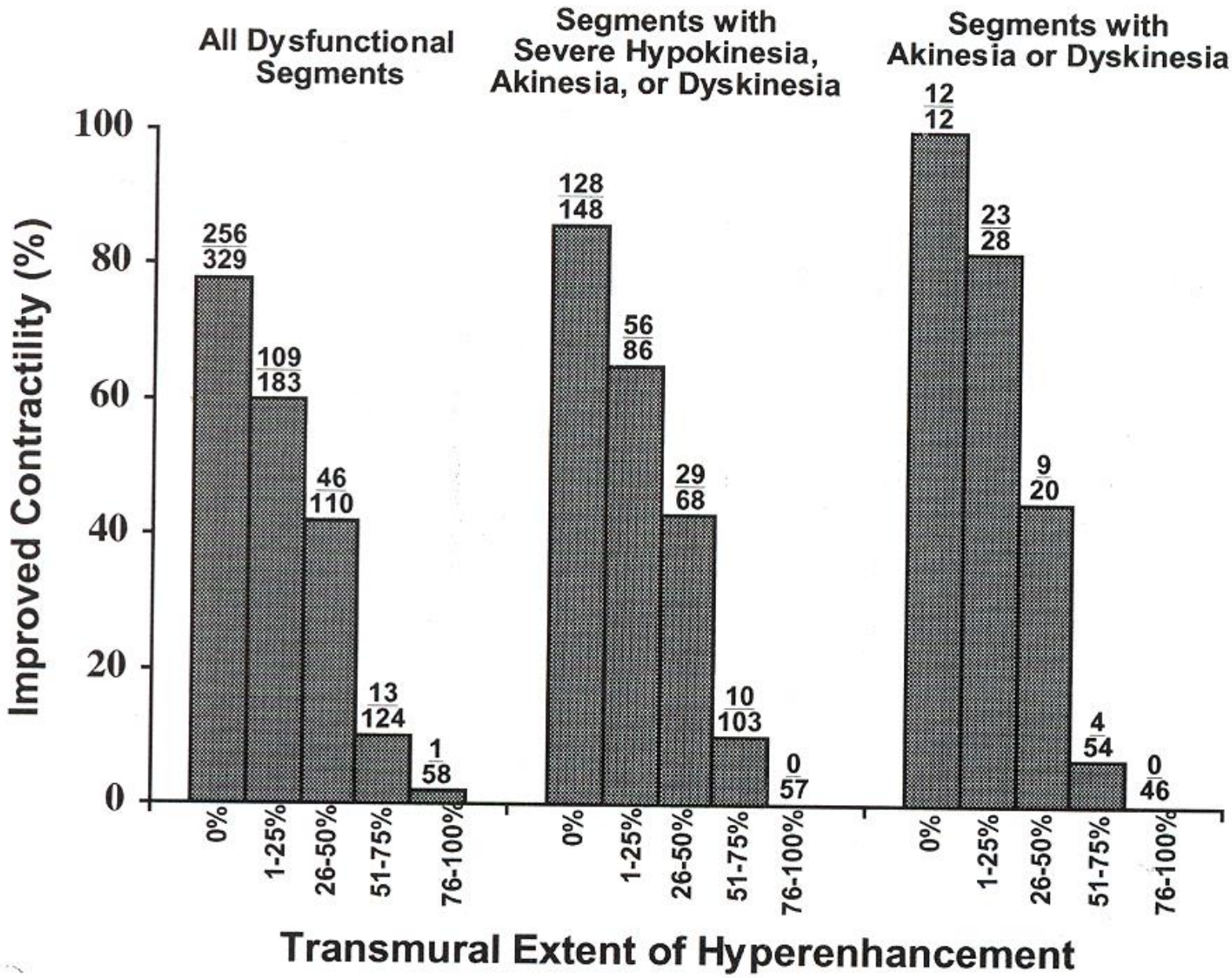
Coronary Artery Territories



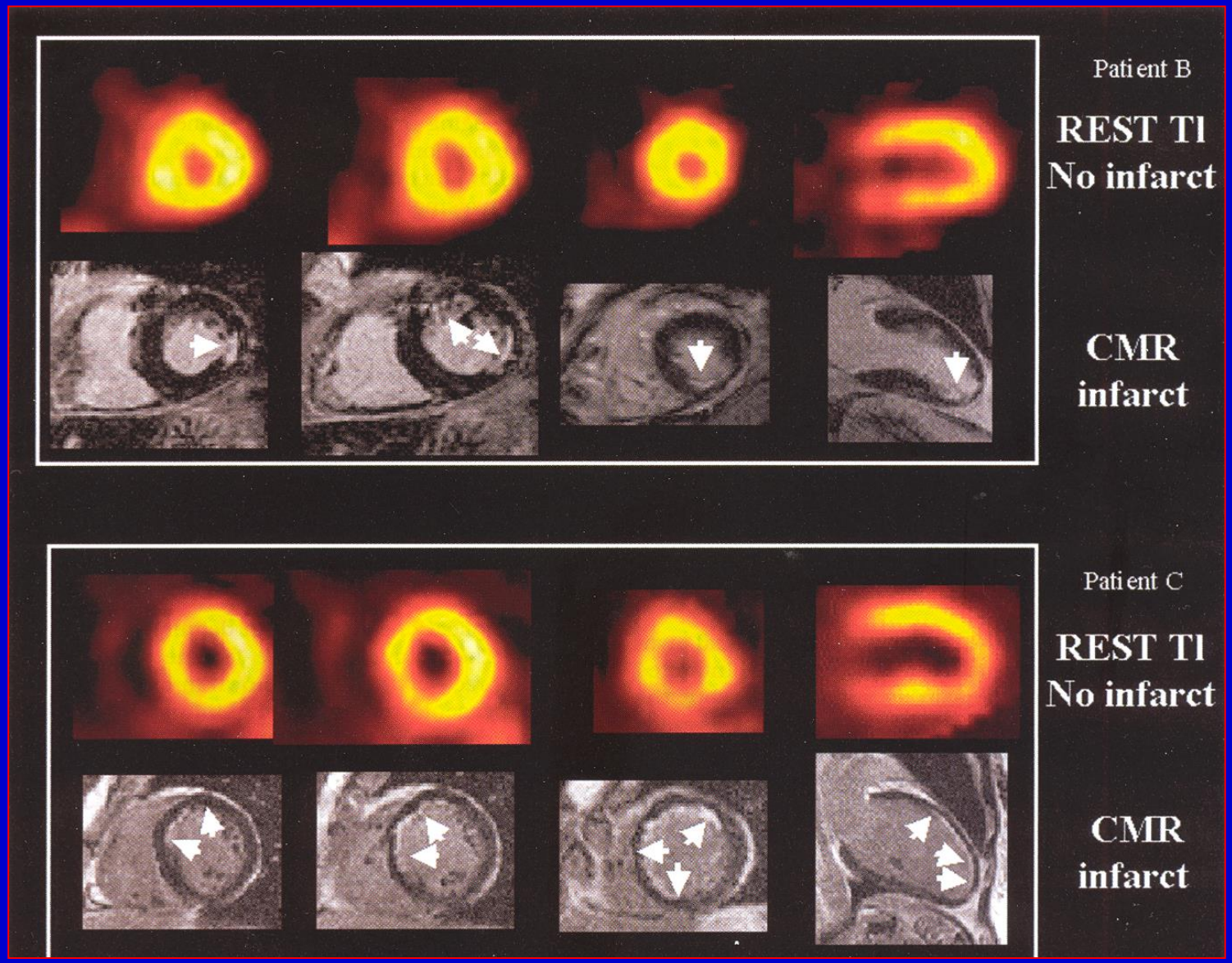
Reproductibilité inter-examen



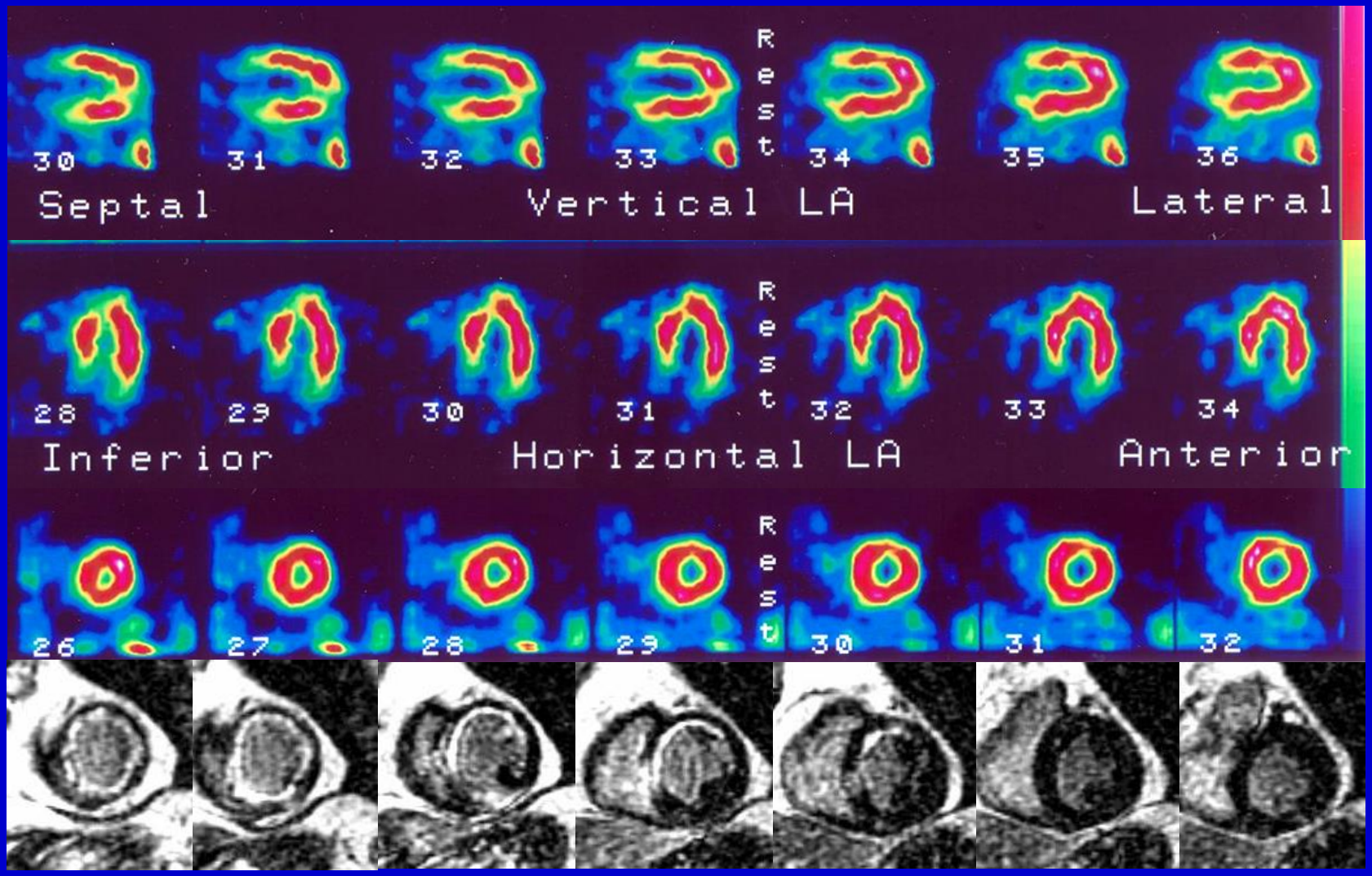
Mahrholdt H et al Circulation 2000



Kim et al. N Engl J Med 2000



Wagner et al. Lancet 2003


Rest
30
31
32
33
34
35
36
Septal
Vertical LA
Lateral
Rest
28
29
30
31
32
33
34
Inferior
Horizontal LA
Anterior
Rest
26
27
28
29
30
31
32

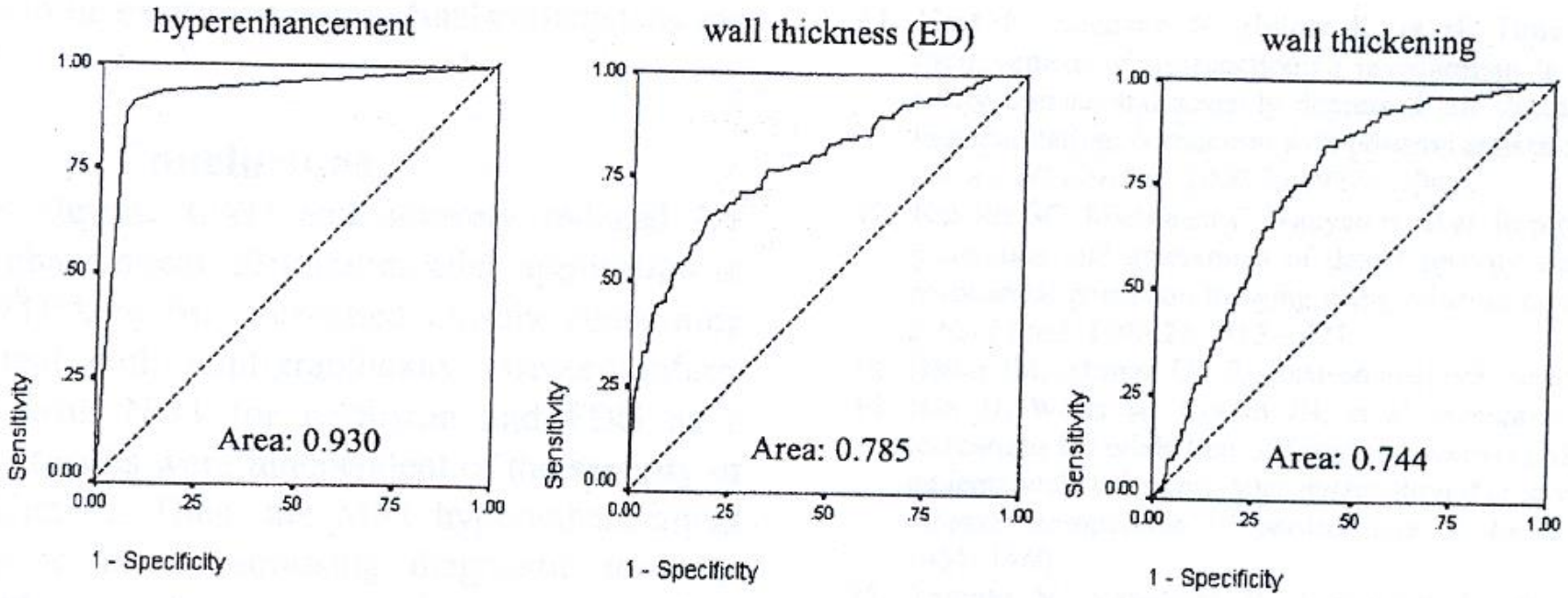
Comparaison avec la TEP

TABLE 3. Accuracy of MRI Hyperenhancement in Assessing Transmural or Both Transmural and Subendocardial Defects as Defined by PET in Relation to the Degree of Dysfunction

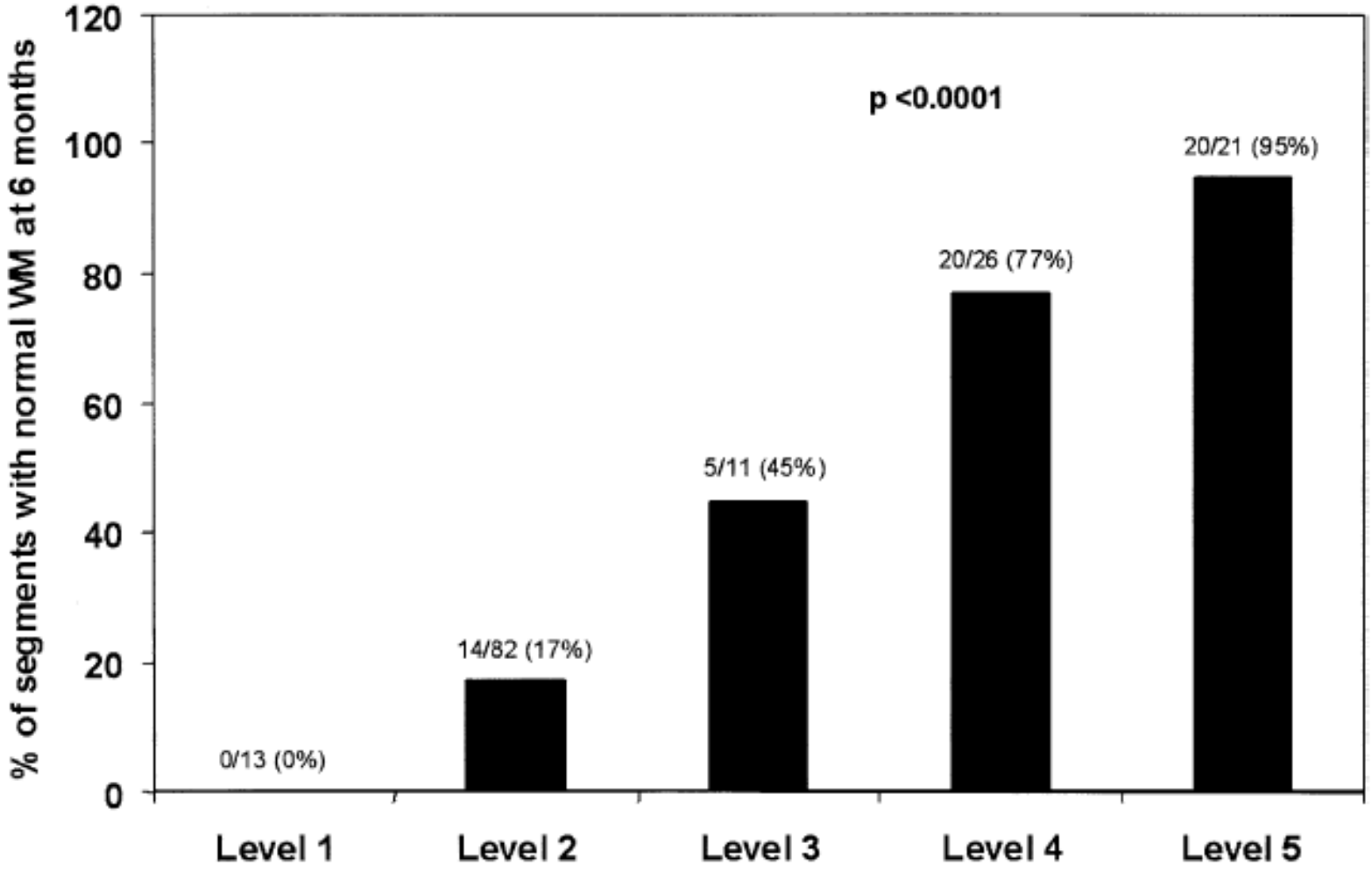
	Transmural		Transmural and Subendocardial	
Segments	Sensitivity	Specificity	Sensitivity	Specificity
All	0.86	0.94	0.83	0.88
Akinetic	0.89	0.84	0.89	0.79
Severe hypokinetic	0.86	0.90	0.95	0.82
Moderate hypokinetic	1.00	0.98	1.00	0.94

11 % des segments viables en TEP ont un hypersignal

Klein et al. Circulation 2002



Klein et al. Circulation 2002



Wall thickness	-	+/-	+/-	+/-	+/-
Perfusion	-	+/-	+/-	+/-	+/-
Response to dobutamine	-	-	+	-	+
Non-transmural necrosis	-	-	-	+	+

Bodi V et al. JACC 2005

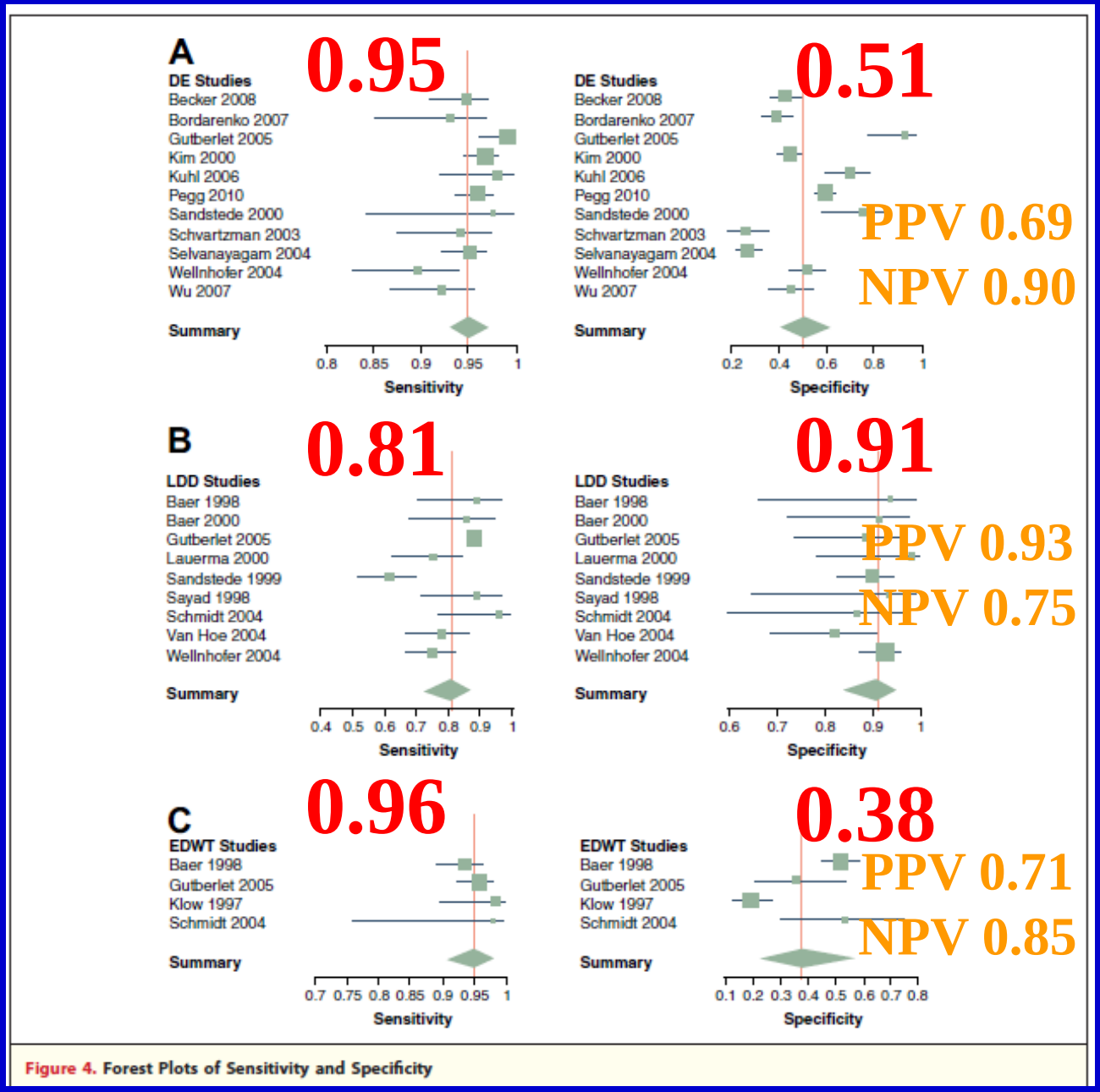


Figure 4. Forest Plots of Sensitivity and Specificity

DE CMR
Best sensitivity
Best NPV

LDD CMR
Best specificity
Best PPV

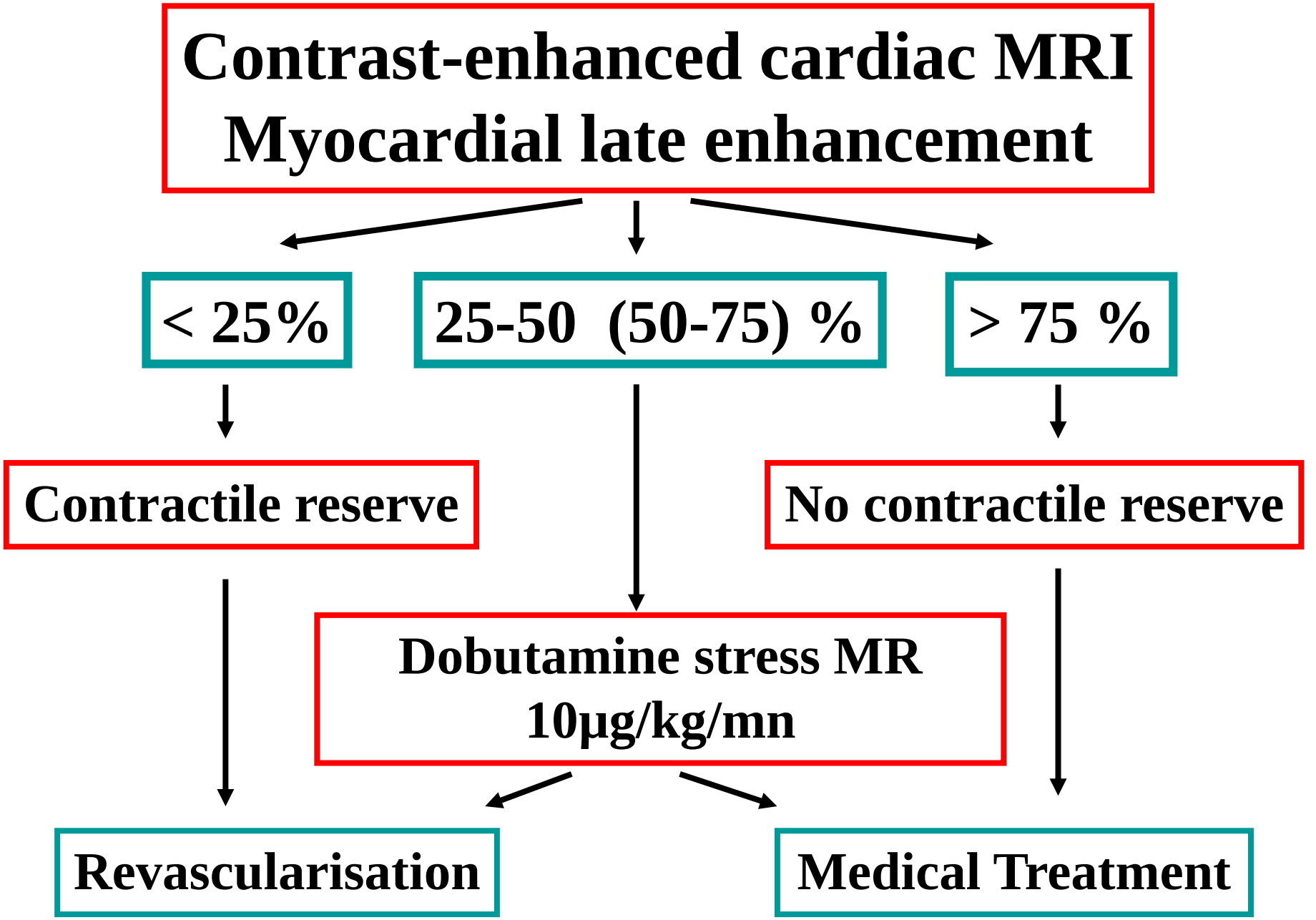
DE delayed enhancement
LDD low-dose dobutamine

Romero J, JACC Imaging 2012

Different imaging modalities

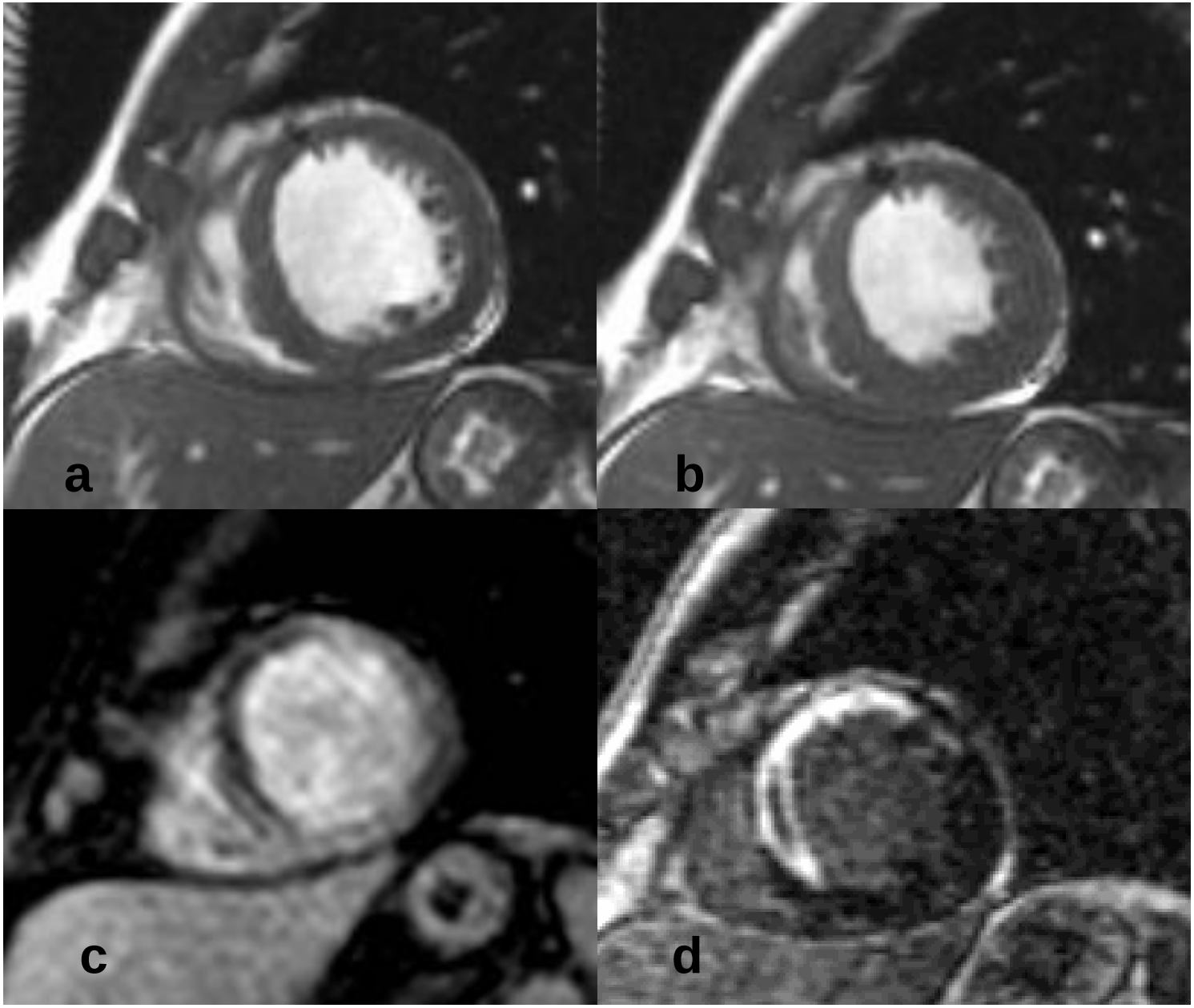
	Sensitivity	Specificity	PPV	NPV
DE CMR	**95 %**			**90 %**
LDD CMR		**91 %**	**93 %**	
PET-FDG	**92 %**	**63 %**	**74 %**	**87 %**
Th-201 SPECT	**87 %**	**54 %**	**67 %**	**79 %**
Tech-99m SPECT	**83 %**	**65 %**	**74 %**	**76 %**
DSE	**80 %**	**78 %**	**75 %**	**83 %**

Bax et al.JACC 1997; Schinkel et al. Curr Probl Cardiol 2007


Contrast-enhanced cardiac MRI
Myocardial late enhancement
< 25%
25-50 (50-75) %
> 75 %
Contractile reserve
No contractile reserve
Dobutamine stress MR
10µg/kg/mn
Revascularisation
Medical Treatment

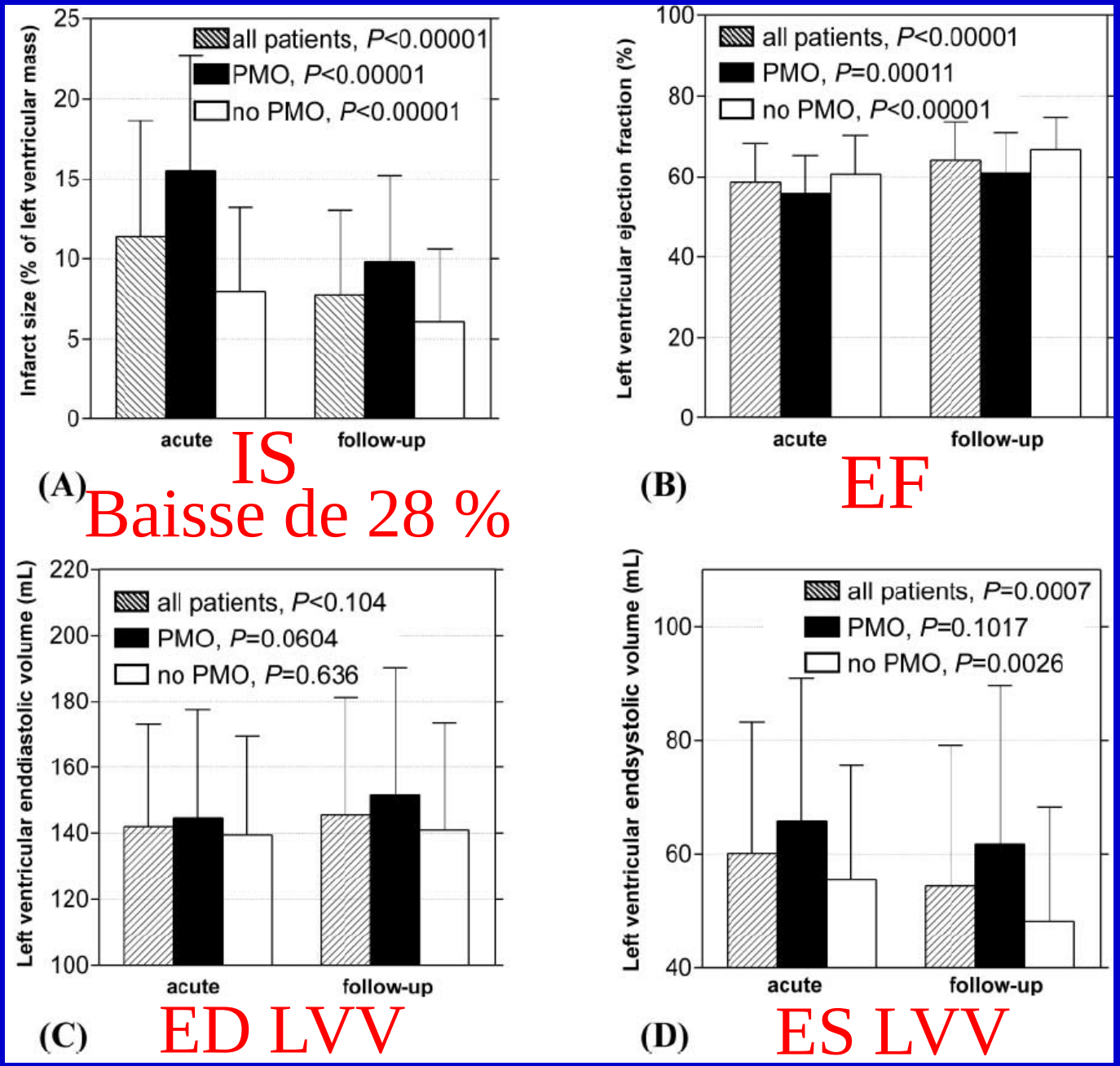
Comment identifier les patients à risque en post-infarctus Les apports de l'IRM cardiaque

- 1 Volumes ventriculaires et FE VG
- 2 Taille de l'infarctus en rehaussement tardif
- 3 No-reflow
- 4 Hémorragie intra-myocardique


a
b
c
d

Comment identifier les patients à risque en post-infarctus Les apports de l'IRM cardiaque

- 1 Volumes ventriculaires et FE VG
  - FE altérée en phase aiguë mais stunning (sidération) du myocarde viable
  - Hypercinésie compensatrice et Baisse FE à distance



Hombach V et al. *EHJ 2005*

Comment identifier les patients à risque en post-infarctus Les apports de l'IRM cardiaque

- 2 Taille de l'infarctus en rehaussement tardif

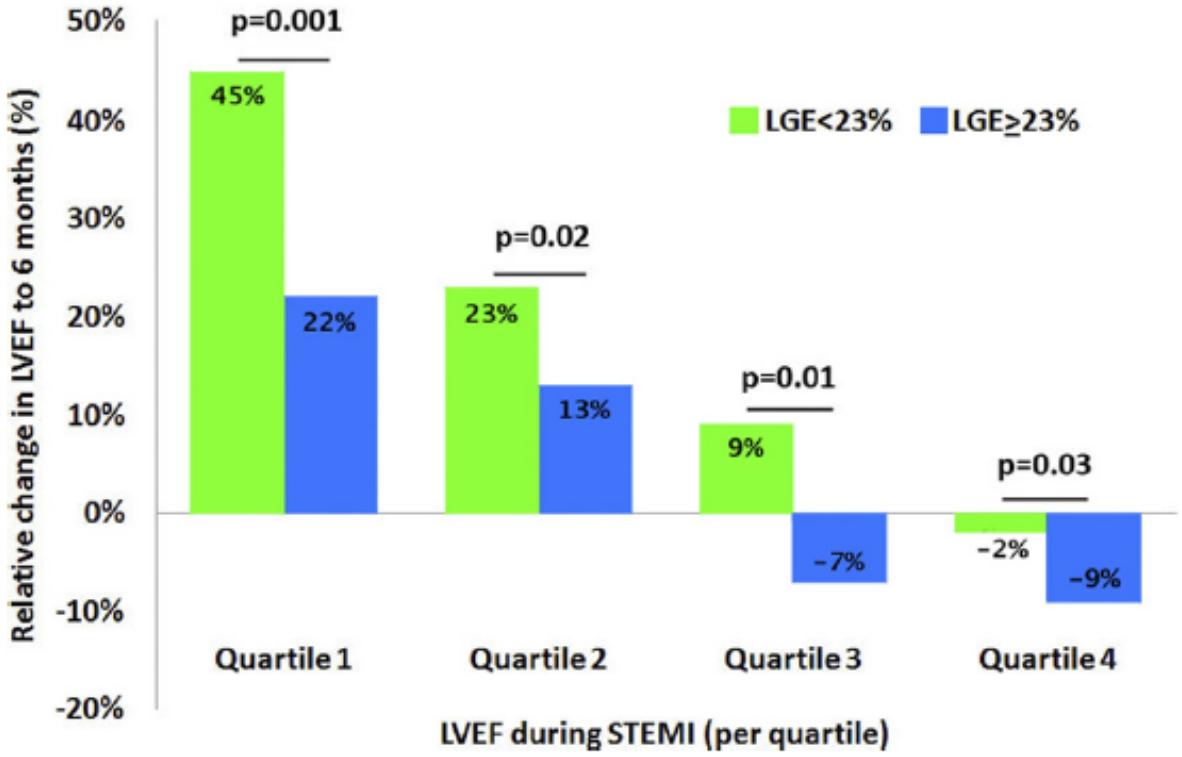


Figure 2 Relative Change In LVEF From STEMI to 6-Month Follow-Up, Assessed According to Quartiles of LVEF During STEMI

The LGE ≥23% during STEMI identifies a subgroup of patients with significantly worse functional recovery compared with those with less LGE, across the entire range of LVEF quartiles during STEMI. Abbreviations as in Figure 1.

Larose E et al. *JACC 2010*

Table 4 Multivariable Associations of Variables Measured During Acute STEMI With 6-Month LVEF <50%

	OR	95% CI	p Value
Best overall multivariable model by stepwise forward selection including all significant variables from Table 3			
Presence of ECG Q waves at presentation	6.27	0.81–74.9	0.08
LGE during STEMI*	1.33	1.09–1.78	0.002
Pain-to-balloon time, min	1.15	1.01–1.32	0.09
Adjusted for LVEF during STEMI, LGE %, and CK-MB			
LVEF during STEMI*	0.95	0.88–1.03	0.20
LGE during STEMI*	1.36	1.11–1.66	0.004
Maximum CK-MB rise after STEMI, mmol/l	1.00	0.99–1.01	0.40

Larose E et al. *JACC 2010*

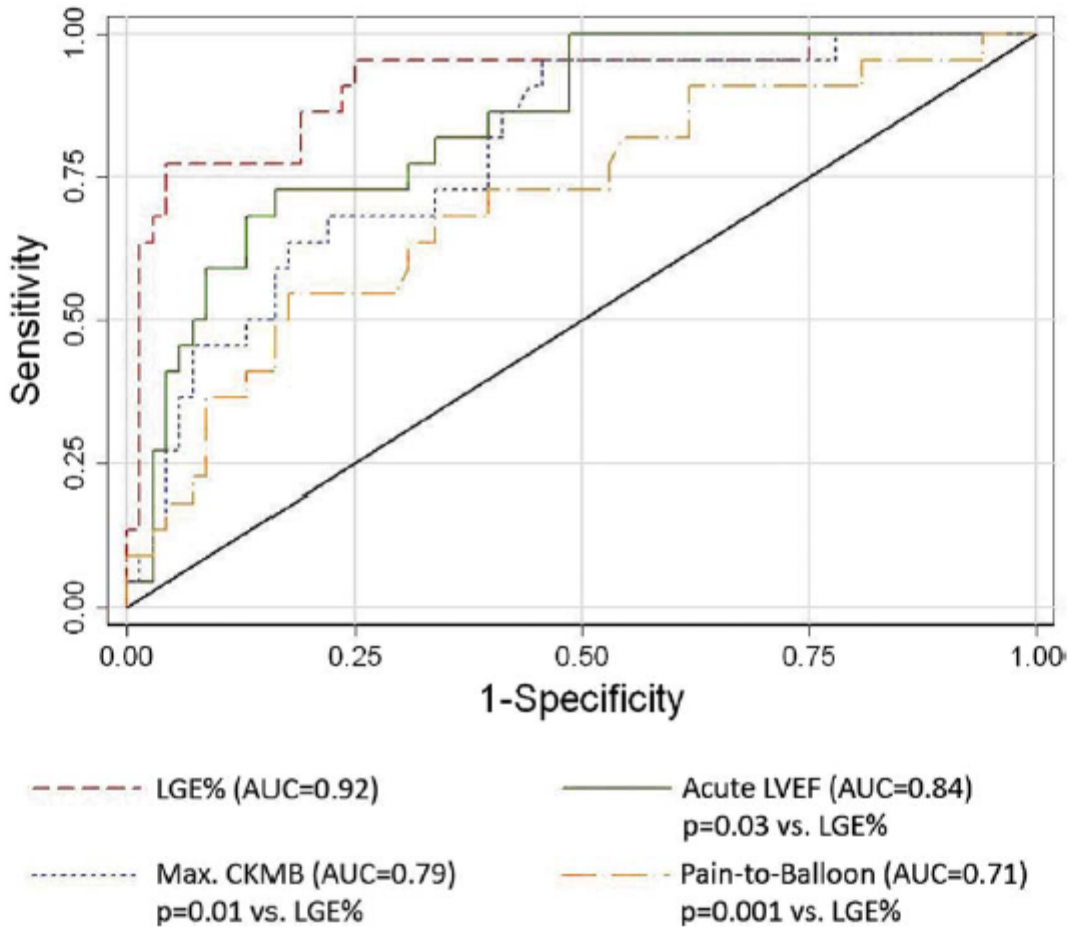


Figure 3 **Receiver-Operator Characteristic Curves for LV Dysfunction at 6 Months**

There is significant added value of LGE percentage during STEMI (per 1%, area under the receiver-operator characteristic curve [AUC]: 0.92) compared with traditional measures including LVEF during STEMI (per 1%, AUC 0.84, p = 0.03 vs. LGE), maximum creatine kinase-myocardial band (CKMB) (per 1 mmol/kg, AUC 0.79, p = 0.01 vs. LGE), and pain-to-balloon time (per 1 min, AUC 0.71, p = 0.001 vs. LGE) for the prediction of LV dysfunction at 6 months. Abbreviations as in Figure 1.

Larose E et al. *JACC 2010*

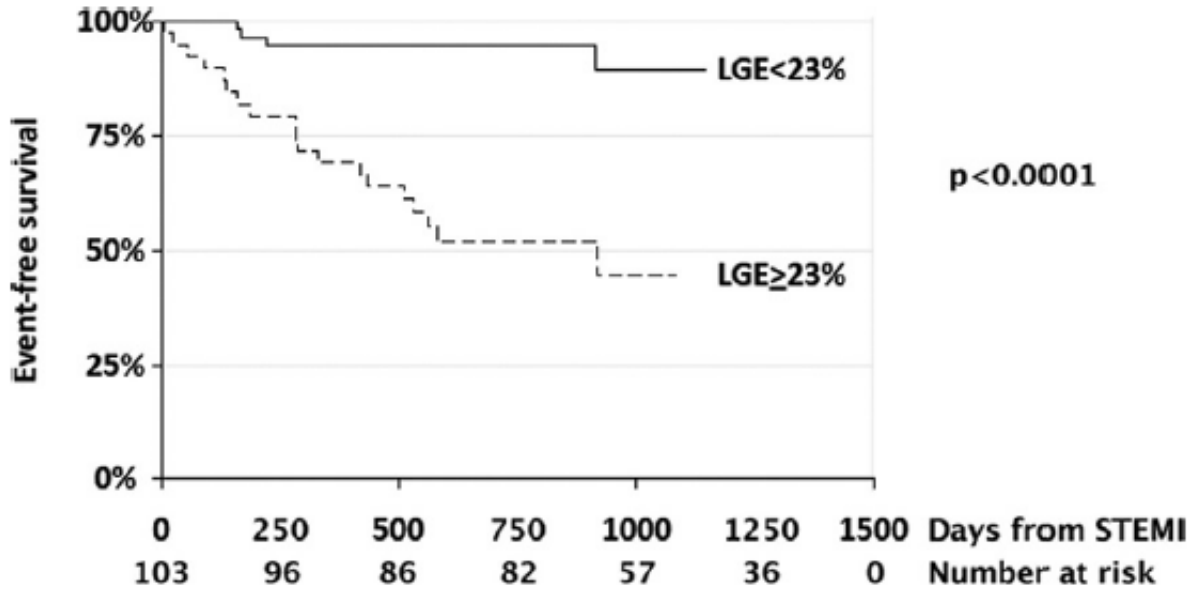
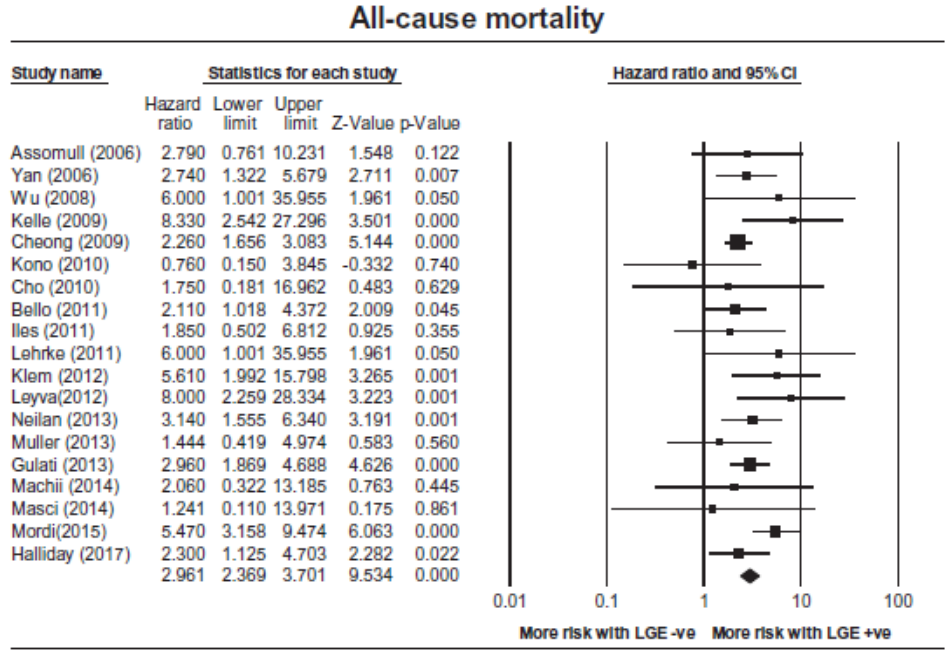


Figure 4 Kaplan-Meier Event-Free Survival Estimates for LGE ≥23% Versus LGE <23% Very Early During STEMI

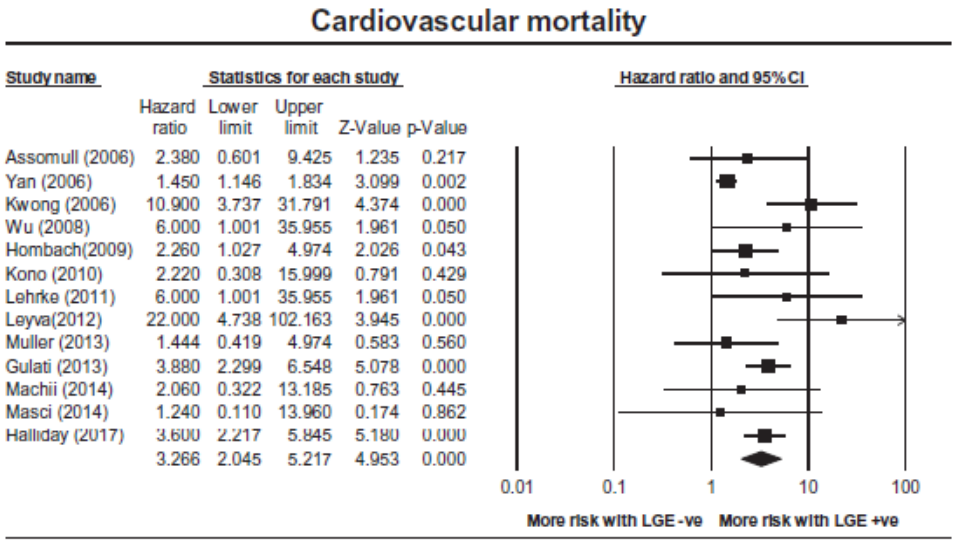
Number at risk reports the number of patients that entered the respective interval event-free, minus one-half of the number of patients who presented an event in the respective interval. LGE = late gadolinium enhancement; other abbreviations as in Figure 1.

Larose E et al. *JACC 2010*

A-All-cause mortality

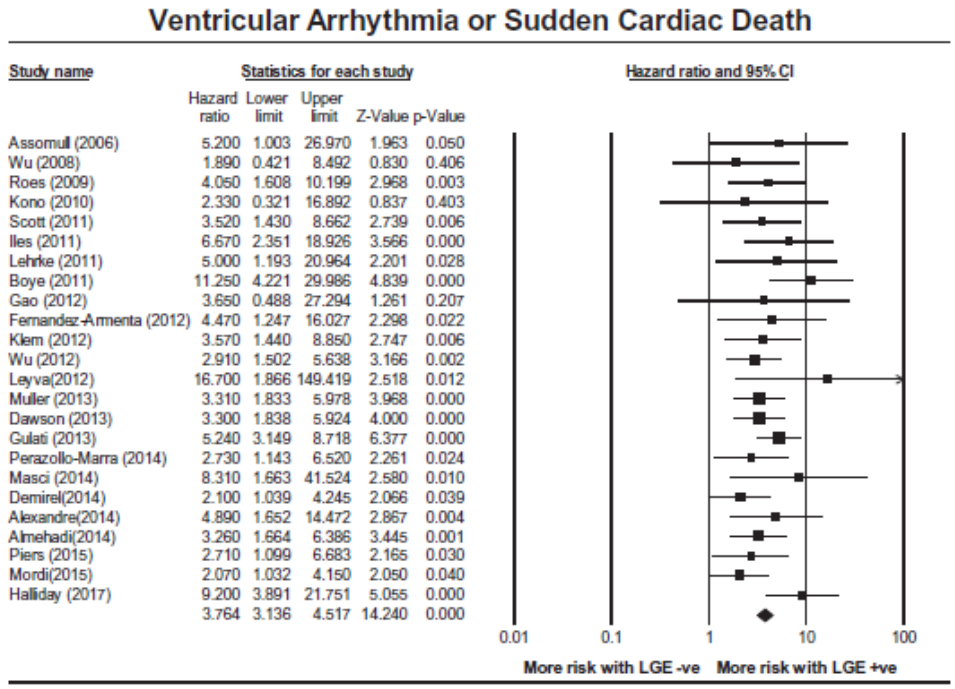


B-Cardiovascular Mortality

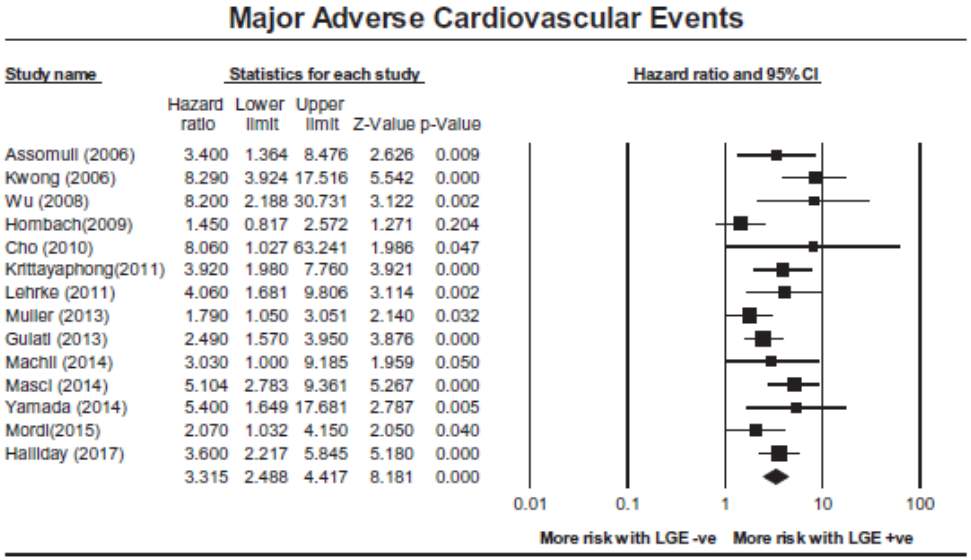


Ganesan A N et al.
Int J Cardiol 2018

C-All-Ventricular Arrhythmia or Sudden Cardiac Death



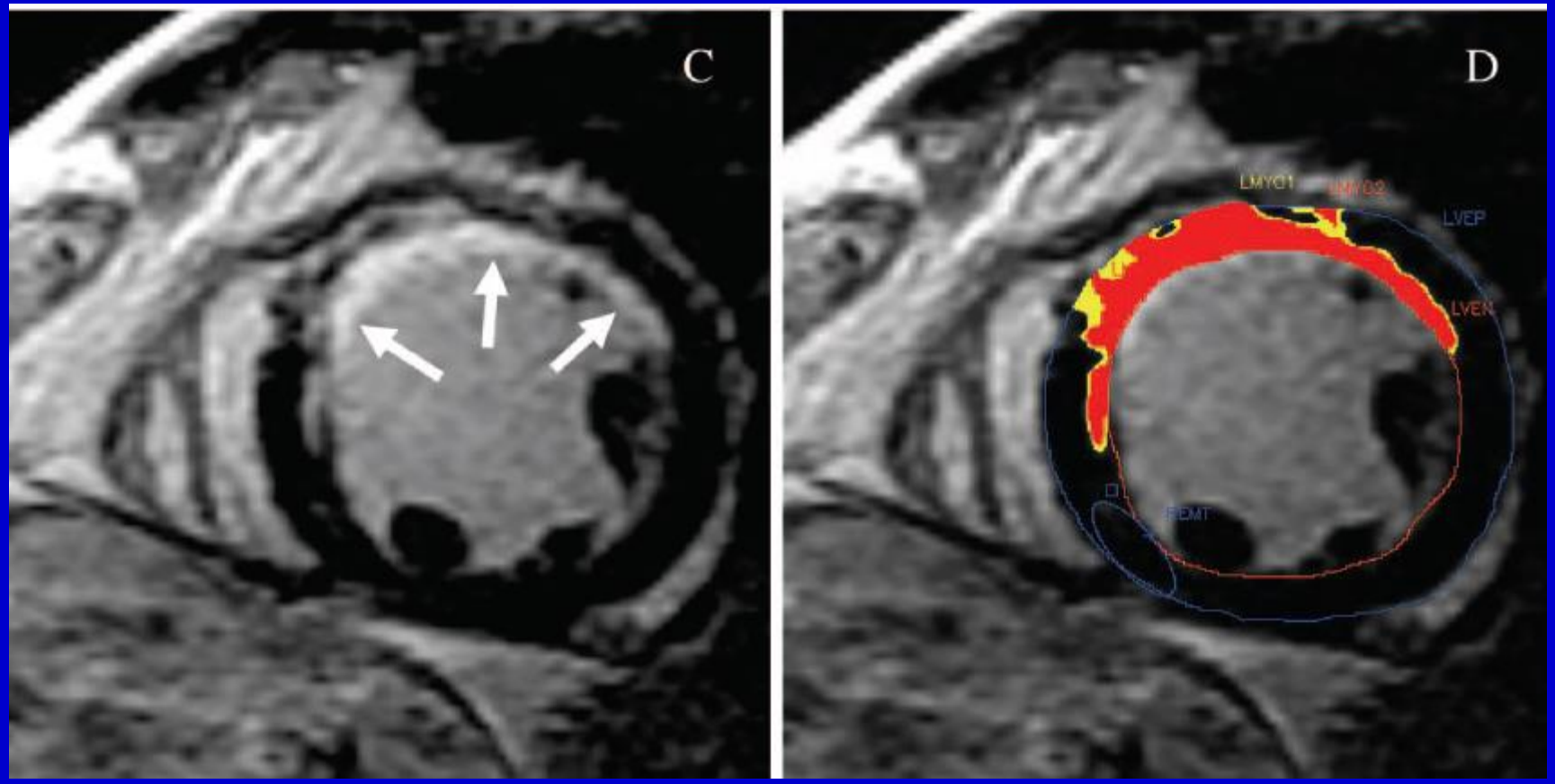
D –Major Adverse Cardiovascular Events



Ganesan A N et al.
Int J Cardiol 2018

Rehaussement tardif et Pronostic

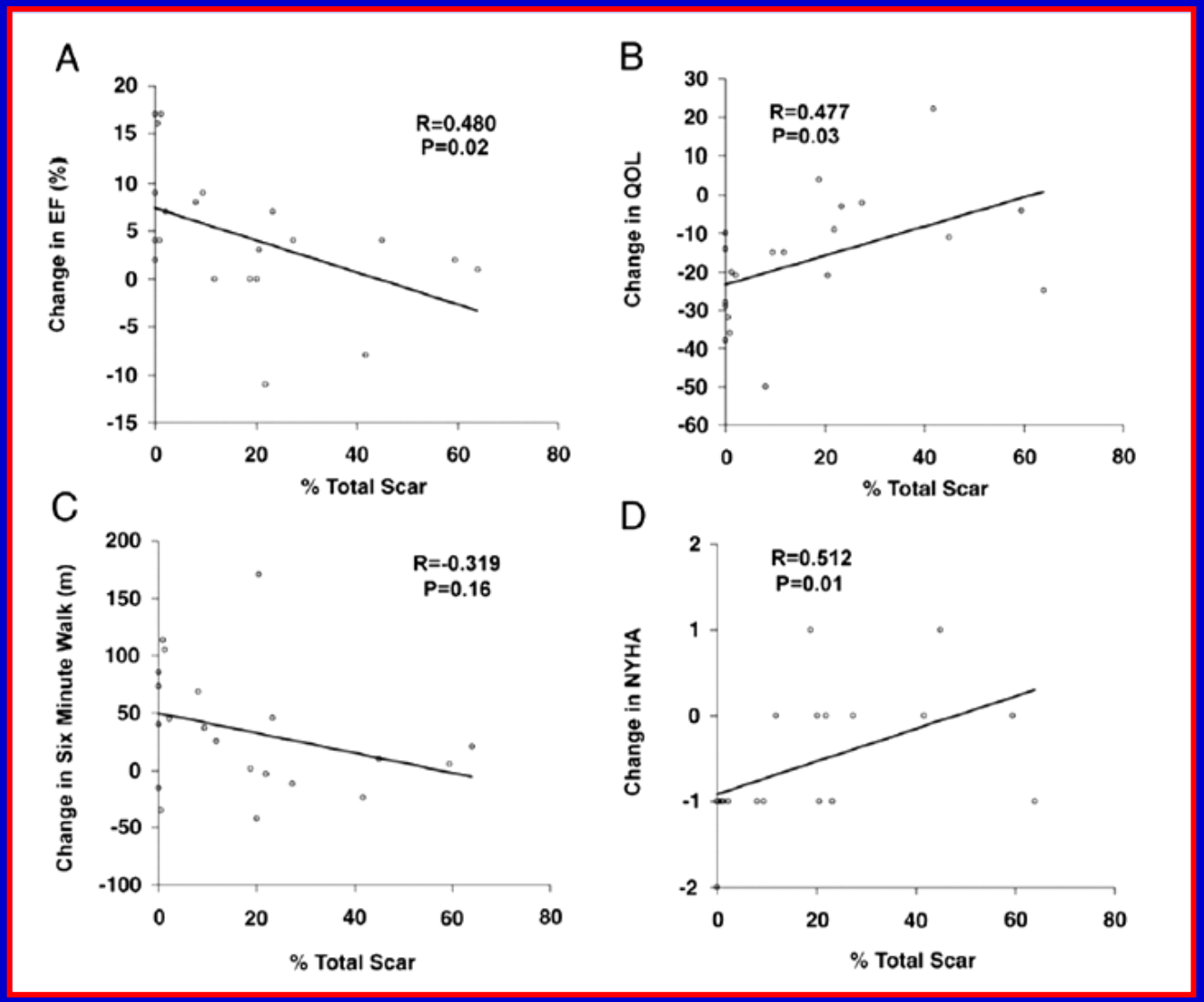
- Hétérogénéité de la zone péri-infarctus
  - Facteur pronostique indépendant de mortalité
  - Facteur prédictif de TV monomorphe après stimulation



Yan et al.

Resynchronisation et IRM

QRS ≥ 120 ms
EF ≤ 35 %
NYHA II to IV
Ventricular
Dyssynchrony ≥ 60ms



White et al JACC 2006

% Scar ≤ 15%
Sensitivity 85%
Specificity 90%

% Septal scar ≤ 40%

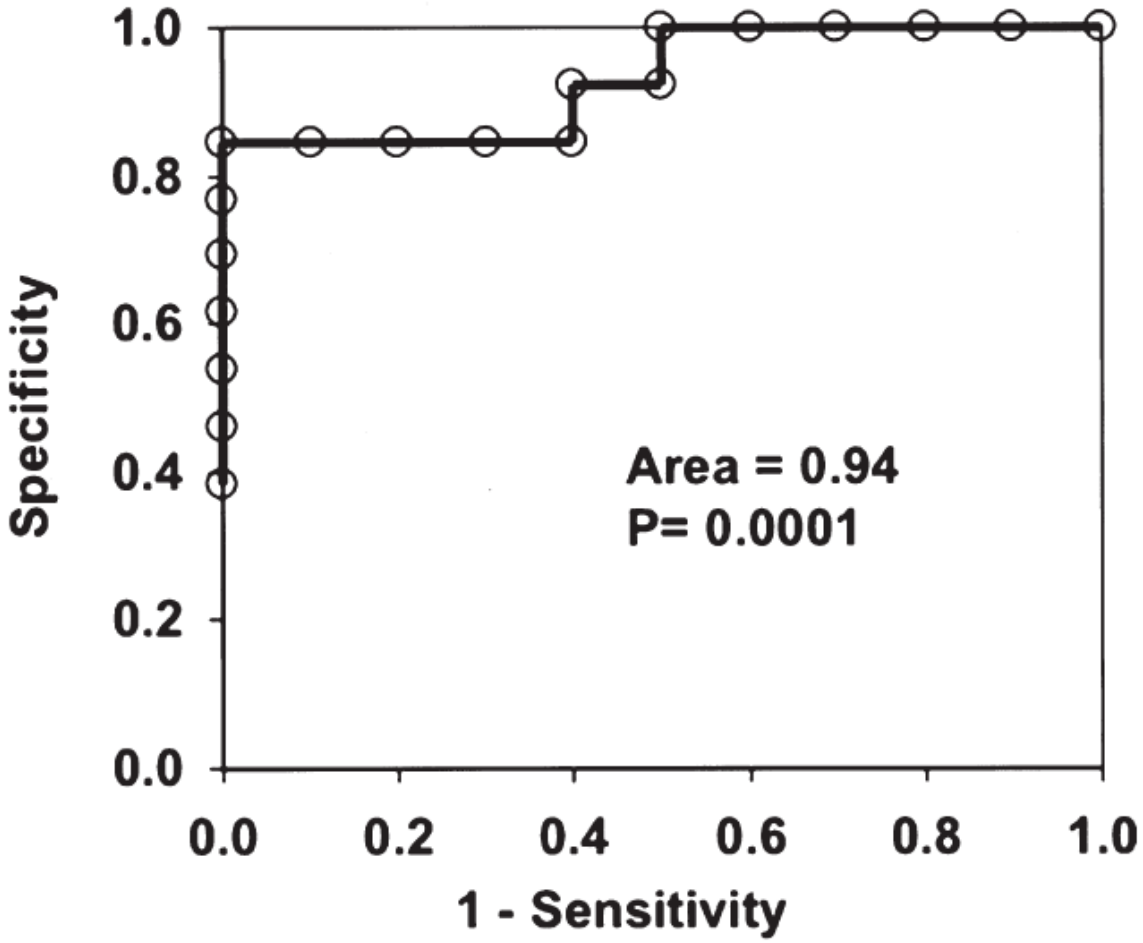
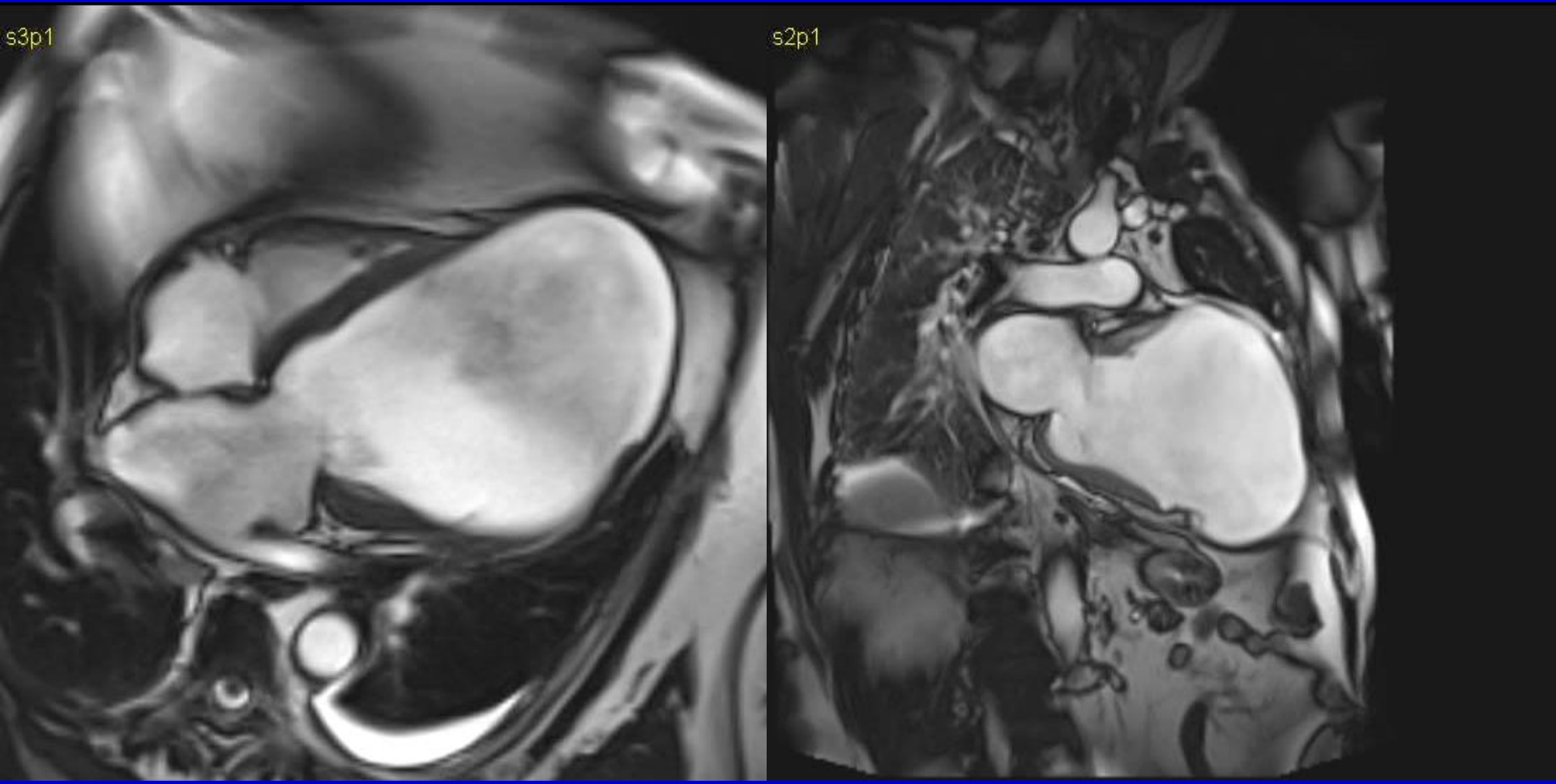


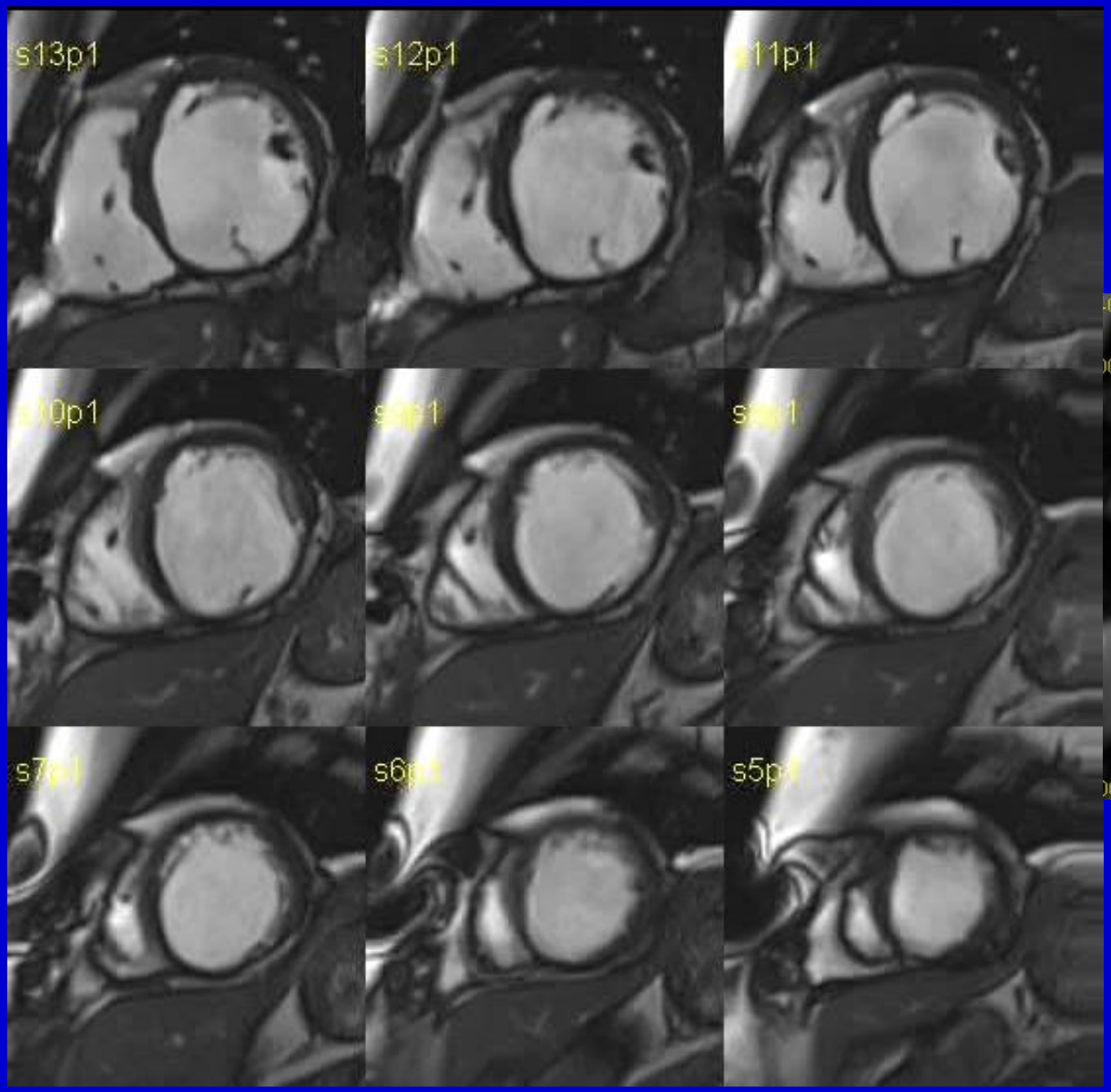
Figure 4. Receiver-operating characteristic analysis of total percent scar for the prediction of clinical response to cardiac resynchronization therapy.

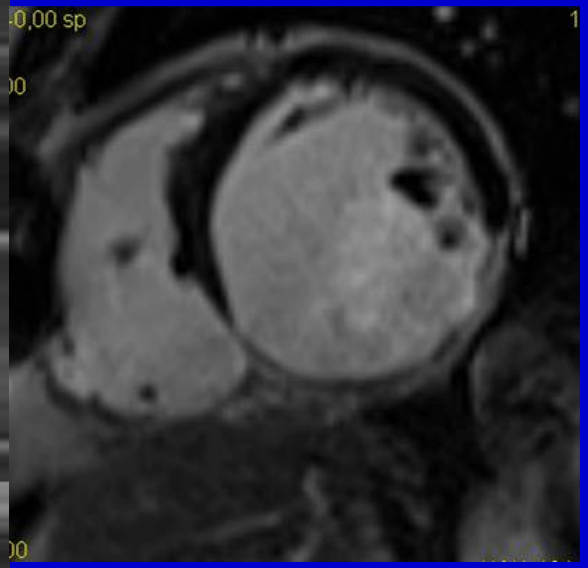
White et al JACC 2006

% Posterolateral scar > 50%
Bleeker Circulation 2006

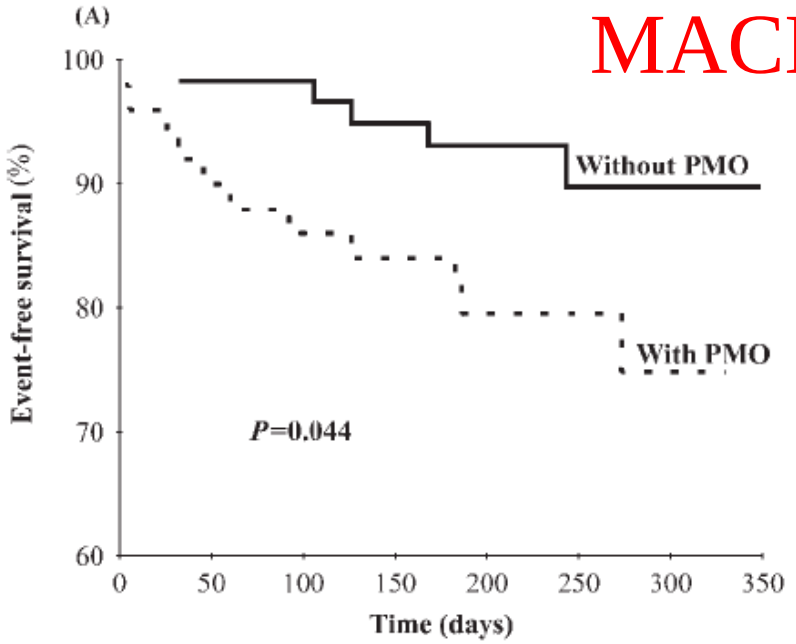
Resynchronisation et IRM

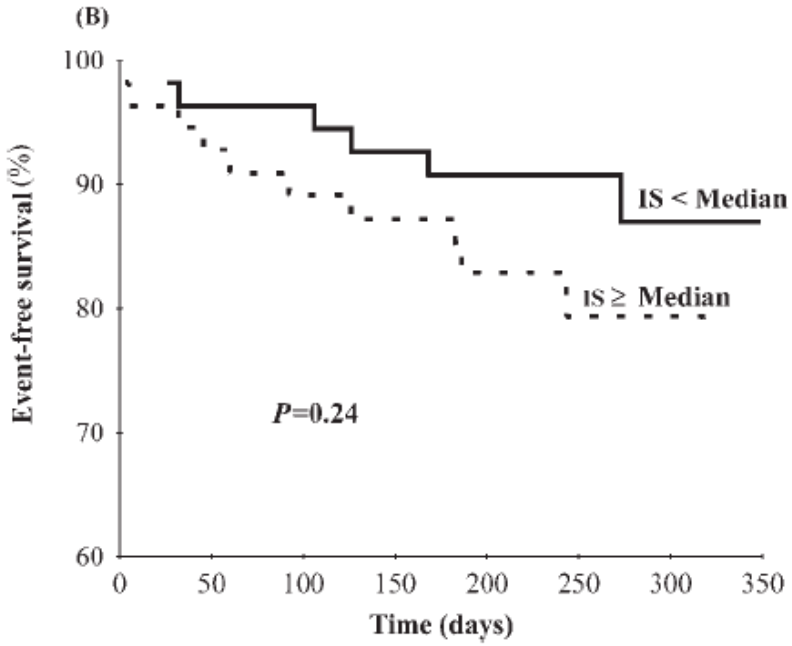



s13p1
s12p1
s11p1



MACE

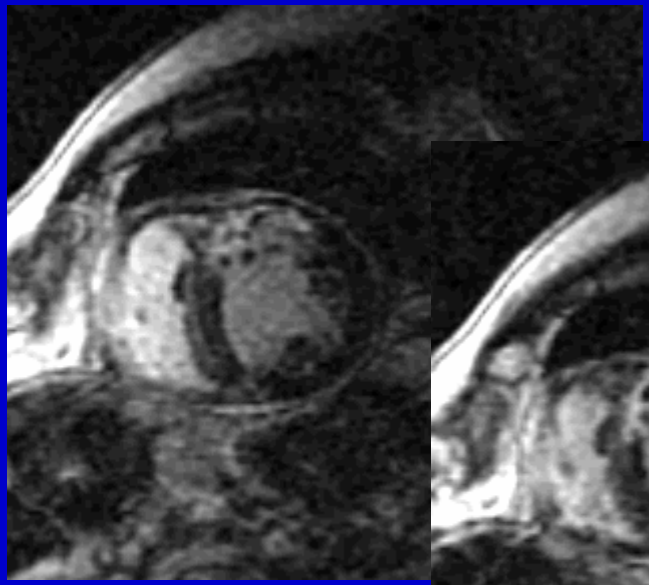
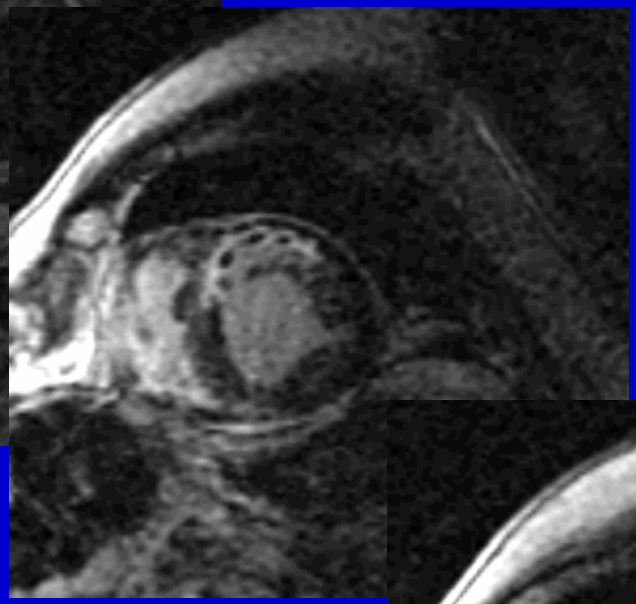
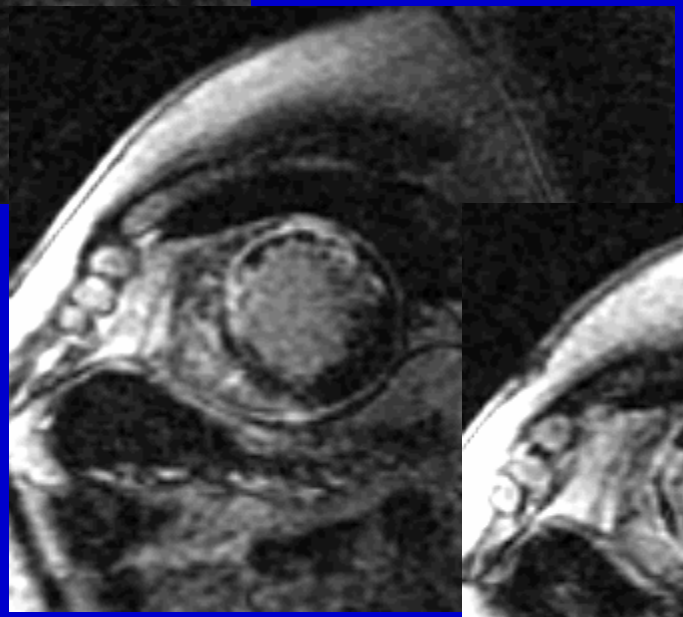
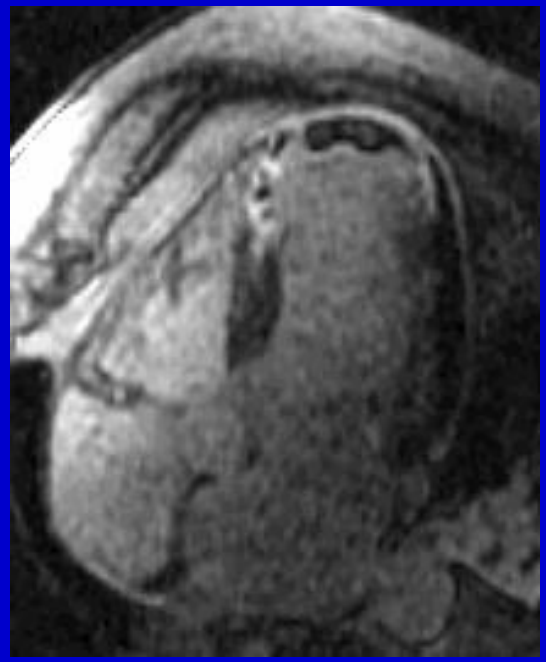
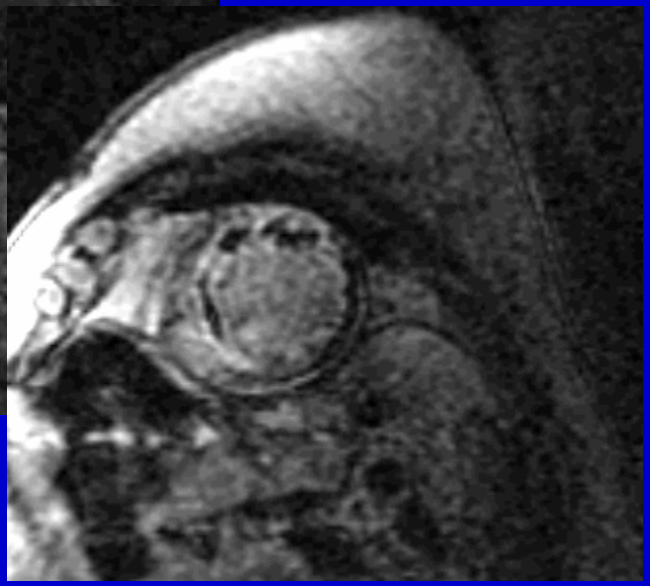




Hombach V et al. *EHJ 2005*

Comment identifier les patients à risque en post-infarctus
Les apports de l'IRM cardiaque

- 3 No-reflow

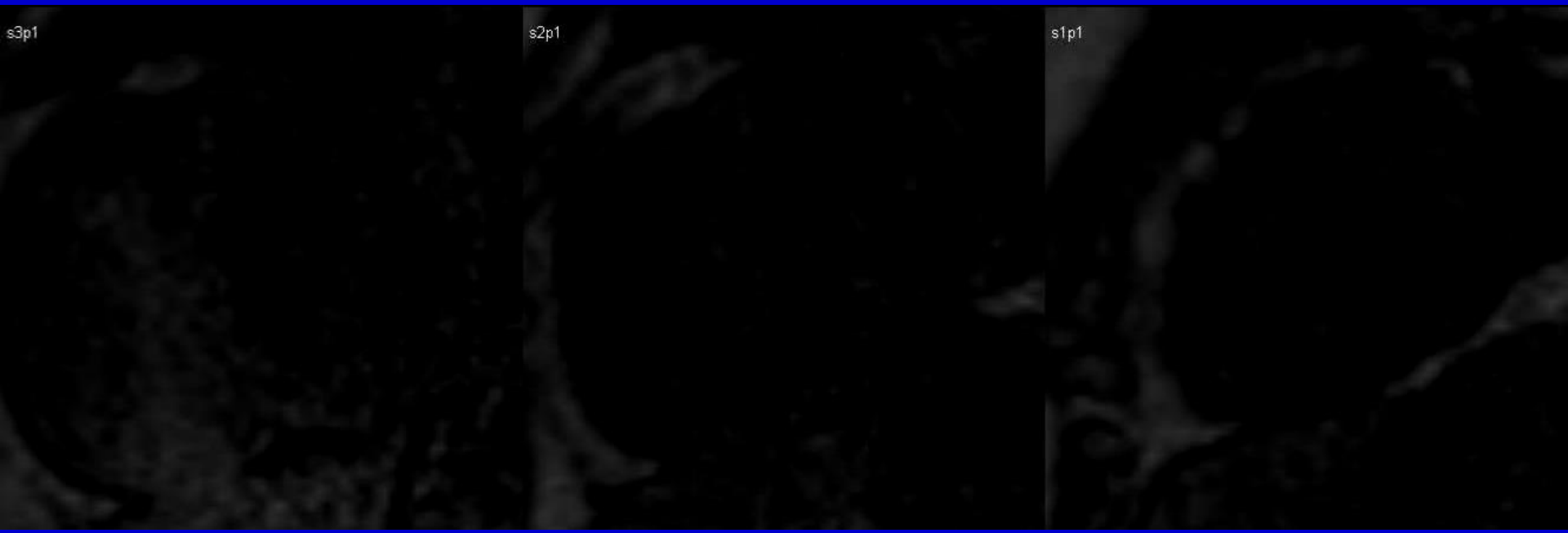






CMR imaging is the gold-standard technique for assessing No-Reflow

SA resting first-pass perfusion sequence

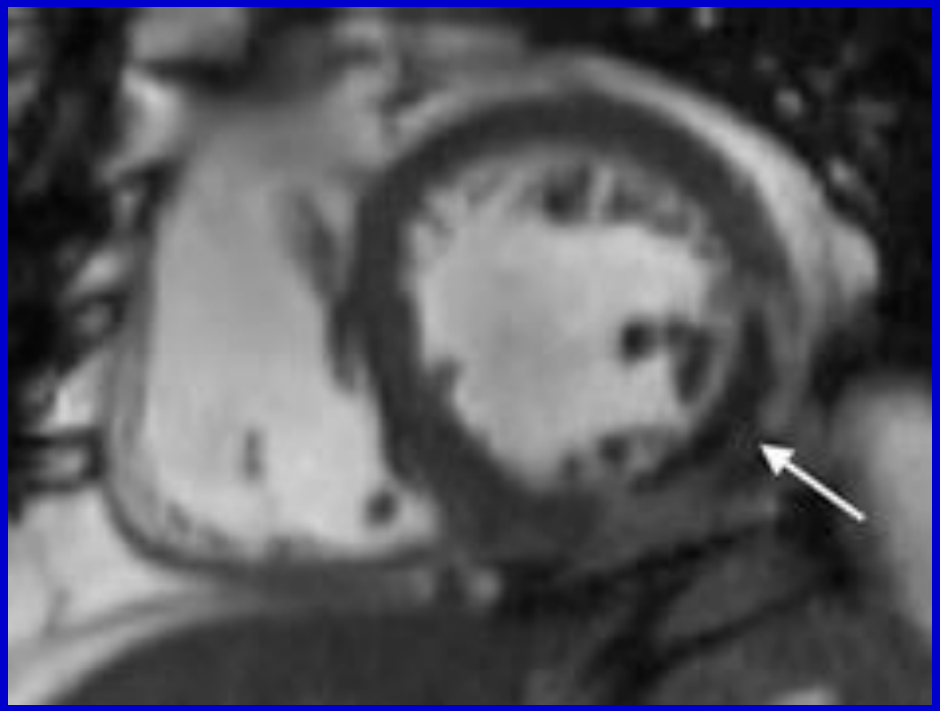
Presence of NR but also slowing of CM in the reperfused myocardium

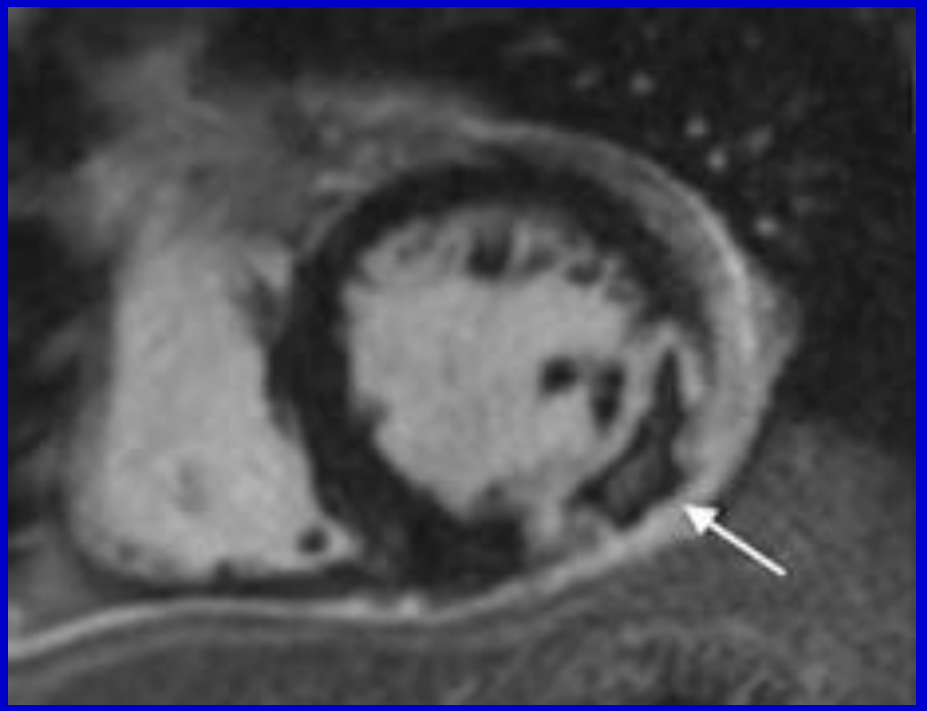
Good sensitivity but lower specificity



CMR imaging is the gold-standard technique for assessing No-Reflow

SA SSFP
3 min post Gd

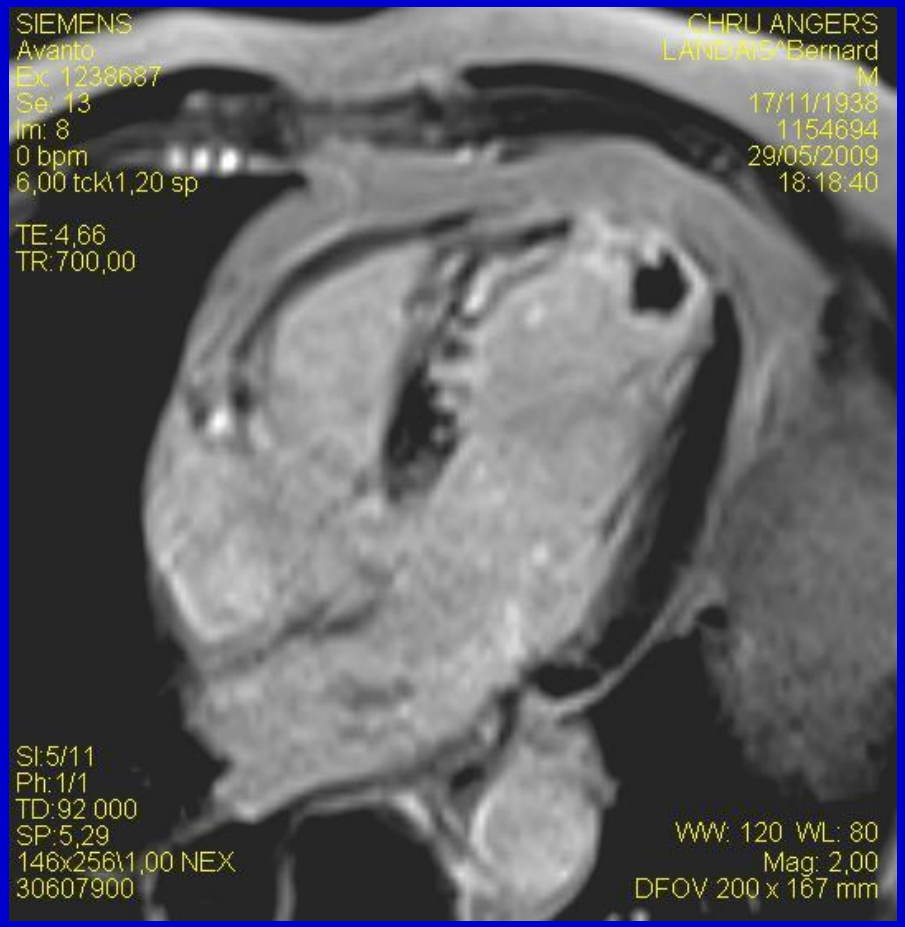


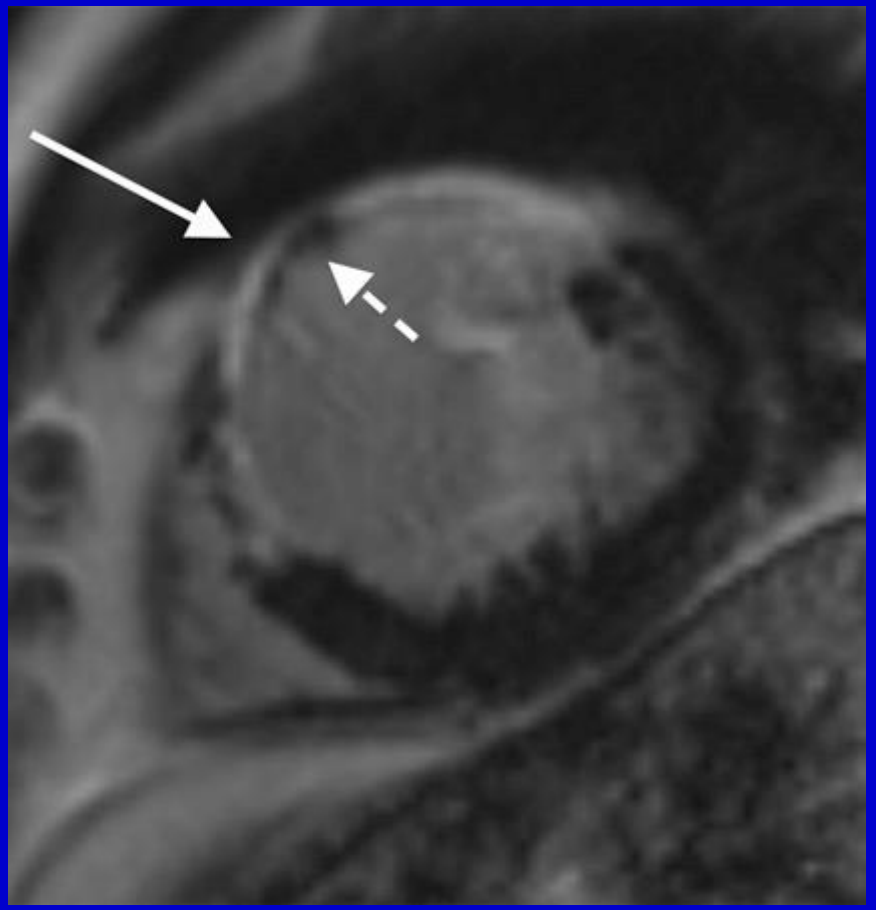


SA LGE More specific for diagnosing MVO

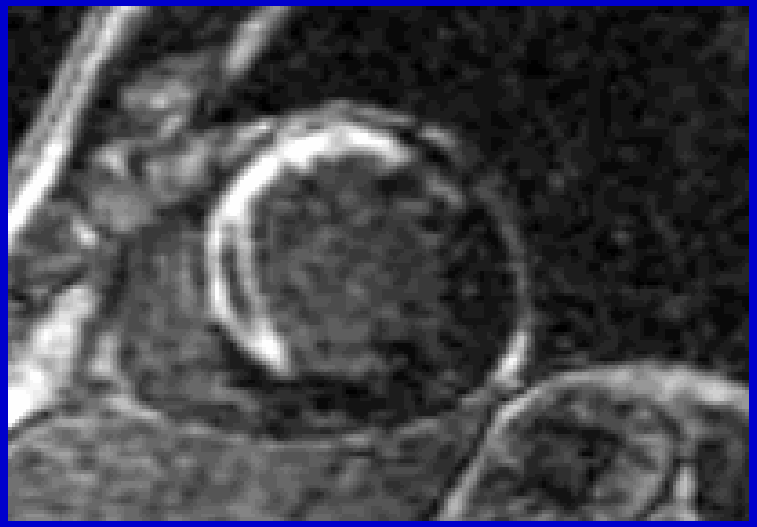
LGE area of MVO < EGE < First-Pass

LV thrombus and Calcified Infarcts

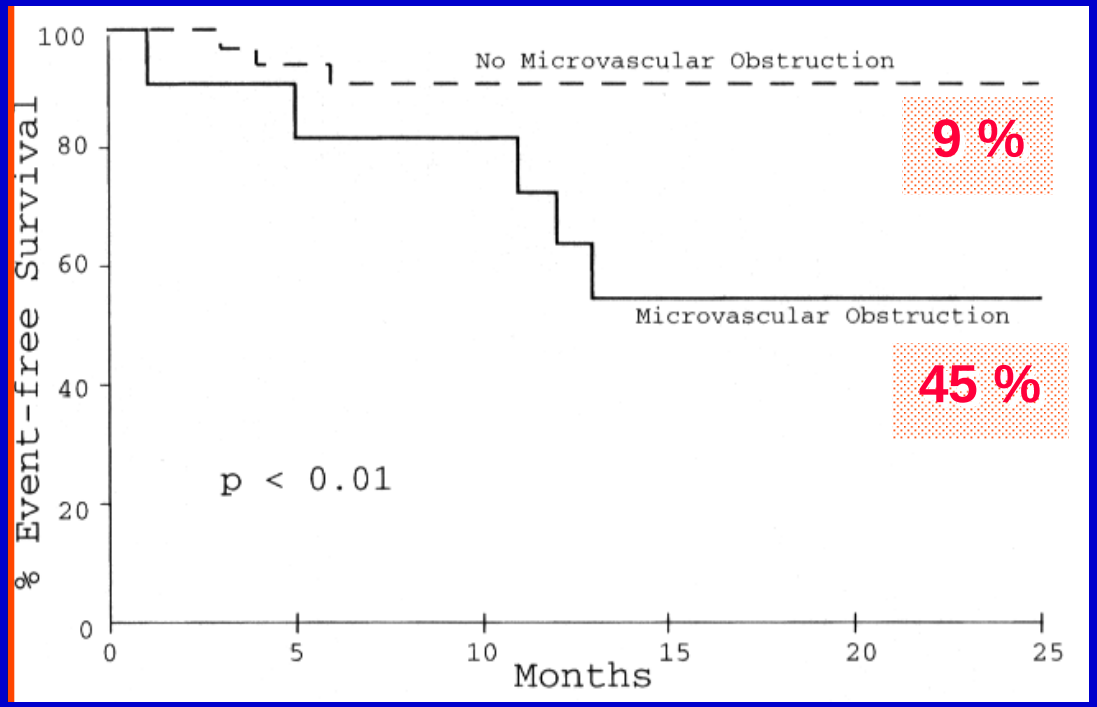




A Abbas et al. *Br J Radiol* 2014



- Microvascular obstruction
  - Correlates with infarct size
  - Identifies nonviable regions
  - Predictor of a lack of recovery
  - Predictor of LV remodeling



Wu et al. Circulation 1998

More powerful predictor of survival than EF or infarct size

Hombach EHJ 2006
Kwong Circulation 2006
Yan Circulation 2006

Prognostic value of No-Reflow

56.3% of STEMI patients

(54.9% TIMI 3 STEMI patients)

n=1025
3.3 h
4 days

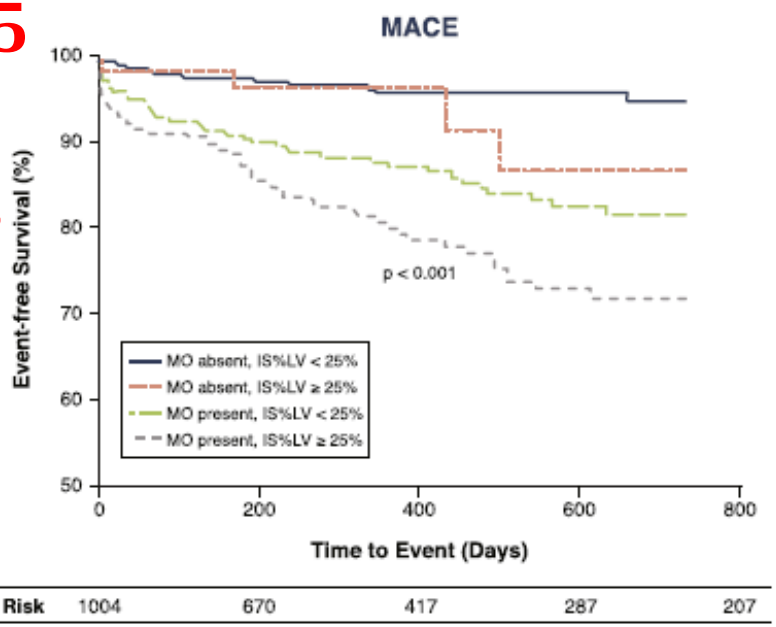


FIGURE 7 Relationship Between MO and IS%LV and Event-Free Survival

Values are Kaplan-Meier estimates in patients with IS%LV ≥25% versus <25%, grouped by the presence or absence of MO, indicating the time to MACE, follow-up 2 years. Abbreviations as in Figures 4 and 5.

TABLE 3 Association of Patient Characteristics With MACE at 2 Years: Multivariate Cox Regression Analysis

	aHR	95% CI	p Value
Model I*			
Age	1.54	1.04–2.27	0.03
Diabetes	1.25	0.80–1.94	0.33
Multivessel disease	1.56	1.07–2.28	0.02
TIMI flow grade after PCI	2.11	1.04–4.27	0.04
Presence of MO	3.74	2.21–6.34	<0.001
IS%LV ≥25%	0.90	0.59–1.37	0.63
LVEF ≤40%	2.30	1.48–3.58	<0.001
LVEDV index	1.00	0.99–1.01	0.58
Model II†			
Age	1.58	1.08–2.30	0.02
Multivessel disease	1.56	1.08–2.27	0.02
TIMI flow grade after PCI	2.25	1.14–4.45	0.02
Presence of MO	3.72	2.22–6.25	<0.001
LVEF ≤40%	2.40	1.63–3.53	<0.001

*Before backward variable selection in 970 patients, 118 events. †Backward variable selection in 984 patients, 118 events.

aHR = adjusted hazard ratios; other abbreviations as in Tables 1 and 2.

Meta-analysis M van Kranenburg et al. *JACC Img* 2014

Cardiac Death

TABLE 5 Association of Patient Characteristics With Cardiac Death at 2 Years: Univariate Cox Regression Analysis

	HR	95% CI	p Value
Demographics			
Age	2.18	0.95–5.01	0.07
Sex	1.33	0.50–3.54	0.57
CV risk factors			
Diabetes	2.25	0.96–5.25	0.06
Hypertension	1.05	0.44–2.49	0.91
Anterior MI	1.41	0.64–3.10	0.40
Angiographic variables			
Multivessel disease	0.78	0.35–1.76	0.55
TIMI flow grade after PCI	2.51	0.58–10.87	0.22
CE-CMR variables			
Presence of MO	15.02	2.01–112.24	0.01
IS%LV ≥25%	1.77	0.80–3.89	0.16
LVEF ≤40%	2.26	1.01–5.05	0.05
LVESV index	1.01	0.99–1.04	0.22
LVEDV index	1.00	0.98–1.02	0.91

M van Kranenburg et al. *JACC Img* 2014

Prognostic value of LGE No-Reflow

MACE

Cardiac Death

Recurrent MI

CHF

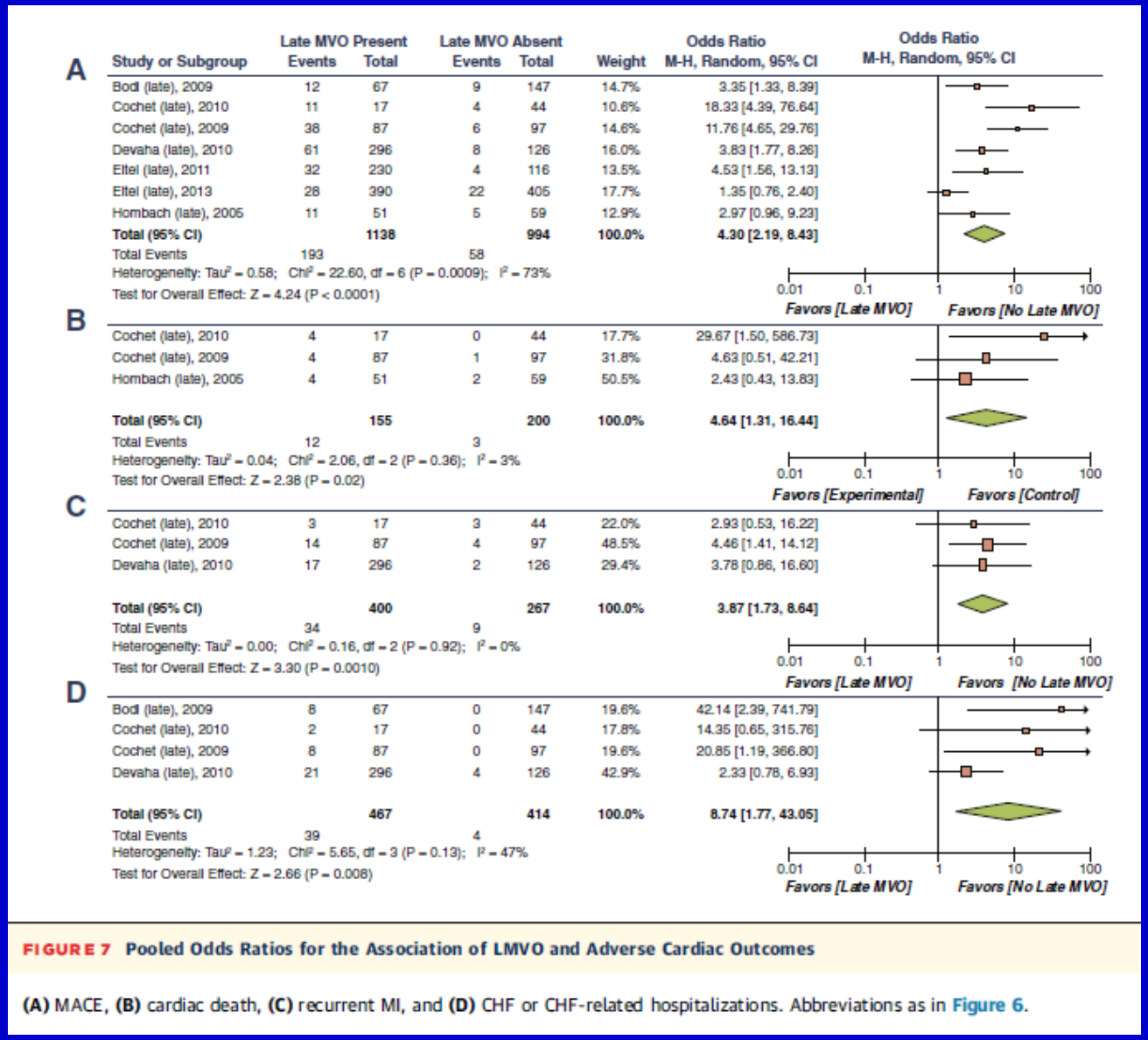


FIGURE 7 Pooled Odds Ratios for the Association of LMVO and Adverse Cardiac Outcomes

(A) MACE, **(B)** cardiac death, **(C)** recurrent MI, and **(D)** CHF or CHF-related hospitalizations. Abbreviations as in Figure 6.

Y Hamirani et al. *JACC Img* 2014

Etude multicentrique
n = 738

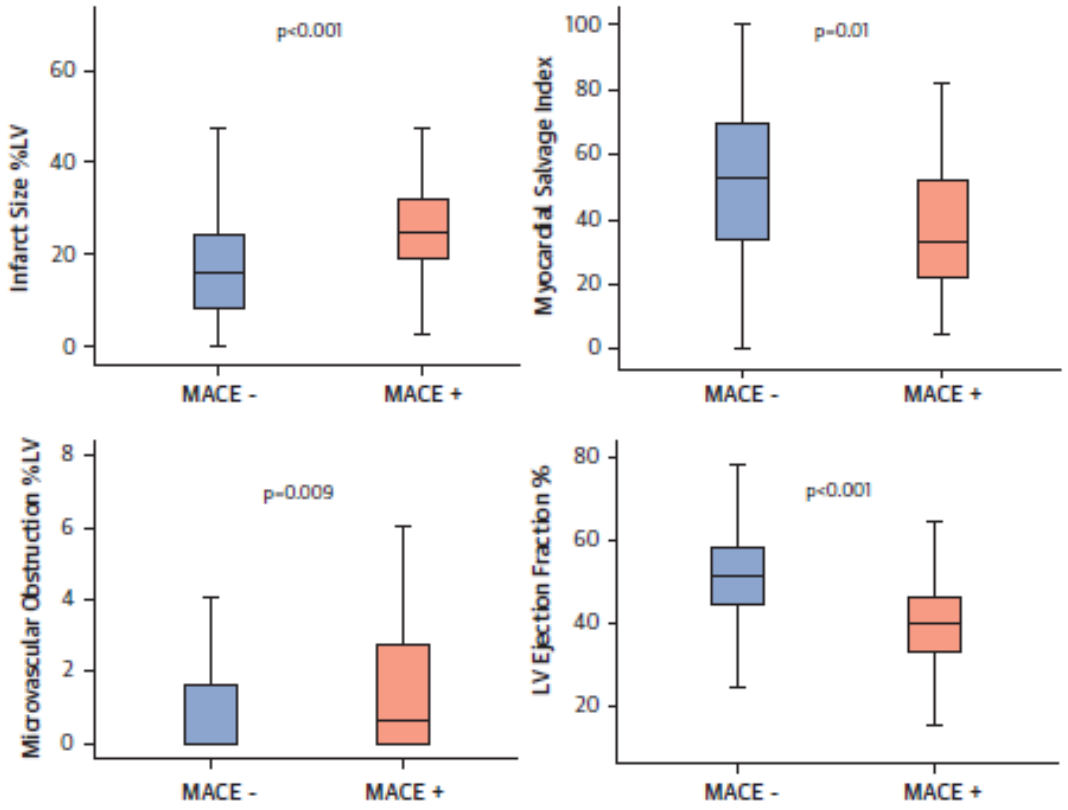


FIGURE 2 **Infarct Size, Myocardial Salvage Index, Microvascular Obstruction, and LV Ejection Fraction According to the Presence or Absence of MACE**

Box-and-whisker plots (box: 25th percentile, median, and 75th percentile; whisker: 10th and 90th percentiles) of infarct size, myocardial salvage index, microvascular obstruction, and left ventricular (LV) ejection fraction according to the occurrence of major adverse cardiac events (MACE).

Eitel I et al. *JACC 2014*

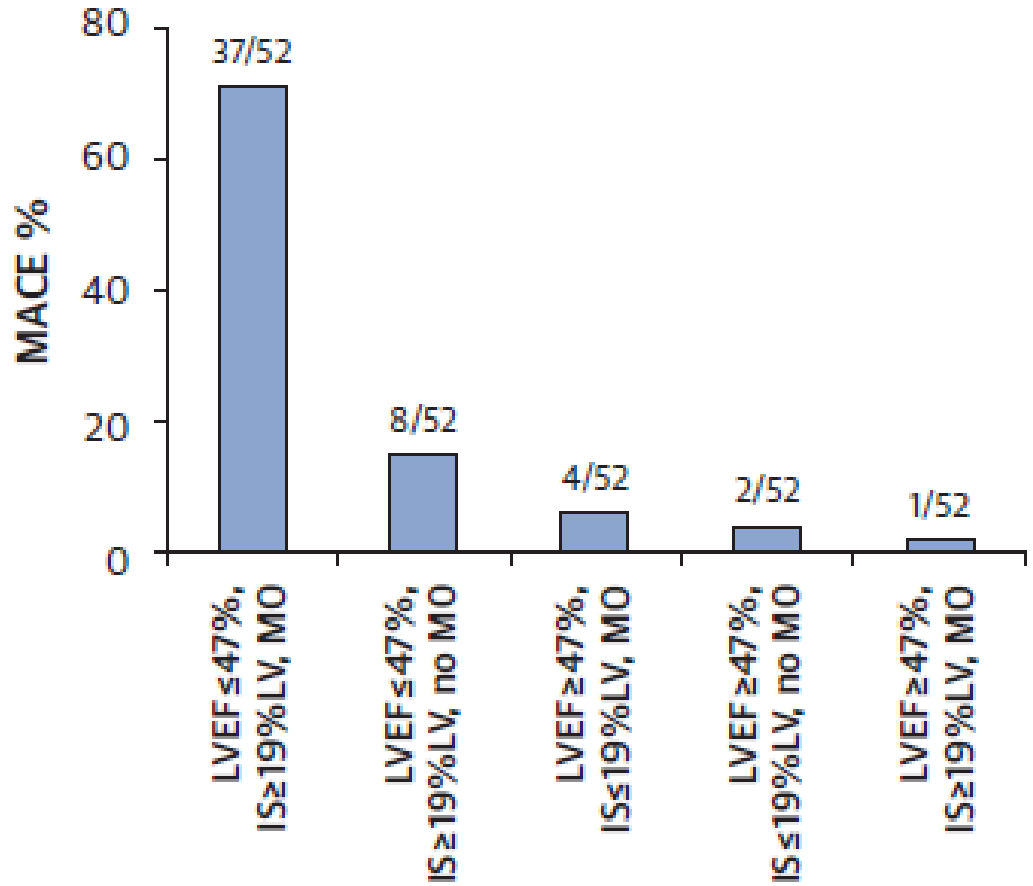


FIGURE 3 MACE Rate According to IS, LVEF, and MO

Number of major adverse cardiac events (MACE) according to left ventricular ejection fraction (LVEF), infarct size (IS), and presence of microvascular obstruction (MO). LV = left ventricle.

Eitel I et al. *JACC 2014*

TABLE 2 Predictors of MACE in Univariate and Multivariate Cox Regression Analysis

	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

CI = confidence interval; LV = left ventricular; MO = microvascular obstruction; other abbreviations as in Table 1.

Eitel I et al. *JACC 2014*

TABLE 3 C-Statistics: Additive Prognostic Value of CMR Markers of Myocardial Damage

	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)

CMR = cardiac magnetic resonance; LVEF = left ventricular ejection fraction; other abbreviations as in Tables 1 and 2.

Eitel I et al. *JACC 2014*

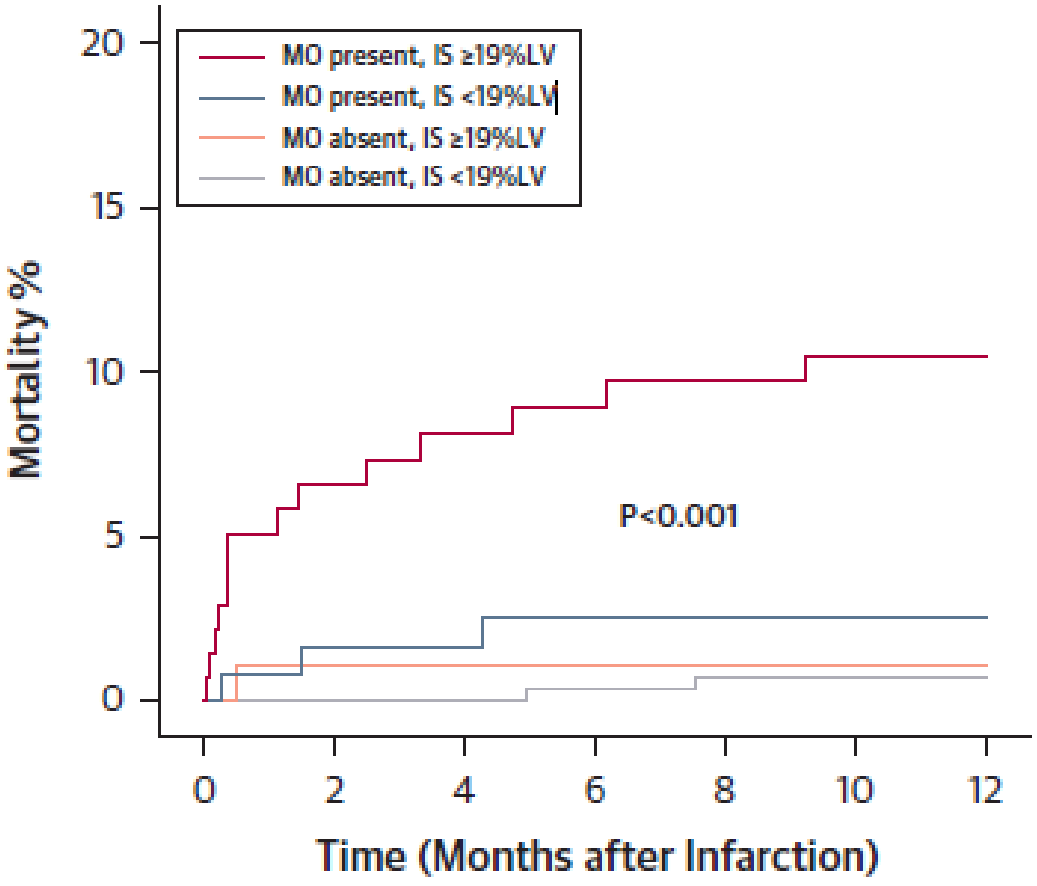
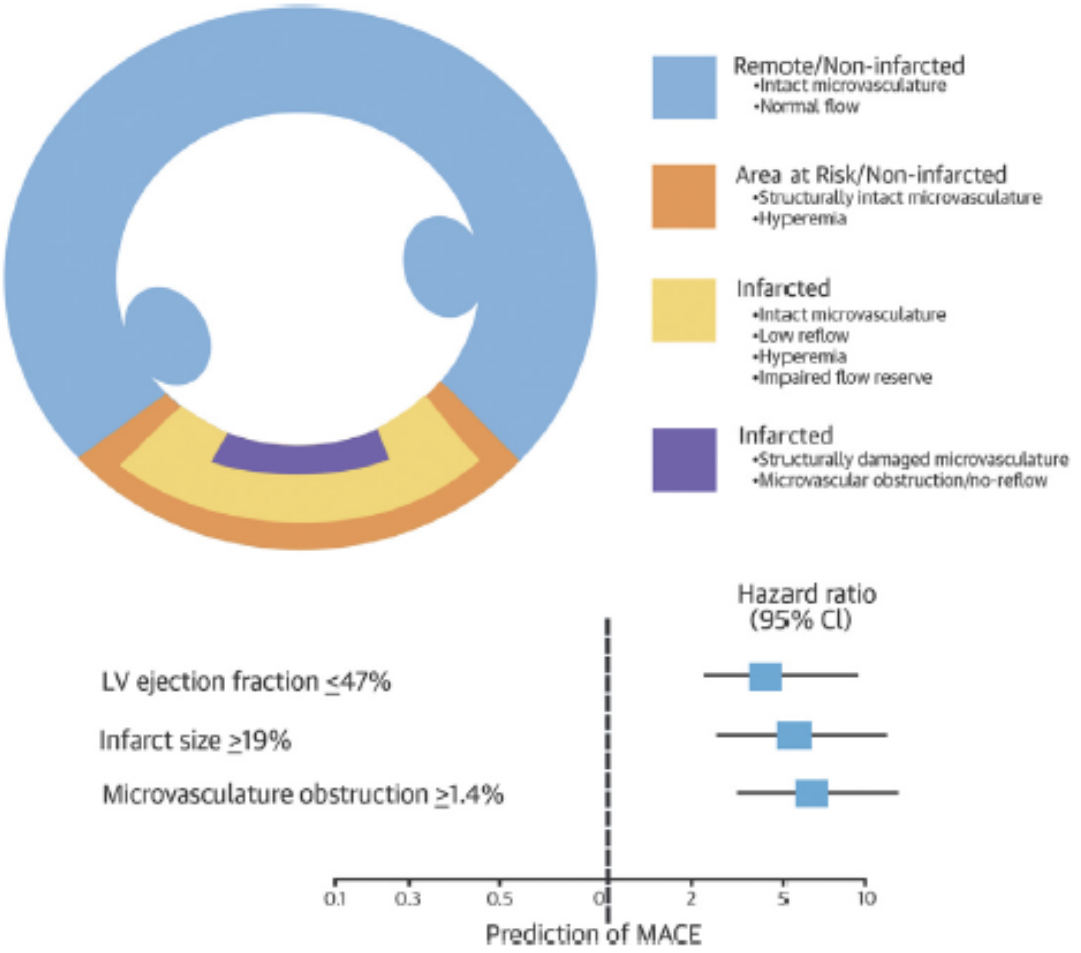


FIGURE 5 Mortality Rate According to IS and MO

Kaplan-Meier curves showing the risk of mortality according to infarct size (IS) and the presence or absence of microvascular obstruction (MO).

Eitel I et al. *JACC 2014*



CENTRAL ILLUSTRATION **Different Regions of Microvascular Flow After Acute Reperfused STEMI**

Schematic short-axis presentation showing the different regions of microvascular flow in reperfused ST-segment elevation myocardial infarction (STEMI). Adapted with permission from Bekkers et al. (22).

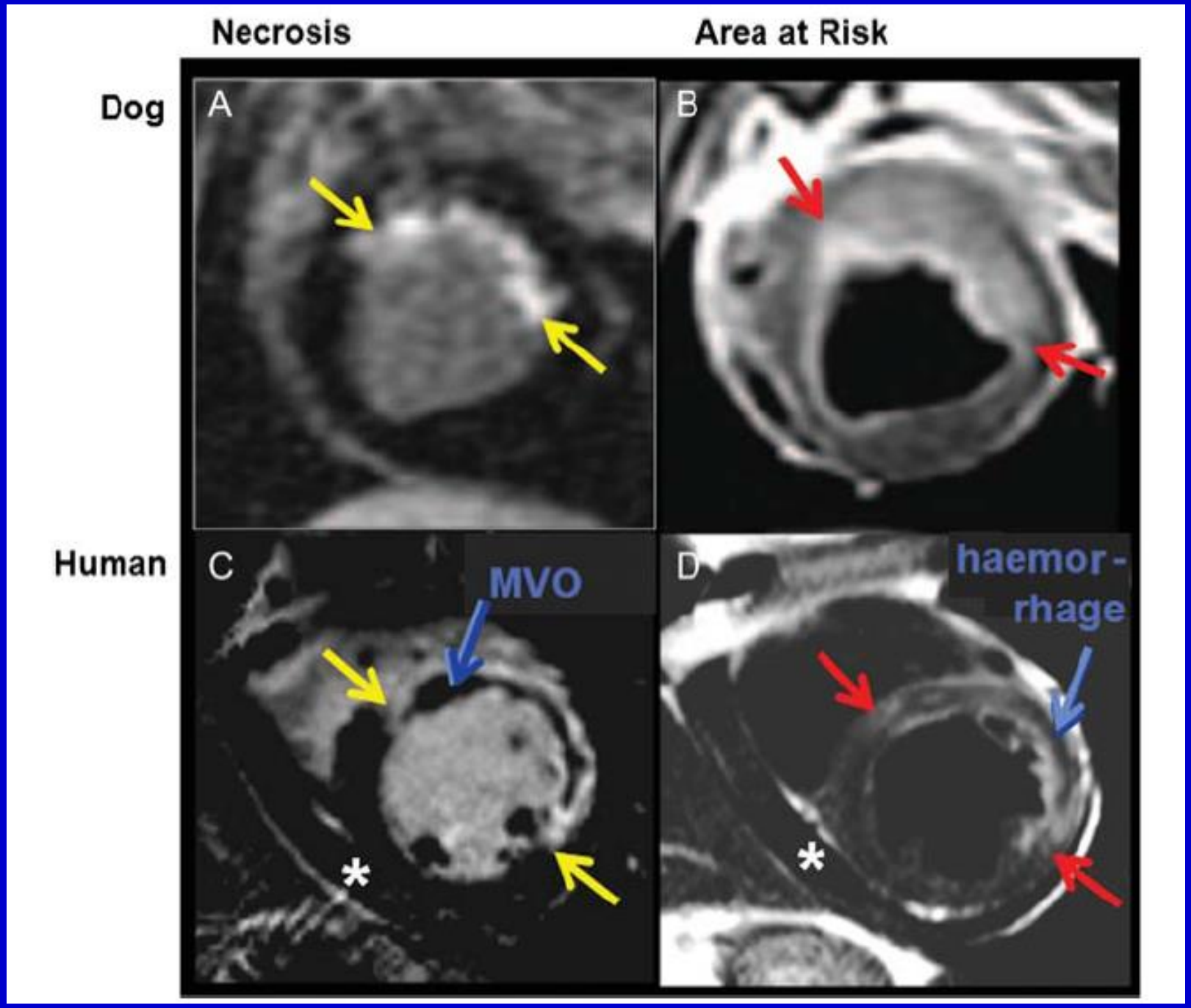
Eitel I et al. *JACC 2014*

Comment identifier les patients à risque en post-infarctus
Les apports de l'IRM cardiaque

- 3 Hémorragie intramyocardique

T2, T2 mapping, T2 *

- Myocardial salvage index
  - Aire à risque – aire de nécrose
  - T2 et T2 maps
  - Délai Douleur thoracique / ATC
  - Evènements cardio-vasculaires (MACE)
- Hémorragie intra-myocardique
  - T2, T2*
  - Facteur prédictif de remodelage VG


Necrosis
Area at Risk
Dog
Human
A
B
C
MVO
D
haemor-
rhage
*
*

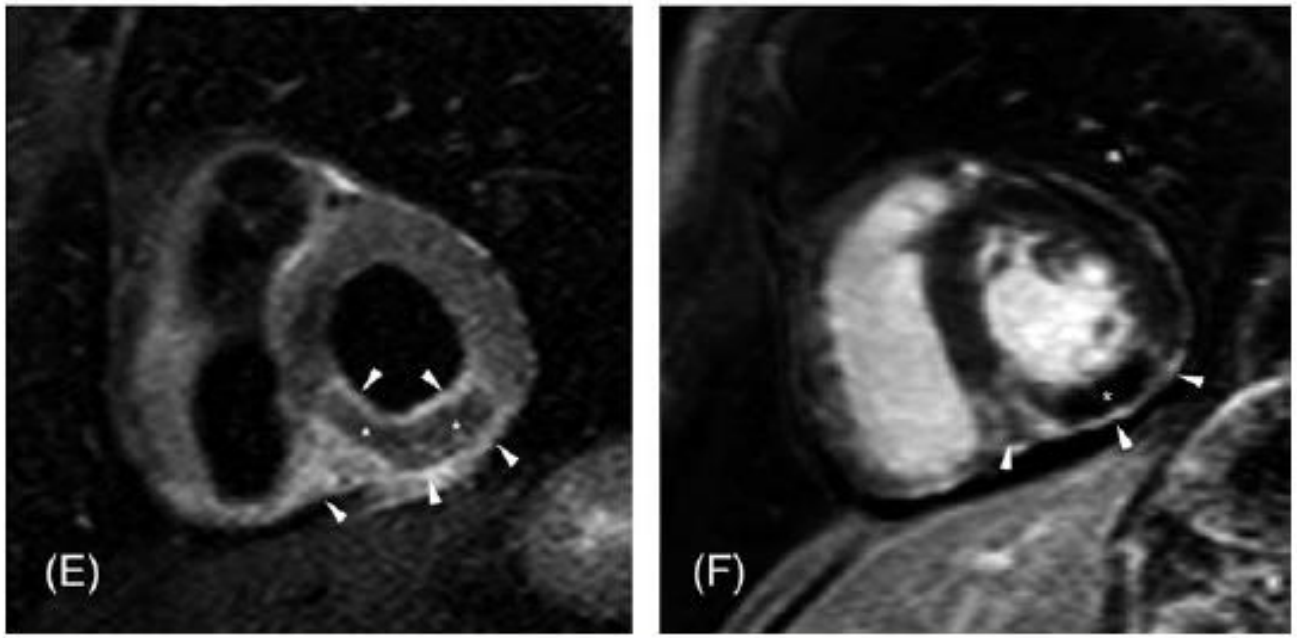


Figure 2 Short-axis T2-weighted (*A*, *C* and *E*) and contrast-enhanced (*B*, *D* and *F*) magnetic resonance images in three patients with acute myocardial infarction. Panels *A* and *B* show matched short-axis views of a patient with an inferoseptal myocardial infarction. High signal intensity on the inferoseptal myocardial segments extending to the inferior right ventricular wall corresponding to the area at risk with myocardial oedema can be seen in panel *A* (arrows). Almost transmural necrosis on the same myocardial segments without evidence of microvascular obstruction (panel *B*, arrows). Panels *C* and *D* show images from a patient with acute anteroseptal myocardial infarction and microvascular obstruction. High signal intensity on the anteroseptal myocardial segments corresponding to myocardial oedema is seen in panel *C* (arrowheads). Early contrast-enhanced images show a hypointense area in the core of the infarct corresponding to microvascular obstruction (panel *D*, asterisks). Panels *E* and *F* show images from a patient with acute inferior myocardial infarction with myocardial haemorrhage and microvascular obstruction. Myocardial haemorrhage is visible as a central hypointense area (panel *E*, asterisks) within the area of myocardial oedema that extends into the right ventricle (panel *E*, arrowheads). Panel *F* shows a large area of transmural necrosis (arrowheads) with a large core of microvascular obstruction (asterisk).

J Ganane Eur Heart J 2009

Table 5 Results of multiple linear regression of left ventricular remodelling

Predictors of endpoint	95% CI	R^2	*F*-value	*P*-value
Haemorrhagic MI	0.15–0.31	0.17	20.19	<0.001
Infarct size at baseline	20.84–27.73	0.16	18.11	0.001
MVO	5.03–9.31	0.12	13.13	0.001
Maximum troponin I	91.91–142.60	0.10	10.75	0.001
Size of area at risk	37.02–46.51	0.09	9.12	0.003
LV mass at baseline	118.62–131.44	0.02	2.31	0.132
Per cent MI transmurality	78.64–87.20	0.03	3.39	0.068
Infarct location	0.37–0.58	<0.01	0.41	0.892
Time to PCI	241.18–305.63	<0.01	0.02	0.874

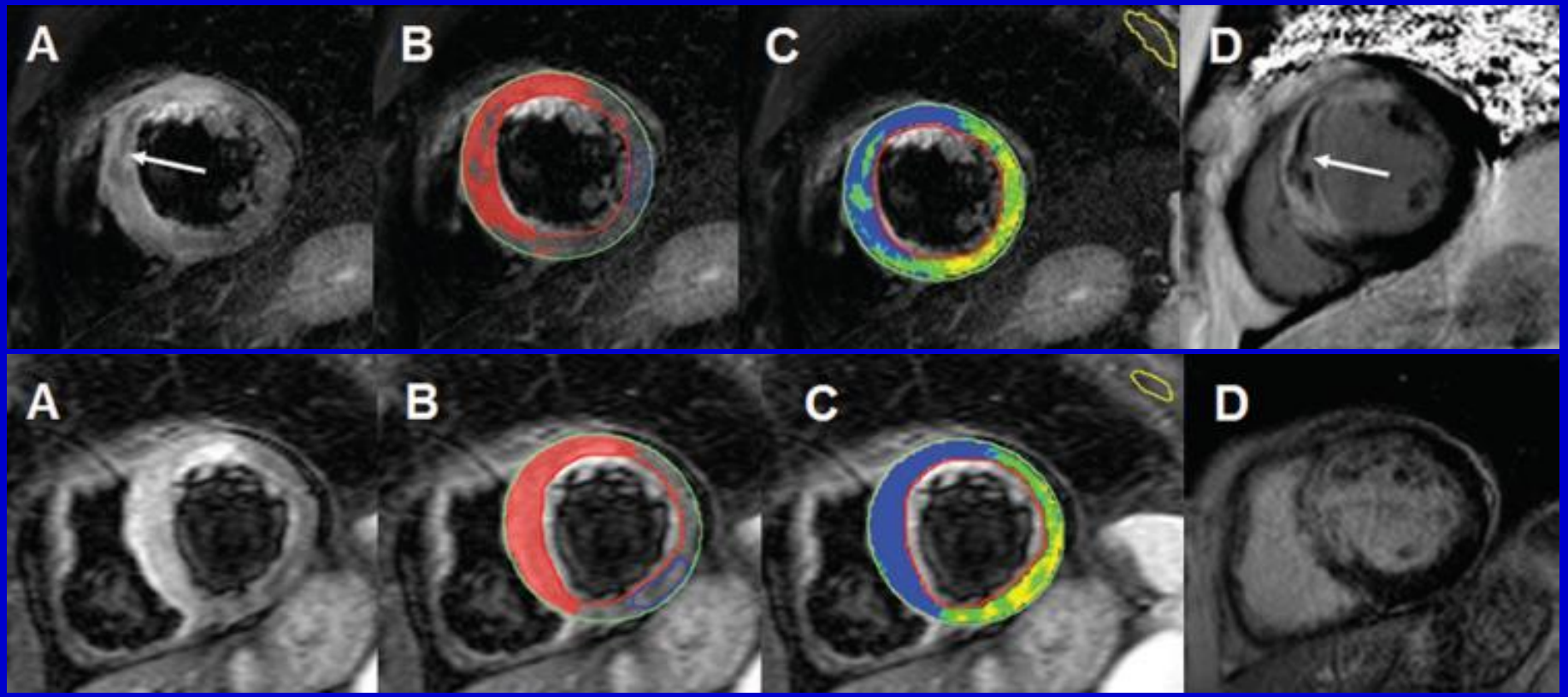
MI, myocardial infarct; PCI, percutaneous coronary intervention; LV, left ventricular; CI, confidence interval; MVO, microvascular obstruction.

J Ganane Eur Heart J 2009

Prognostic Value and Determinants of a Hypointense Infarct Core in T2-Weighted Cardiac Magnetic Resonance in Acute Reperfused ST-Elevation–Myocardial Infarction

- 346 patients, SCA ST+, angioplastie primaire < 12h
- IRM à J3 (T2 + RT)
- Critère primaire : décès, récidive d'IDM, IVG à 6 mois
- 2 groupes selon la présence ou non d'un noyau en hypo signal au sein de la zone en hyper signal sur les séquences T2

Circ Cardiovasc Imaging. 2011;4:354-362.



Hyper signal T2 dans la zone de l'IDM : 100%

Noyau en hypo signal dans l'hyper signal T2 : 35% avec 100 % de no-reflow

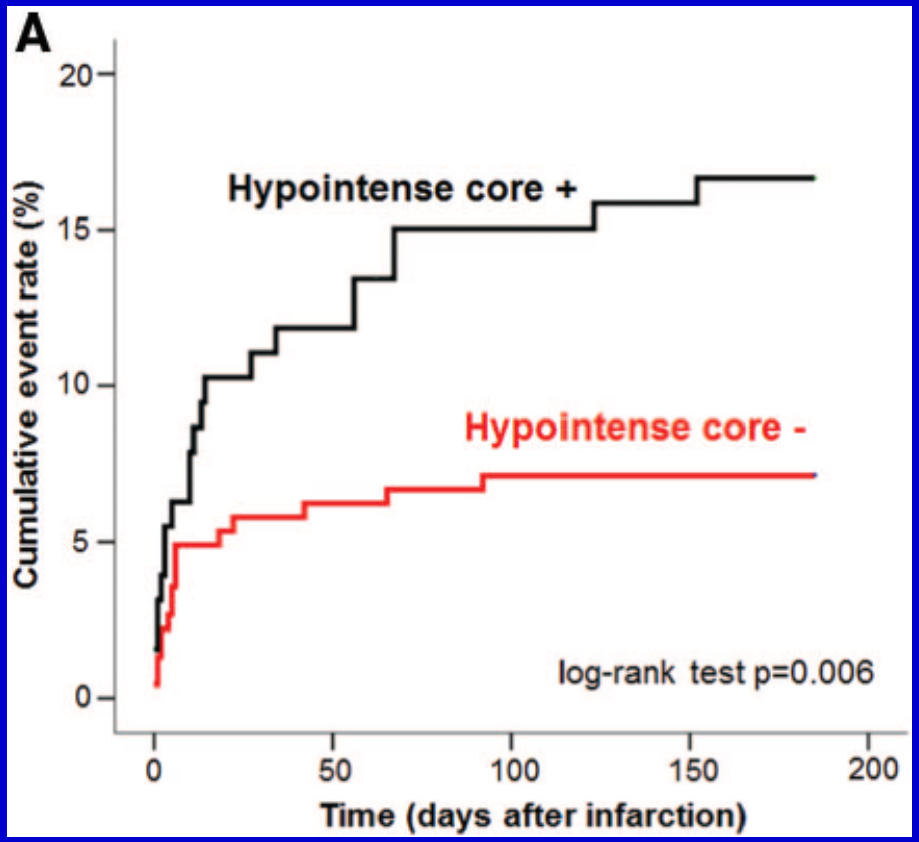
RT+ dans la même zone que hyper signal T2

48 % des no-reflow n'ont pas d'hyposignal T2

Circ Cardiovasc Imaging. 2011;4:354-362.

Table 2. CMR Results

Variable	Hypointense Core Present (n=122)	Hypointense Core Absent (n=224)	*P* Value
Area at risk/edema, %LV	38.9 (31.3–47.4)	32.2 (25.5–39.3)	<0.001
Infarct size, %LV	27.1 (17.5–34.9)	13.0 (5.7–20.8)	<0.001
Late MO present, n (%)	122 (100)	108 (48)	<0.001
Late MO, %LV	2.1 (1.0–3.9)	0.1 (0.0–0.8)	<0.001
Myocardial salvage, %LV	11.5 (6.8–11.5)	15.8 (8.8–27.0)	<0.001
Myocardial salvage index	28.5 (18.9–45.1)	58.1 (31.4–79.7)	<0.001
LV ejection fraction (%)	46.8 (39.0–53.7)	57.0 (48.2–63.6)	<0.001
LV end-diastolic volume, mL	151.1 (128.9–171.0)	129.4 (118.5–152.0)	<0.001
LV end-systolic volume, mL	77.4 (60.6–101.0)	55.0 (42.2–72.7)	<0.001



Circ Cardiovasc Imaging. 2011;4:354-362.

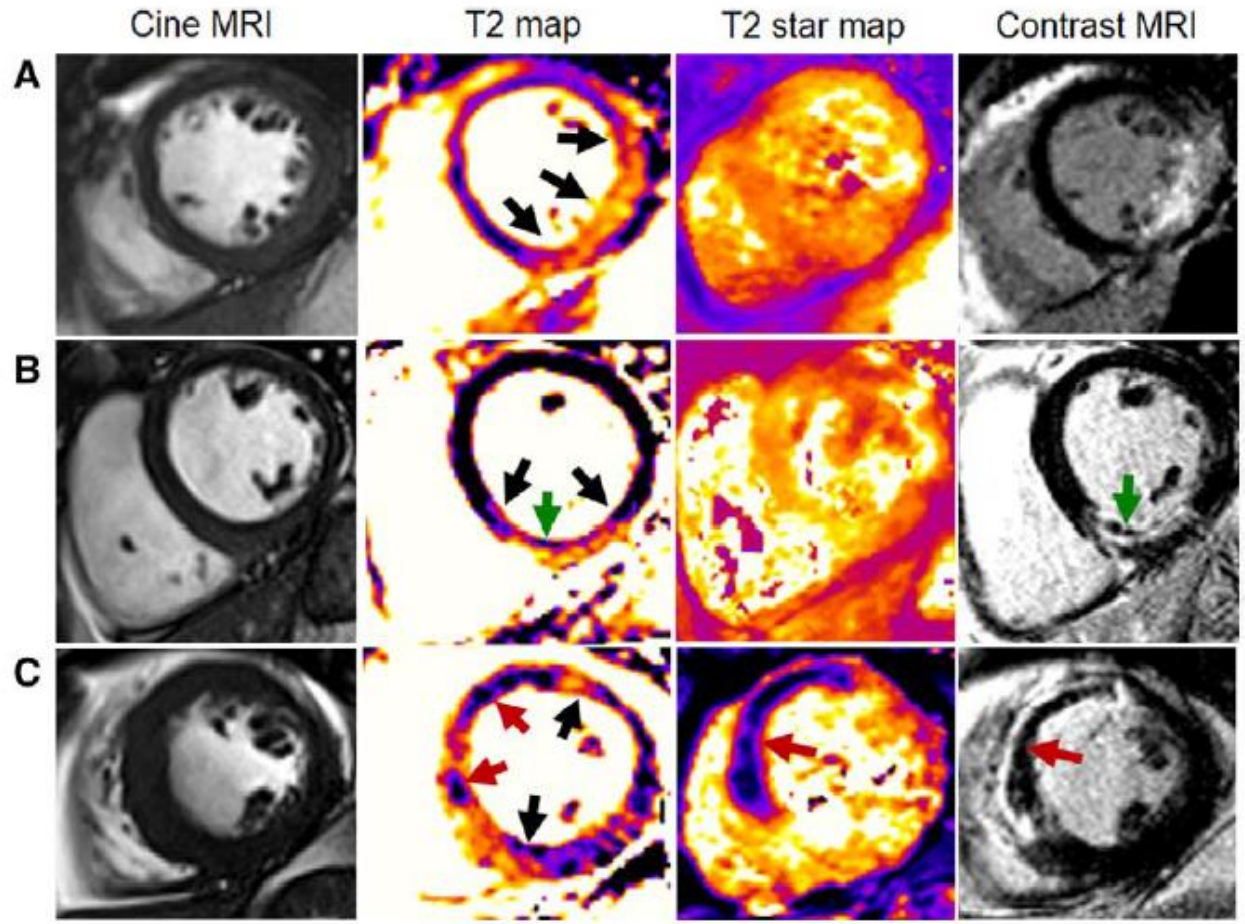


Figure 2. Three patients with acute ST-segment–elevation myocardial infarction treated by primary percutaneous coronary intervention (PCI) using the same antithrombotic strategies. Each patient had normal thrombolysis in myocardial infarction grade 3 flow at the end of PCI. Cardiac magnetic resonance imaging was performed 2 days post reperfusion. **A**, Patient with no evidence of myocardial hemorrhage or microvascular obstruction. **B**, Patient with T2-hypointense core and microvascular obstruction, in the absence of hemorrhage. **C**, Patient with myocardial hemorrhage (Results section in the Data Supplement).

Carrick D et al. *Circ Cardiovasc Imaging 2016*

Table 2. Baseline and 6-Month CMR Findings in 245 Patients With ST-Segment–Elevation Myocardial Infarction According to the Presence or the Absence of Myocardial Hemorrhage and Microvascular Obstruction

Characteristics*	All Patients, n=245	No Hemorrhage or MVO, n=112	MVO only, n=32	Hemorrhage and MVO, n=101	*P* Value
CMR findings 2 d post MI				**42 %**	
LV ejection fraction, %	55 (10)	58 (9)	56 (8)	51 (10)	<0.001
LV end-diastolic volume, mL					
Men	161 (32)	152 (33)	157 (25)	171 (31)	<0.001
Women	124 (23)	122 (24)	126 (20)	127 (26)	0.534
LV end-systolic volume, mL					
Men	76 (26)	67 (24)	71 (16)	86 (27)	<0.001
Women	55 (15)	52 (15)	55 (11)	62 (16)	0.037
LV mass, g					
Men	146 (34)	139 (30)	147 (28)	154 (38)	0.006
Women	99 (24)	94 (23)	94 (14)	111 (26)	0.010
Edema and infarct characteristics					
Area at risk, % LV mass	33 (12)	27 (10)	34 (9)	39 (11)	<0.001
Infarct size, % LV mass	19 (14)	10 (9)	20 (9)	29 (12)	<0.001
Myocardial salvage, % of LV mass	19 (9)	20 (10)	20 (9)	18 (8)	0.064
Myocardial salvage index, %	61 (24)	75 (23)	59 (20)	46 (17)	<0.001
Late microvascular obstruction present, n (%)	133 (54)	0	32 (100)	101 (100)	<0.001
Late microvascular obstruction, % LV mass	0.5 (0.0–4.2)	…	1.2 (0.7–2.4)	5.3 (2.1–9.5)	<0.001
T2 hypointense core present, n (%)	161 (66)	28 (25)	32 (100)	101 (100)	<0.001

Carrick D et al. *Circ Cardiovasc Imaging 2016*

Table 2. Baseline and 6-Month CMR Findings in 245 Patients With ST-Segment–Elevation Myocardial Infarction According to the Presence or the Absence of Myocardial Hemorrhage and Microvascular Obstruction

Characteristics*	All Patients, n=245	No Hemorrhage or MVO, n=112	MVO only, n=32	Hemorrhage and MVO, n=101	*P* Value
CMR findings 6 mo post MI (n=228)					
LV ejection fraction, %	61 (9)	66 (7)	63(6)	56 (10)	<0.001
Change in LV ejection fraction at 6 mo from baseline, %	7 (8)	8 (8)	7 (7)	5 (7)	0.005
LV end-diastolic volume, mL					
Men	169 (42)	152 (30)	160 (27)	188 (48)	<0.001
Women	128 (23)	125 (24)	132 (24)	133 (20)	0.066
Change in LV end-diastolic volume at 6 mo from baseline, mL					
Men	7 (29)	–1 (25)	2 (18)	17 (32)	<0.001
Women	3 (19)	0 (18)	8 (18)	5 (21)	0.621
LV end-systolic volume, mL					
Men	69 (35)	54 (21)	60 (17)	86 (42)	<0.001
Women	48 (17)	41 (14)	49 (15)	62 (13)	<0.001
Change in LV end-systolic volume at 6 mo from baseline, mL					
Men	–7 (24)	–14 (21)	–11 (14)	0 (28)	<0.001
Women	–7 (14)	–11 (14)	–4 (8)	0 (14)	0.023
LV mass, g					
Men	128 (27)	122 (27)	128 (22)	133 (28)	0.007
Women	91 (18)	90 (19)	90 (17)	95 (17)	0.270

CMR indicates cardiac magnetic resonance; MVO, microvascular obstruction; LV, left ventricular; and MI, myocardial infarction.
*Data are reported as mean (SD), median (IQR), or n (%) as appropriate.

Carrick D et al. *Circ Cardiovasc Imaging 2016*

Score de risque IRM

Table 2. Results of Univariable and Multivariable Cox Regression Analysis in the AIDA STEMI Cohort and Determination of the Scoring System

	Univariable Analysis		Multivariable Analysis		
	Hazard Ratio (CI)	*P* Value	Hazard Ratio (CI)	*P* Value	Points
LVEF ≤47%	4.38 (2.49–7.71)	<0.001	2.15 (1.15–4.02)	0.016	1
IS ≥19% LV	5.41 (2.78–10.53)	<0.001	2.18 (0.97–4.88)	0.058	1
MO ≥1.4% LV	5.62 (3.12–10.12)	<0.001	2.81 (1.40–5.62)	0.004	2

% LV indicates percentage of left ventricular mass; AIDA, Abciximab Intracoronary Versus Intravenously Drug Application; CI, confidence interval; IS, infarct size; LVEF, left ventricular ejection fraction; MO, microvascular obstruction; and STEMI, ST-segment–elevation myocardial infarction.

Stiermaier T et al. *Circ Cardiovasc Imaging 2017*

Score de risque IRM

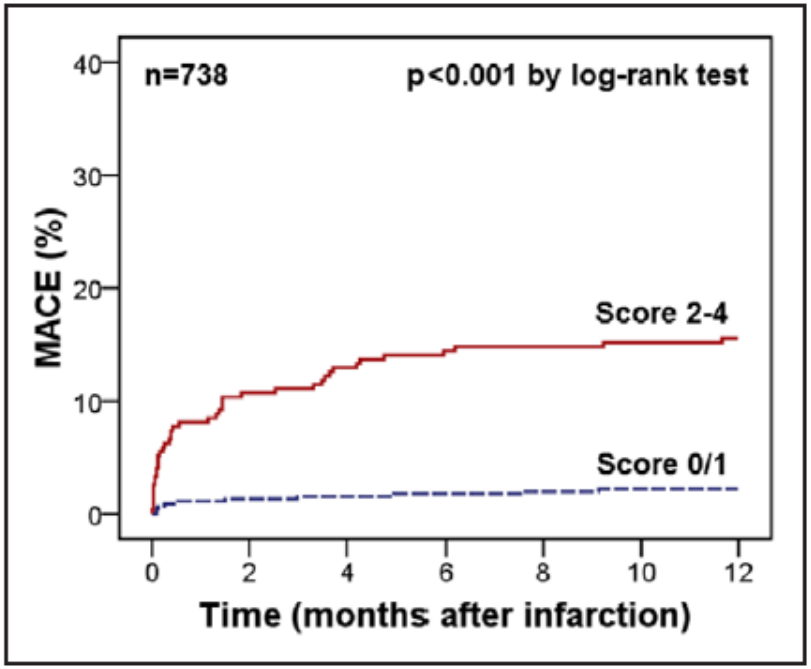


Figure 2. Kaplan–Meier plot for 12-month major adverse cardiovascular events (MACE) rate according to the CMR score categories in the AIDA STEMI (Abciximab Intracoronary Versus Intravenously Drug Application in ST-Segment–Elevation Myocardial Infarction) cohort.

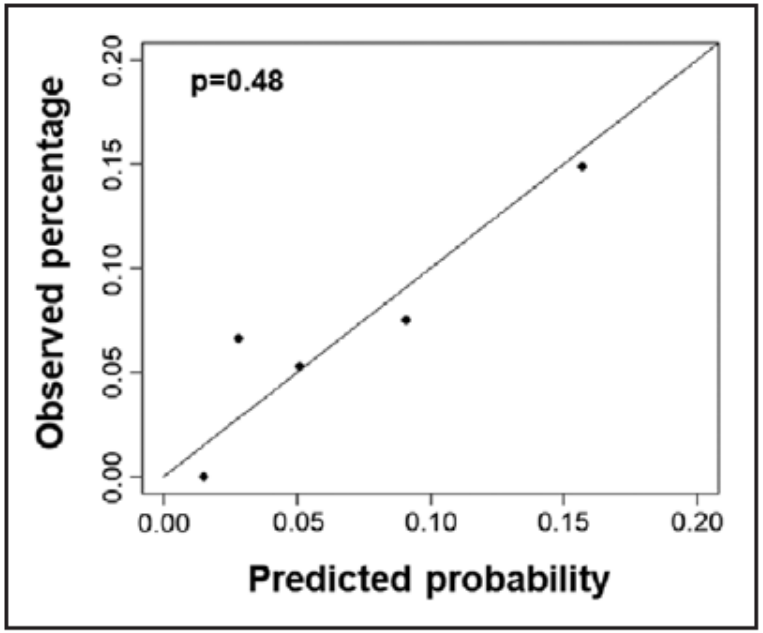
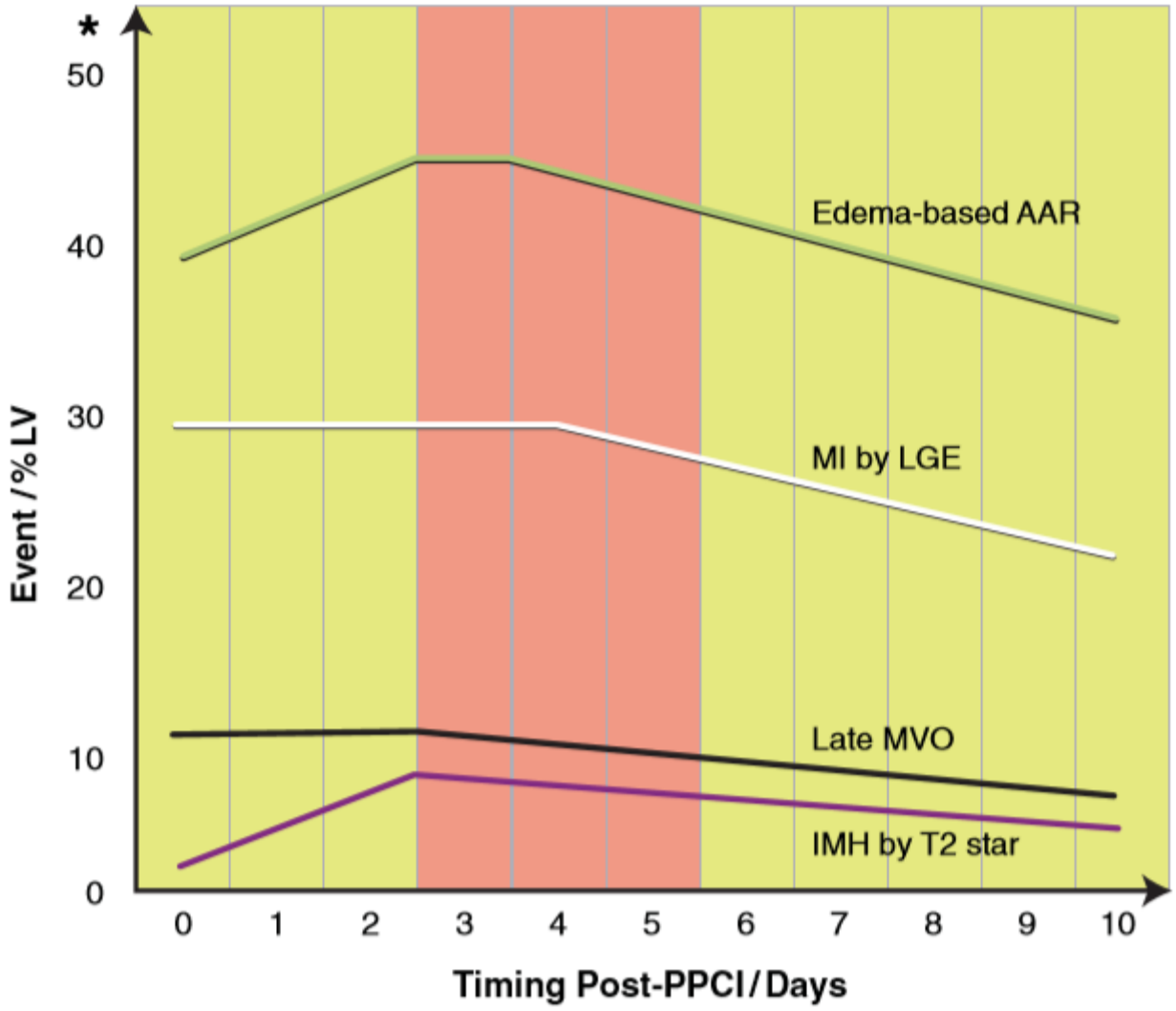


Figure 4. Calibration plot obtained in the validation cohort. The validation cohort was divided into 5 groups according to the predicted probability of 12-month major adverse cardiovascular events (MACE), which was plotted against the observed frequency.

Stiermaier T et al. *Circ Cardiovasc Imaging 2017*

FIGURE 6 Evolution of Edema-Based Area at Risk, MI Size, Microvascular Obstruction, and Intramyocardial Hemorrhage in Patients With ST-Segment Elevation Myocardial Infarction Within the First 10 Days Post-Reperfusion



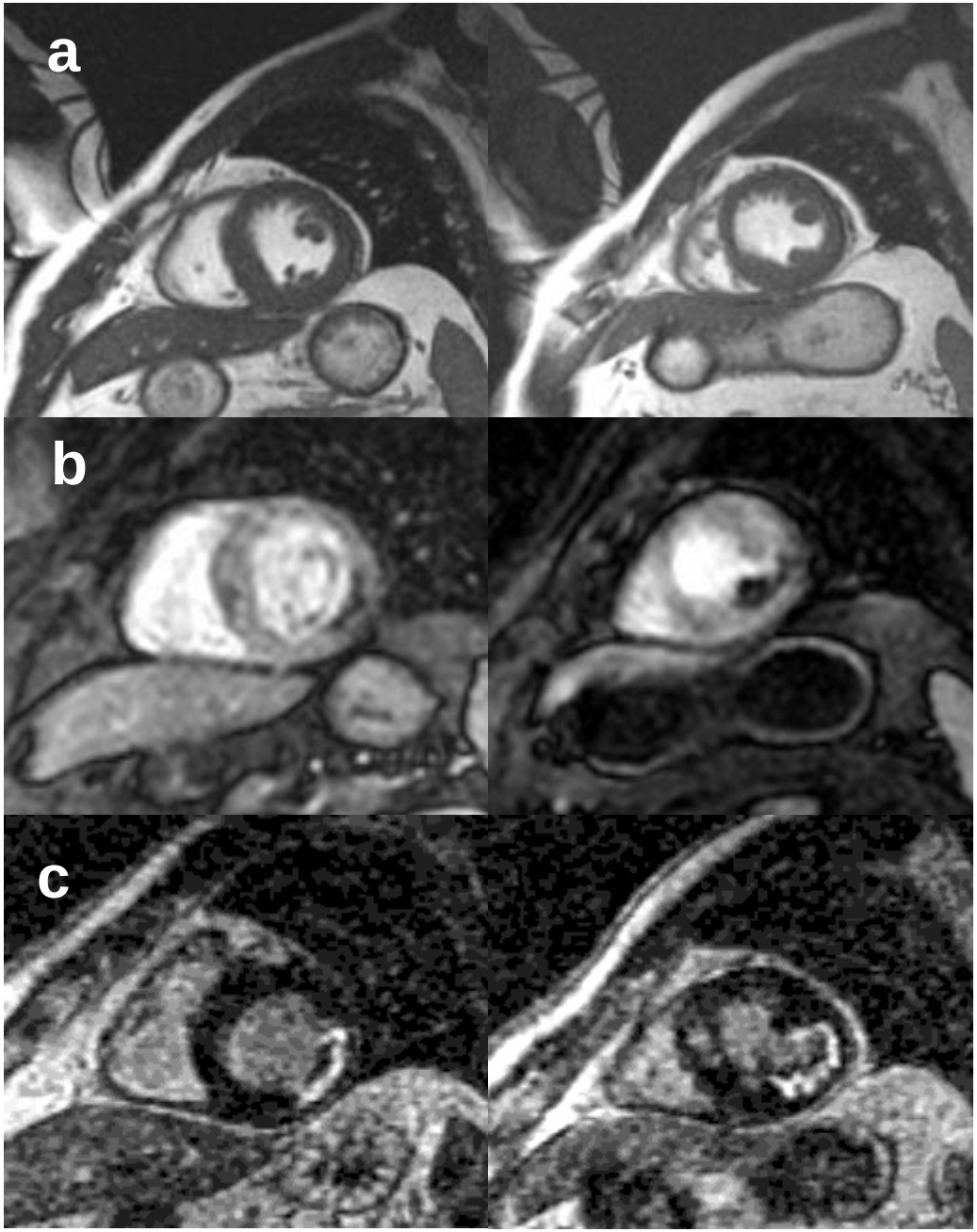
Bulluck H et al. JACC Cardiovasc imaging 2017

Syndrome coronarien aigu sans sus-décalage du segment ST

- Micro-infarctus sous-endocardiques
- ECG normal, Fonction VG régionale normale
- Localisation de l'infarctus
  - Atteinte tritronculaire : lésion coupable
  - Infarctus à coronaires saines

Ricciardi et al Circulation 2001

Figure 2



Infarctus et IRM
Les indications SFC / SFR en 2010

- Dans le post-infarctus
  - **Fonction VG globale et régionale** **I**
  - **Diagnostic des complications**
    - Thrombus intra-VG et Anévrysme VG **I**
  - **Infarctus à coronaires saines** **I**
  - **Viabilité myocardique** **I**
  - Ischémie résiduelle II
    - Fonction VG régionale sous dobutamine
    - Perfusion myocardique régionale sous adénosine