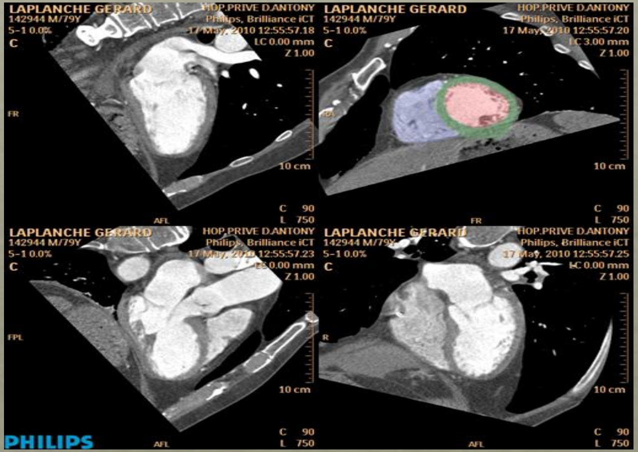
DIU Imagerie CV en coupe Mars 2019

Aspects Fonctionnels en scanner cardiaque

P Dupouy

Pôle d’Imagerie Cardio-Vasculaire Interventionnel Antony-Melun

Hôpital Privé d’Antony ; Clinique les Fontaines, Melun



3 Aspects fonctionnels

- Fonction VG/VD
  - Fraction d'éjection
  - Volumes
  - Diamètre
  - Masse

- Fonction Myocardique
  - Nécrose
  - Motilité segmentaire
  - Perfusion

- Evaluation Fonctionnelle des sténoses

Intérêt de la mesure de la fonction myocardique

- Prédicteur indépendant de
  - Mortalité
  - Morbidité
  - White et col Circulation 1987;76:44-51
    - VTD : 75 ml/m²
    - VTS : 24 ml/m²
    - Masse VG : 165 g 95 g/m²

- Thérapeutique

Table 1
Normal Values for LVEF, EDV, ESV, and Stroke Volume by Gender

Parameter	Males	Females
LVEF (%)	55–73	54–74
EDV (mL)	102–235	96–174
ESV (mL)	29–93	27–71
SV (mL)	66–148	62–110

Source.—Reference 1.
Note.—SV = stroke volume.

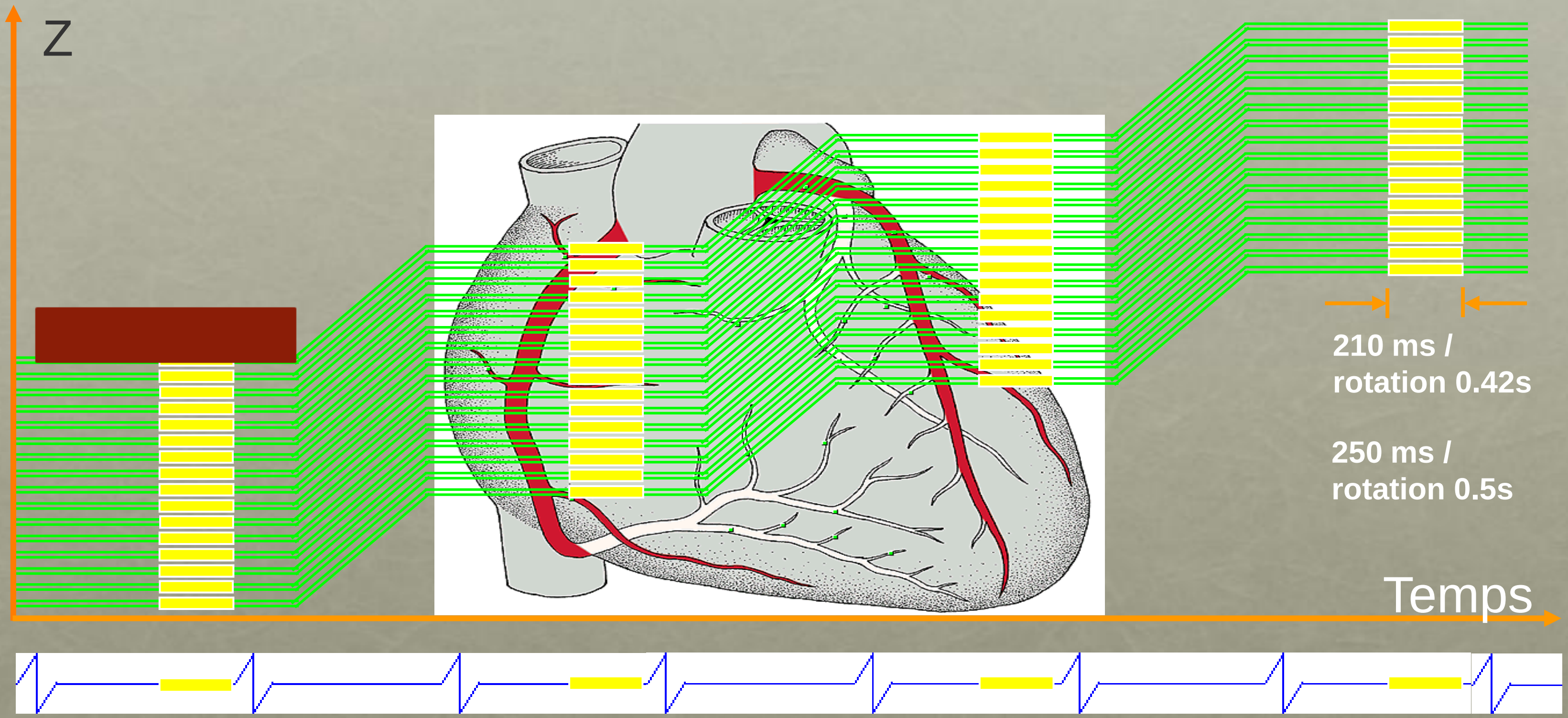
van Ooijen et al, RadioGraphics 2012; 32:589–599

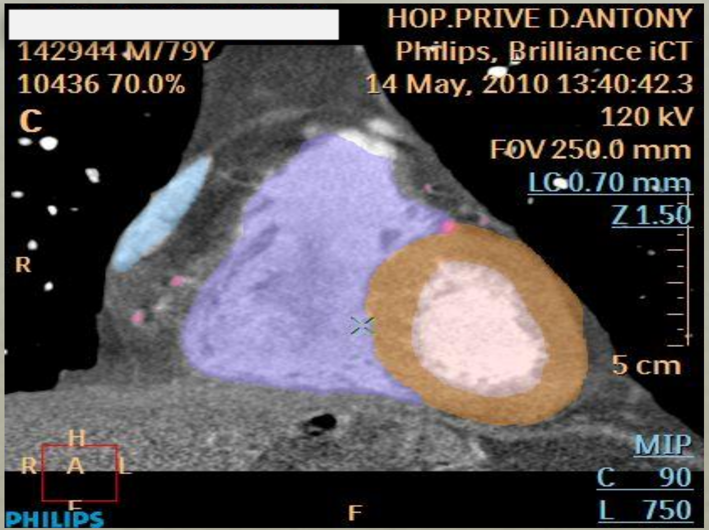
Méthodes de mesure FONCTION contractile

- Echo
  - Opérateur et fenêtre acoustique dépendant
  - Approximation géométrique
  - Résolution temporelle bonne (70 i/sec)
  - Résolution spatiale bonne
- Isotopes
  - Résolution spatiale et temporelle basse
  - PET idem
- Imatron
  - Résolution temporelle ++
- Angio VG
  - Image de projection
  - Approximation géométrique
- IRM = méthode de référence
  - Résolution temporelle ++
  - Résolution spatiale +/-

Principe de l’acquisition Hélicoidale

Axial Retropective Gating

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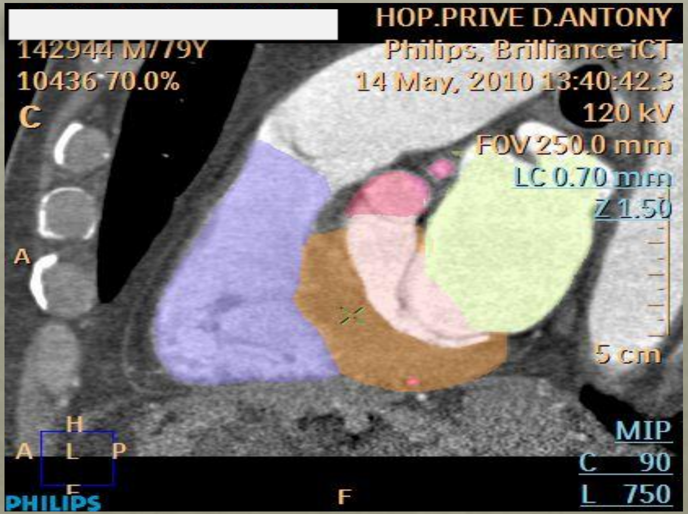
142944 M/79Y
Philips, Brilliance iCT
10436 70.0%
14 May, 2010 13:40:42.3
C
120 kV
FOV 250.0 mm
LC 0.70 mm
Z 1.50
R
5 cm
H
R A L
F
MIP
C 90
L 750
F
PHILIPS


HOP.PRIVE D.ANTONY
142944 M/79Y
Philips, Brilliance iCT
10434-224* 40.0%
14 May, 2010 13:40:42.71
92.3 mm
LC 0.80 mm
C
Z 1.58
R
5 cm
A
R F L
P
MIP
C 90
L 750
P
PHILIPS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120 kV
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LC 0.70 mm
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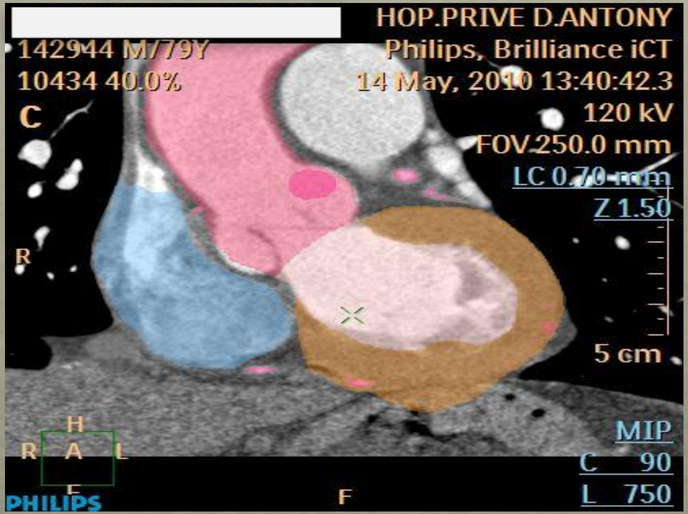
PHILIPS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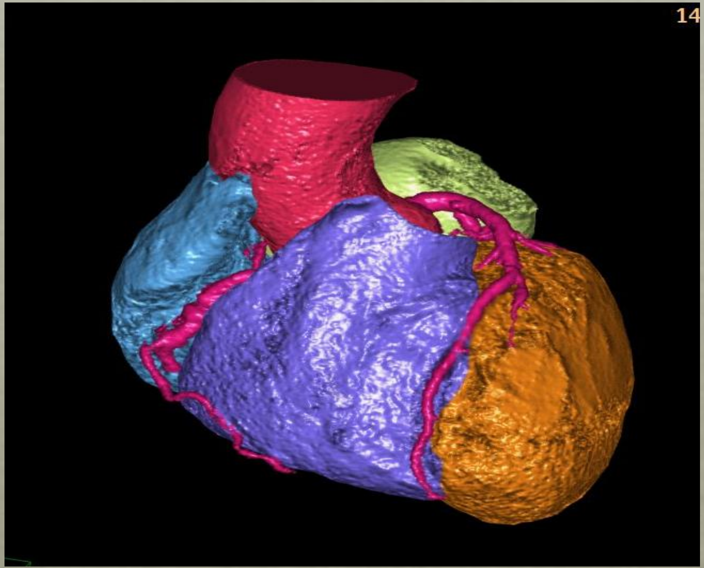
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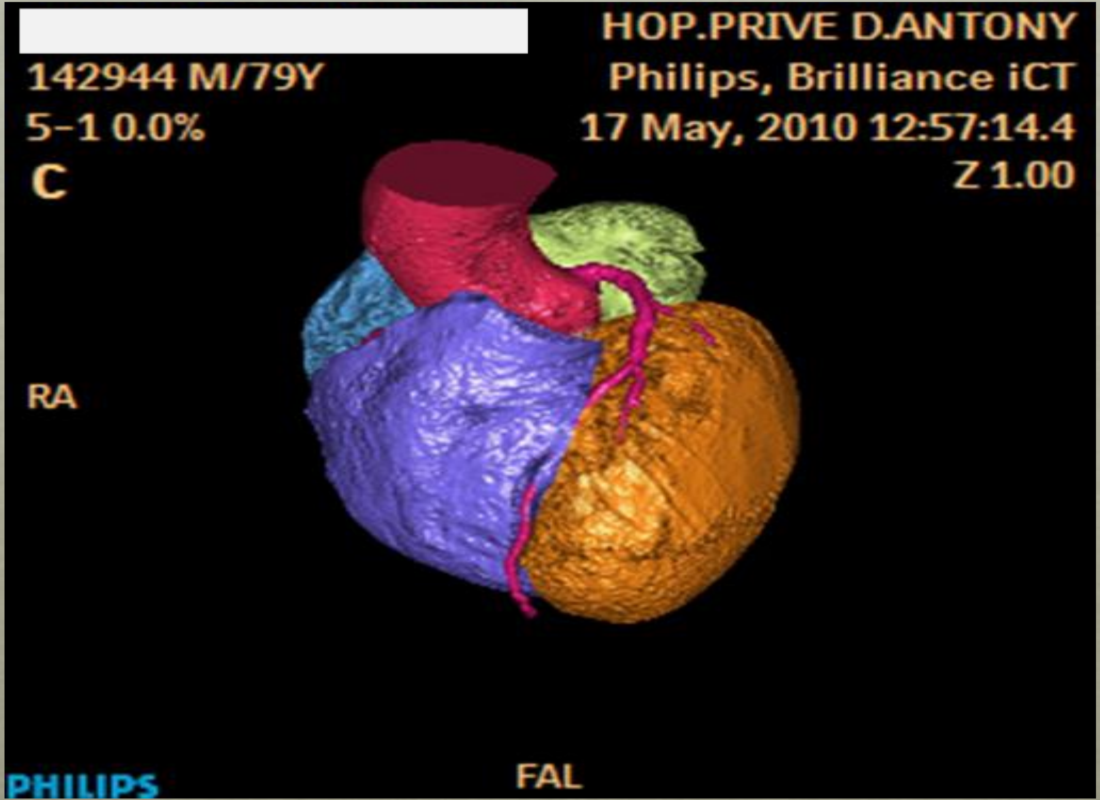
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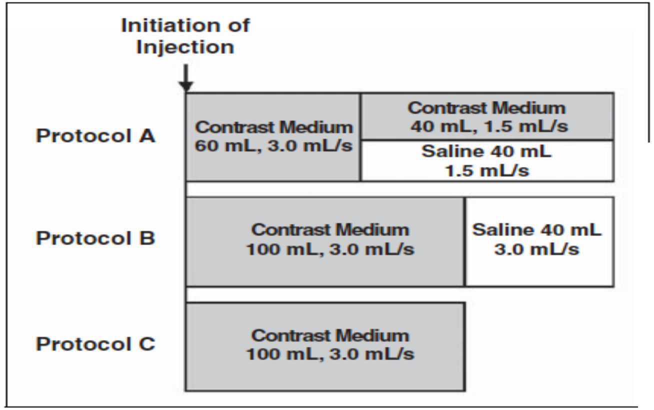
142944 M/79Y
Philips, Brilliance iCT
5-1 0.0%
17 May, 2010 12:57:14.4
C
Z 1.00
RA
PHILIPS
FAL

ProtocoleS d’injection



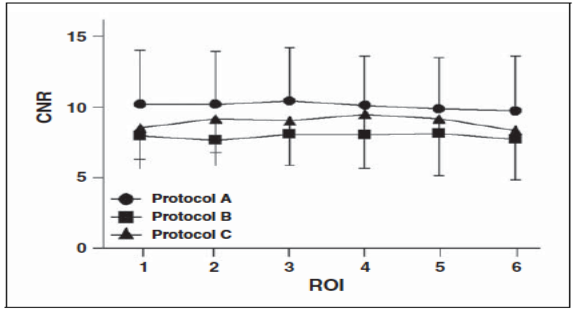


Fig. 2—Graph shows left ventricular–myocardial contrast-to-noise ratio (CNR) profile along *z*-axis with each protocol. Each profile shows constant level during CT. Circular regions of interest (ROIs) were placed in left ventricular cavity and septal myocardial wall from most cranial (ROI 1) to most caudal (ROI 6) position in each patient.

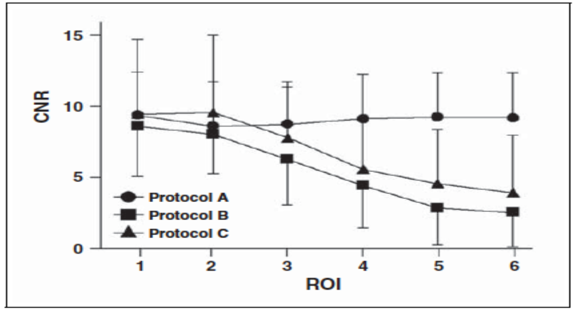
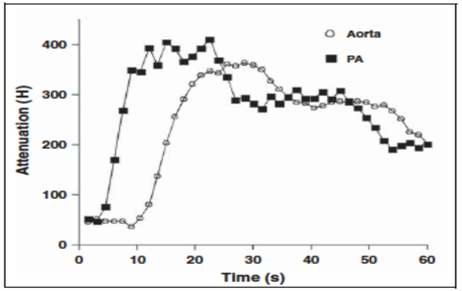
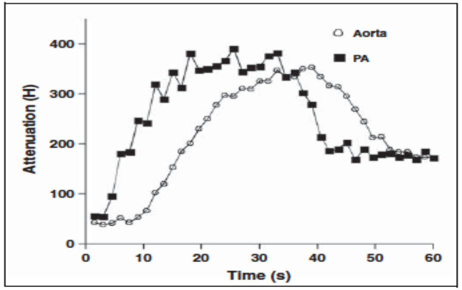


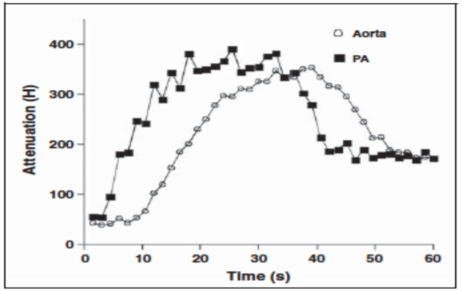
Fig. 3—Graph shows right ventricular–myocardial contrast-to-noise ratio (CNR) profile along *z*-axis with each protocol. Profile obtained with protocol A shows more constant level, whereas profiles obtained with protocols B and C show decrease at caudal levels in right ventricle. Circular regions of interest (ROIs) were placed in right ventricular cavity and septal myocardial wall from most cranial (ROI 1) to most caudal (ROI 6) position in each patient.



A



B



C

Fig. 6—Time–density curves. PA = pulmonary artery.
A, Graph shows time–density curve for protocol A. Adequate and uniform attenuation is present in both aorta and pulmonary artery 20–50 seconds after start of contrast injection.
B, Graph shows time–density curve for protocol B.
C, Graph shows time–density curve for protocol C.

Daisuke Utsunomiya ; *AJR 2006; 187:638–644*

Technique d'injection

1- sérum phy :

- Volume contraste = (T acqui +2) x Q inj   Q inj = 4 à 6 cc/s
- Q inj = 5 x (370/Contrast Conc) pour corriger en fonction du contraste utilisé
- Pour P > 85kg Q inj = Q inj x 1.1   Pour P >100kg Q inj = Q inj x 1.2   Pour P < 70kg Q inj = Q inj x 0.9
- Sérum phy 80 cc même Q inj

2- Sans sérum phy

- Volume contraste = (T acqui +6) x Q inj   Q inj = 5cc/s
- Q inj = 5 x (370/Contrast Conc) pour corriger en fonction du contraste utilisé
- Idem ci dessus pour adaptation poids

Si durée scan > 13 s (Pontages)   Idem avec Qinj = 4 cc/s

Technique d'injection

- ~~Between 120 mL and 140 mL compared with the dose used in coronary anatomy assessment (70–80 mL for 64-slice Technology).~~
- ~~Most of investigators used a single dose injection. In these studies, the concentrations of contrast media vary from 300 to 400 mg of iodine/mL and the total amount of iodine injected varies from 44 g to 56 g per patient, which means a quantity between 0.44 and 0.77 mg/iodine/kg of body weight for a body weight of 80 kg.~~

En Pratique

16 Coupes : 90 à 120 cc PCI 4,5 à 6 ml/sec

64 coupes : 70 à 100 cc PCI 4,5 à 6 ml/sec

> 256 coupes : 50 à 80 cc PCI 4,5 à 6 ml/sec

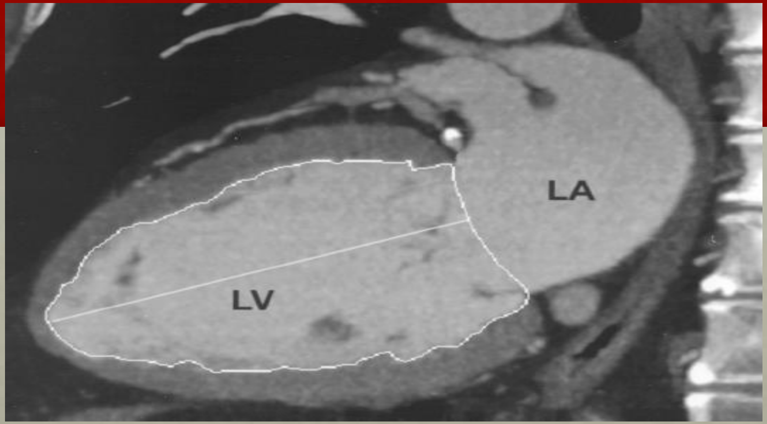
Technique d'acquisition

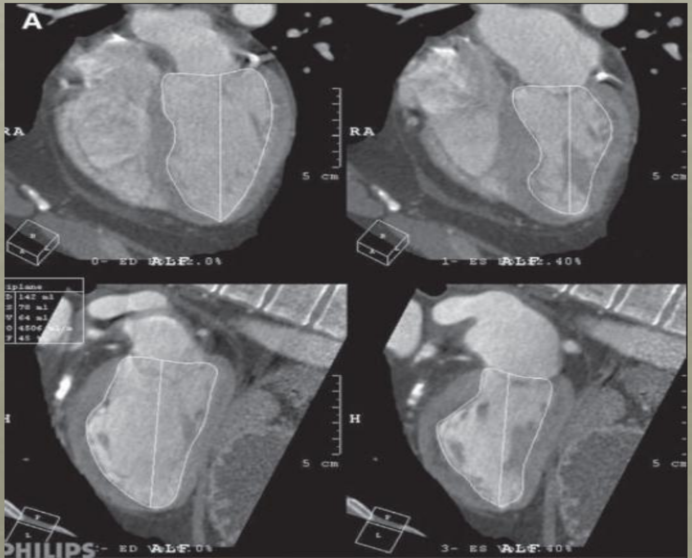
- Temps précoce
  - Coronaires
  - Myocarde :
    - Reconstructions temps diastole/systole
    - MPR coupes larges 6-9 mm.
    - Mesures densités (HU)
- Temps tardif sans réinjection
  - Délai 5-15 minutes
  - 80kv
  - Coupes 1.5 mm
  - MPR coupes larges 6-9 mm.
  - Mesures densités (HU)
- Travail sur le fenêtrage et le moyennage du contraste

Méthodes de Calcul [1]

- Surface-Longueur
  - Contour endocardique
    - Surface : A
    - Longueur (apex-mitrale) : L

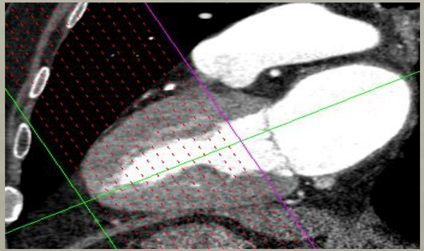
- $V = (8/3) \times (A^2/\Pi.L)$

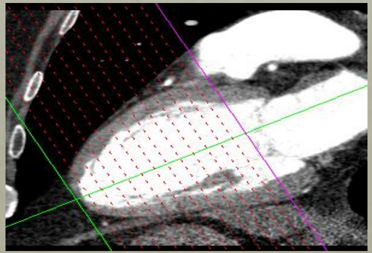


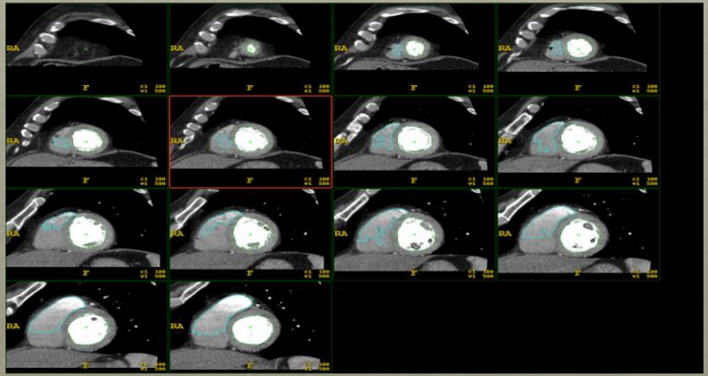


Méthodes de Calcul 2

- Simpson
  - Contour endocardique de toutes les coupes petit axe de l’apex à l’anneau mitral.
  - Muscle papillaire ?



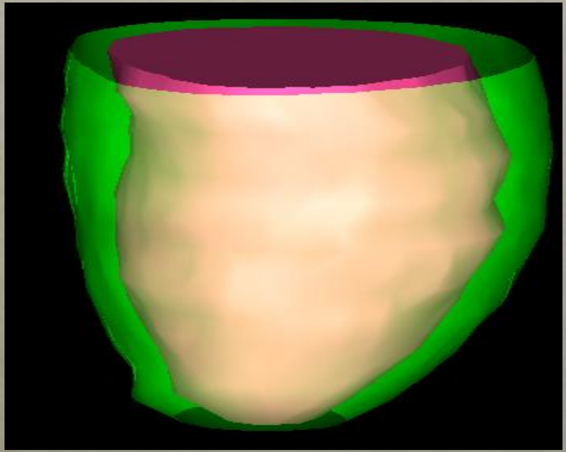


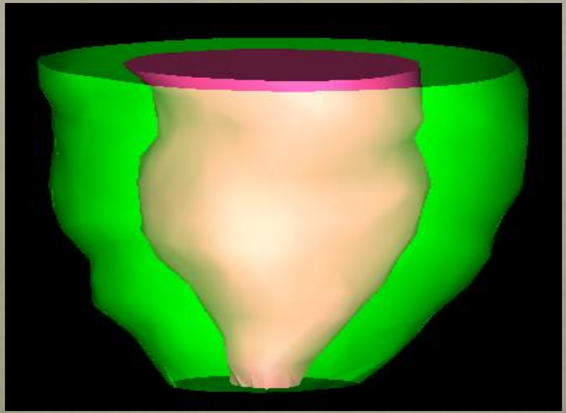


- V = ∑A x S

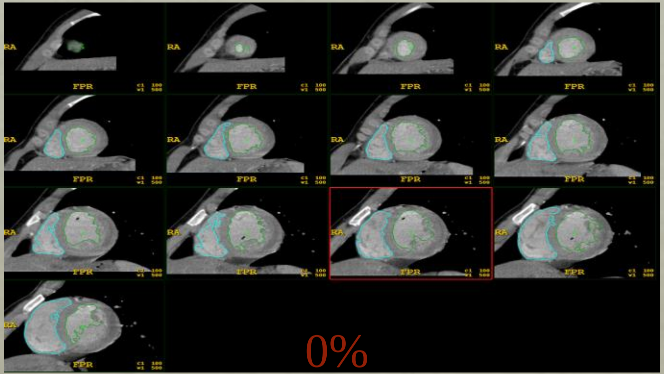
Fraction d'éjection

- FE V = [(Vtd – Vts)/Vtd] x 100%

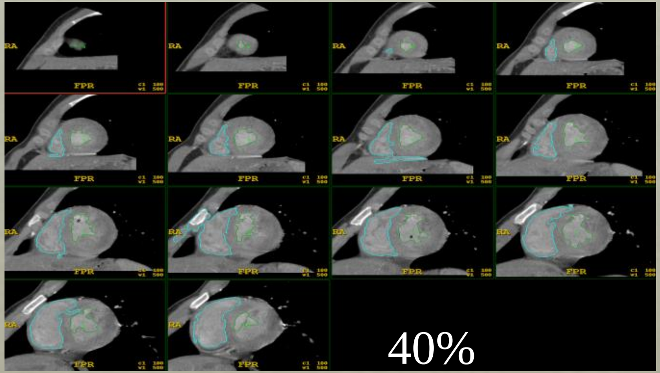


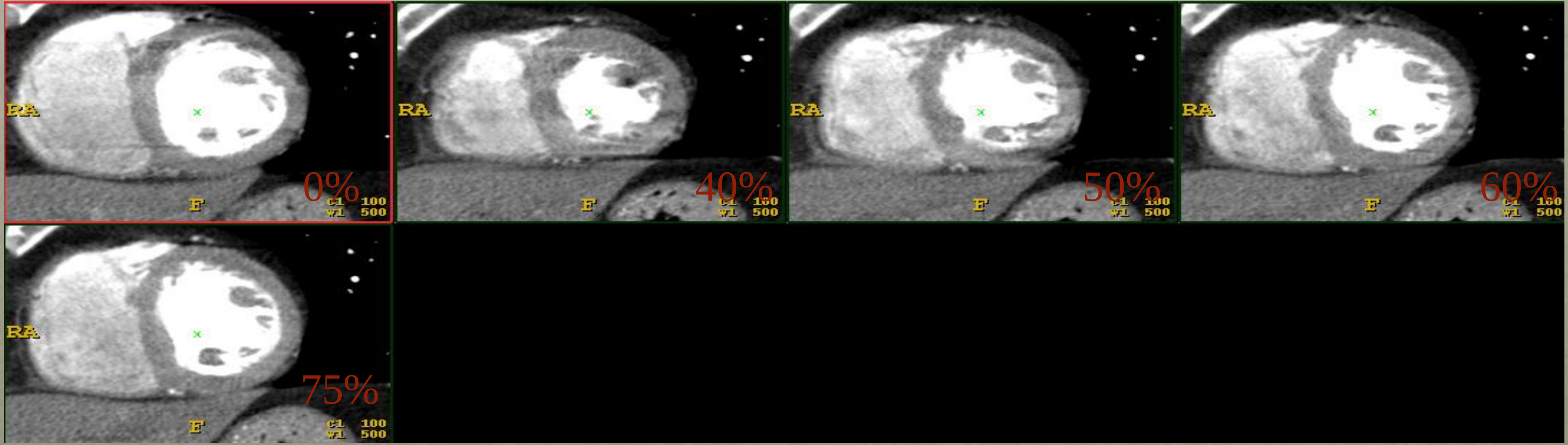


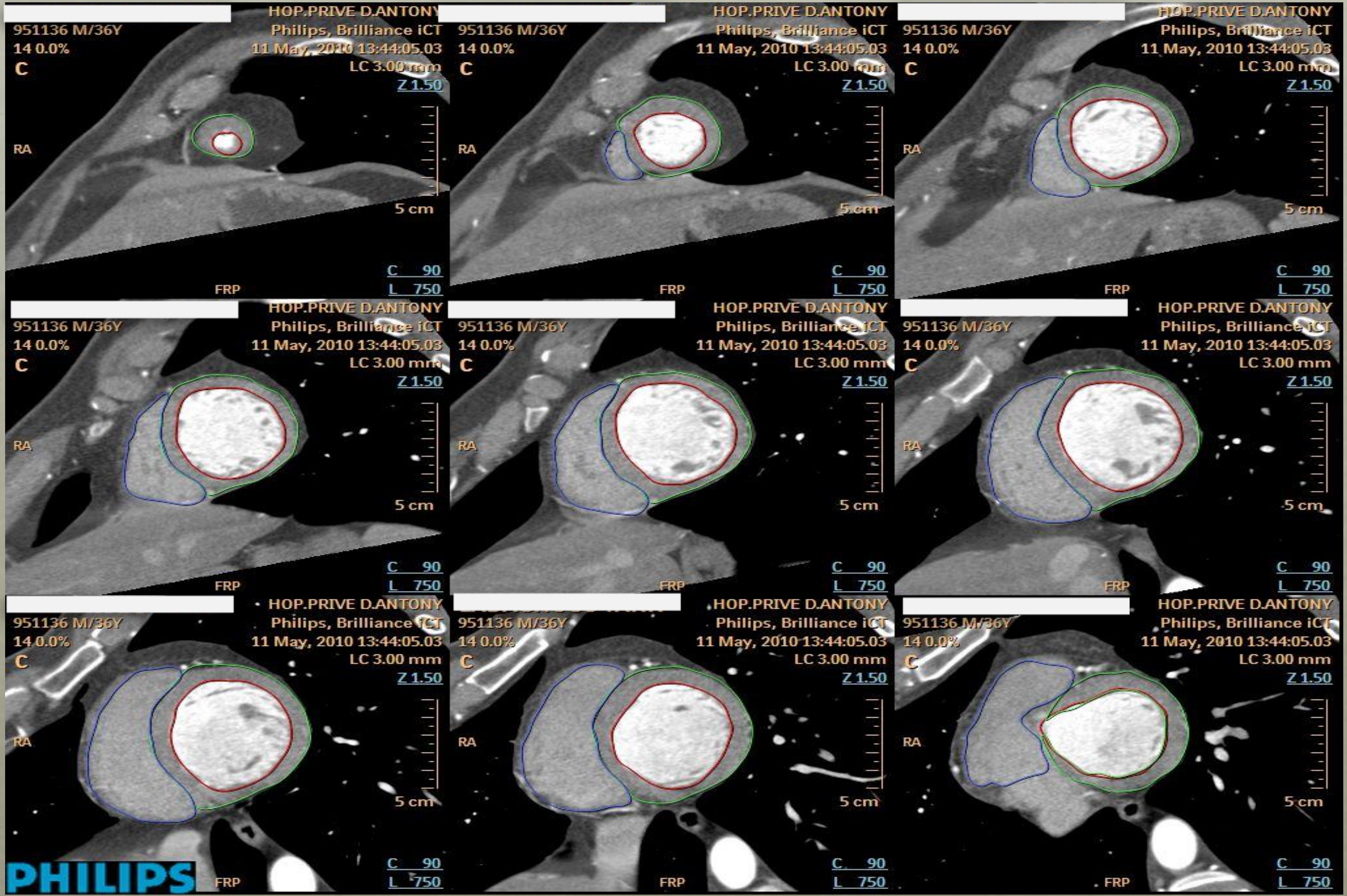
Diastole



Systole






HOP.PRIVE D.ANTONY
951136 M/36Y
Philips, Brilliance iCT
14 0.0%
11 May, 2010 13:44:05.03
C
LC 3.00 mm
Z 1.50
RA
5 cm
C 90
L 750
FRP
PHILIPS

BIPLAN vs SIMPSON

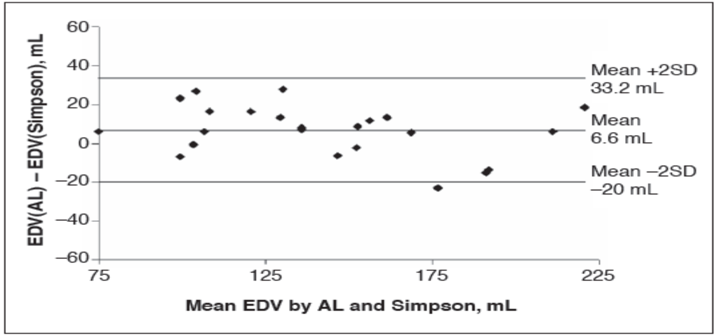


Figure 2) *Bland-Altman analysis for the biplane area-length (AL) method versus Simpson's method by multidetector computed tomography for end-diastolic volume (EDV)*

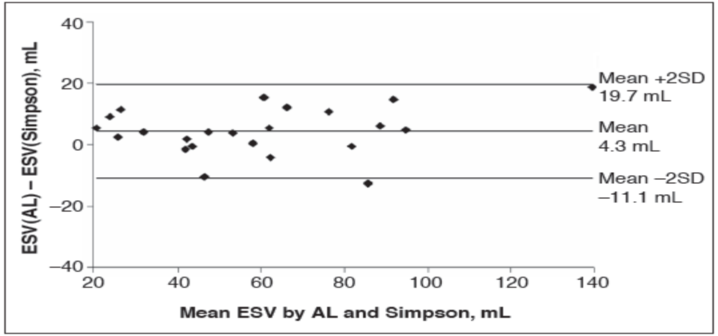


Figure 3) *Bland-Altman analysis for the biplane area-length (AL) method versus Simpson's method by multidetector computed tomography for end-systolic volume (ESV)*

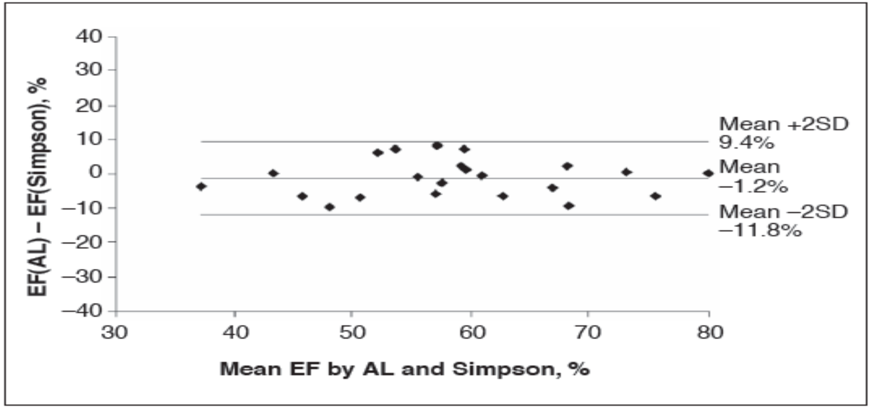


Figure 5) *Bland-Altman analysis for the biplane area-length (AL) method versus Simpson's method by multidetector computed tomography for ejection fraction (EF)*

J Lessick, Can J Cardiol 2008;24(9):685-689.

Quelles phases ?

Fig. 5 Predicting EDV. Abridged plot of the linear regression model comparing left ventricular volume using 95% phase (*y*-axis) vs. 75% phase (*x*-axis)

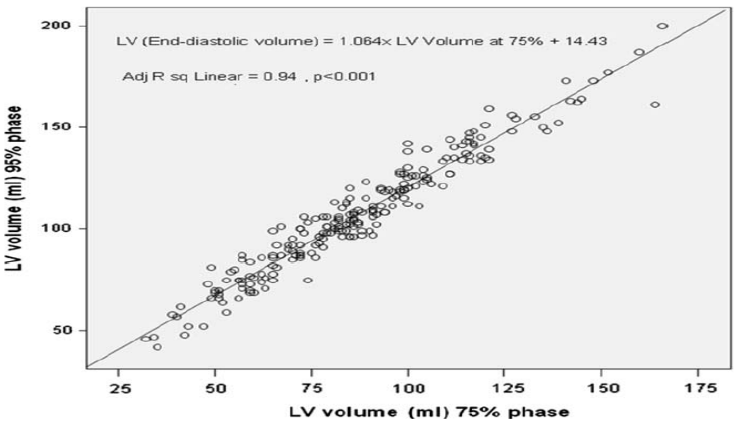
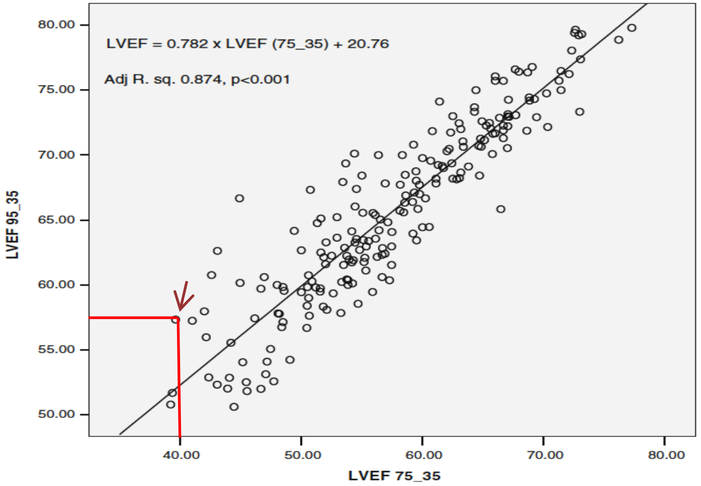


Fig. 6 Predicting LVEF. Abridged plot of the linear regression model comparing LVEF 95_35 vs. LVEF 75_35

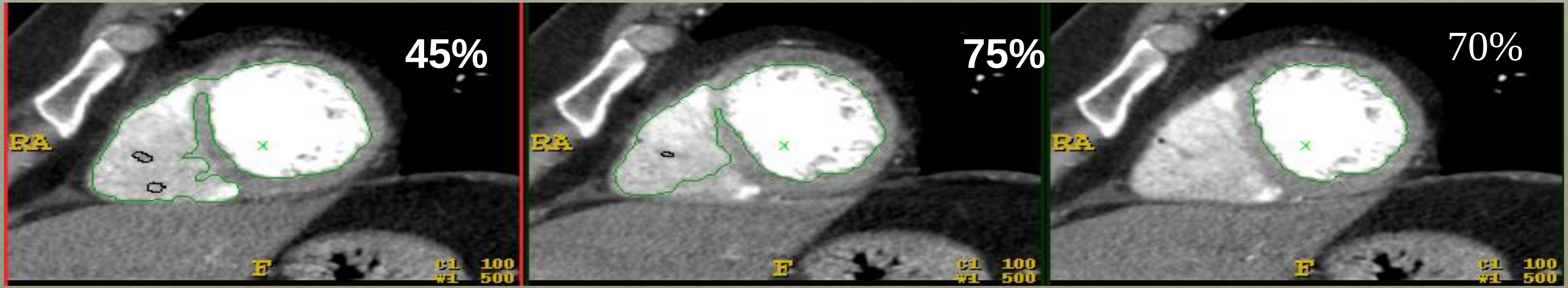


Hussain Isma'eel et col. Int J Cardiovasc Imaging (2009) 25:739–749

Bilan pré chimiothérapie

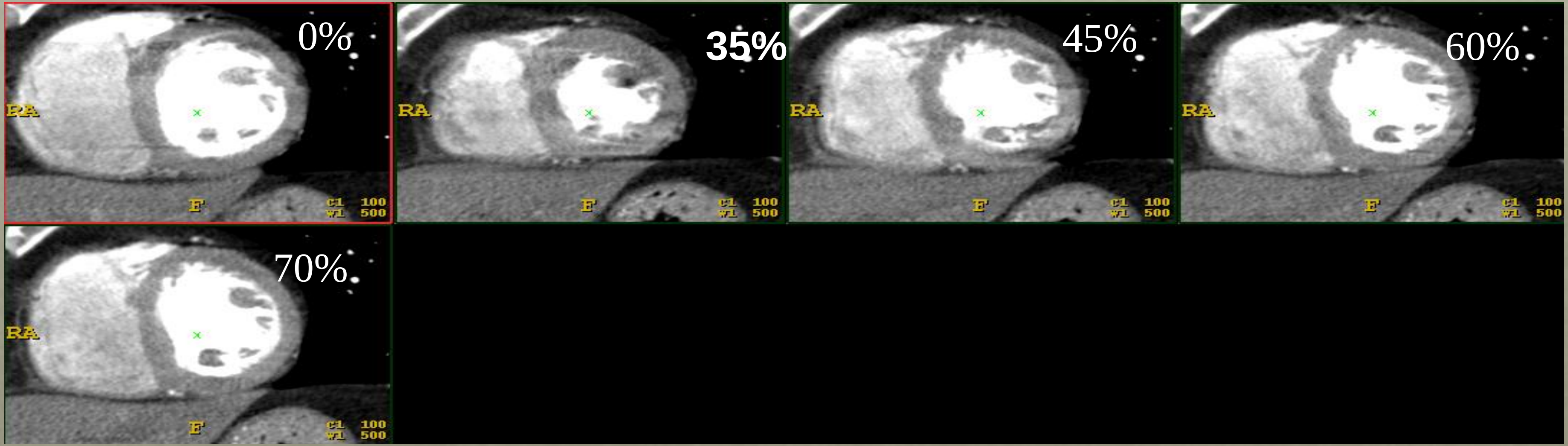
- Patient de 45 ans
- Diagnostic de lymphome
- Douleurs thoraciques
- ECG normal

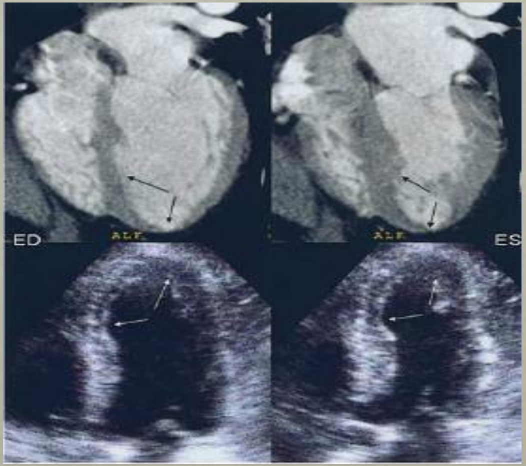
	LV	RV
ED Volume (Phase 0%)(ml)	138.3	***
ES Volume (Phase 55%)(ml)	99.5	***
Stroke Volume (ml)	38.8	***
Ejection Fraction (%)	28.1	***
Cardiac Output (ml/min)	2638.1	***
LV Wall Muscle Mass	0.0 g	
LV Wall Muscle + Papillary Mass	0.0 g	
Heart Rate	68.0 bpm	



ATTENTION à LA PHASE SYSTOLIQUE !

	LV	RV
ED Volume (Phase 0%)(ml)	114.8	97.5
ES Volume (Phase 40%)(ml)	44.4	4.5
Stroke Volume (ml)	70.4	93.0
Ejection Fraction (%)	61.3	95.4
Cardiac Output (ml/min)	4788.5	6325.5
LV Wall Muscle Mass	0.0 g	
LV Wall Muscle + Papillary Mass	0.0 g	
Heart Rate	68.0 bpm	





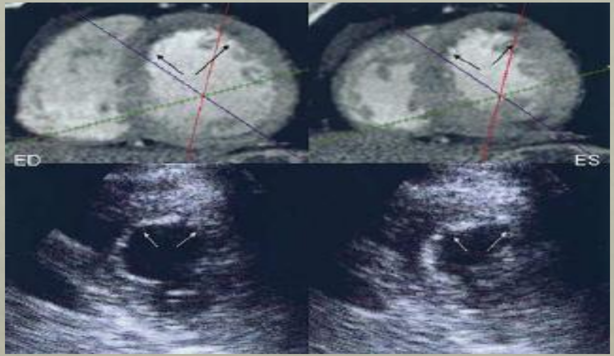


Table 1
Potential error associated with end-diastolic and end-systolic phases

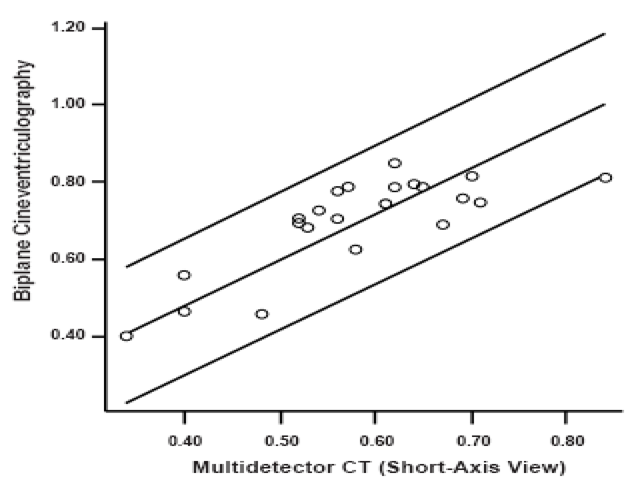
Patient	End-Diastolic Phase (% RR)	End-Systolic Phase (% RR)	Error End-Diastolic Volume (ml)	Error End-Systolic Volume (ml)	Error Ejection Fraction
1	0%	50%	0	0	0.0%
2	0%	45%	0	1	1.1%
3	0%	45%	0.1	1.3	1.5%
4	5%	40%	5.9	0	1.7%
5	5%	50%	2.3	0	1.2%
6	0%	50%	0	0	0.0%
7	10%	50%	2.2	0	1.2%
8	95%	50%	1.7	0	0.7%
9	5%	40%	2.6	0	0.6%
10	0%	45%	0	2.4	2.4%
Mean ± SD	2.0 ± 4.2%	46.5 ± 4.1%	1.5 ± 1.9	0.5 ± 0.8	1.0 ± 0.7%
Maximum			5.9	2.4	2.4%

End-diastolic and end-systolic phases are expressed as a percentage of the RR interval. Errors refer to absolute errors in calculating volumes assuming end-diastolic phase is 0% of the RR interval and end-systolic phase is <40% and 50% of the RR interval.

Lessick et col, AJC 2005 Oct 1;96(7):1011-5

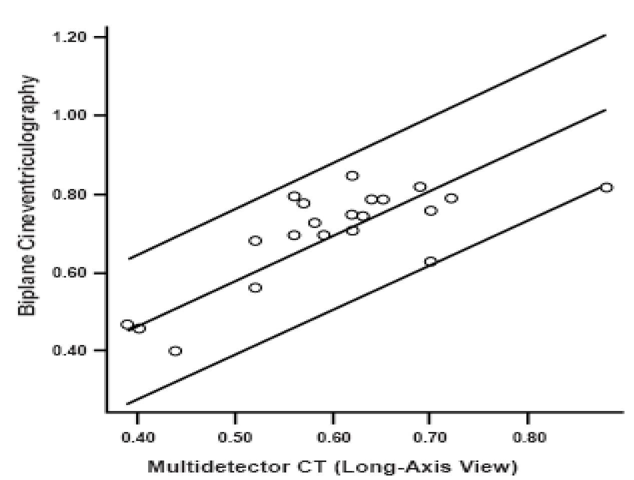
CT/Angio

Surface longueur



R = 0,8 p < 0,05

Simpson



R = 0,76 p < 0,005

Juergens et col AJR 2002;179:1545

Littérature

		N	FE	VTD	VTS
Juergens et col AJR 2002;179:1545	CT 4 /Angio	22	0,8	- 12±7%	
Grude et col Invest Radiol 2003;(38)10:653	CT 4 /IRM	30	0,85	0,8	0,89
Koch et col Eur radiol 2005;15:312	CT VD 16 /IRM	19	0,74	0,98	0,96
Dirksen et col AmJCardiol 2002; 90:1157	CT 4 /Echo	15	0,93		

MRI vs 64 MSCT vs DSCT / PHANTOM

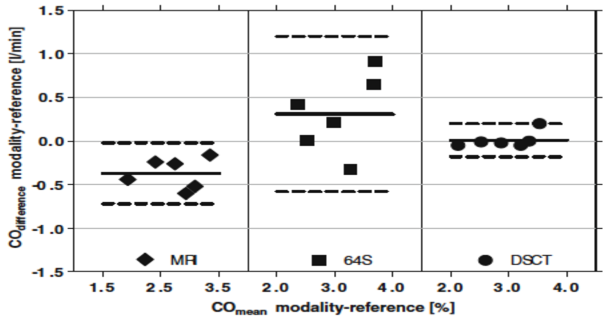


Fig. 6 Bland-Altman plots comparing the cardiac output (CO) of the reference measurement to MRI (◆), 64-slice MDCT (■) and DSCT (●). The solid lines are the means, the dotted lines two times the standard deviation (2 SD)

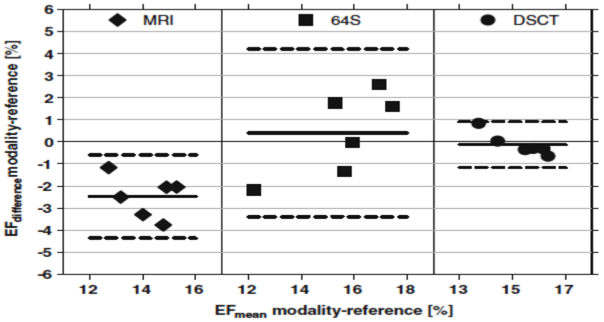


Fig. 5 Bland-Altman plots comparing the ejection fraction (EF) of the reference measurement to MRI (◆), 64-slice MDCT (■) and DSCT (●). The solid lines are the means, the dotted lines two times the standard deviation (2 SD)

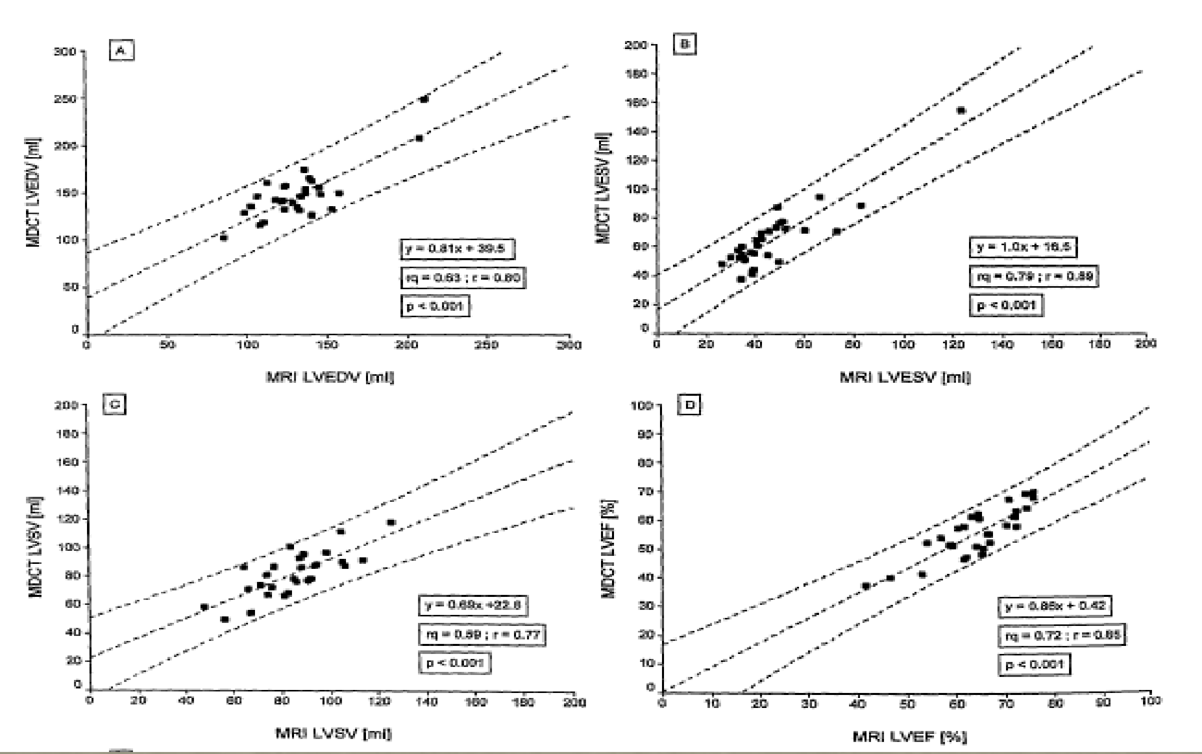
Table 3 Over- or underestimations (accuracy) and relative differences between the reference and the modalities for the ejection fraction (EF) and the cardiac output (CO) averaged over all heart rates

	MRI		64-slice MDCT		DSCT	
	Est	Rel	Est	Rel	Est	Rel
EF	-2.48	16.1	+0.4	2.6	-0.13	0.8
CO	-0.37	12.7	+0.44	15.1	+0.01	0.3

The relative differences and estimations in EF are given as a percentage. The estimation in CO is given in l/min. *Est* =over- or underestimation; *rel* =relative difference

Groen et col; Eur Radiol (2009) 19: 577–583

CT/IRM



Grude et col, Invest Radiol 2003;(38)10:653

Double tube

TABLE 1: Global and Time-Dependent Left Ventricular Functional Parameters Assessed by Dual-Source CT and MRI

Functional Parameter	Dual-Source CT	MRI	p[a]	Pearson's r (p)[b]
EDV (mL)	148.6 ± 55.2	146.4 ± 56.6	0.042	0.98 (< 0.0001)
ESV (mL)	70.5 ± 35.2	69.1 ± 35.8	0.18	0.99 (< 0.0001)
SV (mL)	79.8 ± 26.7	77.3 ± 27.6	0.35	0.96 (< 0.0001)
EF (%)	54.1 ± 10.4	54.8 ± 11.1	0.24	0.95 (< 0.0001)
PER (mL/s)	415.9 ± 123.2	398.6 ± 115.6	0.12	0.79 (< 0.0001)
PFR (mL/s)	416.1 ± 171.3	389.2 ± 182.9	0.069	0.84 (< 0.0001)
Time to PER (ms)	129.3 ± 28.2	121.6 ± 37.5	0.18	0.68 (0.001)
Time to PFR from ES (ms)	167.7 ± 29.1	156.7 ± 34.0	0.32	0.64 (0.0026)

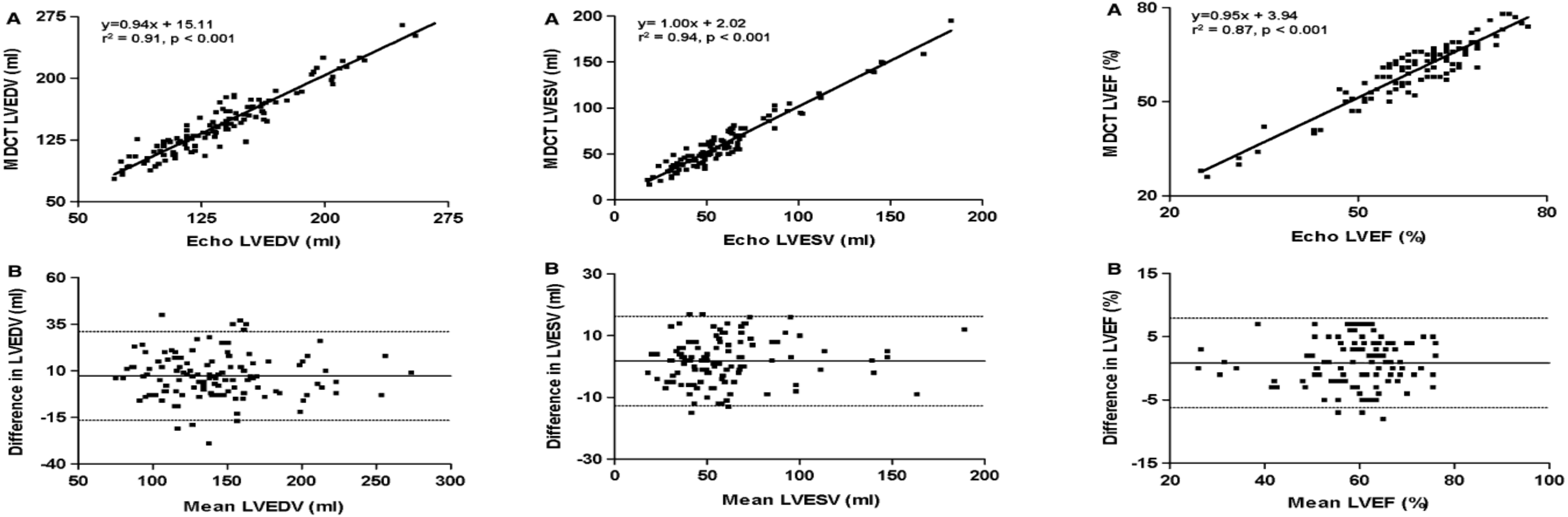
Note—Data are ± SD. EDV = end-diastolic volume, ESV = end-systolic volume, SV = stroke volume, EF = ejection fraction, PER = peak ejection rate, PFR = peak filling rate, ES = end-systole.

[a]For differences between imaging techniques, p was obtained by paired Student's t test.

[b]Pearson's r and the corresponding p quantify the magnitude of correlation.

Harald Brodoefel et col. *AJR 2007; 189:1064–1070*

320 vs Echo



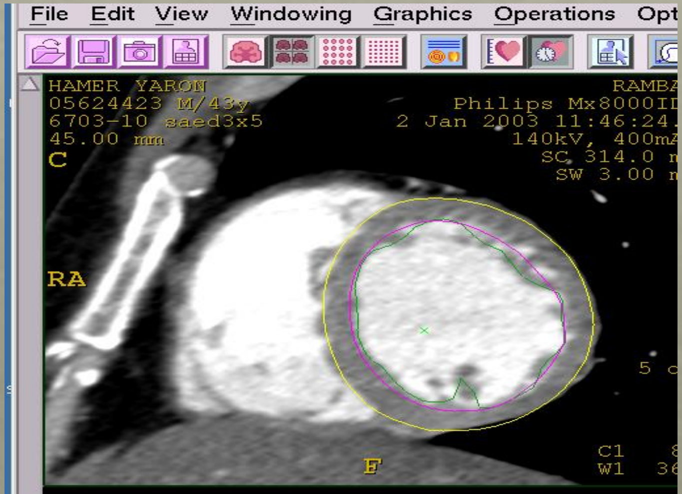
11.5 ± 2.1 mSv

Fleur R. de Graaf, J Nucl Cardiol 2010;17:225–31

Etude du VD

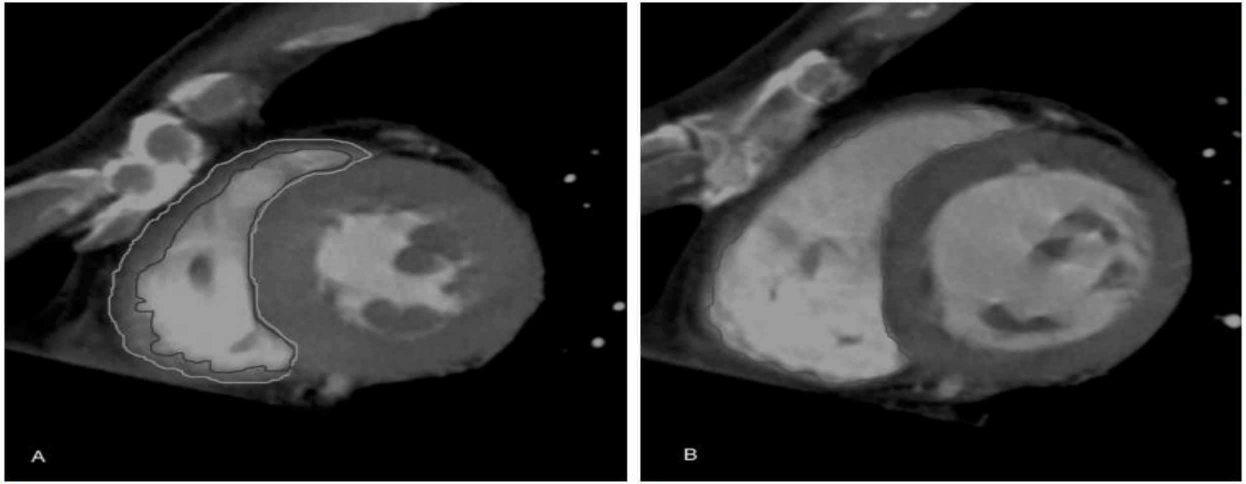
Pour analyse VG/VD ; il faut une injection bi ou triphasique avec une 2ième phase de contraste à débit moindre

Injection supplémentaire de 20 cc à 2cc/s pour augmenter le contraste VD puis 60 cc serum phy à 2 cc/s



Fonction VD

100 ml iodine was administered intravenously at a rate of 4.5 ml for the first 20 seconds followed by the rate of 1.5 ml for 20 seconds using a power injection



A B

Fig. 2. Measurement of the right ventricular myocardial volume. The end systolic multiplanar reformation (**A**) and the end diastolic multiplanar reformation (**B**) images in the short-axis sections with markers indicate how the endocardial and the epicardial borders of these sections were traced. The myocardial mass was assessed using the following equation: myocardial mass = (epicardial volume – endocardial volume) *1.05 (the specific gravity of myocardium).

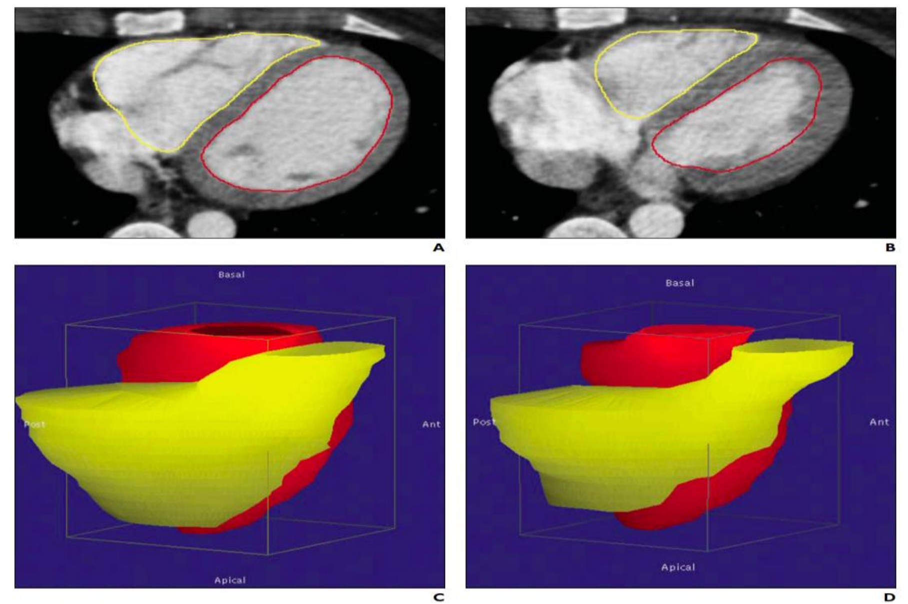
Table 3. Interobserver Variability of the Right Ventricular Measurements with Multidetector CT in 33 Patients with Chronic Obstructive Pulmonary Disease

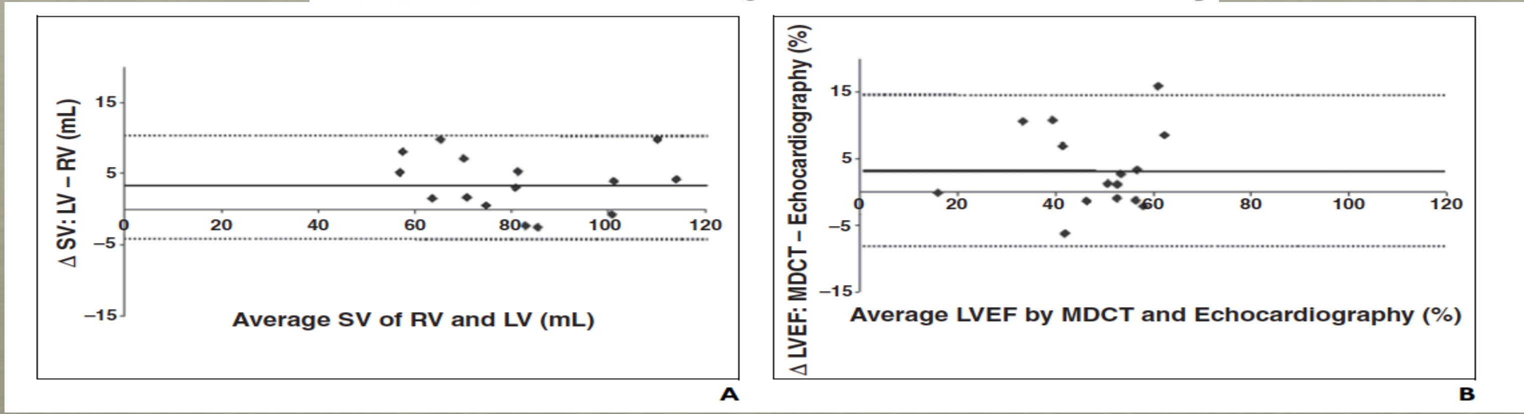
Measurement (n=33)	*r*	*P*-value	B-A Analysis	W(*p*)
RV ejection fraction (%)	0.907	0.001	0.1 ±6.9	0.74
RV wall mass (g)	0.894	0.001	–0.1 ±7.2	0.71

Note.—n = number of patients, B-A Analysis = Bland-Altman analysis, W = Wilcoxon signed ranks test

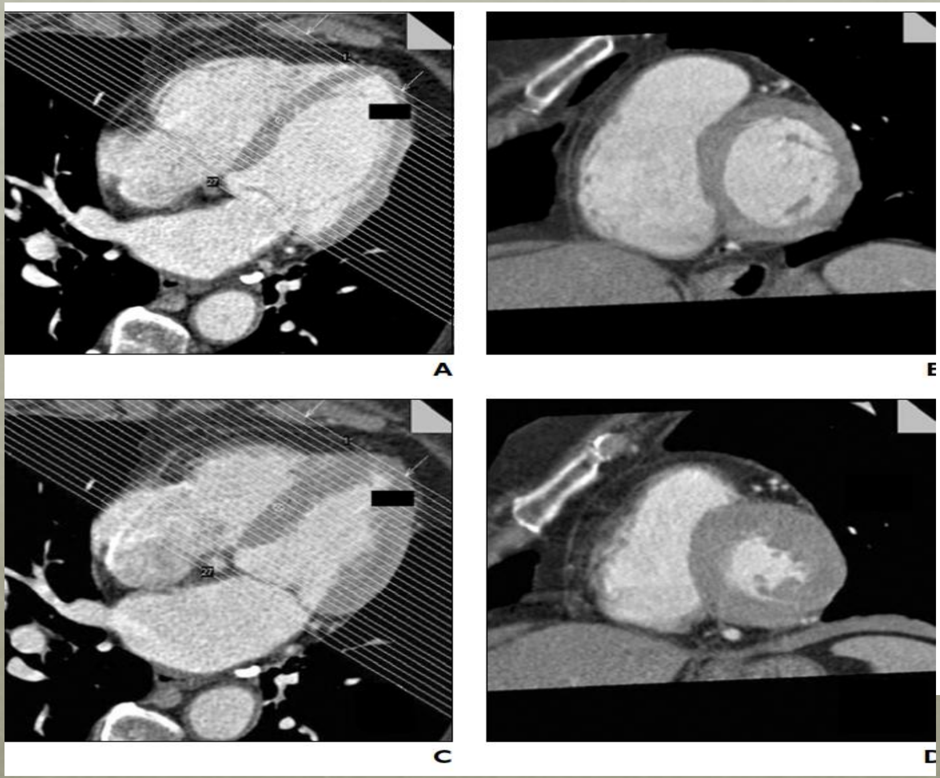
Jin Hur et col, Korean J Radiol 8(1), February 2007

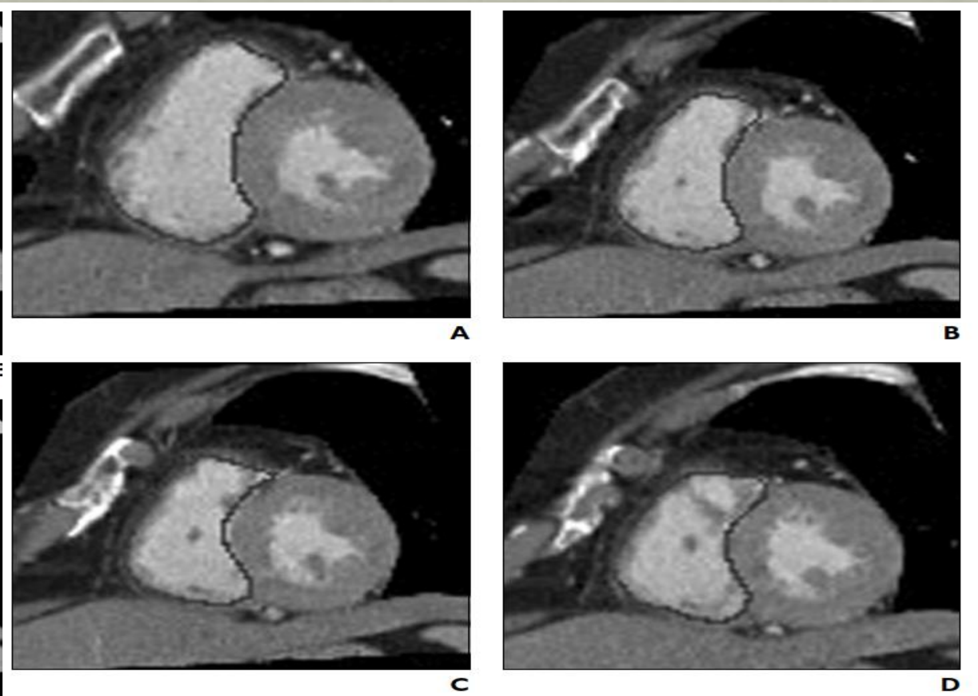
VD





Halil Doğan et col ; *AJR 2006; 186:S366–S370*





Damien Delhaye et col ; *AJR 2006; 187:1597–1604*

TAPSE

0%-40%

Figure 4. End-diastolic and end-systolic reformatted four-chamber view in a patient with abnormal tricuspid annular peak systolic excursion (TAPSE), calculated as the distance from tricuspid annulus to RV apex in systole subtracted from similar distance in diastole in MPR projection with TAPSE = 86 – 72 = 14 mm.

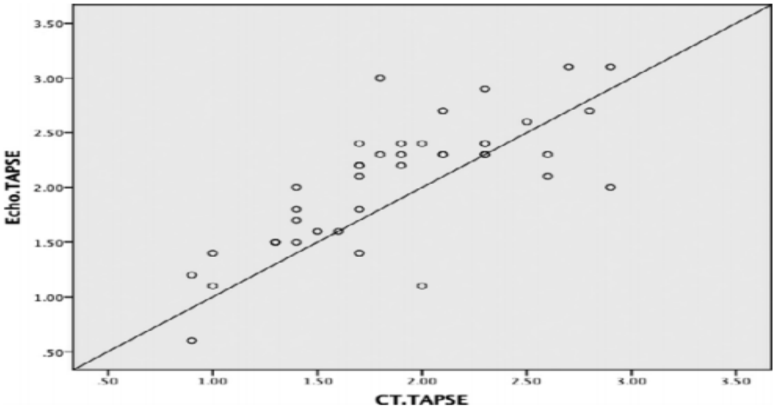
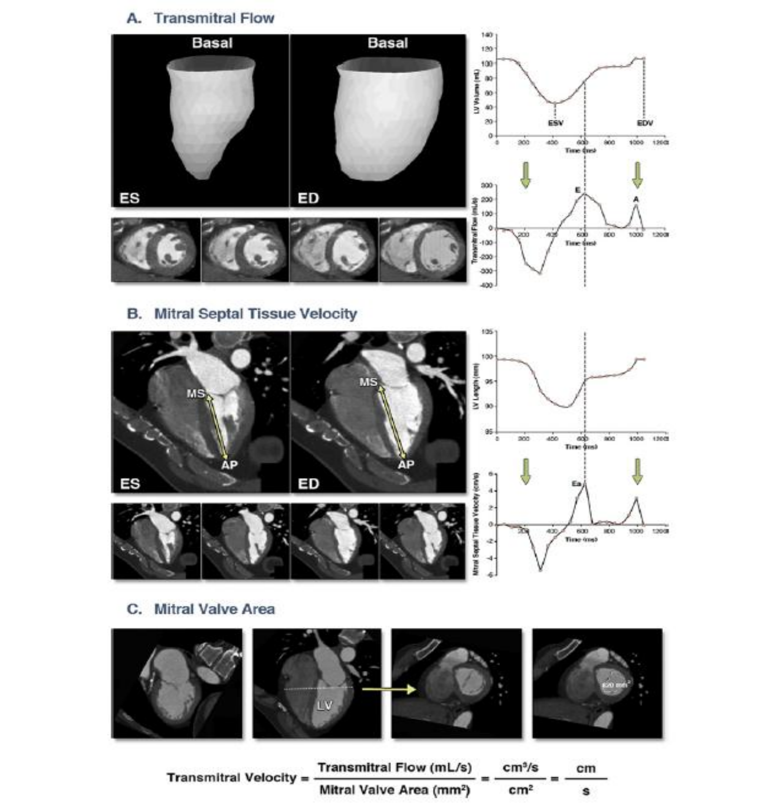
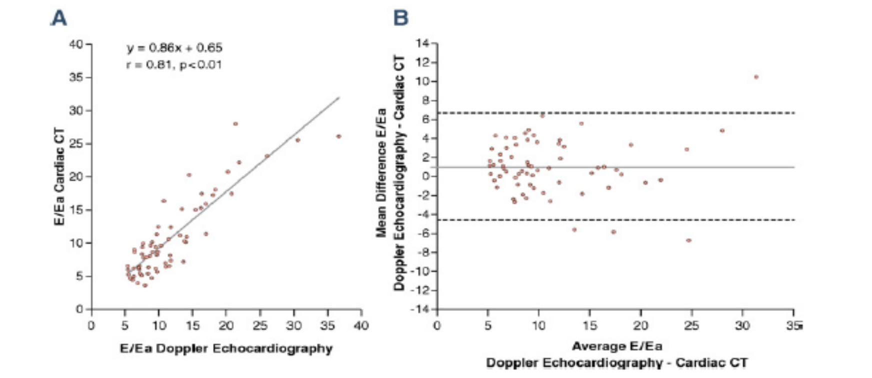


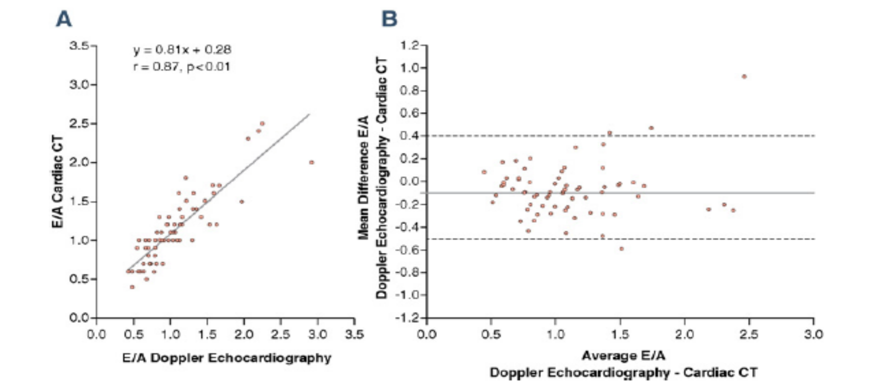
Figure 5. Bland–Altman plot of identity demonstrating comparison of tricuspid annular peak systolic excursion (TAPSE) measurements by Echo and CT showing that the 2 methods provided similar TAPSE measurements with majority of values lying closer to the line y = x.

Jaspreet Singh, Echocardiography 2014;31:773–778

Fonction diastolique VG







Facteurs Limitant

- Résolution temporelle **(42-83 ms pour les machines les plus performantes)**

  - Netteté de l'endocarde en télésystole
    - Artefact de mouvement
  - Définition exacte des pics télé systolique et télé diastolique
    - Systole électromécanique : 0,3 s
    - Volume systolique maintenu 80-200 ms

4/16/40/64 …256…coupes

- Résolution spatiale
  - 1 mm
- Résolution temporelle
  - 250 ms
- Irradiation
  - 4 – 5 mSv
- Durée d'acquisition
  - 30 – 40 sec

- Résolution spatiale
  - 0,75 mm
- Résolution temporelle
  - < 210 ms
- Irradiation
  - 4 – 9 mSv
- Durée d'acquisition
  - 20 – 30 secs

- Résolution spatiale
  - 0,5-0,65 mm
- Résolution temporelle
  - < 150 ms (45-135ms)
- Irradiation
  - ? mSv
- Durée d'acquisition
  - 5-10 secs

Table 4
Influence of Selected Variables on LVEF

Variable	Reported Influence on LVEF
Valve level	Basal section contributes up to 10%–15% of total volume
Computational method	Mean difference of 8% of LVEF
Inclusion or exclusion of papillary muscles	6.5% ± 1.3% of EDV
ES and ED phase selection	Almost one-half of LVEF with fixed ES and ED phases at 20% and 80% of the RR interval, respectively

Note.—ED = end-diastolic, ES = end-systolic.

van Ooijen et al, RadioGraphics 2012; 32:589–599

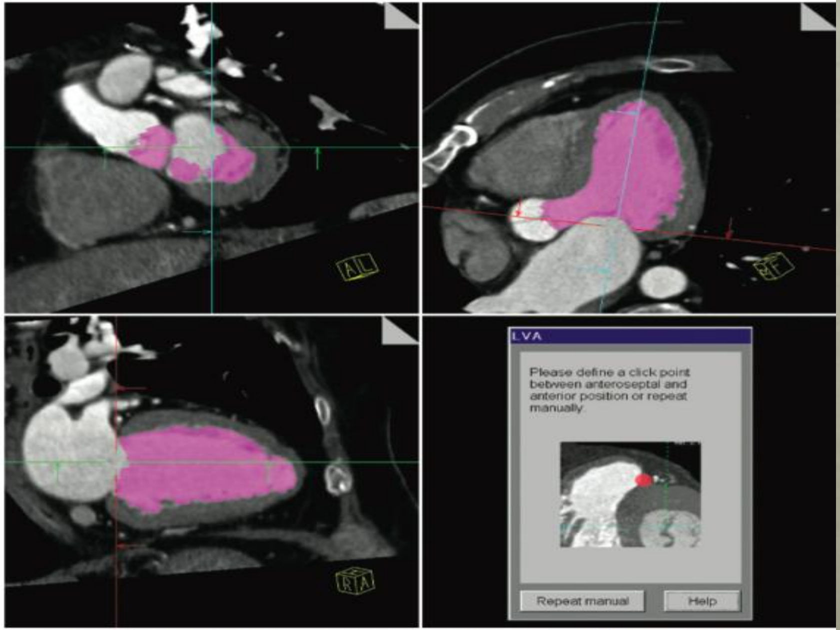


Figure 4. Multiplanar reformatted images of the left ventricle (top left, top right, bottom left) and screen shot of a software window (bottom right) demonstrate the calculation of left ventricular volume with inclusion of the LVOT. Some threshold-based software tools use this segmentation method, whereas others do not include the LVOT. Segmented areas are shown in pink.

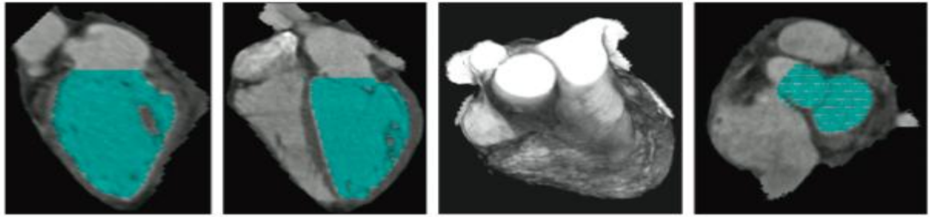


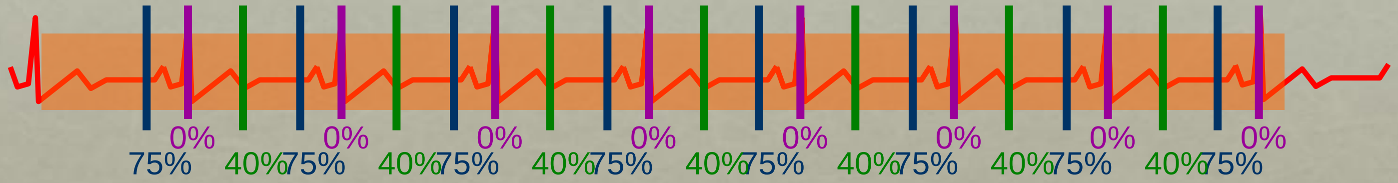
Figure 3. Fully automatic segmentation of the left ventricular blood pool with a threshold-based algorithm. Segmented areas are shown in blue. The software algorithm used in this case defines the most basal section as being at the level of the mitral valve, whereas the modified Simpson method defines the most basal section as the last section in which 50% of the myocardium is visible. **(a, b)** On two-chamber **(a)** and four-chamber **(b)** long-axis images, the left ventricular volume is segmented up to the mitral valve. **(c)** Three-dimensional segmented image of the heart does not show the left ventricular blood pool. **(d)** On a short-axis segmented image, the most basal section no longer depicts 50% of the myocardium, which could cause discrepancies among results obtained with different software packages.

van Ooijen et al, RadioGraphics 2012; 32:589–599

FACTEURS LIMITANTS

- Retrospective Spiral (Reference mode)

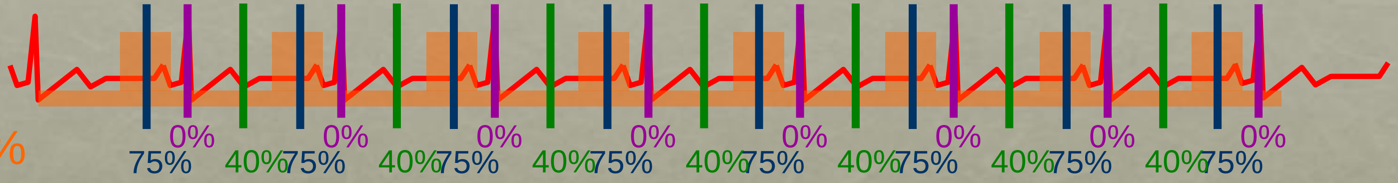
8-16 mSv



- Retrospective Spiral with Cardiac DoseRight (ECG dose modulation)

4-10 mSv

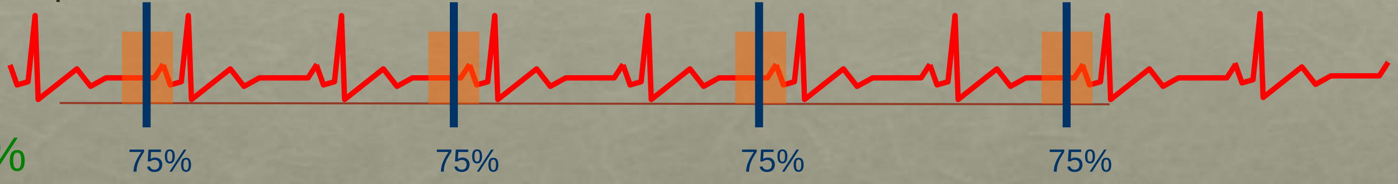
dose ↓ 30-50 %
mAs ↓ 20% of max



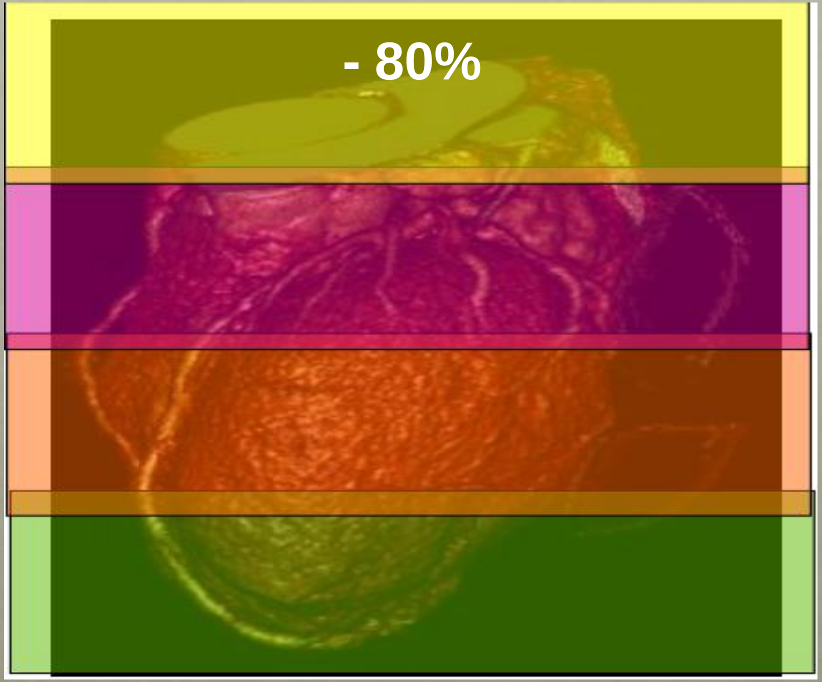
- Prospective Axial: Step & Shoot

2-6 mSv

dose ↓ 70-80 %
2s irradiation / 10s scan time (Br64)



FACTEURS LIMITANTS



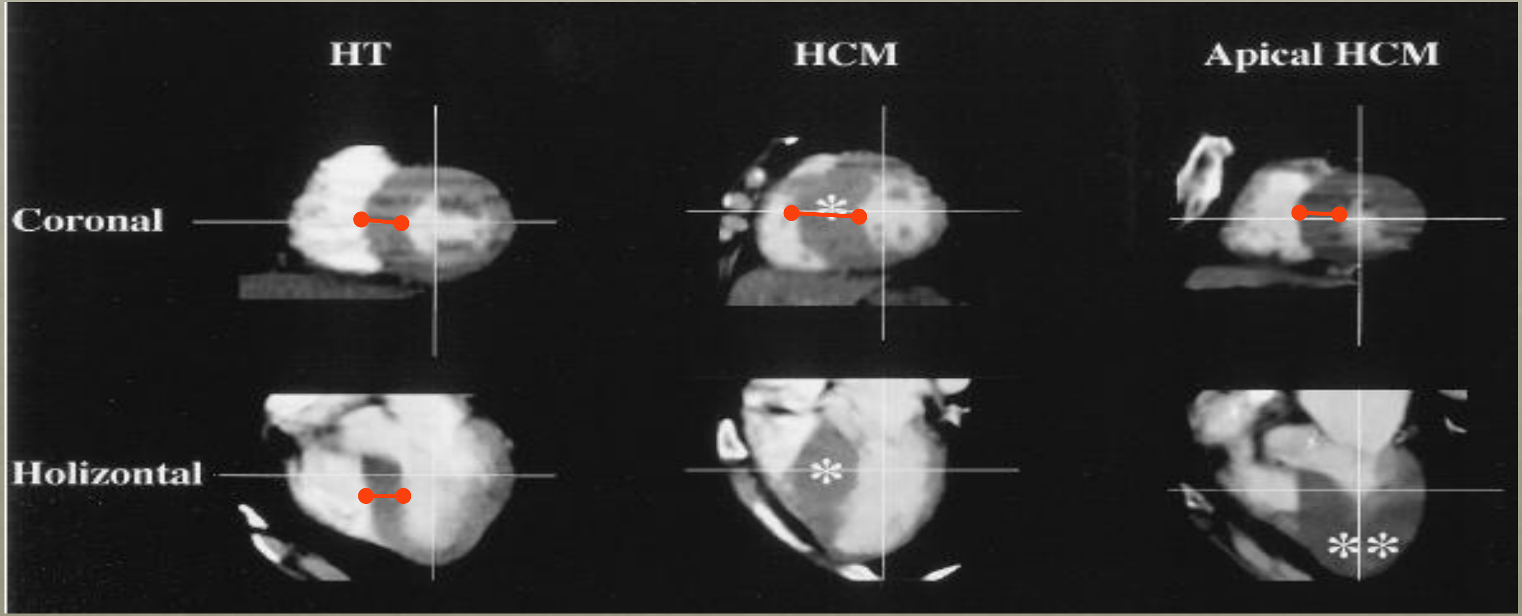
- 40%

STEP AND SHOOT

MODULATION DE DOSE

Motilité segmentaire

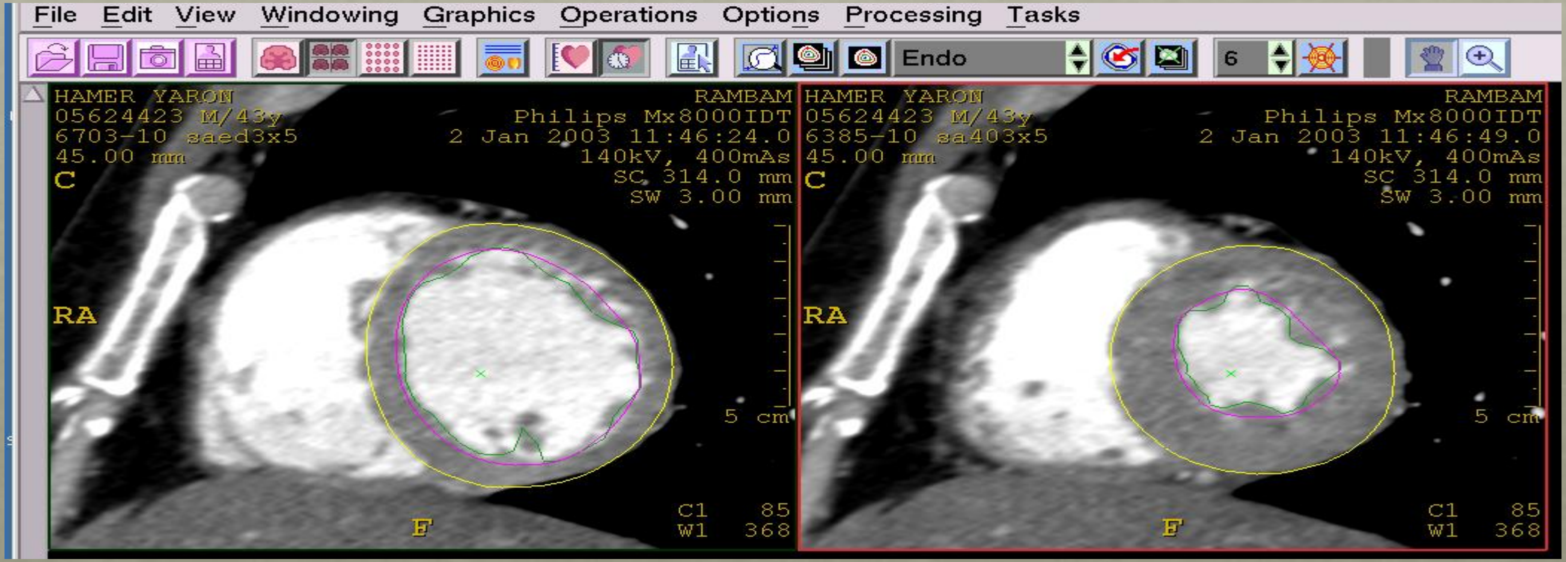
- **Epaisseur pariétale** (mm) = distance perpendiculaire endo - epi



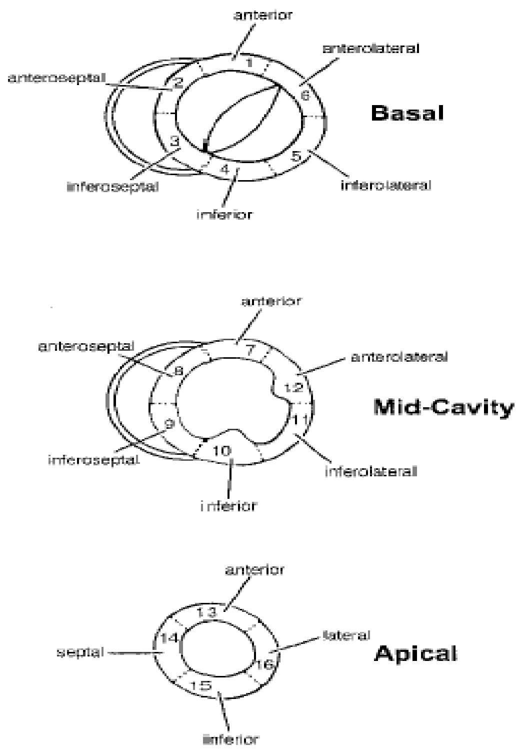
Motilité segmentaire

- Epaississement pariétal = % changement épaisseur pariétale

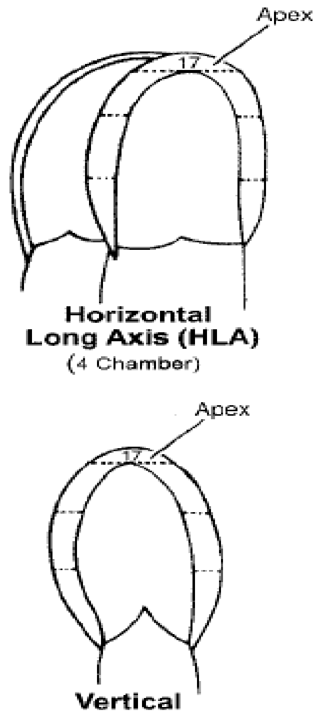
  i.e. (ES-ED)/ED épaisseur



Segmentation myocardique

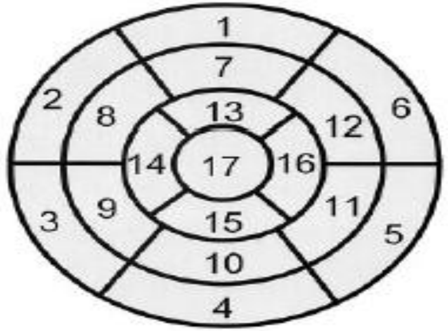


Short Axis (SA)

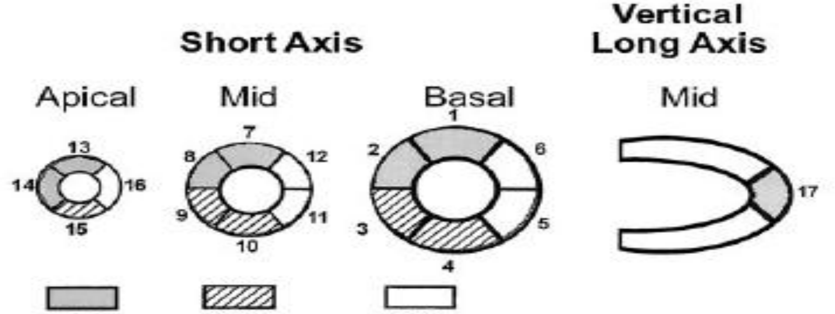


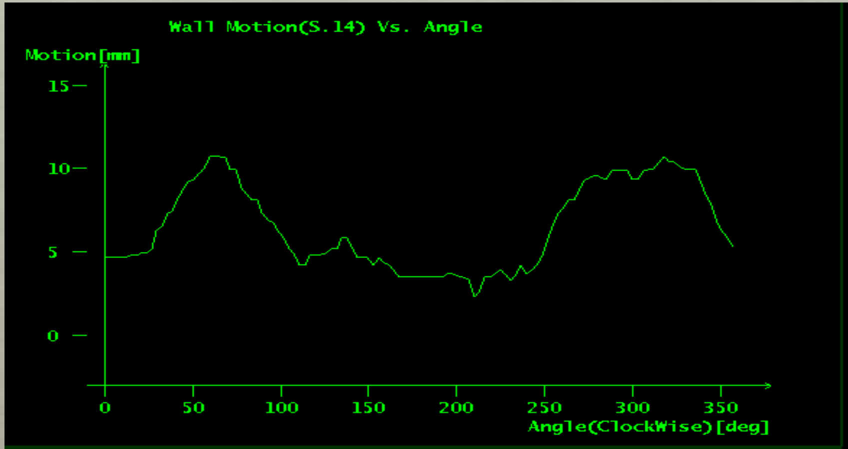
Horizontal Long Axis (HLA) (4 Chamber)

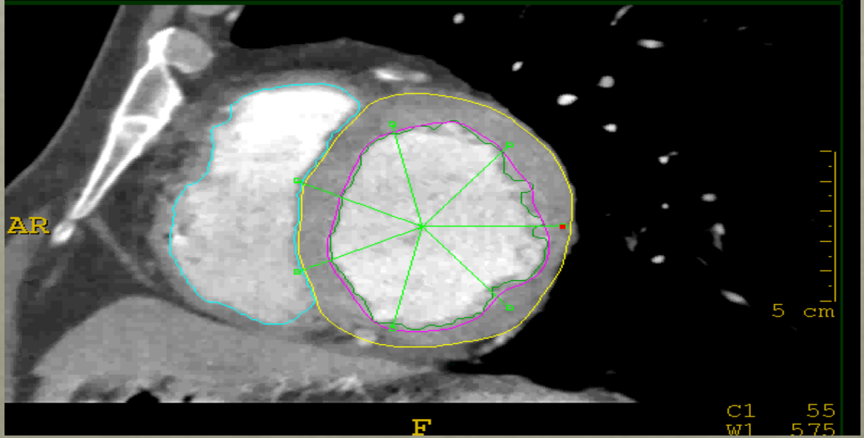
Vertical Long Axis (VLA) (2 Chamber)

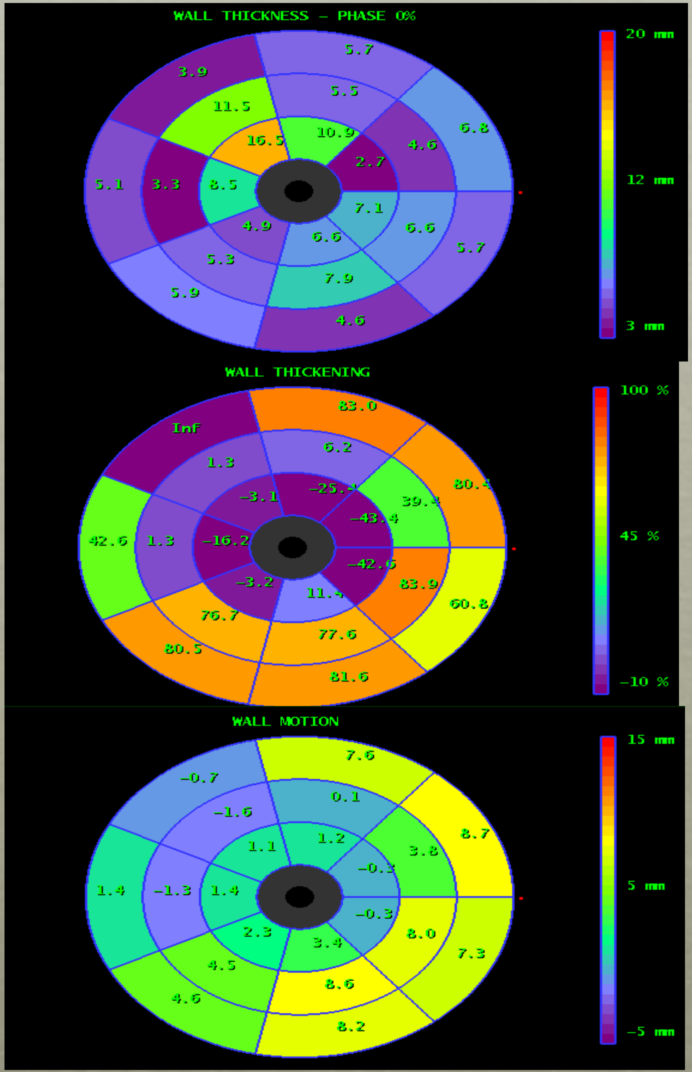


Coronary Artery Territories




Wall Motion(S.14) Vs. Angle
Motion[mm]
15
10
5
0
0
50
100
150
200
250
300
350
Angle(ClockWise)[deg]


AR
5 cm
F
C1 55
W1 575


WALL THICKNESS - PHASE 0%
20 mm
12 mm
3 mm
5.7
3.9
5.5
11.5
10.9
16.5
6.8
4.6
2.7
5.1
3.3
8.5
7.1
6.6
4.9
6.6
5.7
5.3
7.9
5.9
4.6
WALL THICKENING
100 %
45 %
-10 %
83.0
Inf
6.2
1.3
80.4
-3.1
-25.4
39.4
-43.4
42.6
1.3
-16.2
-42.6
-3.2
83.9
11.4
60.8
76.7
77.6
80.5
81.6
WALL MOTION
15 mm
5 mm
-5 mm
7.6
-0.7
0.1
-1.6
8.7
1.1
1.2
3.8
-0.3
1.4
-1.3
1.4
-0.3
2.3
8.0
3.4
7.3
4.5
8.6
4.6
8.2

MDCT vs IRM

TABLE 2: Agreement in Evaluation of Regional Wall Motion Between Dual-Source CT and MRI

Dual-Source CT	MRI				
	Normal	Hypokinetic	Akinetic	Dyskinetic	Total
Normal	298	4	0	0	302
Hypokinetic	2	21	1	0	24
Akinetic	0	3	10	1	14
Dyskinetic	0	0	0	0	0
Total	300	28	11	1	340

Résolution Temporelle 45 à 90 ms

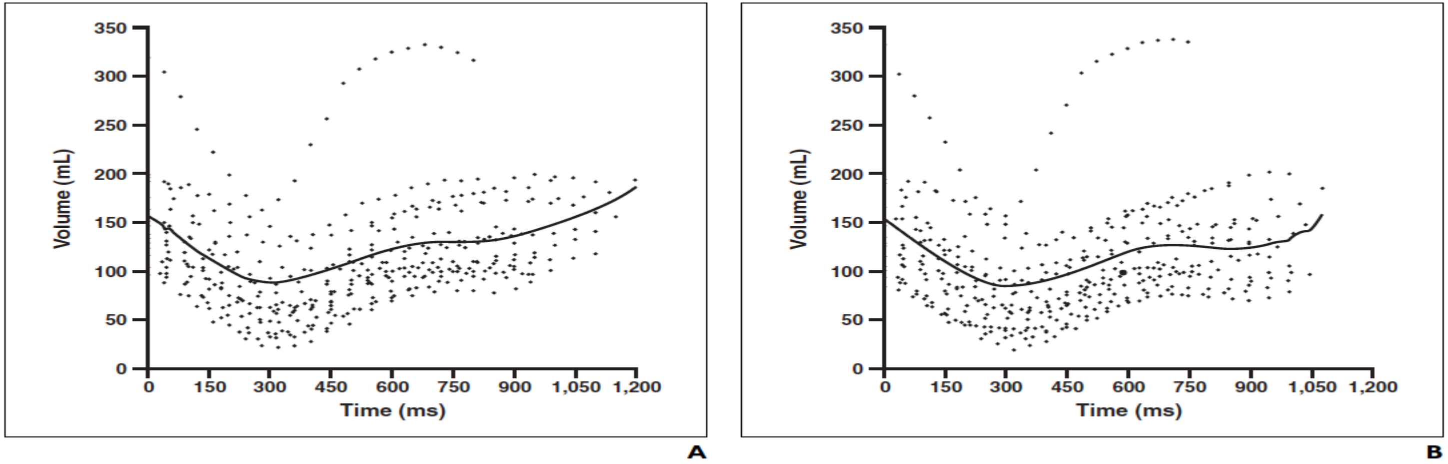


Fig. 2—Graphs show time–volume curves. Data are shown for all 20 patients; overall trend is followed by lowest curves. **A** and **B**, Time–volume curves obtained using dual-source CT (**A**) and MRI (**B**).

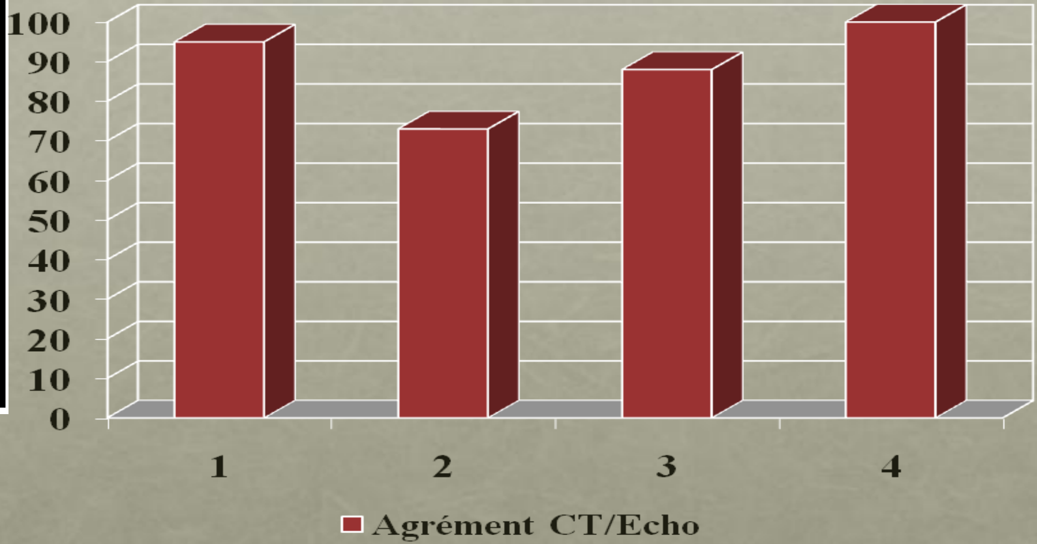
Harald Brodoefel et col; *AJR 2007; 189:1064–1070*

Motilité segmentaire

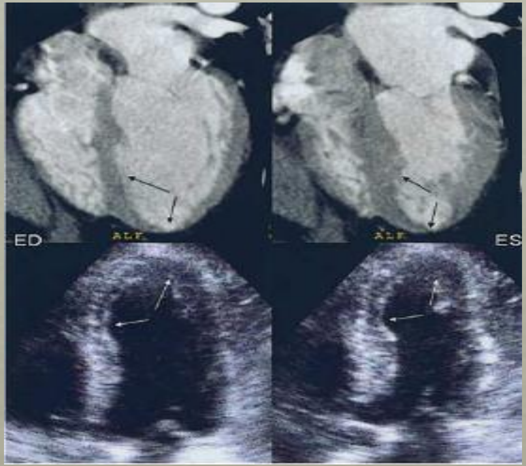
TABLE 1 Agreement Between Multislice CT and Two-Dimensional Echocardiography for Assessing Regional Wall Motion Score

	Echocardiography				
RWMS	1	2	3	4	Total
1 CT	139	17	0	0	156
2 CT	8	58	2	0	68
3 CT	0	4	15	0	19
4 CT	0	0	0	12	12
Total	147	79	17	12	255

RWMS = regional wall motion score; 1 = normal, 2 = hypokinesia, 3 = akinesia, 4 = dyskinesia (agreement 88%, kappa 0.84).



Dirksen et col AmJCardiol 2002; 90:1157



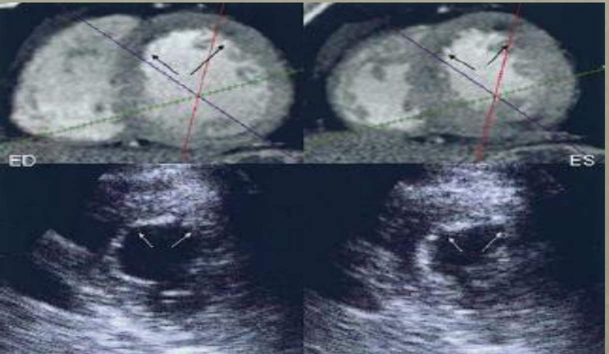


Table 1
Potential error associated with end-diastolic and end-systolic phases

Patient	End-Diastolic Phase (% RR)	End-Systolic Phase (% RR)	Error End-Diastolic Volume (ml)	Error End-Systolic Volume (ml)	Error Ejection Fraction
1	0%	50%	0	0	0.0%
2	0%	45%	0	1	1.1%
3	0%	45%	0.1	1.3	1.5%
4	5%	40%	5.9	0	1.7%
5	5%	50%	2.3	0	1.2%
6	0%	50%	0	0	0.0%
7	10%	50%	2.2	0	1.2%
8	95%	50%	1.7	0	0.7%
9	5%	40%	2.6	0	0.6%
10	0%	45%	0	2.4	2.4%
Mean ± SD	2.0 ± 4.2%	46.5 ± 4.1%	1.5 ± 1.9	0.5 ± 0.8	1.0 ± 0.7%
Maximum			5.9	2.4	2.4%

End-diastolic and end-systolic phases are expressed as a percentage of the RR interval. Errors refer to absolute errors in calculating volumes assuming end-diastolic phase is 0% of the RR interval and end-systolic phase is <40% and 50% of the RR interval.

Table 2
Contingency table showing the relative agreement between MDCT and Echocardiography for scores 1 to 3

All Segments	MDCT Score			
	1	2	3	Total
Echocardiograph score				
1	443	16	2	461
2	41	22	17	80
3	11	27	37	75
Total	495	65	56	616

Table 3
Contingency table showing the relative agreement between MDCT and echocardiography for binary scores

All Segments	MDCT Score		
	Normal	Abnormal	Total
Echocardiographic score			
Normal	443	18	461
Abnormal	52	103	155
Total	495	121	616

Lessick et col, AJC 2005 Oct 1;96(7):1011-5

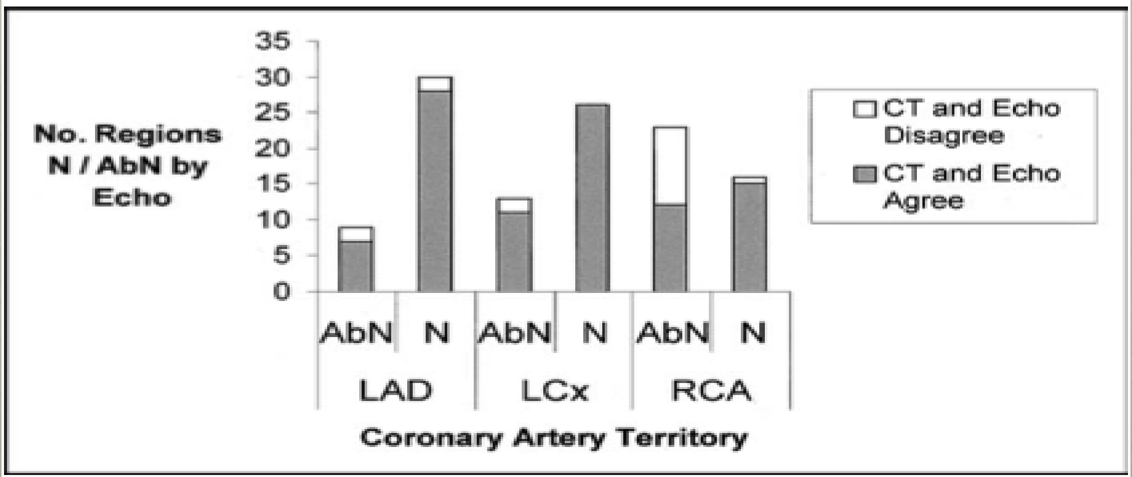
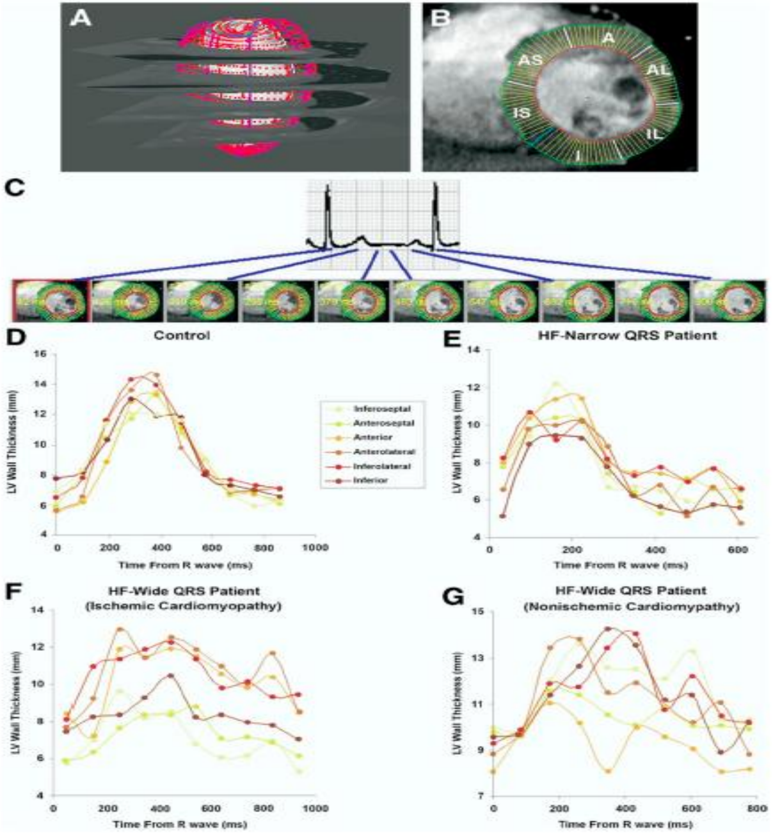


Table 4
MDCT assessment of segmental function versus echocardiography as the gold standard (normal or abnormal)

Segment	No. of Segments	Sensitivity	Specificity	Positive Predictive Value	Negative Predictive Value	Accuracy
16-segment approach	616	66% (103/155)	96% (443/461)	85% (103/121)	89% (443/495)	89% (546/616)
3-segment approach						
All segments	117	67% (30/45)	96% (69/72)	90% (30/33)	82% (69/84)	85% (99/117)
Left anterior descending segments	39	78% (7/9)	93% (28/30)	78% (7/9)	93% (28/30)	90% (35/39)
Left circumflex segments	39	85% (11/13)	100% (26/26)	100% (11/11)	93% (26/28)	95% (37/39)
Right coronary segments	39	52% (12/23)	94% (15/16)	92% (12/13)	58% (15/26)	69% (27/39)

Lessick et col, AJC 2005 Oct 1;96(7):1011-5

Asynchronisme



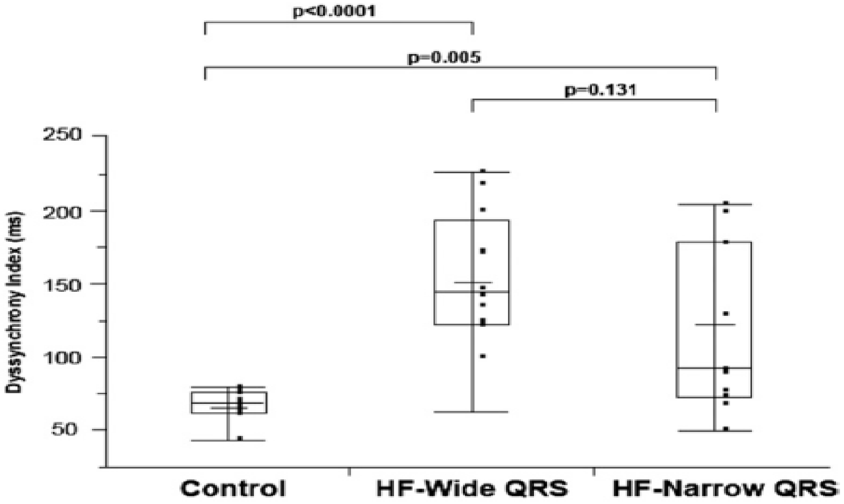


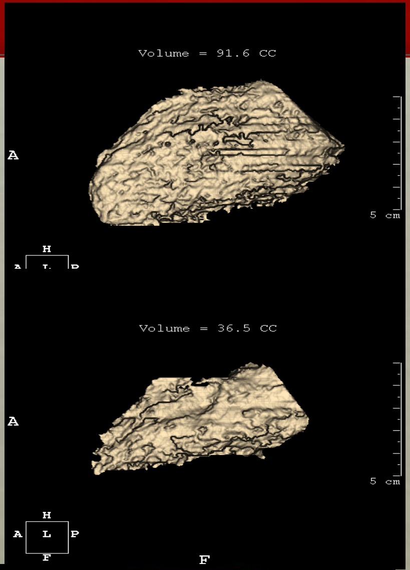
Figure 3. Box and Whisker Plot of DI Using Changes in LV Wall Thickness of the 3 Groups
Mean DI was significantly different between the 3 groups and was greatest in the HF-wide QRS group, followed by the HF-narrow QRS, and then the control group (152 ± 44 ms vs. 121 ± 58 ms vs. 65 ± 12 ms, respectively; $p < 0.0001$). HF = heart failure; LV = left ventricular; other abbreviations, as in Figure 2.

Quynh A. Truong et col; *JACC Cardiovasc Imaging. 2008 November ; 1(6): 772–781*

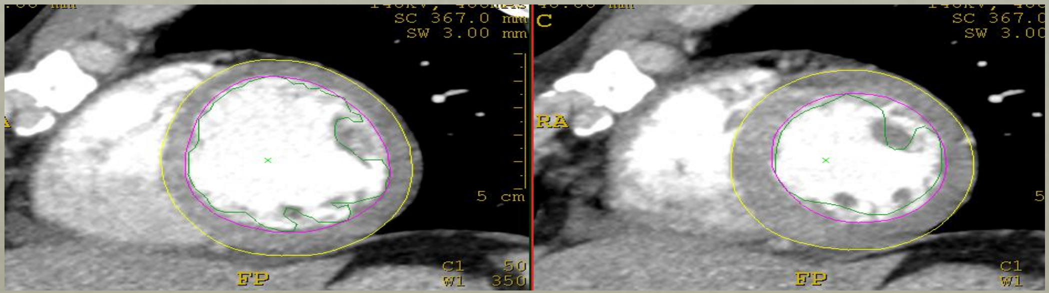
Masse myocardique

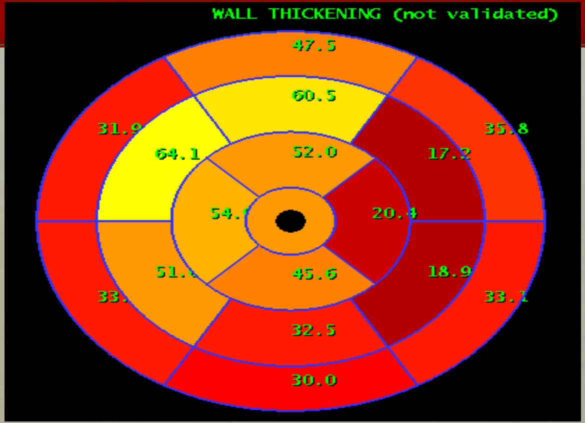
- Volumes (ml):
  - Volume télédiastolique (max)
  - Volume télésystolique (min)
  - Volume d'éjection (VTD - VTS Volumes)
  - Débit cardiaque = VE x Fce (ml/mn)
- Masse myocardique (vert)

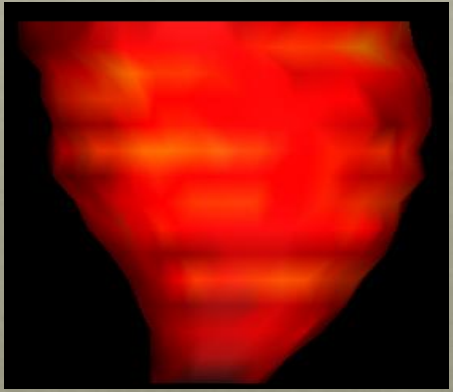
  = 1.04 x (volume épicardique – volume endocardique)

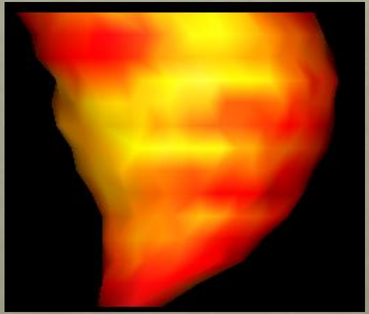


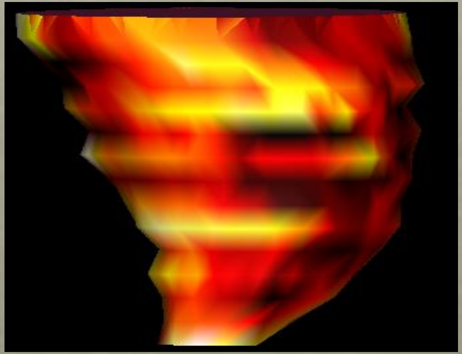
FE = 50%









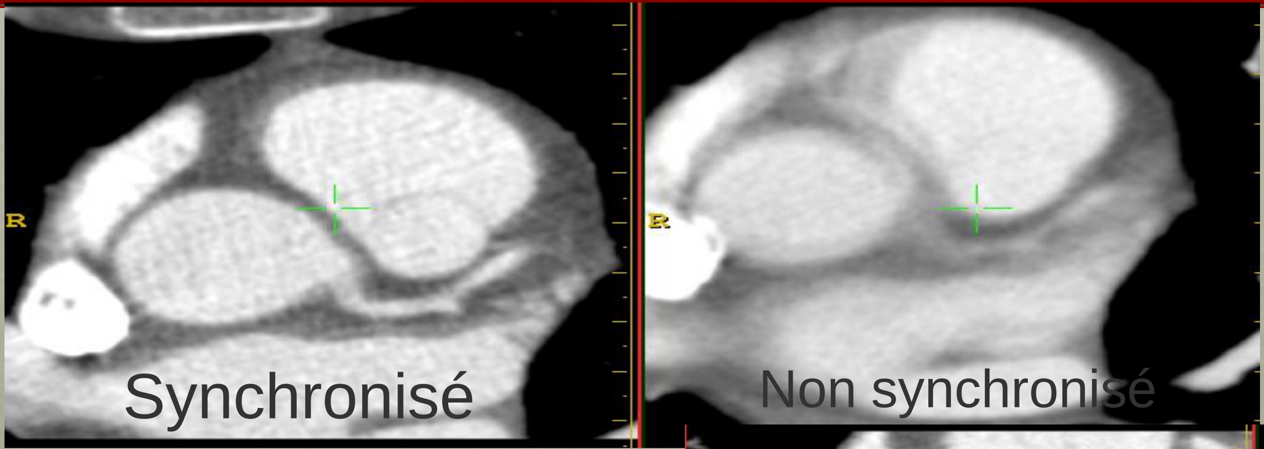


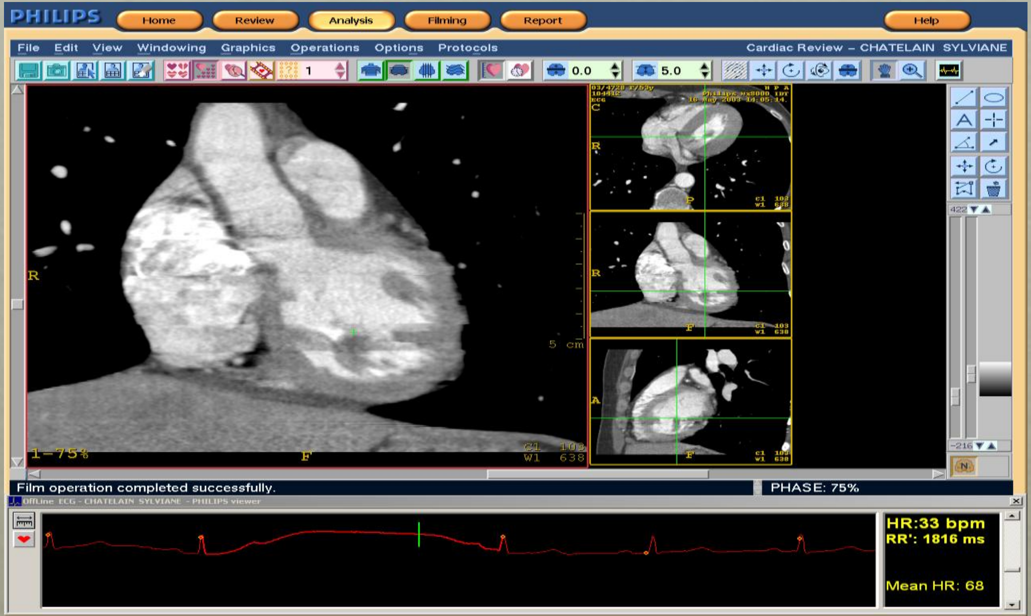
Ep Télé Diastole - Ep Télé Systole = Epaississement

VG / VD toujours mesurables ?

- Contraste
- Défaut de reconstruction
  - Mouvements respiratoires
  - Arythmie
- Défaut de contourage

Synchronisation ECG

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Cardiac Review – CHATELAIN SYLVIANE
1-75%
5 cm
Film operation completed successfully.
PHASE: 75%
OffLine ECG - CHATELAIN SYLVIANE - PHILIPS viewer
HR:33 bpm
RR': 1816 ms
Mean HR: 68


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Report
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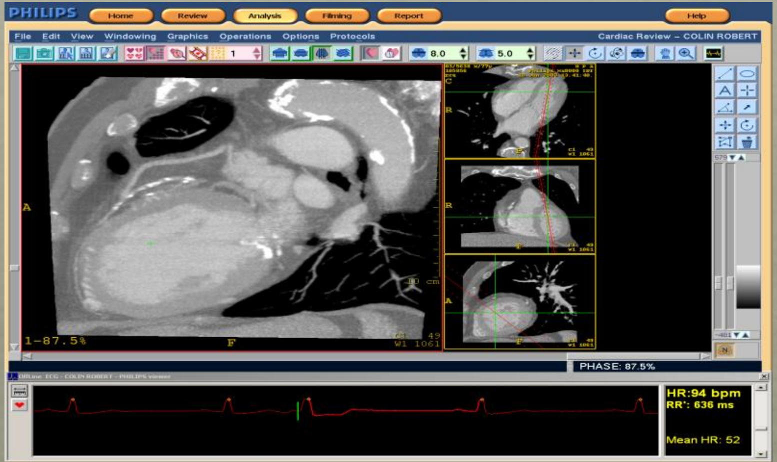
Cardiac Review – COLIN ROBERT
1-87.5%
PHASE: 87.5%
HR:94 bpm
RR': 636 ms
Mean HR: 52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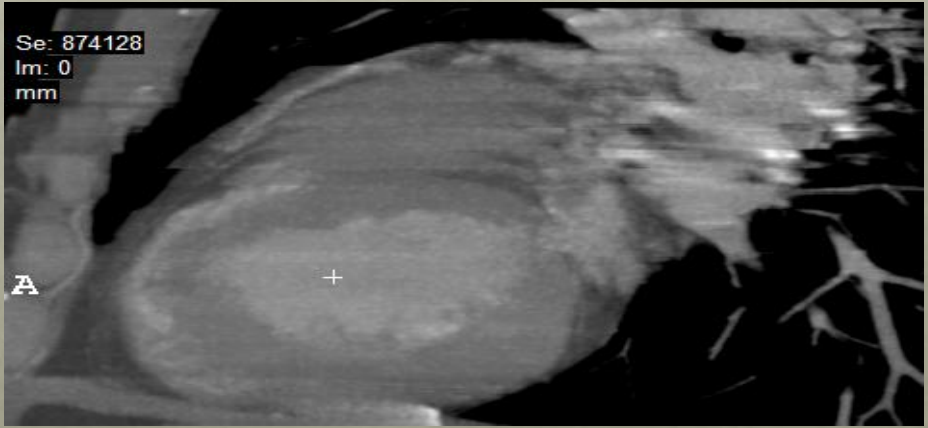
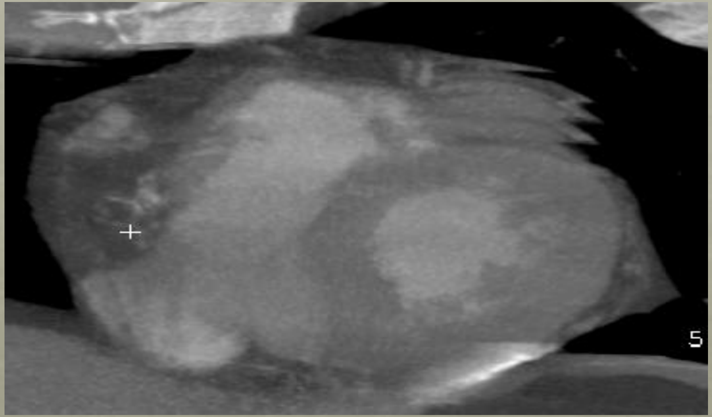
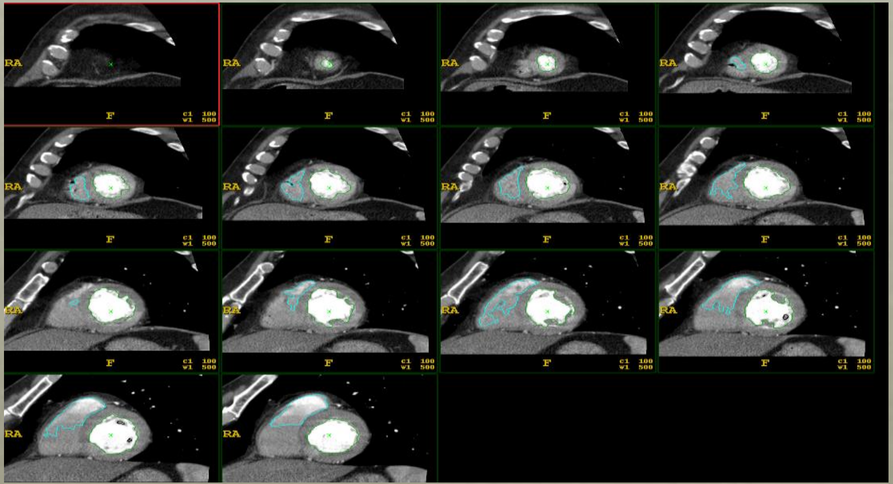
Cardiac Review – COLIN ROBERT
1-87.5%
PHASE: 87.5%
HR:94 bpm
RR': 636 ms
Mean HR: 52

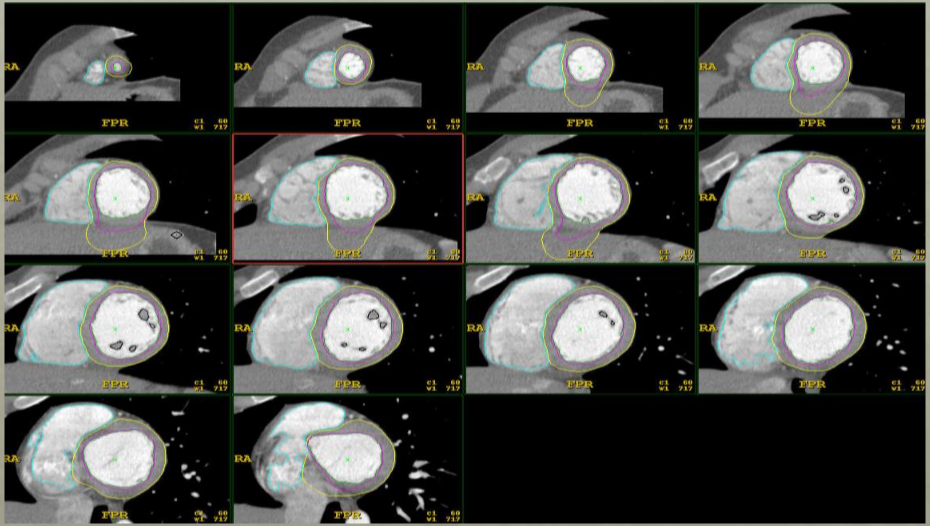
Artefact Respiratoire

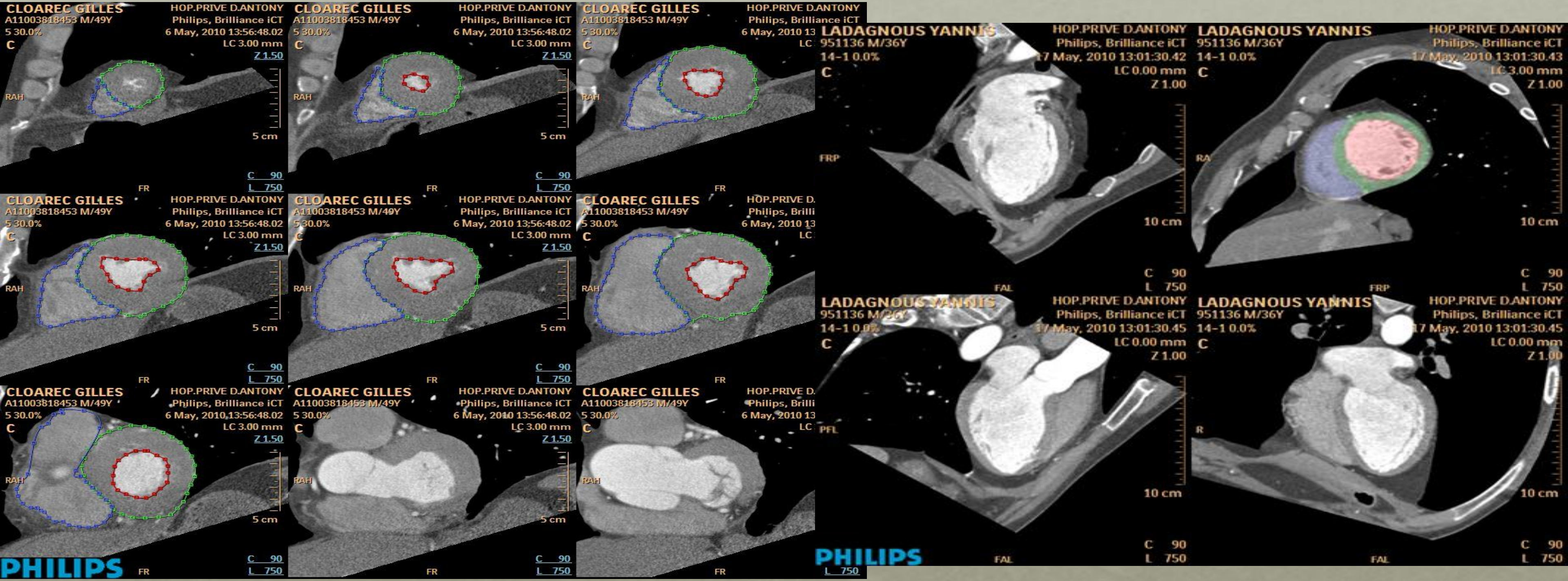




Défaut de contraste, défaut de contourage



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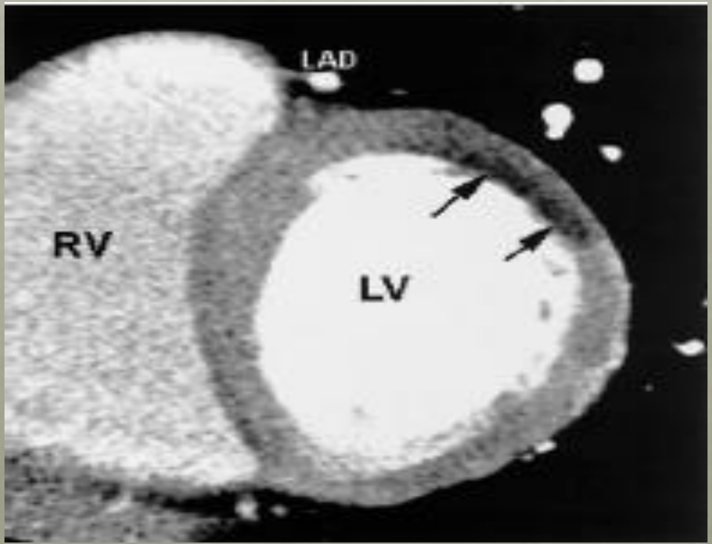
Philips, Brilliance iCT
6 May, 2010 13:56:48.02
LC 3.00 mm
Z 1.50
RAH
5 cm
C 90
L 750
FR
PHILIPS
LADAGNOUS YANNIS
951136 M/36Y
14-1 0.0%
HOP.PRIVE D.ANTONY
Philips, Brilliance iCT
17 May, 2010 13:01:30.42
LC 0.00 mm
Z 1.00
FRP
FAL
RA
PFL
R
10 cm

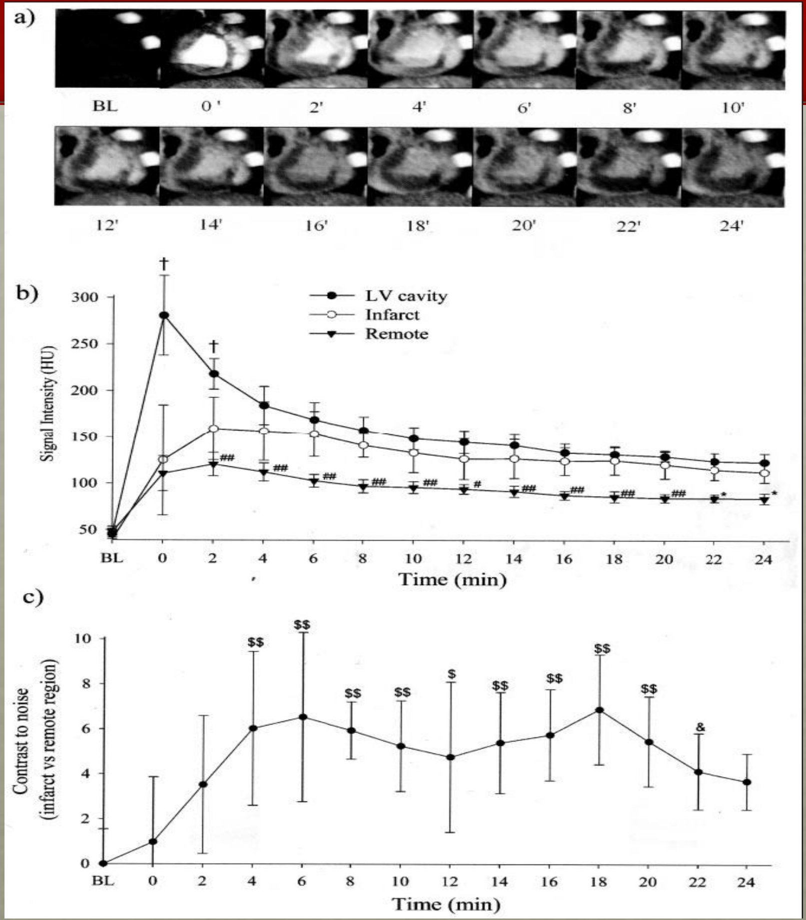
Technique d'acquisition

- Temps précoce
  - Coronaires
  - Myocarde :
    - Reconstructions temps diastole/systole
    - MPR coupes larges 6-9 mm.
    - Mesures densités (HU)
- Temps tardif sans réinjection
  - Délai 5-15 minutes
  - 80kv
  - Coupes 1.5 mm
  - MPR coupes larges 6-9 mm.
  - Mesures densités (HU)
- Travail sur le fenêtrage et le moyennage du contraste

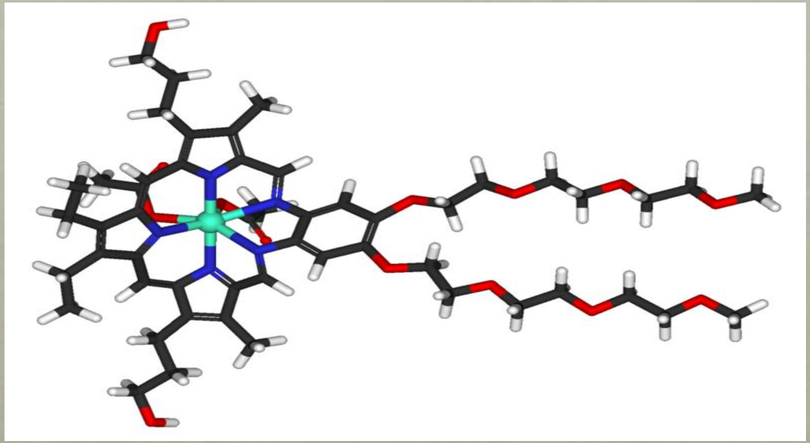
Perfusion myocardique



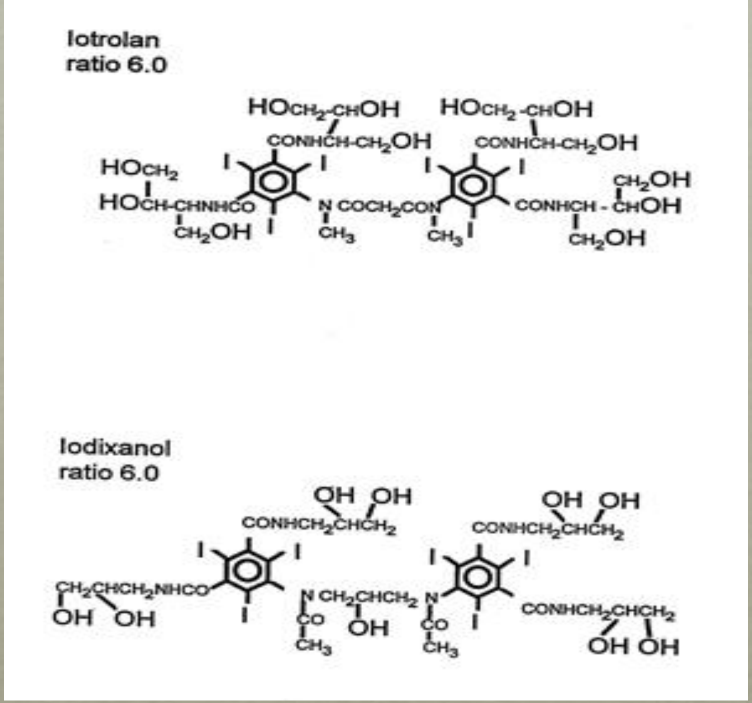
Paul et col, Circulation. 2003;108:373-374.



Gerber et al. *Circulation* 2006 113(6):823-33



Gadolinium



PCNI

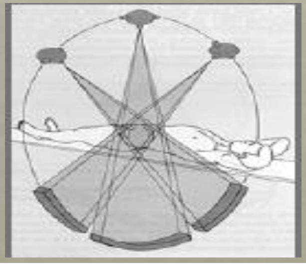
Mêmes caractéristiques biologiques, mêmes poids moléculaire, diffusion Extracellulaire. Mêmes propriétés pour évaluer la perfusion myocardique.

Sémiologie de l'image scannographique myocardique

- Idem IRM
- Morphologie
- Hypodensité
  - Précoce
  - Persistante tardive
- Hyperdensité
  - tardive

Protocole scanner myocardique

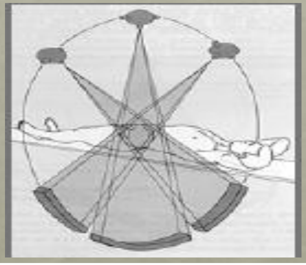
Temps Précoce



T0

Contraste 100-140 ccc

Temps Tardif

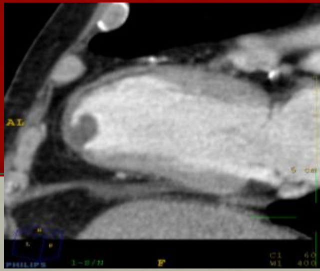


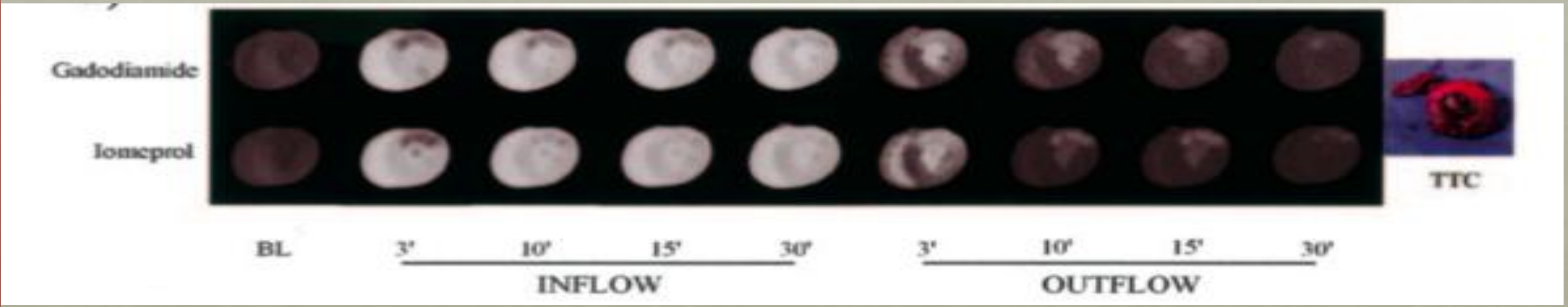
T 5-10 mn

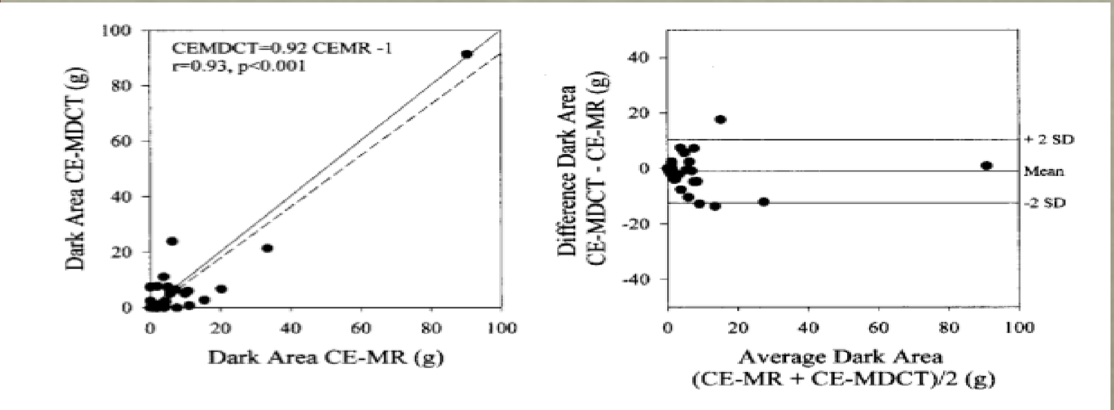
80Kv

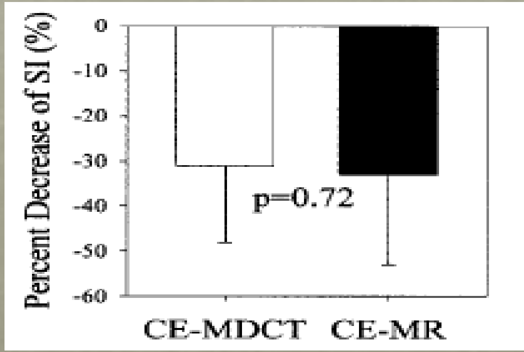
+ 2 msv

Hypodensité précoce



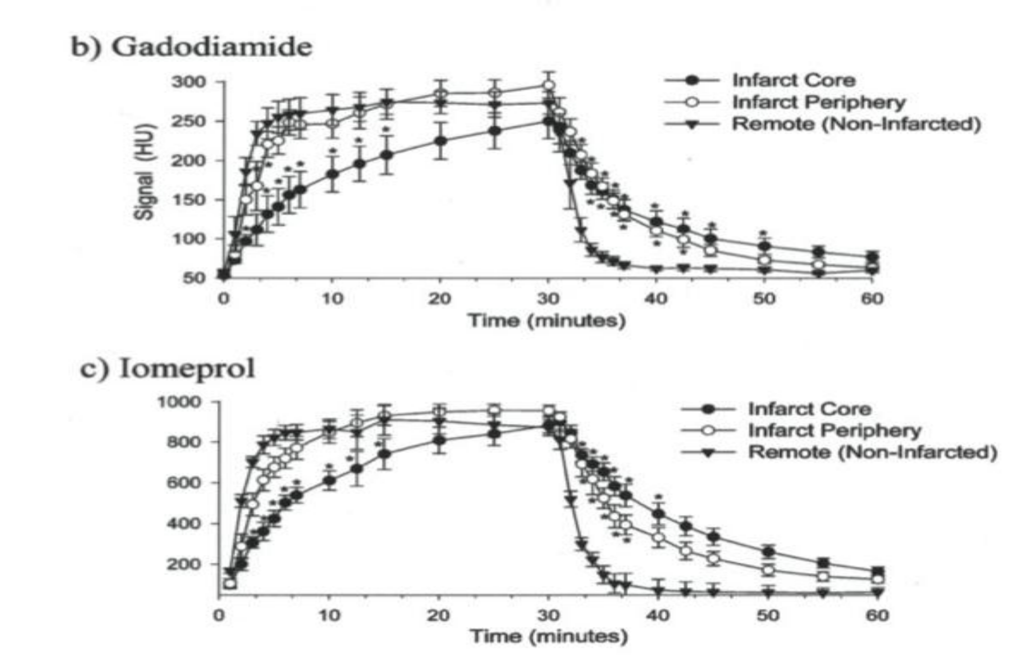


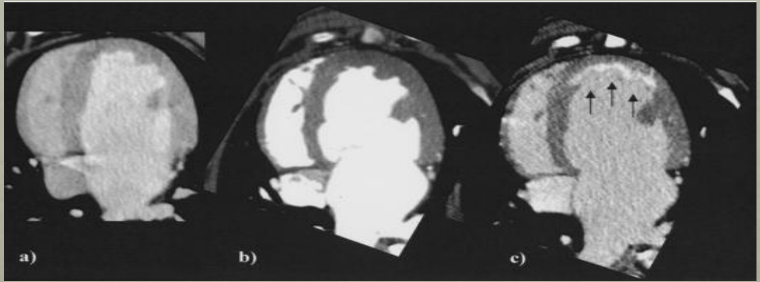


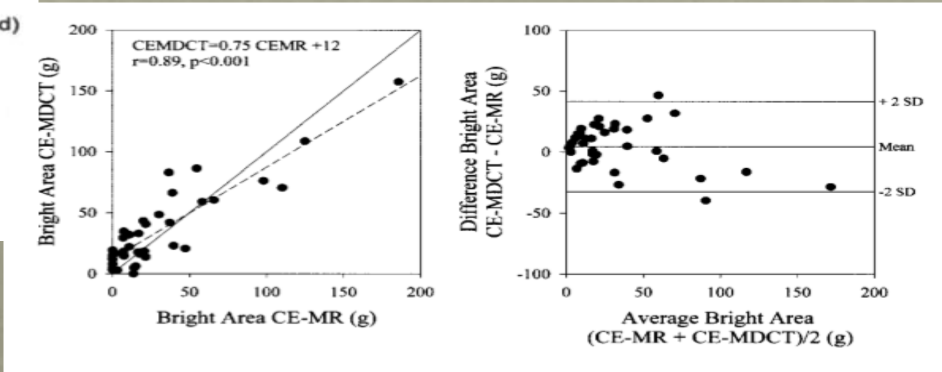


Gerber et al. *Circulation* 2006 113(6):823-33

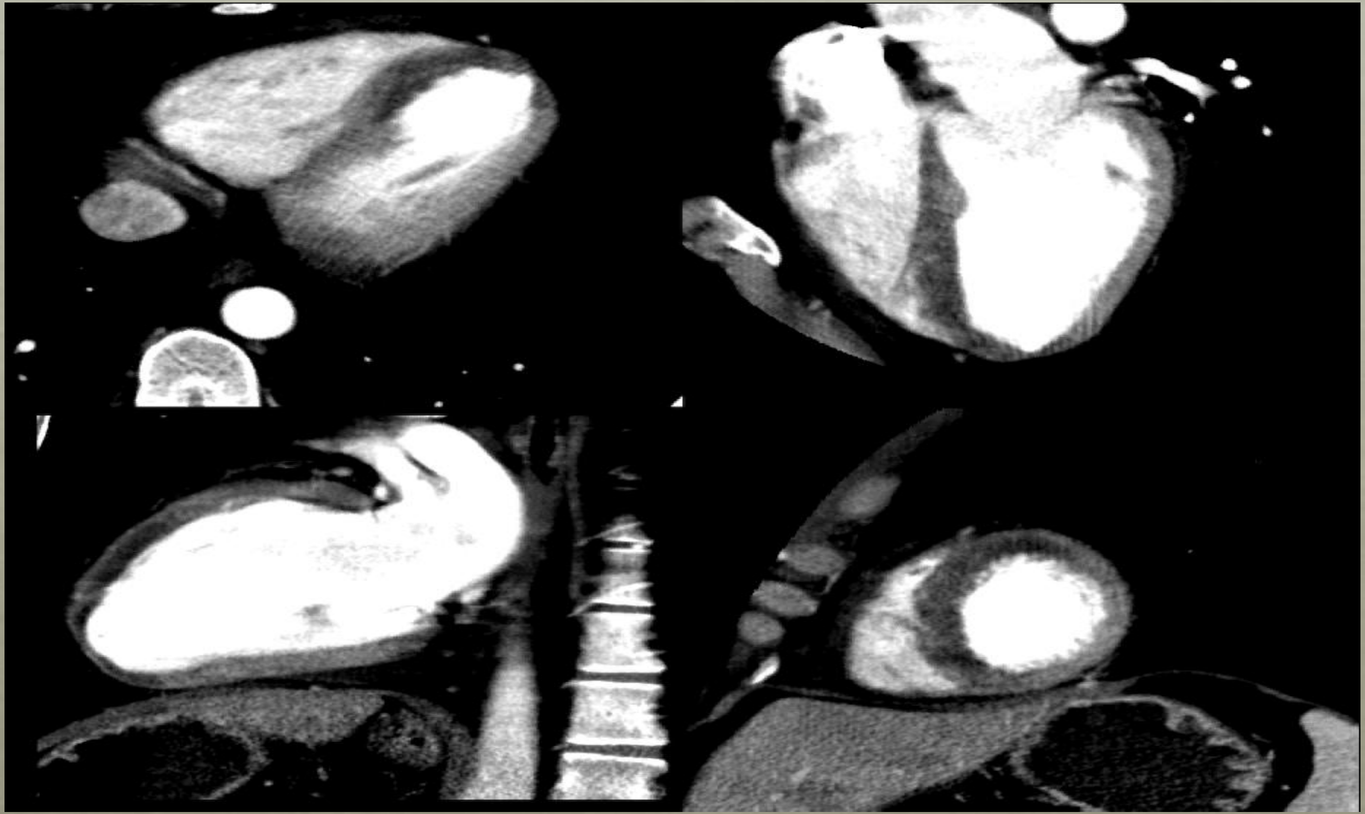
Hyperdensité tardive



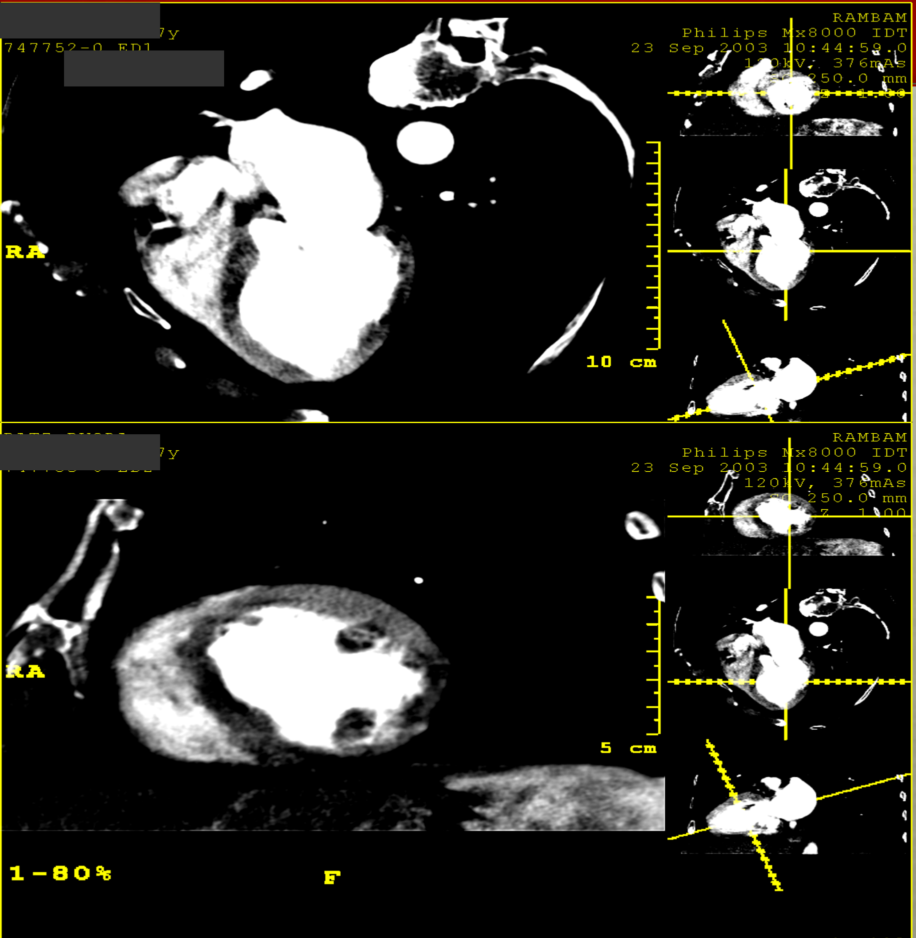


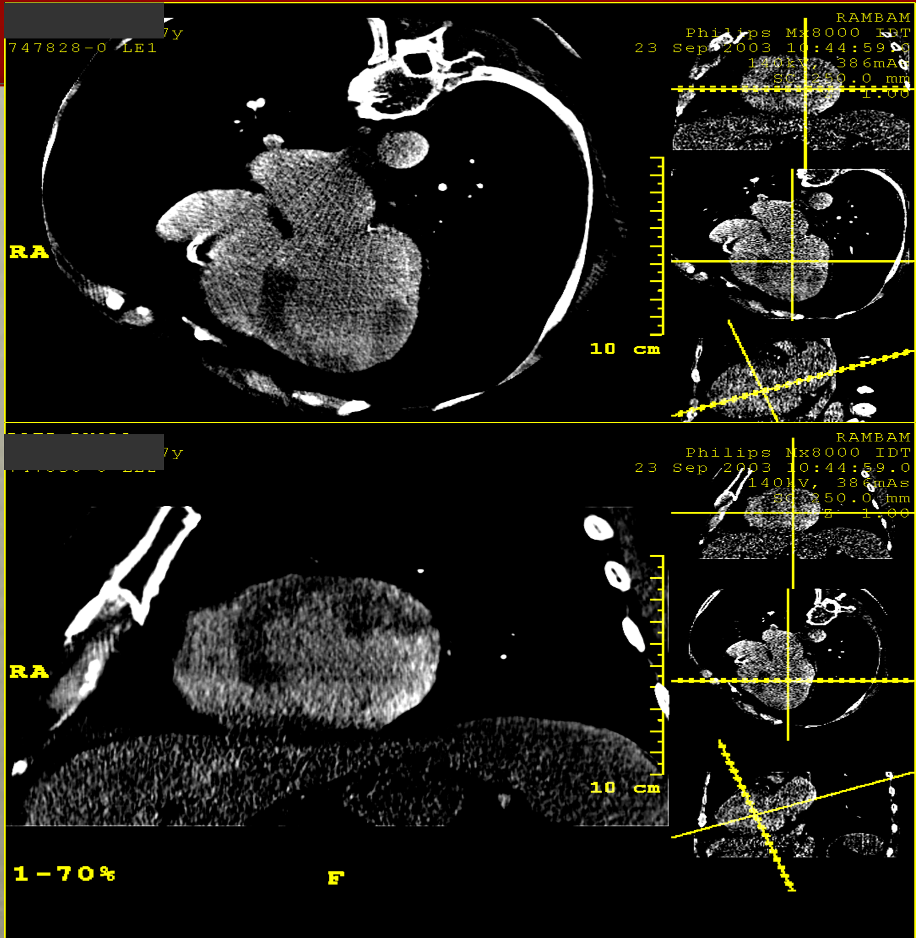


Gerber et al. *Circulation* 2006 113(6):823-33



IDM postéro latéral – IDM septal





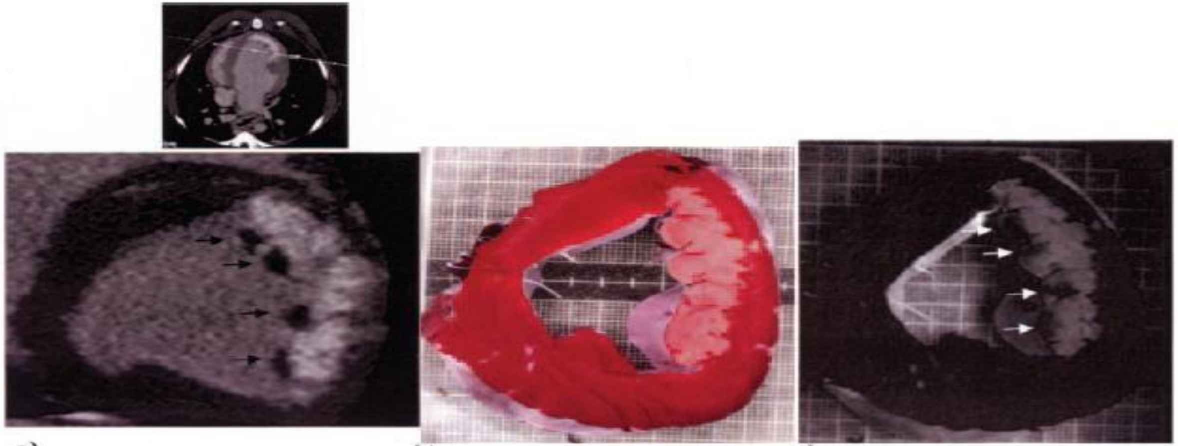
Contrast-Enhanced Multidetector Computed Tomography Viability Imaging After Myocardial Infarction

Characterization of Myocyte Death, Microvascular Obstruction, and Chronic Scar

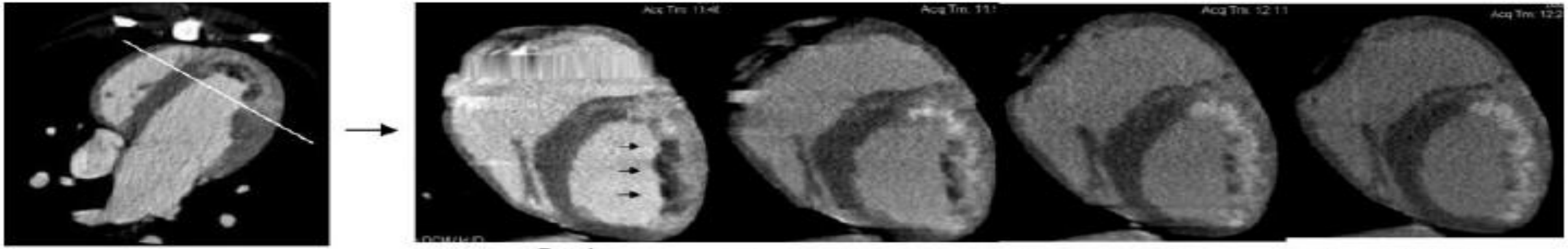
Albert C. Lardo, PhD; Marco A.S. Cordeiro, MD, PhD; Caterina Silva, MD; Luciano C. Amado, MD; Richard T. George, MD; Anastasios P. Saliaris, MD; Karl H. Schuleri, MD; Veronica R. Fernandes, MD; Menekhem Zviman, PhD; Saman Nazarian, MD; Henry R. Halperin, MD, MA; Katherine C. Wu, MD; Joshua M. Hare, MD; Joao A.C. Lima, MD

Methods and Results—Ten dogs and 7 pigs underwent balloon occlusion of the left anterior descending coronary artery (LAD) followed by reperfusion. Contrast-enhanced (Visipaque, 150 mL, 325 mg/mL) MDCT (0.5 mm × 32 slice) was performed before occlusion and 90 minutes (canine) or 8 weeks (porcine) after reperfusion. MDCT images were analyzed to define infarct size/extent and microvascular obstruction and compared with postmortem myocardial staining (triphenyltetrazolium chloride) and microsphere blood flow measurements. Acute and chronic infarcts by MDCT were characterized by hyperenhancement, whereas regions of microvascular obstruction were characterized by hypoenhancement. MDCT infarct volume compared well with triphenyltetrazolium chloride staining (acute infarcts $21.1 \pm 7.2\%$ versus $20.4 \pm 7.4\%$, mean difference 0.7%; chronic infarcts $4.15 \pm 1.93\%$ versus $4.92 \pm 2.06\%$, mean difference -0.76%) and accurately reflected morphology and the transmural extent of injury in all animals. Peak hyperenhancement of infarcted regions occurred ≈5 minutes after contrast injection. MDCT-derived regions of microvascular obstruction were also identified accurately in acute studies and correlated with reduced flow regions as measured by microsphere blood flow.

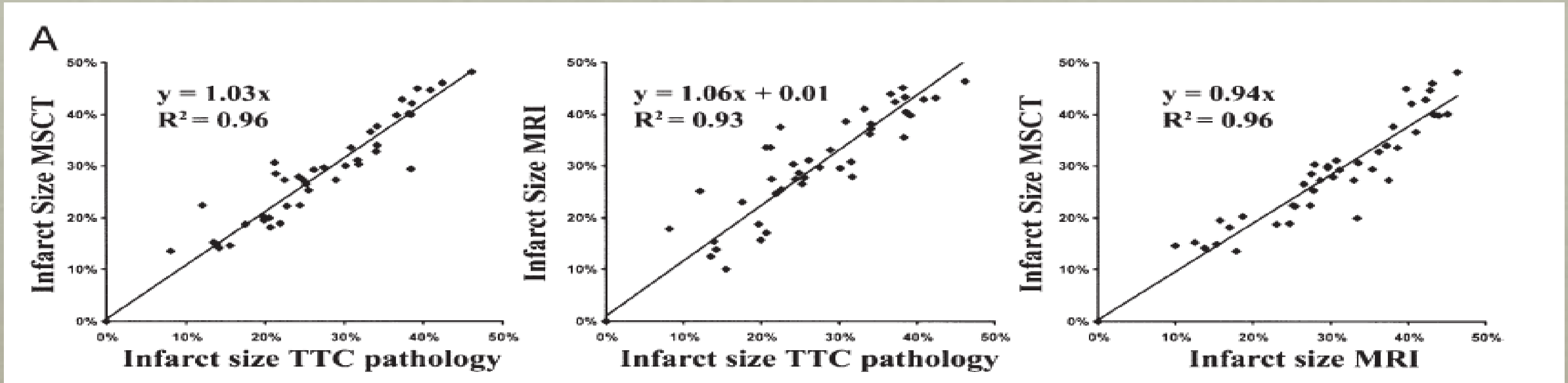
Conclusions—The spatial extent of acute and healed myocardial infarction can be determined and quantified accurately with contrast-enhanced MDCT. This feature, combined with existing high-resolution MDCT coronary angiography, may have important implications for the comprehensive assessment of cardiovascular disease. (***Circulation*. 2006;113:394-404.**)

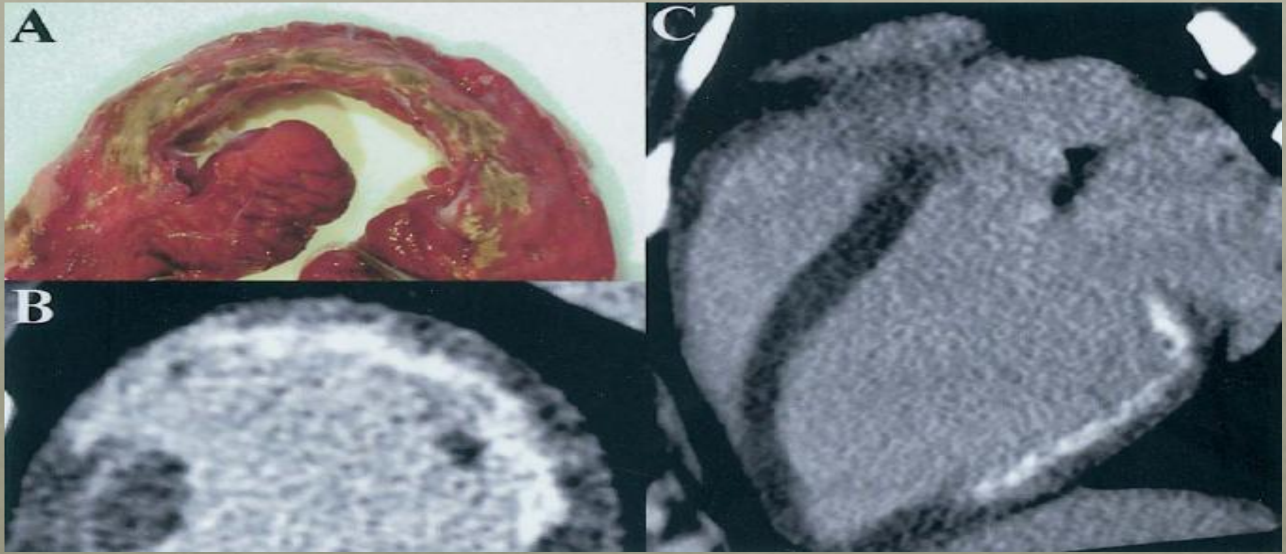


a) b) c)

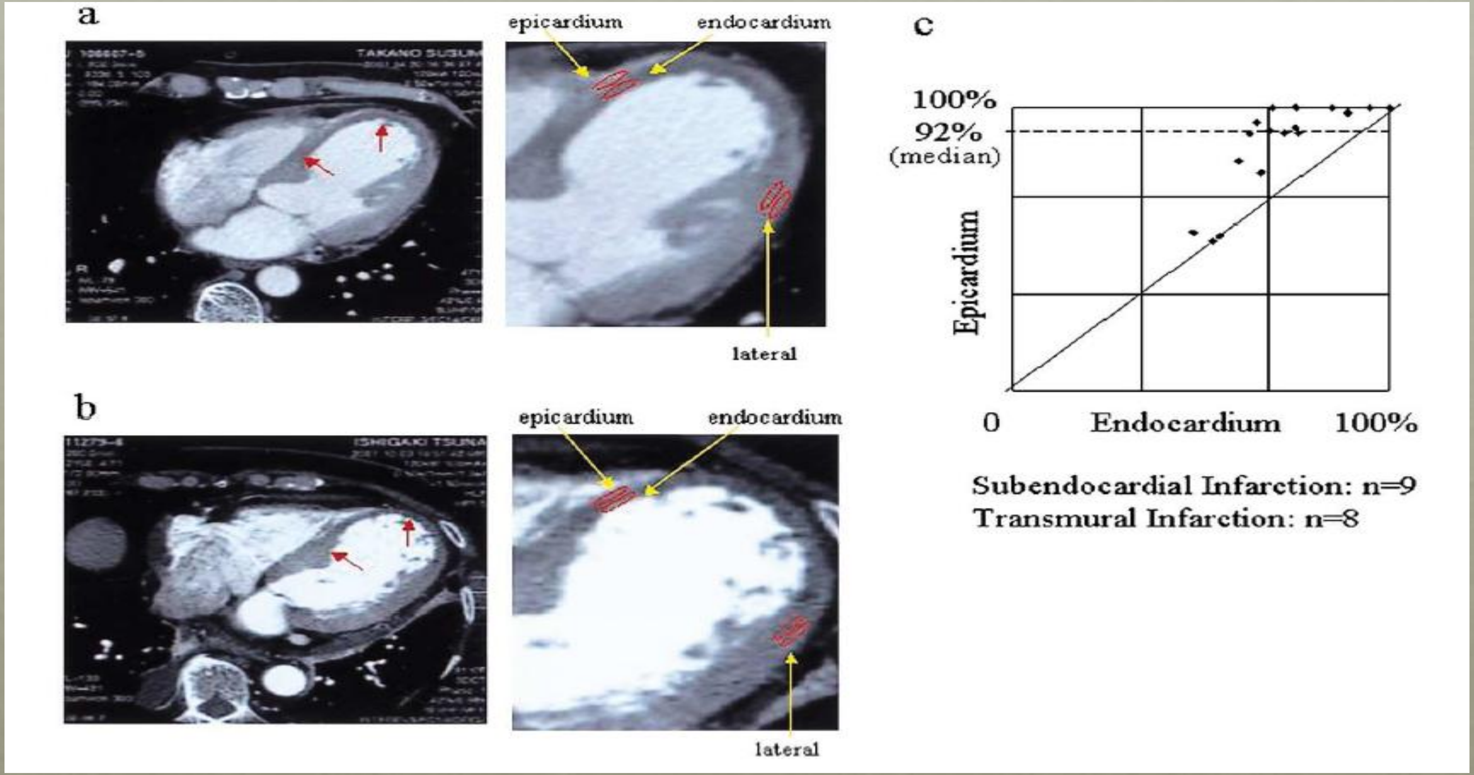


a) b) 5 min c) 15 min d) 25 min e) 40 min


A
y = 1.03x
R² = 0.96
Infarct Size MSCT
Infarct size TTC pathology
y = 1.06x + 0.01
R² = 0.93
Infarct Size MRI
Infarct size TTC pathology
y = 0.94x
R² = 0.96
Infarct Size MSCT
Infarct size MRI
0%
10%
20%
30%
40%
50%


A
B
C

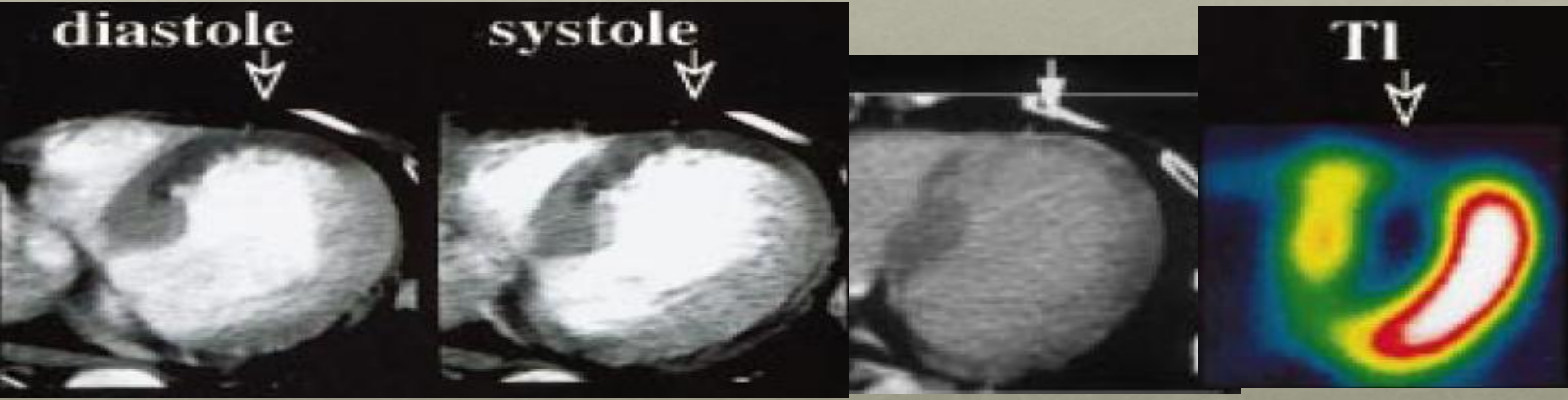
Perfusion myocardique

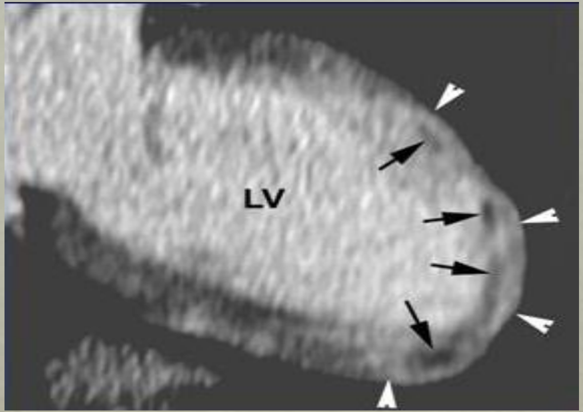


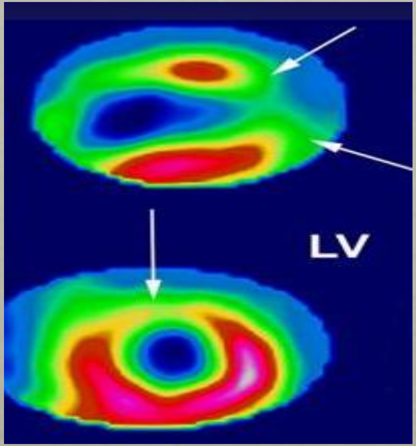
Wada et col, Circ J 2004;68:512

Valeur Pronostique ?

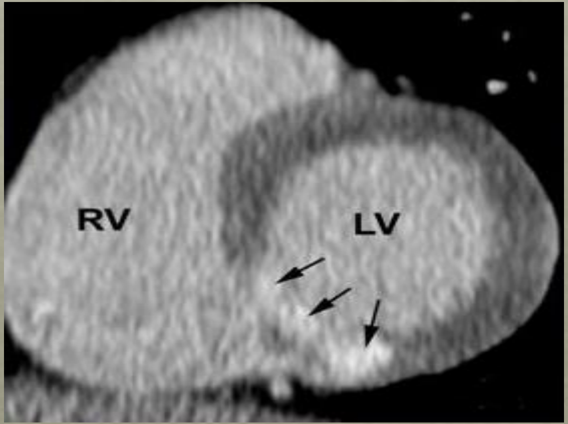
Hyper contraste tardif

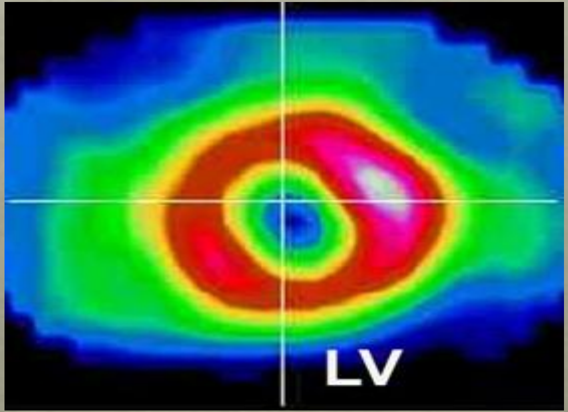






Hypodensité persistante sur temps tardif / Séquelle scintigraphique à distance

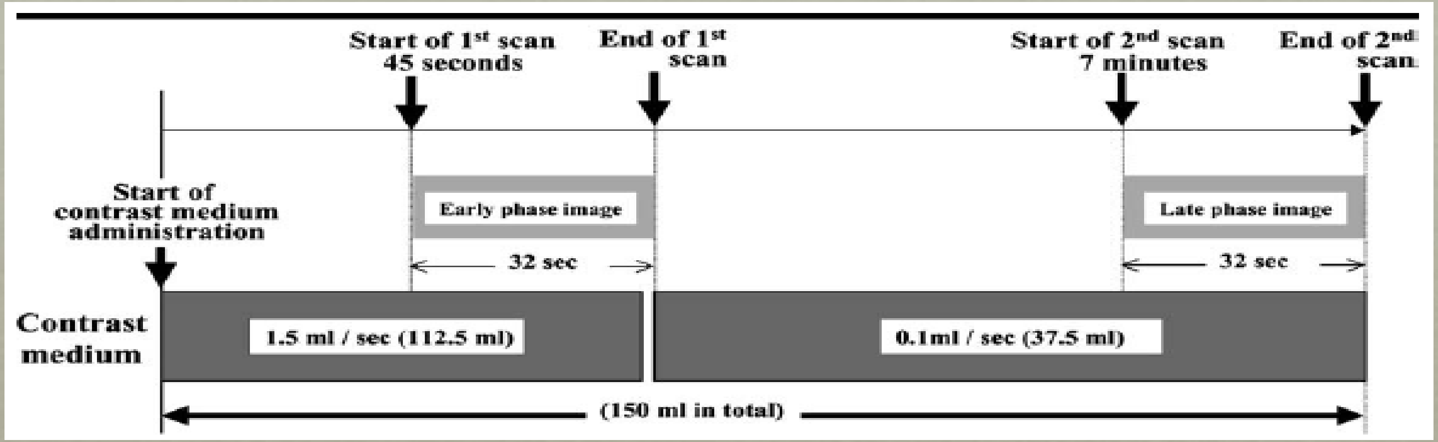


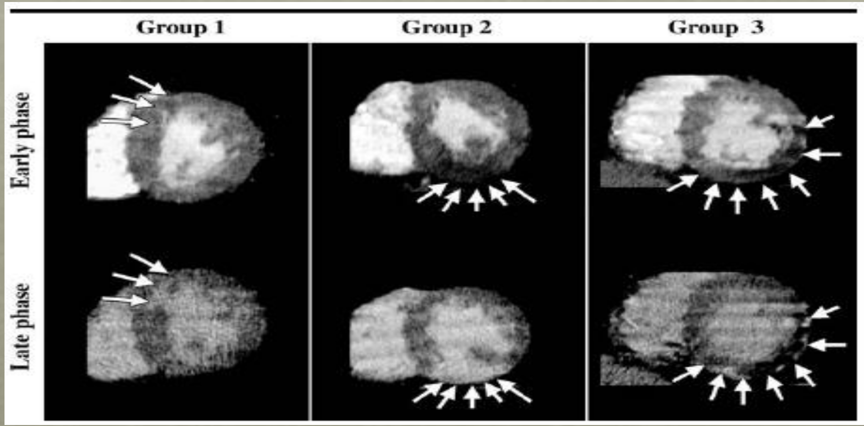


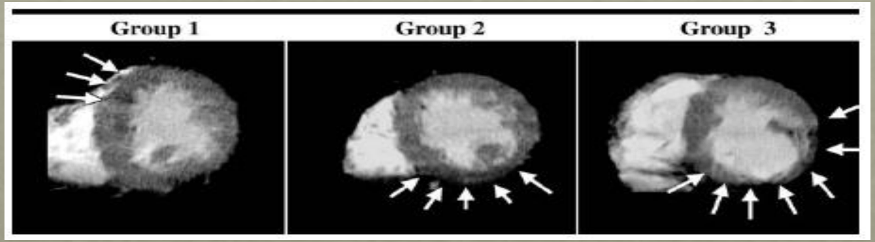
Pas d'hypodensité persistante au temps tardif / Pas de séquelle d'infarctus

Sensibilité 78%   Spécificité 91%

Paul et al. Radiology 236 (2): 485. (2005







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Koyama et col; Radiology 2005

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doi:10.1016/j.jacc.2006.12.032

Cardiac Imaging

Acute Myocardial Infarction Early Viability Assessment by 64-Slice Computed Tomography Immediately After Coronary Angiography

Comparison With Low-Dose Dobutamine Echocardiography

Michel Habis, MD,* André Capderou, MD, PHD,† Saïd Ghostine, MD,* Béatrice Daoud, MD,‡ Christophe Caussin, MD,* Jean-Yves Riou, MD,‡ Philippe Brenot, MD,‡ Claude Yves Angel, MD,‡ Bernard Lancelin, MD,* Jean-François Paul, MD‡

Le Plessis Robinson, France

Abstract

OBJECTIVES: Early evaluation of myocardial viability in acute myocardial infarction is useful to guide therapy. Therefore, we assessed 64-slice computed tomography (CT) immediately after coronary angiography in this setting.

BACKGROUND: Recent preliminary studies have shown the promising usefulness of late hyperenhancement multislice computed tomography (MSCT) for non-viability assessment.

METHODS: Thirty-six patients admitted for a first acute myocardial infarction had a coronary angiogram early after admission followed by 64-slice CT without iodine reinjection. The 16 segments of the left ventricle depicted by the American Society of Echocardiography were graded: no, subendocardial, or transmural hyperenhancement. No or subendocardial hyperenhancement were expected to reflect viability. Two to 4 weeks later, the same segments' contractility was evaluated at rest. Low-dose dobutamine echocardiography was performed in case of akinetic segment at rest.

RESULTS: Mean delay between coronary angiography and MSCT was 24 +/- 11 min (range 7 to 51 min). We compared 576 segments evaluated by each method. Agreement was noted for 560 segments (97%) and disagreement for 16 segments (3%). Thus, 64-slice CT after coronary angiography for an acute myocardial infarction had 98% sensitivity, 94% specificity, 97% accuracy, and 99% positive and 79% negative predictive values for detecting viable myocardial segments at a very early stage of an acute myocardial infarction. On a per-patient analysis, sensitivity, specificity, accuracy, and positive and negative predictive values were 92%, 100%, 94%, and 100% and 85%, respectively.

CONCLUSIONS: A 64-slice CT after coronary angiography for an acute myocardial infarction is a promising method for early evaluation of viable myocardium.

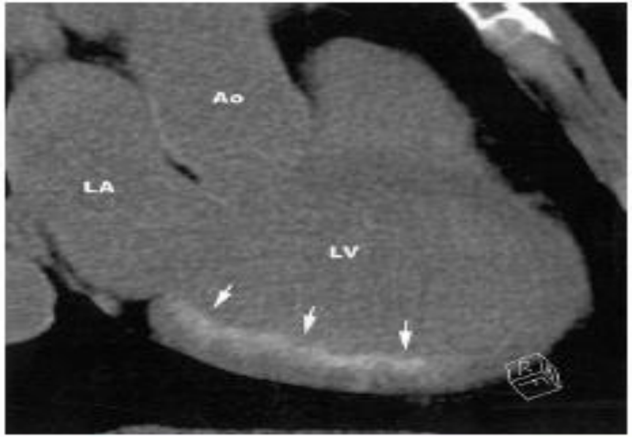
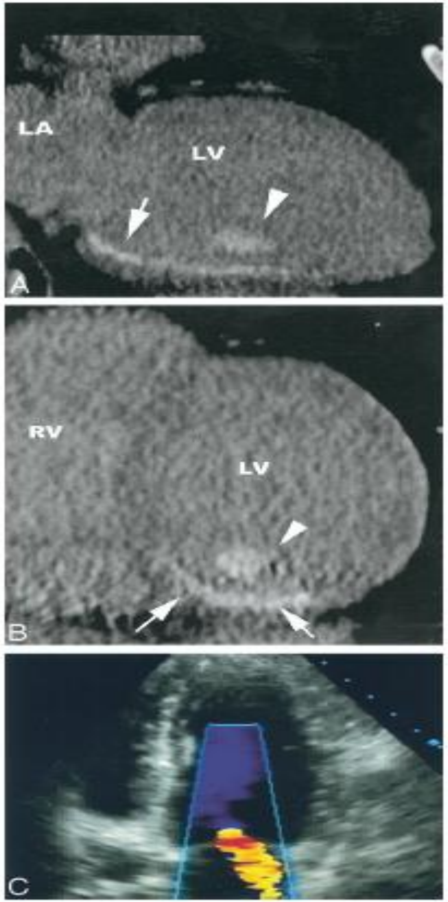


Figure 1 **64-Slice CT Scan 51 Min After a Primary Angioplasty for an AMI of a 59-Year-Old Patient**

Parasternal long-axis view (8-mm slice thickness) shows subendocardial hyperenhancement of the posterior wall (segments 4 and 10) (**arrows**). Low-dose dobutamine echocardiography confirmed myocardial viability of these segments. AMI = acute myocardial infarction; Ao = aorta; CT = computed tomography; LA = left atrium; LV = left ventricle.



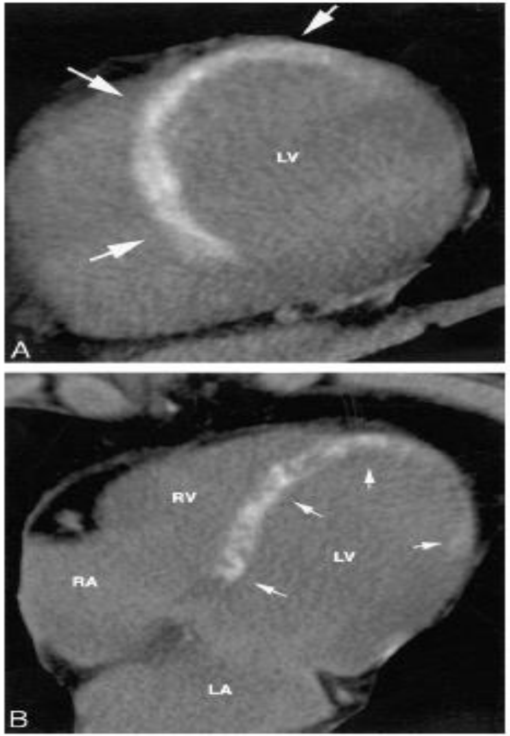


Figure 3 **64-Slice CT Scan 21 Min After Left Anterior Descending Coronary Artery Reperfusion**

(A) Parasternal short-axis view shows transmural hyperenhancement of segments 7, 8, 11, and 12 (**arrows**). **(B)** Apical 4-chamber view shows transmural hyperenhancement of segments 6, 12, 13, and 15 (**arrows**). This patient was confirmed having no viability at low-dose dobutamine echocardiography in all the involved segments. CT = computed tomography; LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle.

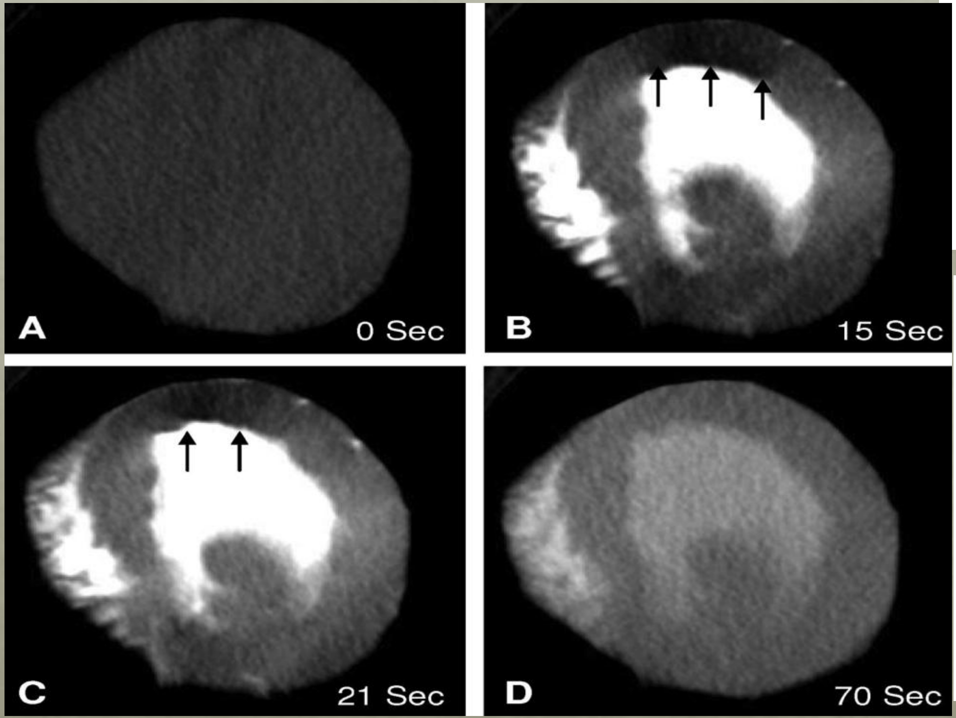
Table 2 Comparison of 64-Slice CT Myocardial Lack of Hyperenhancement With Low-Dose Dobutamine Echocardiography

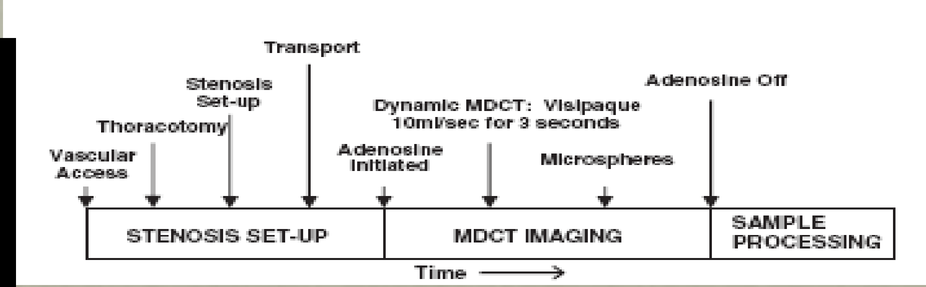
	n	TP	TN	FP	FN	Sensitivity	Specificity	Accuracy	PPV	NPV
Patients	36	23	11	0	2	92 (74–99)	100 (72–100)	94 (81–99)	100 (85–100)	85 (55–98)
All segments	576	510	50	3	13	98 (96–99)	94 (84–99)	97 (96–98)	99 (98–100)	79 (67–89)
RCA	13	10	2	0	1	91 (59–100)	100 (16–100)	92 (64–100)	100 (69–100)	67 (9–99)
Cx	6	5	0	0	1	83 (36–100)	—	83 (36–100)	100 (48–100)	0 (0–97)
LAD	17	8	9	0	0	100 (63–100)	100 (66–100)	100 (80–100)	100 (63–100)	100 (66–100)

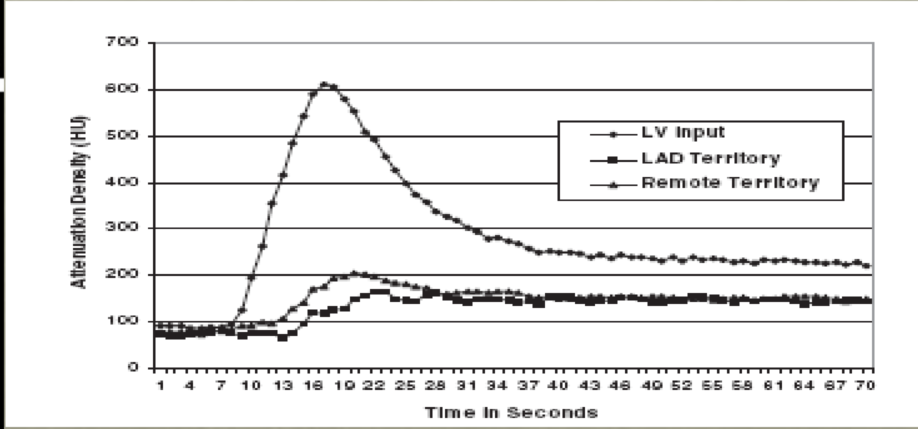
of Hyperenhancement With Low-Dose Dobutamine Echocardiography

Sensitivity	Specificity	Accuracy	PPV	NPV
92 (74–99)	100 (72–100)	94 (81–99)	100 (85–100)	85 (55–98)
98 (96–99)	94 (84–99)	97 (96–98)	99 (98–100)	79 (67–89)
91 (59–100)	100 (16–100)	92 (64–100)	100 (69–100)	67 (9–99)
83 (36–100)	—	83 (36–100)	100 (48–100)	0 (0–97)
100 (63–100)	100 (66–100)	100 (80–100)	100 (63–100)	100 (66–100)

Valeur diagnostique : Scanner myocardique de stress ?







George RT . Invest Radiol 2007;42: 815–822

Stress CT perfusion vs. SPECT double tube 64

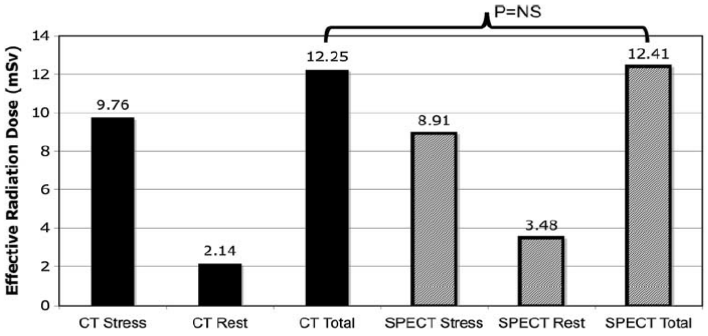
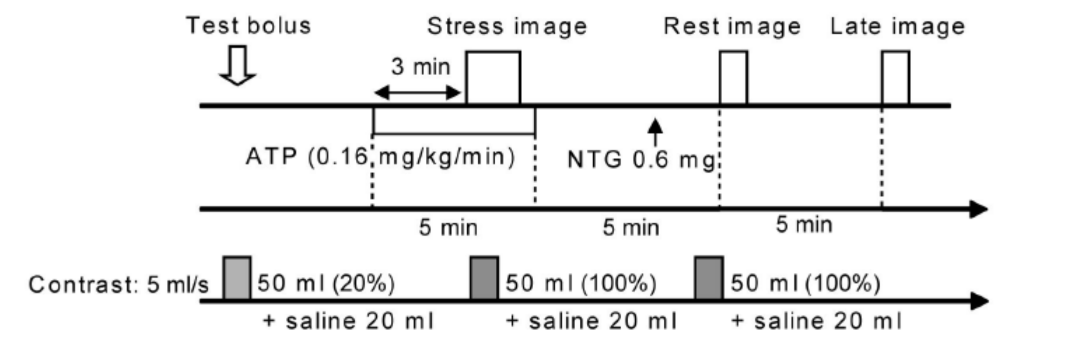


Figure 3. Radiation exposure of CT perfusion versus SPECT-MPI. Estimated effective radiation dose in milisivert (mSv) is displayed for CTP (*solid bars*) and SPECT (*striped bars*). The total effective radiation dose was not statistically different between the two modalities.

A. Stress Perfusion Defect Severity (SSS) in 141 Vascular Territories		CT Perfusion		
		Mild	Moderate	Severe
SPECT	Mild	94	22	1
	Moderate	10	12	1
	Severe	0	0	1

David R. Okada, J Nucl Cardiol 2010;17:27–37

Stress myocardial CT scan 256 slices



	Stress image	Rest image	Late image
Scan mode	Dynamic scan	Axial scan	Axial scan
ECG triggering	Prospective	Prospective	Prospective
Cardiac phase	RR 40%	RR 75%	RR 40%
Phase tolerance (%)	0	5	0
Tube voltage (kV)	100	100	100
Tube current (mAs/ rotation)	80	210	210
Rotation speed (s/ rotation)	0.27	0.27	0.27
Detector collimation (mm)	64 × 1.25	128 × 0.625	128 × 0.625
Coverage (cm)	8	Whole heart	Whole heart
Scan time	30 consecutive beats	3-5 s	3-5 s
Reconstruction	Full reconstruction	Half reconstruction	Half reconstruction
Estimated dose (mSv)	10.4	4.3	3.1

Akira Kurata ,December 2013 | Volume 8 | Issue 12 | e83950

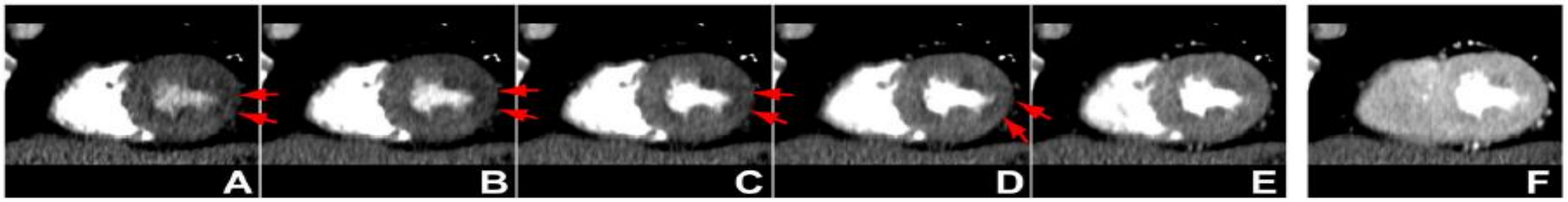


Table 5. Diagnostic accuracy for detecting coronary stenosis with > 50% lumen diameter reduction.

	Sensitivity	Specificity	PPV	NPV
Coronary CTA alone	11/11, 100% (71.3-100%)	11/16, 68.8% (41.4-88.8%)	11/16, 68.8% (41.4-88.8%)	11/11, 100% (71.3-100%)
Coronary CTA + MBF cut-off (184.5 ml/100g/min)	13/13, 100% (75.1-100%)	11/14, 78.6% (49.2-95.1%)	13/16, 81.2% (54.6-95.7%)	11/11, 100% (71.3-100%)

Coronary CTA + MBF cut-off (184.5 ml/100g/min): combined assessment of coronary computed tomography angiography and the receiver operating characteristic curve based myocardial blood flow cut-off value for detecting significant coronary artery stenosis (> 50%). PPV and NPV: positive and negative predictive values. Data are expressed as n/N, %, 95% confidence interval.

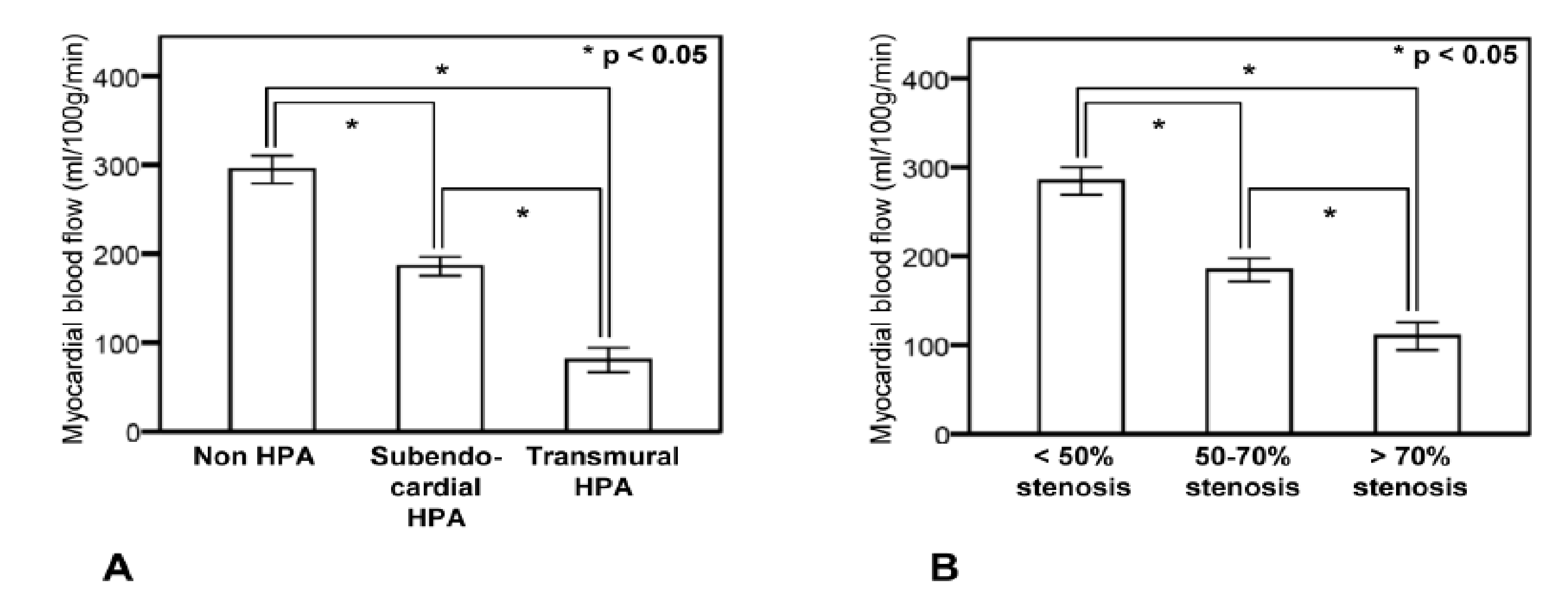
doi: 10.1371/journal.pone.0083950.t005

Table 1. Scan parameters of the ATP-stress dynamic CT perfusion imaging.

	Stress image	Rest image	Late image
Scan mode	Dynamic scan	Axial scan	Axial scan
ECG triggering	Prospective	Prospective	Prospective
Cardiac phase	RR 40%	RR 75%	RR 40%
Phase tolerance (%)	0	5	0
Tube voltage (kV)	100	100	100
Tube current (mAs/ rotation)	80	210	210
Rotation speed (s/ rotation)	0.27	0.27	0.27
Detector collimation (mm)	64 × 1.25	128 × 0.625	128 × 0.625
Coverage (cm)	8	Whole heart	Whole heart
Scan time	30 consecutive beats	3-5 s	3-5 s
Reconstruction	Full reconstruction	Half reconstruction	Half reconstruction
Estimated dose (mSv)	10.4	4.3	3.1

Radiation dose is estimated from cardiac phantom study.

doi: 10.1371/journal.pone.0083950.t001



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Core 320 Study

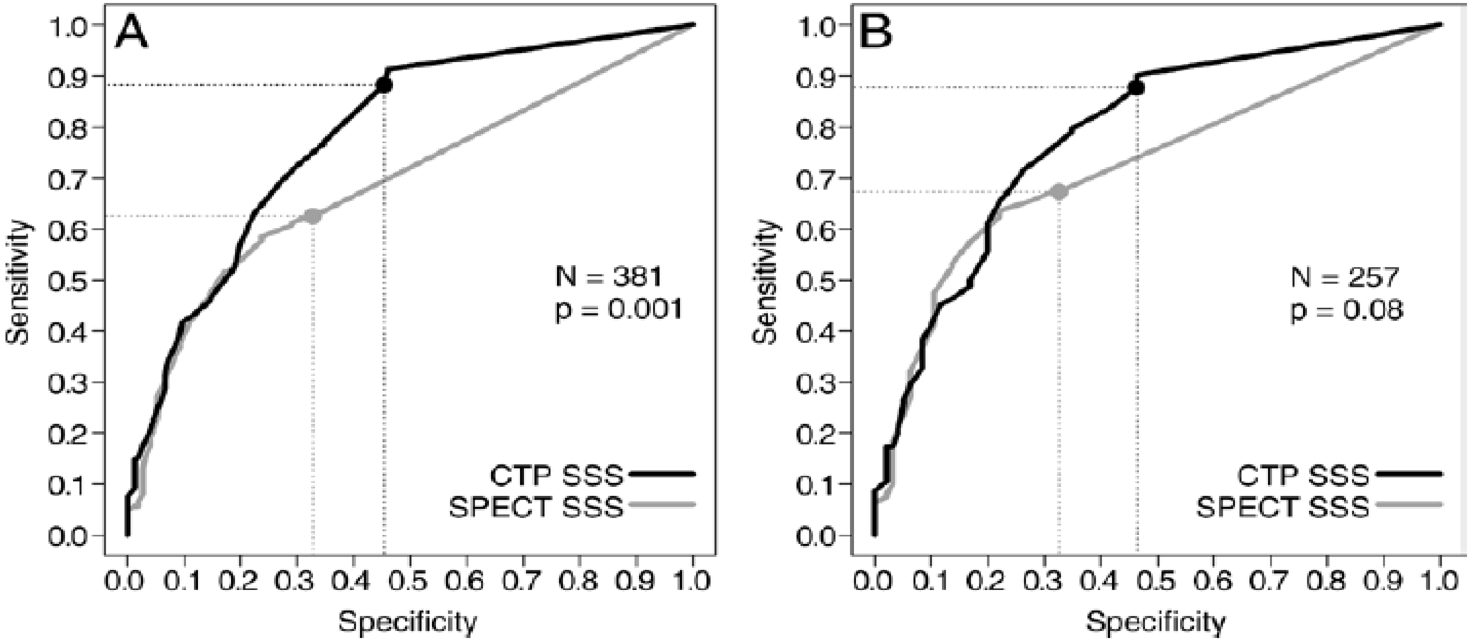

Figure 1: Receiver operating characteristic curves for myocardial CT perfusion imaging (*CTP*) and SPECT in, *A*, all patients and, *B*, only the patients who underwent pharmacologic stress SPECT.

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Core 320 Study

Table 2

Diagnostic Performance of Myocardial CT Perfusion Imaging: Per-Patient Analysis

	All Patients (n = 381)			Pharmacologic Stress Only (n = 257)		
Parameter	CT Perfusion Imaging	SPECT	*P* Value	CT Perfusion Imaging	SPECT	*P* Value
A_z	0.78 (74, 82)	0.69 (64, 74)	.001	0.78 (73, 83)	0.72 (66, 78)	.08
Sensitivity (%)	88 (83, 92) [202/229]	62 (56, 69) [143/229]	<.001	88 (82, 92) [142/162]	67 (59, 74) [109/162]	<.001
Specificity (%)	55 (46, 63) [83/152]	67(59, 75) [102/152]	.02	54 (43, 64) [51/95]	67 (57, 77) [64/95]	.06
PPV (%)	75 (69, 80) [202/271]	74 (67, 80) [142/193]	.87	76 (70, 82) [142/186]	78 (70, 84) [109/140]	.64
NPV (%)	75 (66, 83) [83/110]	54 (47, 62) [102/188]	<.001	72 (60, 82) [51/71]	55 (45, 64) [64/117]	.003

Note.—Numbers in parentheses are 95% CIs. Numbers in brackets are raw data.

Table 4

Sensitivity of CT Perfusion Imaging and SPECT for Left Main, Three-Vessel, Two-Vessel, and One-Vessel Disease

Disease Type	CT Perfusion Imaging	SPECT
Left main	92 (62–100) [11/12]	75 (43–95) [9/12]
Three vessel	92 (83–97) [61/66]	79 (67–88) [52/66]
Two vessel	89 (80–95) [67/75]	68 (56–78) [51/75]
One vessel	83 (73–91) [63/76]	41 (30–53) [31/76]

Note.—Data are percentages. Numbers in parentheses are 95% CIs. Numbers in brackets are raw data.

Radiology 2014: Volume 272: Number 2

Figure 2

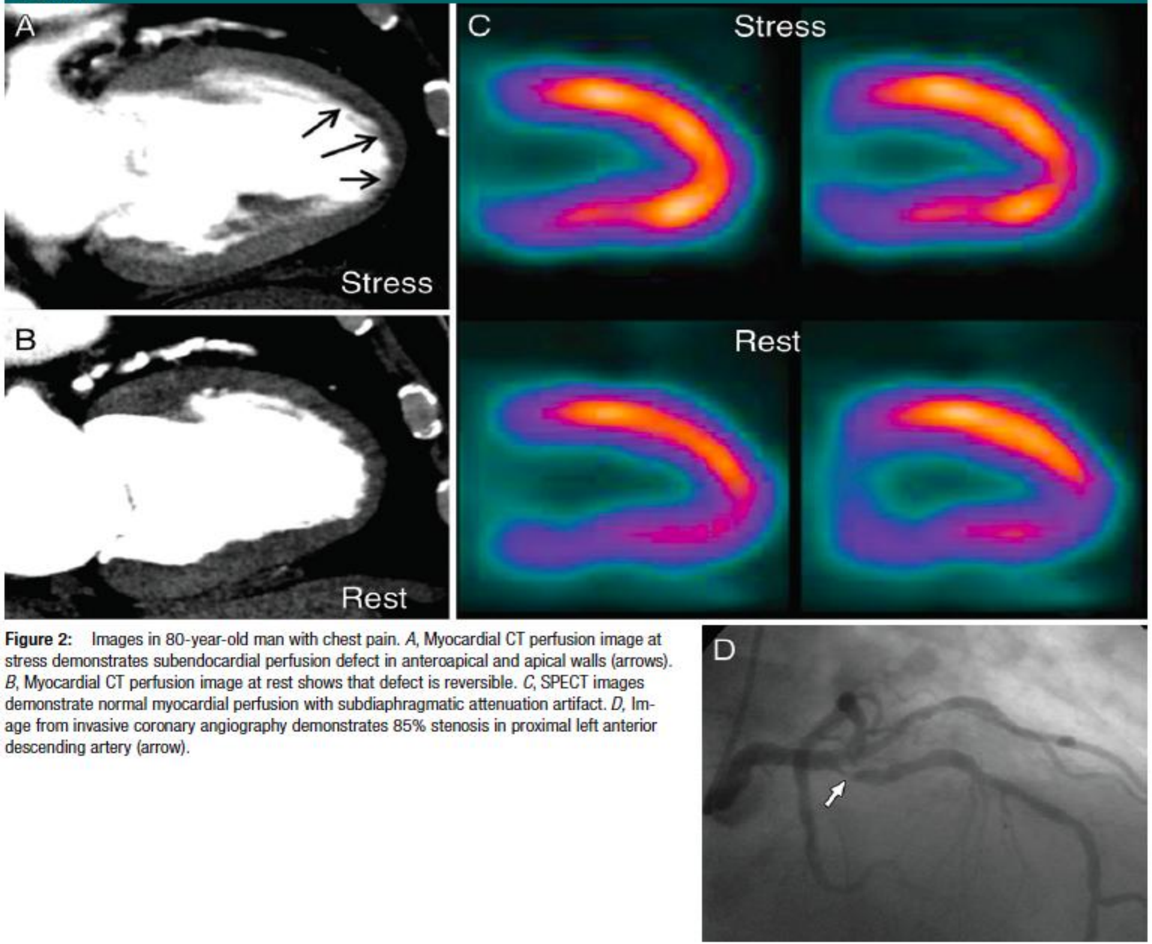


Figure 2: Images in 80-year-old man with chest pain. *A*, Myocardial CT perfusion image at stress demonstrates subendocardial perfusion defect in anteroapical and apical walls (arrows). *B*, Myocardial CT perfusion image at rest shows that defect is reversible. *C*, SPECT images demonstrate normal myocardial perfusion with subdiaphragmatic attenuation artifact. *D*, Image from invasive coronary angiography demonstrates 85% stenosis in proximal left anterior descending artery (arrow).

Acquisition dynamique

- Irradiation 11+/-0,2 mSv - Apnée longue 30 sec –
- Durée examen 20 mn

J A C C : C A R D I O V A S C U L A R IMA G I N G , V O L . 7 , N O . 3 , 2 0 1 4

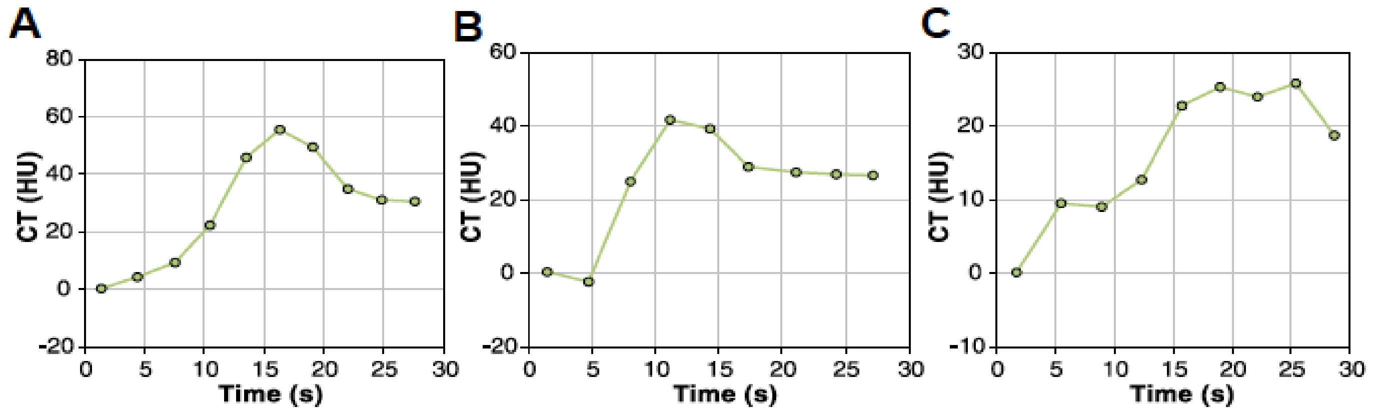


Figure 5. Tissue Attenuation Curves Obtained From Dynamic CT Perfusion Imaging

Normal myocardium (**A**), ischemic myocardium (**B**), infarcted myocardium (**C**). CT = computed tomography; HU = Hounsfield units.

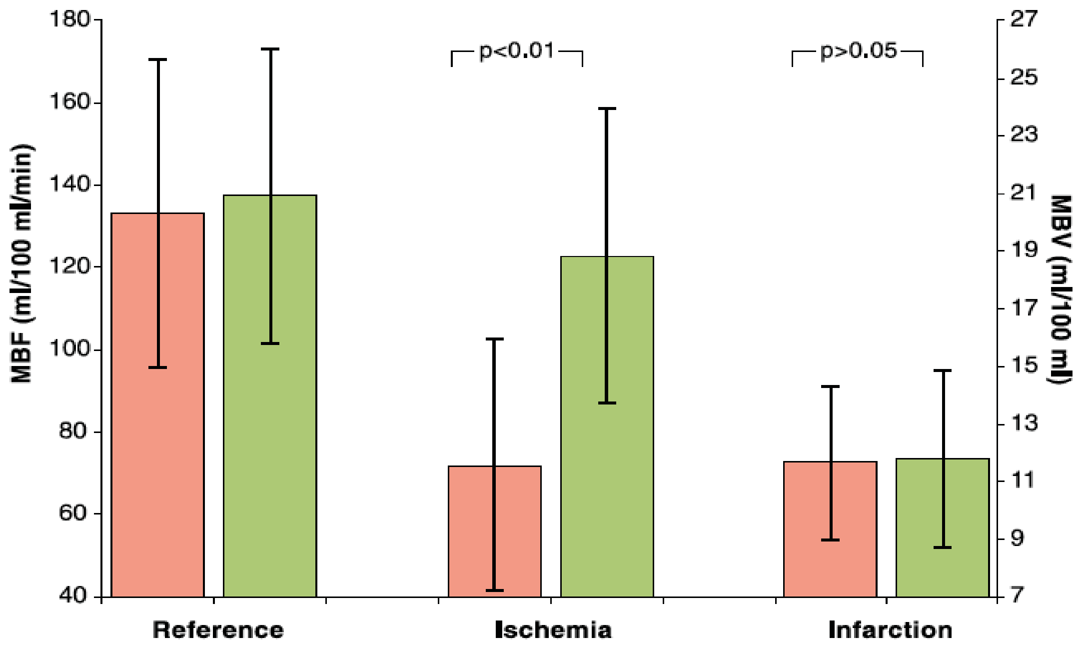
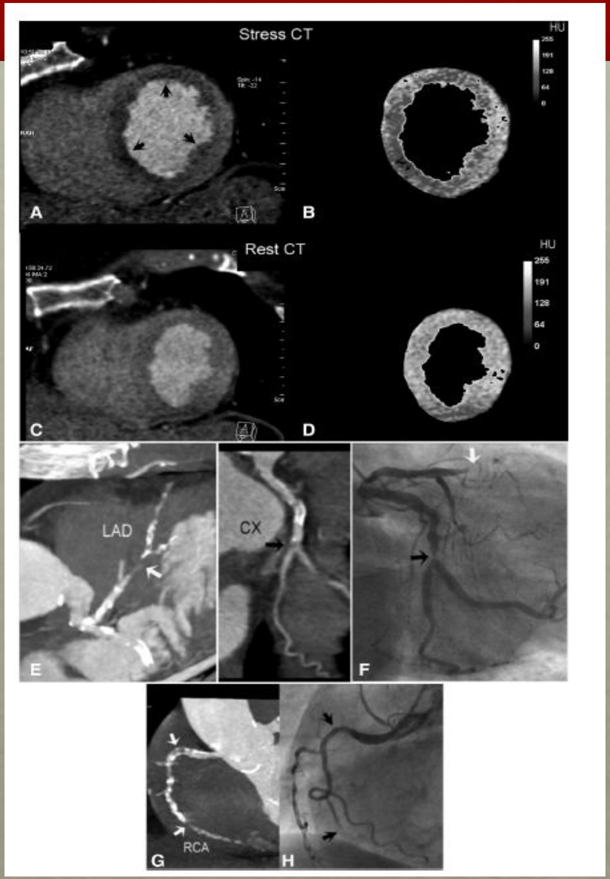


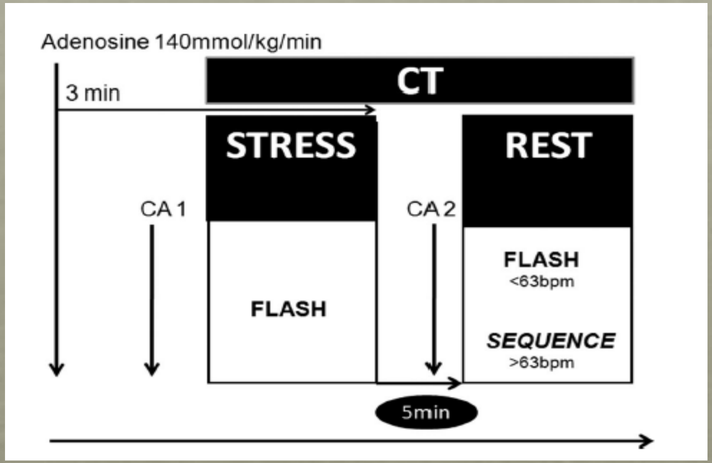
Figure 6. Bar Diagram for Differences in MBF and MBV

Differences in myocardial blood flow (MBF) **(pink)** and myocardial blood volume (MBV) **(green)** between reference myocardium as well as ischemic and infarcted myocardium in 17 subjects with excellent image quality.

Acquisition statique



- Scan time for highpitch stress CTP was 0.31 seconds (range, 0.24 to 0.37) and scan length 14.3 cm (range, 10.9 to 17.4).
- Effective radiation dose for stress and rest was 1 mSv (range, 0.75 to 1.48) and 1.5mSv (range, 0.53 to 5.8 mSv), respectively



Circ Cardiovasc Imaging. 2011;4:540-549

Table 5. CTP, CTA, and Combined CTA/CTP Versus Invasive Angiography for Detection of >70% Stenosis, Per Vessel (n=75)

	CTP			CTA			CTA/CTP		
	n/n		95% CI	n/n		95% CI	n/n		95% CI
Sensitivity	59/60	98%	91–99	59/60	98%	91–99	60/60	100%	94–100
Specificity	9/15	60%*	36–80	4/15	27%*	11–52	11/15	74%*	48–89
PPV	59/65	91%	81–95	59/70	84%	86–99	60/64	97%	85–97
NPV	9/10	90%*	60–98	4/5	80%*	38–96	11/11	100%	87–97
Accuracy	68/75	90%		63/75	84%		72/75	95%	
κ	0.67 (0.45–0.89)			0.33 (0.14–0.52)			0.81 (0.59–1.04)		

CTA indicates computed tomography angiography; CTP, CT perfusion; CI, confidence interval; PPV, positive predictive value; and NPV, negative predictive value.
*Specificity and NPV are biased.

Circ Cardiovasc Imaging. 2011;4:540-549

Statique / Dynamique

TABLE 1 Summarized Myocardial Perfusion Protocols

	Static Stress MPI	Dynamic Stress MPI
Scanner requirement	64-slice CT	Second-generation dual-source CT Wide detector CT with complete cardiac coverage
Acquisition mode	ECG-triggered axial scan mode ECG-gated spiral scan mode	ECG-triggered shuttle mode (dual-source CT) Stationary ECG-triggered mode (wide detector CT)
Contrast protocol	50–70 ml @ 4–5 ml/s	Short, high-rate bolus (≈50 ml)
Image data	Single high-resolution dataset	Sequence of low-resolution datasets
Effective dose	1–5 mSv*	5–10 mSv*
Output parameters	Attenuation values Relative attenuation values	Myocardial blood flow Myocardial blood volume

*Dose dependent on scanner technology and acquisition parameters.

CT = computed tomography; ECG = electrocardiogram; MPI = myocardial perfusion imaging.

En pratique

Patient preparation

Patients abstained from caffeine (coffee, tea, chocolate, energy drinks etc.) for 18 h and from methylxanthine-containing products, theophylline, oral dipyridamole, beta-blockers, and nitrates for 24 h before the scan;

18-gauge cannula in the right antecubital vein for contrast injection; 20-gauge cannula in the left antecubital vein for adenosine infusion;

30-s breath hold practiced; if unable to hold the breath for longer than 20 s, patients were asked to exhale gently over 10 s.

Non-enhanced coronary calcium scoring

Collimation 2 × 32 × 1.2 mm;

Gantry rotation time 285 ms;

Voltage 120 kV;

Tube current–time product 75 mAs;

Slice thickness 3 mm, reconstruction increment 1.5 mm;

Image acquisition triggered 250 ms after the R-wave.

European Heart Journal – Cardiovascular Imaging (2014) 15, 85–94

CTCA

Prospectively electrocardiogram (ECG)-triggered protocol (Adaptive Sequential, Siemens Healthcare);

Collimation $2 \times 64 \times 0.6$ mm with z-flying focal spot (2×128 sections);

Gantry rotation time 285 ms;

Voltage/tube current–time product 100 kV/370 mAs if body mass index (BMI) <30; 120 kV/320 mAs if BMI >30;

Image acquisition triggered at 60–75% of R–R interval in heart rates of <65 bpm; 35–75% of R–R interval in heart rates between 65 and 80 bpm; 35–50% of R–R interval in heart rates >80 bpm.

Test bolus scan obtained with 6 s delay at the level of the ascending aorta after injection of 15 mL of contrast (Omnipaque 300, GE Healthcare or Ultravist 370, Schering, Berlin), followed by 40 mL of saline;

Main bolus of 50 or 60 mL of contrast (depending on the type used); Injection rates adjusted to achieve an iodine delivery rate of 2.2 g of iodine/s;

CTCA images reconstructed with 0.75 mm slice thickness and 0.4 mm increment using a medium-smooth convolution kernel (B26f).

10–15 min delay

CTP

Adenosine infused intravenously at a dose of 140 μg/kg/min and CTP acquisition started 3 min into the adenosine infusion;

ECG-triggered axial shuttle mode used (the scanner alternates rapidly between two table positions and acquires prospectively ECG-triggered axial images in these two positions over 30 s);

Collimation $2 \times 32 \times 1.2$ mm;

Gantry rotation time 285 ms;

Voltage 100 kV;

Tube current–time product 300 mAs;

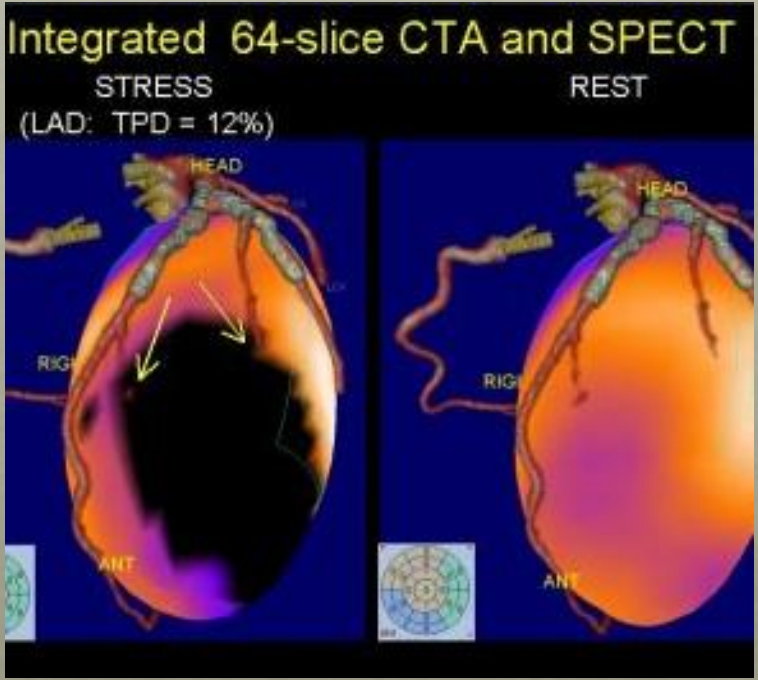
Image acquisition triggered 250 ms after the R-wave;

Scan delay calculated from the test bolus time-attenuation curve and set 6 s before arrival of contrast in the aorta;

50 or 60 mL of contrast injected with an iodine delivery rate of 2.2 g of iodine/s followed by 40 mL of saline;

Stress CTP images reconstructed with 3 mm slice thickness and 2 mm increment using a smooth-medium kernel that includes correction for iodine beam hardening (B23f).

European Heart Journal – Cardiovascular Imaging (2014) 15, 85–94


Integrated 64-slice CTA and SPECT
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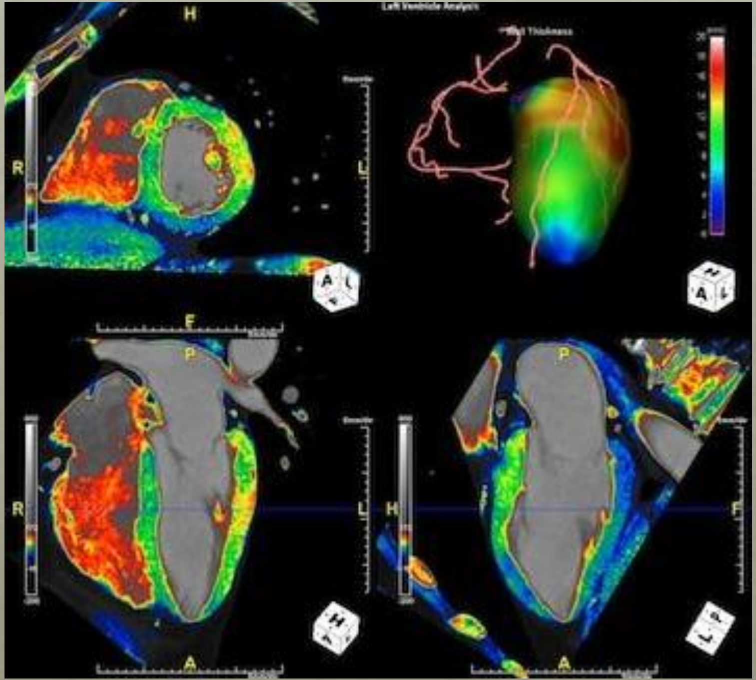
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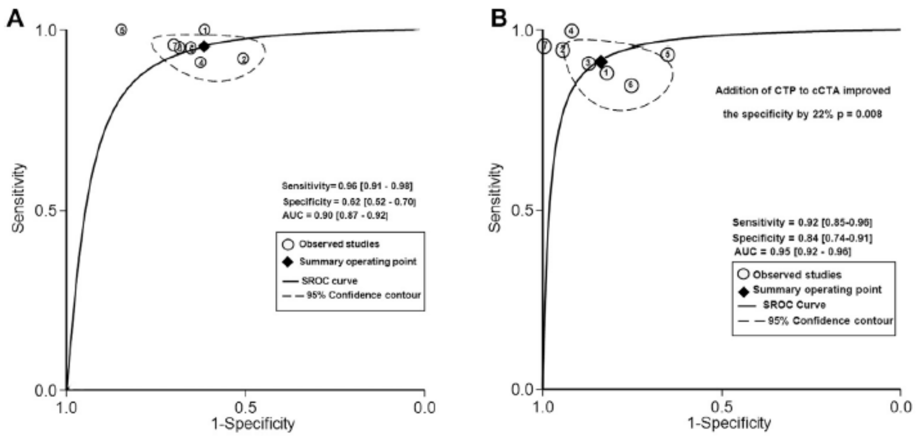
Meta-analyse perfusion statique 19 études

M.H. Sørgaard et al. / Journal of Cardiovascular Computed Tomography 10 (2016) 450–457



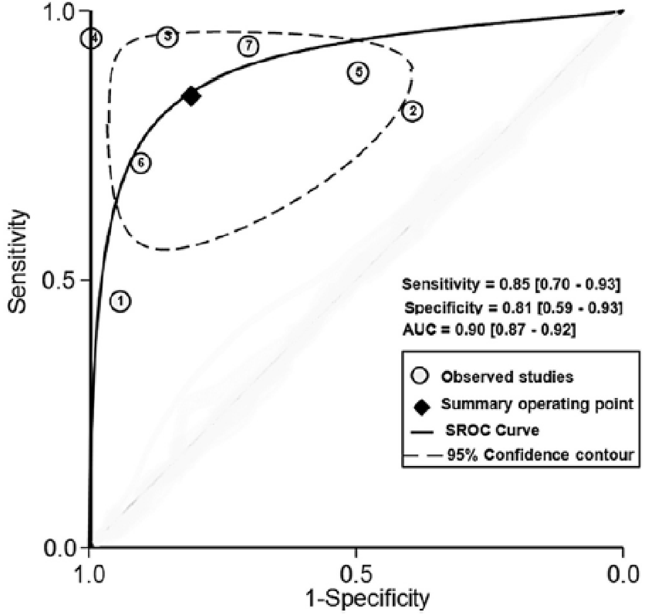


Fig. 2. SROC of the diagnostic accuracy per patient of CTP compared to MRP and SPECT. Summary receiver operating curve (SROC) of the diagnostic accuracy of per-patient data of seven studies comparing myocardial computed tomography perfusion (CTP) with myocardial single photon emission computed tomography (SPECT) or magnetic resonance perfusion (MRP). Contributing studies: 1.Bettencourt[14] 2. Rochitte,[8] 3.De Cecco,[12] 4.Feuchtner,[4] 5. George-2009,[5] 6. George-2012,[15] 7. Kim.[16] AUC = area under curve.

.H. Sørgaard et al. 454 / Journal of Cardiovascular Computed Tomography 10 (2016)

Meta-analyse perfusion statique 19 études

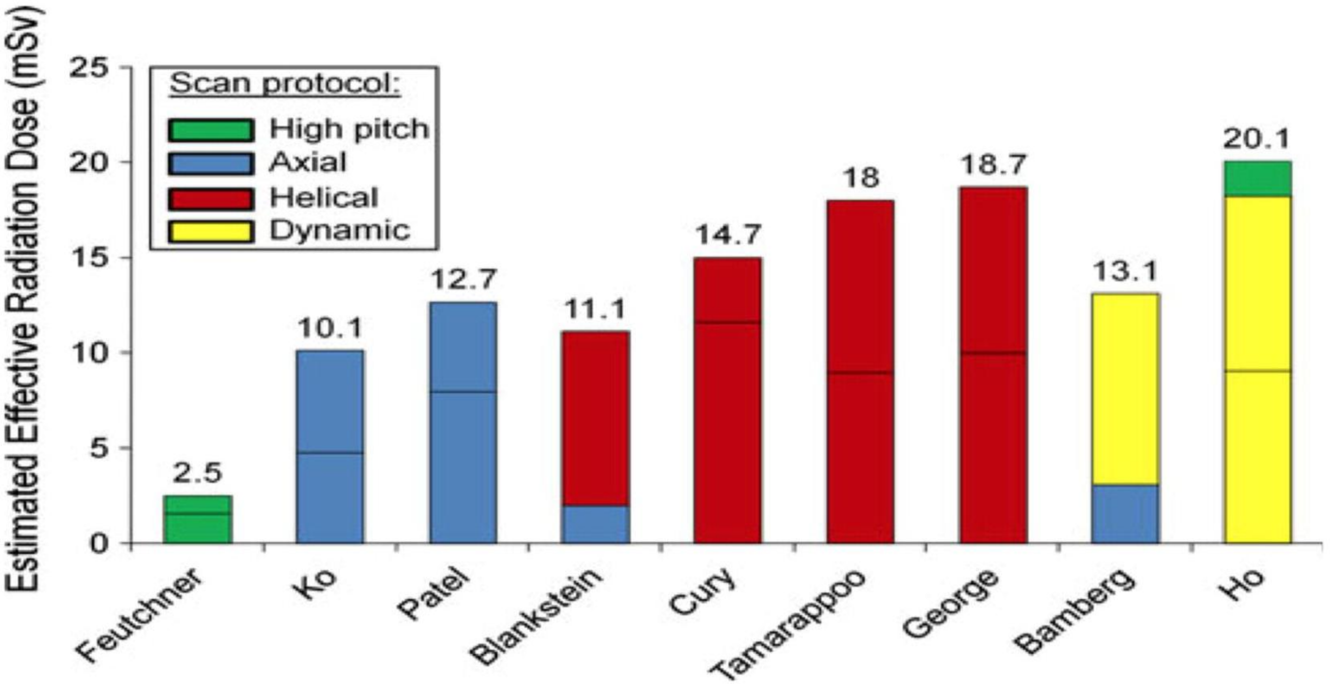
Table 2
Summary results of the main and sub-analyses, all values are with 95% confidence interval.

Type of analyses	Number of included studies and type of data	Number of analyzed patients or arterial territories	Sensitivity %	Specificity %	PPV[g]%	PNV[f]%	DOR	AUC[a]%	Prevalence of disease %
CTP[b] vs. SPECT[h]/MRP[e]	7 Per-patient	663	85(70–93)	81(59–93)	82(77–86)	84(80–88)	24(7–85)	90(87–92)	50
cCTA alone vs. ICA[d] or ICA[d] + SPECT[h]/MRP[e]/FFR[c]	7 Per-patient	701	96(91–98)	62(52–70)	69(65–73)	95(91–97)	35(14–85)	90(87–92)	47
cCTA + CTP[b] vs. ICA[d] or ICA[d] + SPECT[h]/MRP[e]/FFR[c]	7 Per-patient	706	92(85–96)	84(74–91)	89(85–92)	88(84–92)	59(20–173)	95(92–96)	58
cCTA alone vs. ICA[d] or ICA[d] + SPECT[h]/MRP[e]/FFR[c]	12 Per-artery	2740	92(88–94)	72(63–79)	58(56–61)	95(94–96)	27(15–48)	92(89–94)	30
cCTA + CTP[b] vs. ICA[d] or ICA[d] + SPECT[h]/MRP[e]/FFR[c]	12 Per-artery	2730	87(80–92)	90(85–93)	79(76–81)	94(93–95)	61(28–133)	95(92–96)	30
cCTA + CTP[b] vs. ICA[d]	4 Per-patient	546	91(82–95)	77(66–86)	87(82–90)	83(77–88)	33(11–90)	84(80–87)	63
cCTA + CTP[b] vs. ICA[d]	6 Per-artery	2064	90(77–96)	90(84–93)	85(83–88)	93(91–95)	80(26–252)	94(92–96)	40

[a] AUC = area under receiver operating characteristic curve.

.H. Sørgaard et al. 454 / Journal of Cardiovascular Computed Tomography 10 (2016)

Irradiation



Andrea L. Vavere, J Cardiovasc Comput Tomogr . 2011 ; 5(6)

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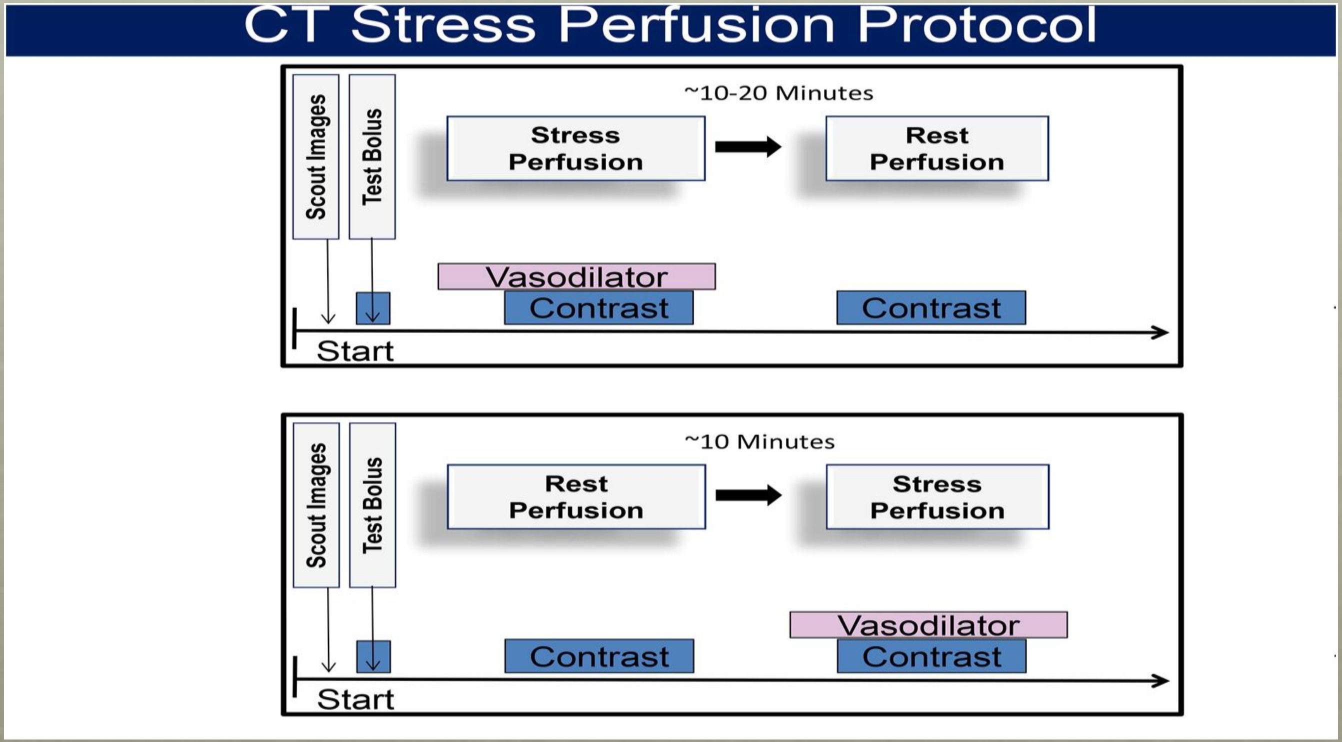
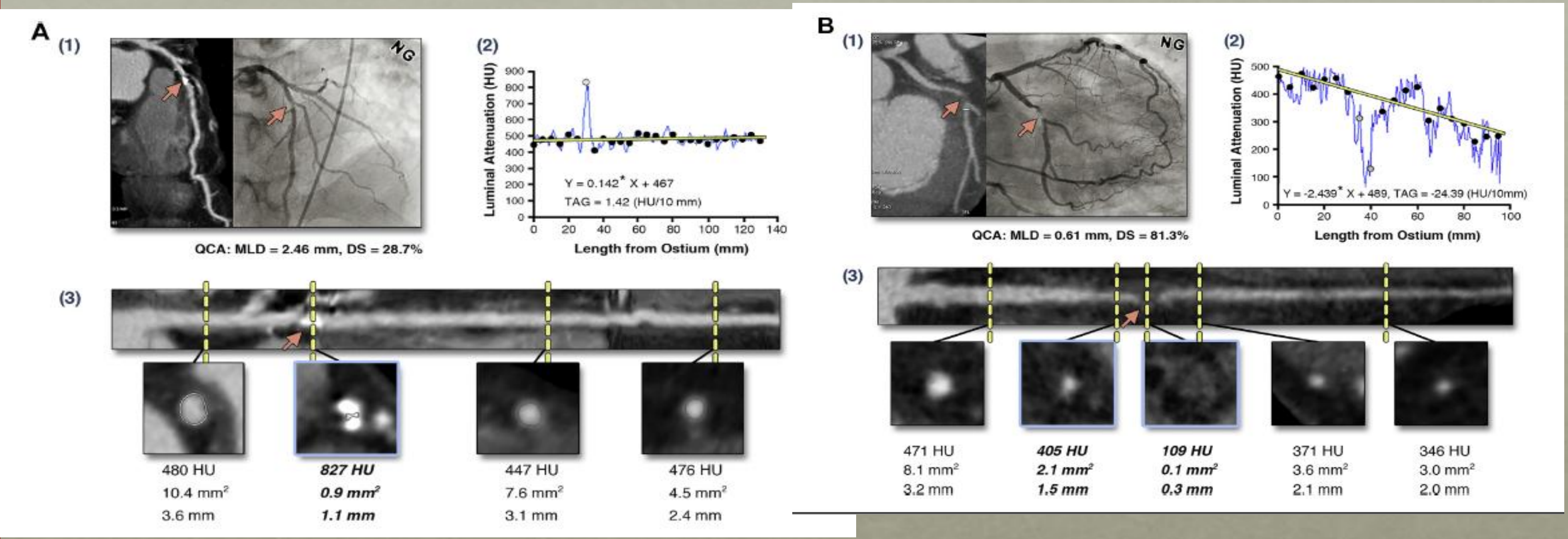


Andrea L. Vavere, J Cardiovasc Comput Tomogr . 2011 ; 5(6)

TAG Coronaire

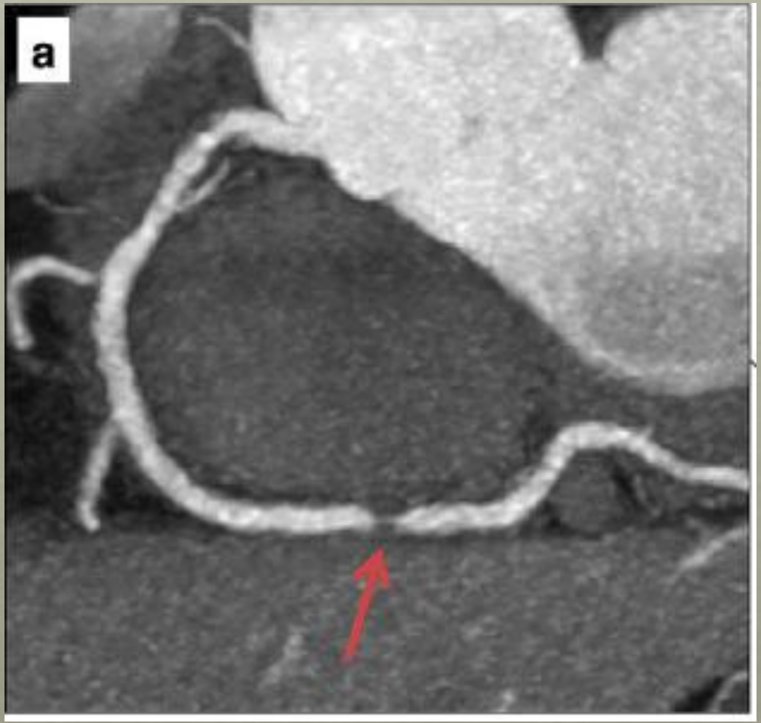


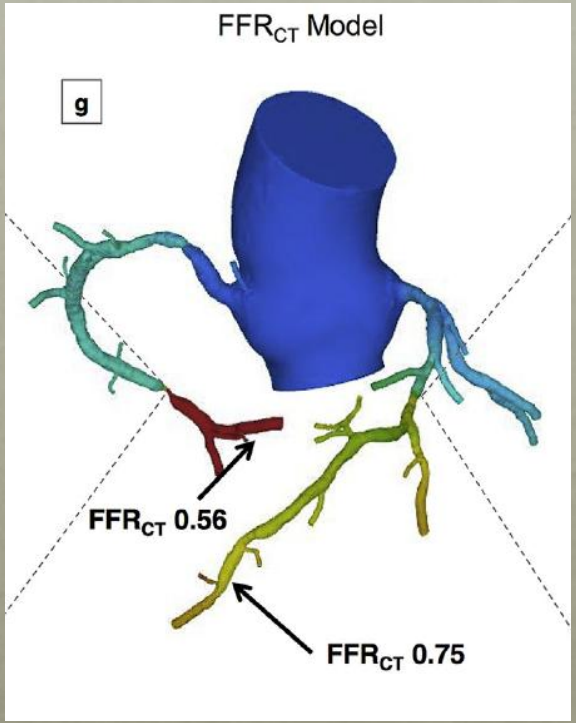
LE 2 **Studies Evaluating TAG for the Identification of Ischemic Lesions**

First Author (Ref. #)	CT Generation	No. of Vessels (n)	Calcified Lesions (%)	Reference	Improved Diagnostic Accuracy	Cutoffs and Components	Se	Sp	PPV	NPV	Signifi NR
Choi et al. (56)	64	370 (126)	27	CAG ≥50%	Yes	≤−1.80 HU/cm + DS ≥50%	84	94	96	75	Ye
Choi et al. (59)	64	97 (63)	32	FFR <0.80	Yes	≤−0.654 HU/mm + DS ≥50%	90	63	63	90	No
Yoon et al. (60)	64	82 (53)	29	FFR ≤0.80	NA	≤−0.654 HU/mm	38	88	67	69	NA
Wong et al. (55)	320	78 (54)	69	FFR ≤0.80	Yes	≤−15.1 HU/cm	77	74	67	83	Ye
Zheng et al. (58)	64	309 (107)	37	CAG ≥50%	Yes	≤−11.33 HU/cm + DS ≥50%	94	94	90	96	No
Wong et al. (79)	320	97 (75)	39	FFR ≤0.80	Yes	≤−15.1 HU/cm + DS ≥50%	73	97	92	87	Ye
Stuijfzand et al. (61)	256	225 (85)	34	FFR ≤0.80	No	≤−7.51 HU/cm	69	44	83	27	No
Hell et al. (80)	Dual-source	72 (59)	NA	FFR ≤0.80	No	≤−0.65 HU/mm	57	61	28	31	NA
Wang et al. (81)	Dual-source	32 (32)	NA	FFR <0.80	No	≤−1.51 HU/mm	37	58	23	73	NA

= coronary angiography; DS = diameter stenosis; FFR = fractional flow reserve; HU = Hounsfield units; NA = not available; NPV = negative predictive value; NRI = net reclassification improve
= positive predictive value; Se = sensitivity; Sp = specificity; TAG = transluminal attenuation gradient.

FFR CT





FFR CT

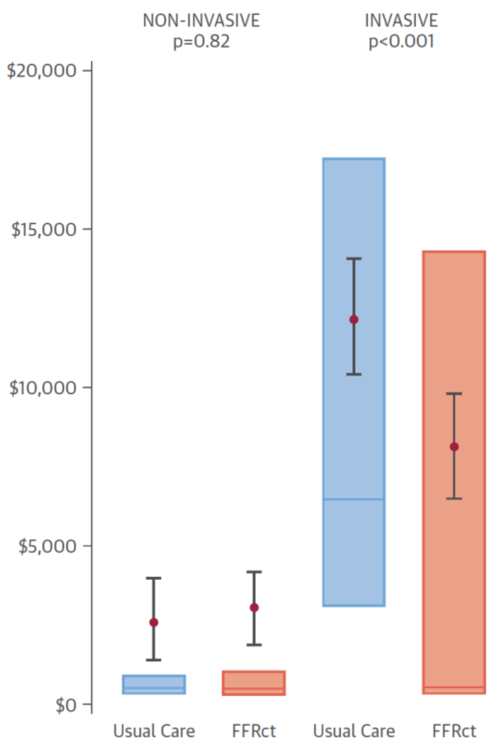
TABLE 3 Trials Comparing FFR-$_{CT}$ (HeartFlow) and Invasive FFR

	DISCOVER-FLOW (67)	DeFACTO (68)	NXT (69)
Publication year	2011	2012	2014
Patients profile, n	Stable CAD, 103	Stable CAD, 252	Stable CAD, 254
Coronary CTA ≥50%–AUC	0.61	0.64	0.53
Coronary CTA ≥50%			
Specificity	25%	42%	34%
Sensitivity	94%	84%	94%
PPV	58%	61%	40%
NPV	80%	72%	92%
FFR_{CT} ≤0.80			
AUC	0.87	0.73	0.81
Specificity	82%	54%	79%
Sensitivity	93%	90%	86%
PPV	85%	67%	65%
NPV	91%	84%	93%
Prevalence of FFR ≤0.80	56%	54%	42%
% patients excluded due to nonevaluable scans	NA	12%	13%
CT generation	≥64 detector row	≥64 detector row	≥64 detector row
Primary CT reading	Core laboratory	Core laboratory	Local investigator
Software version	NA	1.2	1.4

AUC, specificity, sensitivity, PPV, and NPV are for per-patient analysis.

AUC = area under the curve; CT = computed tomography; CTA = computed tomographic angiography; DeFACTO = Determination of Fractional Flow Reserve by Anatomic Computed Tomographic Angiography; DISCOVER-FLOW = Diagnosis of Ischemia-Causing Stenoses Obtained Via Noninvasive Fractional Flow Reserve; FFR = fractional flow reserve; NPV = negative predictive value; NXT = Analysis of Coronary Blood Flow Using CT Angiography: Next Steps; PPV = positive predictive value.

FIGURE 2 1-Year Costs by Stratum and Evaluation Strategy

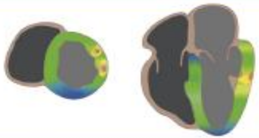


J A C C : C A R D I O V A S C U L A R IMA G I N G , V O L . 8 , NO. 1 1 , 2 0 1 5

J Am Coll Cardiol 2016;68:435–45

CENTRAL ILLUSTRATION **Functional Evaluation by Cardiac CT**

MYOCARDIAL PERFUSION IMAGING



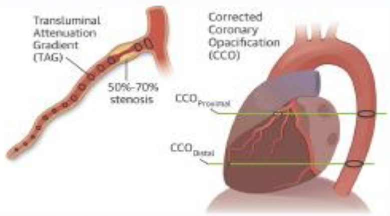
Main Features:

- Static Stress MPI: single high-resolution CT angiogram during pharmacological vasodilation for semi-quantitative analyses
- Dynamic Stress MPI: sequence of low-resolution datasets to calculate the absolute myocardial blood flow from time-attenuation curves

Current Limitations:

- Additional contrast medium, pharmacological stress and radiation
- Beam hardening artifacts
- Dynamic MPI requires wide detector coverage and shuttle mode acquisition
- Limited experience and validation, and requires more radiation

CORONARY ATTENUATION PATTERNS



Main Features:

- TAG: linear regression coefficient between luminal contrast attenuation (HU) and length from the ostium
- CCO: contrast opacification corrected for the descending aorta in the same axial plane

Current Limitations:

- Lack of standardized cut-off values for functional significance
- Limited data and some conflicting results

CTA DERIVED FRACTIONAL FLOW RESERVE

Main Features:

- Computed using computational fluid dynamics from regular CT angiograms without protocol modification or additional medication
- Improved diagnostic accuracy vs CTA alone, mainly due to higher specificity

Current Limitations:

- Remote evaluation
- Dependence on high image quality

ATHEROSCLEROTIC PLAQUE CHARACTERISTICS

Main Features:

- Lesion length, low attenuation plaque, positive remodeling, and aggregate plaque volume associated with ischemia by invasive FFR

Current Limitations:

- Dependence on high image quality
- Spatial resolution
- Low attenuation plaque cut-off influenced by several factors

de Araújo Gonçalves, P. et al. J Am Coll Cardiol Img. 2015; 8(11):1322-35.

This illustration depicts the main features and current limitations of 4 different lines developed in the search for functional information with cardiac CT. CCO = corrected coronary opacification; CT = computed tomography; FFR = fractional flow reserve; MPI = myocardial perfusion imaging; TAG = transluminal attenuation gradients.

ACCF/ACR/SCCT/SCMR/ASNC/NASCI/SCAI/SIR 2006 Appropriateness Criteria for Cardiac Computed Tomography and Cardiac Magnetic Resonance Imaging*

A Report of the American College of Cardiology Foundation Quality Strategic Directions Committee Appropriateness Criteria Working Group, American College of Radiology, Society of Cardiovascular Computed Tomography, Society for Cardiovascular Magnetic Resonance, American Society of Nuclear Cardiology, North American Society for Cardiac

Journal of the American College of Cardiology
Published by Elsevier Inc.
Vol. 48, No. 7, 2006
ISSN 0735-1097/06/$32.00
doi:10.1016/j.jacc.2006.07.003

Expert Consensus Document

ACCF/ACR/AHA/NASCI/SAIP/SCAI/SCCT 2010 Expert Consensus Document on Coronary Computed Tomographic Angiography

A Report of the American College of Cardiology Foundation Task Force on Expert Consensus Documents

Circulation. 2010;121:2509-2543

Table 8. Structure and Function

Indication		Appropriateness Criteria (Median Score)
Morphology (Use of CT Angiogram)		
28.	• Assessment of complex congenital heart disease including anomalies of coronary circulation, great vessels, and cardiac chambers and valves	A (7)
29.	• Evaluation of coronary arteries in patients with new onset heart failure to assess etiology	A (7)
Evaluation of Ventricular and Valvular Function (Use of CT Angiogram)		
30.	• Evaluation of LV function following myocardial infarction OR in heart failure patients	I (3)
31.	• Evaluation of LV function following myocardial infarction OR in heart failure patients • Patients with technically limited images from echocardiogram	U (5)
32.	• Characterization of native and prosthetic cardiac valves • Patients with technically limited images from echocardiogram, MRI, or TEE	U (5)
Evaluation of Intra- and Extra-Cardiac Structures (Use of Cardiac CT)		
33.	• Evaluation of cardiac mass (suspected tumor or thrombus) • Patients with technically limited images from echocardiogram, MRI, or TEE	A (8)
34.	• Evaluation of pericardial conditions (pericardial mass, constrictive pericarditis, or complications of cardiac surgery) • Patients with technically limited images from echocardiogram, MRI, or TEE	A (8)
35.	• Evaluation of pulmonary vein anatomy prior to invasive radiofrequency ablation for atrial fibrillation	A (8)
36.	• Noninvasive coronary vein mapping prior to placement of biventricular pacemaker	A (8)
37.	• Noninvasive coronary arterial mapping, including internal mammary artery prior to repeat cardiac surgical revascularization	A (8)
Evaluation of Aortic and Pulmonary Disease (Use of CT Angiogram*)		
38.	• Evaluation of suspected aortic dissection or thoracic aortic aneurysm	A (9)
39.	• Evaluation of suspected pulmonary embolism	A (9)

*Non-gated, CT angiogram which has a sufficiently large field of view for these specific indications.

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ESC GUIDELINES

2013 ESC guidelines on the management of stable coronary artery disease

Table 16 **Use of coronary computed tomography angiography for the diagnosis of stable coronary artery disease**

Recommendations	Class [a]	Level [b]
Coronary CTA should be considered as an alternative to stress imaging techniques for ruling out SCAD in patients within the lower range of intermediate PTP for SCAD in whom good image quality can be expected.	IIa	C
Coronary CTA should be considered in patients within the lower range of intermediate PTP for SCAD after a non conclusive exercise ECG or stress imaging test or who have contraindications to stress testing in order to avoid otherwise necessary invasive coronary angiography if fully diagnostic image quality of coronary CTA can be expected.	IIa	C
Coronary calcium detection by CT is not recommended to identify individuals with coronary artery stenosis.	III	C
Coronary CTA is not recommended in patients with prior coronary revascularization.	III	C
Coronary CTA is not recommended as a 'screening' test in asymptomatic individuals without clinical suspicion of coronary artery disease.	III	C

CTA = computed tomography angiography; ECG = electrocardiogram; PTP = pre-test probability; SCAD = stable coronary artery disease.
[a] Class of recommendation.
[b] Level of evidence.

Conclusion

- Méthode validée des mesures de fonction ventriculaire
  - Valeurs sous estimées
  - Peu utilisé en pratique
- Intérêt croissant dans l'étude de la perfusion myocardique
  - 1 ou 2 acquisitions (temps tardif)
  - Sur-irradiation
  - Alternative à l'IRM cardiaque
- Tout en 1
  - Fonctionnel lésion coronaire
  - Fonctionnel perfusion myocardique