Tomo-ventriculographie isotopique en routine clinique

Ventriculographie isotopique ☺ et ☹

Tomo-ventriculographie isotopique

Segmentation et analyse globale

Modélisation de CTA et analyse locale

Validation clinique

Denis MARIANO-GOULART Service de médecine nucléaire. CHRU Lapeyronie. Montpellier

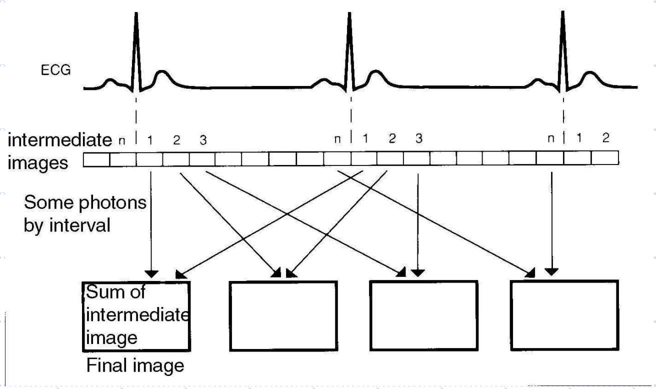
Université Montpellier I

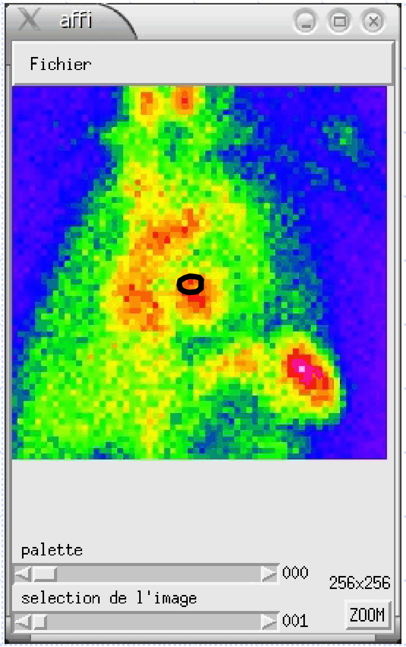
Faculté de Médecine Montpellier - Nîmes

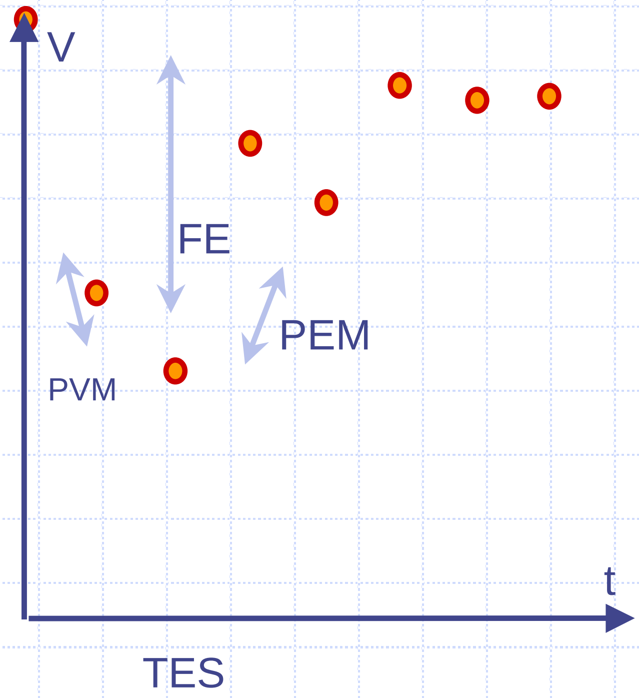
CHRU Montpellier Centre Hospitalier Régional Universitaire

Ventriculographie isotopique

- Marquage des GR au ^{99m}Tc : Contraste
- Synchronisation ECG



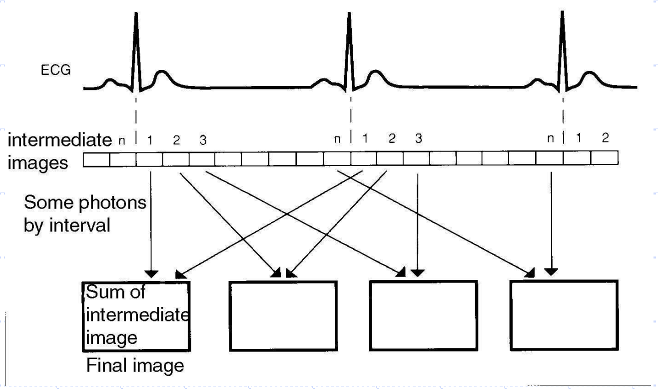


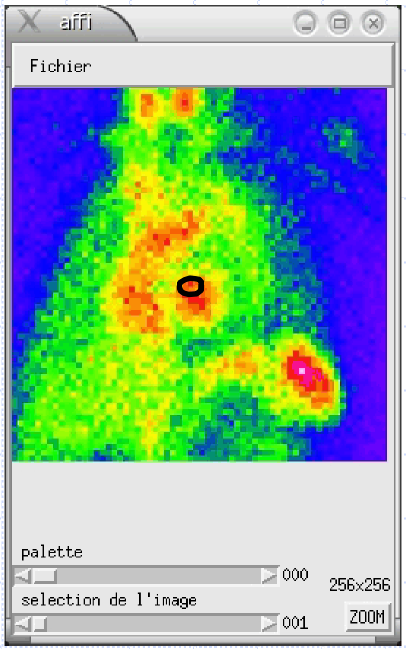


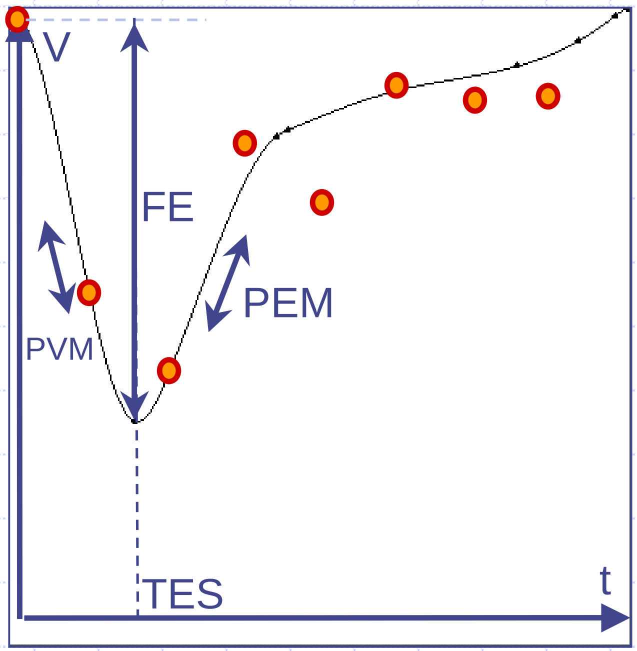
- Analyse de CTA
  - Activité $\propto$ Volume
  - Globale ou locale

Ventriculographie isotopique

- Marquage des GR au ^{99m}Tc : Contraste
- Synchronisation ECG

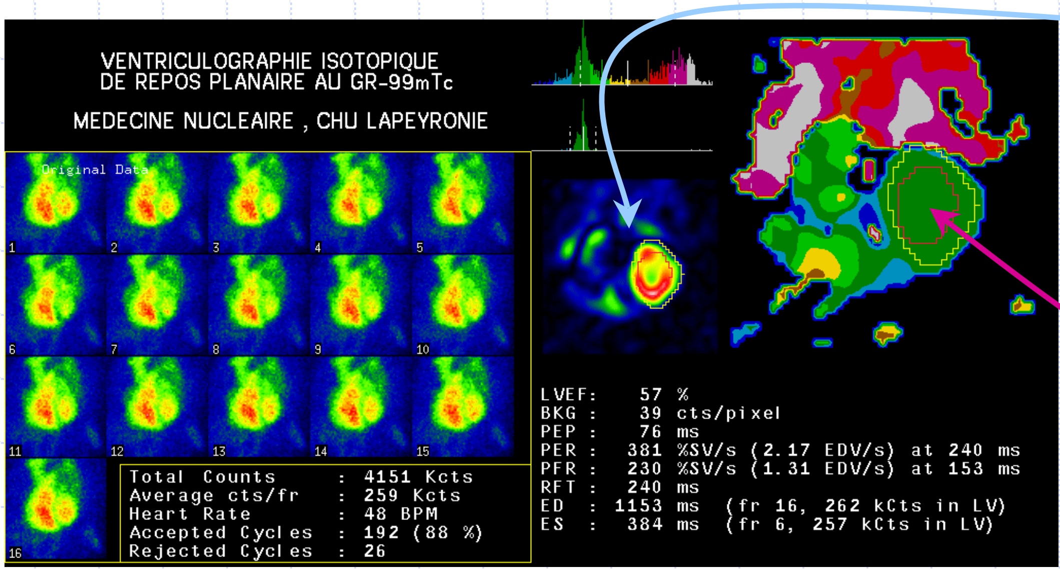


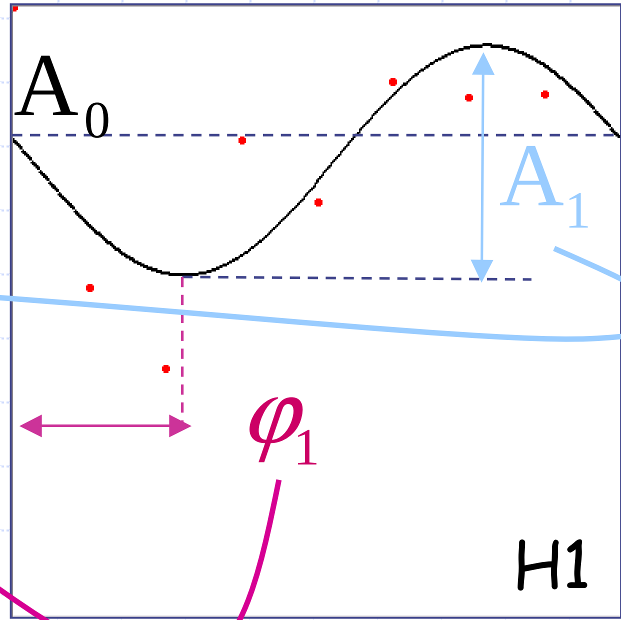




- Analyse de CTA
  - Activité $\propto$ Volume
  - Globale ou locale

1° harmonique





$$\frac{1}{N}\hat{s}(k)$$

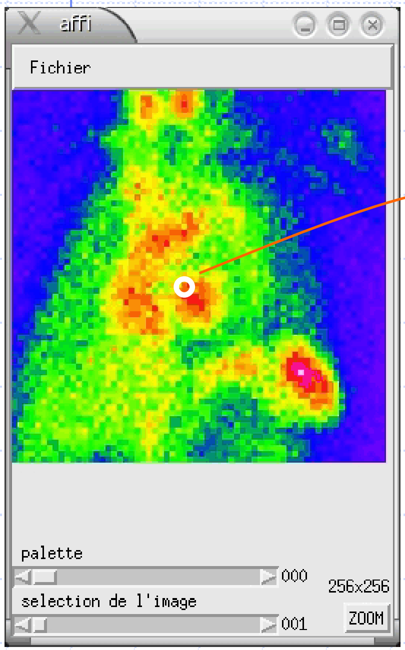
$$s(t) = \sum_{k=0}^{N} A_k . e^{j.(k\omega_0 t+\varphi_k)} = \sum_{k=0}^{N} A_k . e^{j.\varphi_k} . e^{j.k\omega_0 t}$$

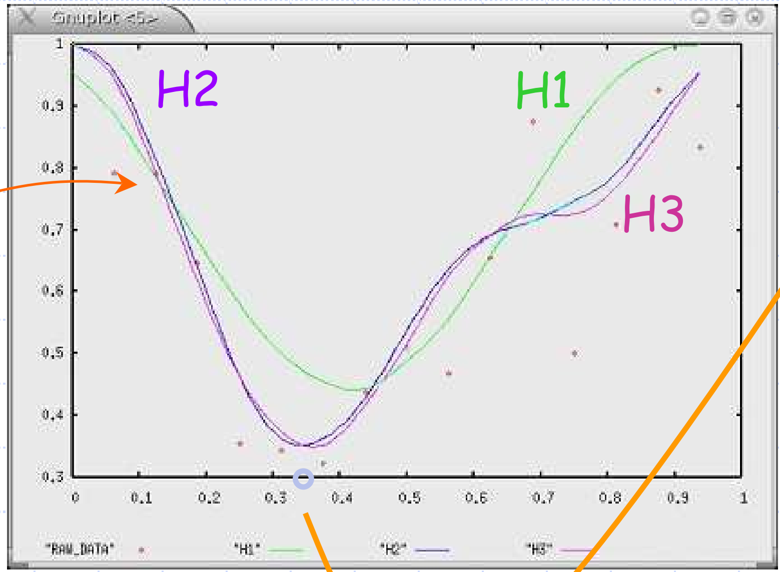
$$s(t) \approx \frac{\hat{s}(0)}{N} + \frac{\hat{s}(1)}{N} e^{j.(\omega_0)t} = A_0 + A_1 e^{j.(\omega_0 t+\varphi_1)}$$

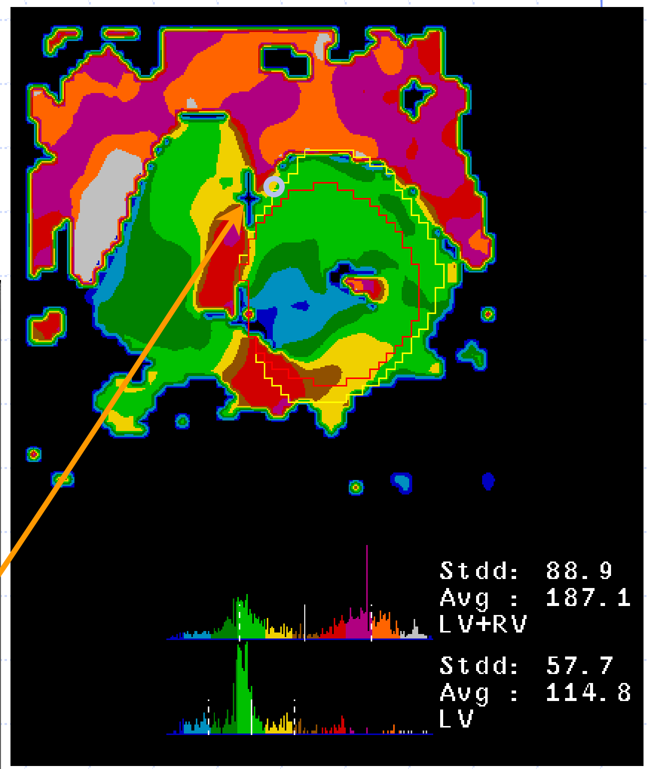
Analyse multi-harmonique

Rythmologie :

- Analyse locales et mesure de σ_{TES}
- Pb : Superposition ⇒ OAG, OAD, PG
- Pb : bruit ⇒ ↑ stat, H3 et filtrages…



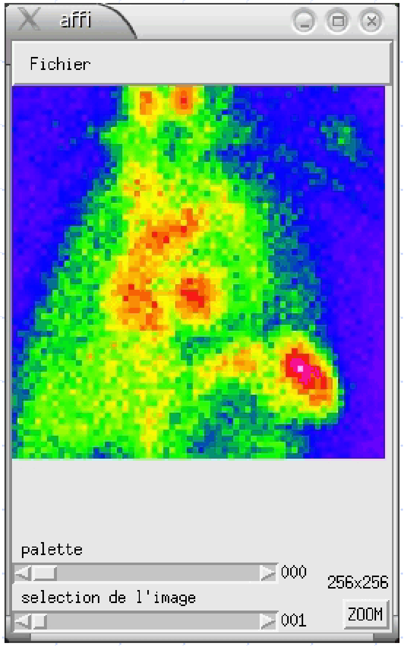




(Le Guludec, *JACC* 95)

Ventriculographie isotopique planaire

- Etalon or pour le suivi de FEVG
  - Simple
  - Automatique : H1 en OAG
  - Variabilité inter-op. = 2-3%
  - Analyse sectorielle possible
- FEVD
  - Exacte au premier passage (seulement)
  - Acquisition délicate (ESV, bolus)

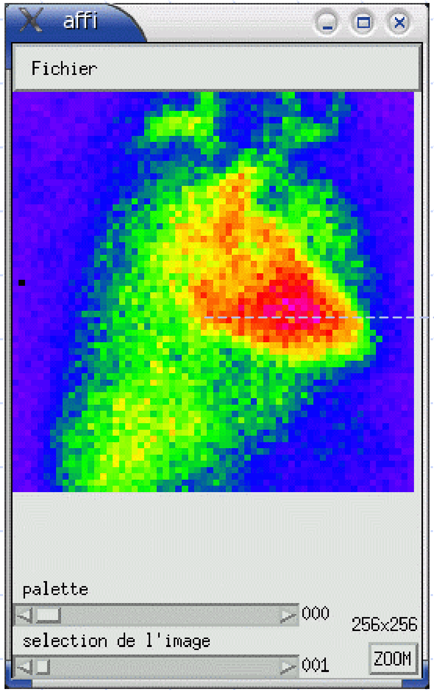


Pb1 : Superposition des plans

Acquisition de projection :

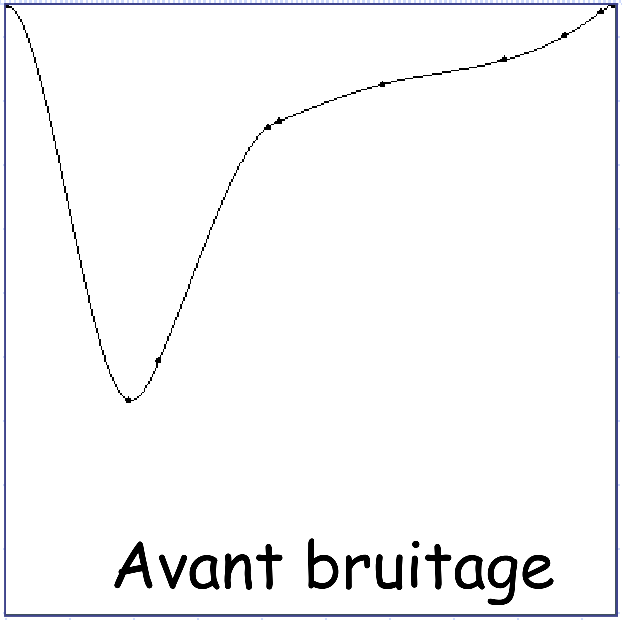
- FEVD planaire au 1° passage
- FEVG planaire sous estimée
- Volumes ?
- Débits ?

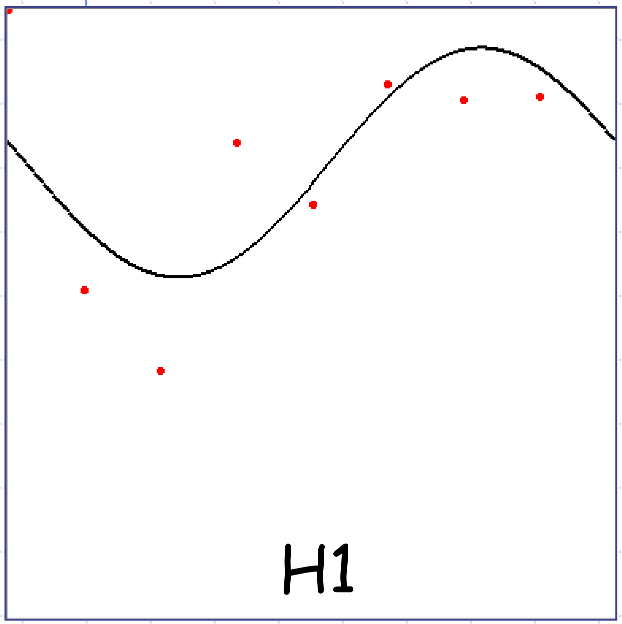
Mode tomographique:
QBS, BP-SPECT, QBE, TOMPOOL…

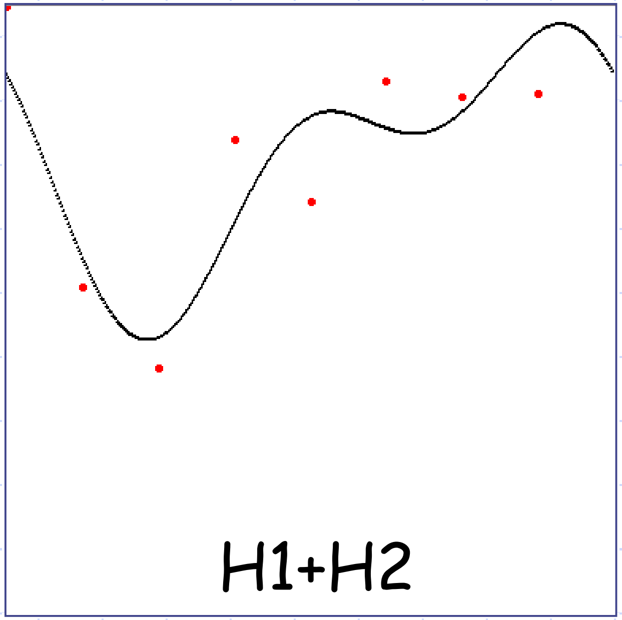


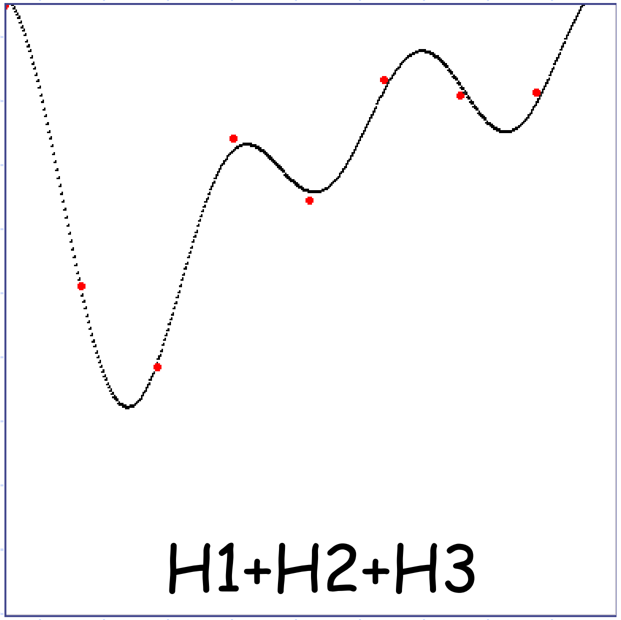
Pb2: Fits multi-H bruités

$$s(t) = \frac{1}{N}\sum_{k=0}^{N-1} \hat{s}(k).e^{j.(k\omega_0)t}$$





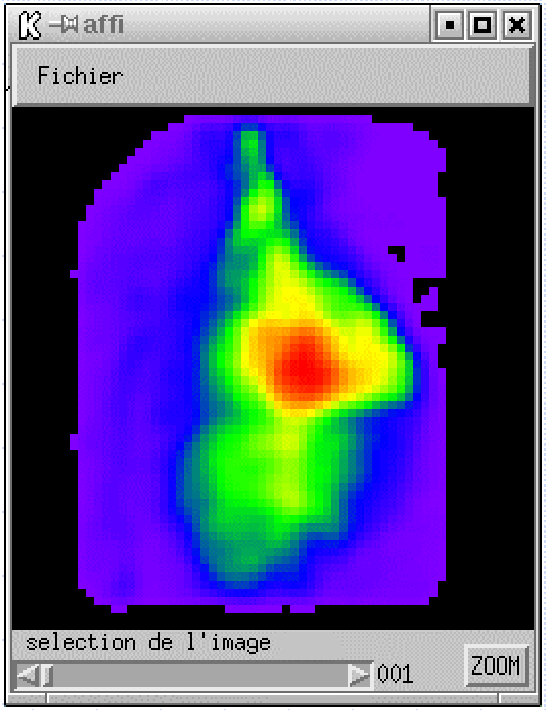


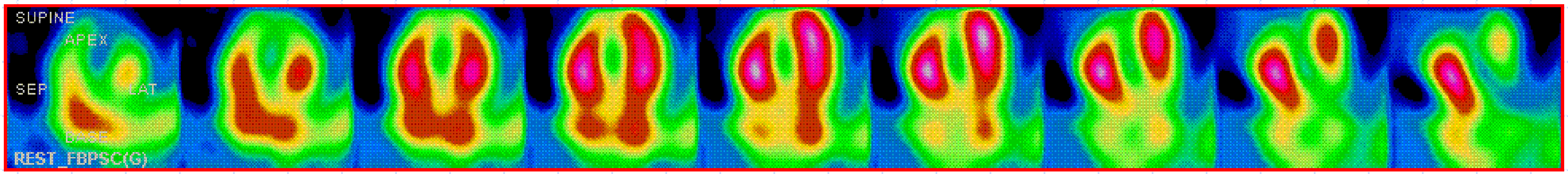


Améliorations possibles

- Tomoventriculographie isotopique
  - Mesures non sous-estimées de FEVG
  - Mesures de FEVD à l'équilibre
  - Mesures des volumes ventriculaires D et G
  - Mesures des débits cardiaques D et G
  - Dépolarisation intraventriculaire
- Optimisation du fit de la CTA

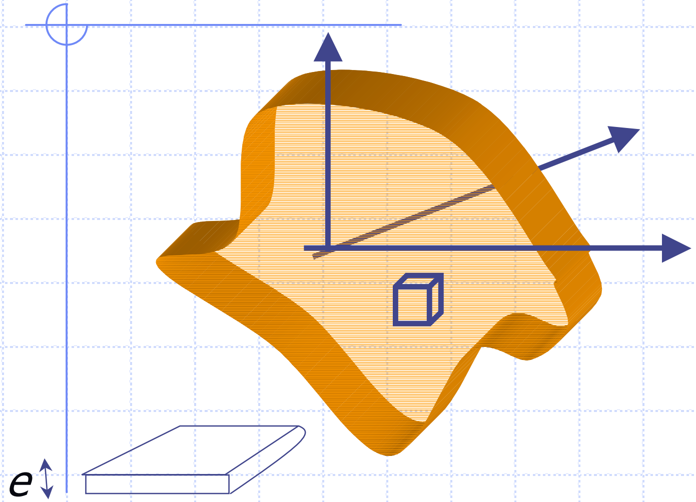
TOMO-VENTRICULOGRAPHIE

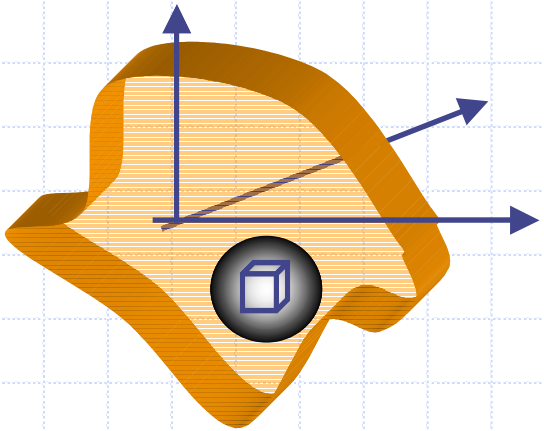




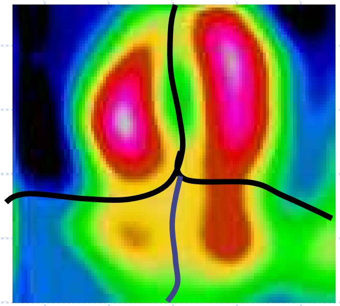
(Bergmann, Nichols, Franken, Mariano-Goulart)

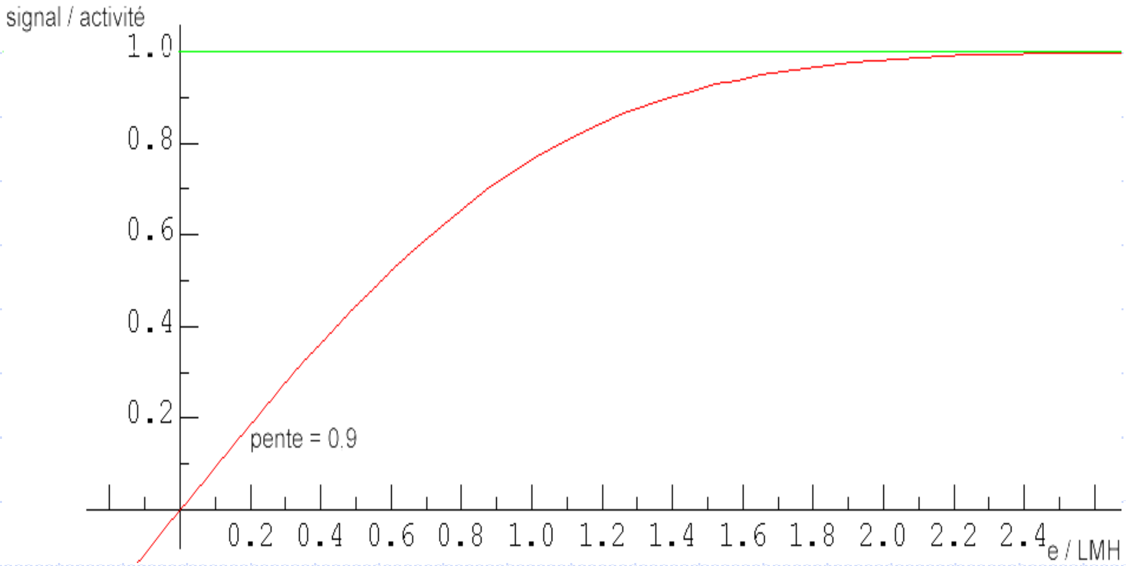
« Effet de volume partiel »





$$S = \frac{2\sqrt{\frac{\ln 2}{\pi}}}{LMH} \int_{-e/2}^{e/2} e^{-\frac{4.\ln 2}{LMH^2} z^2} dz$$





JR Galt et al. «Effects of myocardial wall thichness on SPECT quantification». IEEE TMI 1990;9

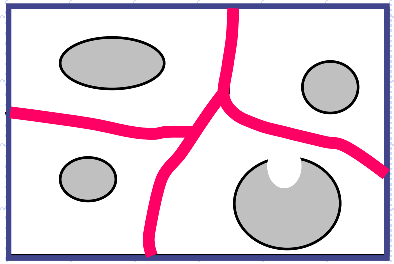
Squelette

Soit $X = \bigcup X_i$ une réunion de régions compactes disjointes.

On définit la zone d'influence de X_i :

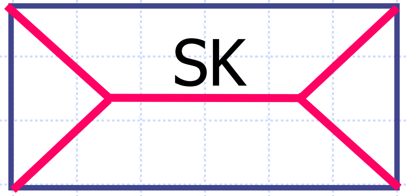
$$IZ(X_i) = \{ x, d(x, X_i) < d(x, X \setminus X_i) \}$$

SKIZ



le squelette par zones d'influences de X :

$$SKIZ(X) = X \setminus \bigcup_i IZ(X_i)$$



et le squelette de X :

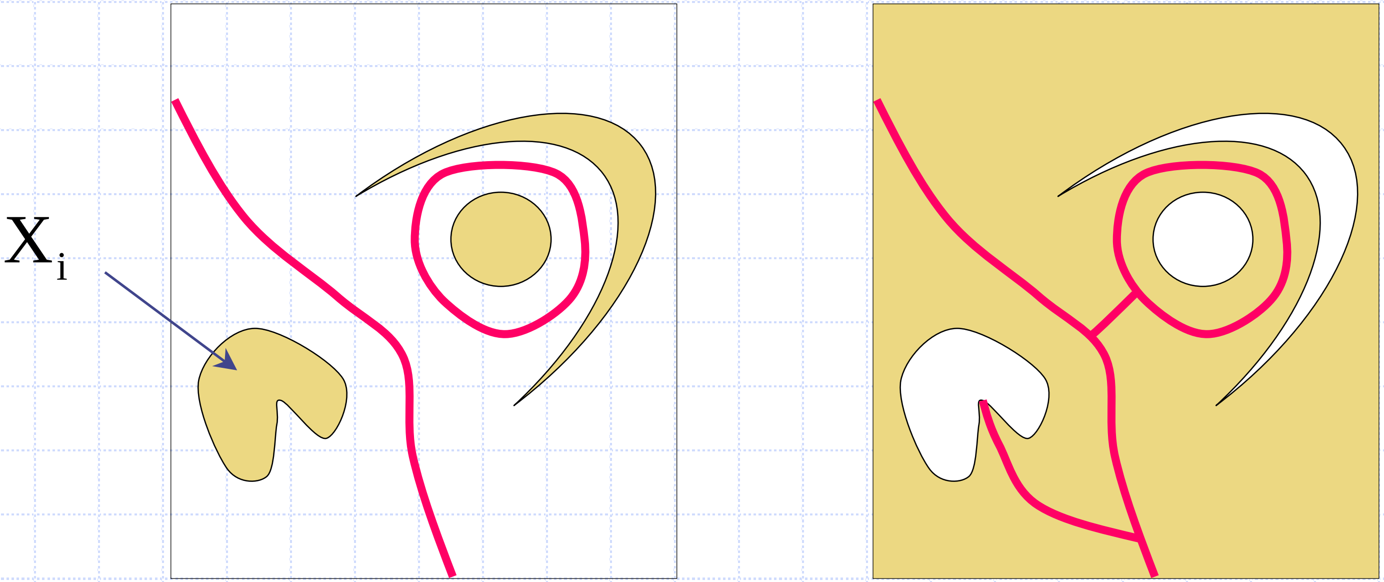
$$SK(X) = \{ x \in X, \exists (p,p') \in \partial X^2, p \neq p' / d(x, \partial X) = d(s,p) = d(s,p') \}$$

J. Serra. Image Analysis & Mathematical Morphology. Academic Press. Vol 1(1982) et 2 (1988).
M. Schmidt & J. Mattioli. « Morphologie Mathématique ». 1994. Masson.

Squelette : propriété

$$SK(X) = \left\{ x \in X, \exists (p,p') \in \partial X^2, p \neq p' / d(x,\partial X) = d(s,p) = d(s,p') \right\}$$

$$SKIZ(X) = X \setminus \bigcup_i \left\{ x, d(x, X_i) < d(x, X \setminus X_i) \right\}$$



$SKIZ(X) \subset SK(X^C)$

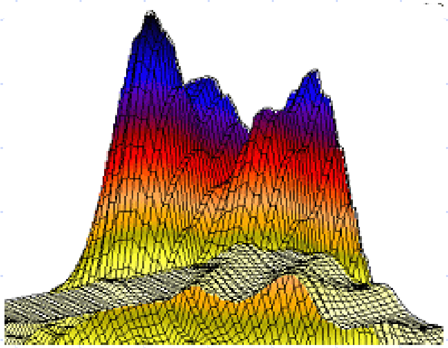
Ligne de partage des eaux

Soit f de classe C^1 / f(m)= 0 si m est un minimum local.
On définit :

$$LPE(f)=\{x,\exists(m,m')\text{minima locaux}/\mathrm{d_f}(x,m)=\mathrm{d_f}(x,m')\}$$

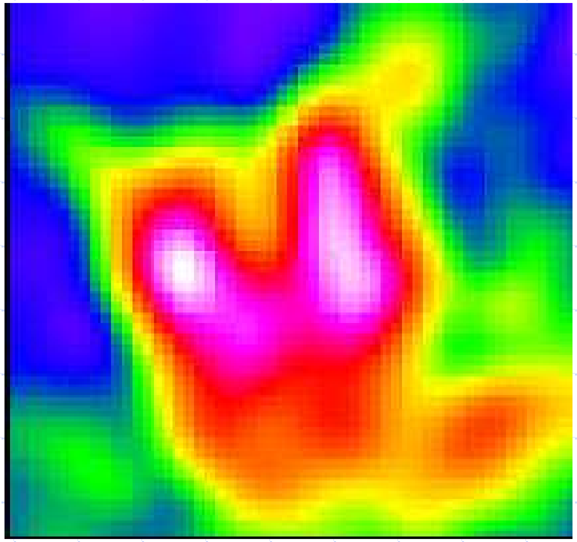
où :

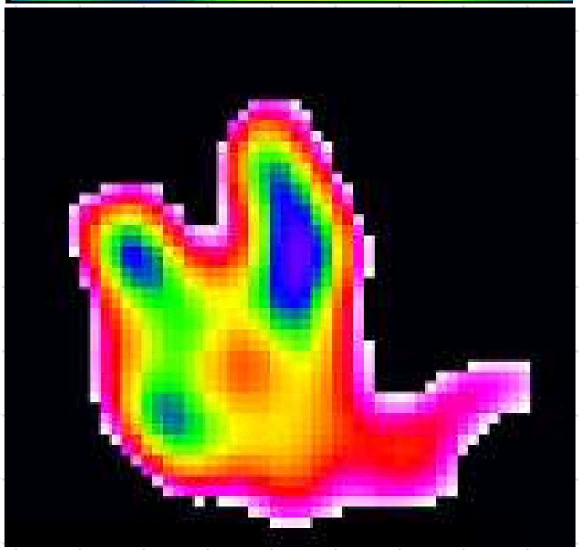
$$\mathrm{d_f}(a,b)=\inf_{\gamma_{a,b}}\int_a^b\left\|\nabla f\left(\gamma_{a,b}(s)\right)\right\|ds$$

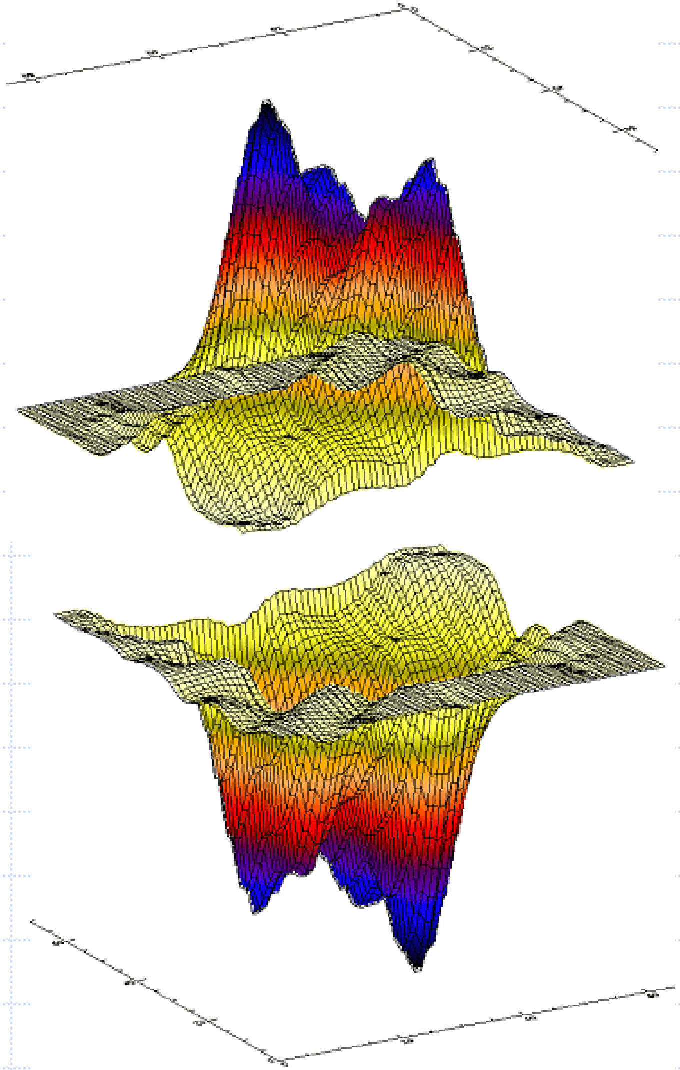


Propriété : la LPE est un SKIZ(U{m_i}) pour d_f

Intérêt en segmentation



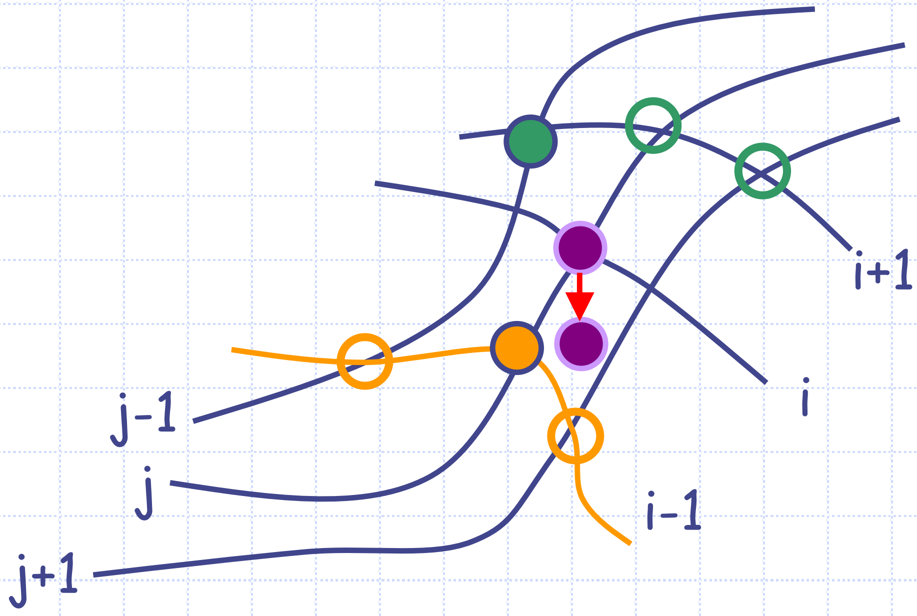




LPE par amincissement homotopique

$$\text{si} \quad f_{max} < f(i,j) \leq f_{min} \quad \text{alors} \quad f(i,j) = f_{max}$$

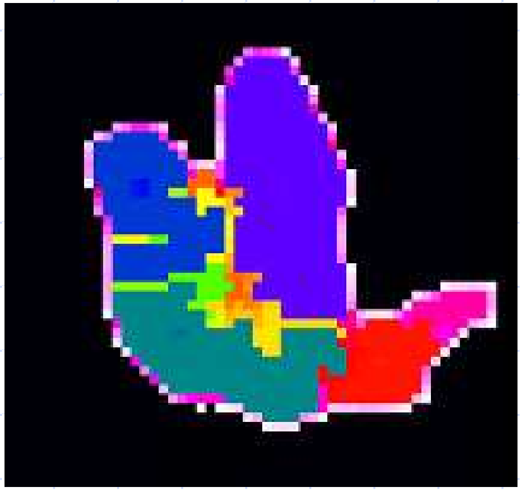
$$L = \begin{bmatrix} 1 & 0 & -1 \\ 1 & 0 & -1 \\ 1 & 0 & -1 \end{bmatrix}$$



Mariano-Goulart et al.EJNM 1998; 22:1300-07 et Revue Acomen 2000;6:69-77

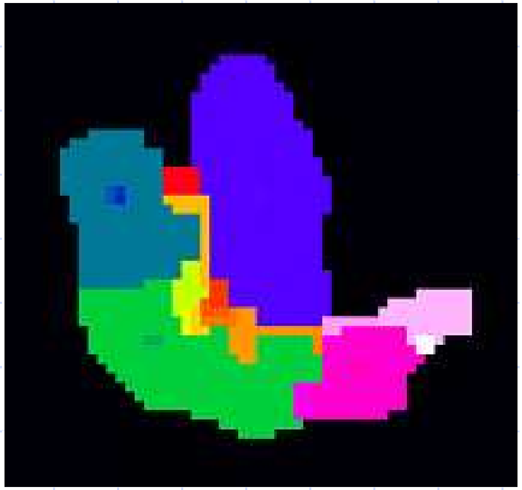
Ebarbulage par amincissement

$$Sq = (f \circ L_i)^{\infty}$$



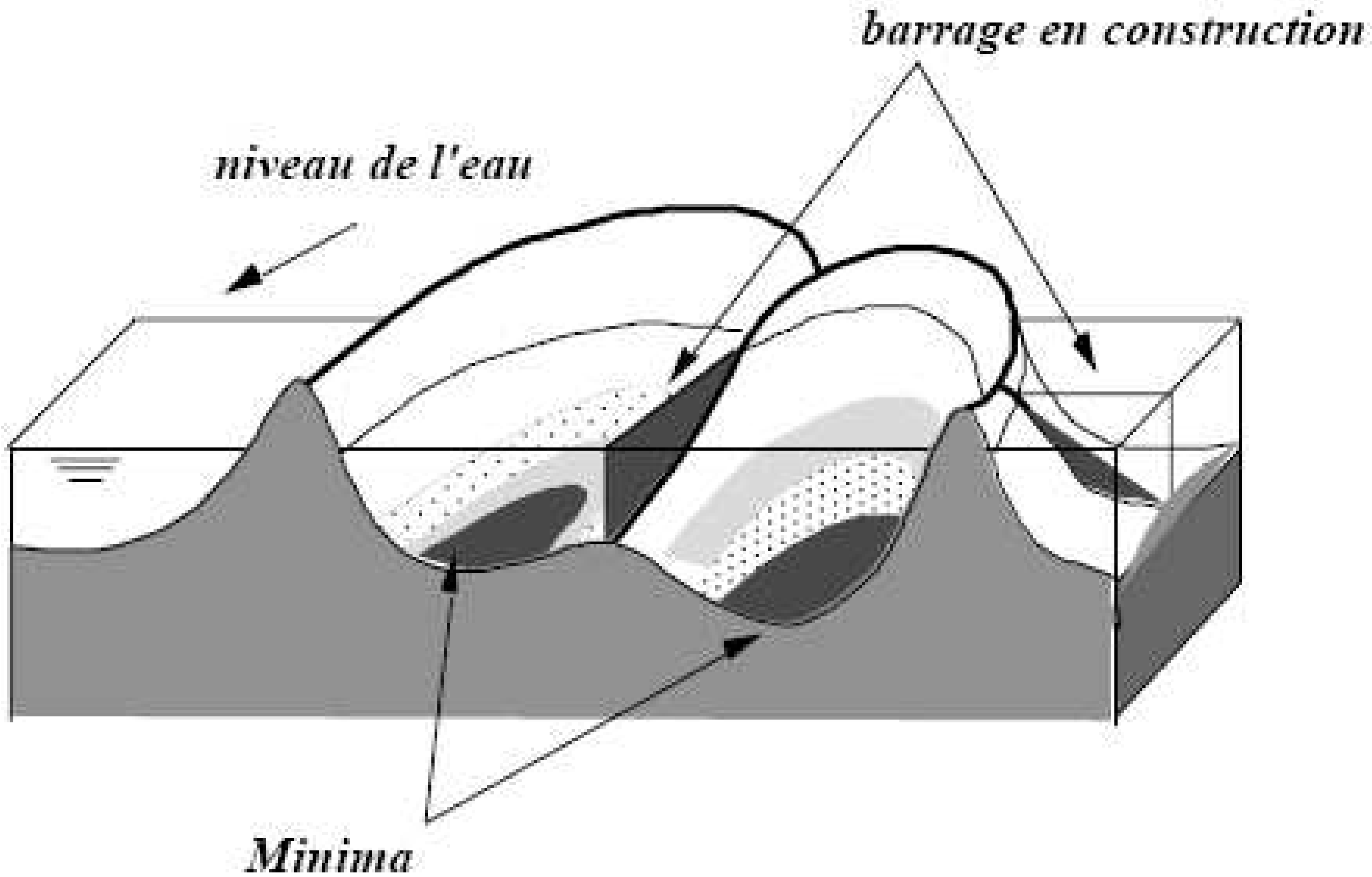
Ebarbulage : 2° amincissement par:

$$L' = \begin{bmatrix} 0 & 1 & 0 \\ 1 & -1 & 1 \\ 0 & 0 & 0 \end{bmatrix}$$



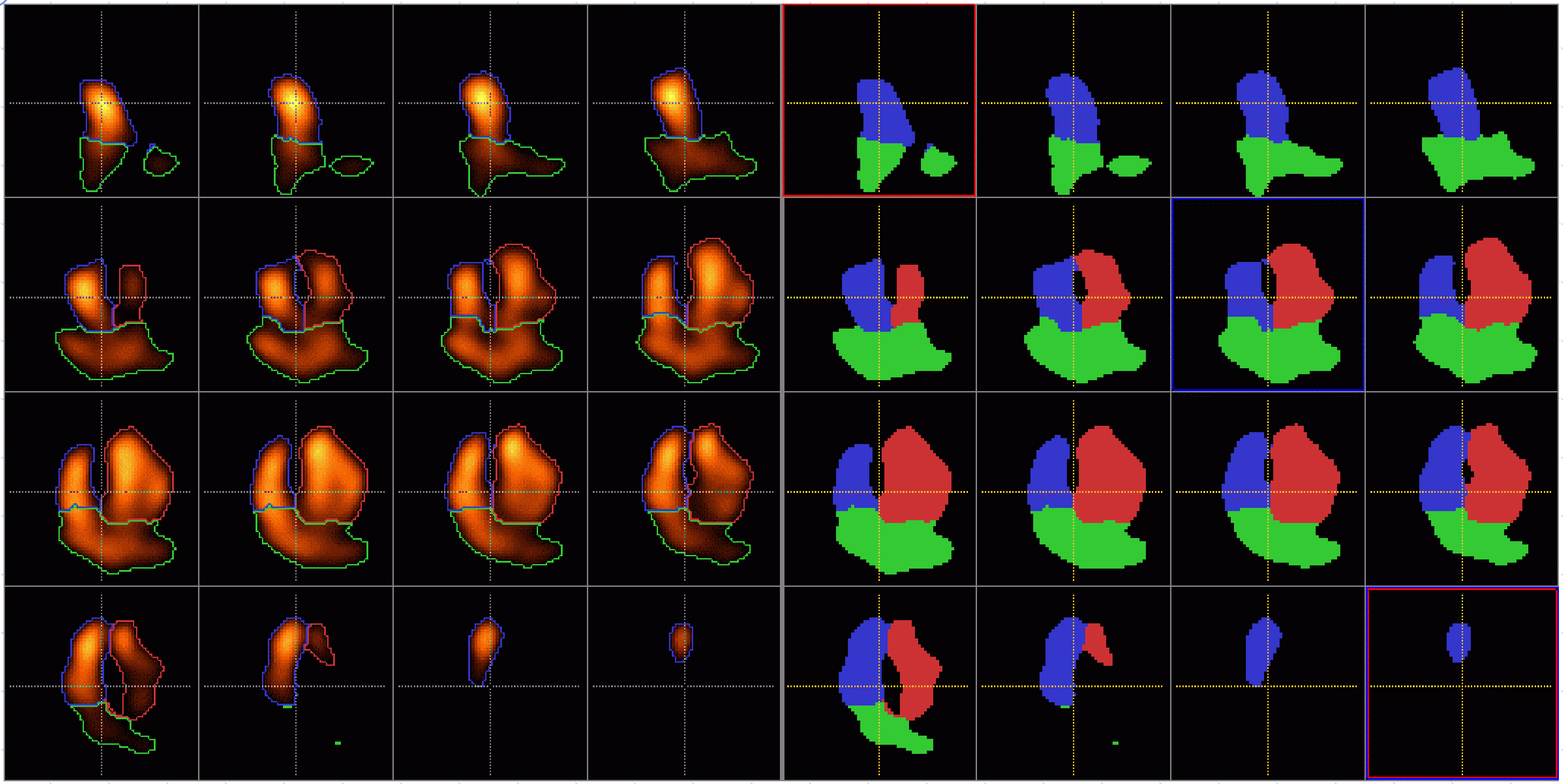
Mariano-Goulart et al.EJNM 1998; 22:1300-07 et Revue Acomen 2000;6:69-77

LPE par immersion



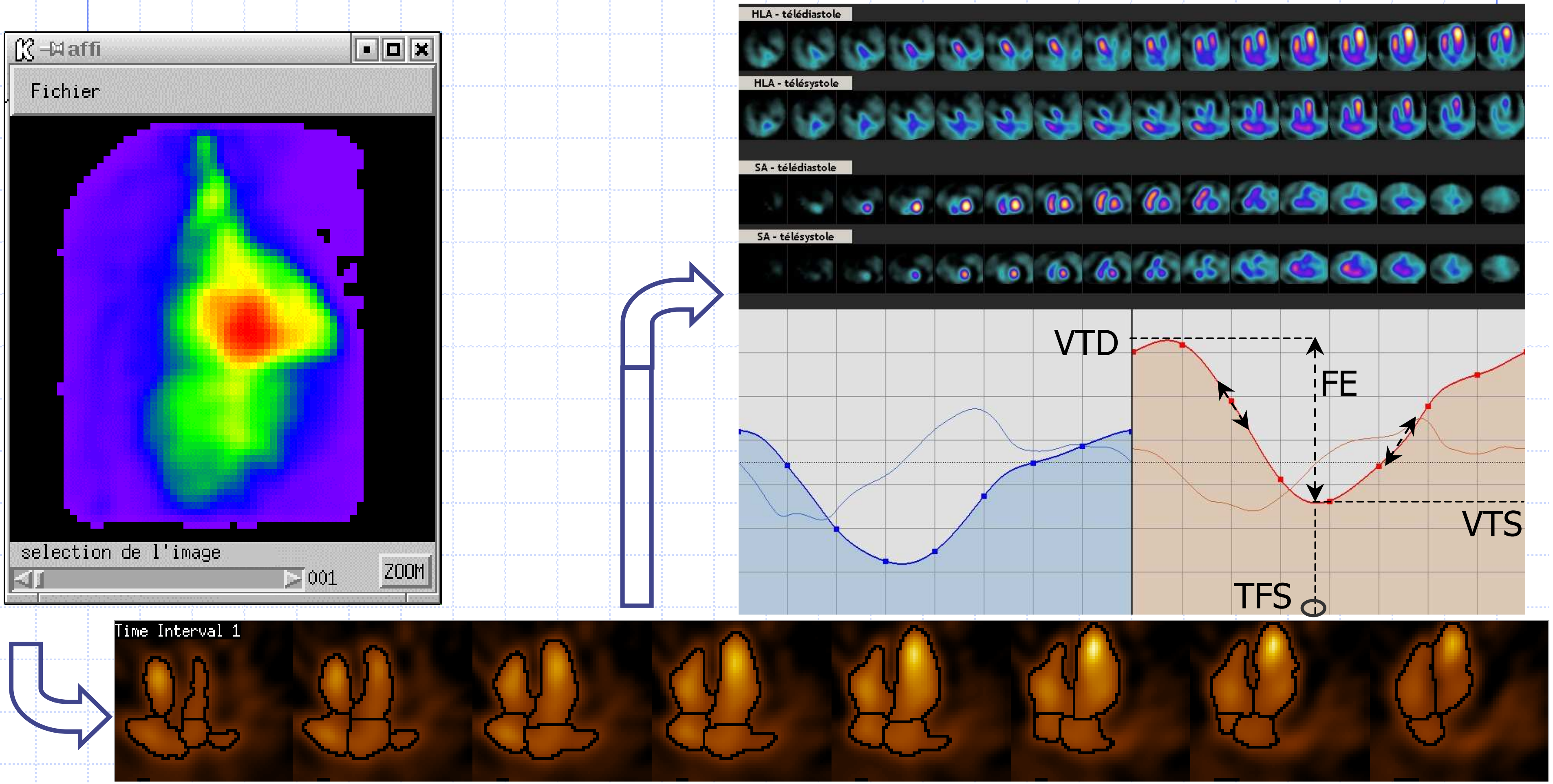
Schmitt M, Mattioli J. « Morphologie mathématique ». Paris, Masson, 1993.

Résultats



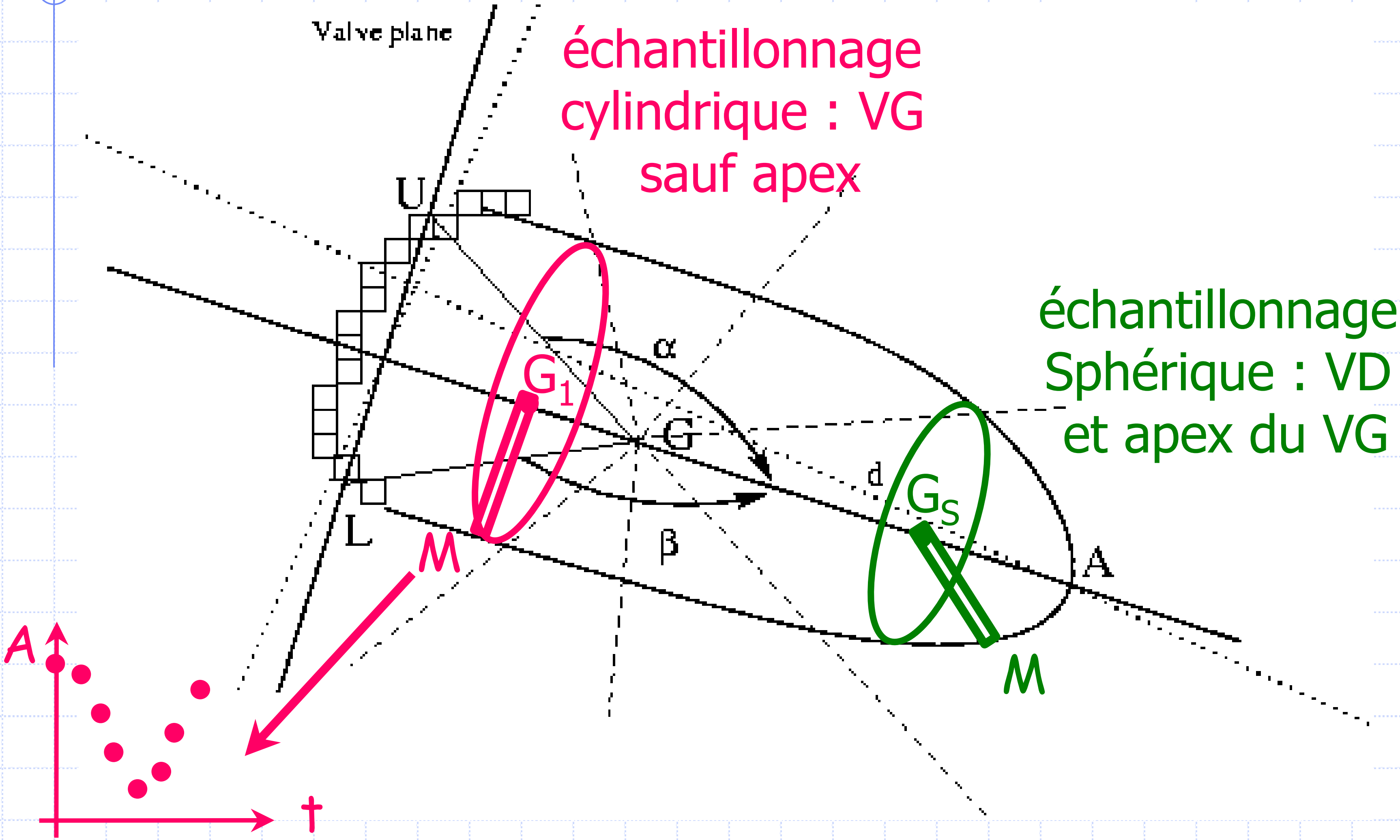
Mariano-Goulart et al.EJNM 1998;22 et EJNM 2001;28

TOMO-VENTRICULOGRAPHIE



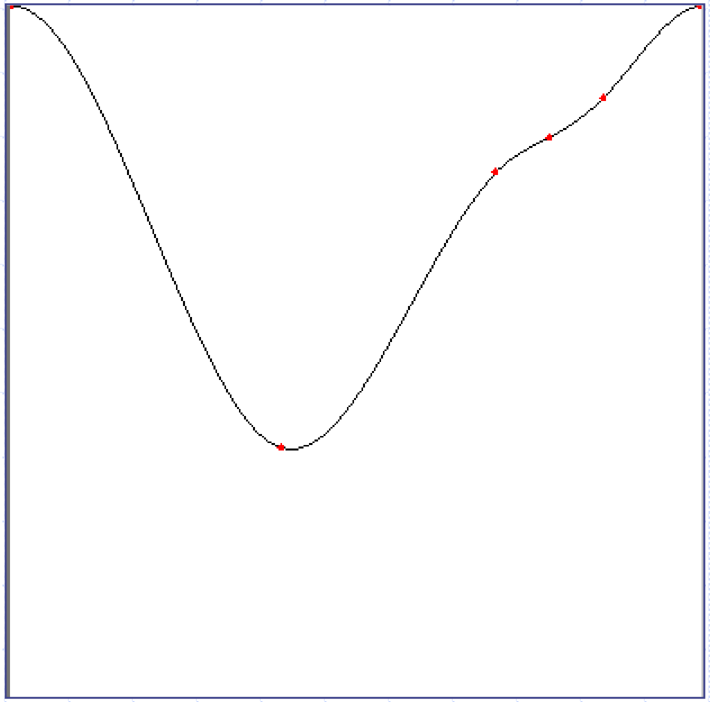
Mariano-Goulart et al.EJNM 1998;22 et EJNM 2001;28- Daou et al. JNM 2001;42

Analyse locale

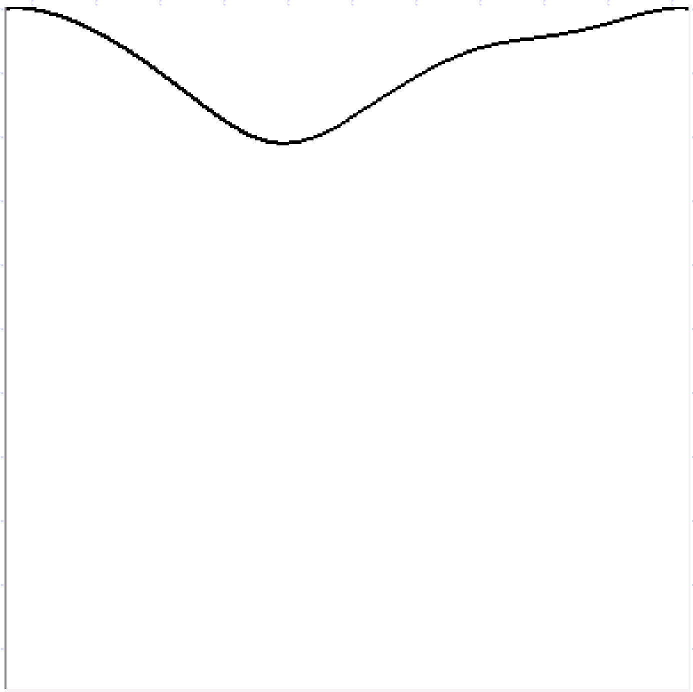


Vilain, J Nucl Cardiol 01

Ajustement en amplitude



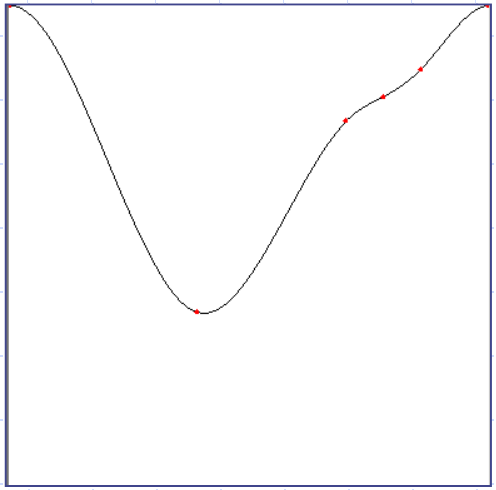
M(t)

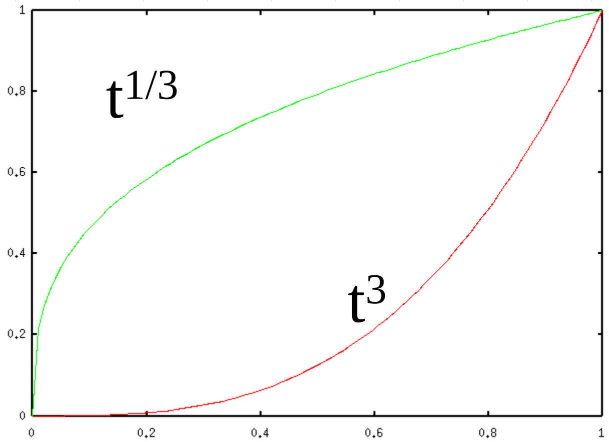


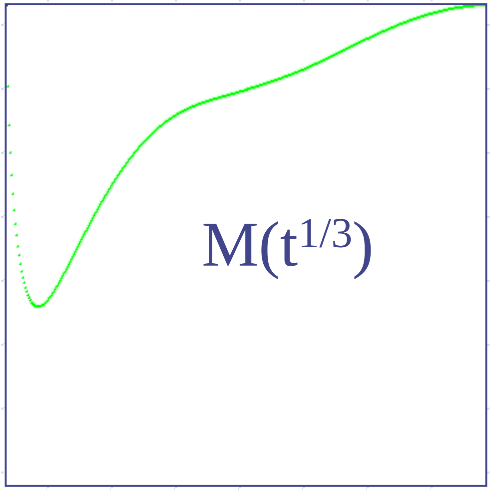
$D(t) = M(t)^{\beta}$

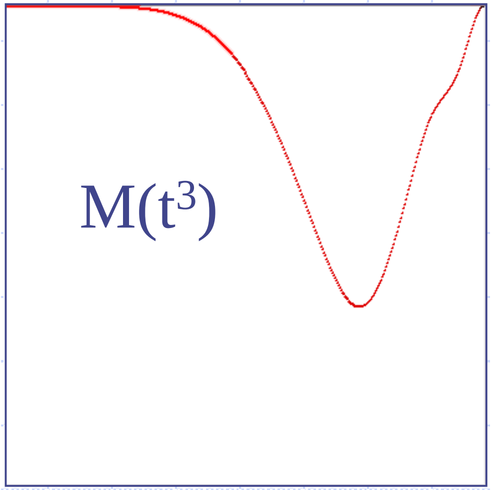
C. Caderas de Kerleau et al. IEEE Trans Med Imaging. 2004;23: 485-491

Ajustement en temps

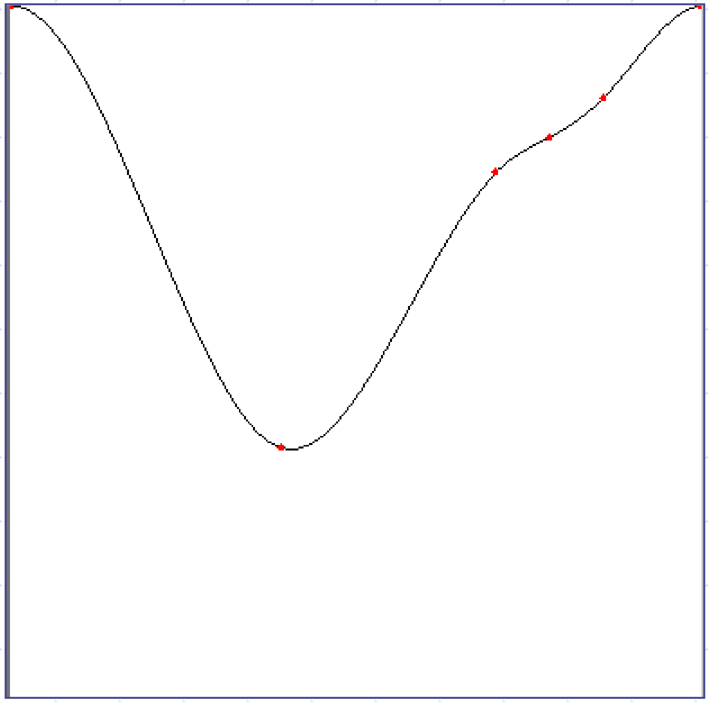




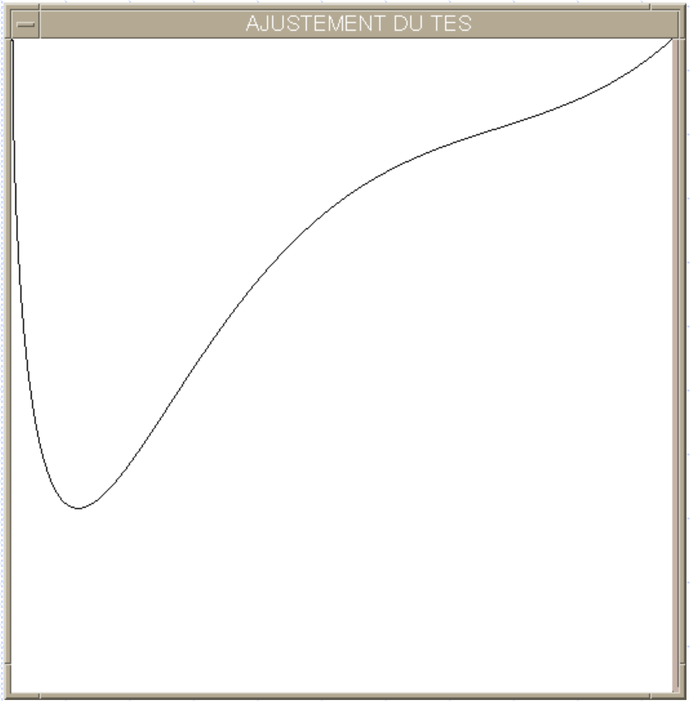




Ajustement en temps



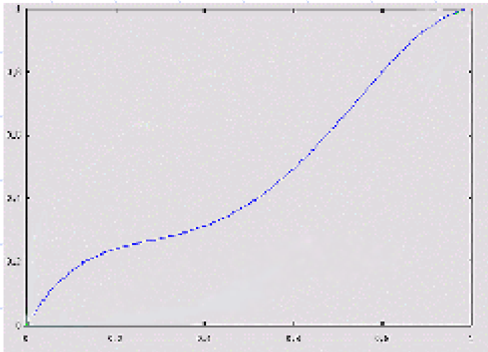
M(t)

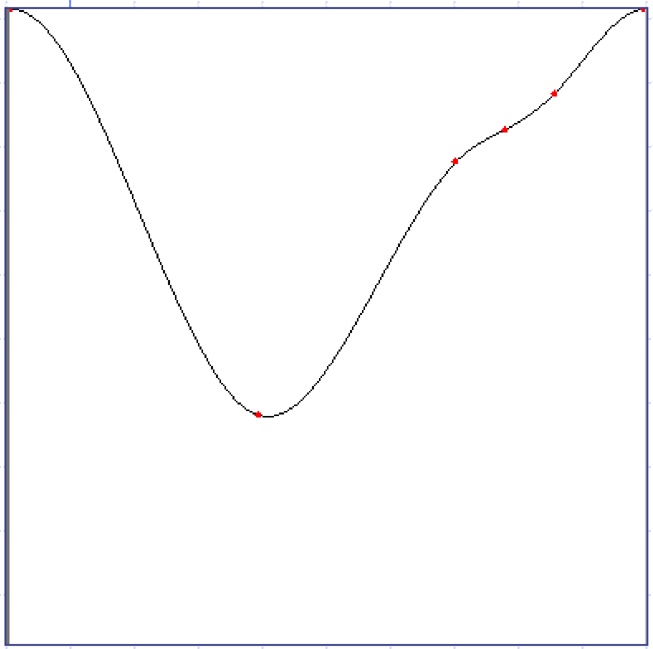


$D(t) = M(t^{\alpha})$

Ajustement en temps

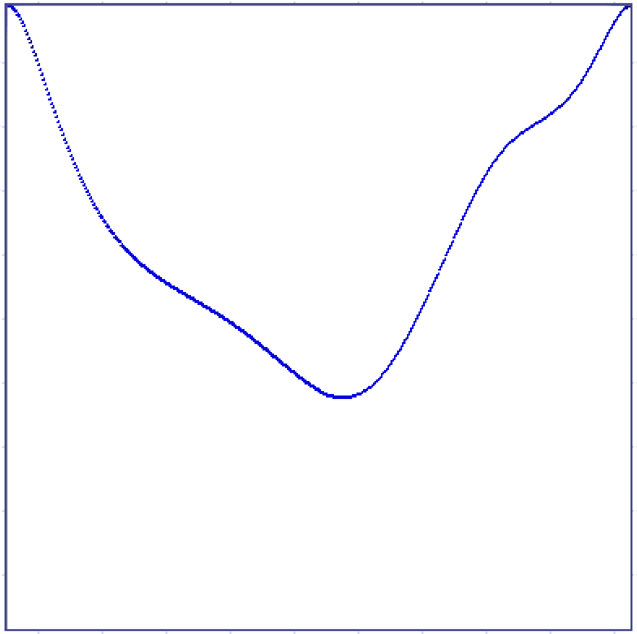
Polynôme en t





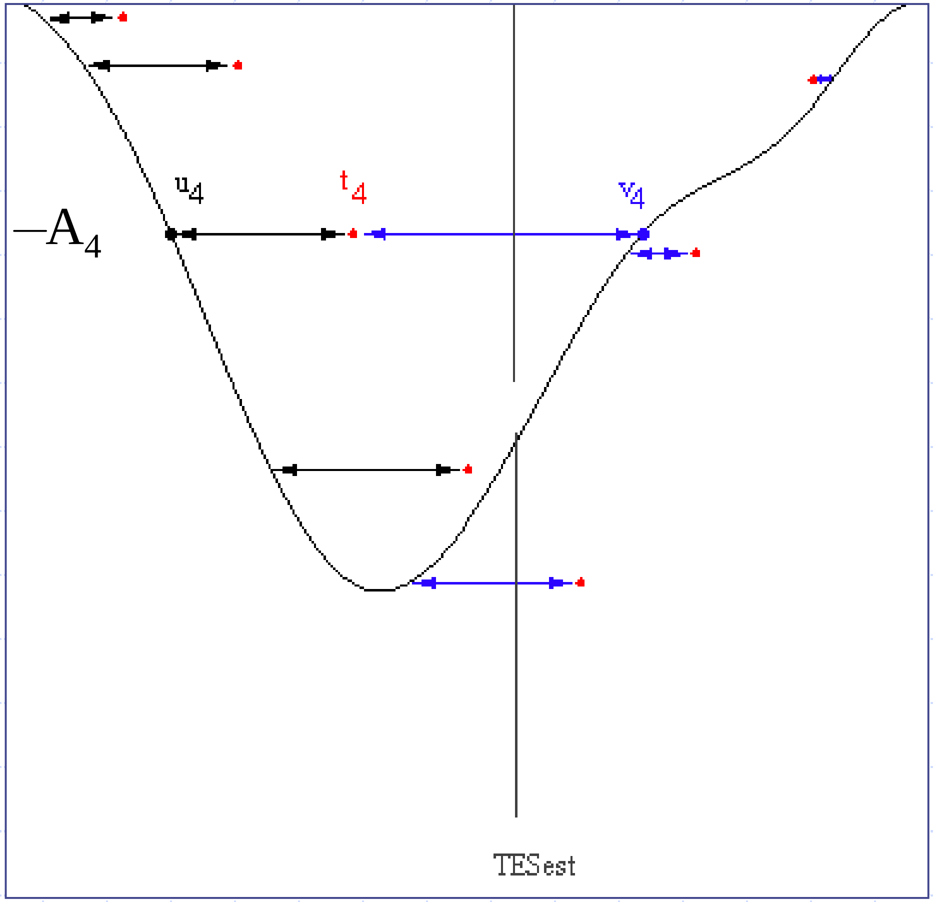
M(t)

P(t)



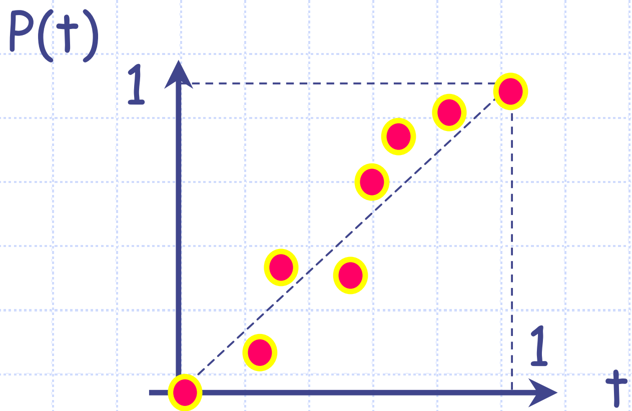
D(t) = M[P(t)]

AJUSTEMENT D'UN MODELE



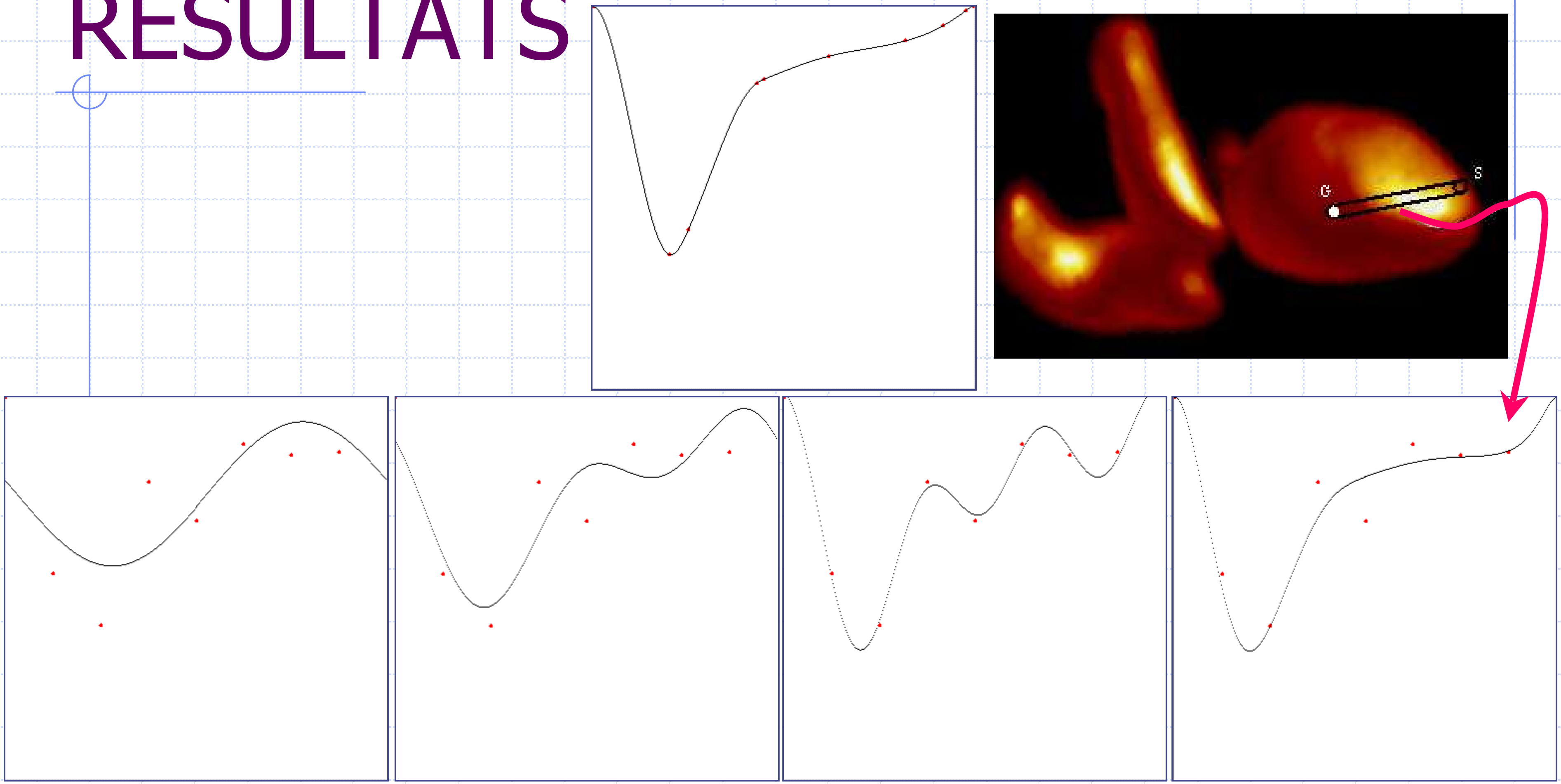
Acquisition bruitée (t_4 , A_4)

$$A_4 = M(u_4)$$
$$A_4 = D(t_4) = M[\,P(t_4)]$$
$$\boxed{P(t_4) = u_4}$$



C. Caderas de Kerleau et al. IEEE Trans Med Imaging. 2004;23: 485-491

RESULTATS



H1 H1+H2 H1+H2+H3 D(t)

C. Caderas de Kerleau et D. Mariano-Goulart, *IEEE Trans Med Imaging* 2004

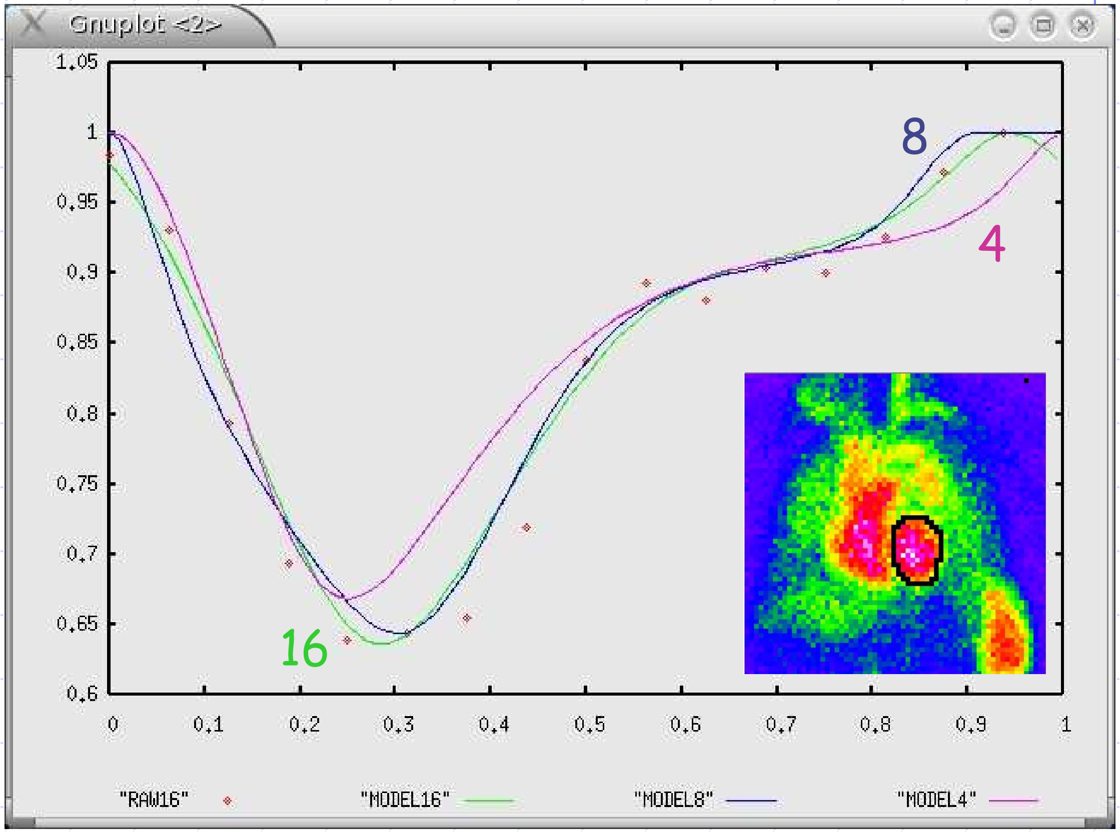
Validation

200 *ms*, 65%	H1	H2	H3	M
TES (ms)	81.4±9.9	44.2±6.2	24.2±6.8	15.0±12
EF (%)	-16.5±2	-2.5±2.2	0.9±2.3	0.4±3.4
PER (EDA.s^{-1})	3.74±0.06	2.15±0.14	1.21±0.27	0.48±0.63
PFR (EDA.s^{-1})	-0.80±0.06	0.20^* ± 0.19	0.23±0.3	0.20^* ± 0.42
400 *ms*, 65%	H1	H2	H3	M
TES (ms)	29.5±7.7	-8.6±8.9	0.8±16.6	-6.5±15.7
EF (%)	-5.4±1.8	-0.6±2.0	-0.7±2.1	0.5±2.1
PER (EDA.s^{-1})	0.54±0.06	-0.28±0.16	-0.25±0.29	-0.19±0.37
PFR (EDA.s^{-1})	0.13±0.06	0.05±0.19	0.25±0.27	0.20±0.39
600 *ms*, 65%	H1	H2	H3	M
TES (ms)	-27.7±8.2	-19.8±7.5	-13.4±8.4	-7.3±11.4
EF (%)	-9.5±1.8	-3.5±2.0	-0.24±2.3	-0.05±2.4
PER (EDA.s^{-1})	0.36±0.06	0.38±0.2	-0.47±0.3	0.3±0.3
PFR (EDA.s^{-1})	-1.65±0.06	-0.73±0.18	0.3±0.3	-0.17±0.39
200 *ms*, 20%	H1	H2	H3	M
TES (ms)	48.7±40.9	21.1±25.6	6.9±27.3	15.9±44.2
EF (%)	-6.6±2.9	-1.4±3.2	1.14±3.5	0.16±3.7
PER (EDA.s^{-1})	1.08±0.09	0.57±0.2	0.16±0.32	0.37±0.43
PFR (EDA.s^{-1})	-0.47±0.09	-0.07±0.19	0.30±0.3	-0.06±0.33
400 *ms*, 20%	H1	H2	H3	M
TES (ms)	32.4±28.2	-1.9^* ± 37	7.8±57.2	-2.3^* ± 48.1
EF (%)	-1.66±2.2	0.48±3.0	1.82±3.2	0.90±3.2
PER (EDA.s^{-1})	0.17±0.09	-0.12±0.19	-0.28±0.26	-0.20±0.31
PFR (EDA.s^{-1})	-0.01±0.09	0.09±0.16	0.33±0.25	0.14±0.25
600 *ms*, 20%	H1	H2	H3	M
TES (ms)	-7.0±28.6	7.0±37.6	-6.2±42.9	0.1±42.4
EF (%)	-1.94±2.8	-0.27±2.9	2.00±3.2	0.87±3.2
PER (EDA.s^{-1})	0.15±0.09	0.01±0.18	0.27±0.27	-0.07±0.25
PFR (EDA.s^{-1})	-0.19±0.09	0.03±0.19	0.21±0.24	0.14±0.3

C. Caderas de Kerleau et al. IEEE Trans Med Imaging. 2004;23: 485-491

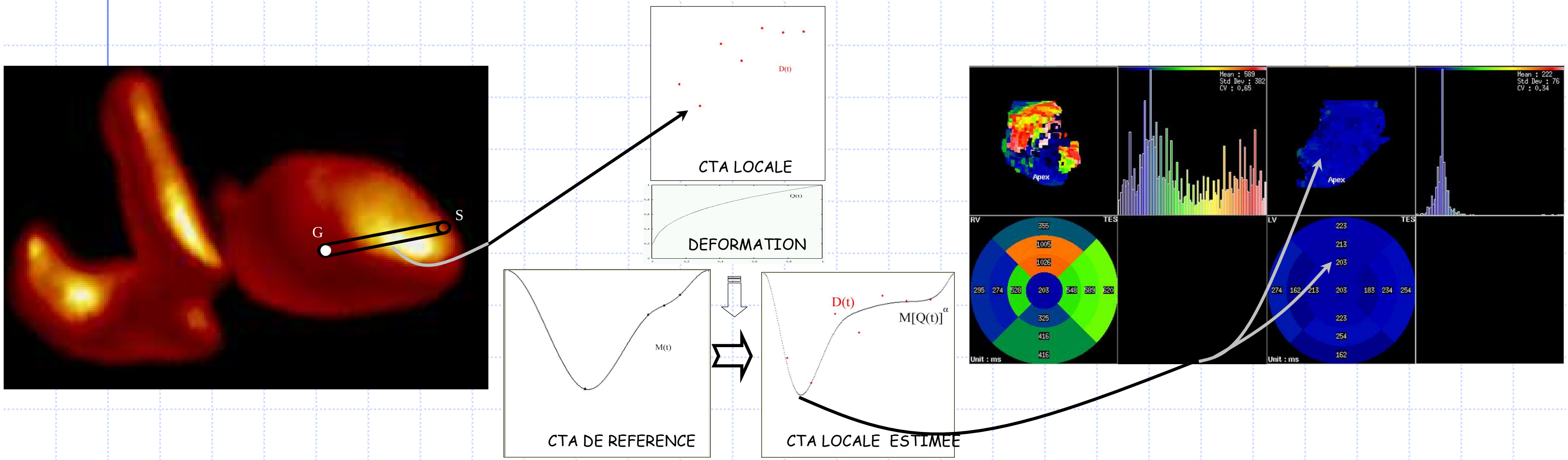
SENSIBILITE A L'ECHANTILLONNAGE

Erreur 16 ➤ 8	20 %	65 %
TES (ms)	3	6
FE (%)	0.3	2.9
PVM (ATD/s)	0.06	0.3
PEM (ATD/s)	0.04	0.19



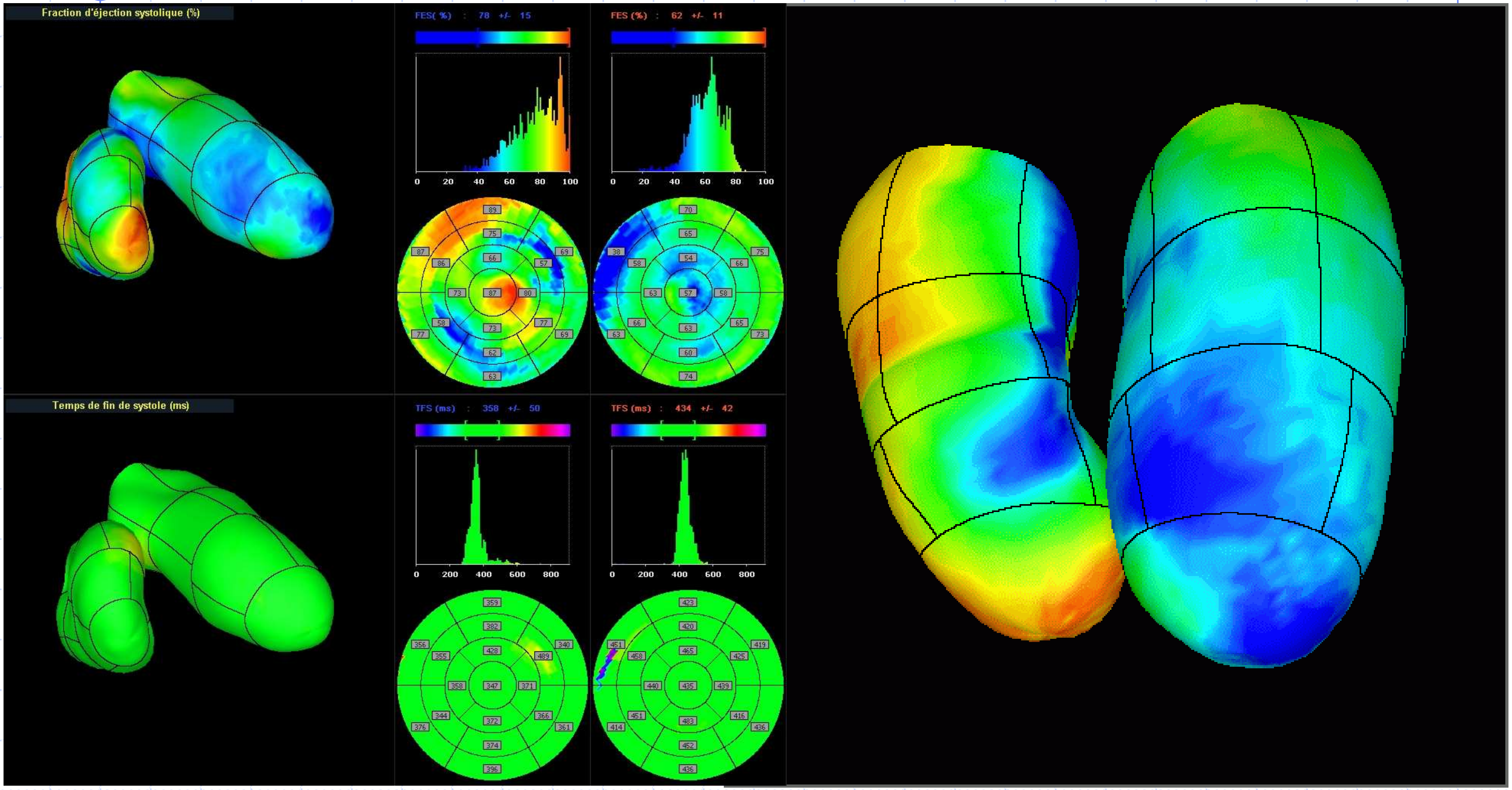
C. Caderas de Kerleau et al. IEEE Trans Med Imaging. 2004;23: 485-491

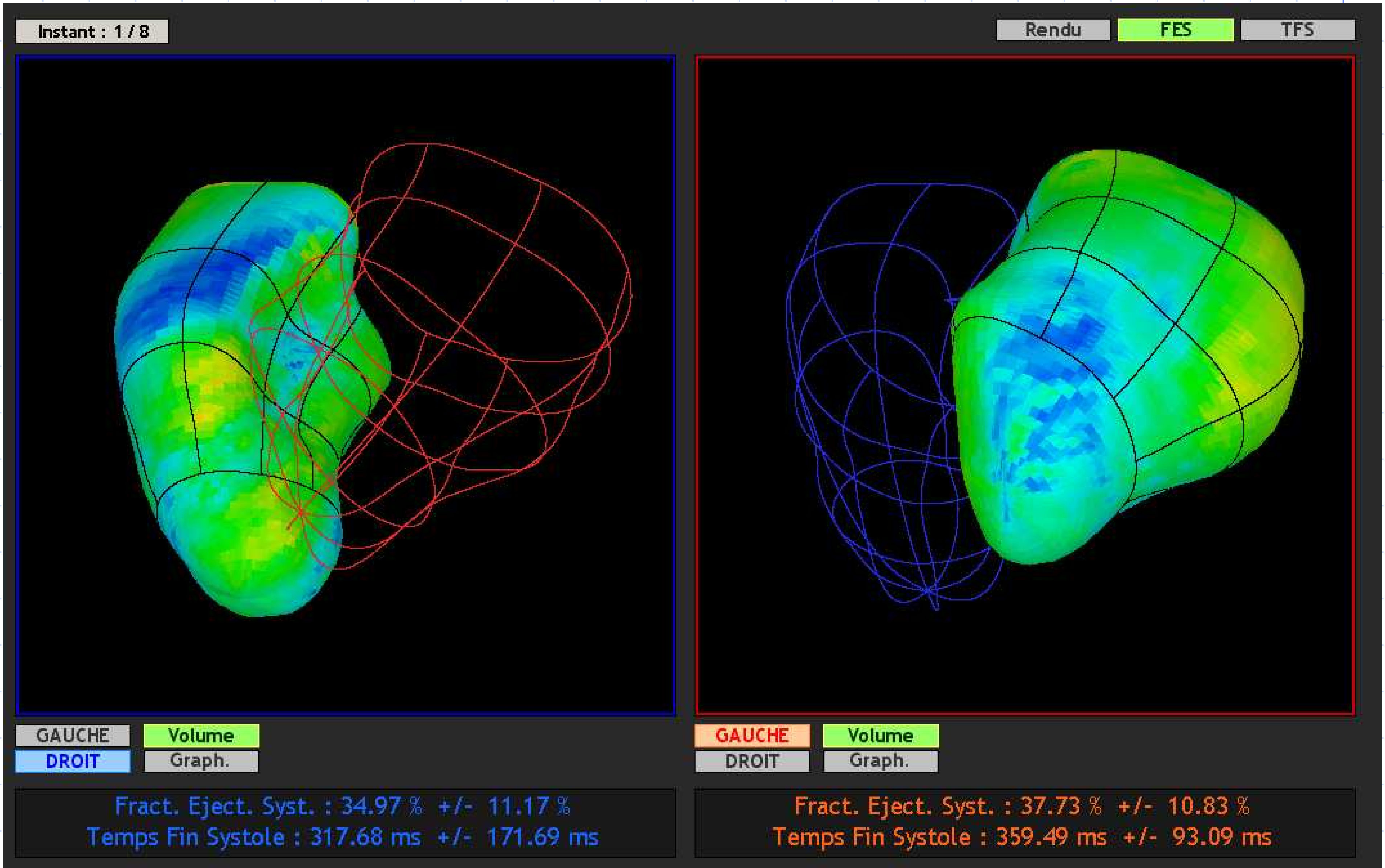
ANALYSE 3D DE CTA LOCALES



Mariano-Goulart, JBMN 05; Vilain, J Nucl Cardiol 01

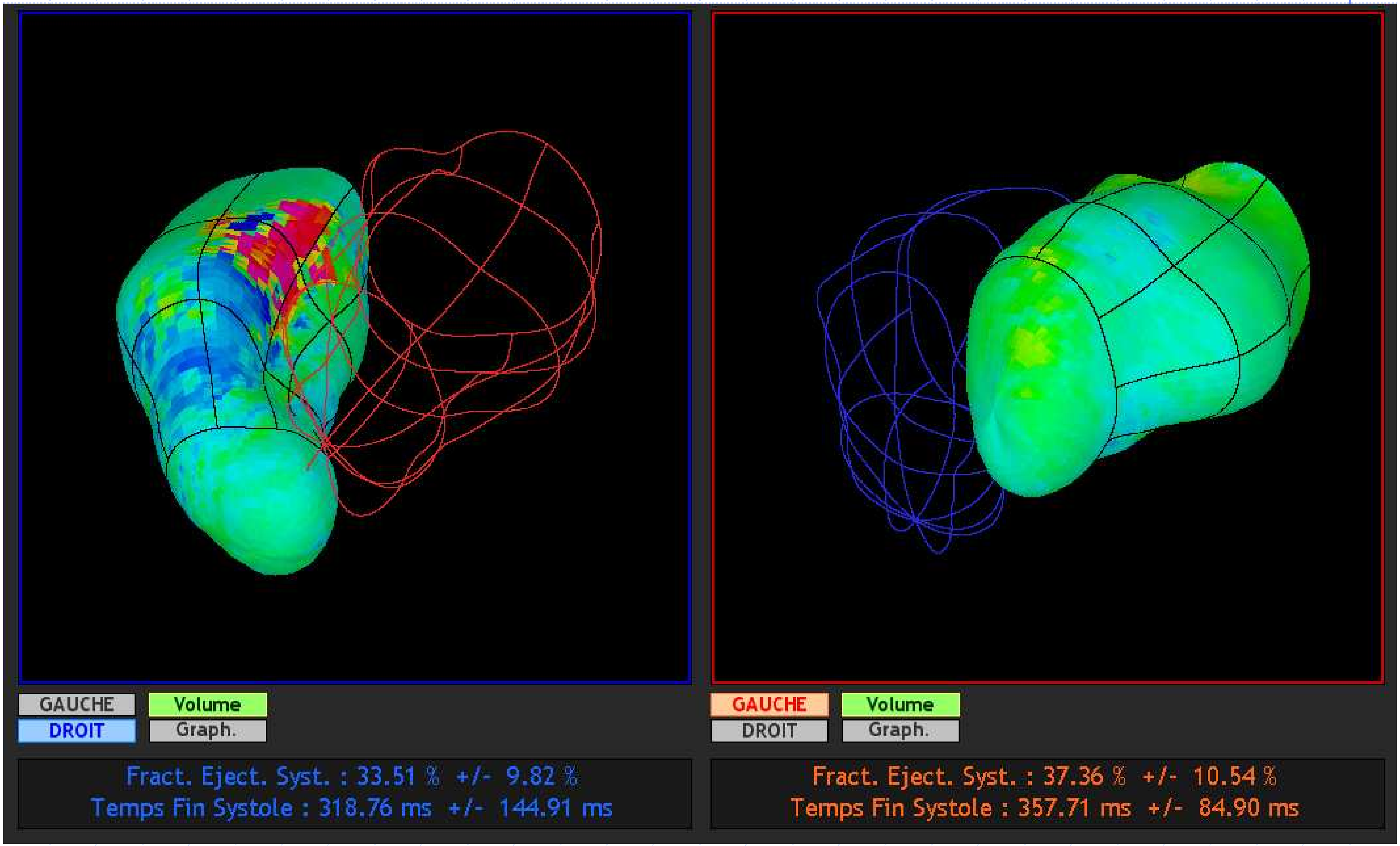
ANALYSE 3D DE CTA LOCALES



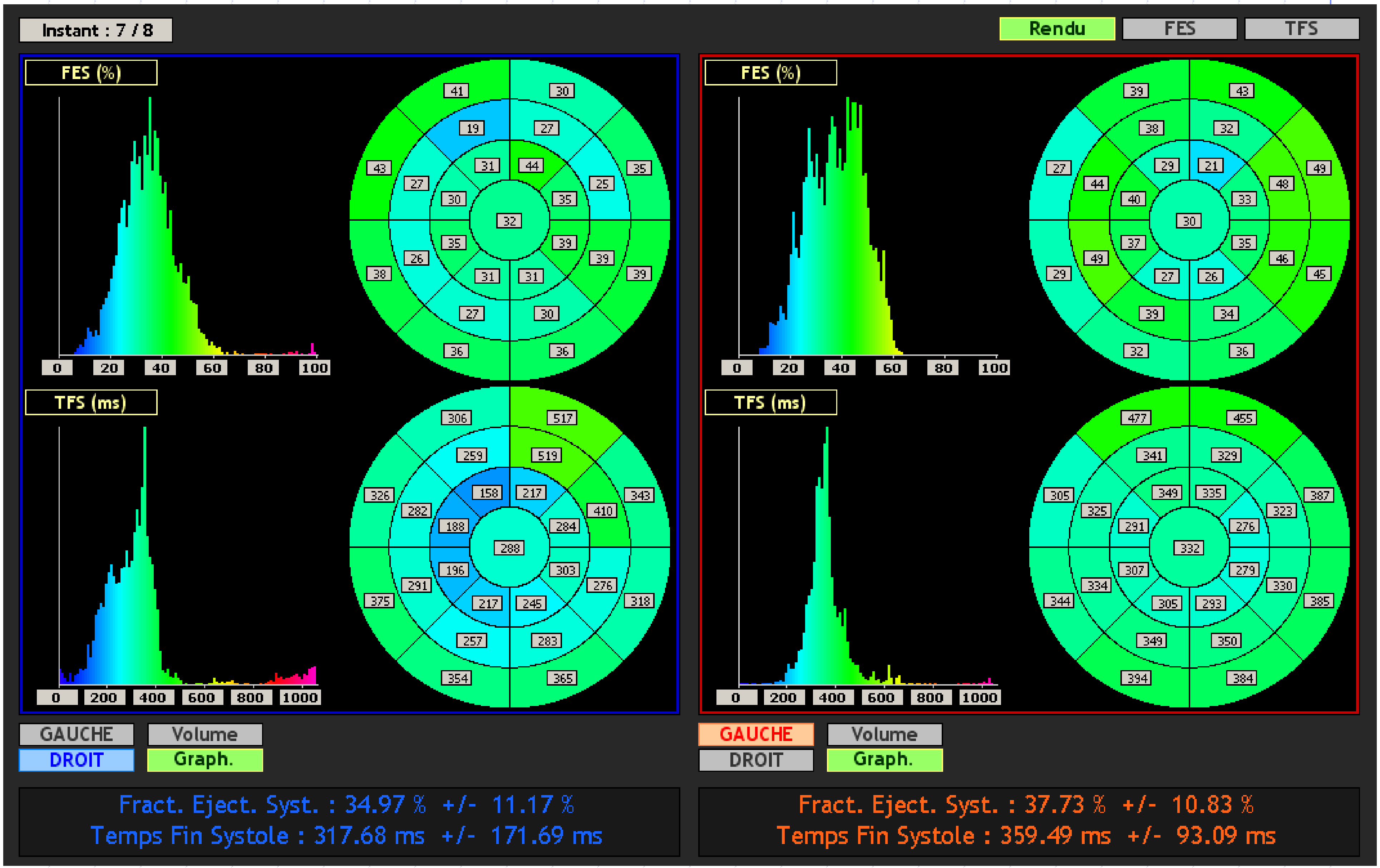


Commentaires :

Fraction d'éjection systolique locale



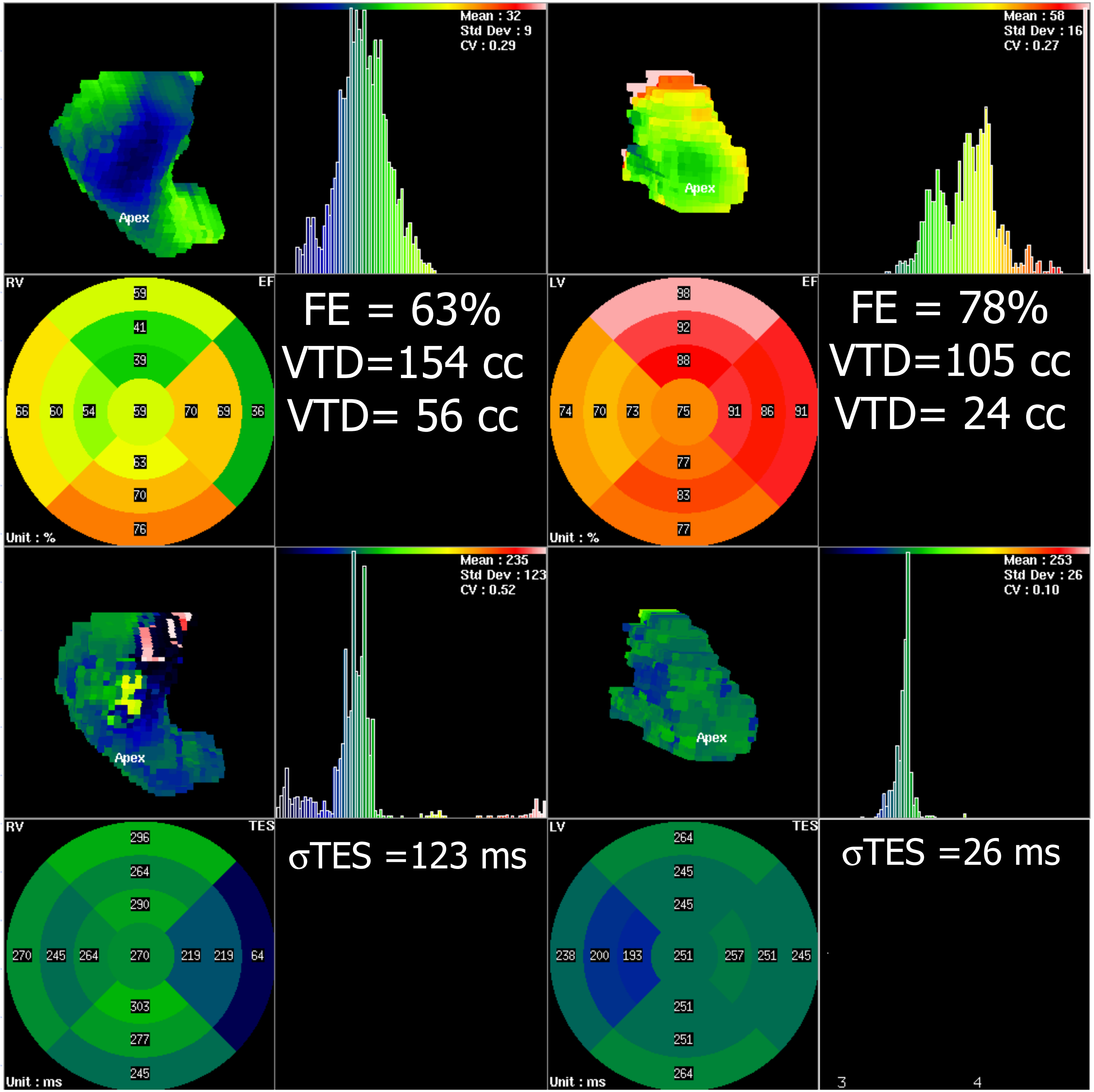
Instant de fin de systole local


Instant : 7 / 8
Rendu
FES
TFS
FES (%)
0 20 40 60 80 100
41 30 19 27 43 31 44 35 27 25 30 35 32 35 39 26 39 38 39 31 31 27 30 36 36
TFS (ms)
0 200 400 600 800 1000
306 517 259 519 326 158 217 343 282 410 188 284 288 196 303 291 276 375 318 217 245 257 283 354 365
GAUCHE
DROIT
Volume
Graph.
Fract. Eject. Syst. : 34.97 % +/- 11.17 %
Temps Fin Systole : 317.68 ms +/- 171.69 ms
FES (%)
0 20 40 60 80 100
39 43 38 32 27 29 21 49 44 48 40 33 30 37 35 49 46 29 45 27 26 39 34 32 36
TFS (ms)
0 200 400 600 800 1000
477 455 341 329 305 349 335 387 325 323 291 276 332 307 279 334 330 344 385 305 293 349 350 394 384
GAUCHE
DROIT
Volume
Graph.
Fract. Eject. Syst. : 37.73 % +/- 10.83 %
Temps Fin Systole : 359.49 ms +/- 93.09 ms

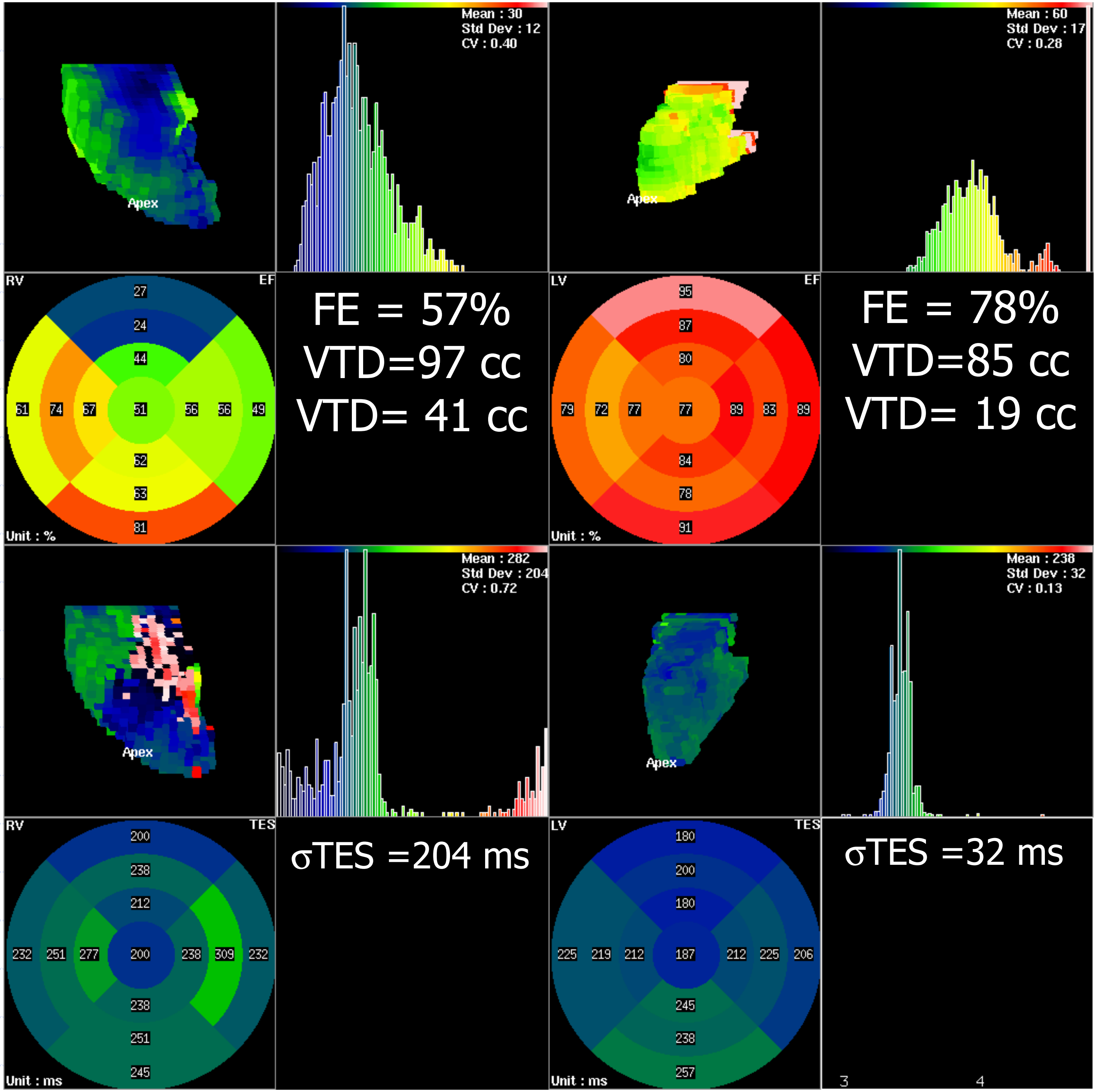
AINE

Décès du père
par arrêt cardiaque.
Nécropsie : DVDA

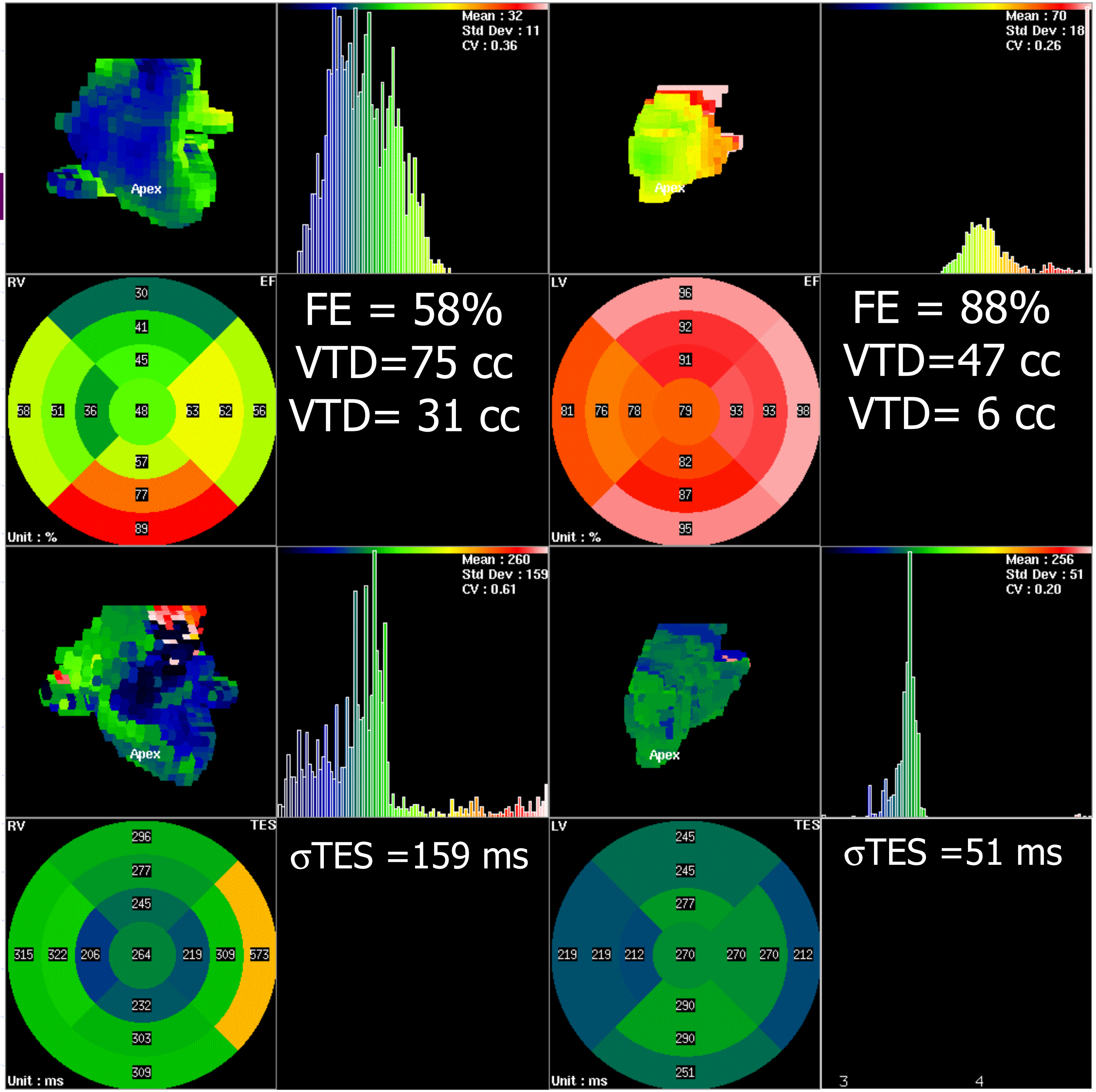
Acquisitions :
Dr E. Grémillet
(St Etienne)



CADET

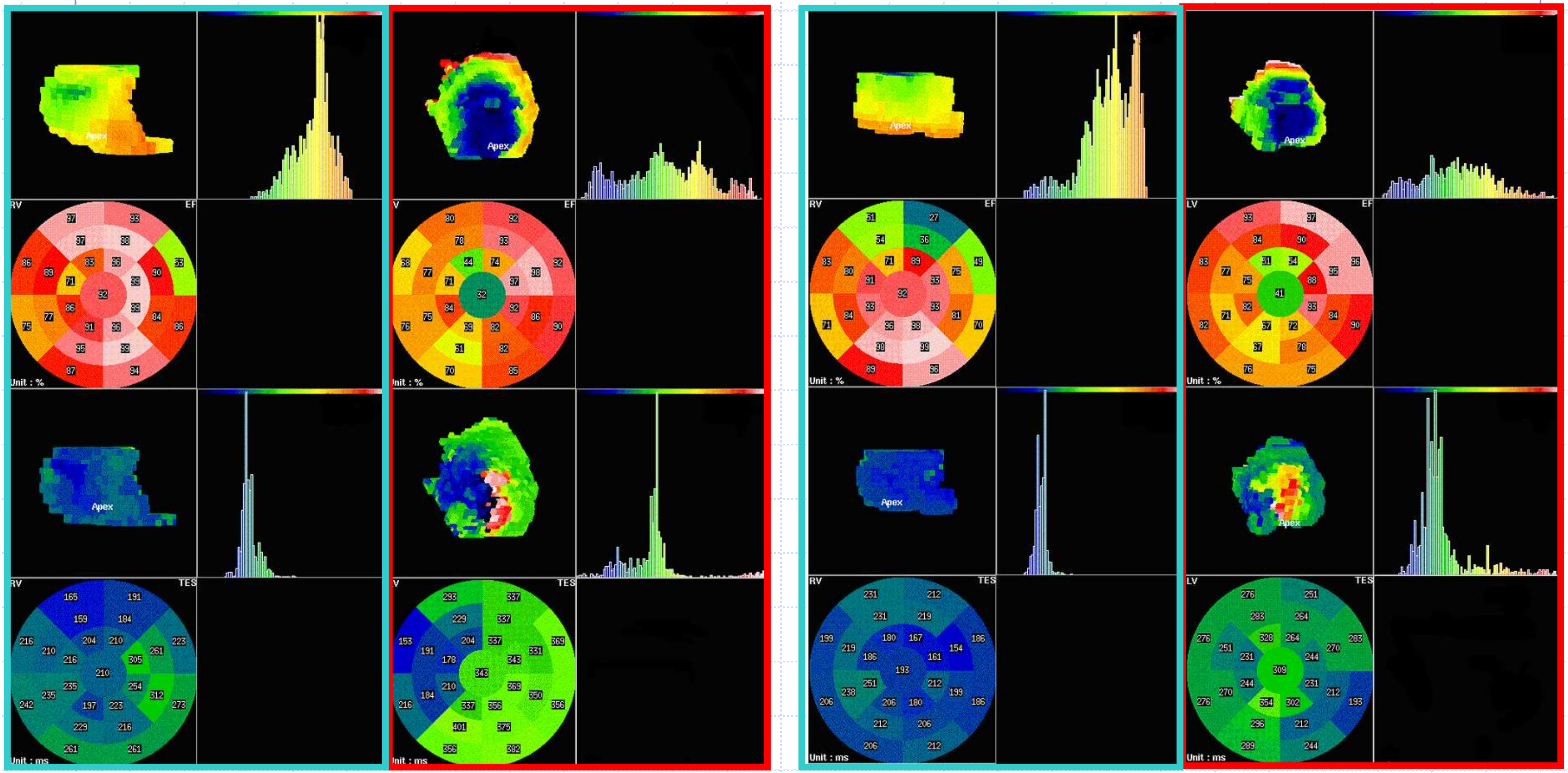

Apex
Mean : 30
Std Dev : 12
CV : 0.40
Apex
Mean : 60
Std Dev : 17
CV : 0.28
RV
EF
27
24
44
61 74 67 51 56 56 49
52
53
81
Unit : %
FE = 57%
VTD=97 cc
VTD= 41 cc
LV
EF
95
87
80
79 72 77 77 89 83 89
84
78
91
Unit : %
FE = 78%
VTD=85 cc
VTD= 19 cc
Apex
Mean : 282
Std Dev : 204
CV : 0.72
Apex
Mean : 238
Std Dev : 32
CV : 0.13
RV
TES
200
238
212
232 251 277 200 238 309 232
238
251
245
Unit : ms
σTES =204 ms
LV
TES
180
200
180
225 219 212 187 212 225 206
245
238
257
Unit : ms
σTES =32 ms
3
4

BENJAMIN



Conclusion:
Suspicion
de maladie
de Hühl

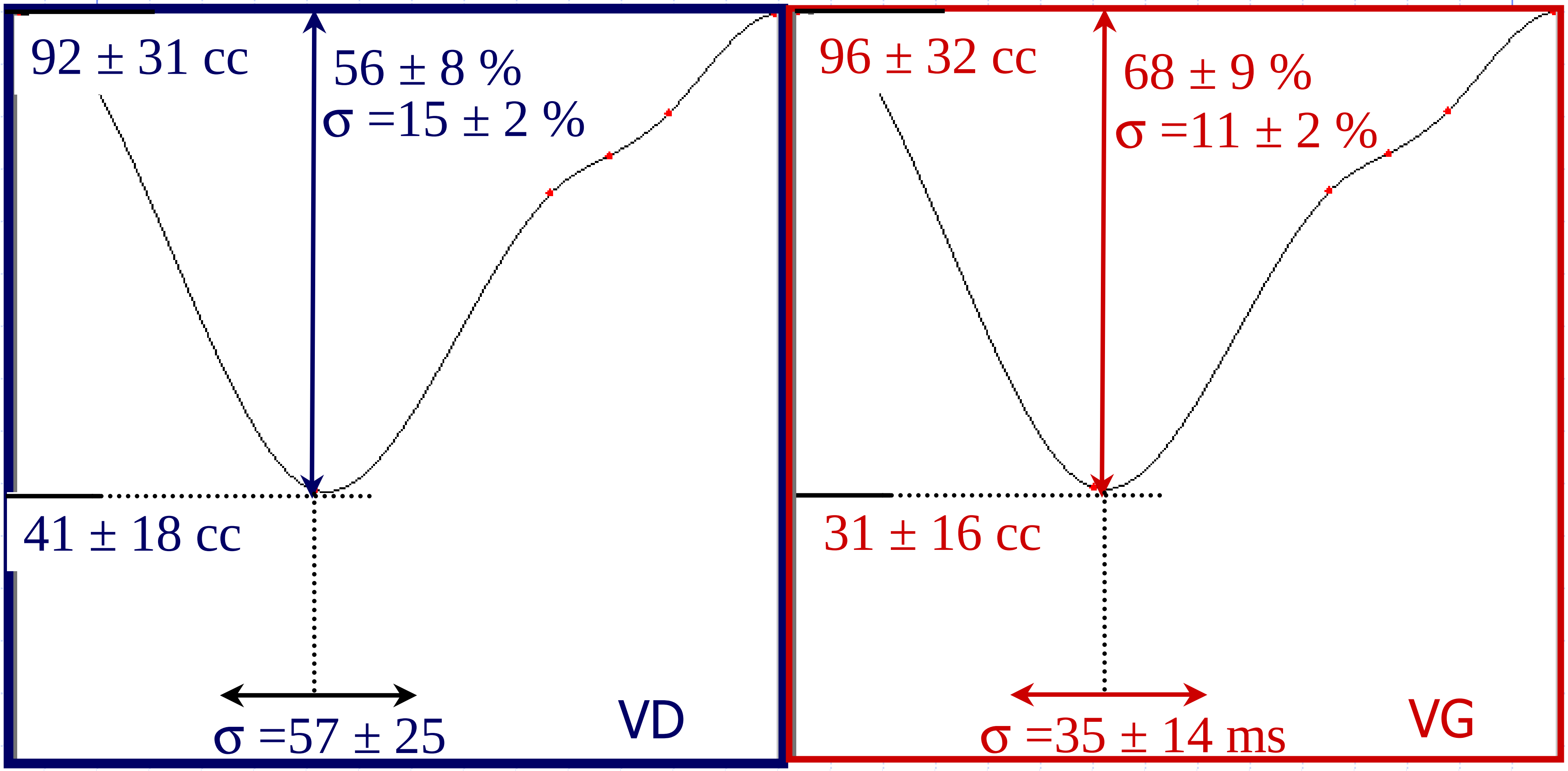
STIMULATION : DIV, Δt, σ_{TES} …



Non stimulé

Stimulé

Valeurs normales: Moyenne ± σ



Q = 3.8 ± 1.1 L/min

Q = 4.7 ± 0.8 L/min

QUID DU GATED SPECT ?

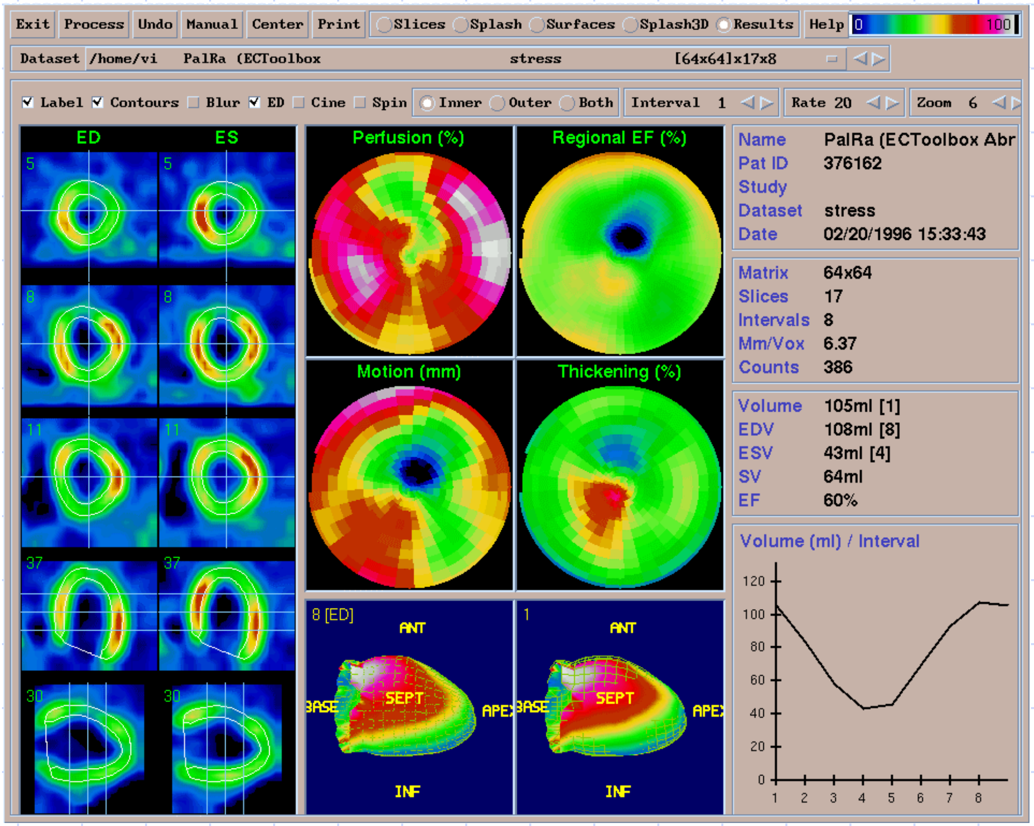
Limité au VG

EF, VTS ⇨ Pronostic

< Echo 3D et IRM

Imprécis

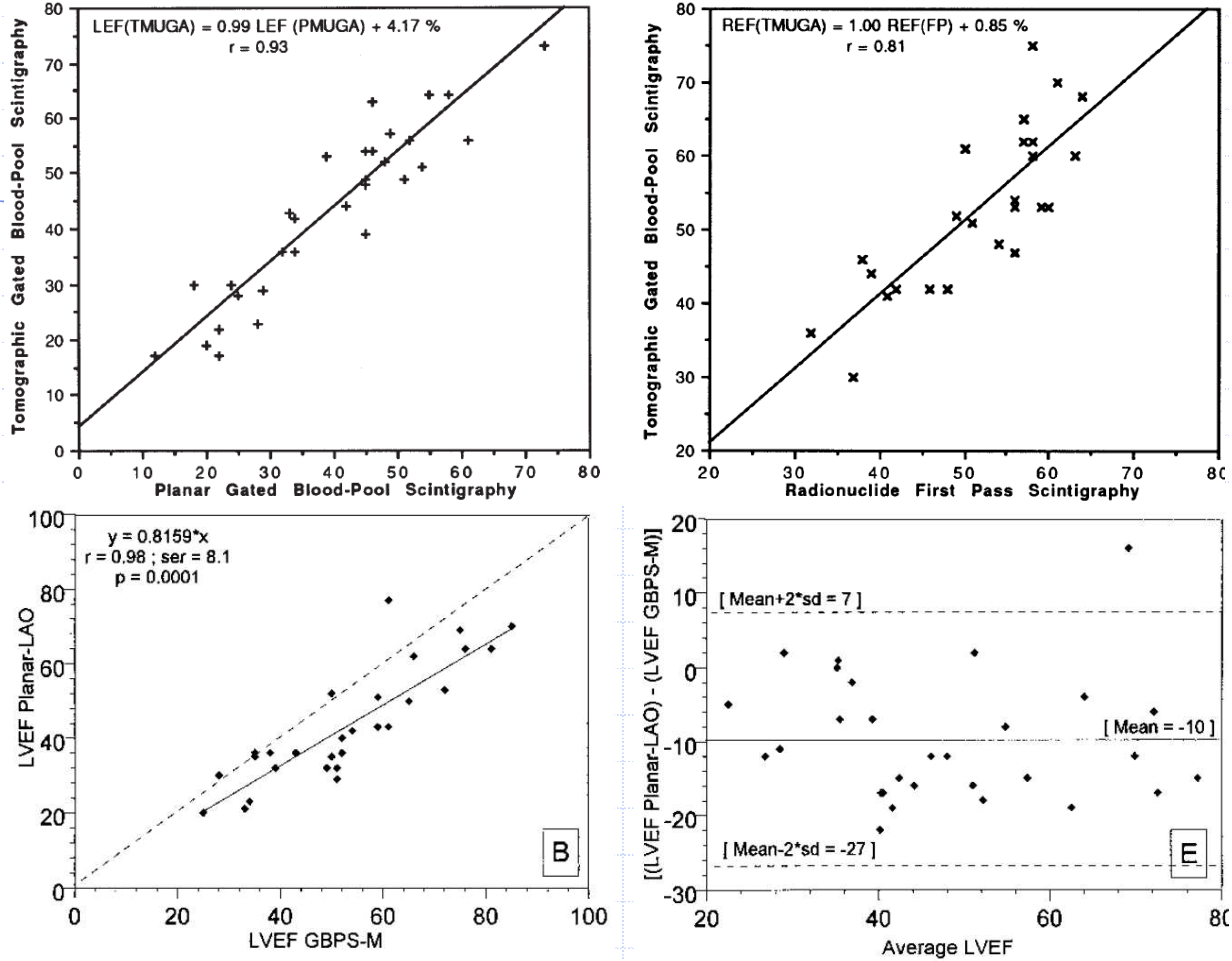
- Hypoperfusion > 50%
- Activité digestive
- FE ↗ (Petits cœurs)
- Volumes ↘



De Winter,JNC 05; Chan,J. Am. Soc. Echo. 06; Achtert,JNC 98; Ford, JNM 01

VALIDATION CLINIQUE

FE



D. Mariano-Goulart et al. Eur J Nucl Med.1998; 25: 1300-1307 - D. Doumit et al. J Nucl Med 2001; 42: 1043-1049

FE-BNP

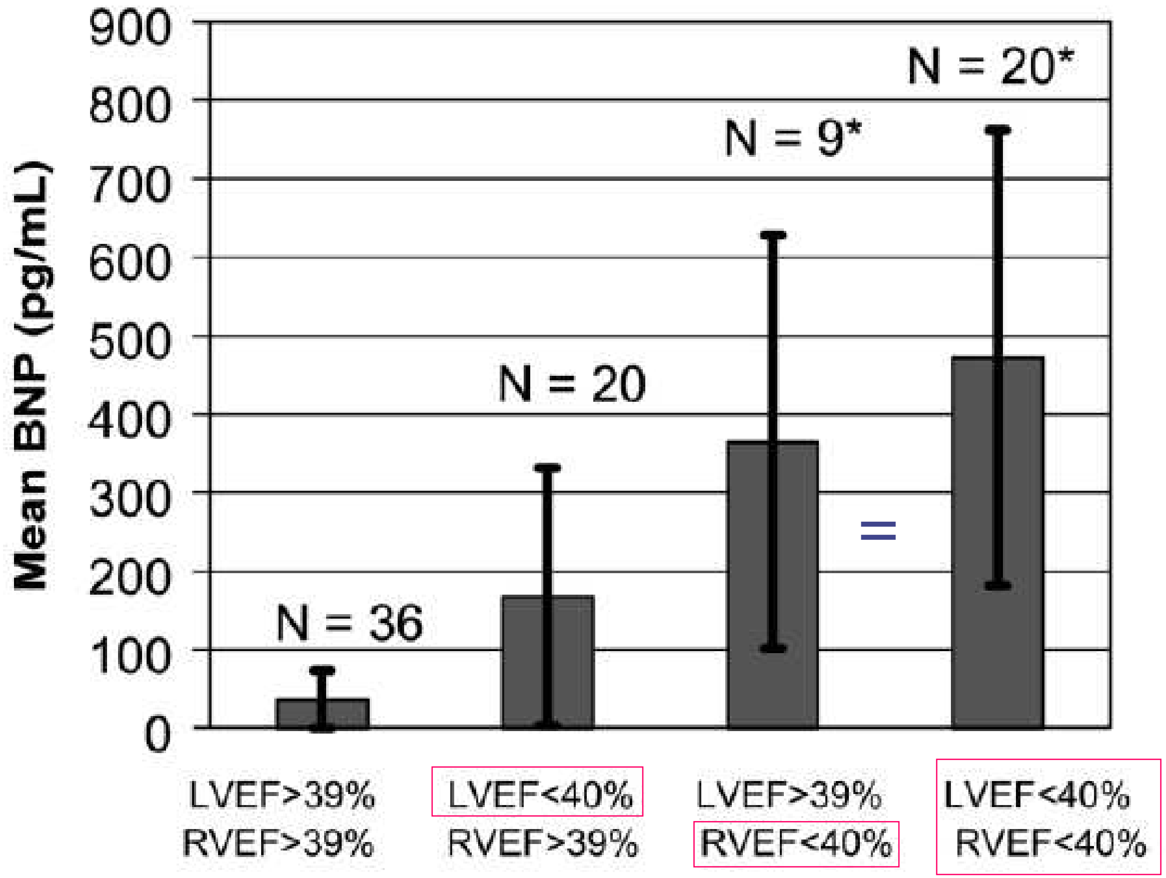
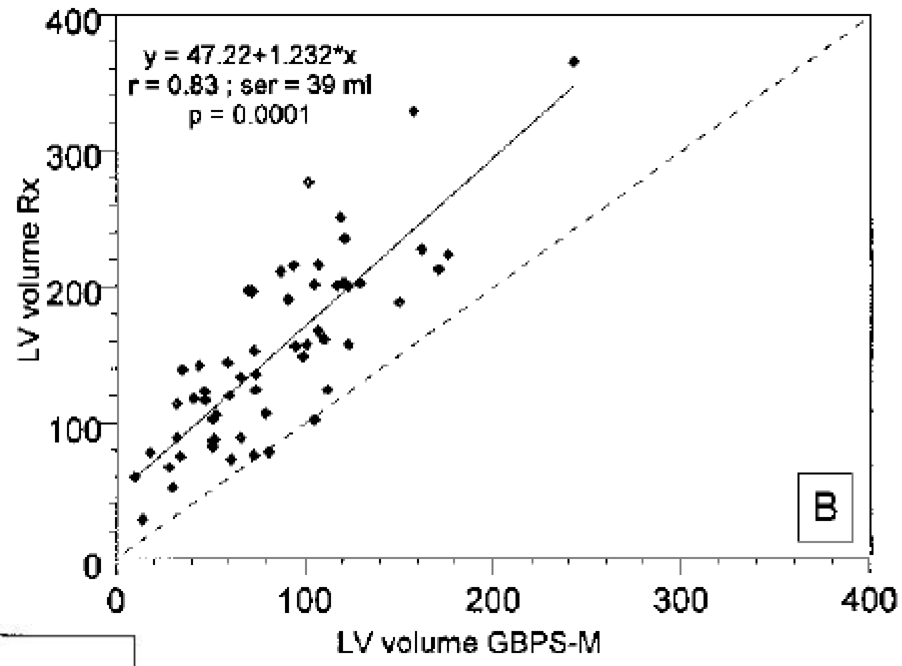
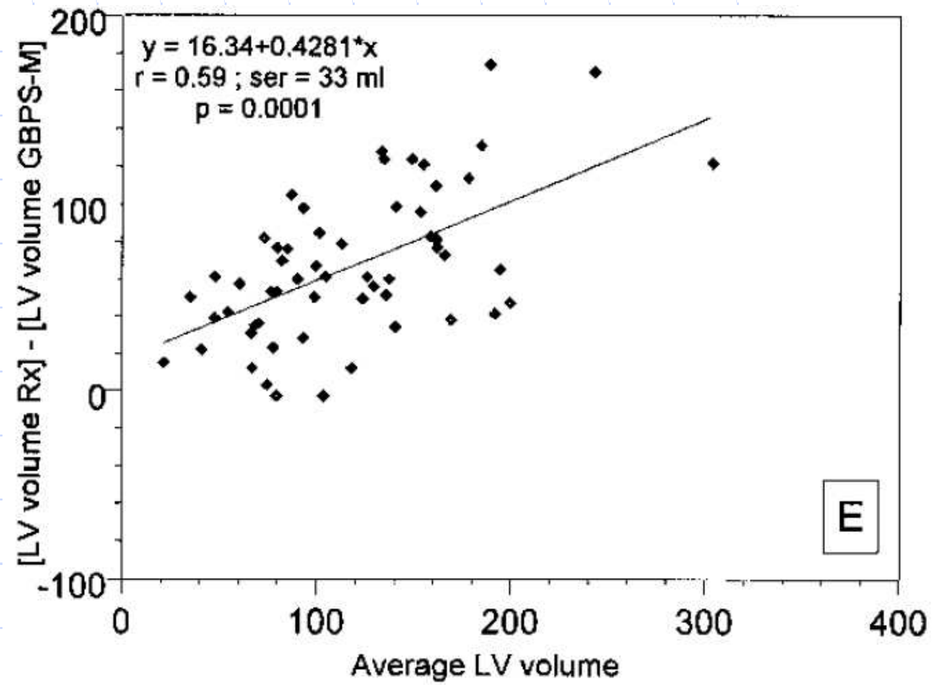


Fig. 1. Mean plasma BNP level vs. left (LVEF) and right (RVEF) ejection fraction. *N* is the number of patients and error bars represent ±S.D. Mean BNP levels are significantly different ($P=0.0001$) except between the two groups marked by a star (*: $P=0.51$).

D. Mariano-Goulart et al. Eur J Heart Fail. 2003;5:481-488

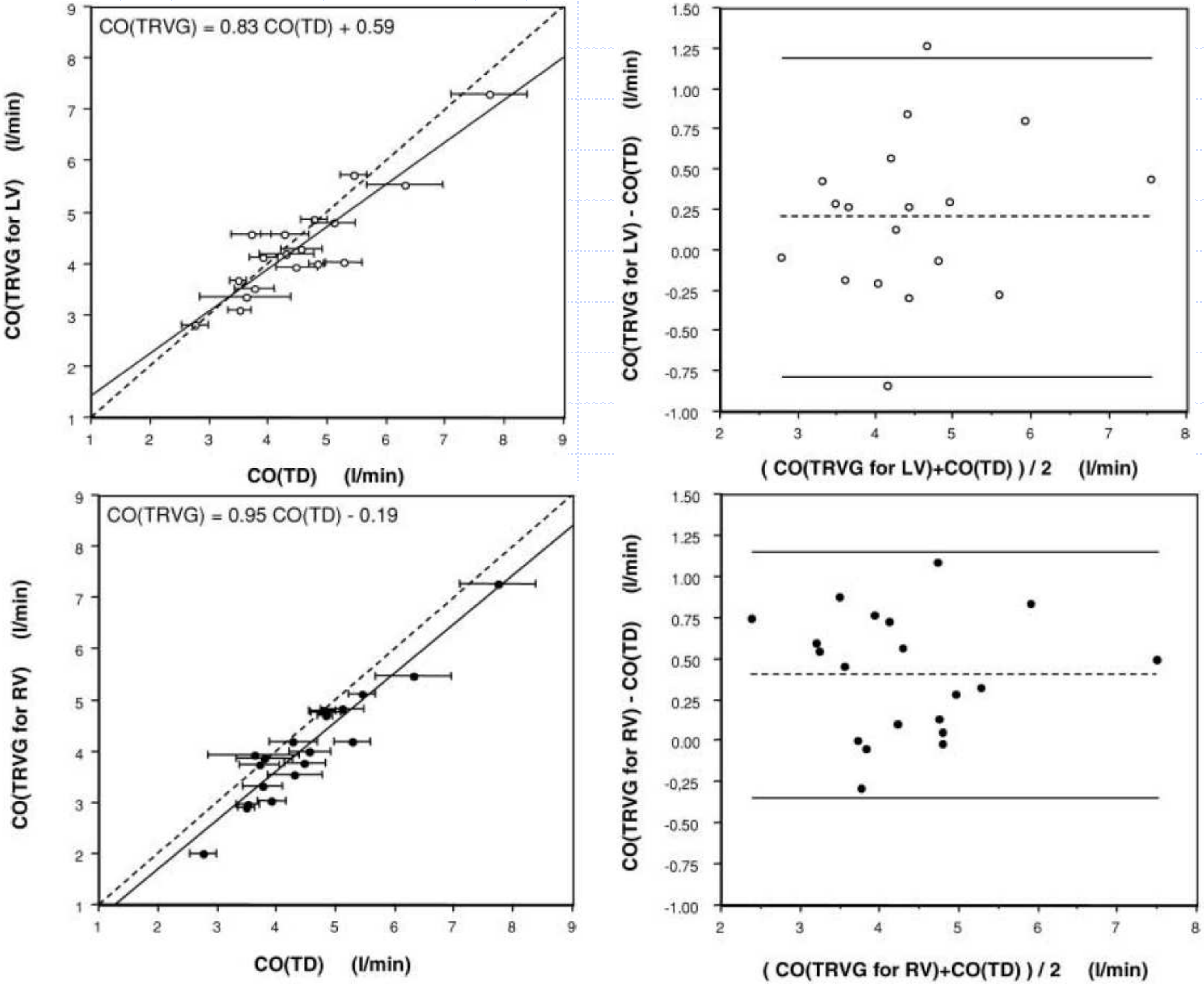
VOLUMES





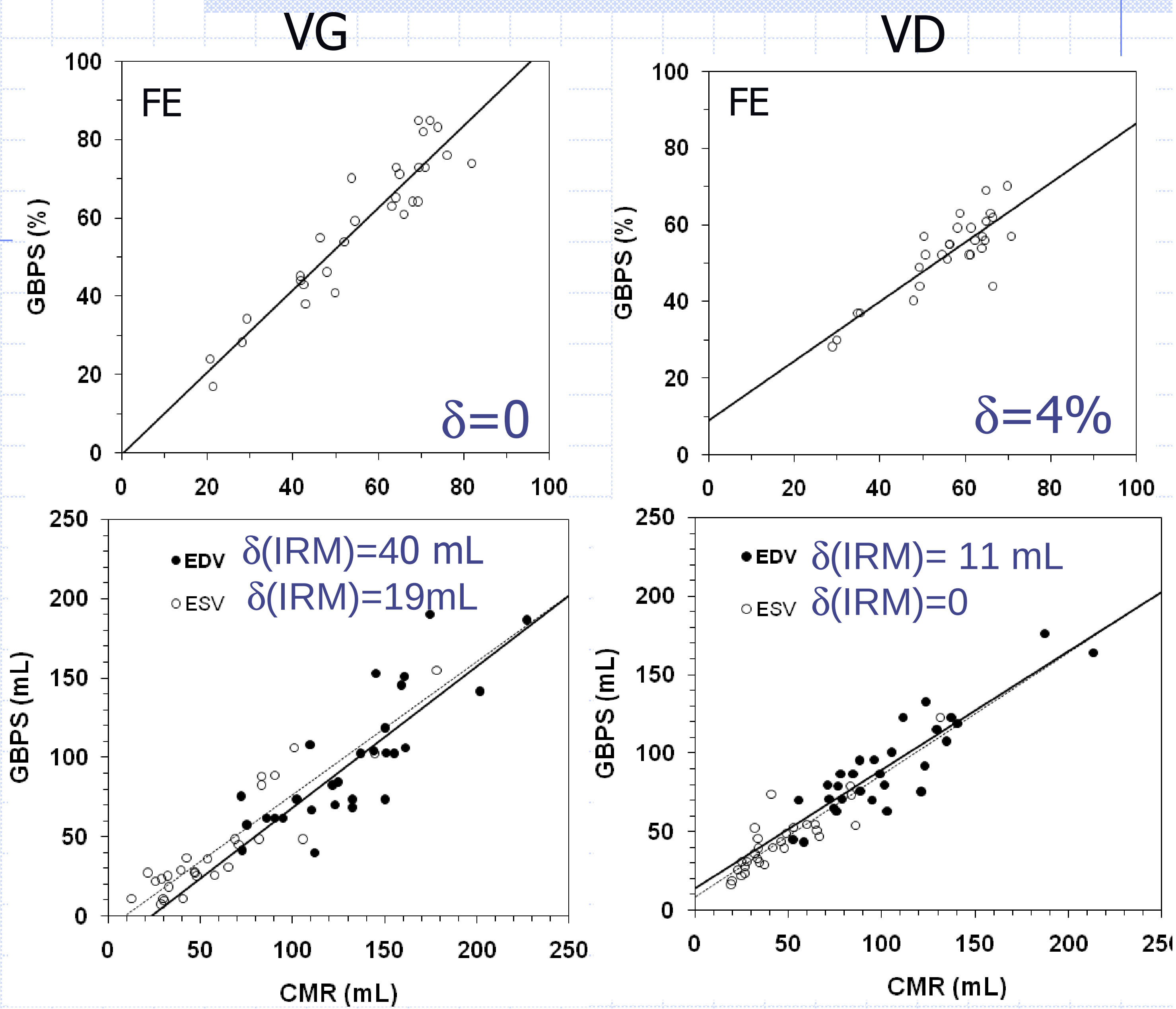
D. Doumit et al. J Nucl Med 2001; 42: 1043-1049.

Q



D. Mariano-Goulart et al. Eur J Nucl Med. 2001;28:506-513

IRM



VES(G-D): 9±14 (GBPS) versus 18±13 (IRM)

L. Sibille et al. J Nucl Cardiol (soumis)

σ-TES

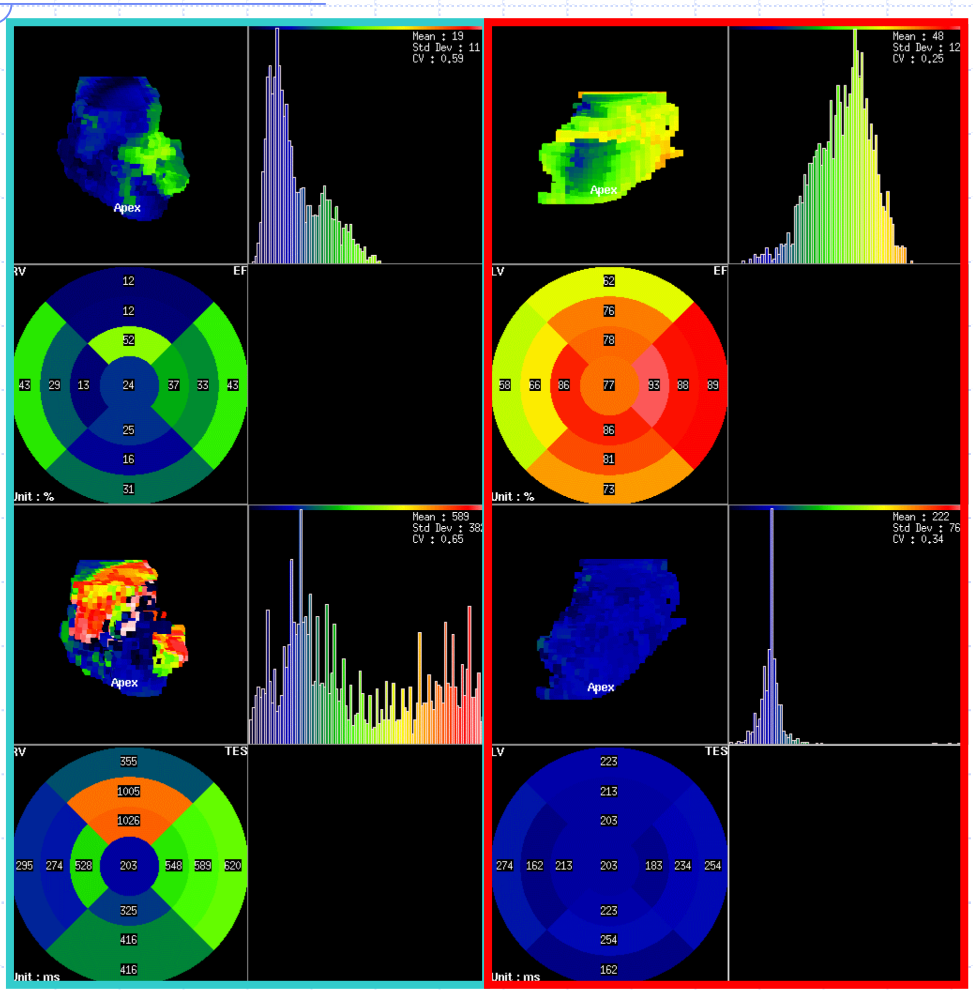
Parameter	Control subjects	Patients with localized ARVD	Patients with diffuse ARVD
EF (%)	63 ± 7	60 ± 5	33 ± 12†
EDV (mL)	101 ± 17	107 ± 20	180 ± 81‡
ESV (mL)	37 ± 8	43 ± 10	124 ± 70†
σ-EF (%)	13 ± 3	14 ± 2	11 ± 3
σ-TES (ms)	63 ± 24	167 ± 64†	277 ± 106†

Sensitivity, Specificity, Positive Predictive Value (PPV), and Negative Predictive Value (NPV) of Right Ventricular EF, Volumes, and σ-TES for Diagnosis of Diffuse ARVD in Patients with Symptomatic Ventricular Arrhythmias

Parameter	Threshold	% Sensitivity (95% CI)	% Specificity (95% CI)	% PPV (95% CI)	% NPV (95% CI)
EF	49%	95 (77–100)	100 (84–100)	100 (84–100)	95 (77–100)
EDV	104 mL	91 (71–99)	71 (52–91)	77 (61–93)	88 (64–98)
ESV	53 mL	95 (77–100)	100 (84–100)	100 (84–100)	95 (77–100)
σ-TES	123 ms	91 (71–99)	100 (84–100)	100 (83–100)	91 (72–99)

D. Mariano-Goulart et al. J Nucl Med. 2007; 47: 1416-1423

DYSPLASIE ARYTHMOGENE VD



FE

σ -TES

VD VG

DVDA locales:

σ_{TES} > 80 ms

Se = 100%
VPN = 100%

Sp = 81 %
VPP = 80%

D. Mariano-Goulart et al. JNM 2007;48

Perspectives de recherche

- Evaluation pronostique des IC
  - FEVD, Volumes, dyskinésies
- Rythmologie
  - Diagnostic
  - Indications de PMK multisites, def. implantables
- Débits ventriculaires D et G
  - CIV, valvulopathies…
- Lien MIBG – σTES ?

Références en anglais

Semi-automatic segmentation of gated blood-pool emission tomographic images by watersheds. Application to the determination of right and left ejection fractions. D Mariano-Goulart, H Collet, PO Kotzki, M Zanca, M Rossi.
Eur J Nucl Med 1998; 25(9): 1300-07.

Routine measurements of left and right ventricular output by gated blood-pool emission tomography in comparison with thermodilution measurements : a preliminary study. D Mariano-Goulart, C Piot, V Boudousq, F Raczka, F Comte, MC Eberlé, M Zanca, PO Kotzki, JM Davy, M Rossi.
Eur J of Nucl Med. 2001; 28(4): 506-513.

Electrocardiographically gated blood-pool spect and left ventricular function: comparative value of 3 methods for ejection fraction and volume estimation. D Daou, F Harel, BO Helal, T Fourme, P Colin, R Lebtahi, D Mariano-Goulart, M Faraggi, M Slama, D Le Guludec.
J Nucl Med 2001; 42(7): 1043-9.

Major increase of brain natriuretic peptide indicates right ventricular systolic dysfunction in patients with heart failure. D Mariano-Goulart, MC Eberlé, V Boudousq, A Hejazi-Moughari, C Piot, C Caderas de Kerleau, R Verdier, ML Barge, F Comte, N Bressot, M Rossi, PO Kotzki.
Eur J Heart Failure 2003; 5(4): 481-488.

Automatic generation of noise-free time-activity curve with gated blood-pool emission tomography using deformation of a reference curve. C Caderas de Kerleau, E Ahronowitz, M Rossi, D Mariano-Goulart.
IEEE Trans Med Imaging 2004 ; 23(4) : 485-91

Diagnosis of Diffuse and Localized Arrhythmogenic Right Ventricular Dysplasia using Gated Blood-Pool SPECT. D Mariano-Goulart, L Déchaux, F Rouzet, E Barbotte, C Caderas de Kerleau, M Rossi, D Le Guludec.
J Nucl Med 2007; 48(9):1416-1423

Références en français

Détermination des fractions d'éjection et des débits cardiaques par tomoventriculographie isotopique. Méthodologie et validation clinique. D Mariano-Goulart, V Boudousq, MC Eberlé, H Collet, F Comte, M Rossi.
Revue de l'Acomen 2000; 6(1) :69-77.

Corrélation entre les valeurs du BNP plasmatique et les mesures isotopiques de la fraction d'éjection ventriculaire gauche. M Rasamisoa, N Bressot, C Vergnes, D Mariano-Goulart, M Rossi.
Immunoanalyse & Biologie Spécialisée 2002; 17(5) :311-315

Extraction automatique des paramètres ventriculaires locaux en tomo-ventriculographie isotopique. D Mariano-Goulart, C Caderas de Kerleau, M Rossi.
Médecine nucléaire 2005; 29(3): 115-130.

Apport de la tomo-ventriculographie isotopique dans le diagnostic de la dysplasie arythmogène du ventricule droit . L. Déchaux, F. Rouzet, D. Le Guludec, M. Rossi, D. Mariano-Goulart.
Médecine nucléaire 2006 ; 30(5) :261-269.

Actes de congrès internationaux

Routine measurements of right and left ejection fractions thanks to the segmentation of gated blood pool emission tomographic images by a watershed algorithm. D Mariano-Goulart, H Collet, MC Eberle, V Boudousq, PO Kotzki, M Zanca, M Rossi.
Eur J of Nucl Med 1999; 26(9): 1078

Accuracy of two different softwares for left ventricular ejection fraction and volume estimation with ECG-gated blood pool imaging. D. Daou, F. Harel, D. Mariano-Goulart, R. Lebtahi, I. Carel, T. Fourme, P. Colin, B.O. Helal, M. Slama, M. Faraggi, D. Le Guludec.
Eur J of Nucl Med 2000 ; 27(8) :1048.

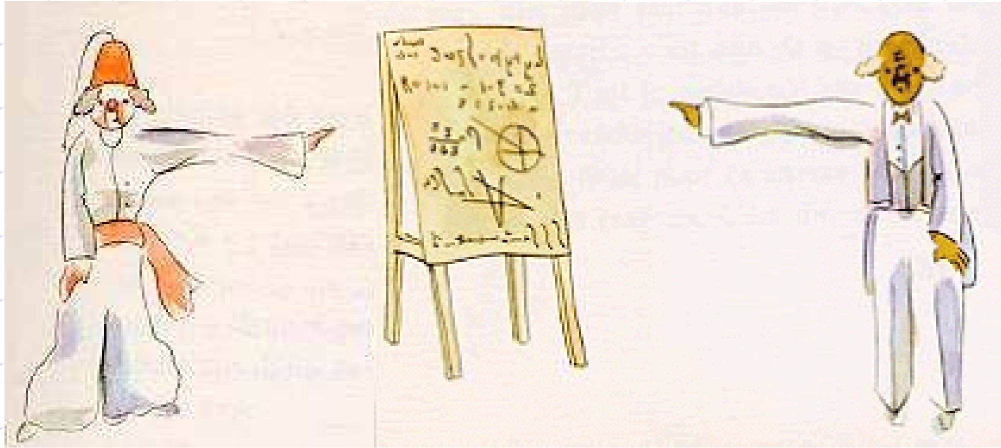
Calculation of left ventricular ejection fraction from planar and tomographic radionuclide ventriculography studies : a dynamic left ventricular study. P. De Bondt, S Vandenberghe, J De Sutter, S De Mey, T Cottens, C Van de Wielel, O De Winter, P Segers, D Mariano-Goulart, P Verdonck, RA Dierckx. Xth Triennal Symposium of the Belgian Society for Nuclear Medicine. Knokke: 2001:21.

Comparative value of two different processing softwares for left ventricular ejection fraction and volume estimation with ECG gated blood pool imaging. D. Daou, F. Harel, D. Mariano-Goulart, B. Helal, M. Slama, M. Faraggi, D. Le Guludec.
5th International Conference of Nuclear cardiology. May 2-5,2001.Vienne. Autriche.

ECG-gated blood pool SPECT versus planar imaging for the determination of left ventricular filling pressure coronary artery disease. D Daou, BO Helal, Carol , C Coaguila, D Vilain, T Fourme, S Dinanian , M Slama. *J Nucl Cardiol.* 2001;S109:16.50

A template-based model dedicated to the analysis of Time Activity Curves in Gated Blood-Pool Ventriculography. Denis Mariano-Goulart, Charles Caderas de Kerleau and Michel Rossi. (communication orale).
Eur J of Nucl Med 2005;32(1):S42.

Evaluation of tomographic gated blood-pool ventriculography in the diagnosis of arrhythmogenic right ventricular dysplasisa. D. Mariano-Goulart, L. Déchaux, E. Barbotte, D. Le Guludec, Michel Rossi.
Eur J of Nucl Med 2006;33(2):P091.



Merci de votre attention…