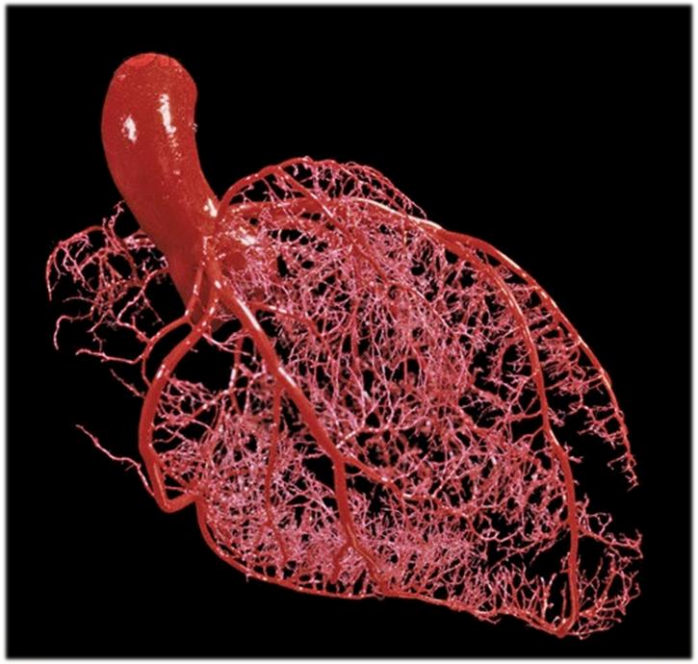
Dépistage et caractérisation de la pathologie coronarienne sévère par SPECT myocardique dynamique

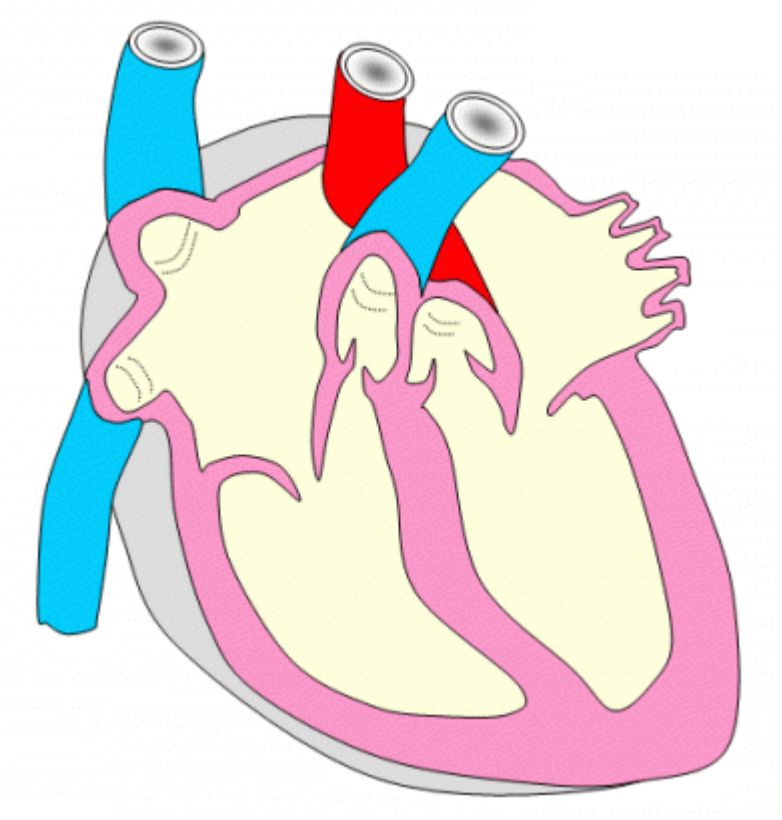
—o—



Fayçal Ben Bouallègue
CHU Montpellier – Service de Médecine Nucléaire

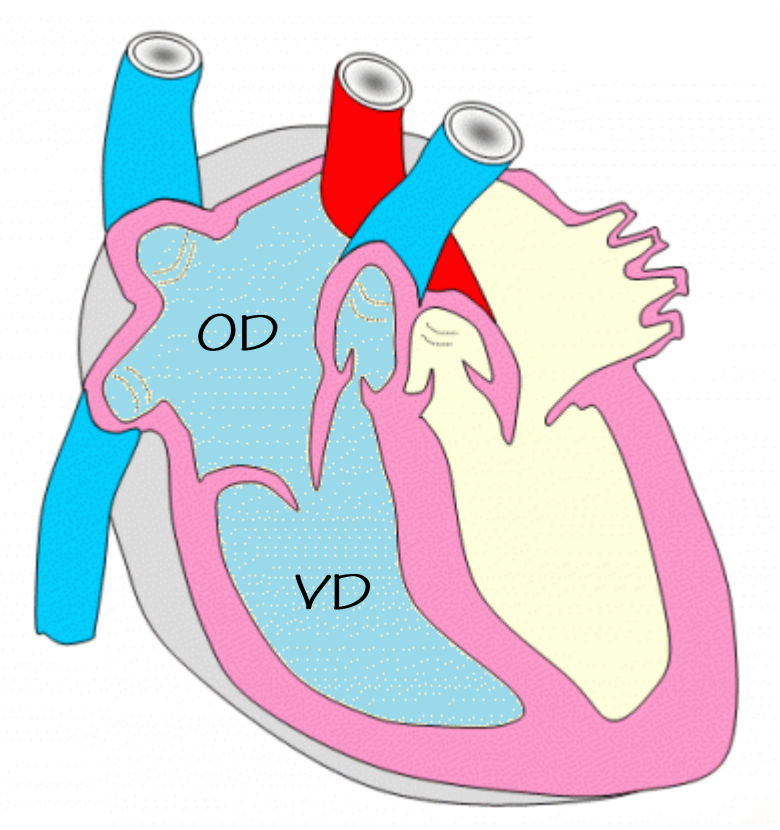
Pathologie coronarienne

Physiologie du cœur



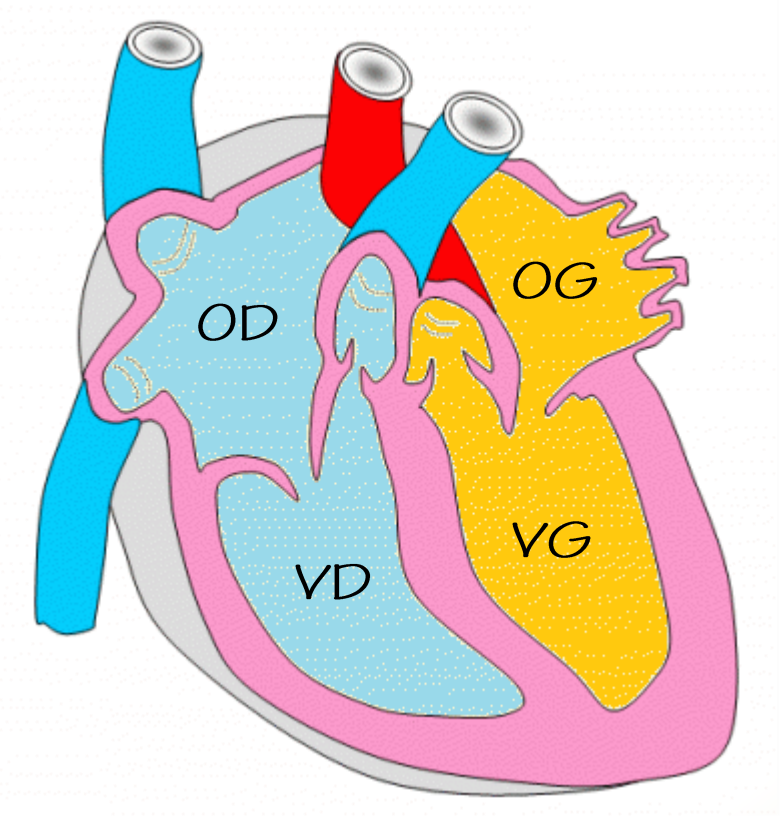
Pathologie coronarienne

Physiologie du cœur



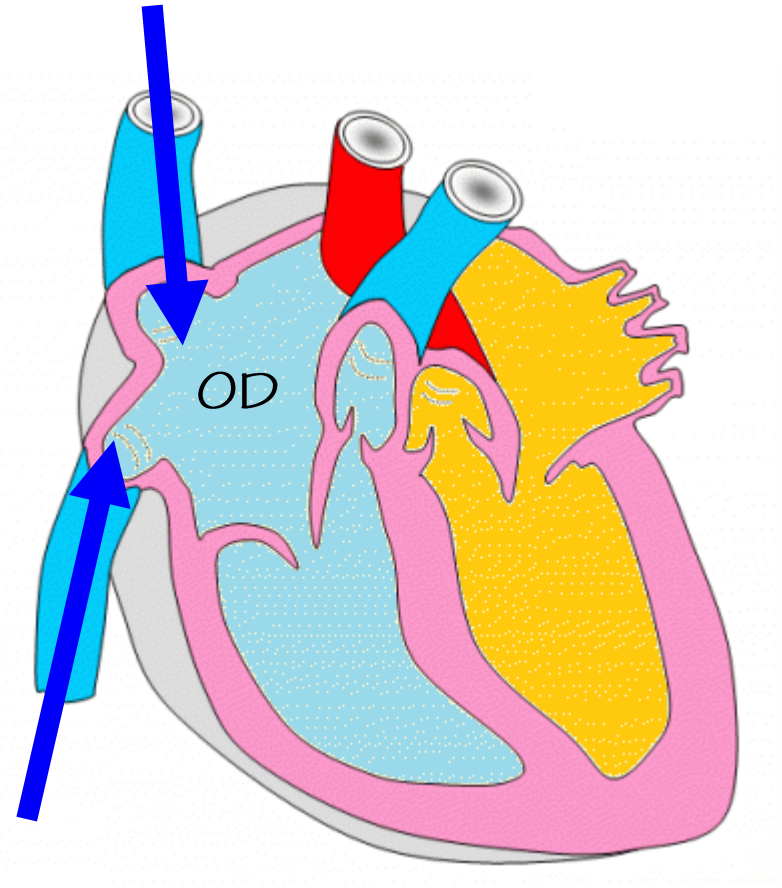
Pathologie coronarienne

Physiologie du cœur



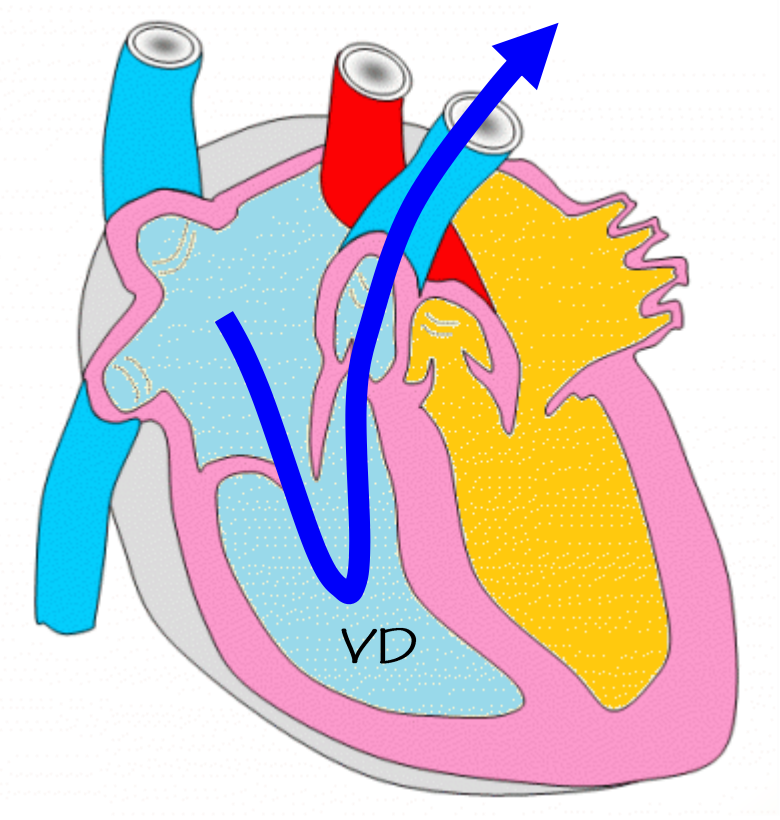
Pathologie coronarienne

Physiologie du cœur



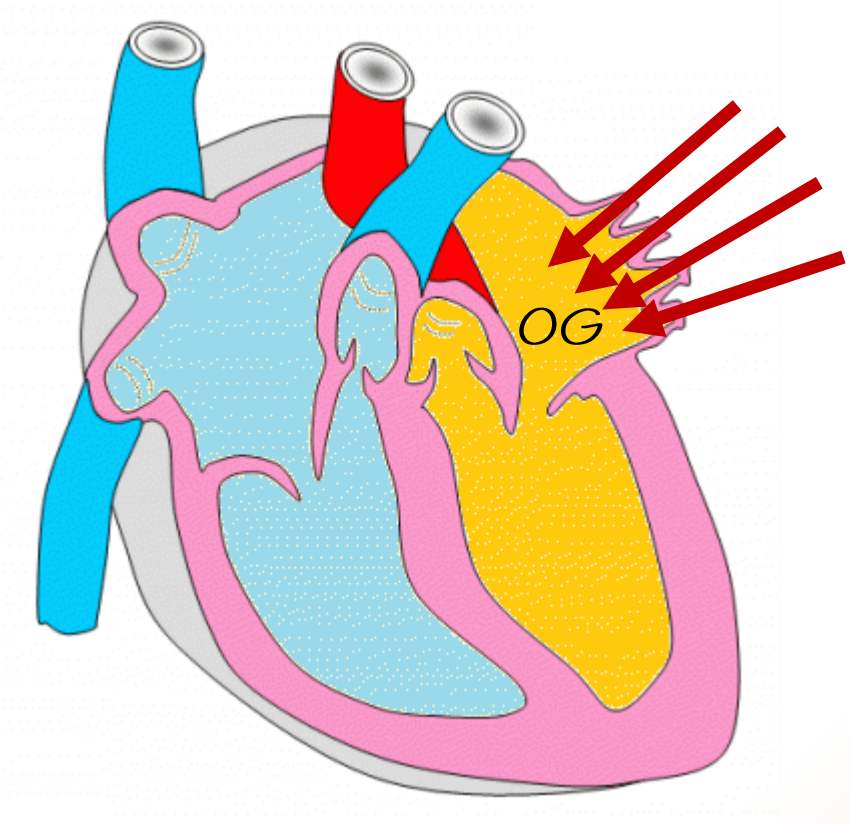
Pathologie coronarienne

Physiologie du cœur



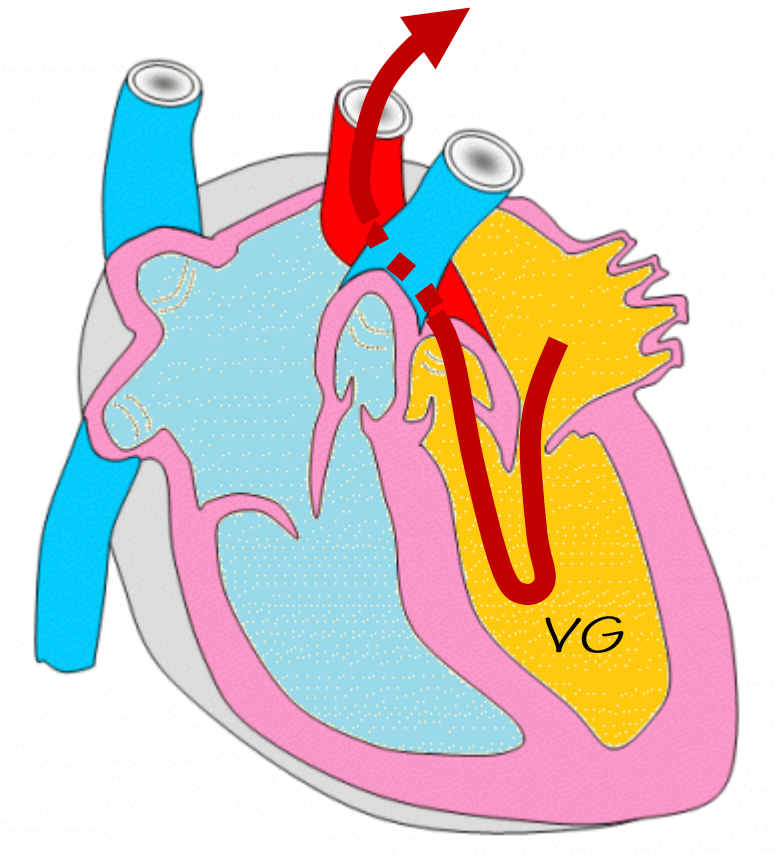
Pathologie coronarienne

Physiologie du cœur



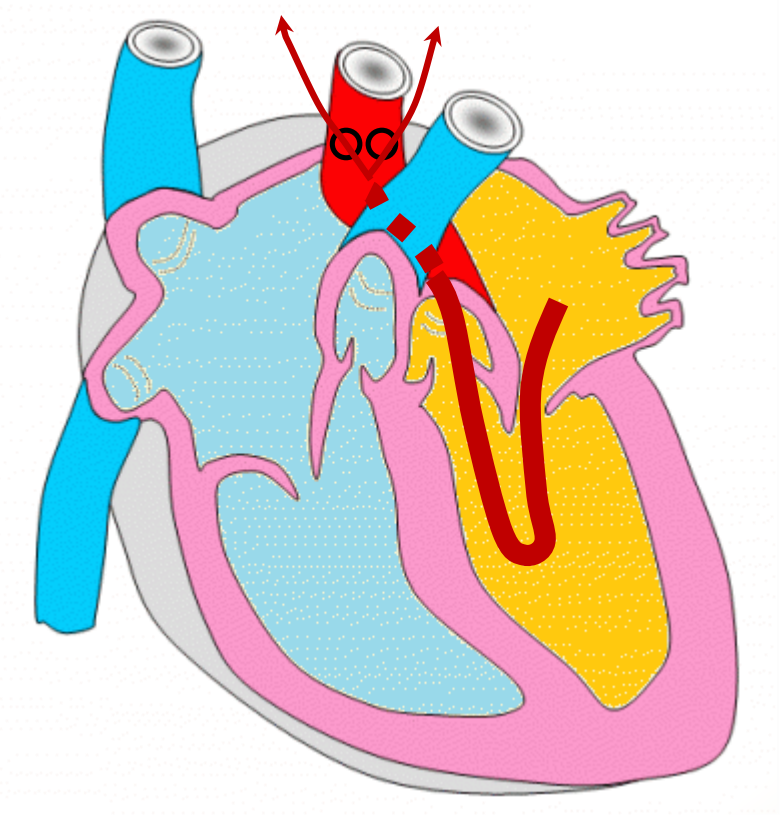
Pathologie coronarienne

Physiologie du cœur



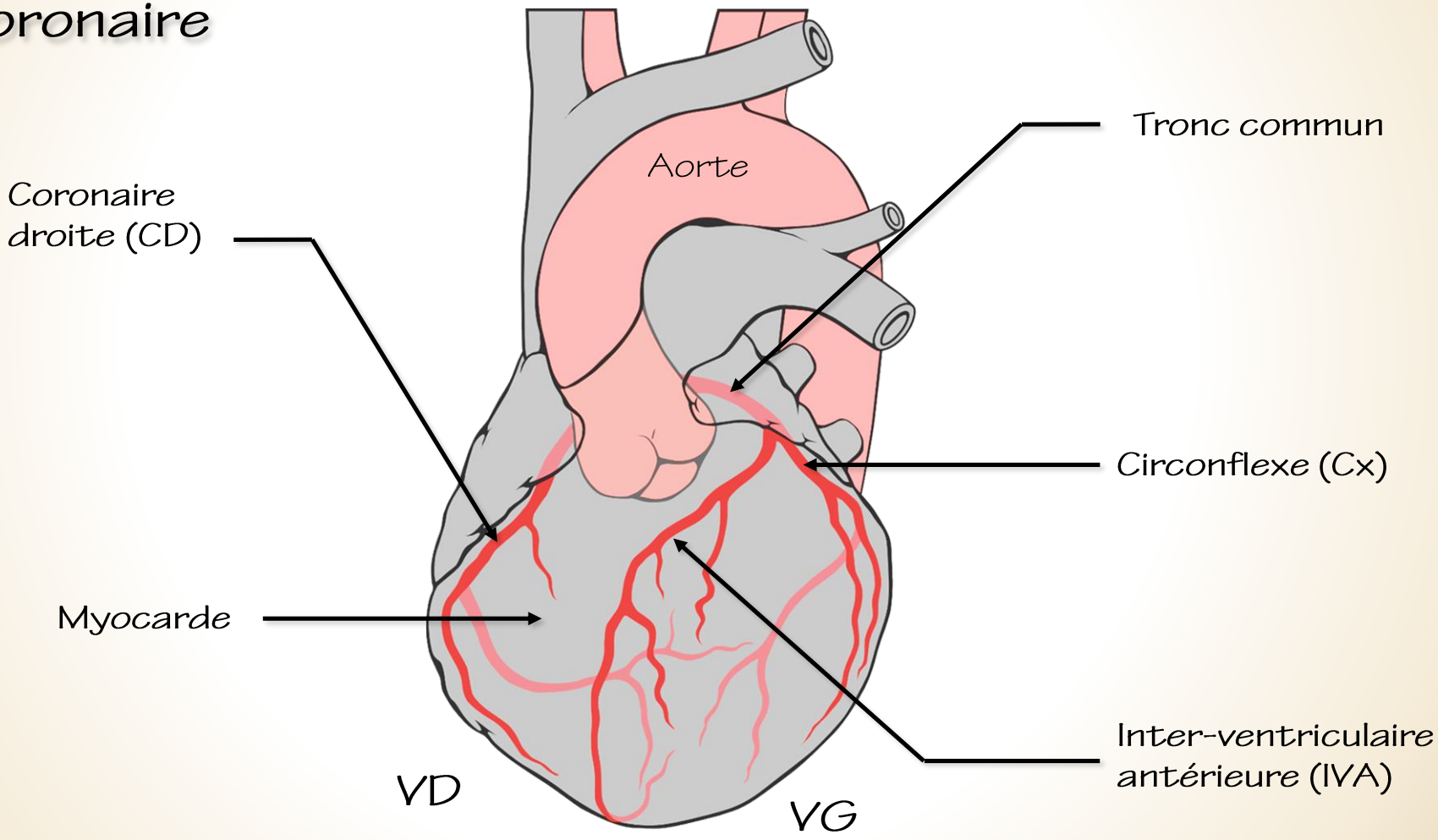
Pathologie coronarienne

Physiologie du cœur



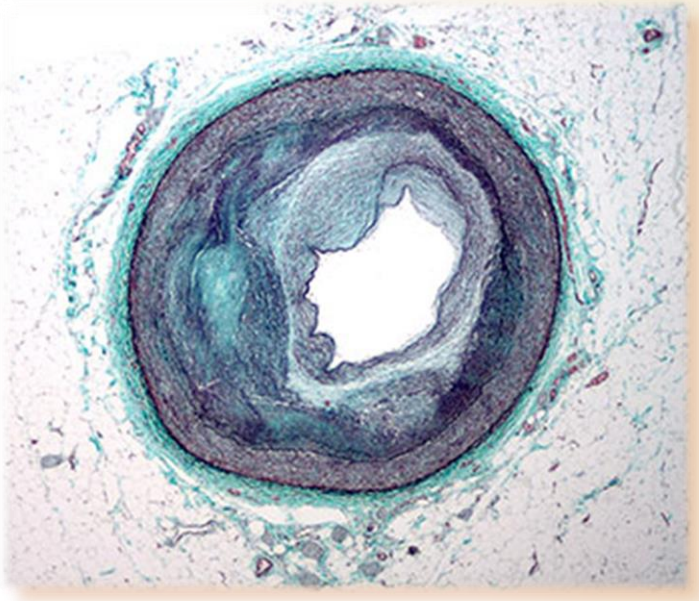
Pathologie coronarienne

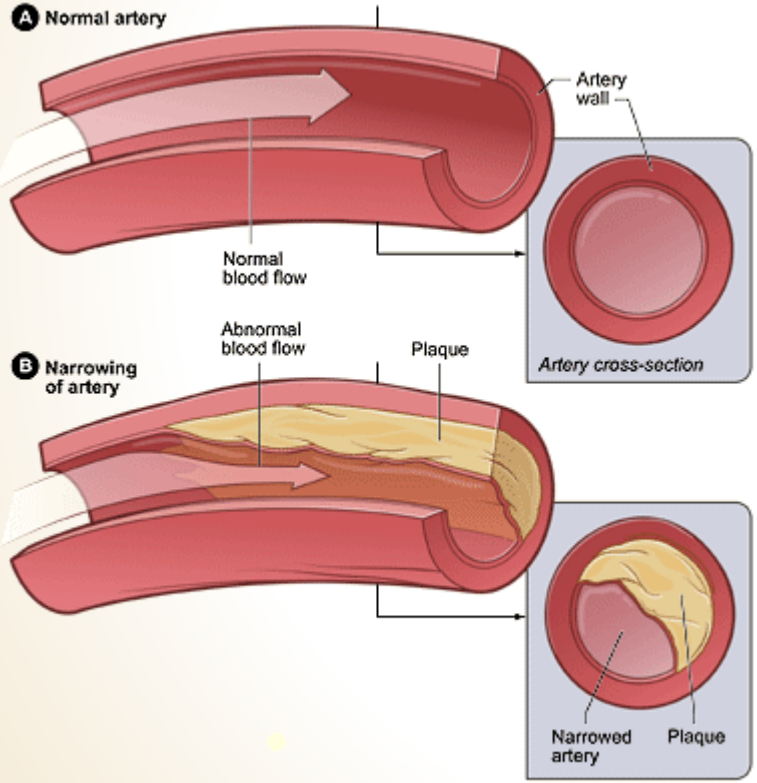
Vascularisation coronaire



Pathologie coronarienne

Ischémie myocardique

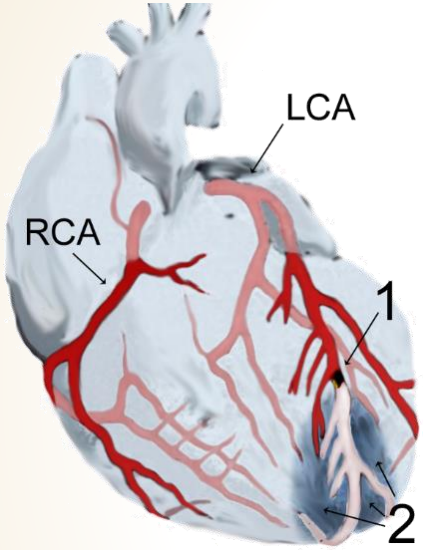




Sténose coronaire → Ischémie myocardique

Pathologie coronarienne

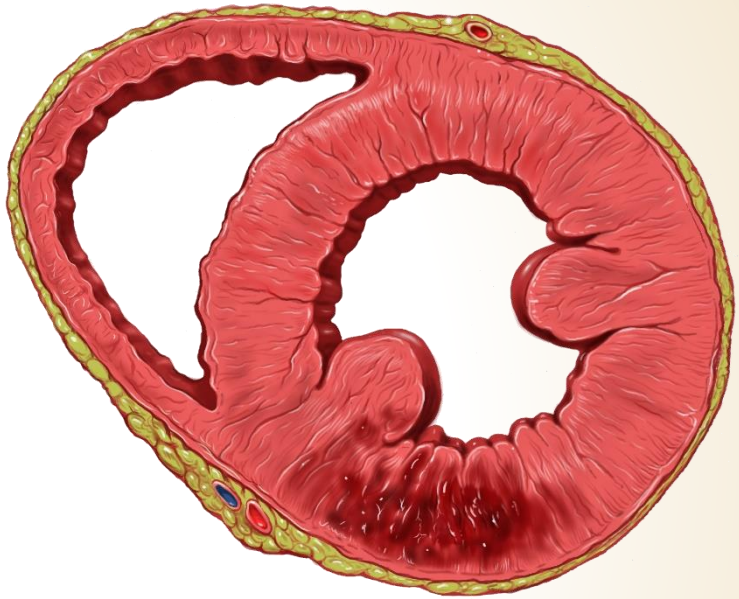
Ischémie myocardique



Sténose obstructive

↓

Infarctus



< 24h →

Nécrose myocardique

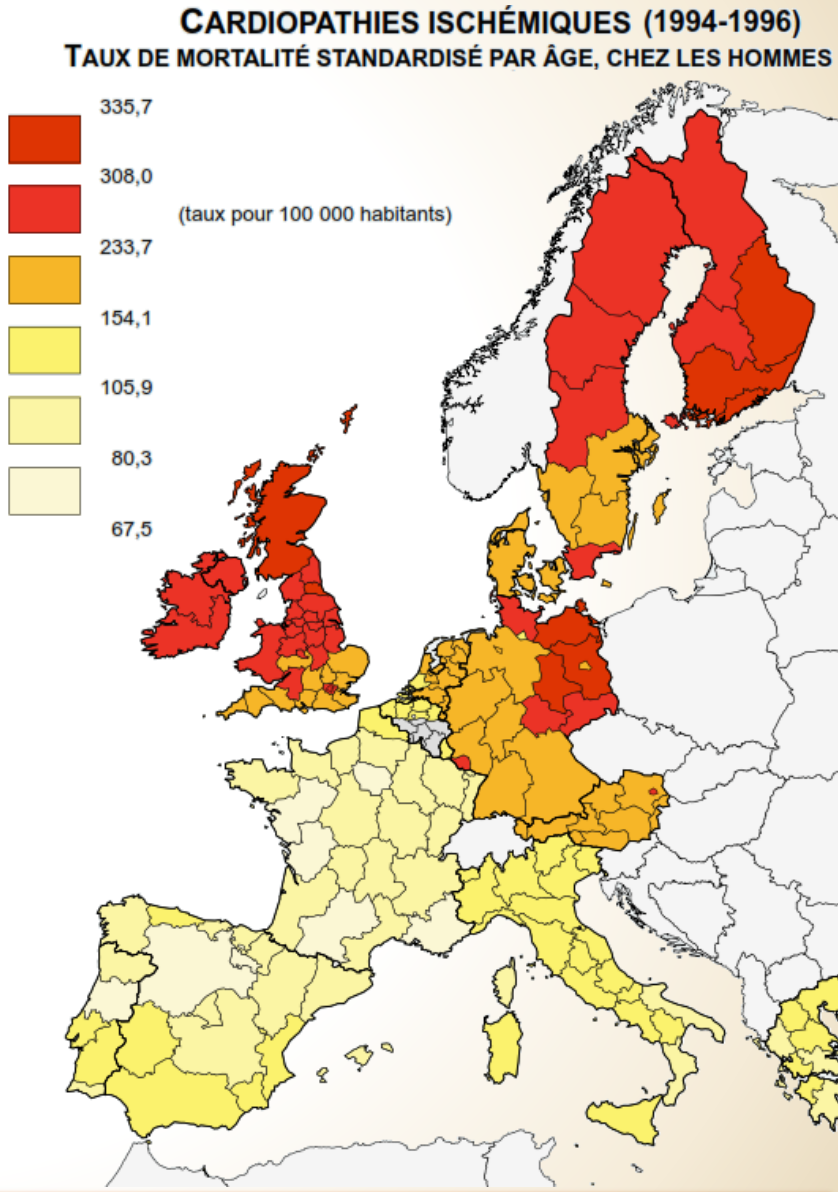
↓

Insuffisance cardiaque
Troubles du rythme
Mort subite

Pathologie coronarienne

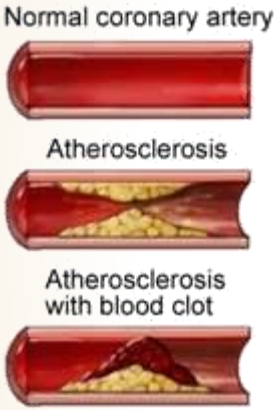
Statistiques
France 2008

Prévalence	1,800,000 (3%)
dont IDM	800,000 (1,2%)
Hospitalisations	> 300,000
Décès	38,000
ALD	> 1,000,000



Pathologie coronarienne

La cascade ischémique



↓ Flux coronaire

Modifications métaboliques

Dysfonction ventriculaire

Modifications électriques

Douleur

Pathologie coronarienne

Sténose coronaire

↓ Flux coronaire

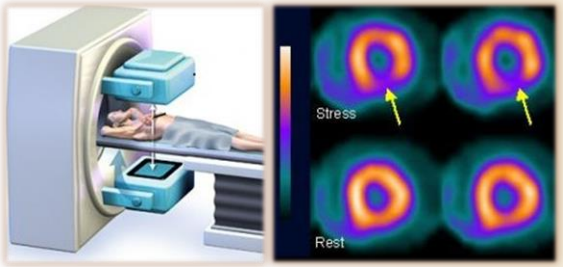
Modifications métaboliques

Dysfonction ventriculaire

Modifications électriques

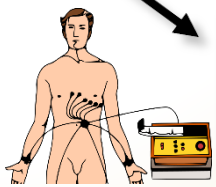
Douleur

coronarographie



tomoscintigraphie

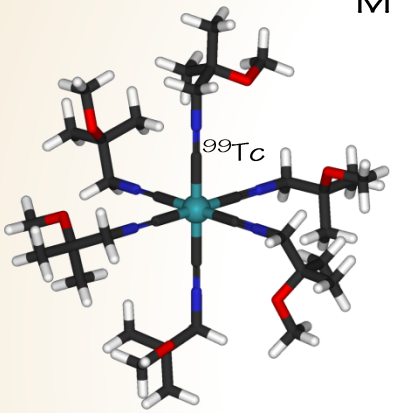
échocardiographie



ECG

Scintigraphie myocardique

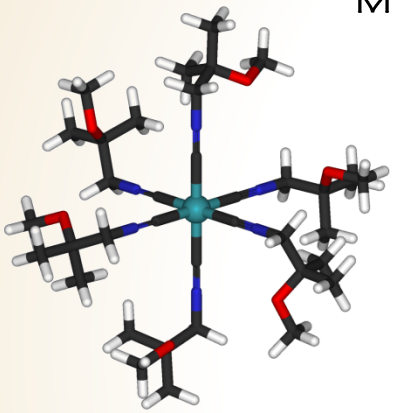
- Protocole



MIBI – 4 mCi

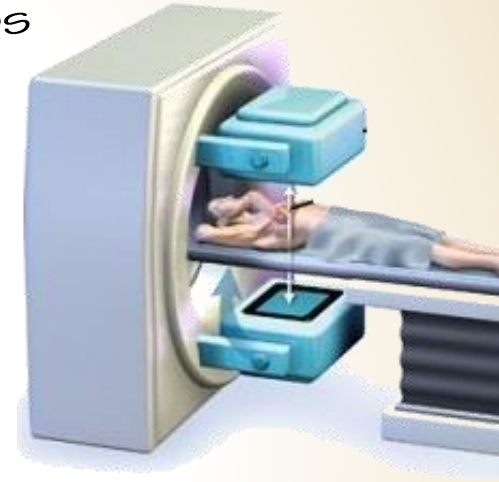
Scintigraphie myocardique

- Protocole



MIBI – 4 mCi

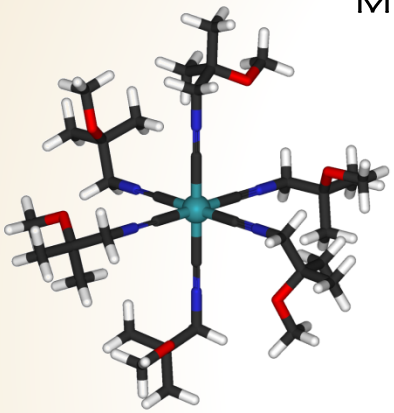
Repos



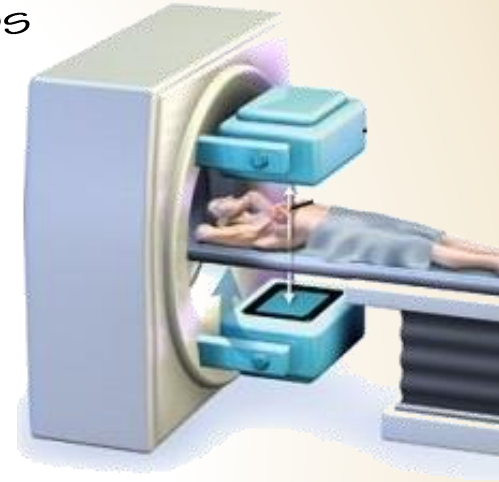
Scintigraphie myocardique

- Protocole

MIBI – 4 mCi



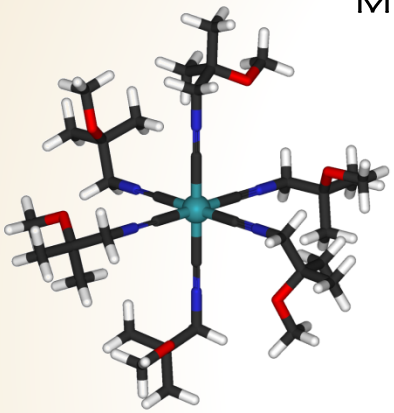
Repos

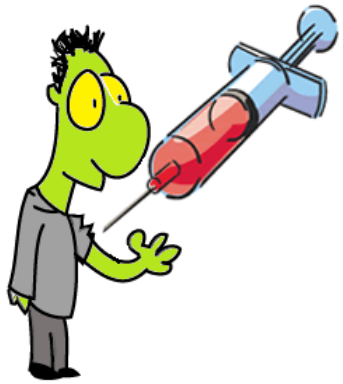


Scintigraphie myocardique

- Protocole

MIBI – 4 mCi





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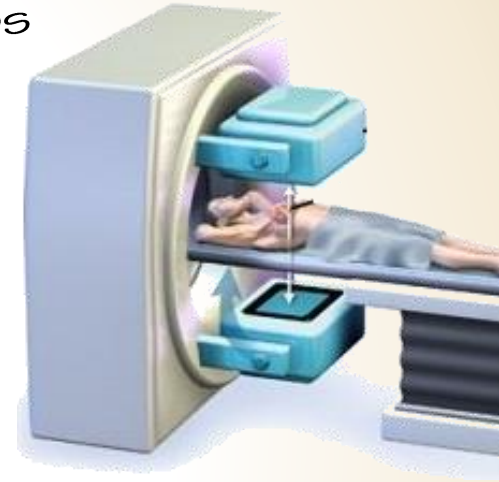
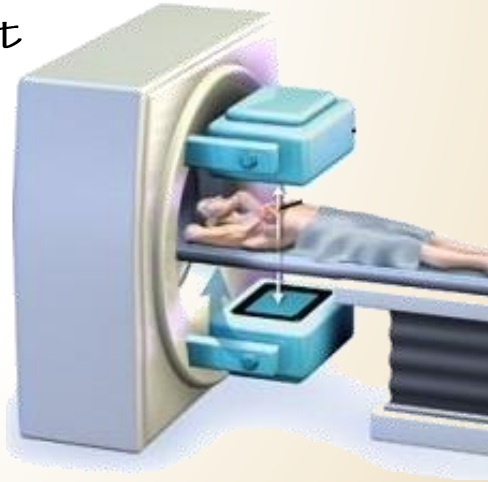


MIBI – 12 mCi

Effort

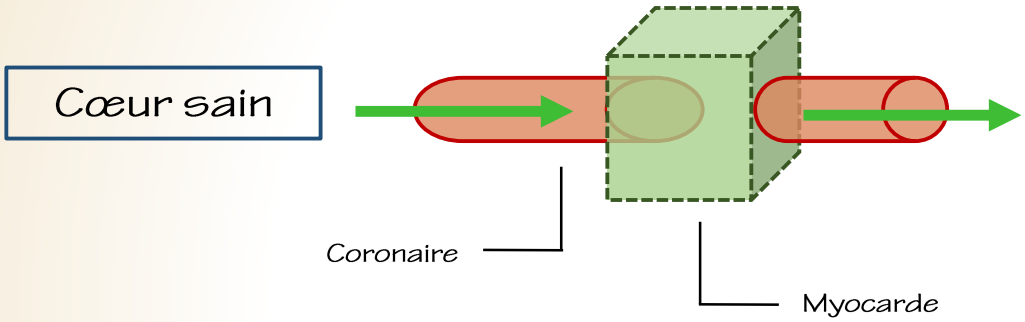


Scintigraphie myocardique

- Physiologie

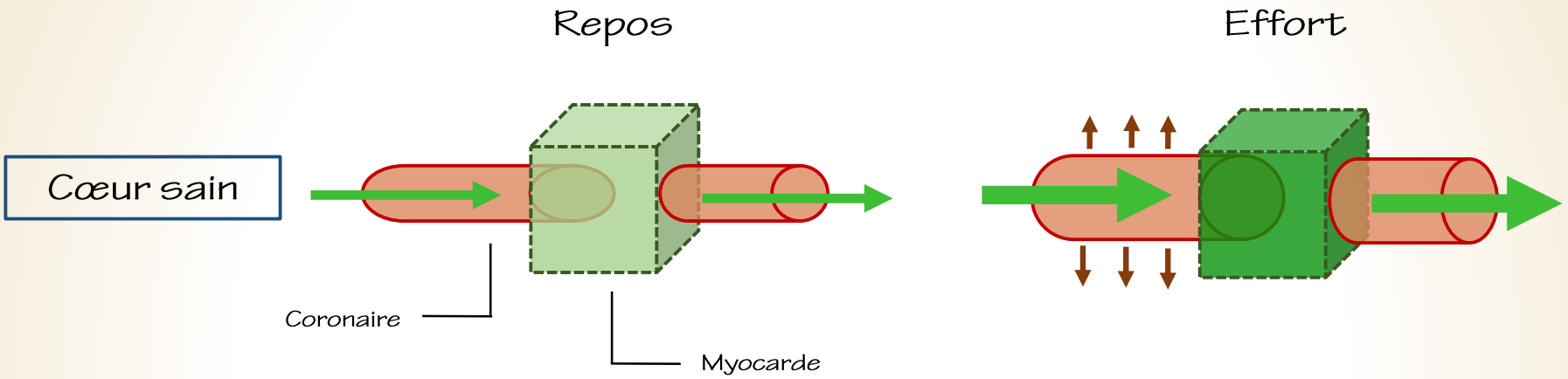
Repos

Effort



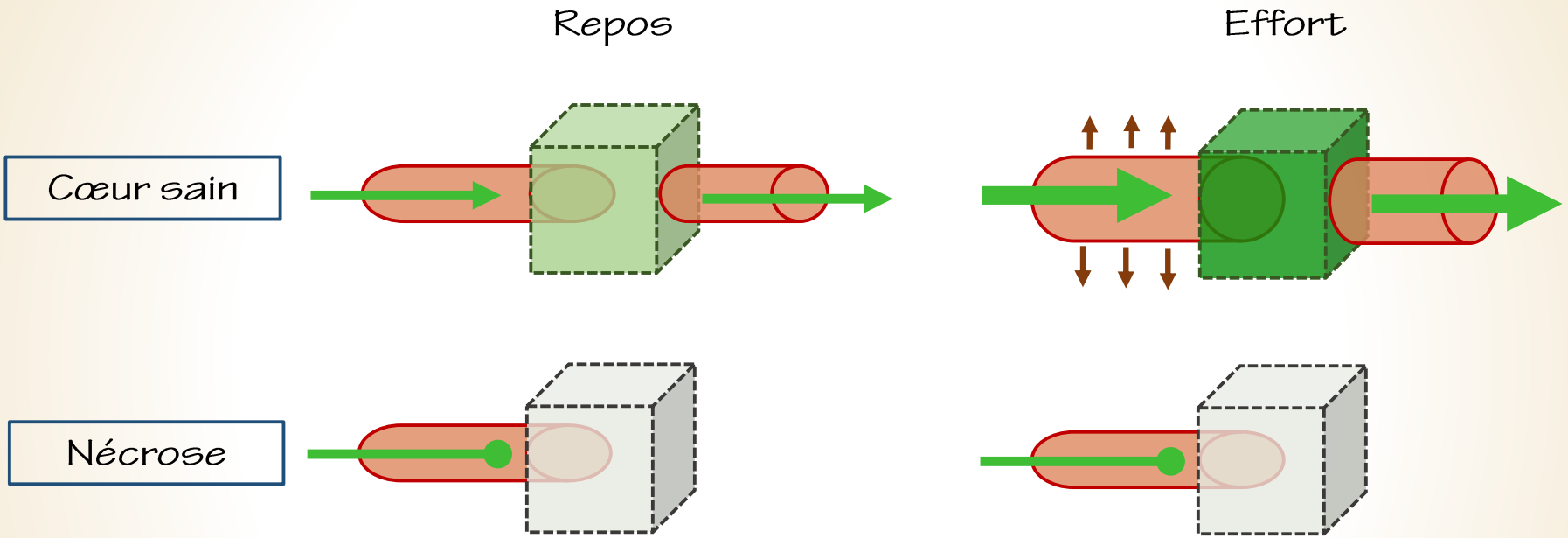
Scintigraphie myocardique

- Physiologie



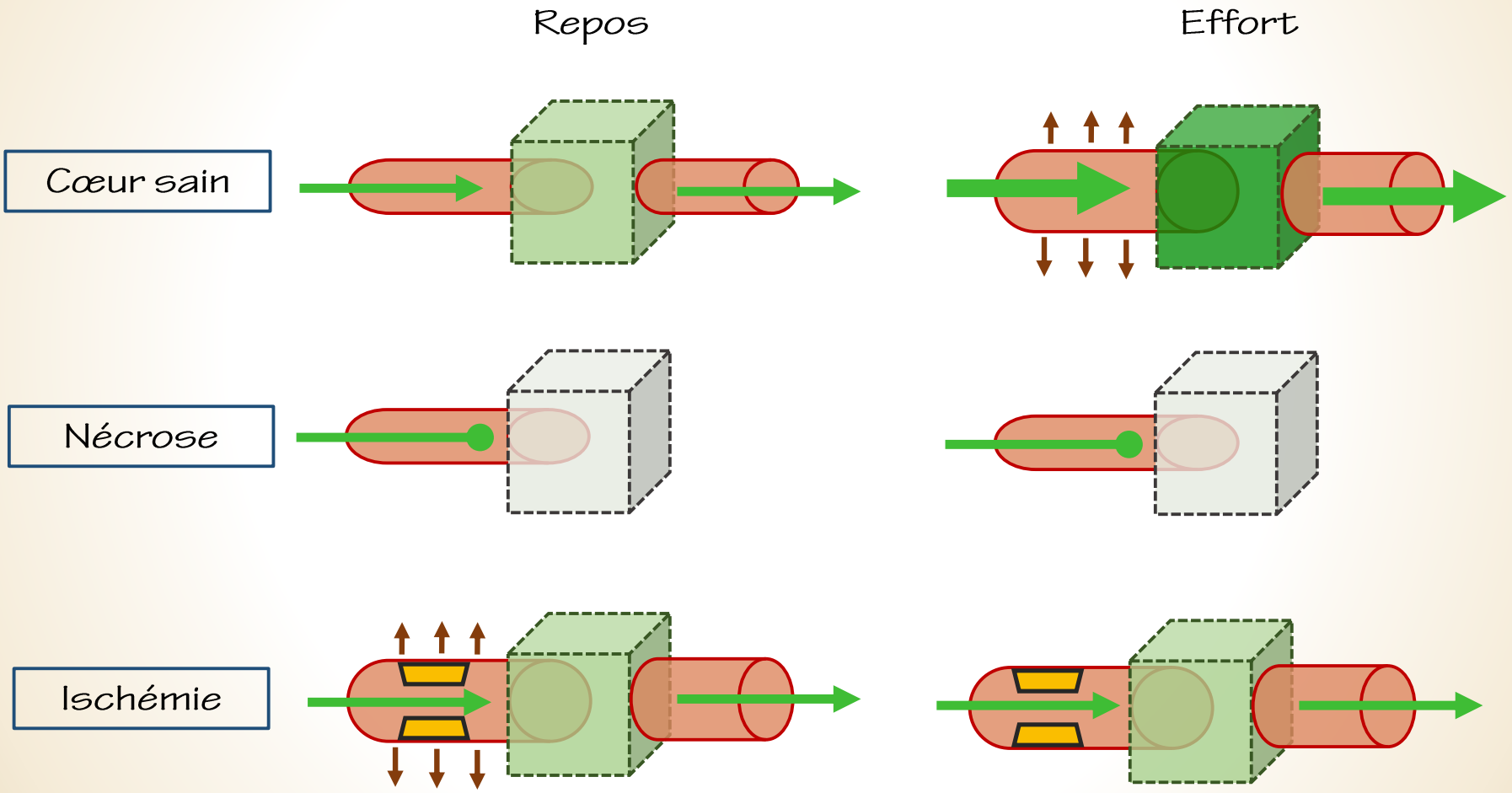
Scintigraphie myocardique

- Physiologie



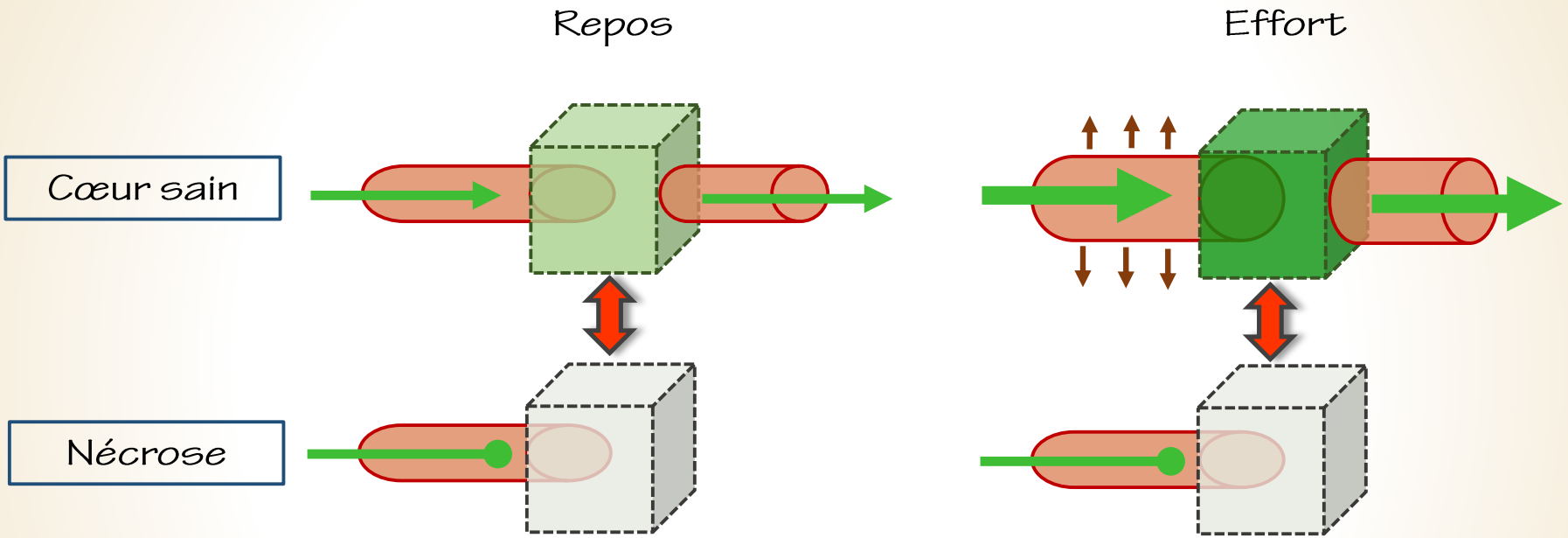
Scintigraphie myocardique

- Physiologie



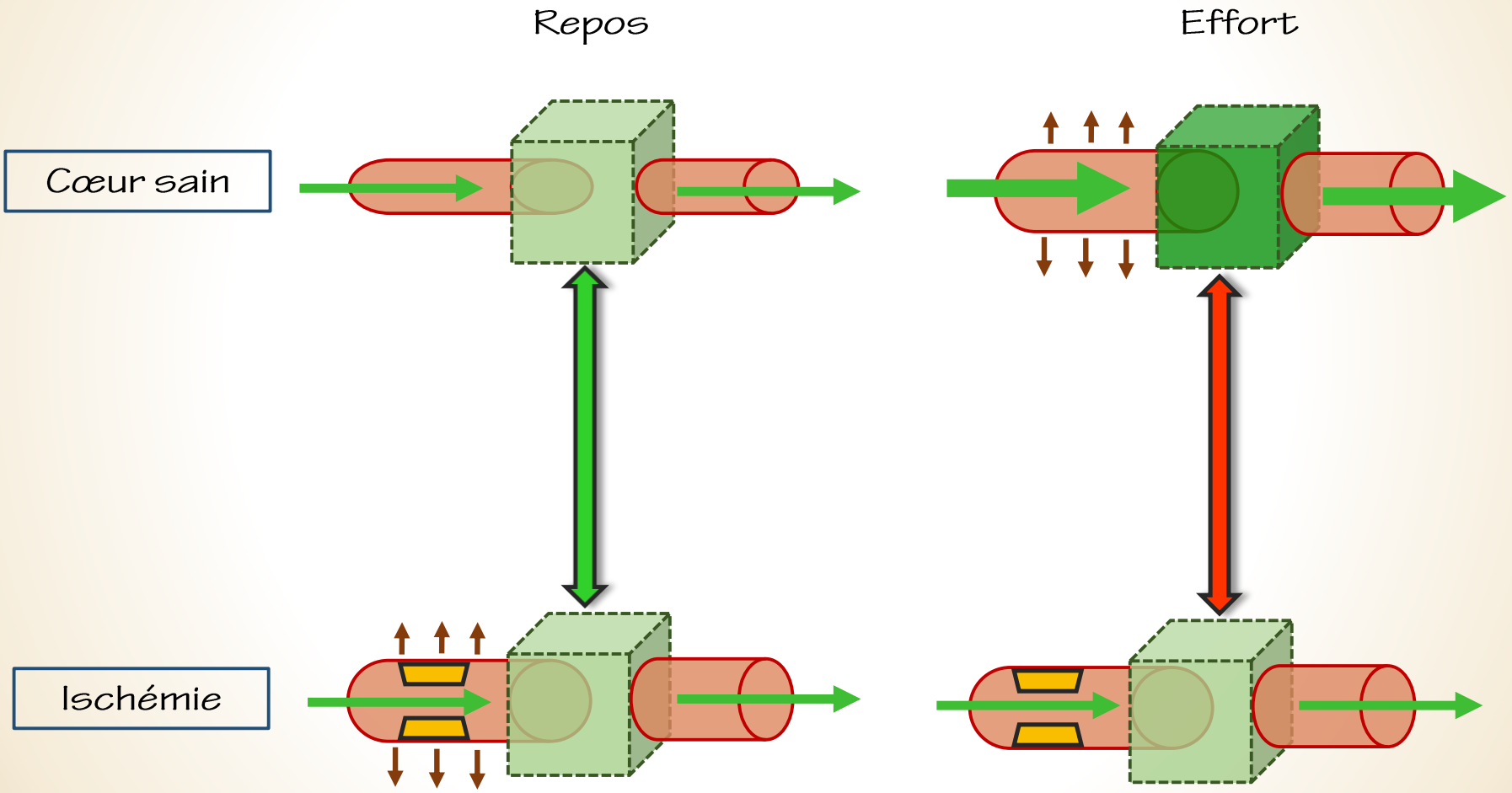
Scintigraphie myocardique

- Physiologie



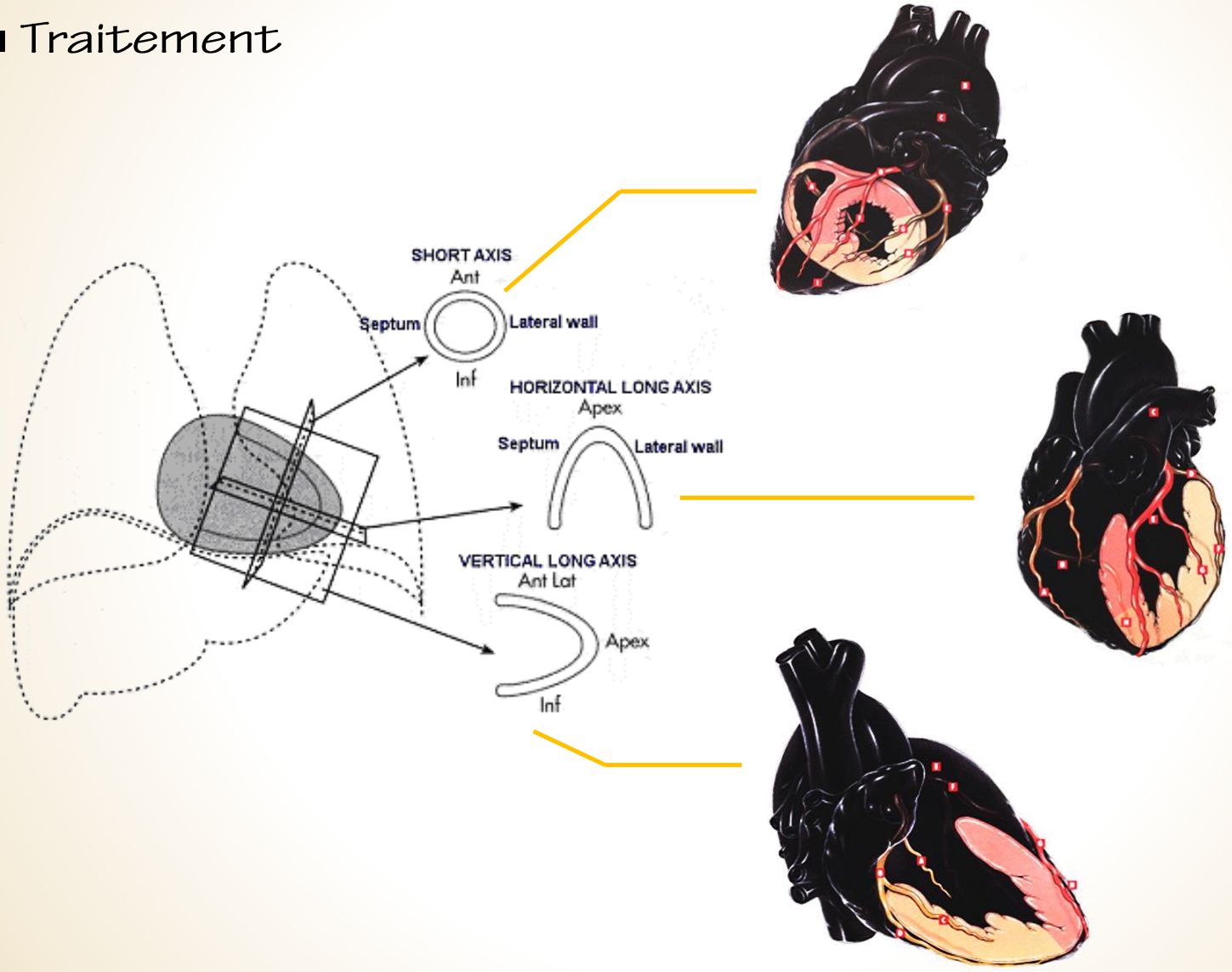
Scintigraphie myocardique

- Physiologie



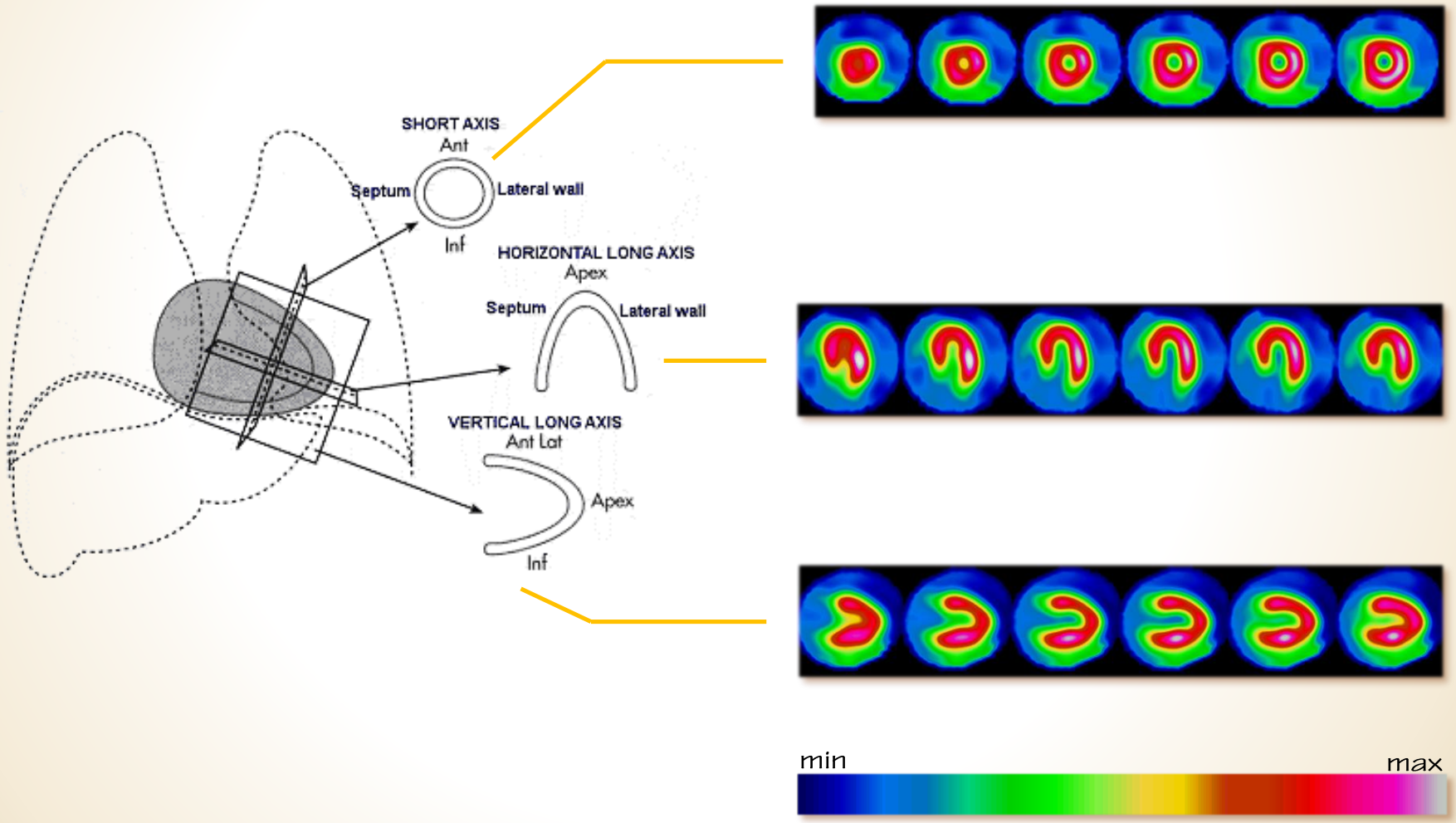
Scintigraphie myocardique

- Traitement



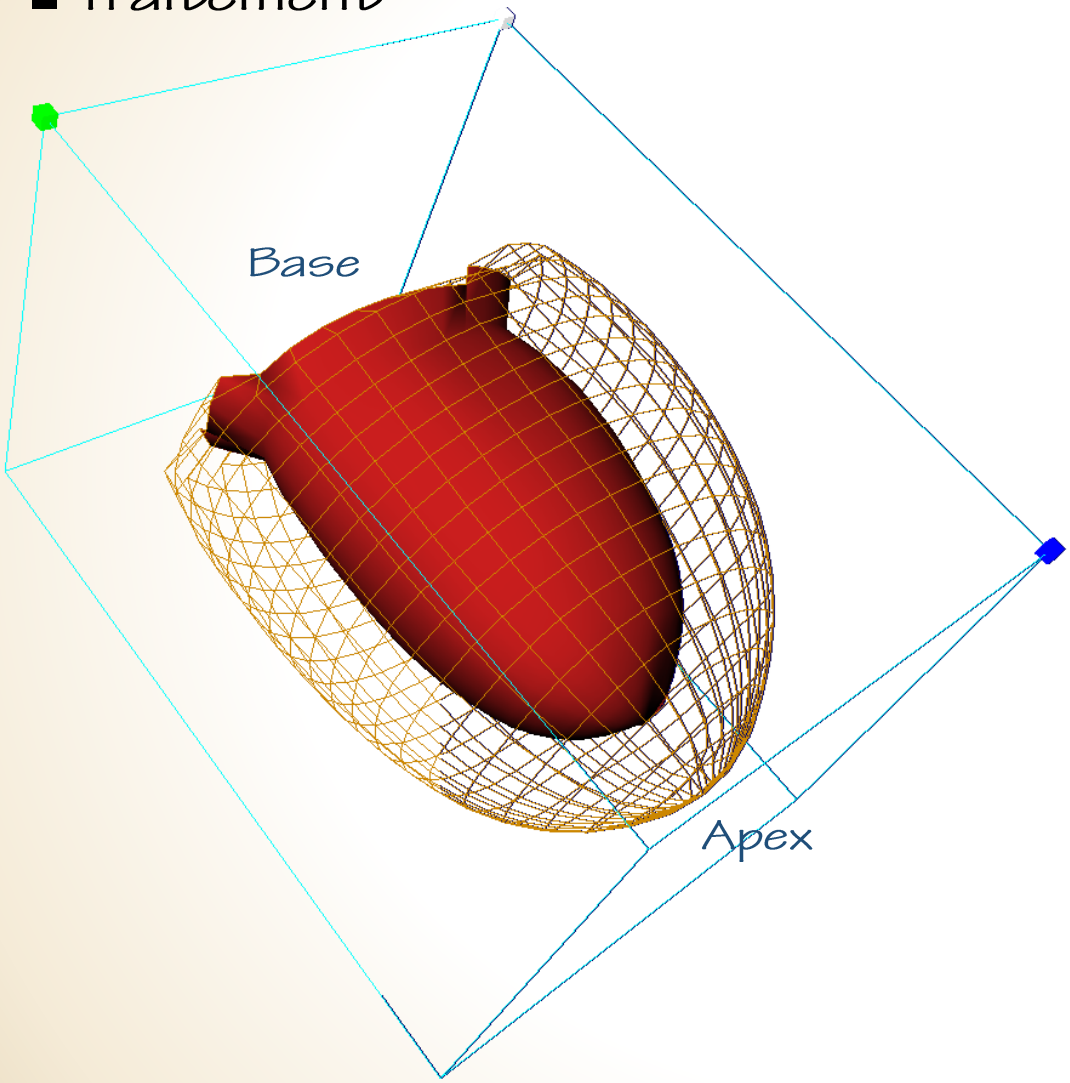
Scintigraphie myocardique

- Traitement



Scintigraphie myocardique

- Traitement



Scintigraphie myocardique

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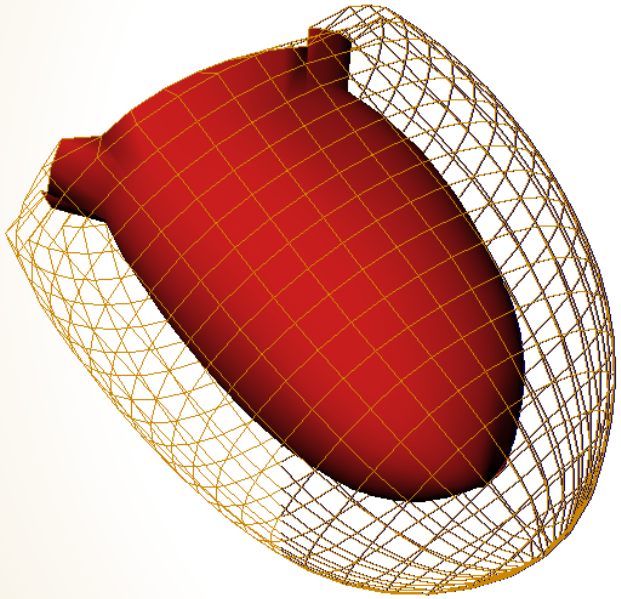
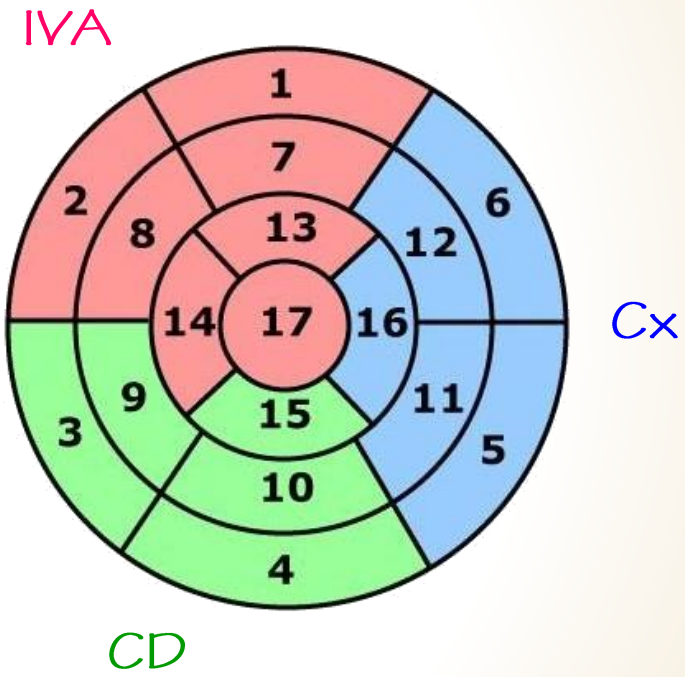
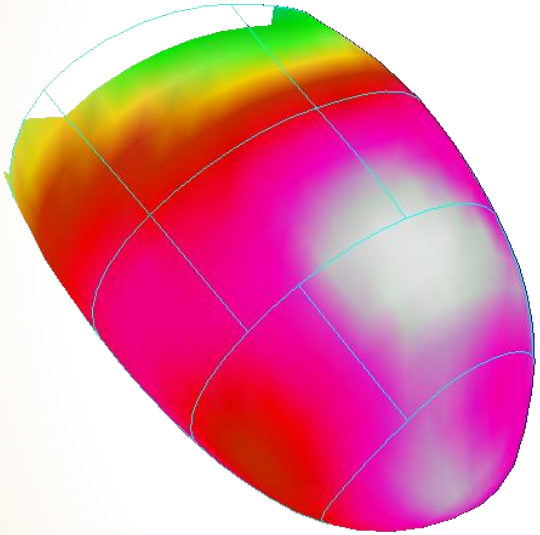
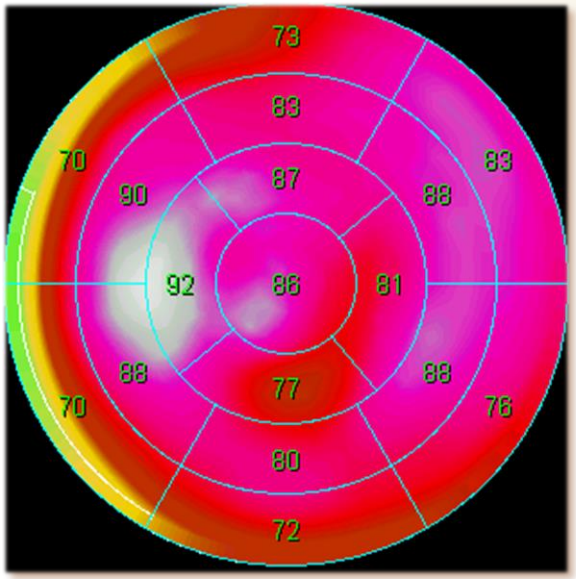


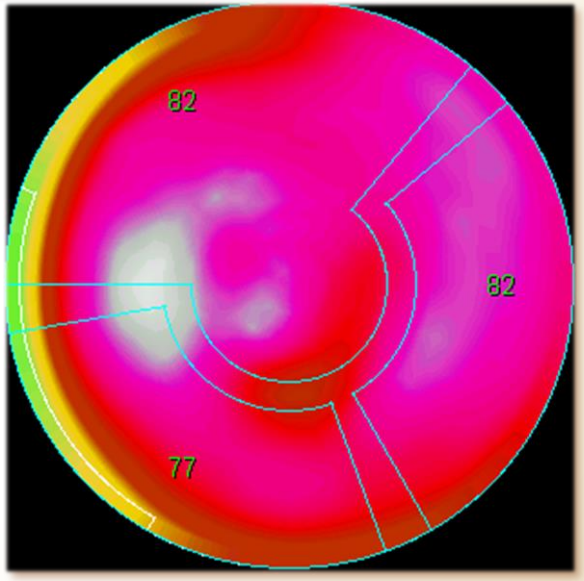


Scintigraphie myocardique

- Traitement

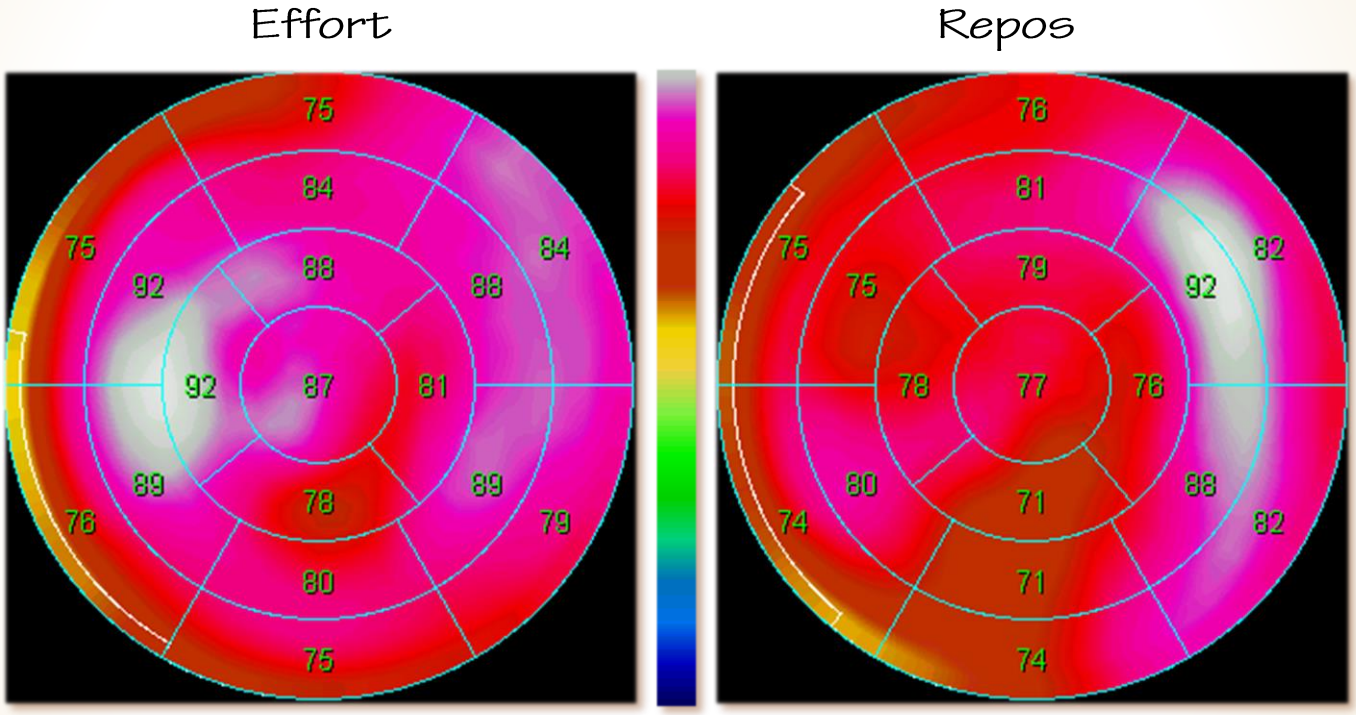






Scintigraphie myocardique

- Interprétation

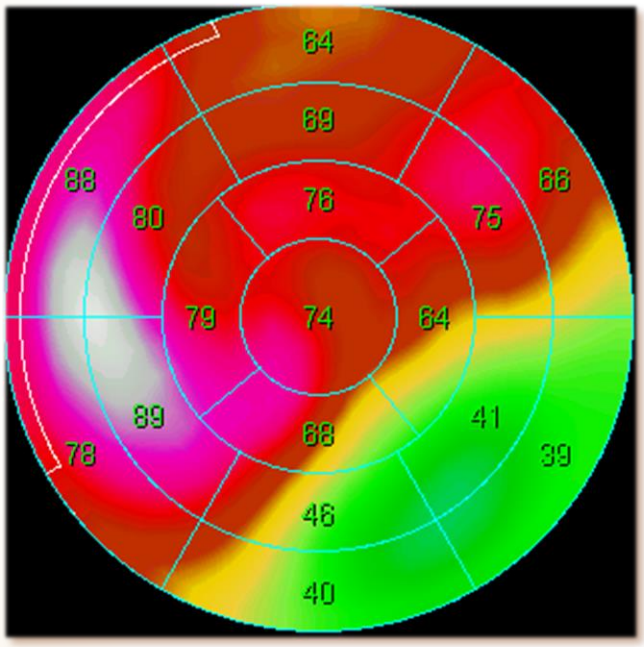


Scintigraphie normale

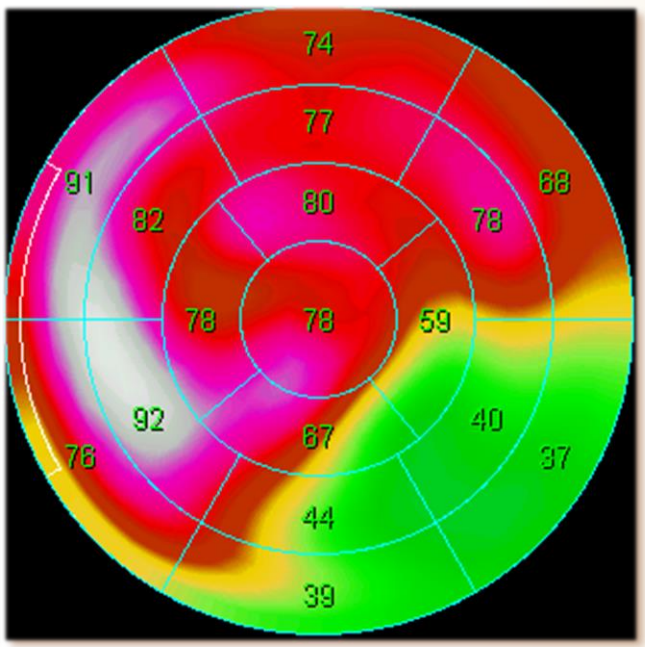
Scintigraphie myocardique

- Interprétation

Effort



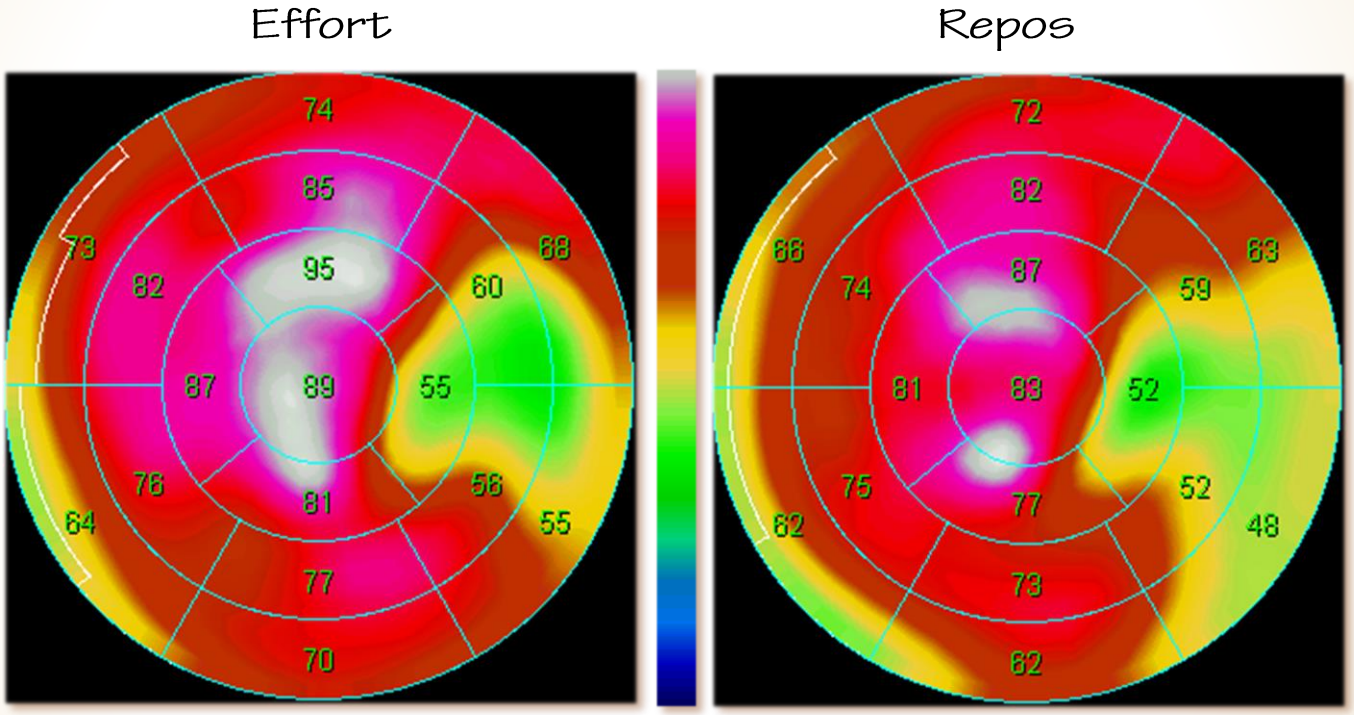
Repos



Séquelle d'infarctus

Scintigraphie myocardique

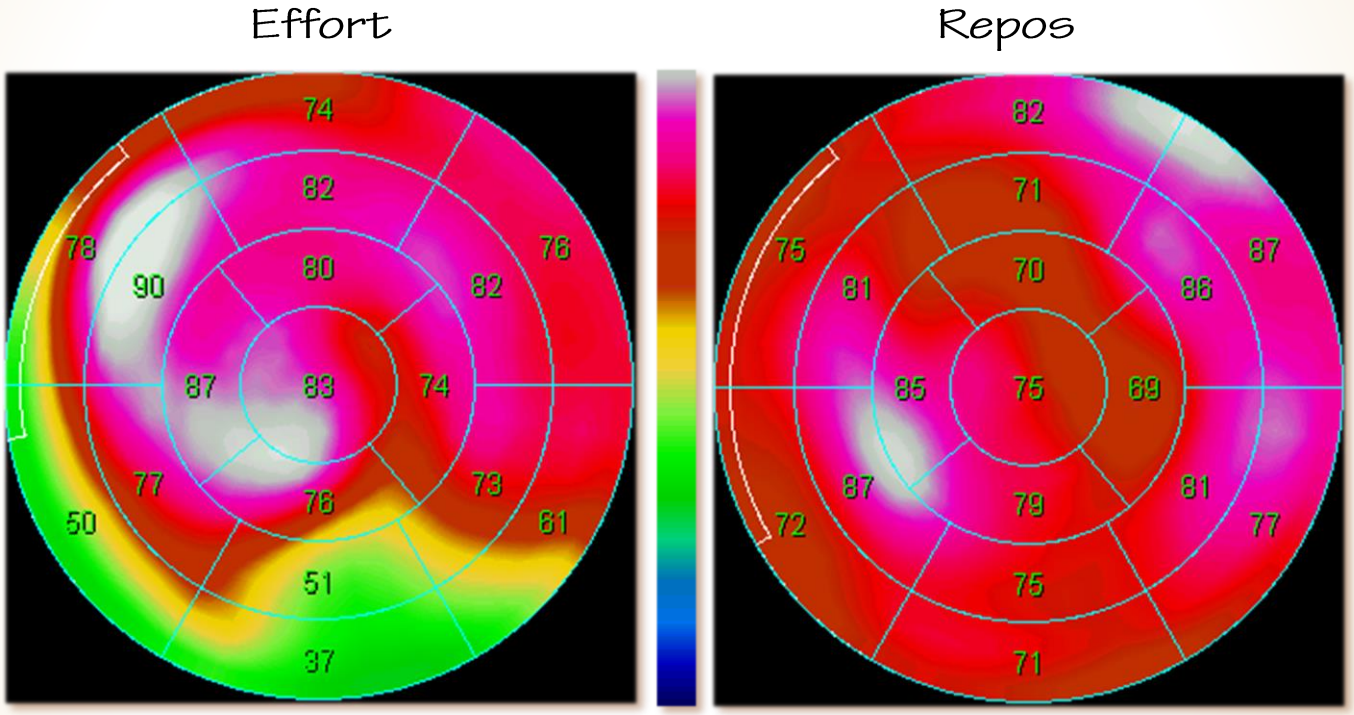
- Interprétation



Séquelle d'infarctus

Scintigraphie myocardique

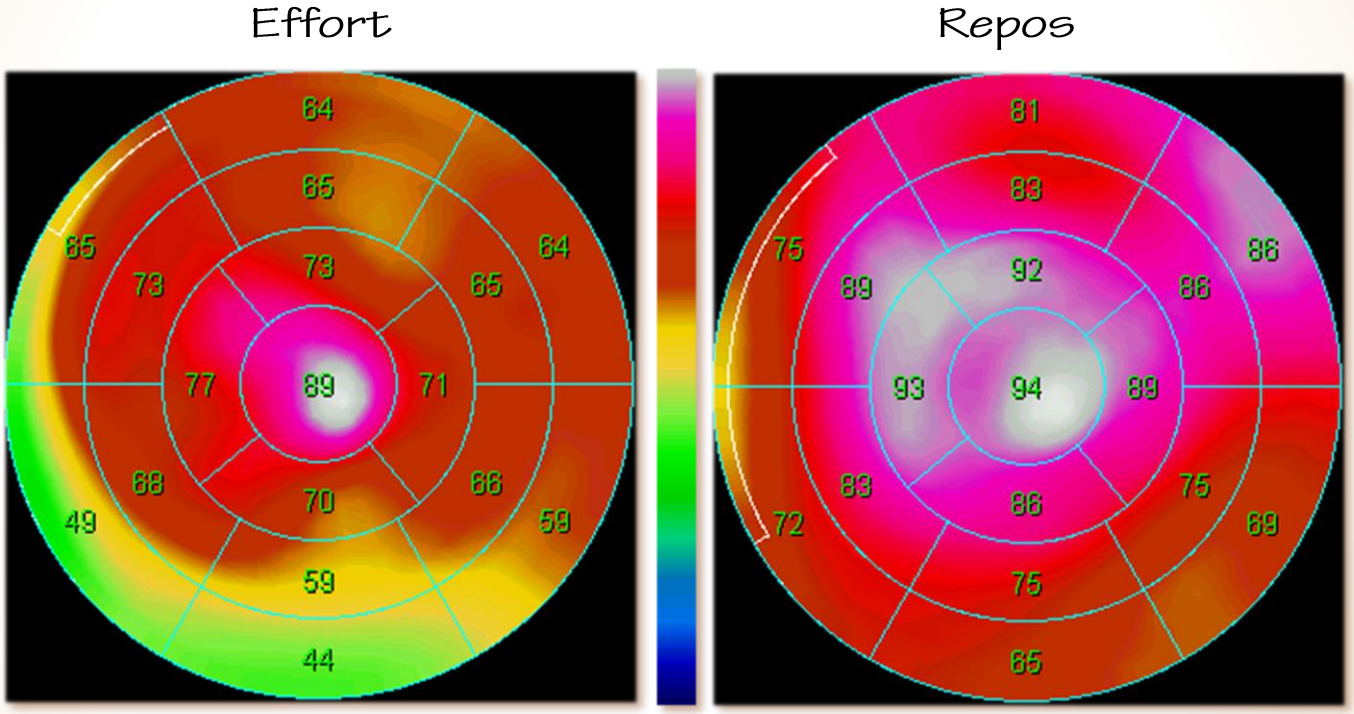
- Interprétation



Ischémie myocardique

Scintigraphie myocardique

- Interprétation

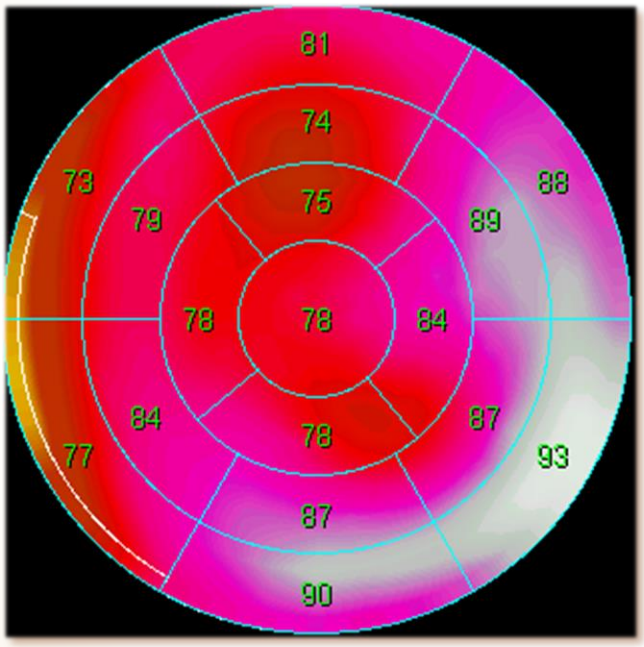


Ischémie myocardique

Scintigraphie myocardique

- Interprétation

Effort



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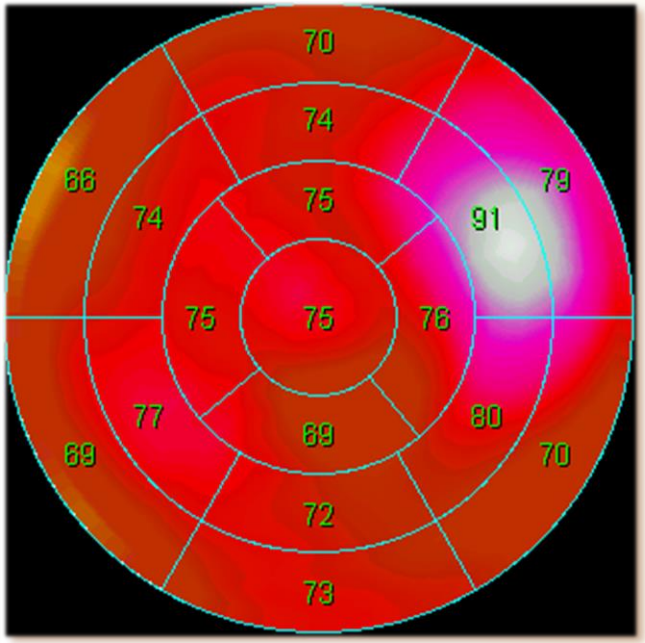
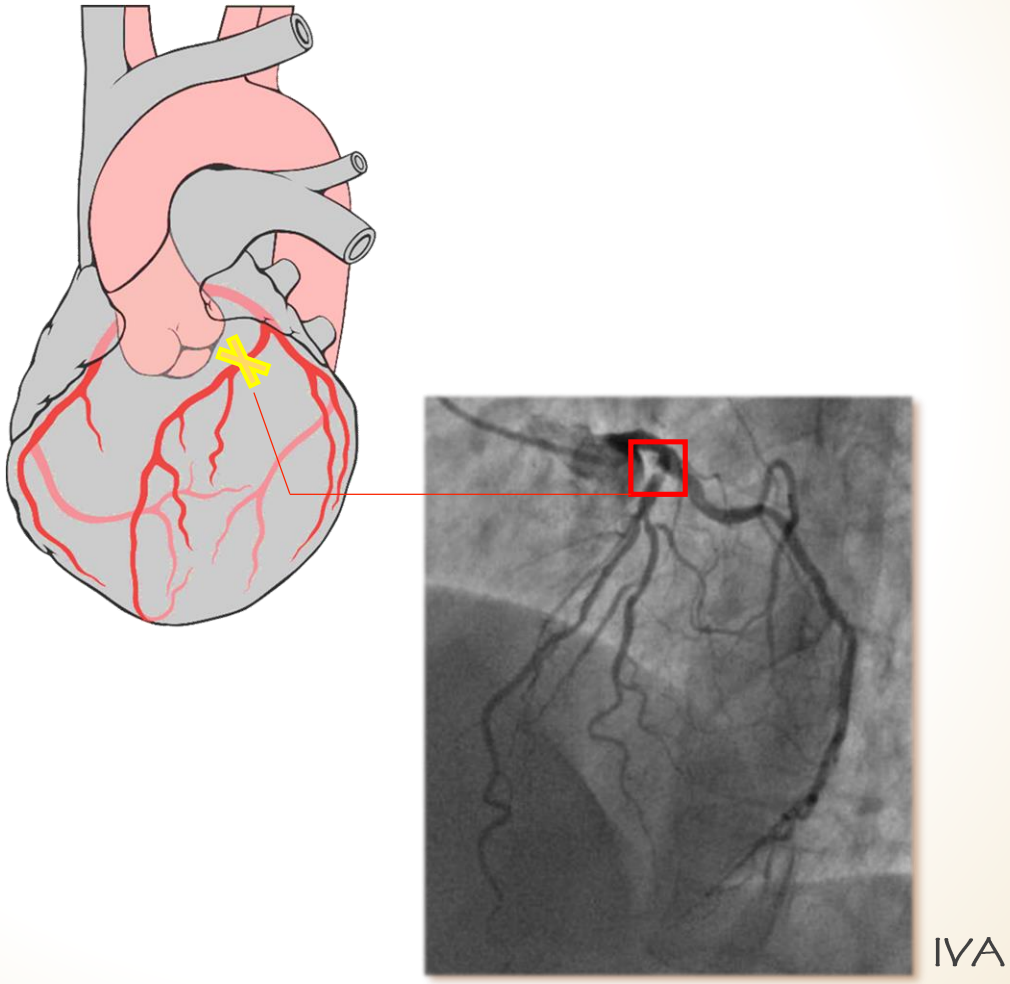


…???…

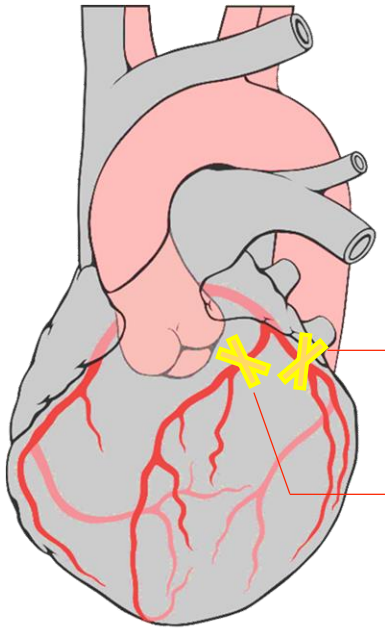
Scintigraphie myocardique

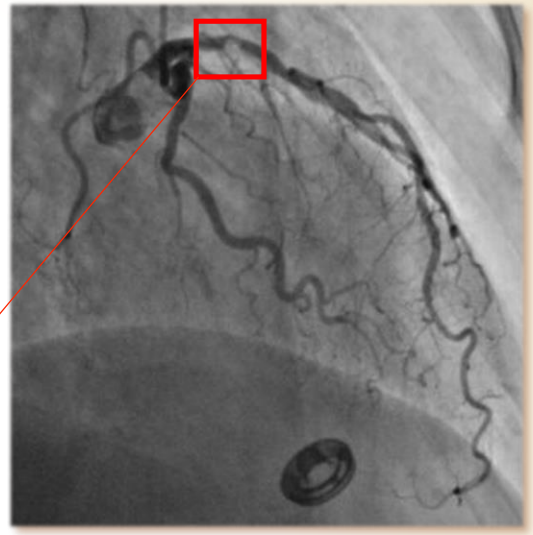
- Interprétation



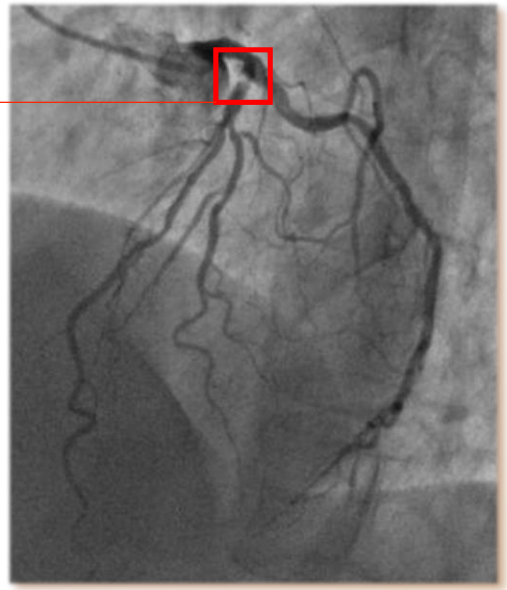
Scintigraphie myocardique

- Interprétation





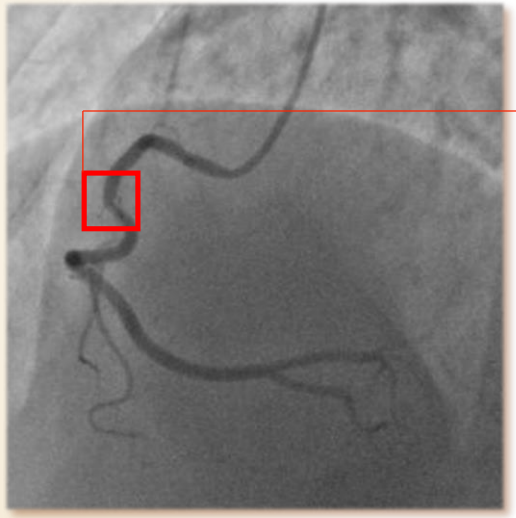
Cx



IVA

Scintigraphie myocardique

- Interprétation



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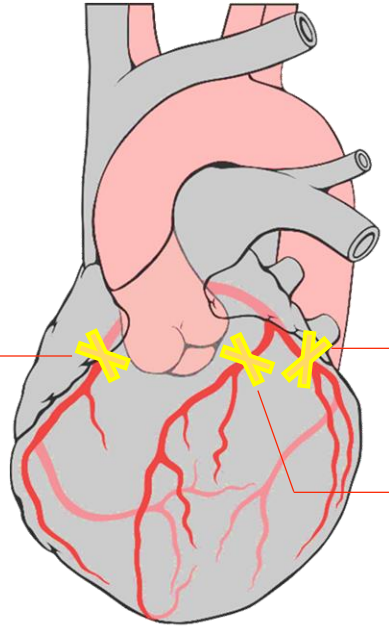
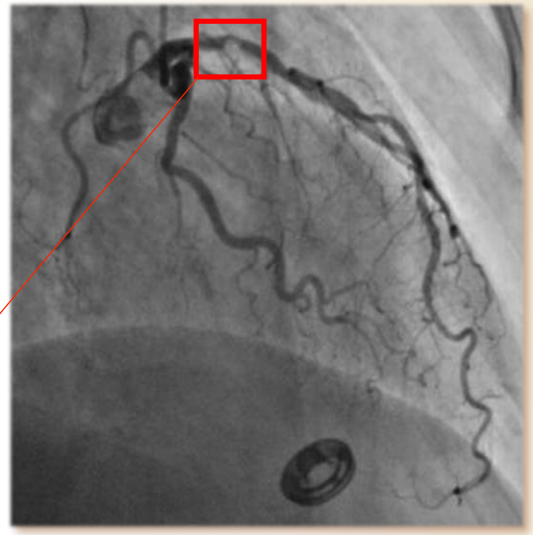
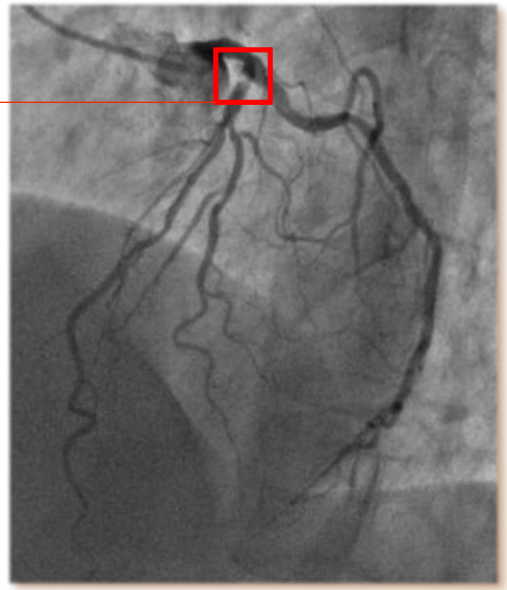




Cx



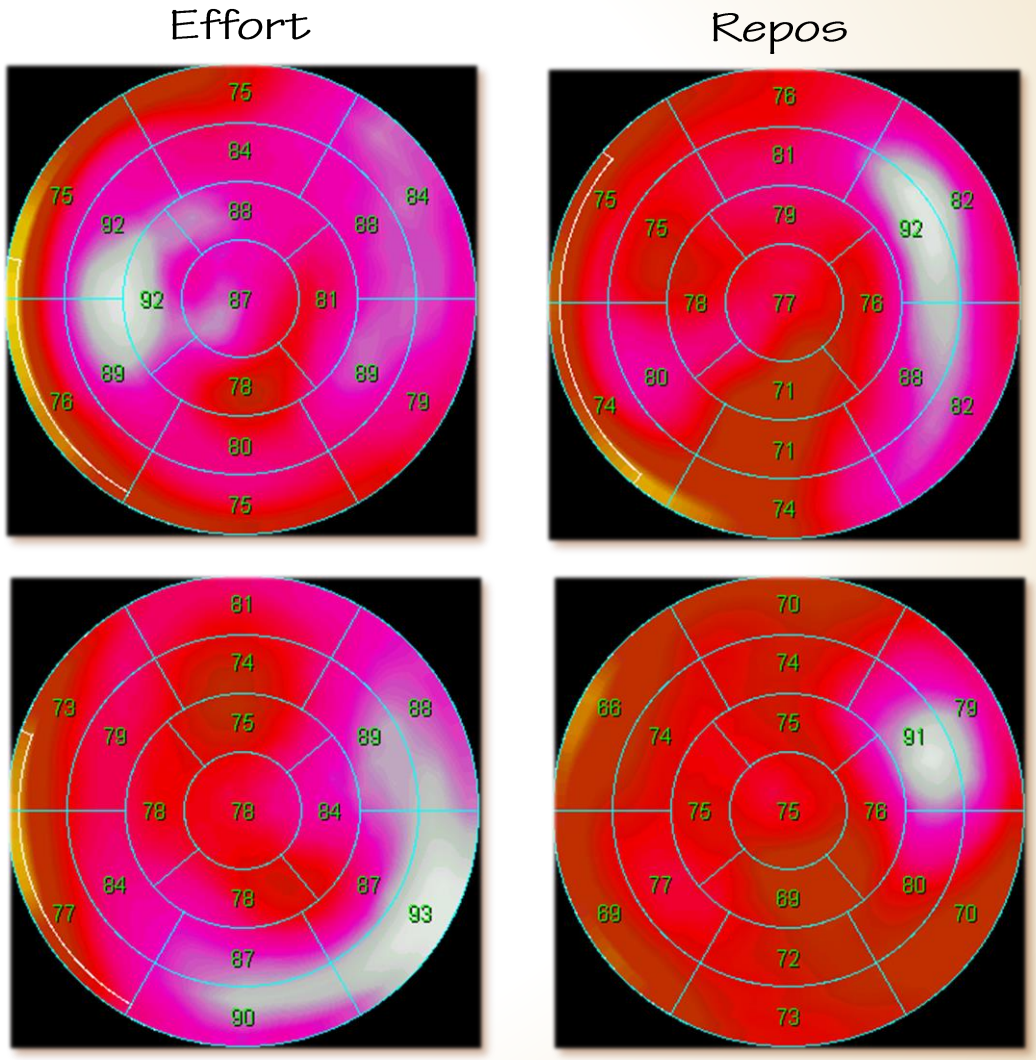
IVA

Scintigraphie myocardique

- Interprétation

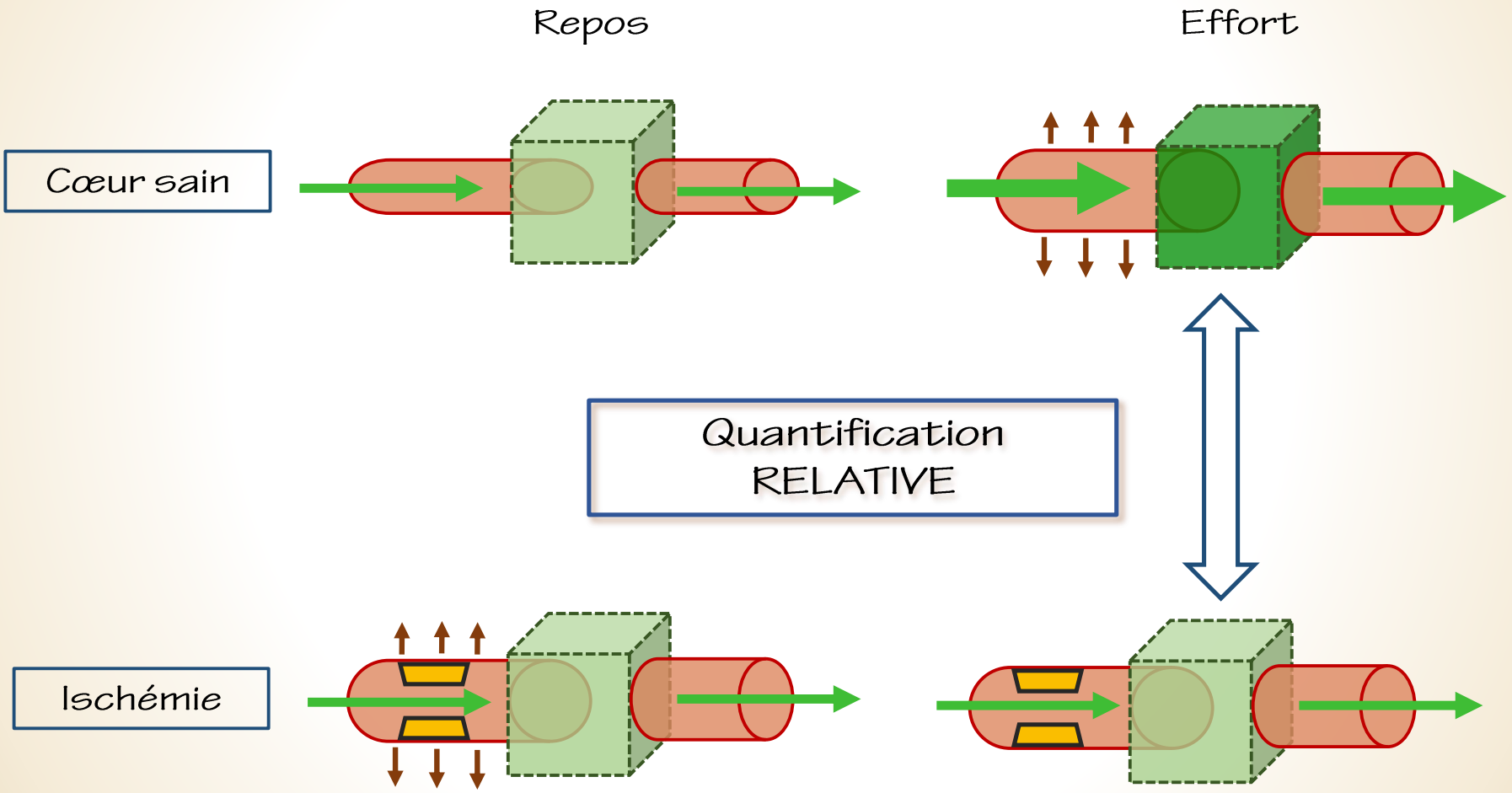
Scintigraphie normale

Pathologie
tri-tronculaire
« équilibrée »



Scintigraphie myocardique

- Interprétation

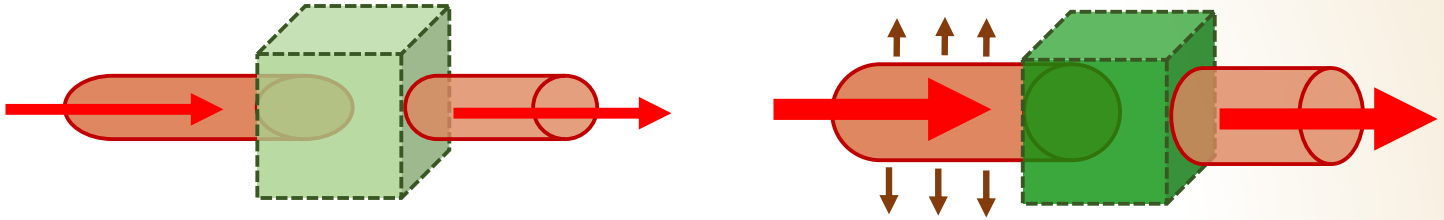


Scintigraphie myocardique

Repos

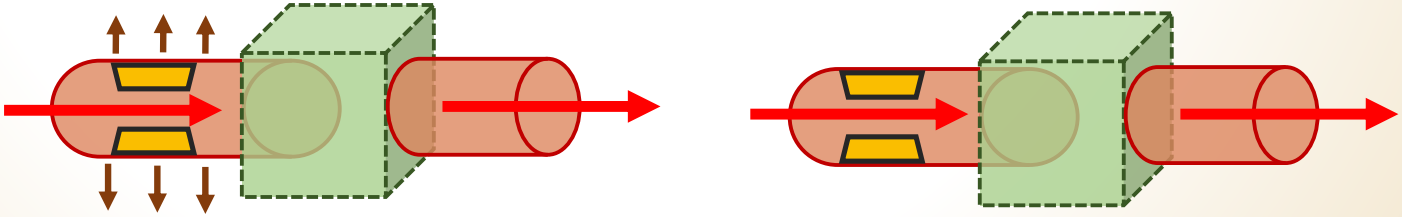
Effort

Cœur sain



Quantification
ABSOLUE ???

Ischémie



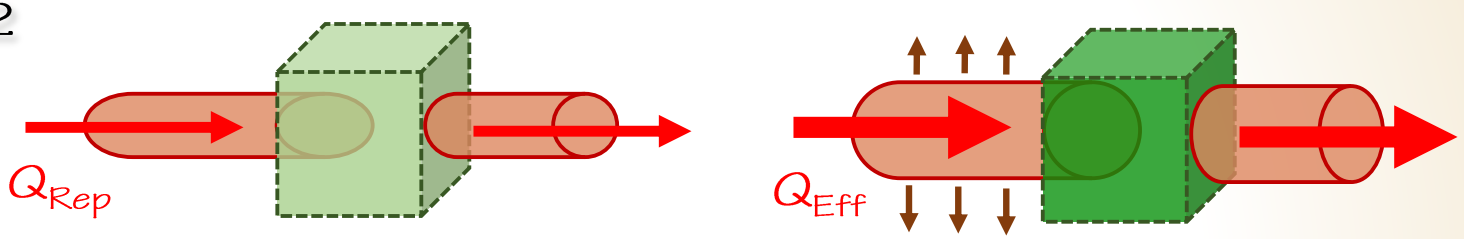
Réserve coronaire

Repos

Effort

$Q_{Eff} / Q_{Rep} > 2$

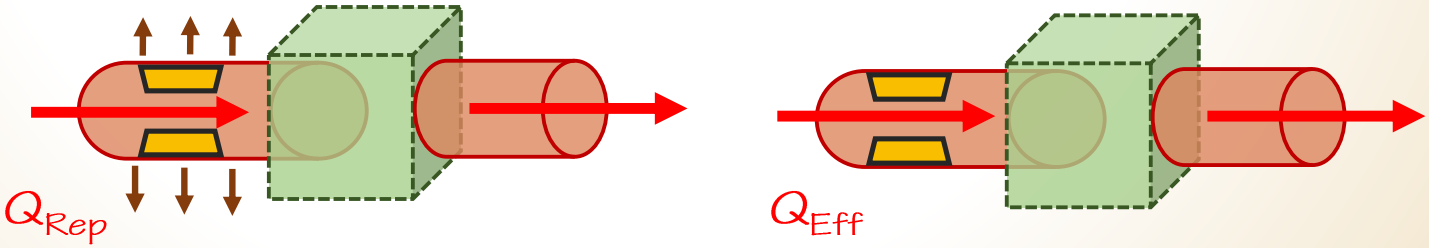
Cœur sain



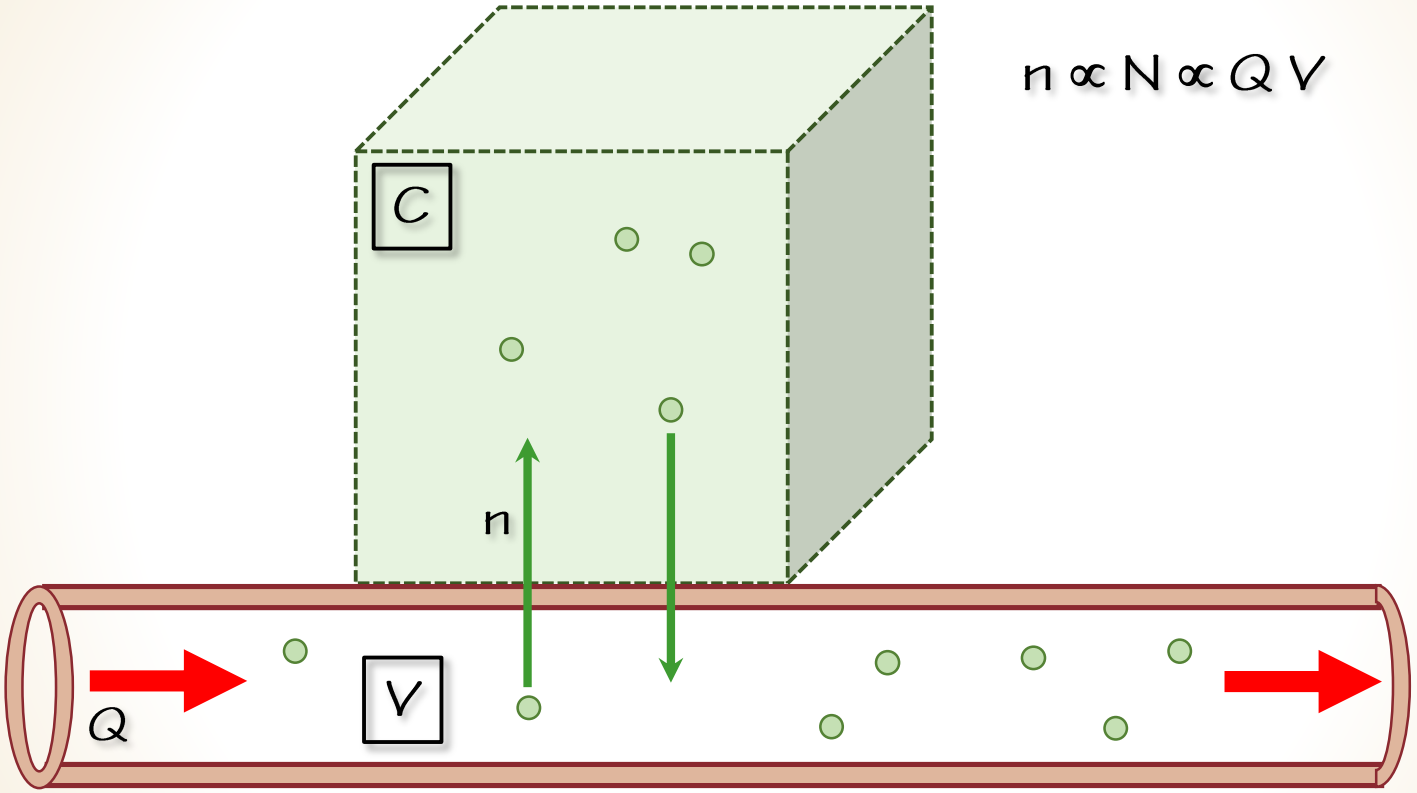
Réserve coronaire =

$$Q_{Eff} / Q_{Rep}$$

Ischémie

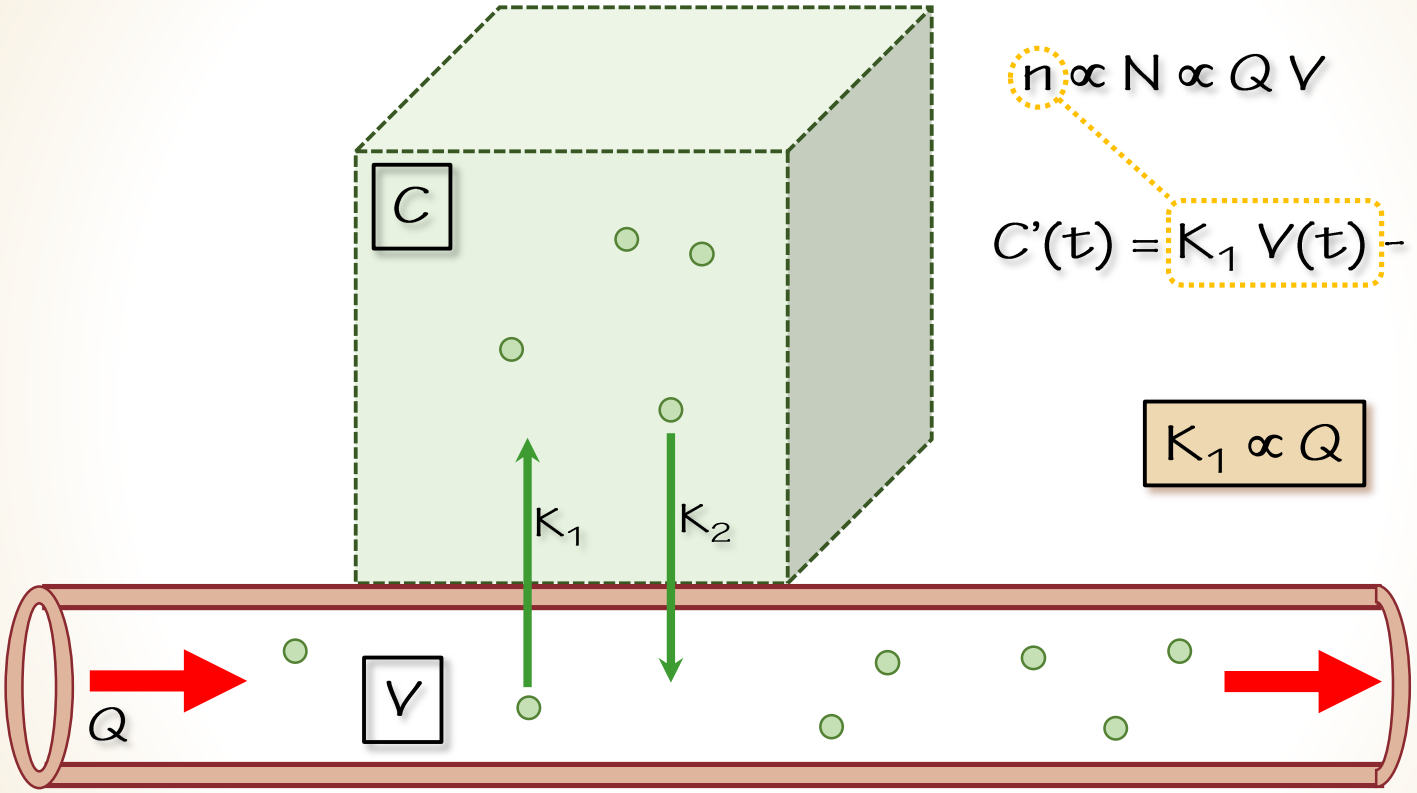


Réserve coronaire



$n \propto N \propto Q\,V$

Réserve coronaire

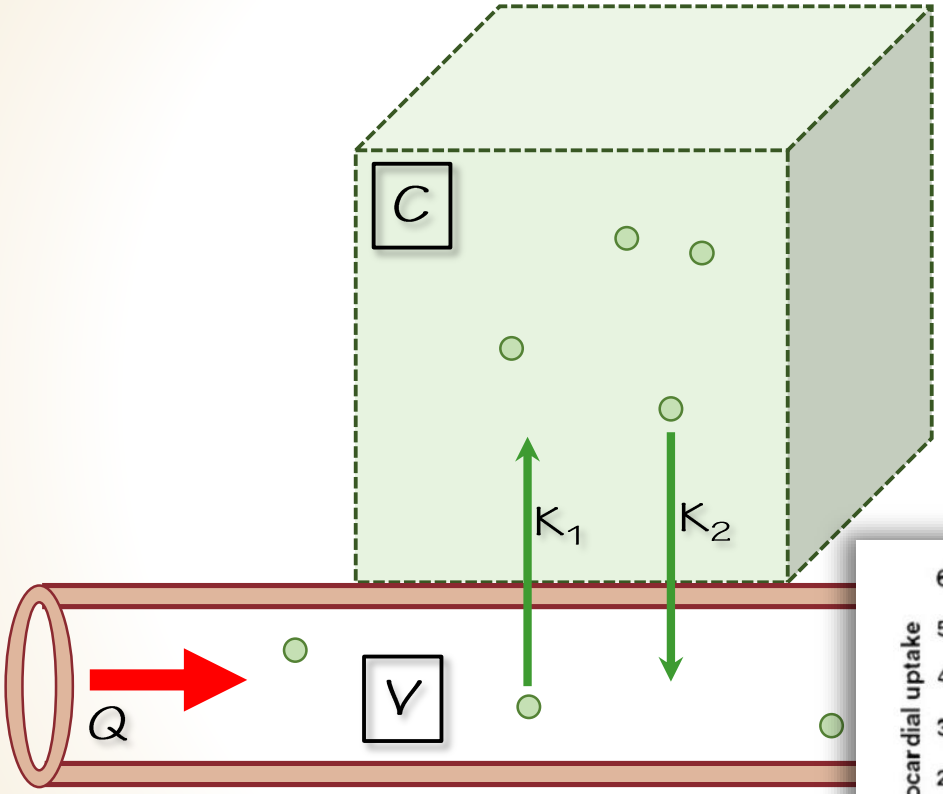


$n \propto N \propto Q\,V$

$C'(t) = K_1\,V(t) - K_2\,C(t)$

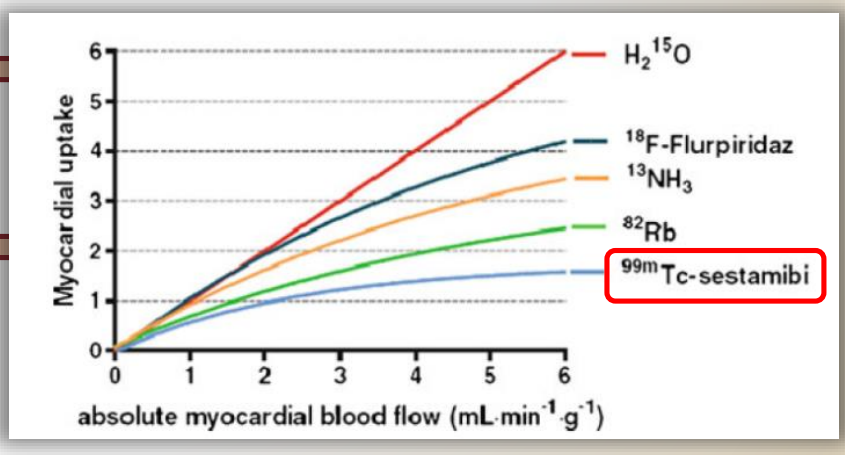
$K_1 \propto Q$

Réserve coronaire

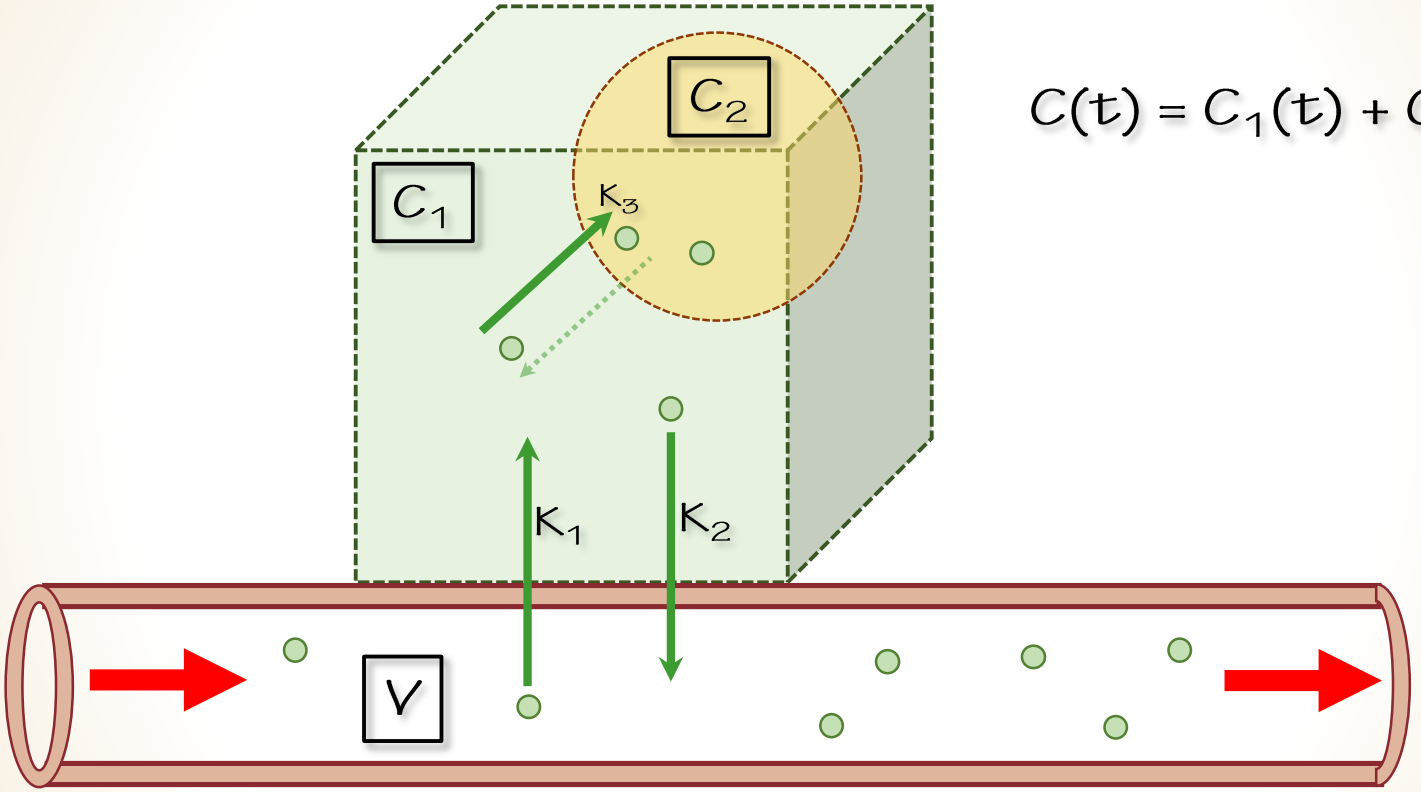


$$C'(t) = K_1 V(t) - K_2 C(t)$$

$$K_1 \propto Q$$



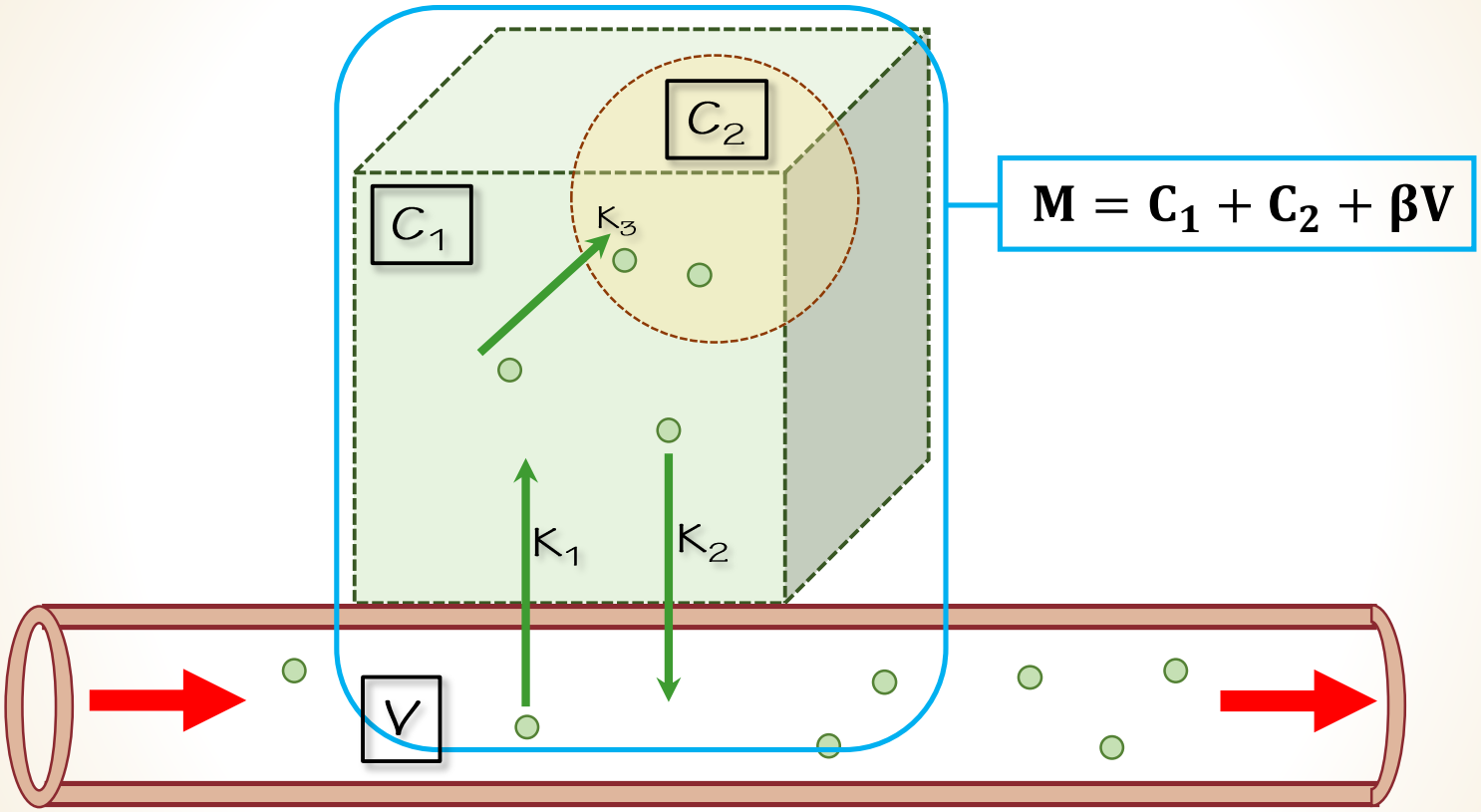
Réserve coronaire



$$C(t) = C_1(t) + C_2(t)$$

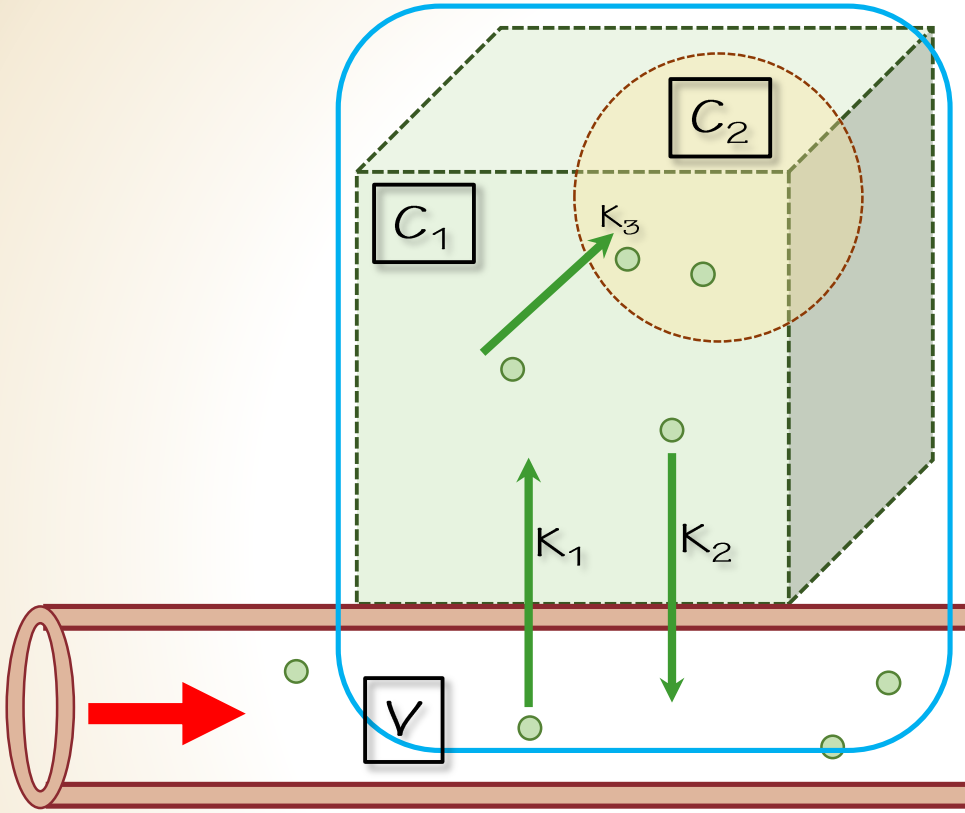
$$\mathbf{C'' + (K_2 + K_3)C' = K_1V' + K_1K_3V}$$

Réserve coronaire



$$M'' + (K_2 + K_3)M' = \beta V'' + [K_1 + \beta(K_2 + K_3)]V' + K_1K_3V$$

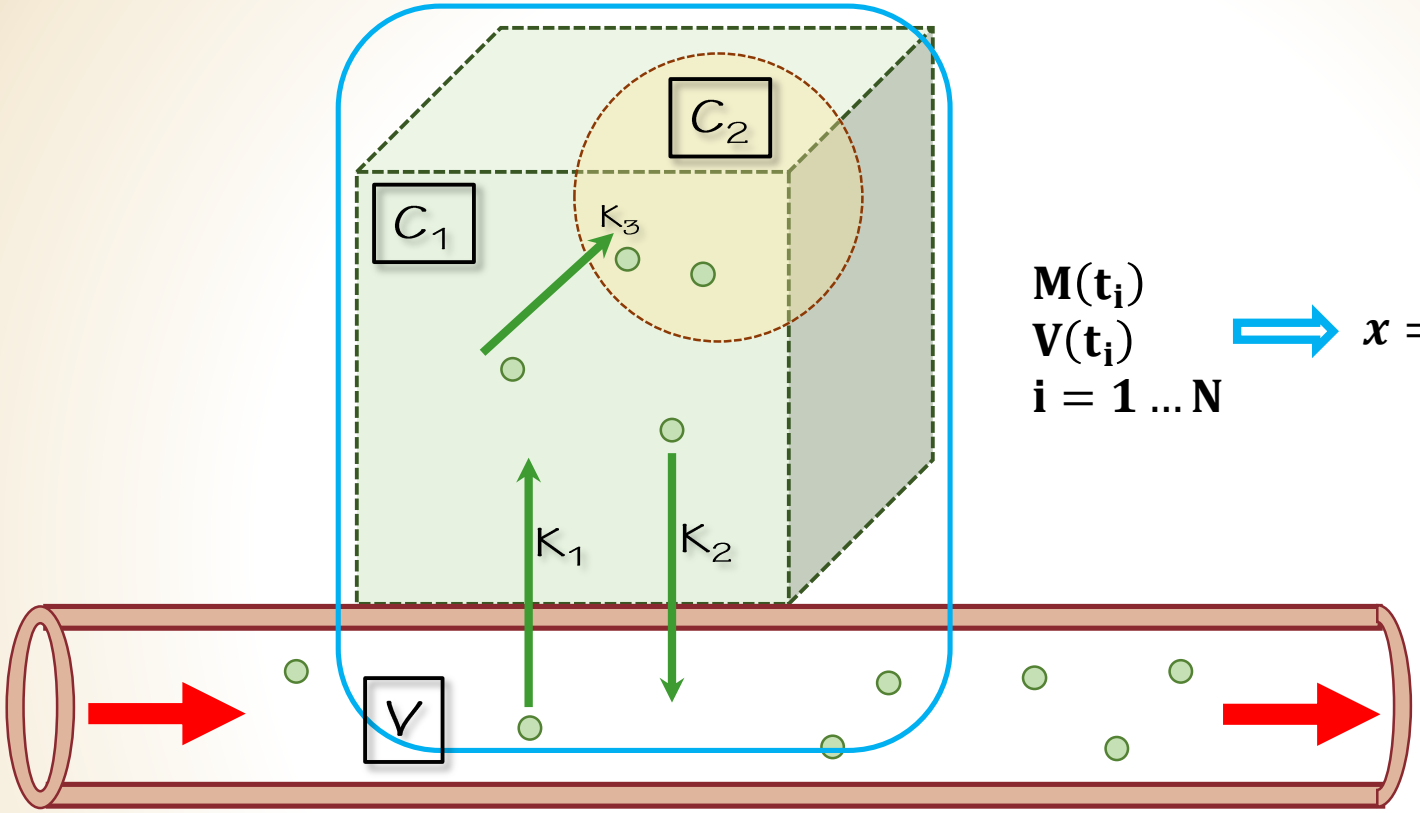
Réserve coronaire



$$\mathbf{M(t_i)} \quad \mathbf{V(t_i)} \quad \mathbf{i = 1 \ldots N} \Rightarrow x = \begin{pmatrix} \mathbf{K_1} \\ \mathbf{K_2} \\ \mathbf{K_3} \\ \boldsymbol{\beta} \end{pmatrix} \Rightarrow Q$$

$$\mathbf{M'' + (K_2 + K_3)M' = \beta V'' + [K_1 + \beta(K_2 + K_3)]V' + K_1K_3V}$$

Réserve coronaire



$$\mathbf{M(t_i)} \quad \mathbf{V(t_i)} \quad \mathbf{i = 1 \ldots N} \Rightarrow x = \begin{pmatrix} \mathbf{K_1} \\ \mathbf{K_2} \\ \mathbf{K_3} \\ \boldsymbol{\beta} \end{pmatrix} \Rightarrow Q$$

$$\mathbf{M'' + (K_2 + K_3)M' = \beta V'' + [K_1 + \beta(K_2 + K_3)]V' + K_1K_2V}$$

$$\mathbf{M(t) = \alpha_1 \int_0^t e^{-s_1(t-\tau)} V(\tau) d\tau + \alpha_2 \int_0^t e^{-s_2(t-\tau)} V(\tau) d\tau}$$

NLLS

Réserve coronaire

LLS

$$\mathbf{M''} = \underbrace{-(\mathbf{K_2} + \mathbf{K_3})}_{a_1}\mathbf{M'} + \underbrace{\boldsymbol{\beta}\mathbf{V''}}_{a_2} + \underbrace{[\mathbf{K_1} + \boldsymbol{\beta}(\mathbf{K_2} + \mathbf{K_3})]}_{a_3}\mathbf{V'} + \underbrace{\mathbf{K_1}\mathbf{K_3}\mathbf{V}}_{a_4}$$

Réserve coronaire

LLS

$$M'' = \underbrace{-(K_2 + K_3)}_{a_1} M' + \underbrace{\beta}_{a_2} V'' + \underbrace{[K_1 + \beta(K_2 + K_3)]}_{a_3} V' + \underbrace{K_1 K_3}_{a_4} V$$

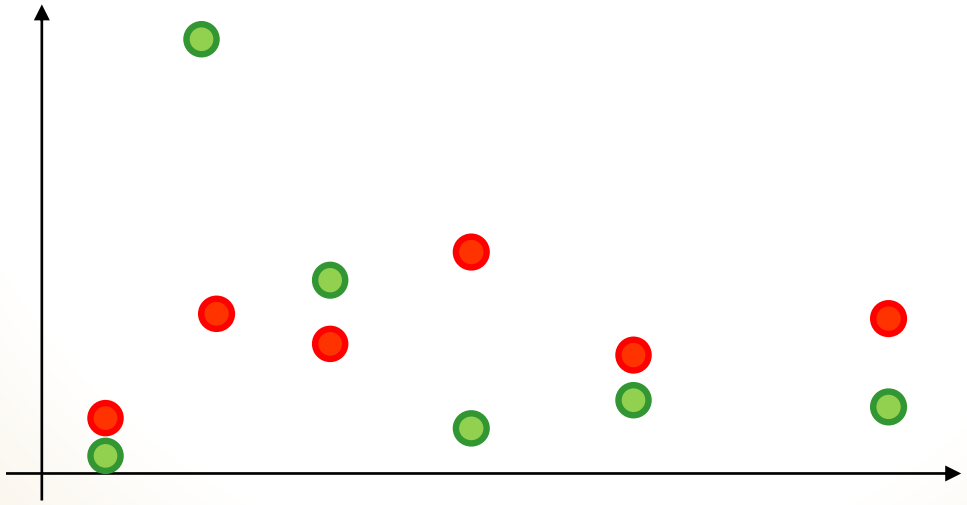
$$M''(t_i) = a_1 M'(t_i) + a_2 V''(t_i) + a_3 V'(t_i) + a_4 V(t_i) \qquad i = 0 \dots N$$

Réserve coronaire

LLS

$$M'' = \underbrace{-(K_2 + K_3)}_{a_1} M' + \underbrace{\beta}_{a_2} V'' + \underbrace{[K_1 + \beta(K_2 + K_3)]}_{a_3} V' + \underbrace{K_1 K_3}_{a_4} V$$

$$M''(t_i) = a_1 M'(t_i) + a_2 V''(t_i) + a_3 V'(t_i) + a_4 V(t_i) \qquad i = 0 \dots N$$



Réserve coronaire

LLS

$$M'' = \underbrace{-(K_2 + K_3)}_{a_1} M' + \underbrace{\beta}_{a_2} V'' + \underbrace{[K_1 + \beta(K_2 + K_3)]}_{a_3} V' + \underbrace{K_1 K_3}_{a_4} V$$

$$M(t_i) = a_1 \int_0^{t_i} M + a_2 V(t_i) + a_3 \int_0^{t_i} V + a_4 \int_0^{t_i} \int V$$

Réserve coronaire

LLS

$$M'' = \underbrace{-(K_2 + K_3)}_{a_1} M' + \underbrace{\beta}_{a_2} V'' + \underbrace{[K_1 + \beta(K_2 + K_3)]}_{a_3} V' + \underbrace{K_1 K_3}_{a_4} V$$

$$M(t_i) = a_1 \int_0^{t_i} M + a_2 V(t_i) + a_3 \int_0^{t_i} V + a_4 \int_0^{t_i} \int V$$

$$\boldsymbol{b = H\,a}$$

$$b = \begin{pmatrix} M(t_0) \\ \vdots \\ \vdots \\ M(t_N) \end{pmatrix} \qquad H = \begin{bmatrix} \int_0^{t_0} M & V(t_0) & \int_0^{t_0} V & \int_0^{t_0} \int V \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ \int_0^{t_N} M & V(t_N) & \int_0^{t_N} V & \int_0^{t_N} \int V \end{bmatrix}$$

Réserve coronaire

LLS

$$M'' = \underbrace{-(K_2 + K_3)}_{a_1} M' + \underbrace{\beta}_{a_2} V'' + \underbrace{[K_1 + \beta(K_2 + K_3)]}_{a_3} V' + \underbrace{K_1 K_3}_{a_4} V$$

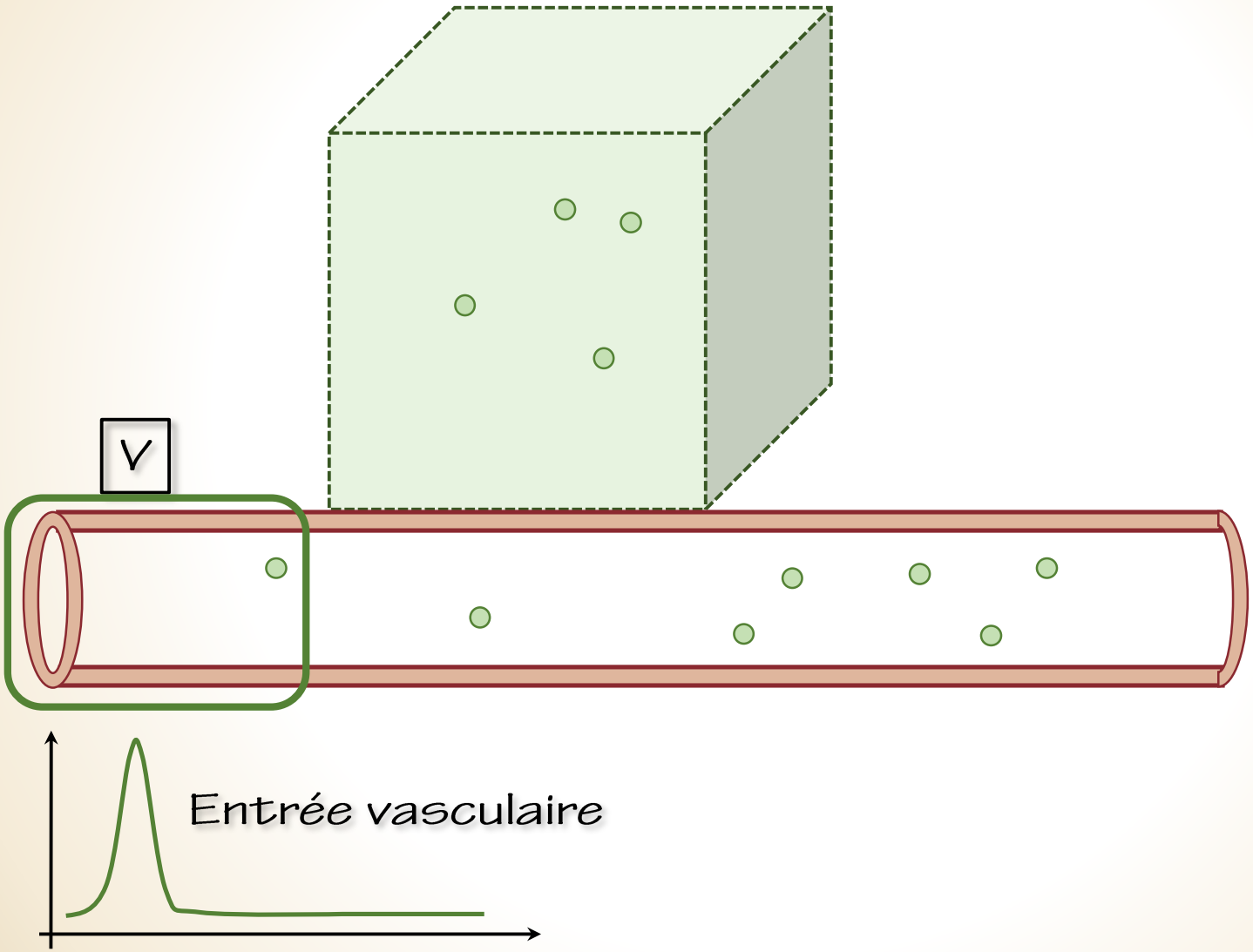
$$M(t_i) = a_1 \int_0^{t_i} M + a_2 V(t_i) + a_3 \int_0^{t_i} V + a_4 \int_0^{t_i} \int V$$

$$b = H\,a$$

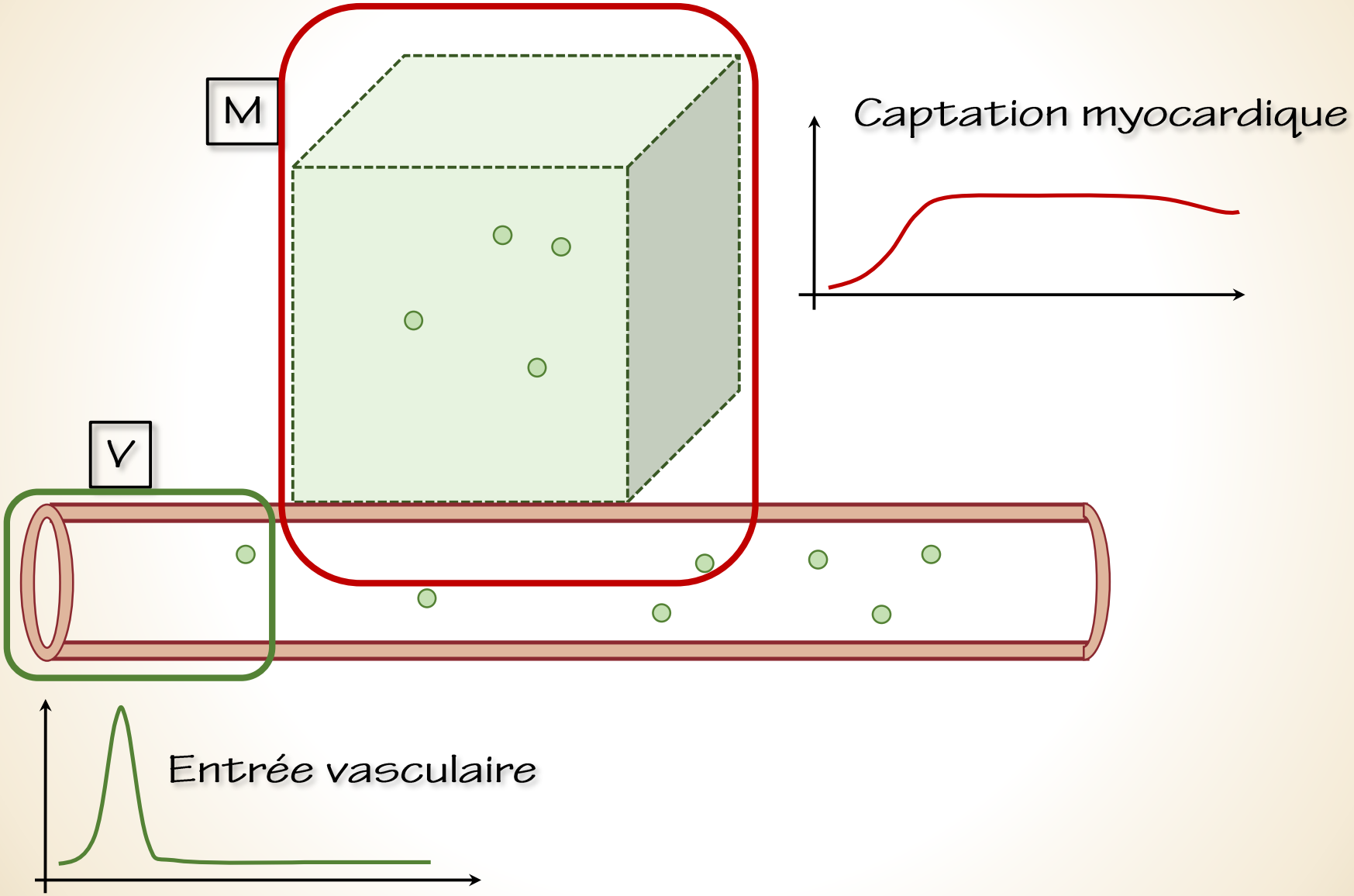
$$a = \left(H^T H\right)^{-1} H^T b$$

$$K_1 = a_4 - a_1 a_3$$

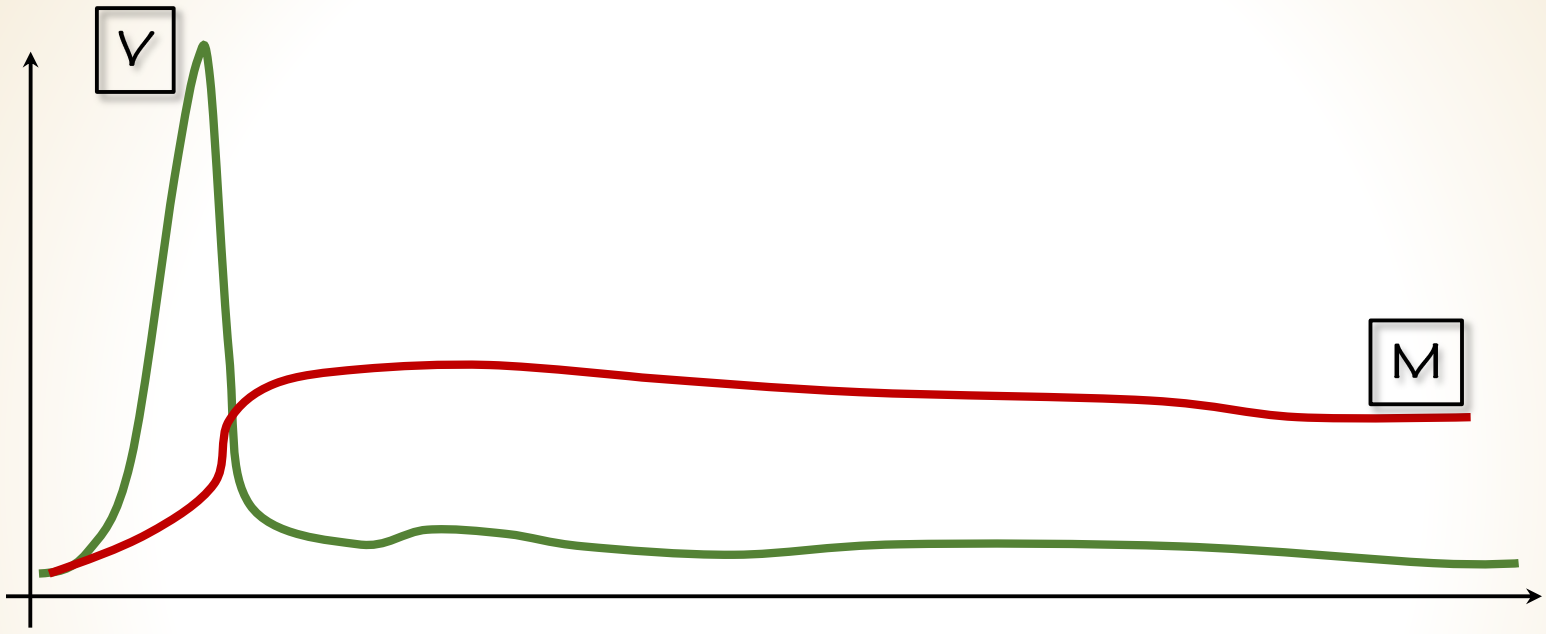
Réserve coronaire



Réserve coronaire

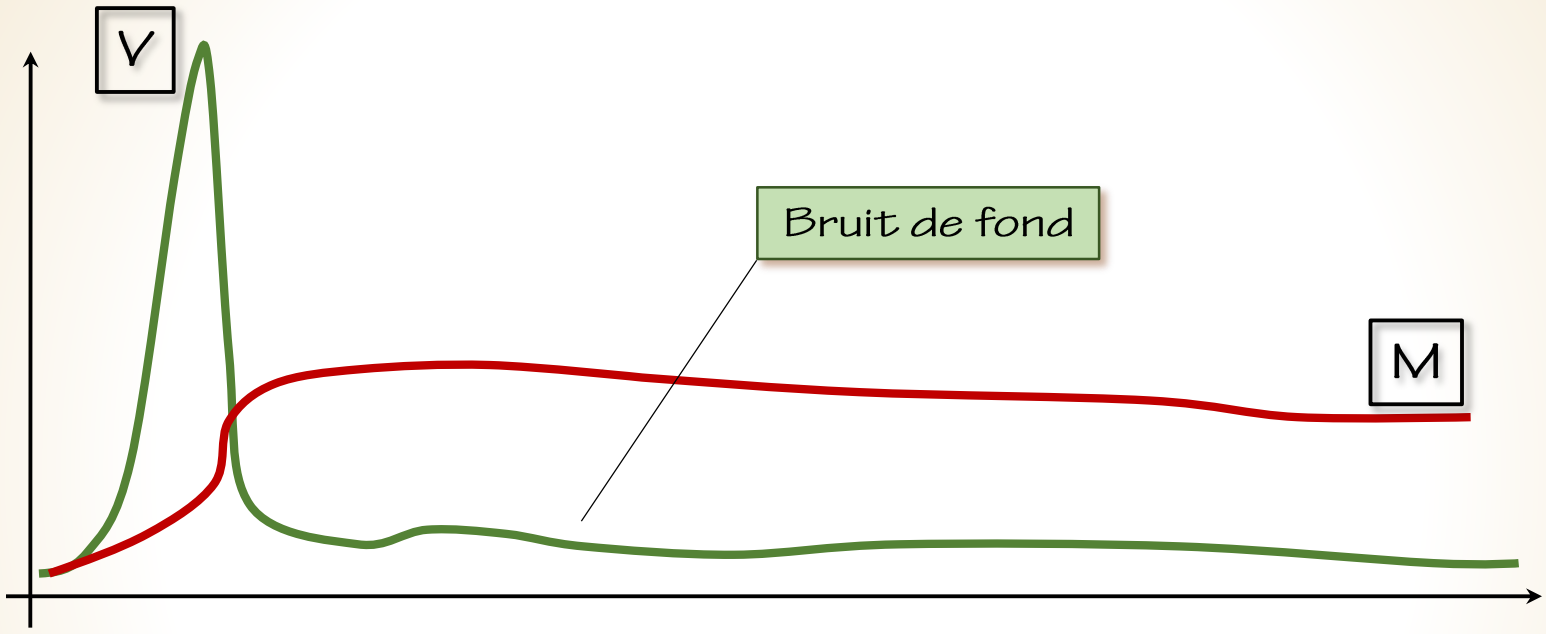


Réserve coronaire

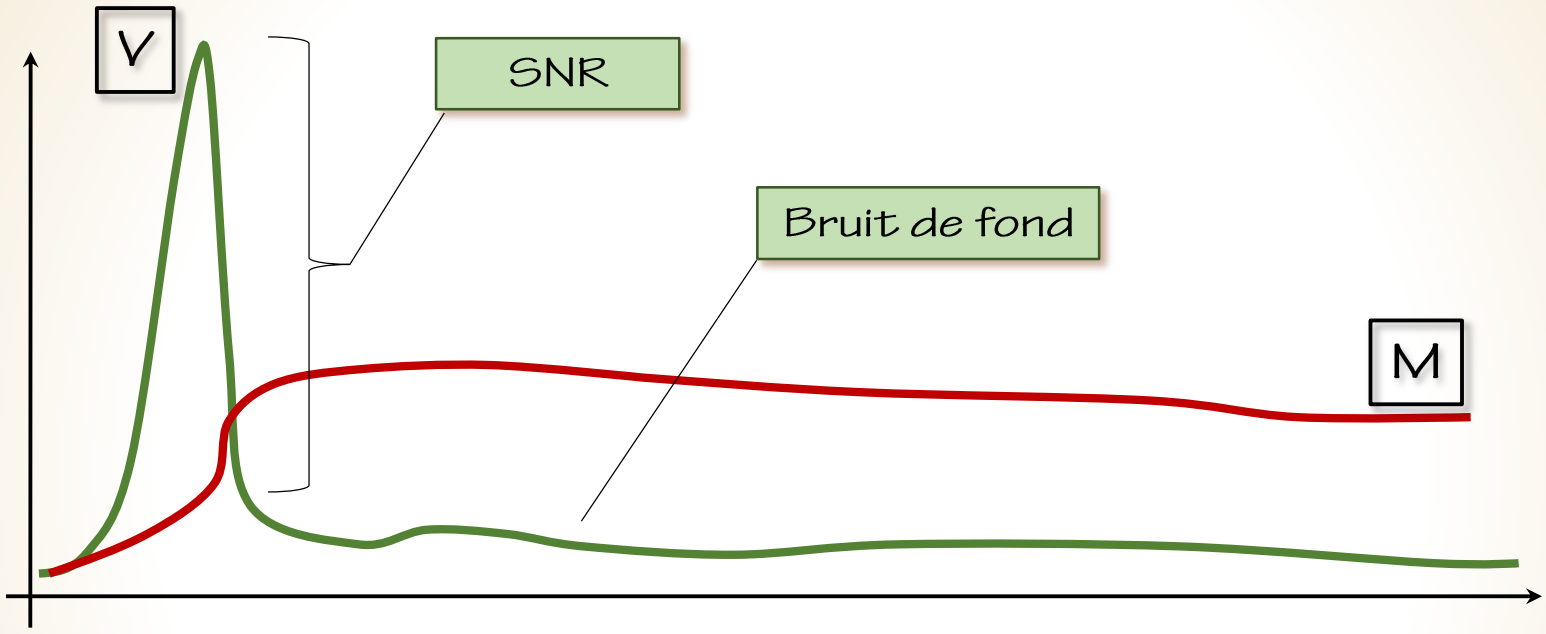


$$\mathbf{M'' + (K_2 + K_3)M' = \beta V'' + [K_1 + \beta(K_2 + K_3)]V' + K_1K_2V}$$

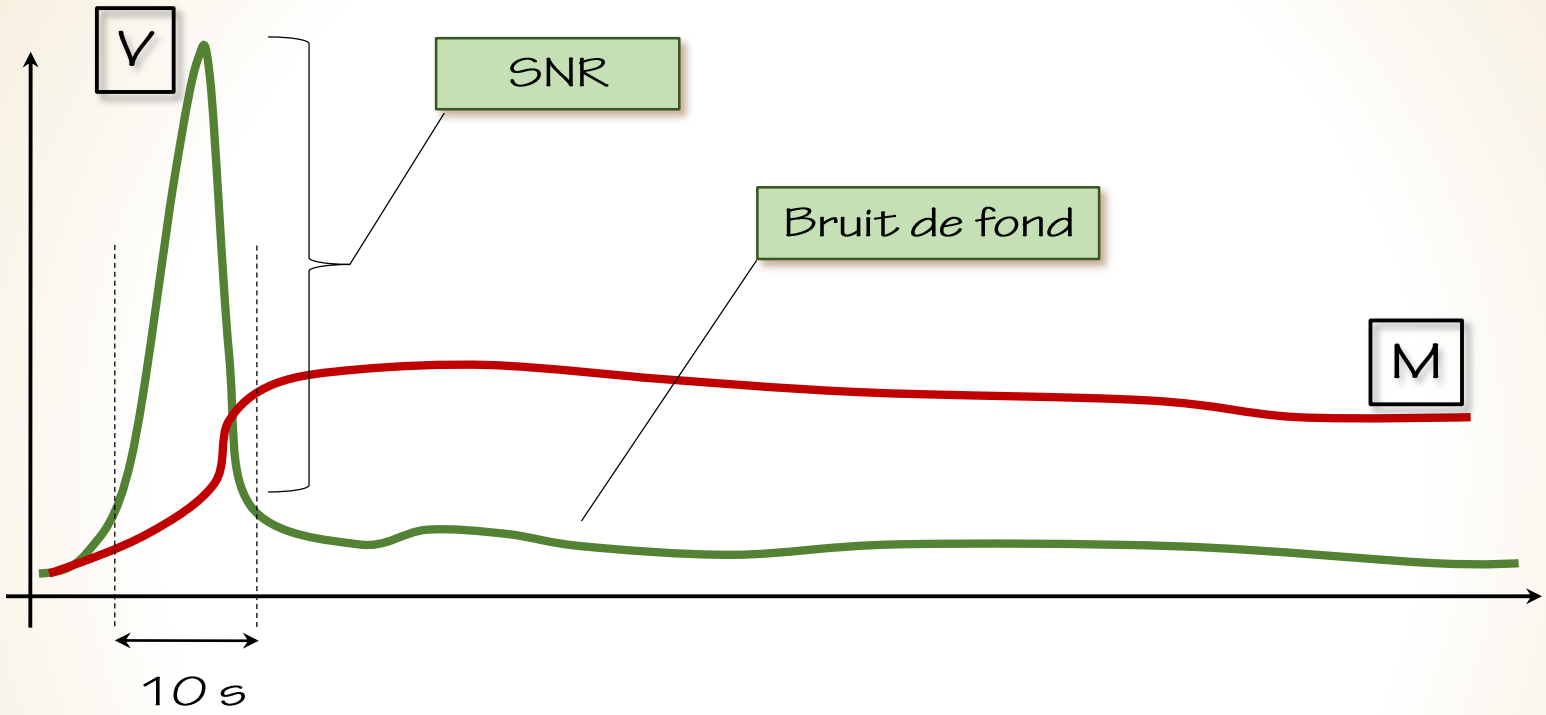
Réserve coronaire



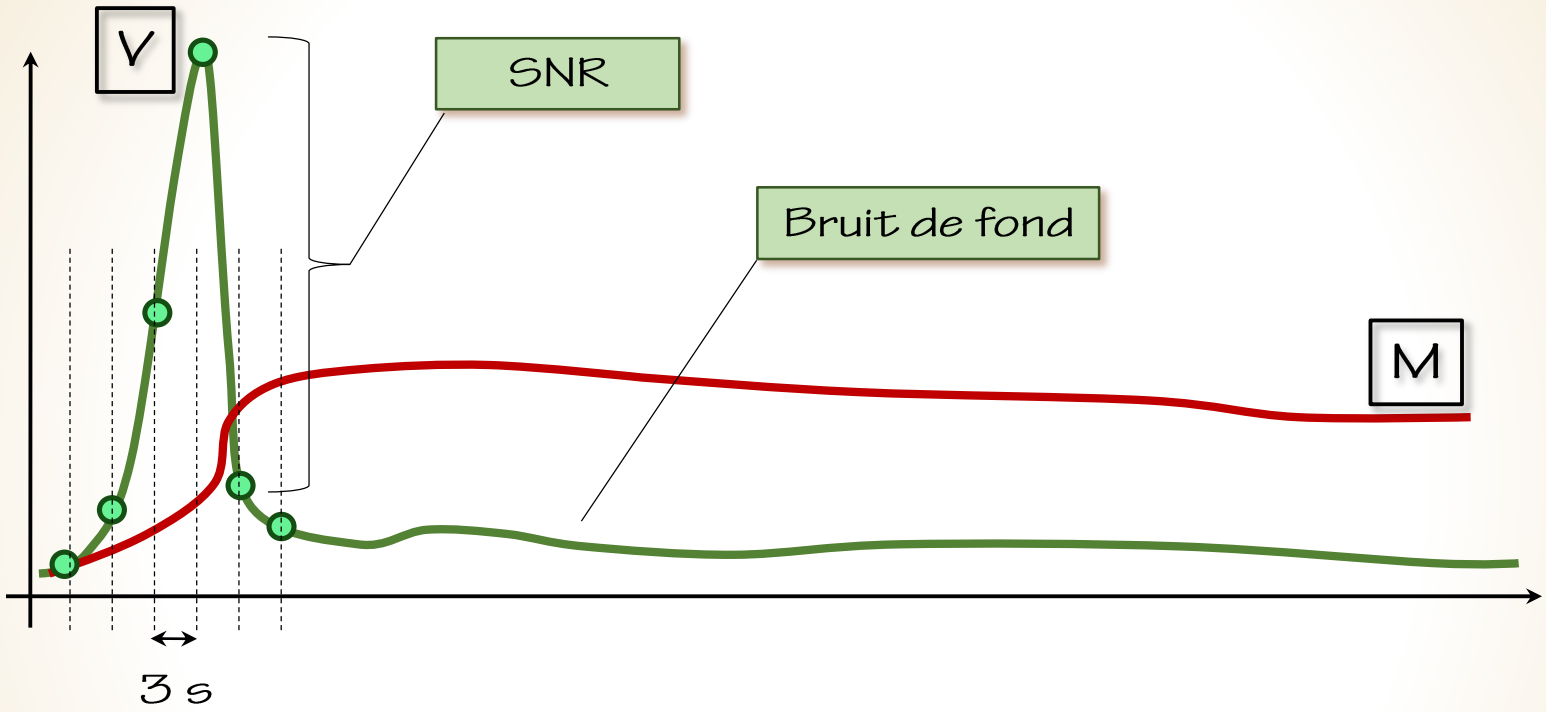
Réserve coronaire



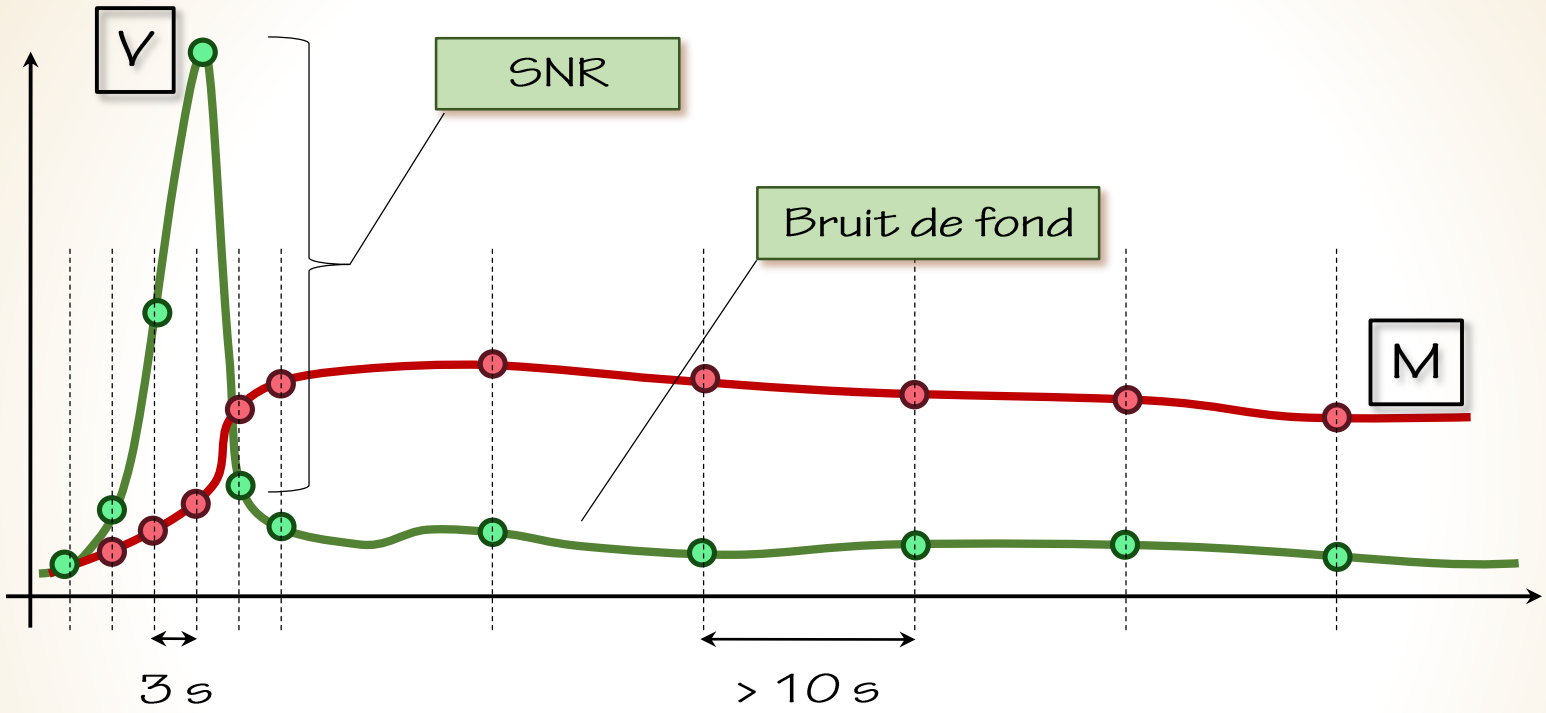
Réserve coronaire



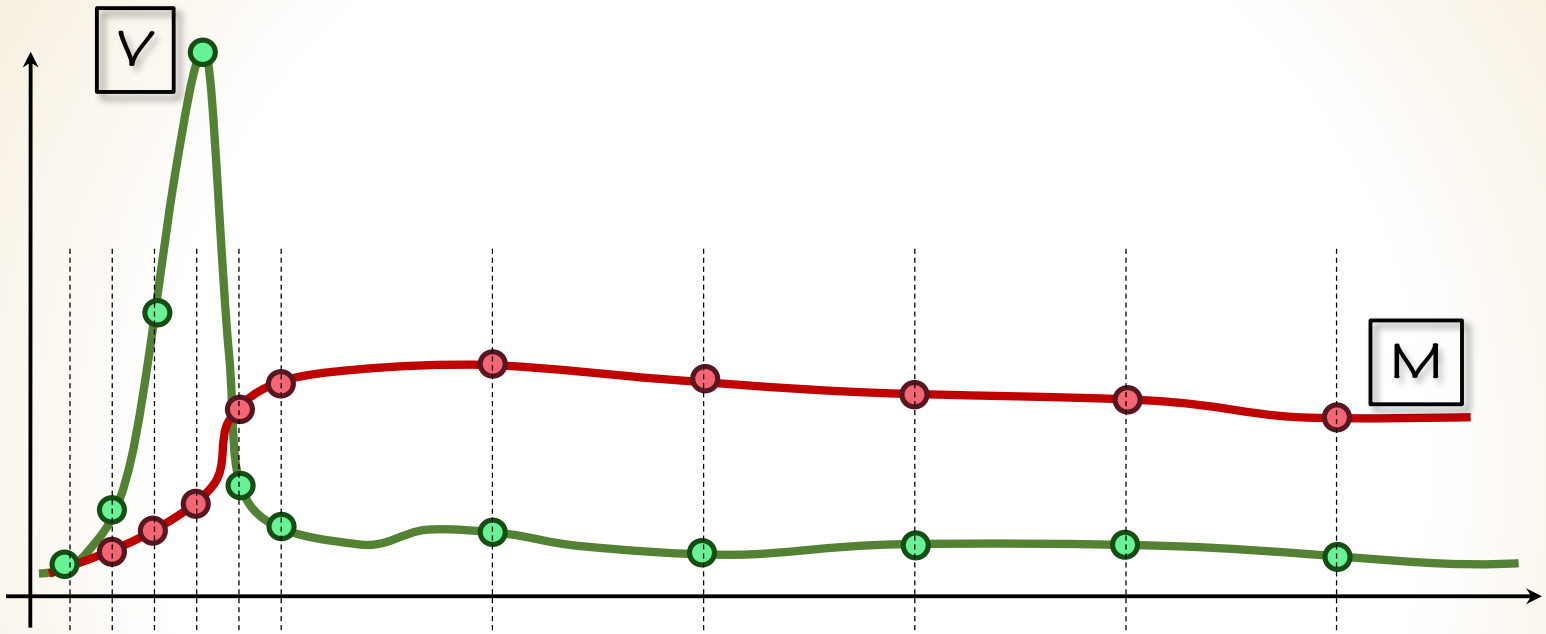
Réserve coronaire



Réserve coronaire



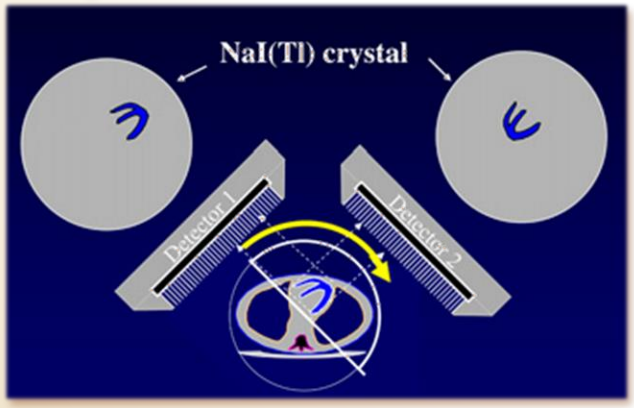
Réserve coronaire

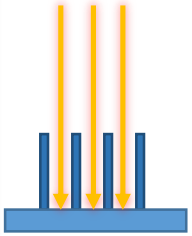


Tomographie dynamique ???

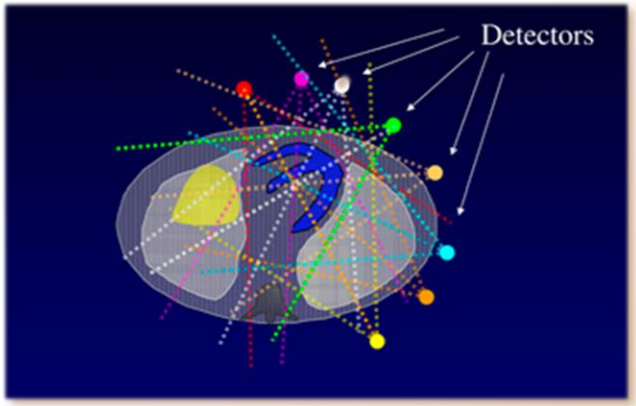
Caméra CZT

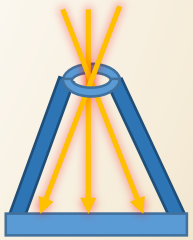
Anger



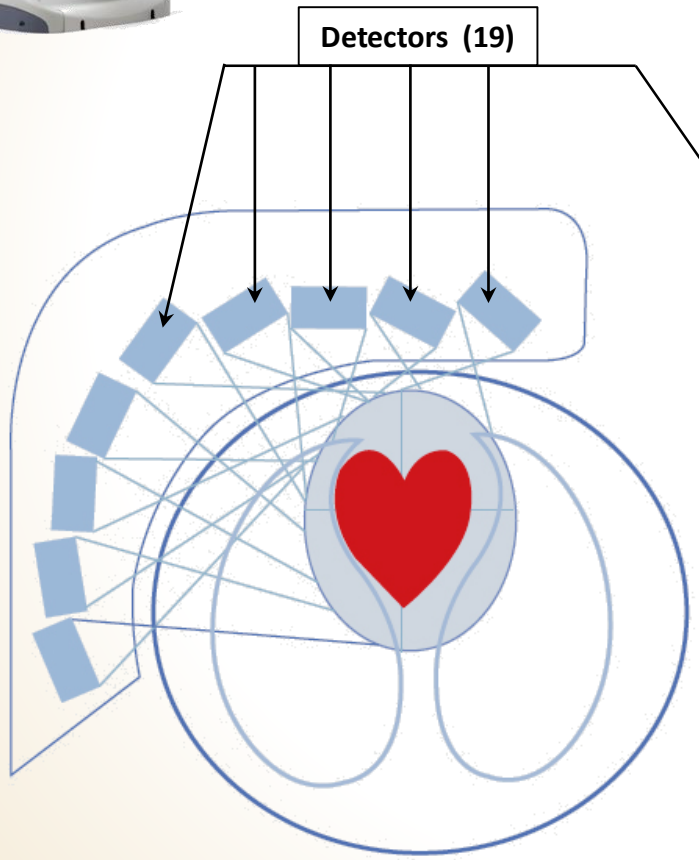


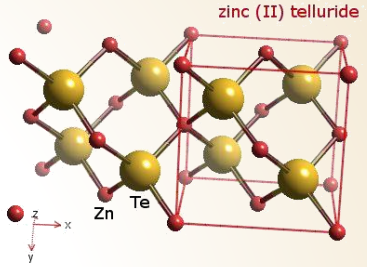
CZT

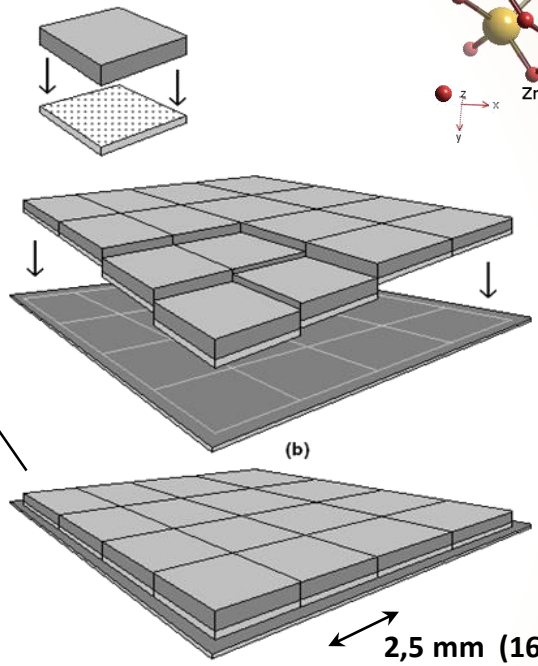


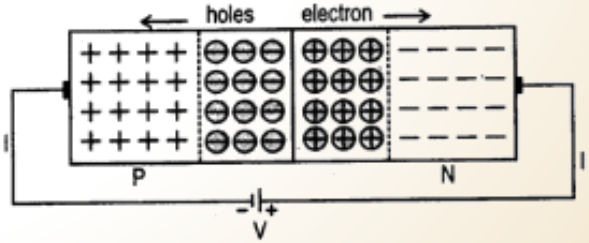


Caméra CZT

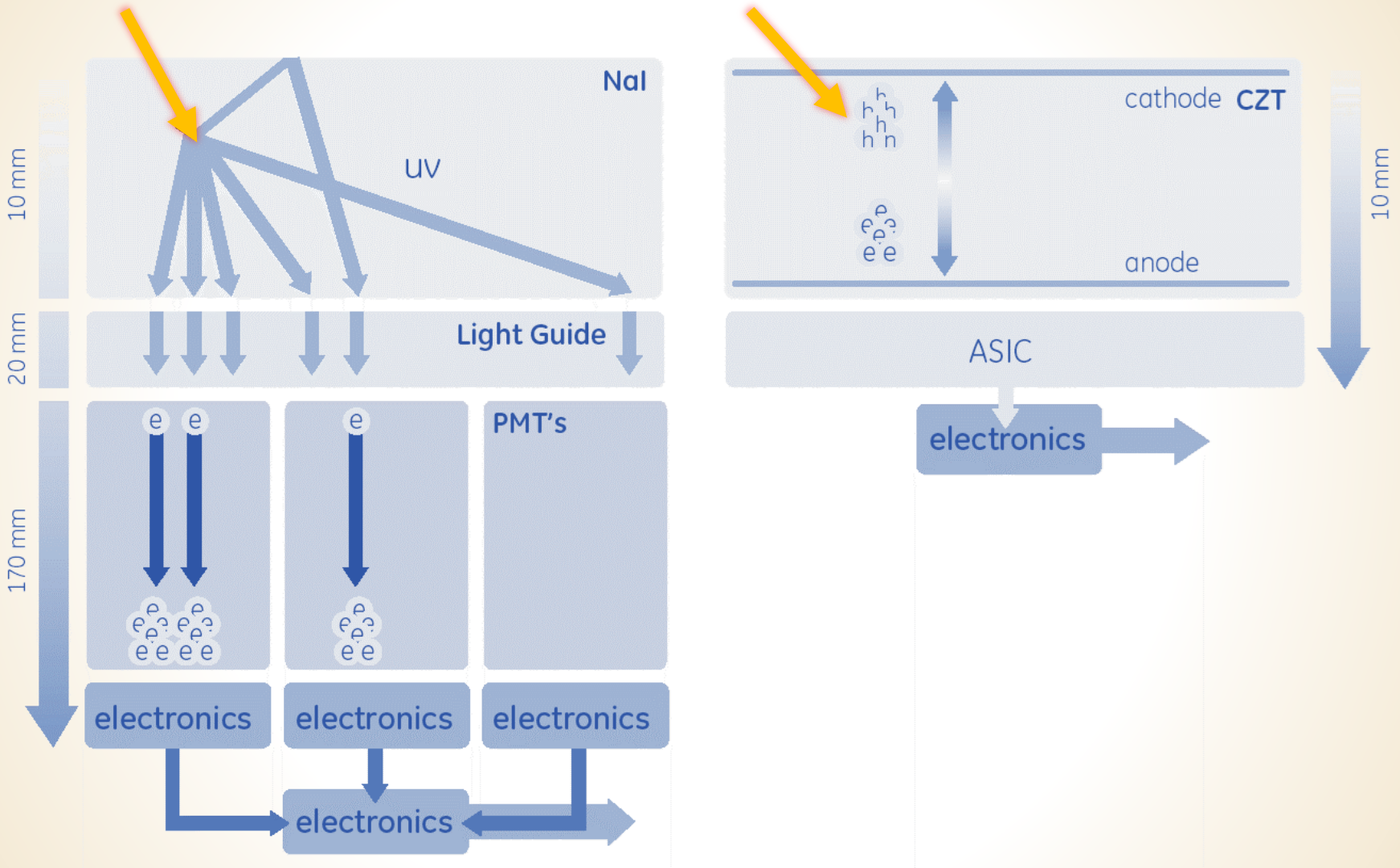

Detectors (19)


zinc (II) telluride
Zn
Te

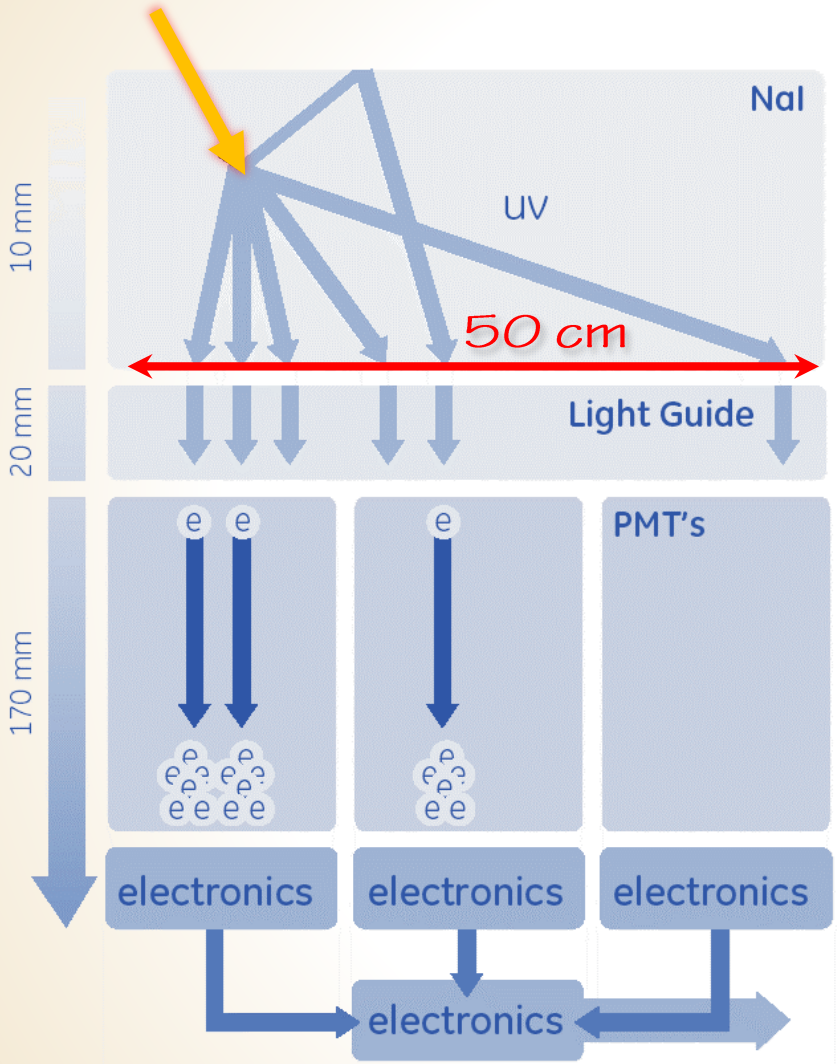

(b)
2,5 mm (16x16)

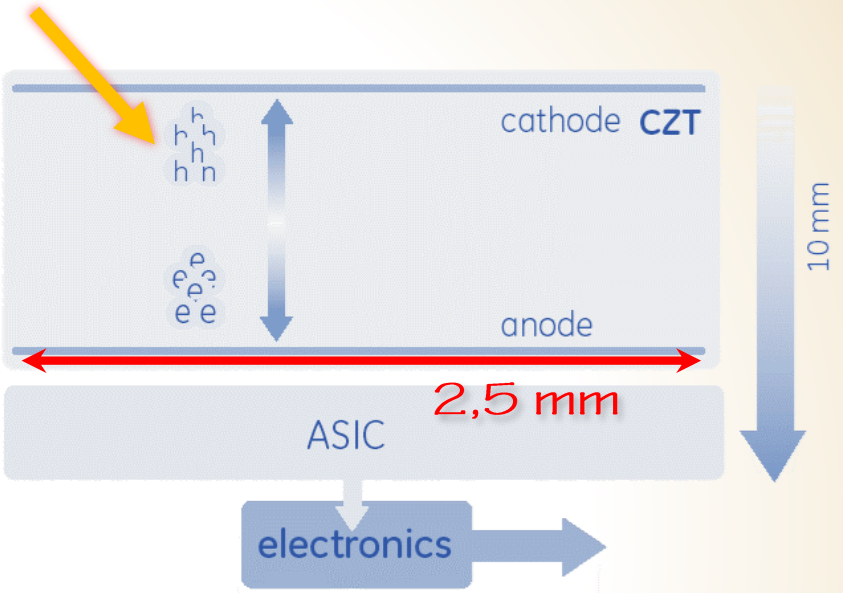

holes
electron
P
N
I
I
V

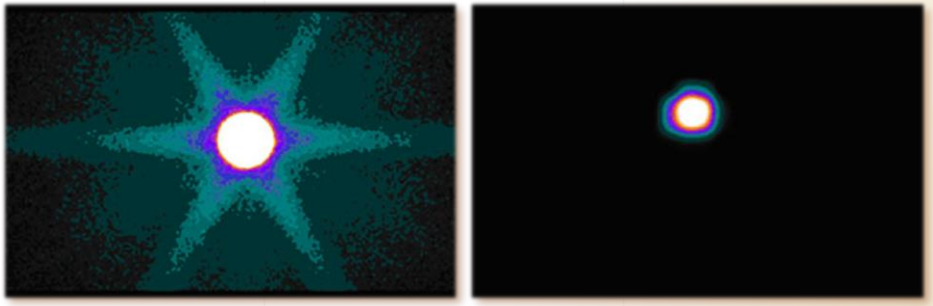
Caméra CZT


NaI
UV
10 mm
20 mm
Light Guide
170 mm
PMT's
electronics
electronics
electronics
electronics
cathode CZT
anode
10 mm
ASIC
electronics

Caméra CZT

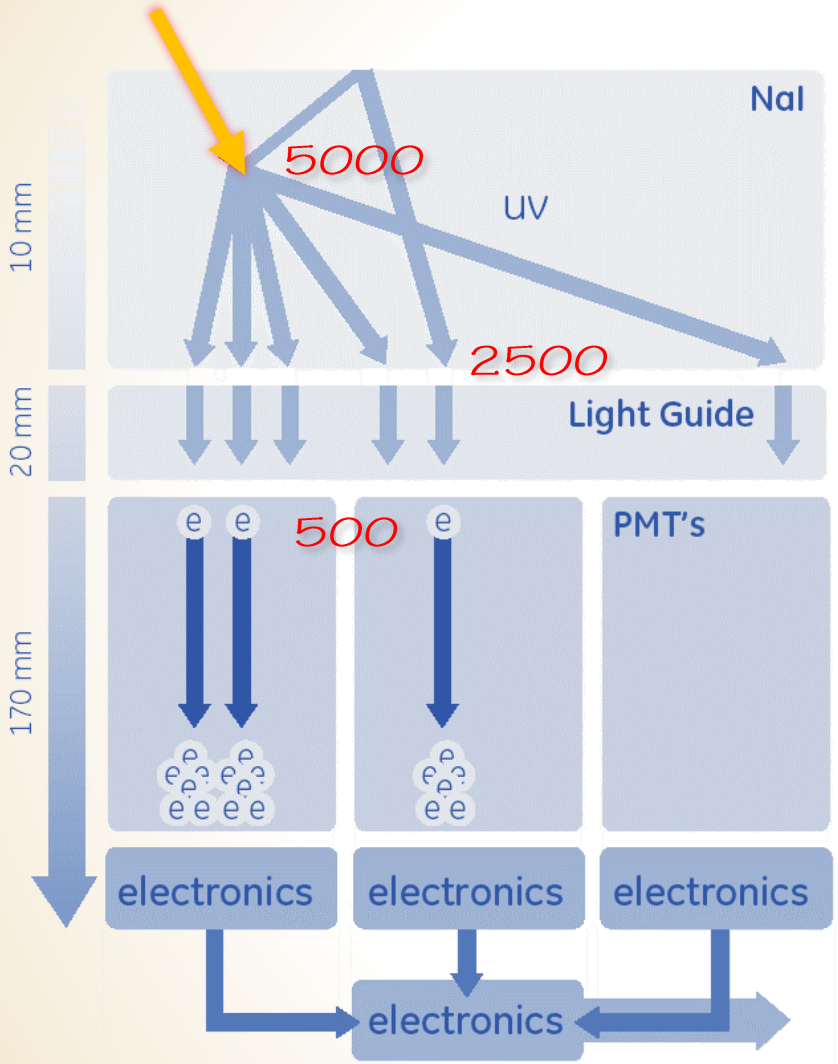


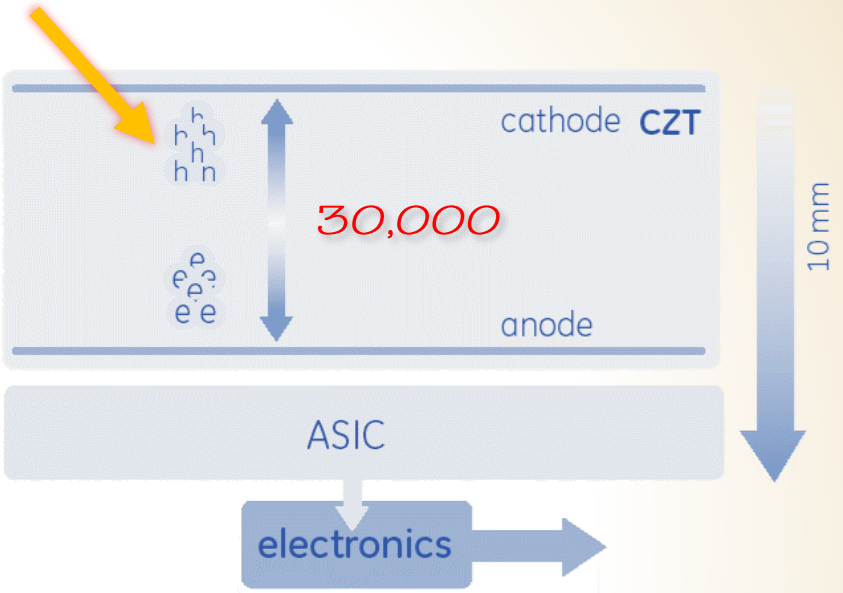


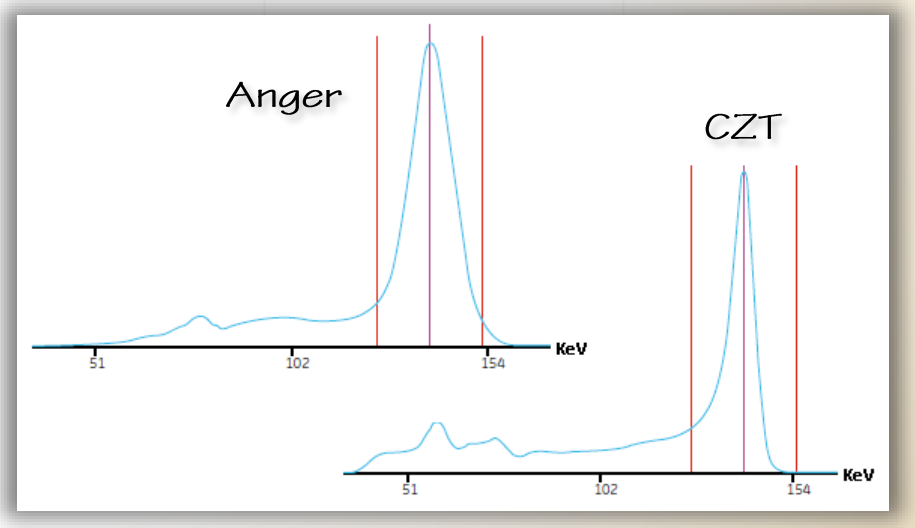


Résol. spatiale 5mm → 2,5 mm

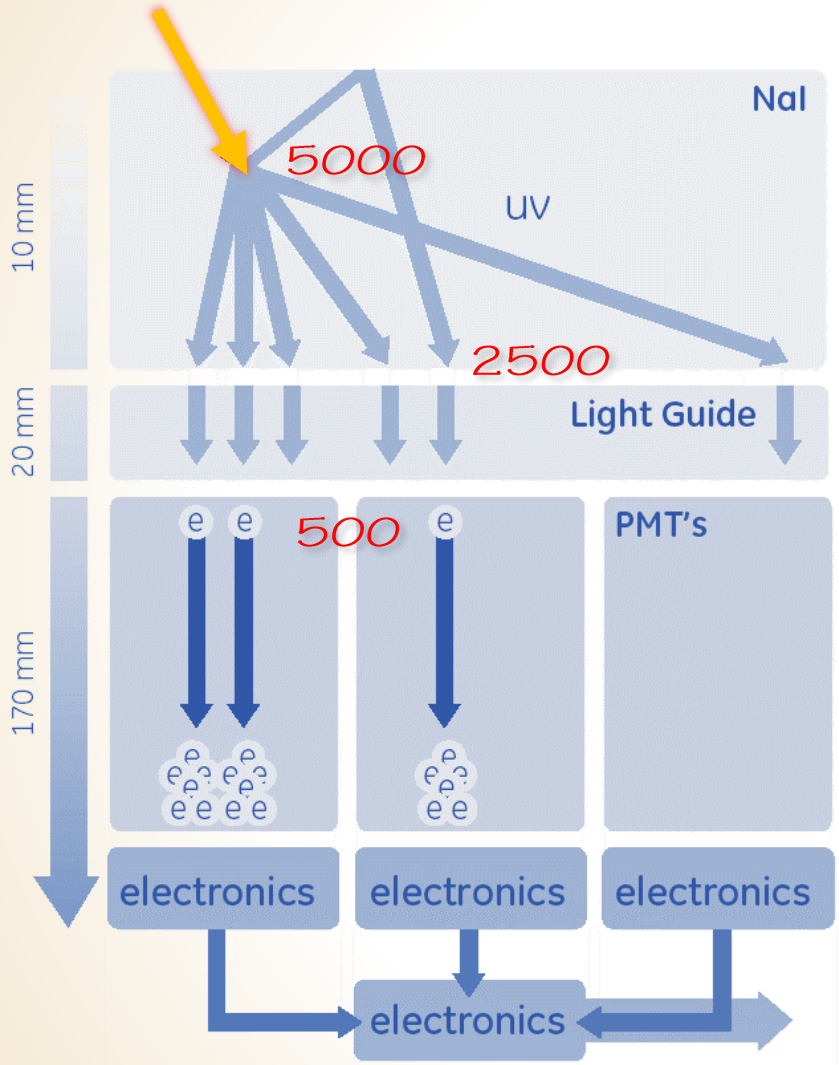
Caméra CZT

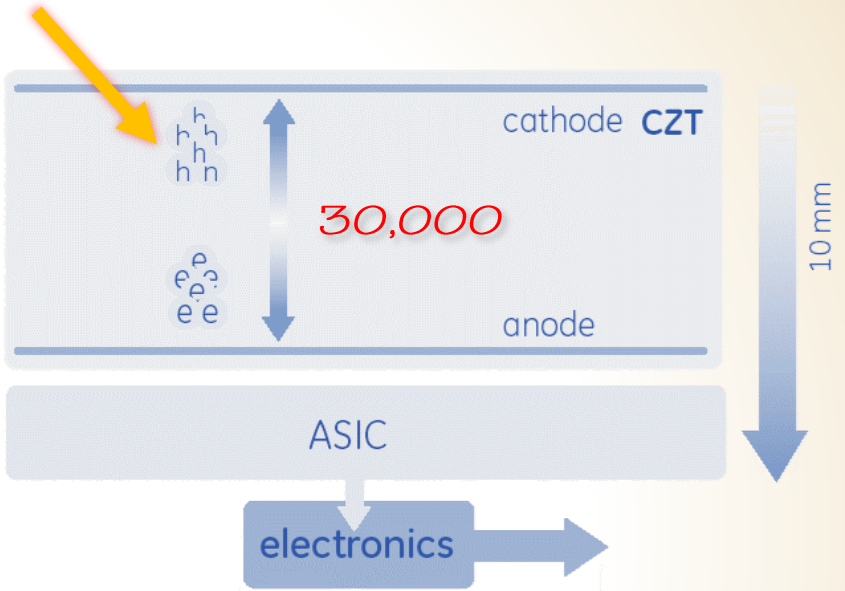

NaI
5000
UV
2500
Light Guide
500
PMT's
10 mm
20 mm
170 mm
electronics
electronics
electronics
electronics


cathode CZT
30,000
anode
10 mm
ASIC
electronics


Anger
CZT
KeV
51
102
154
KeV
51
102
154

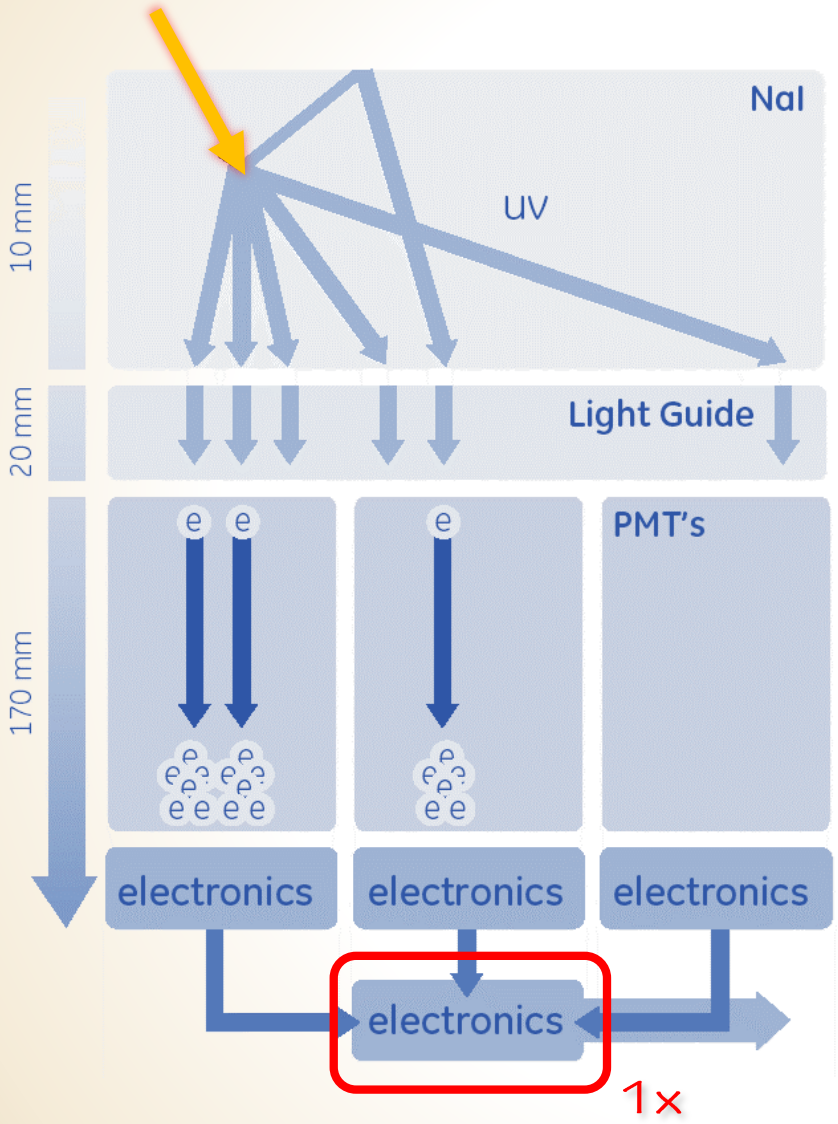
Caméra CZT

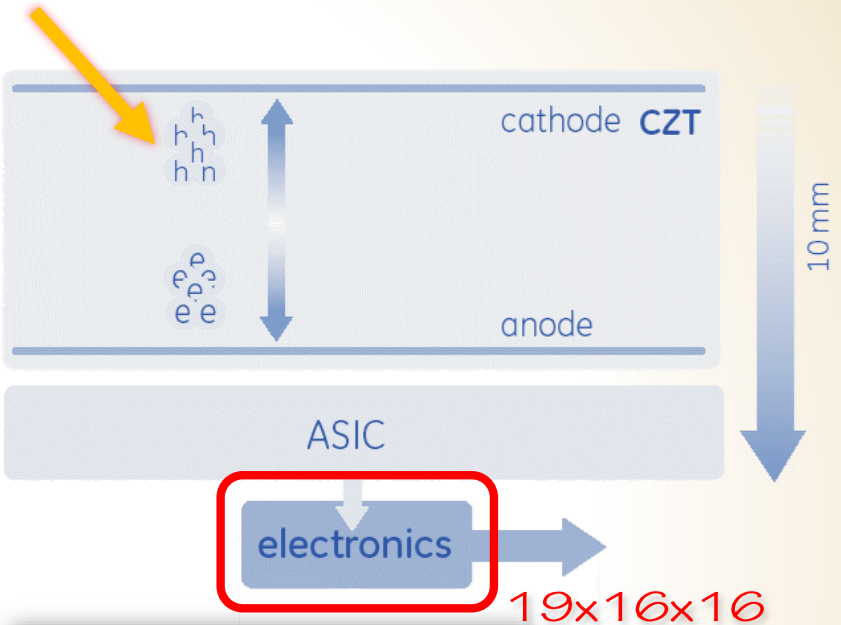


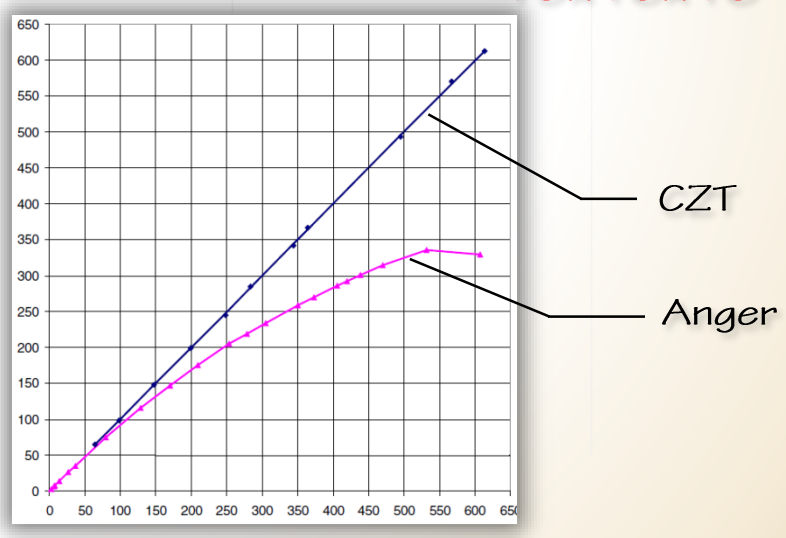


Résol. spatiale	5mm → 2,5 mm
Résol. en énergie	10% → 5%

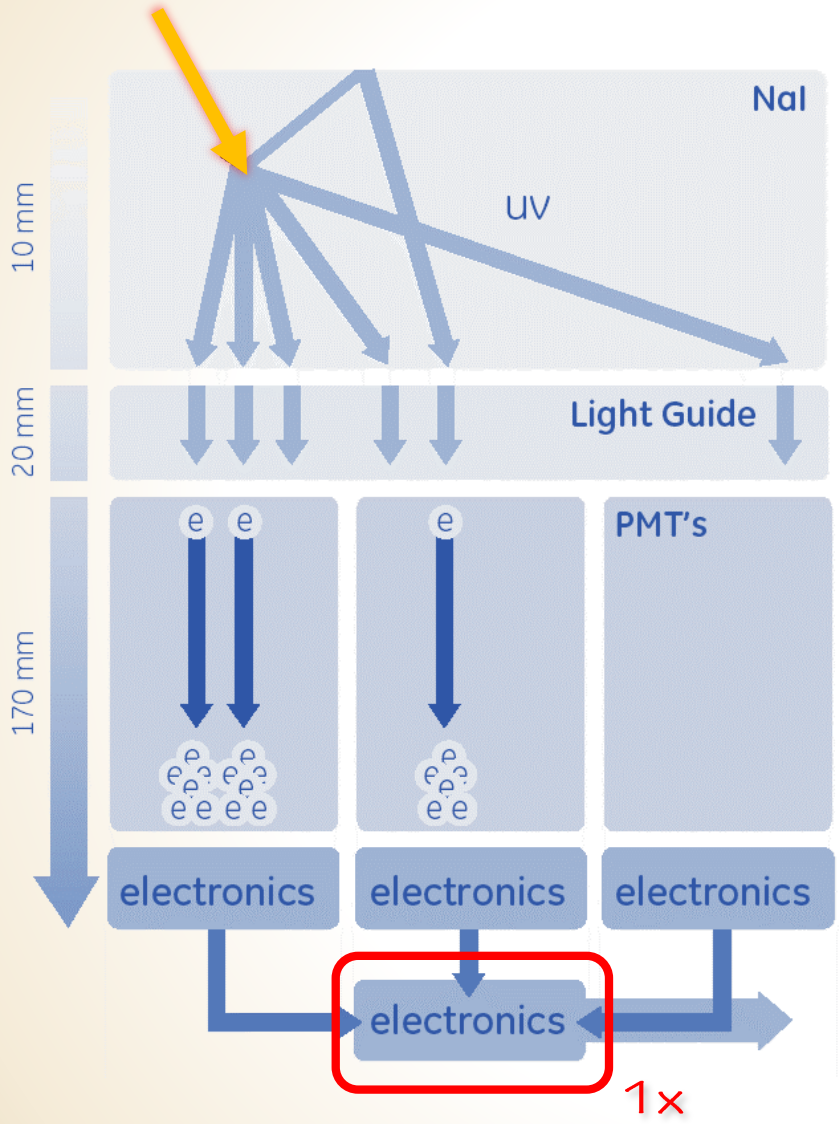
Caméra CZT

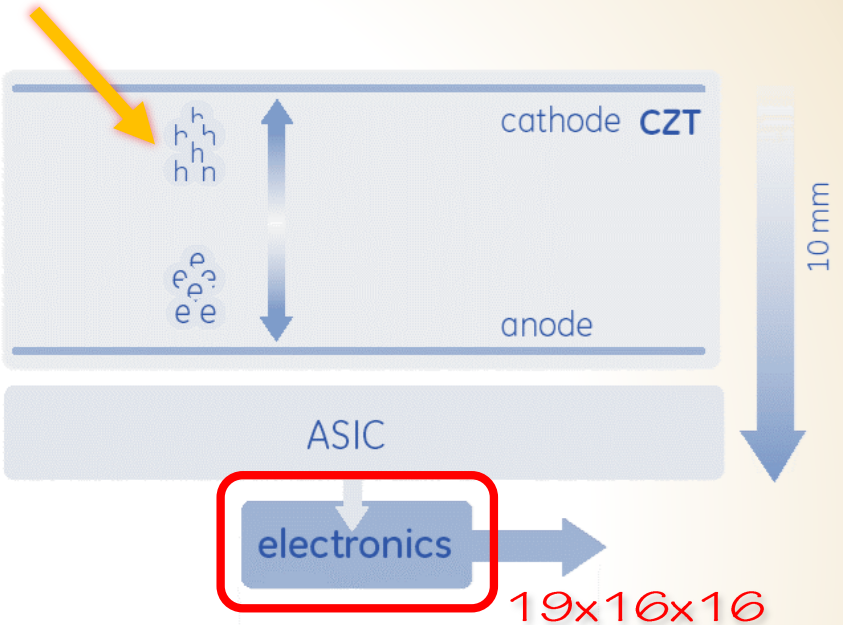

NaI
UV
10 mm
20 mm
Light Guide
170 mm
PMT's
e
electronics
electronics
electronics
electronics
1x


cathode CZT
anode
10 mm
ASIC
electronics
19x16x16


650
600
550
500
450
400
350
300
250
200
150
100
50
0
0 50 100 150 200 250 300 350 400 450 500 550 600
CZT
Anger

Caméra CZT





Résol. spatiale	5mm → 2,5 mm
Résol. en énergie	10% → 5%
Sensibilité	X 4

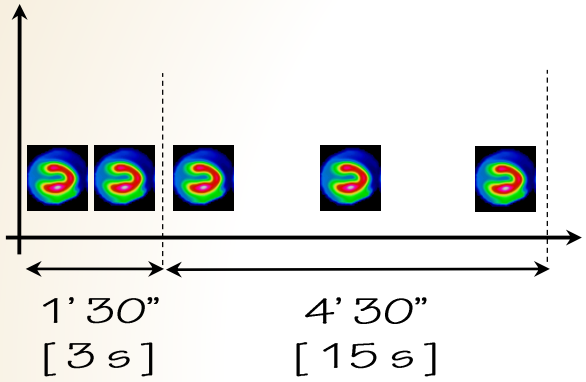
Protocole

REPOS

MIBI
5 mCi

Protocole

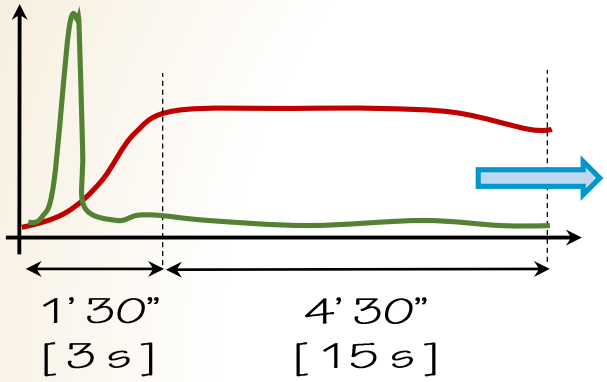
REPOS



MIBI
5 mCi

Protocole

REPOS

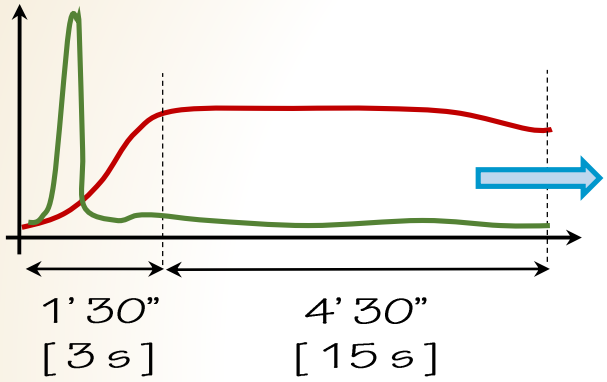


$K_1 \propto Q_{Repos}$

MIBI
5 mCi

Protocole

REPOS

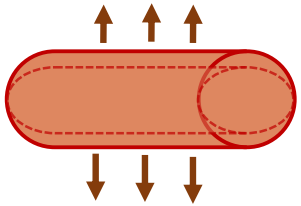


$K_1 \propto Q_{Repos}$

MIBI
5 mCi

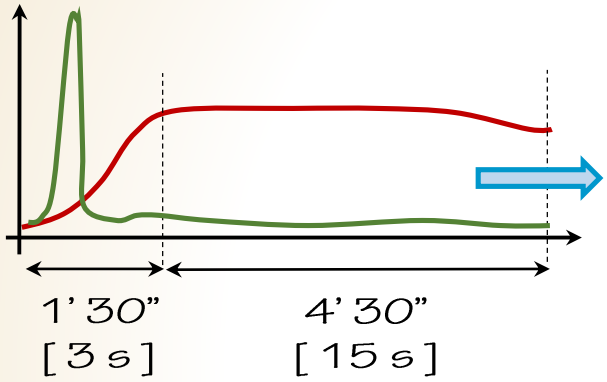
STRESS

Dipyridamole



Protocole

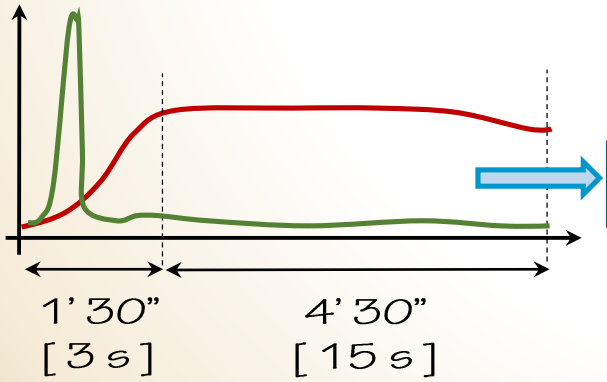
REPOS



$K_1 \propto Q_{Repos}$

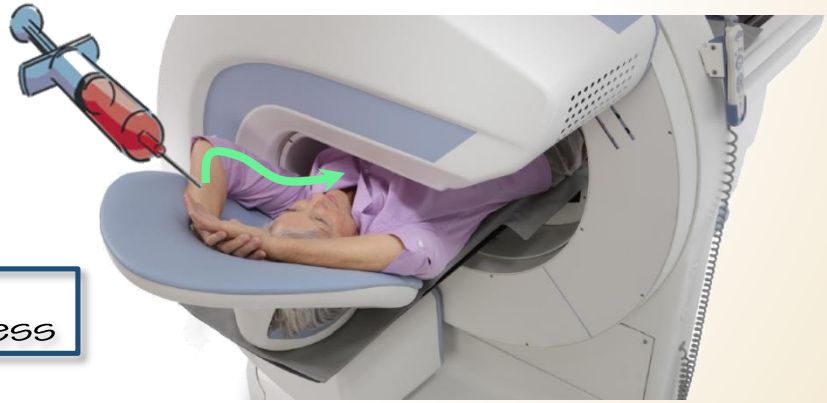
MIBI
5 mCi

STRESS



$K_1 \propto Q_{Stress}$

MIBI
20 mCi



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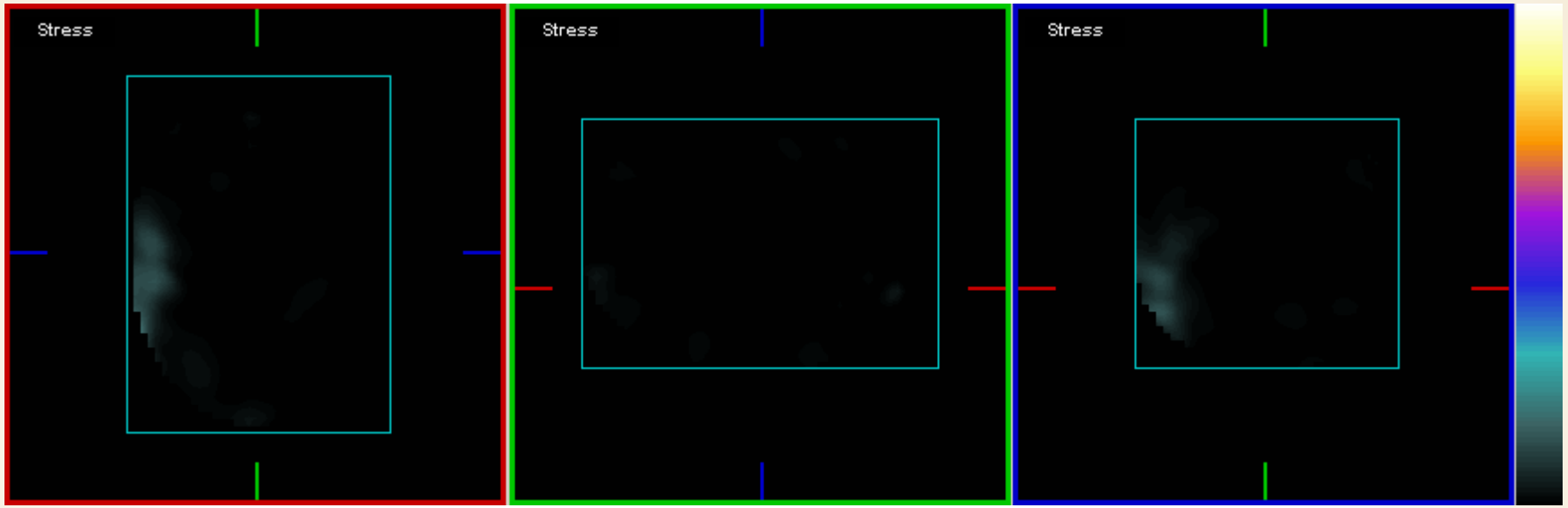

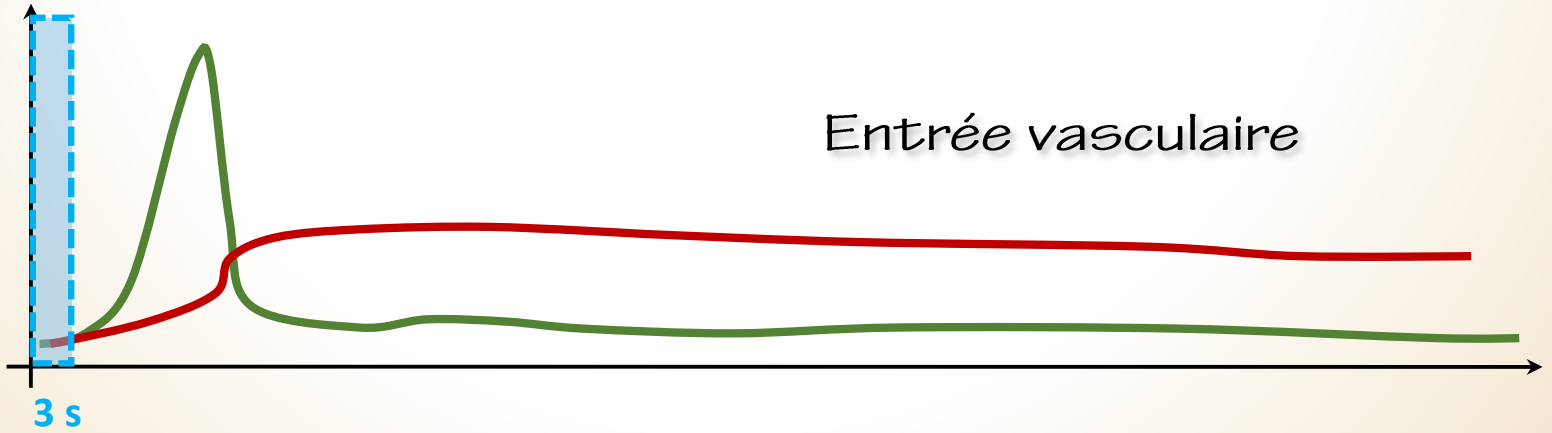

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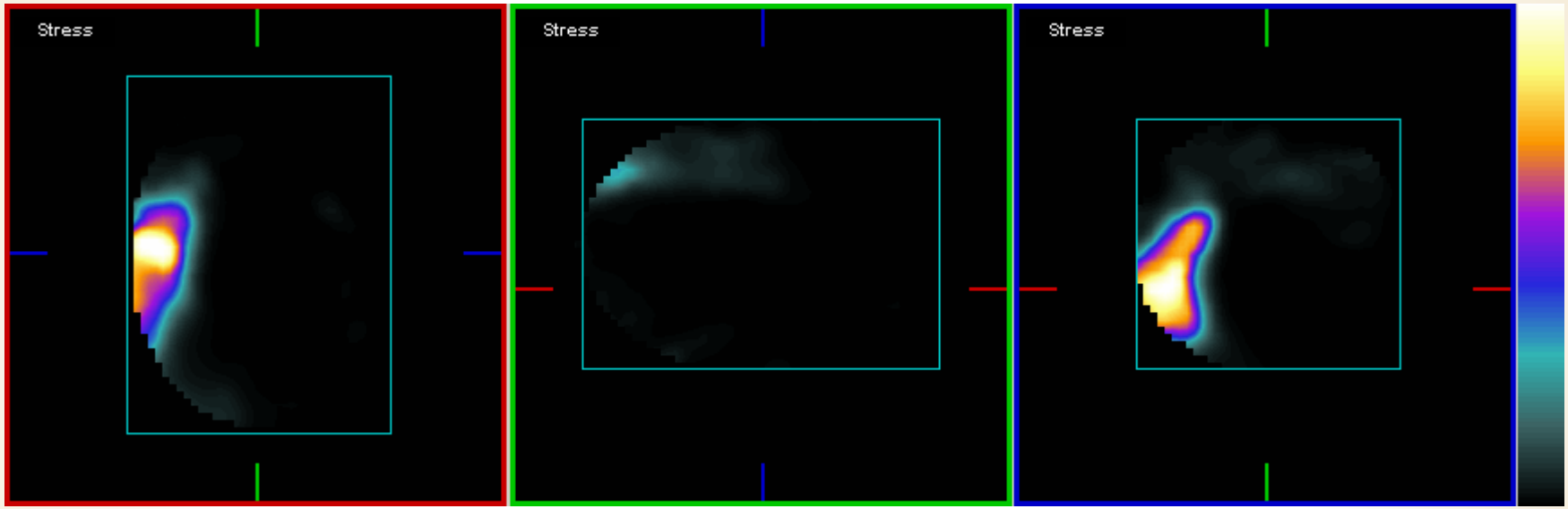

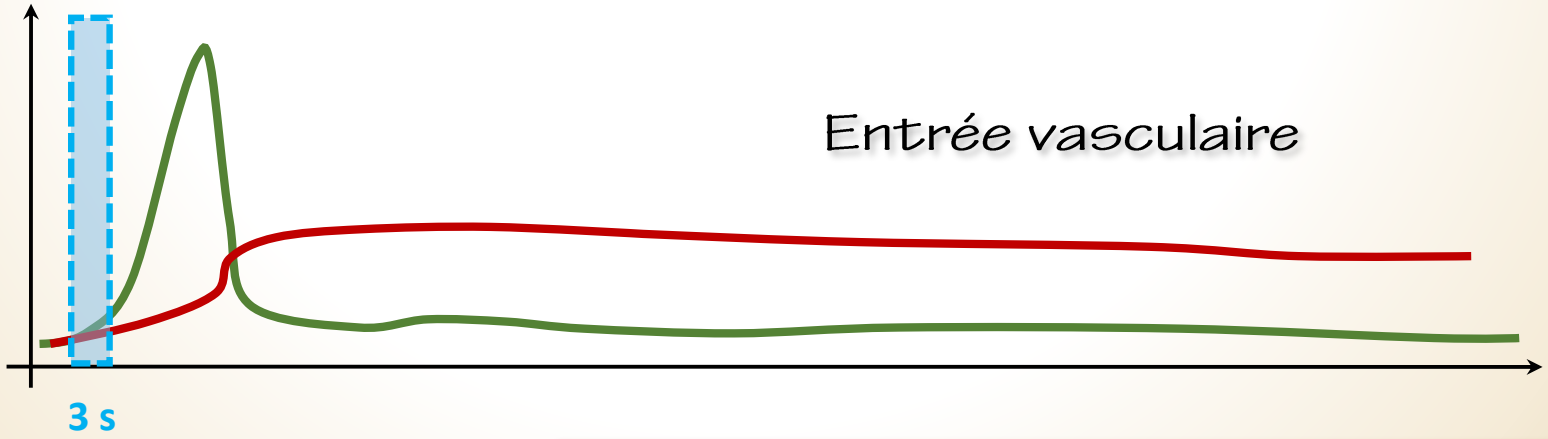

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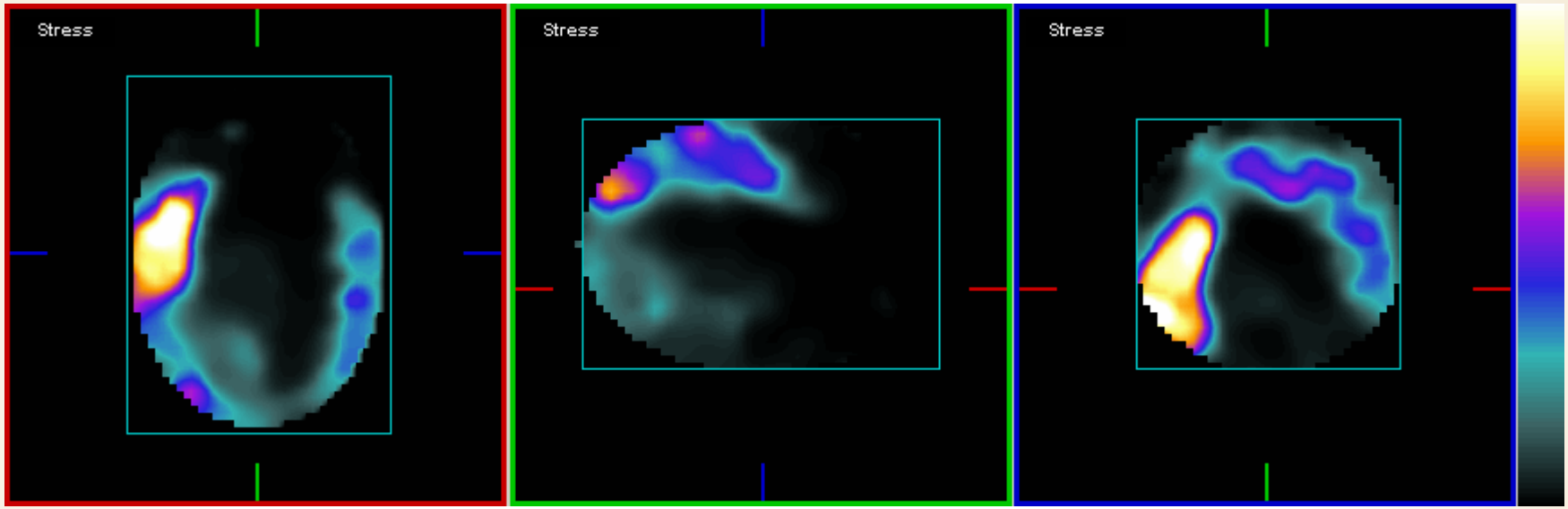

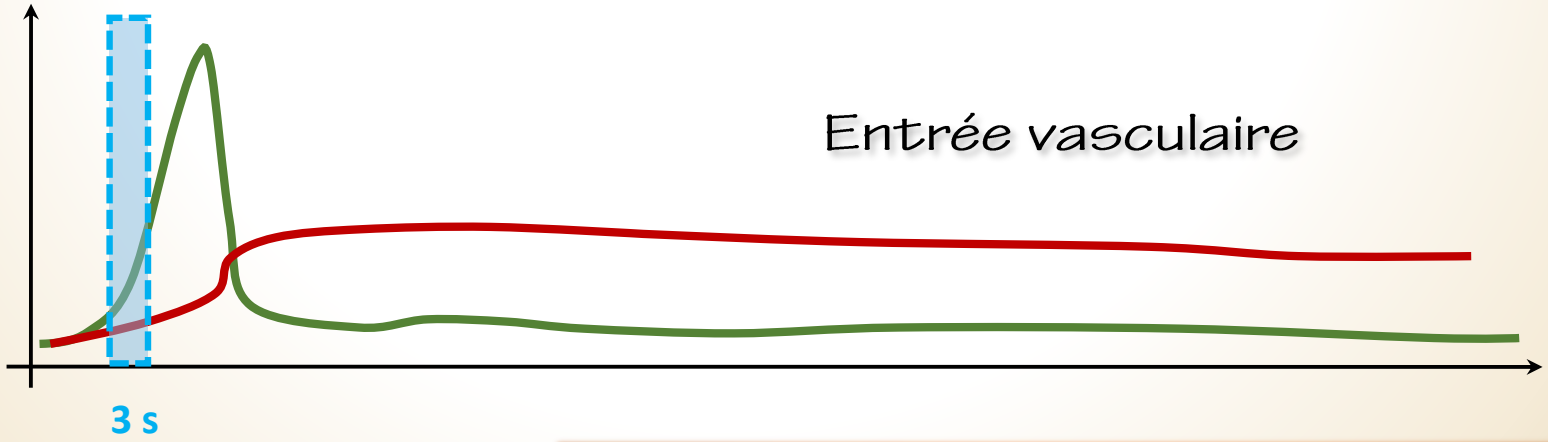

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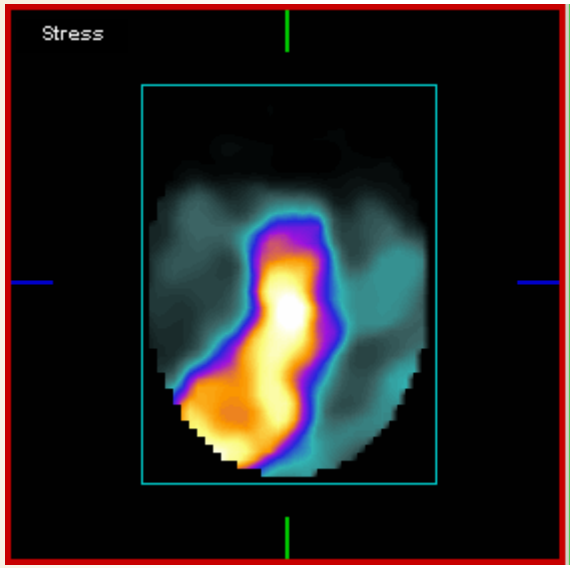

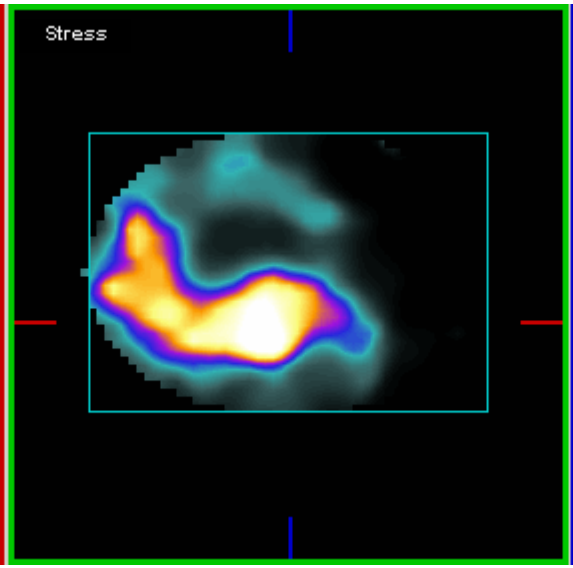

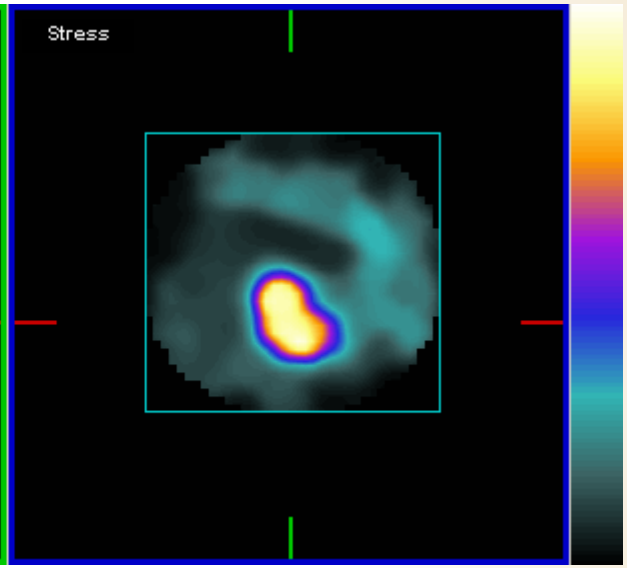

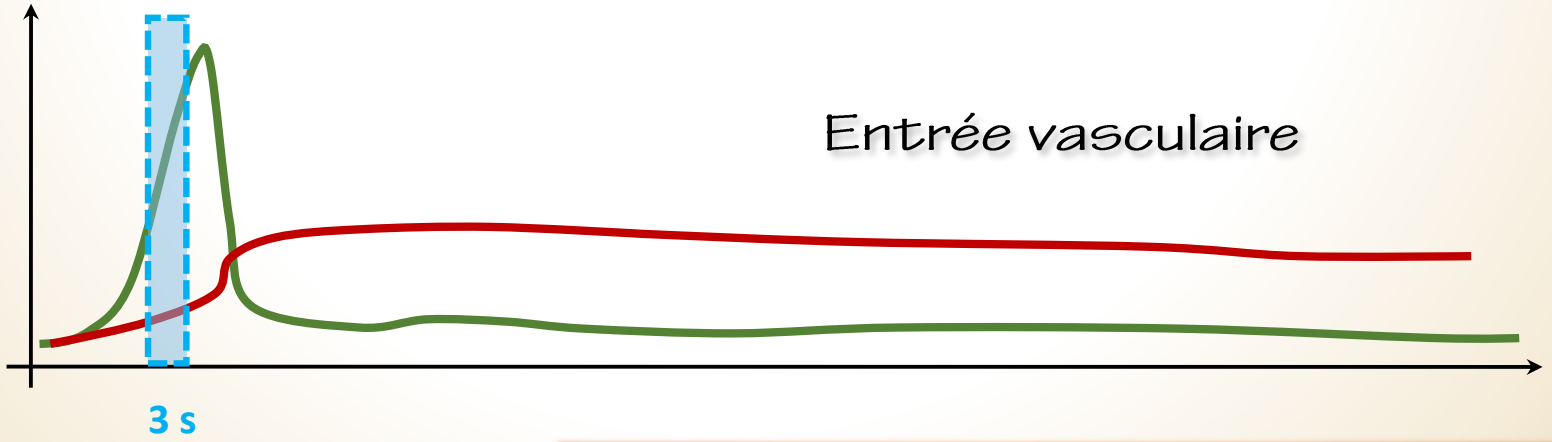

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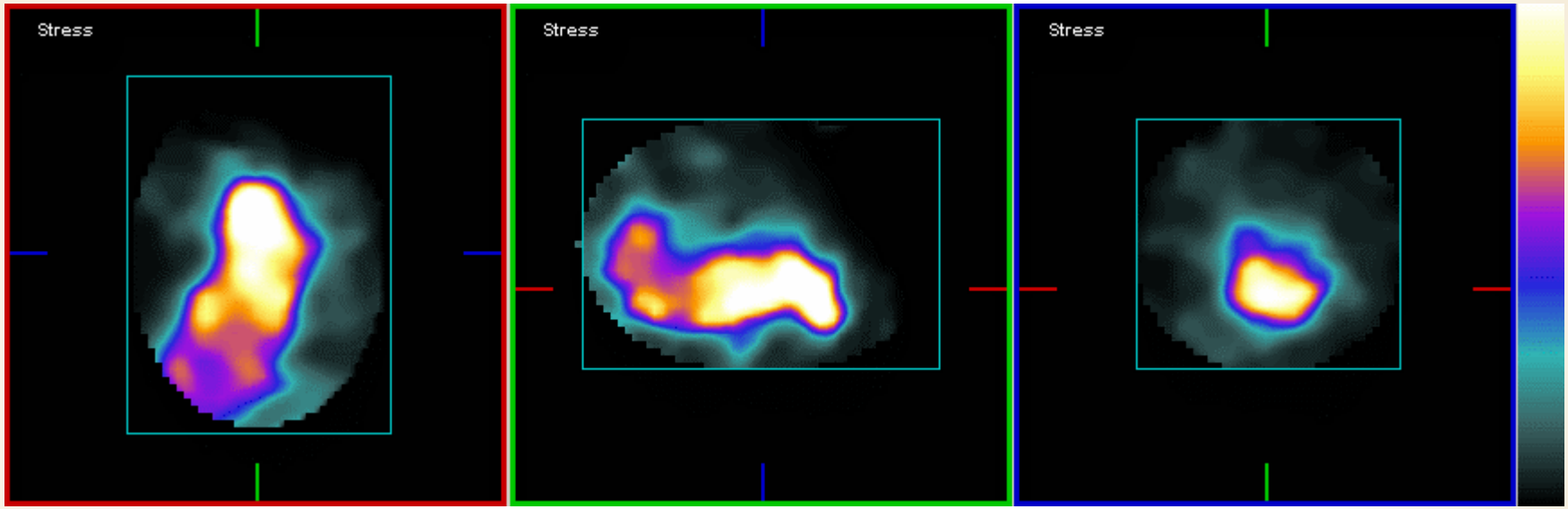

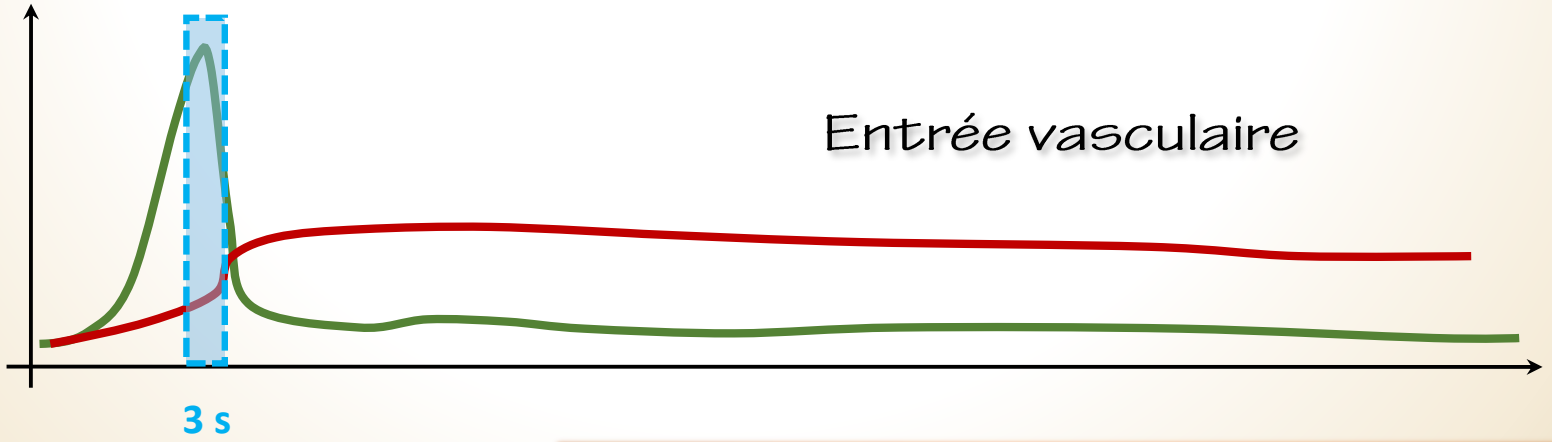

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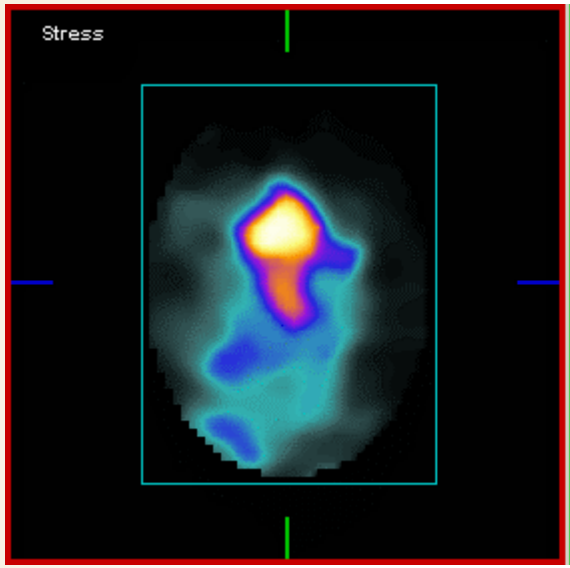

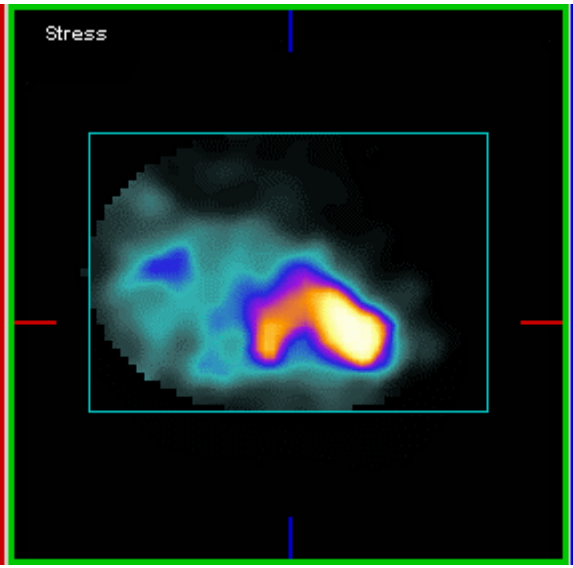

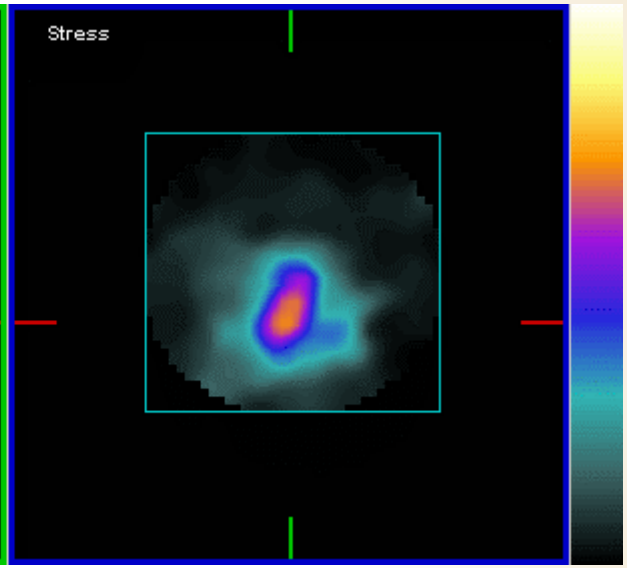

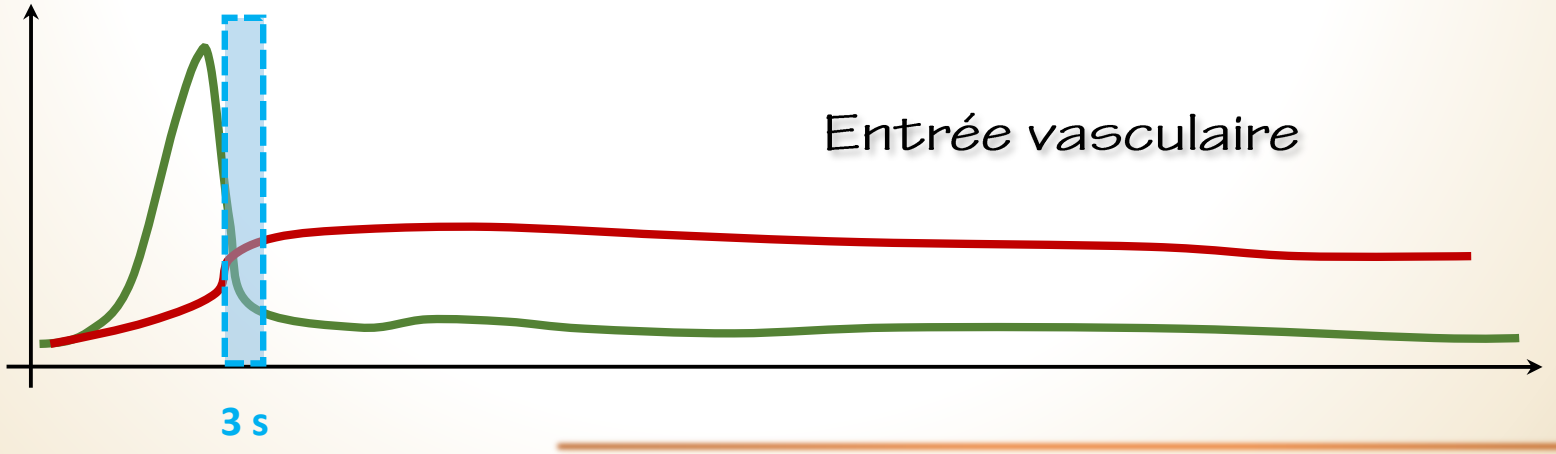

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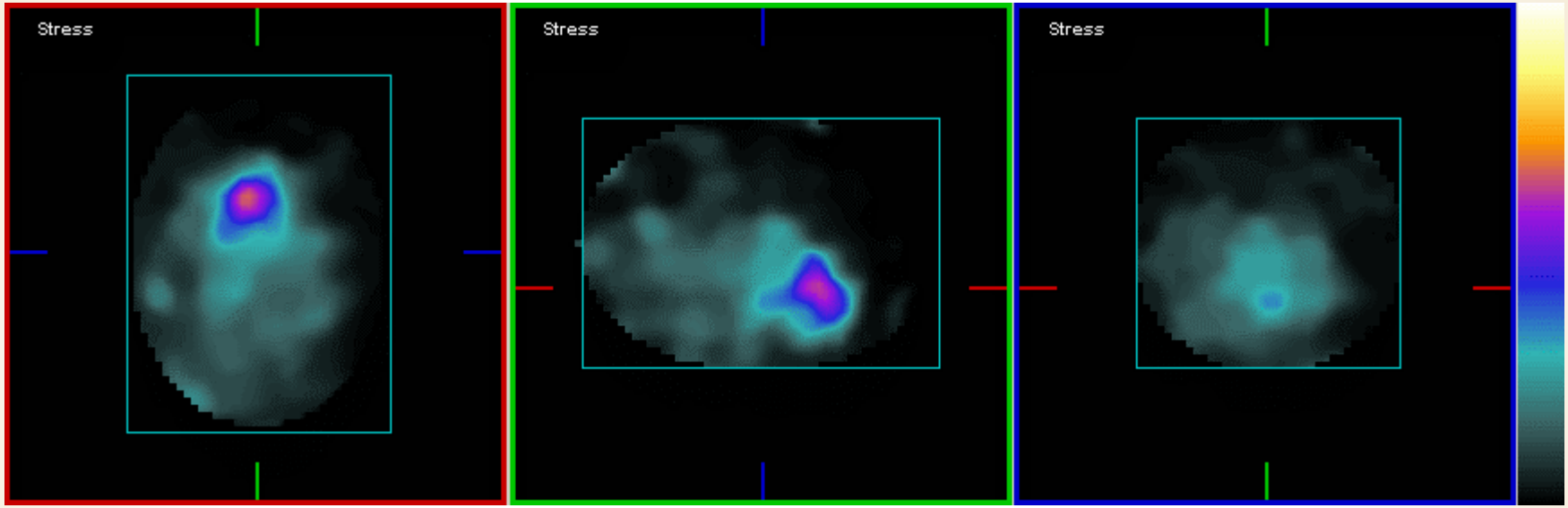

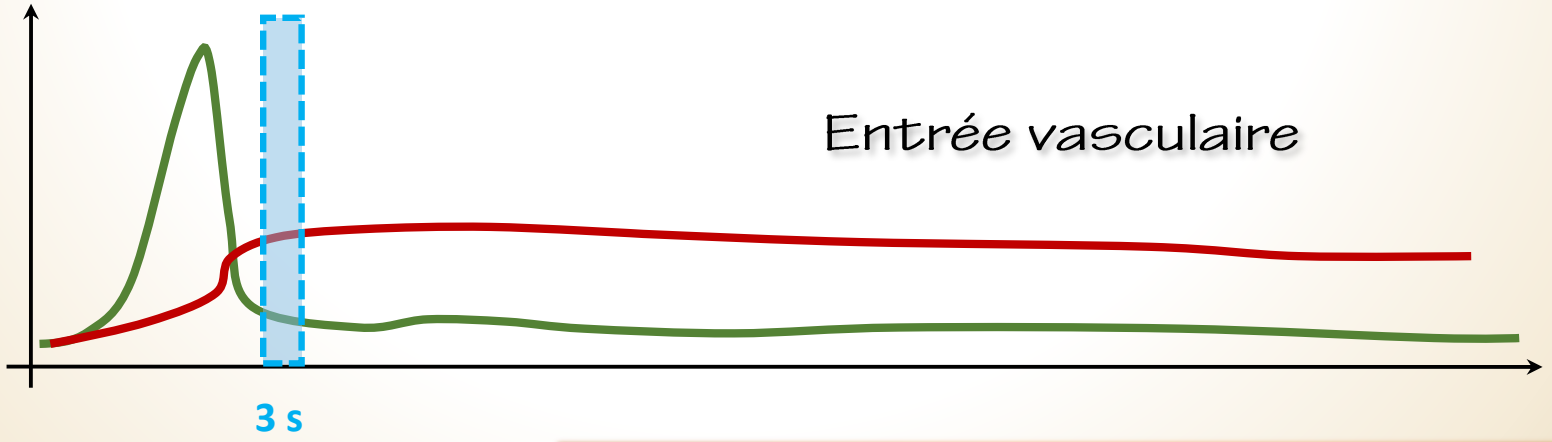

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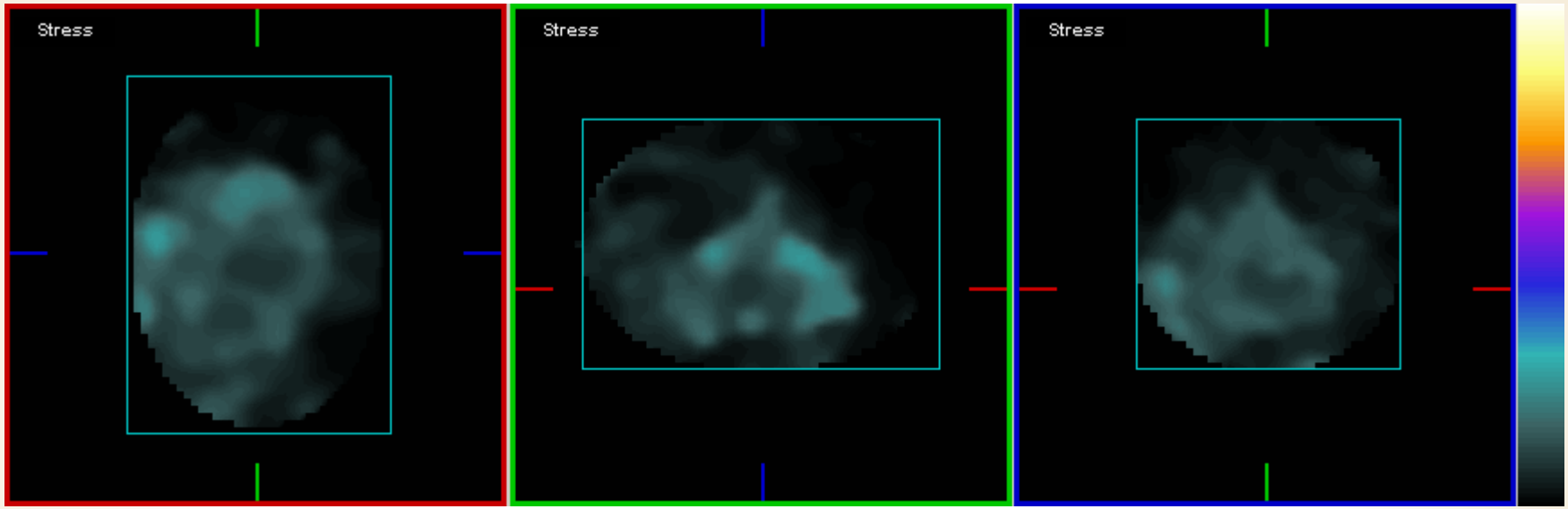

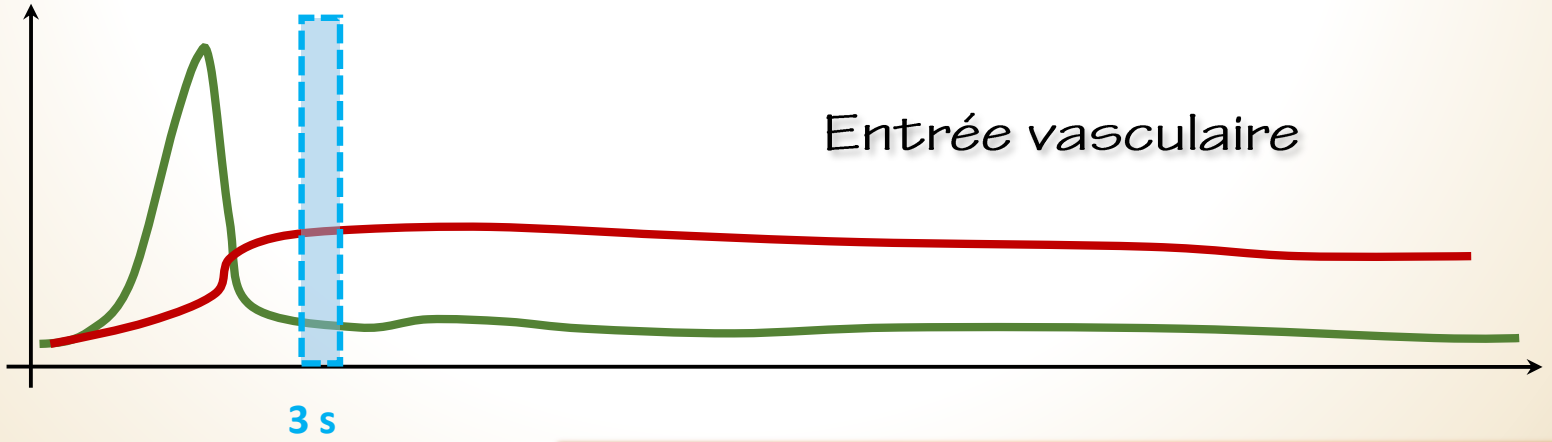

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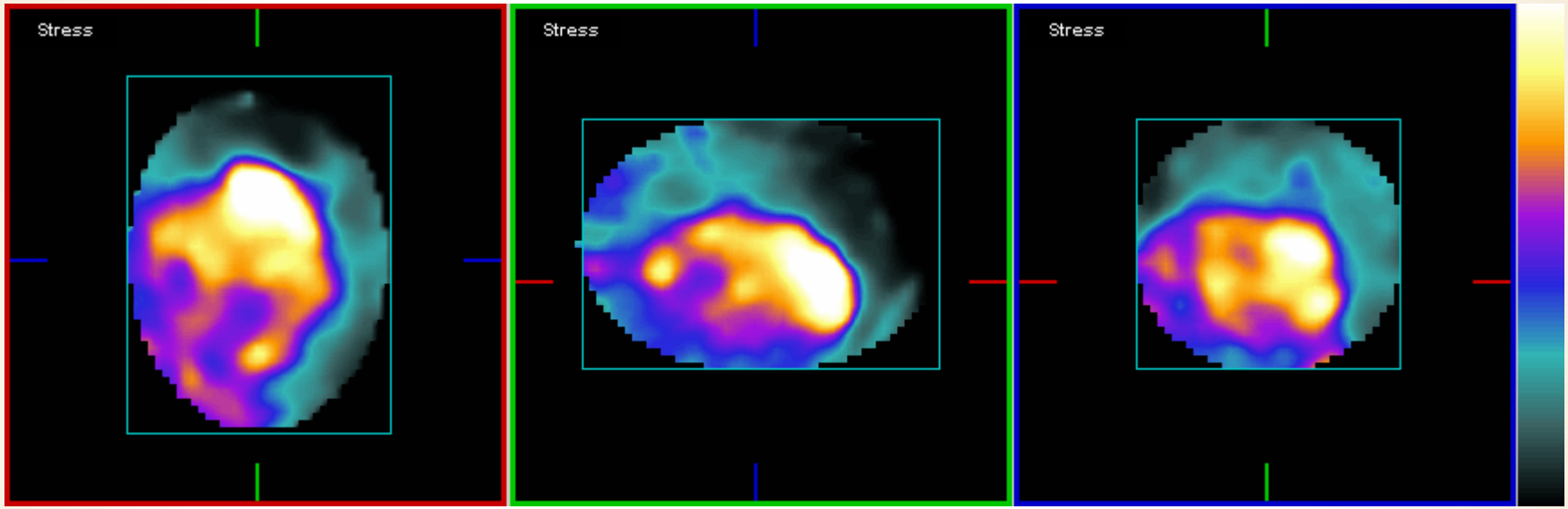

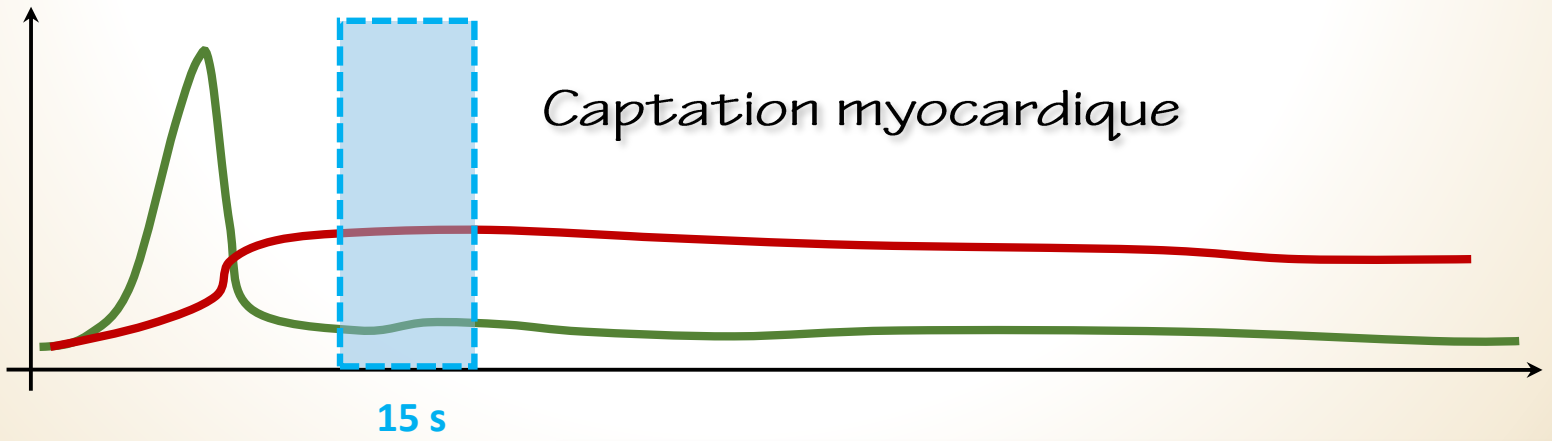

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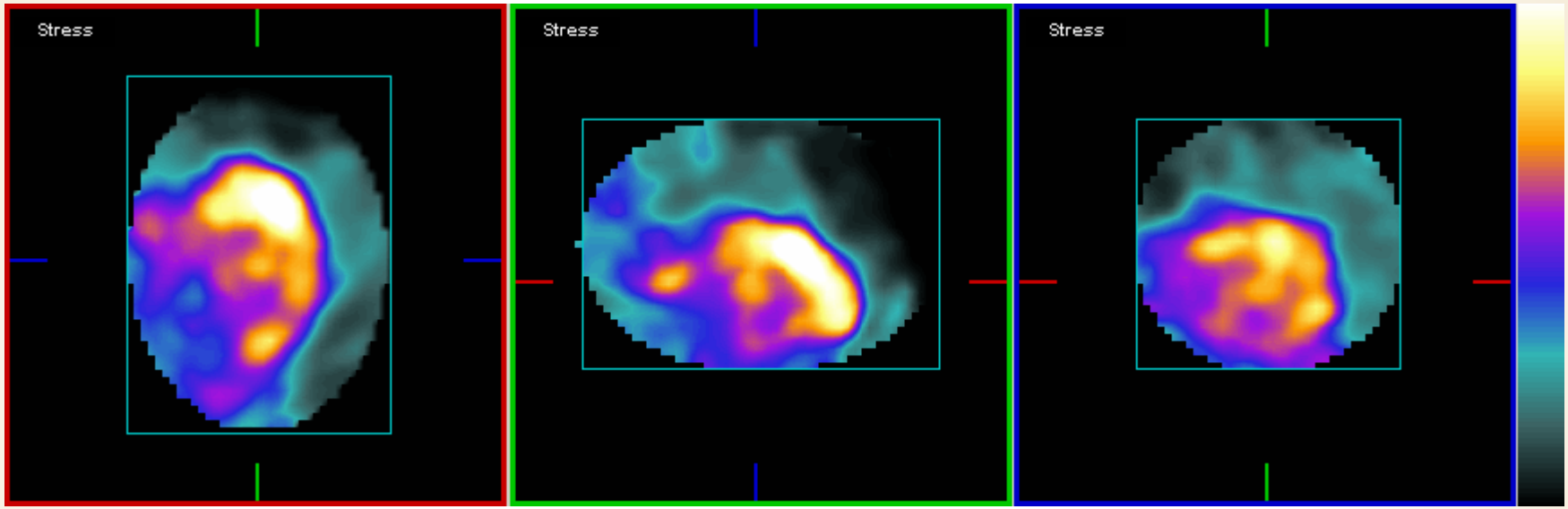

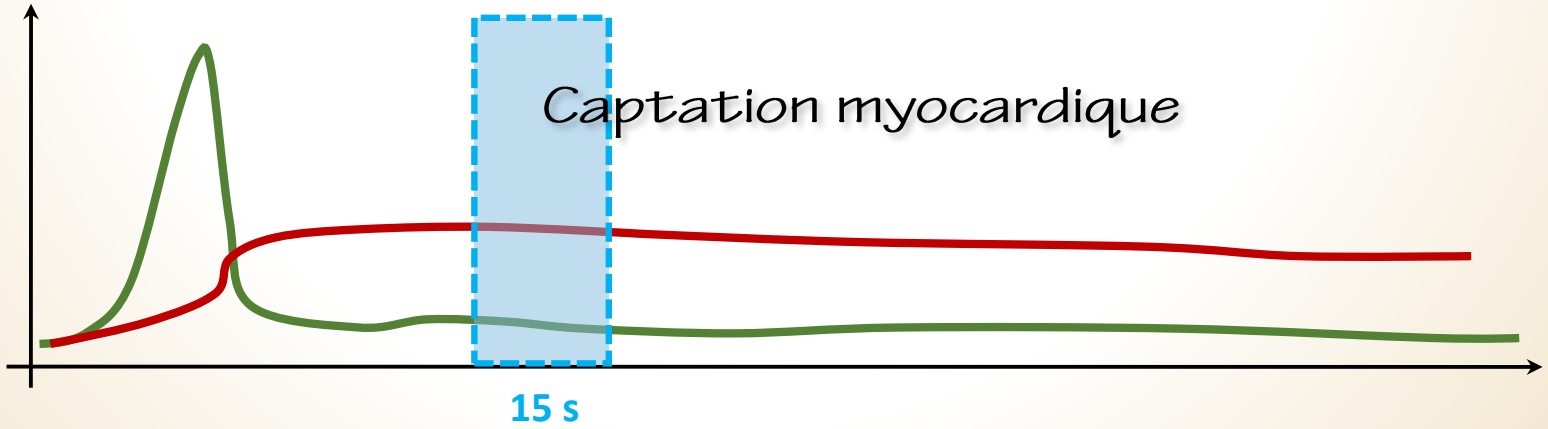

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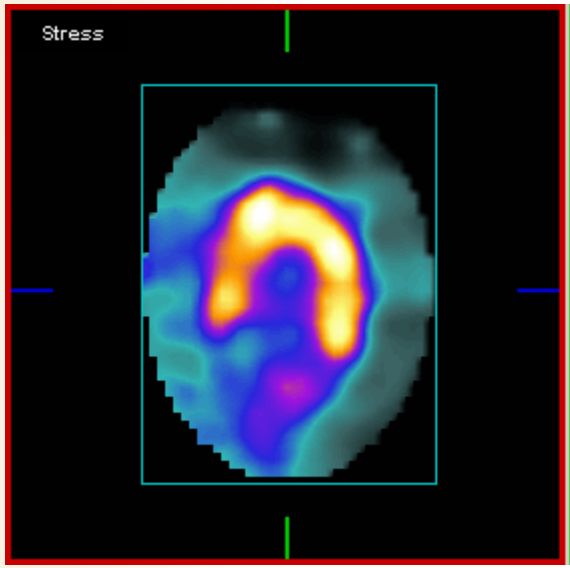

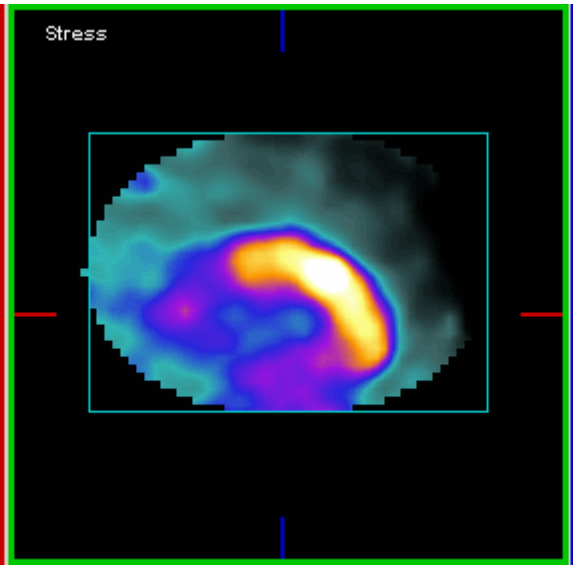

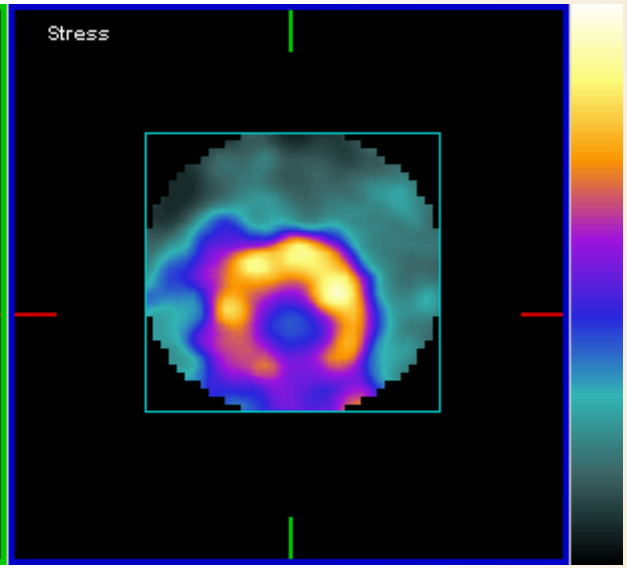

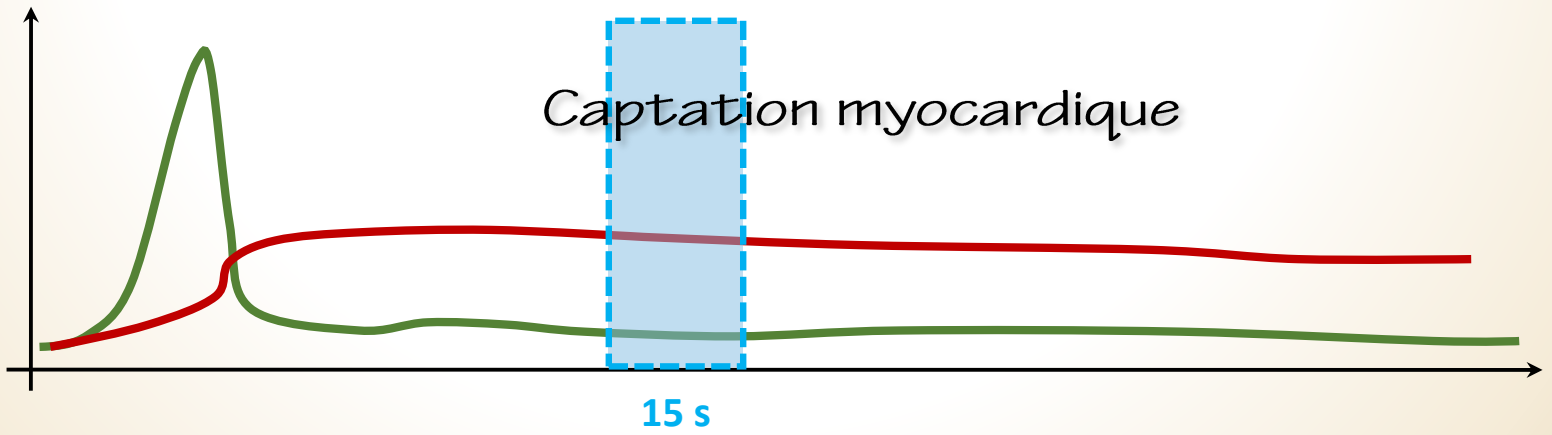

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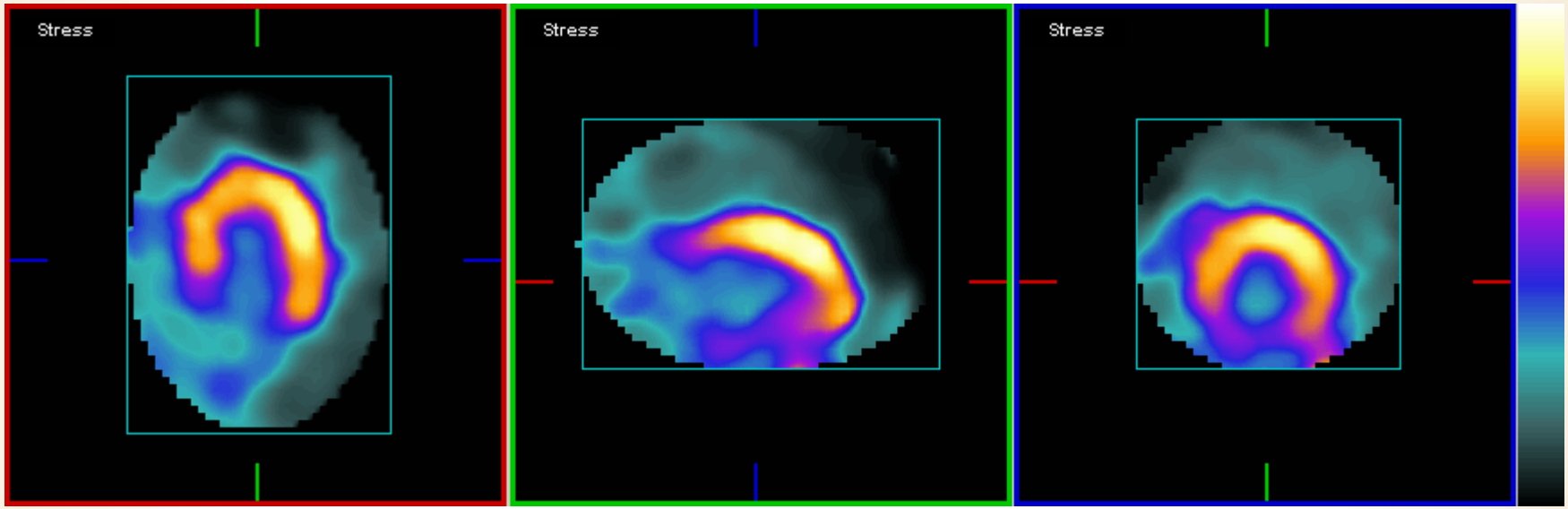

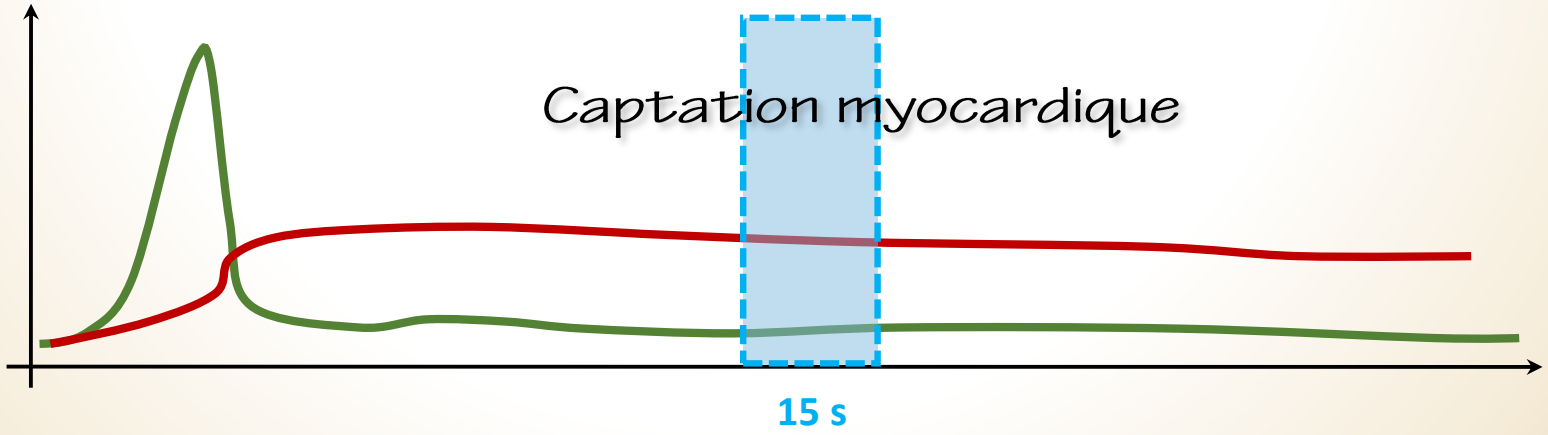

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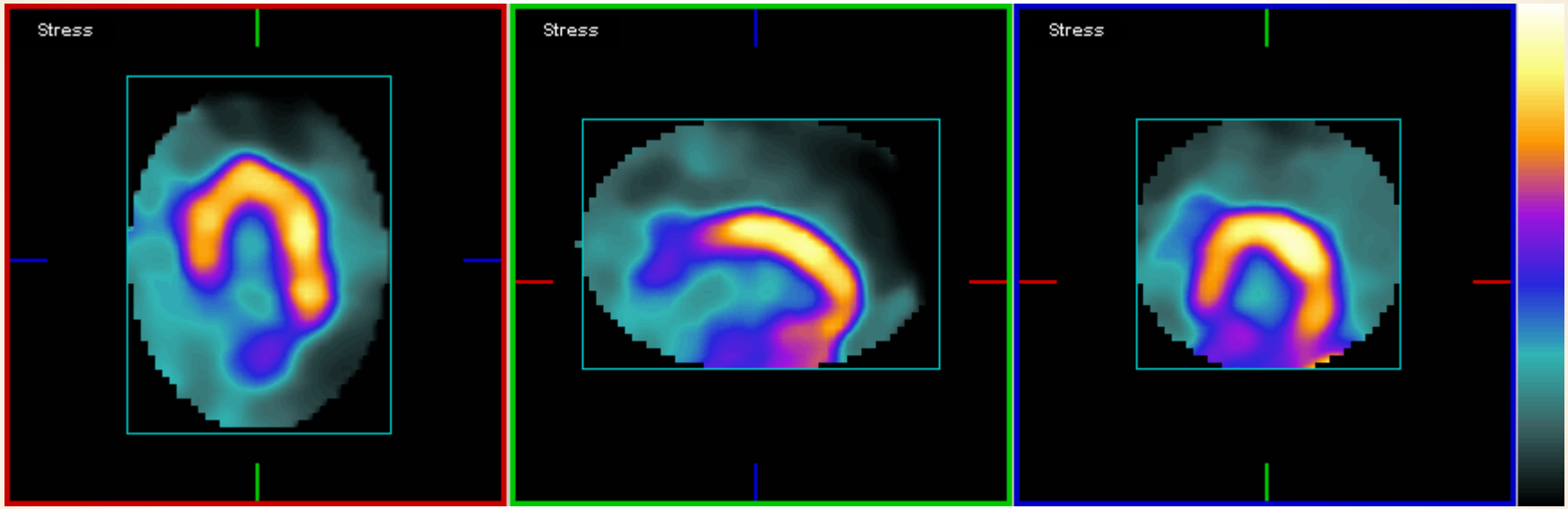

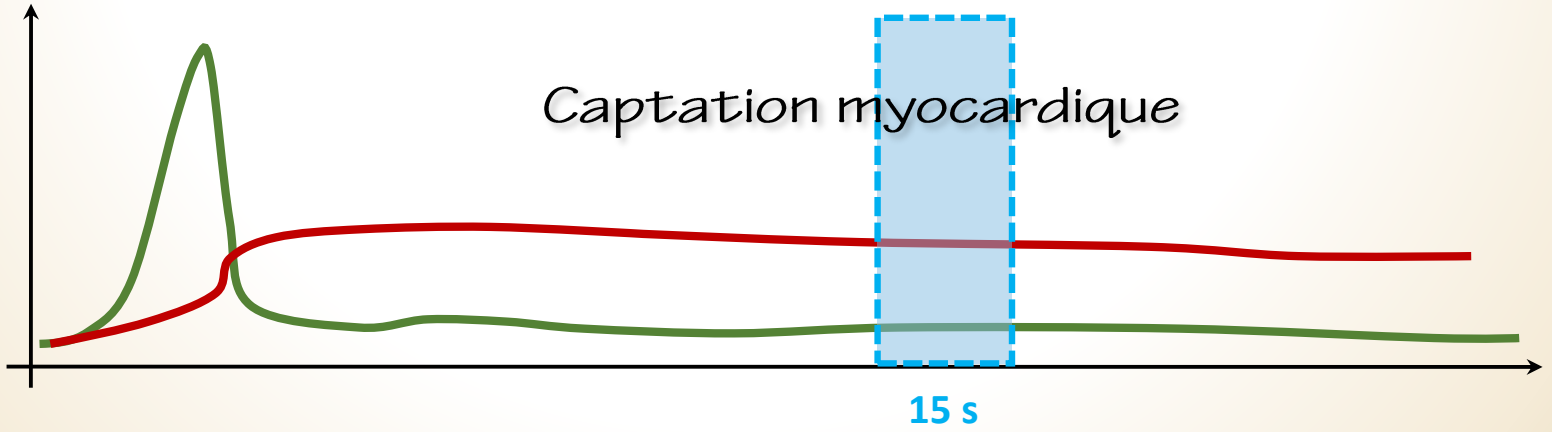

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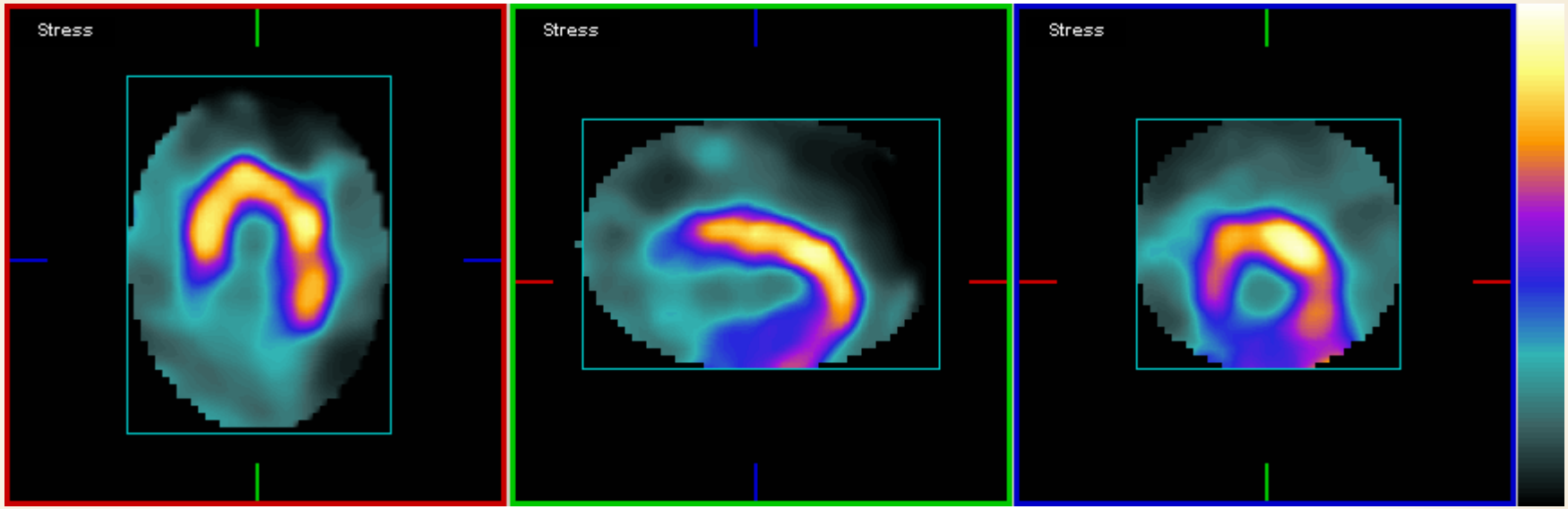

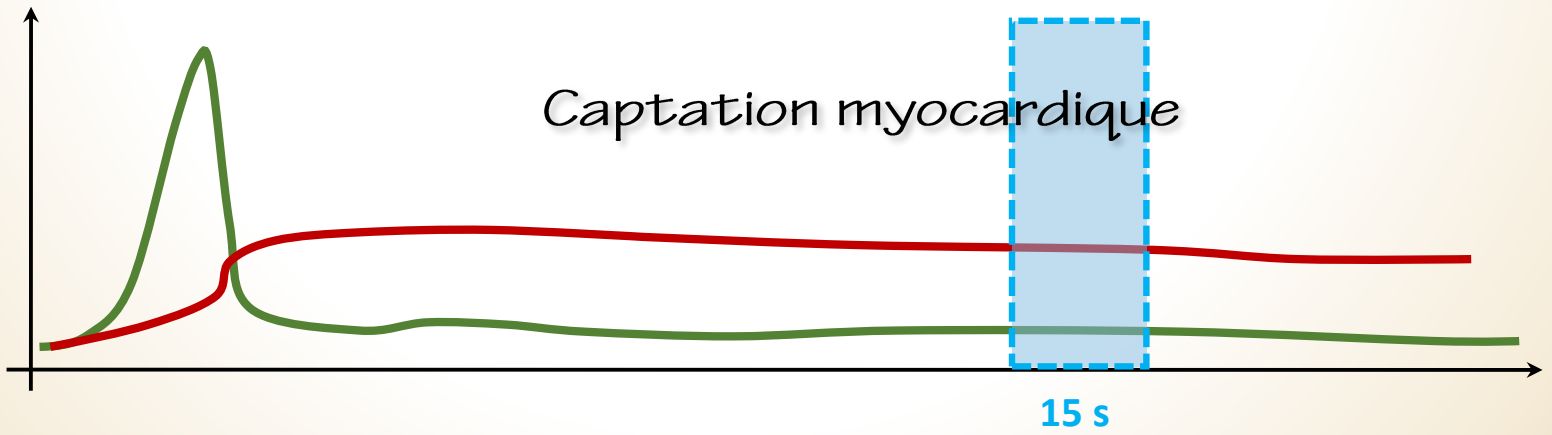

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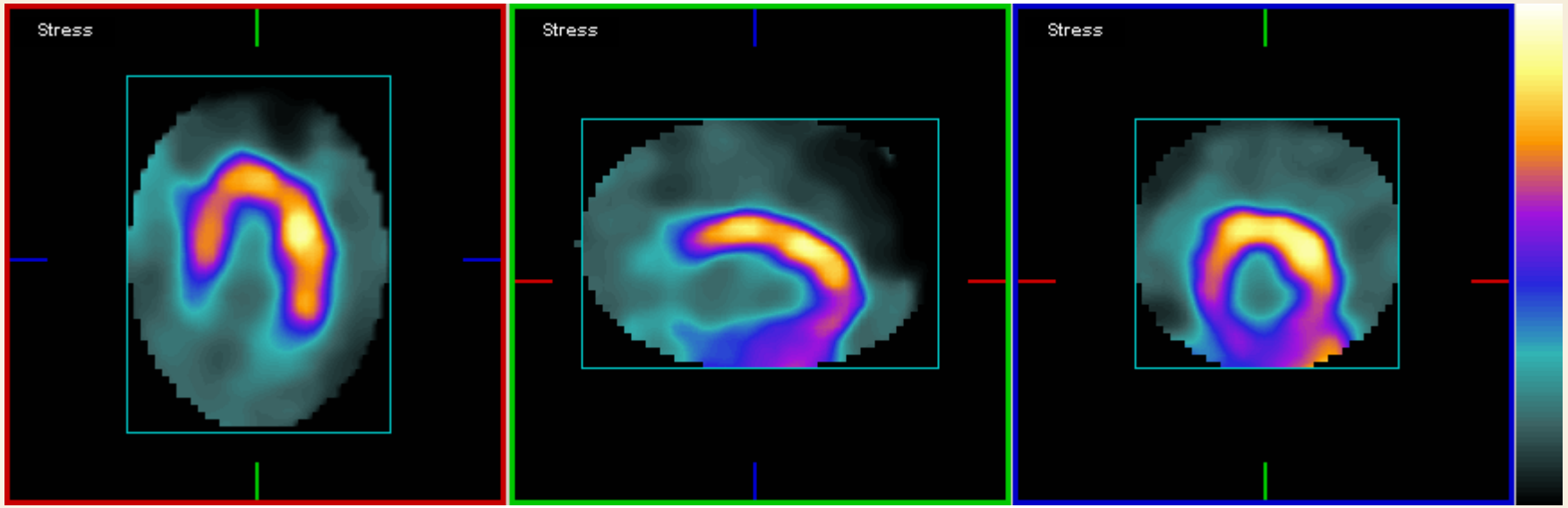

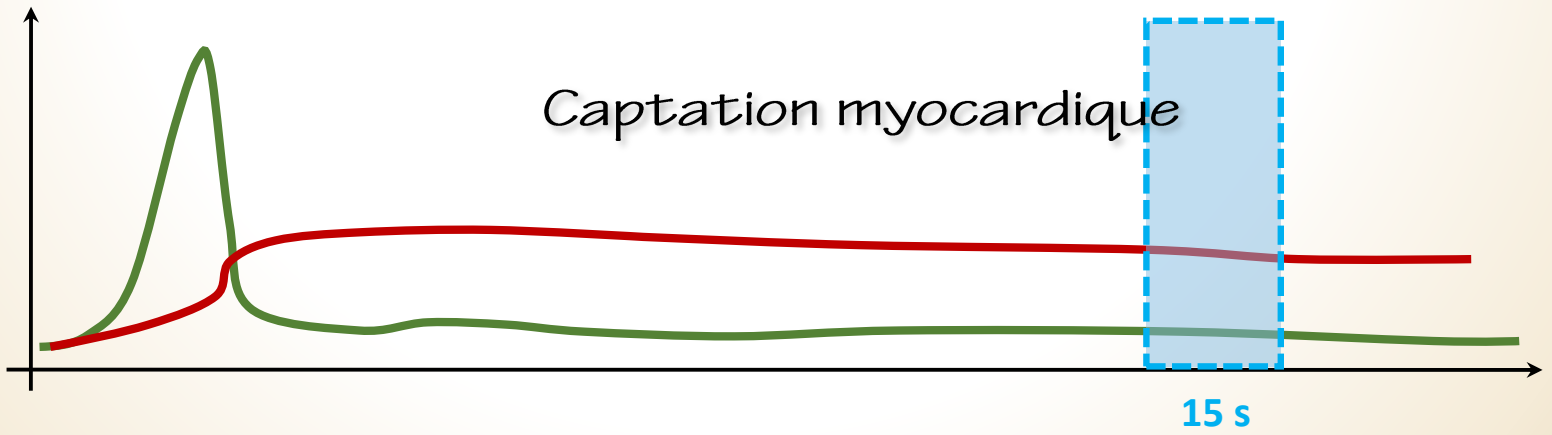

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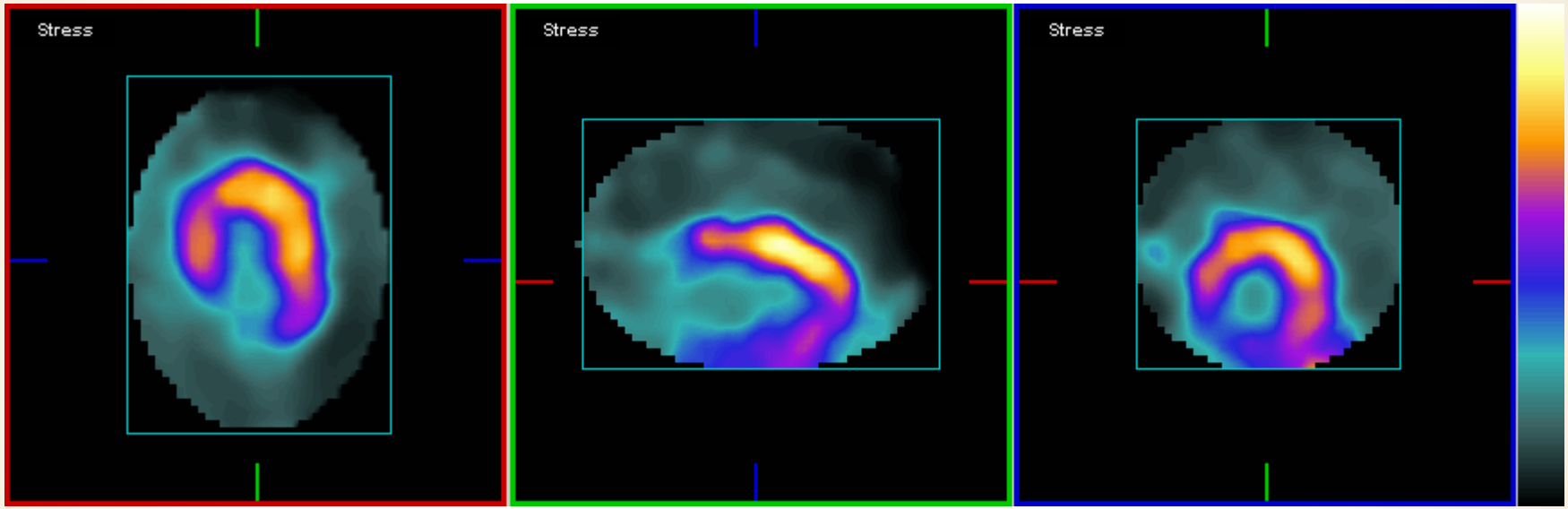

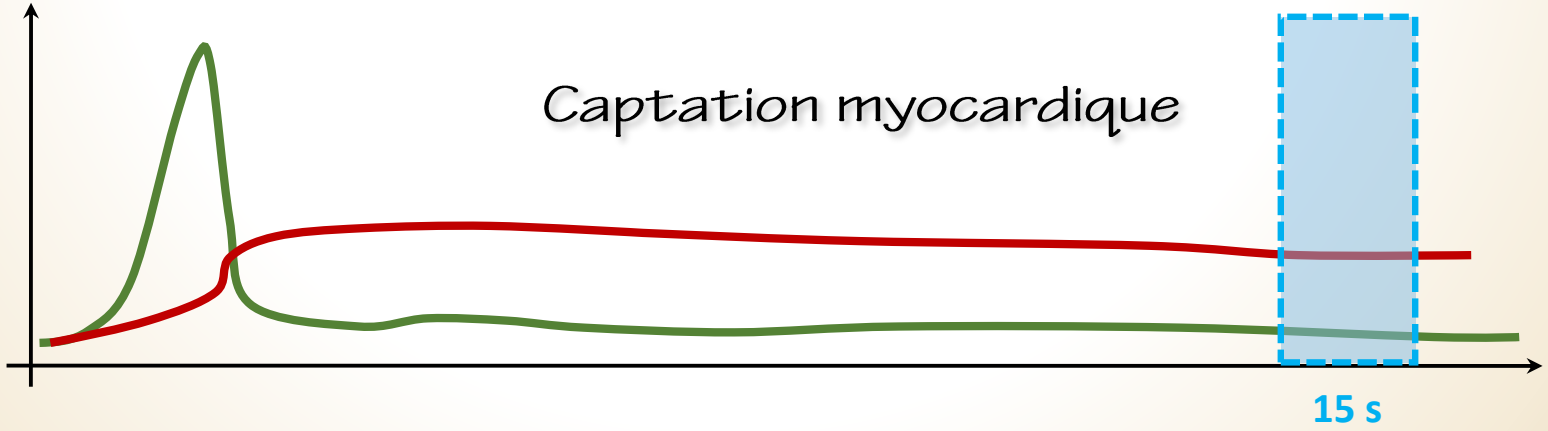

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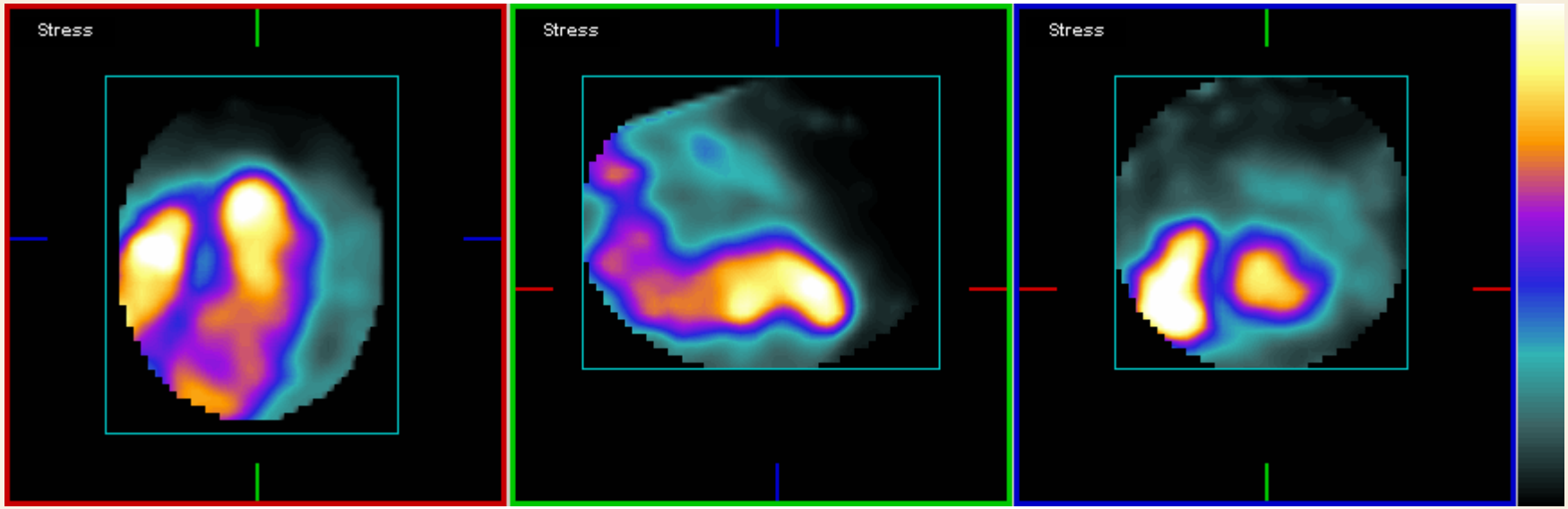

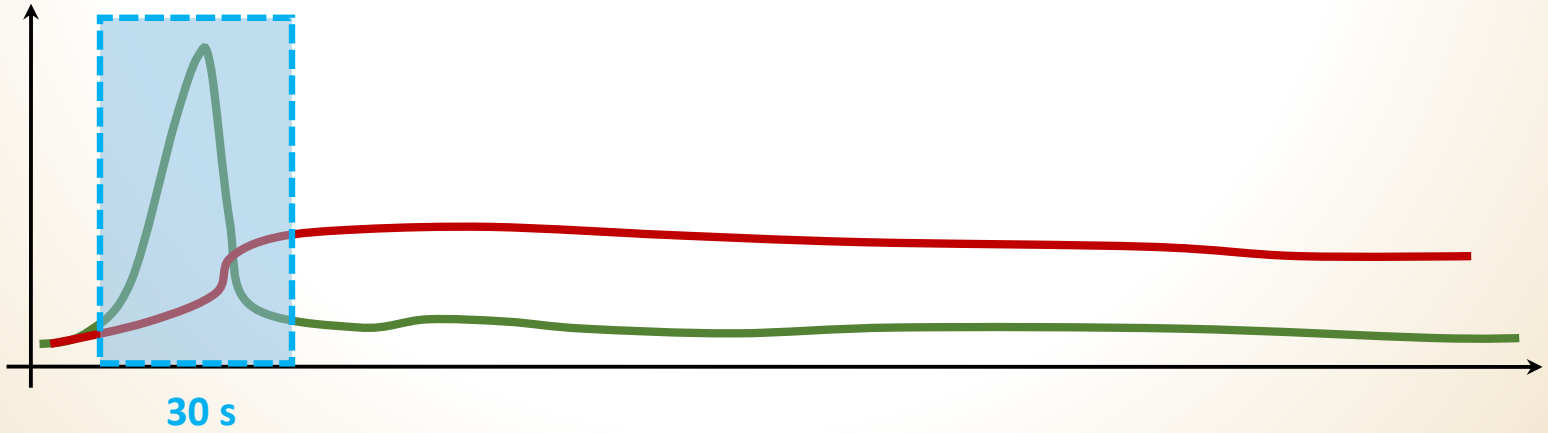

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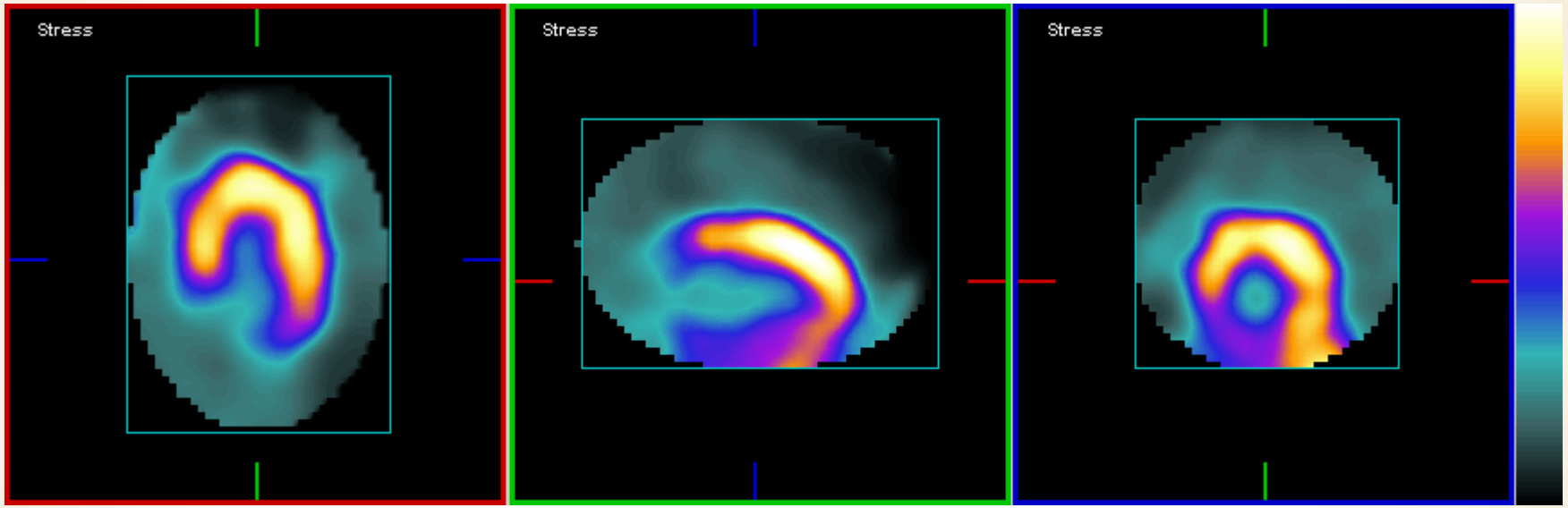

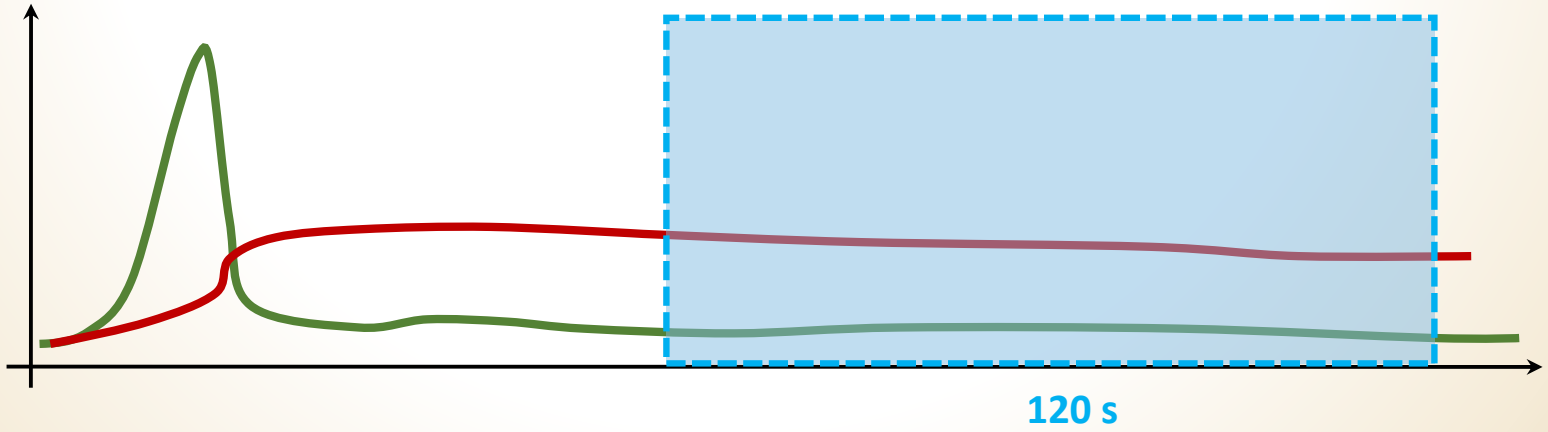

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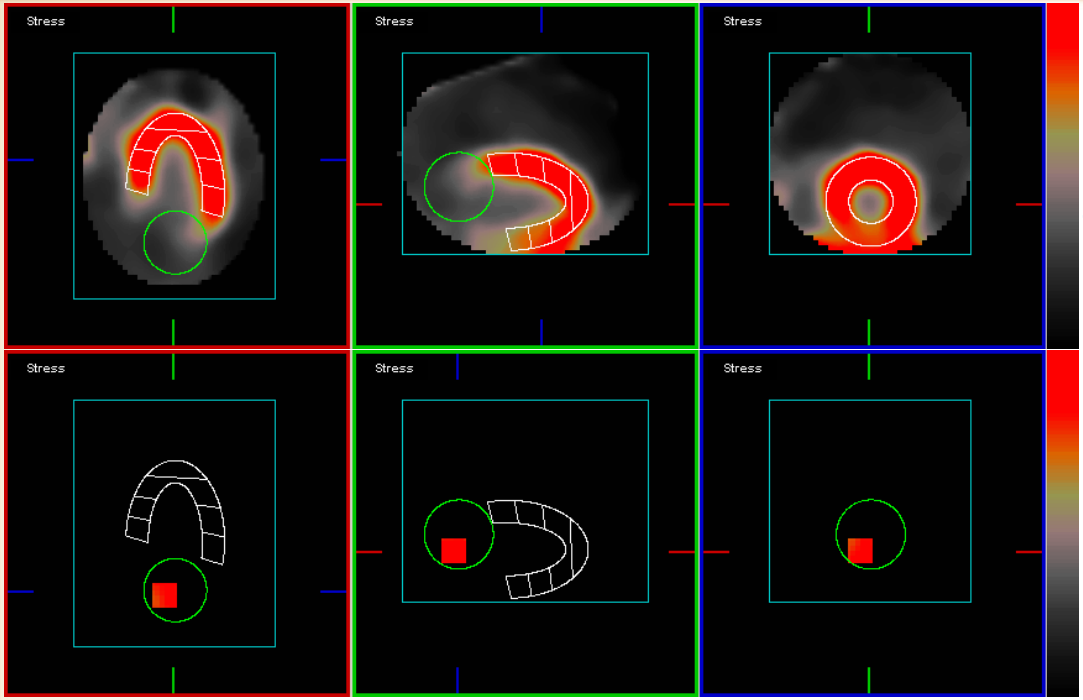
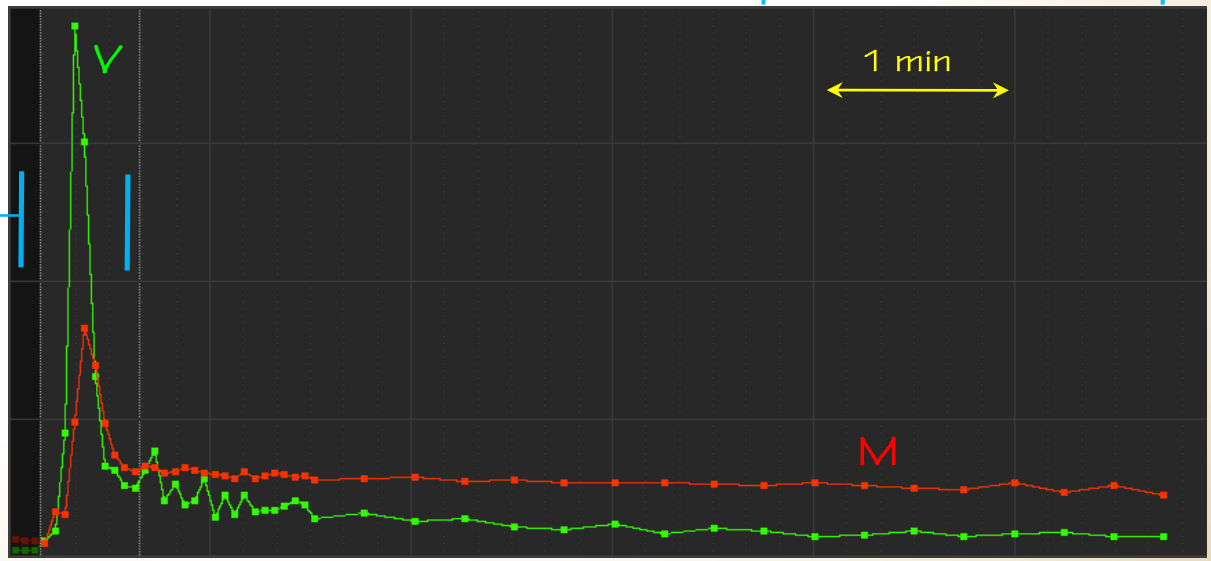


Segmentation myocardique

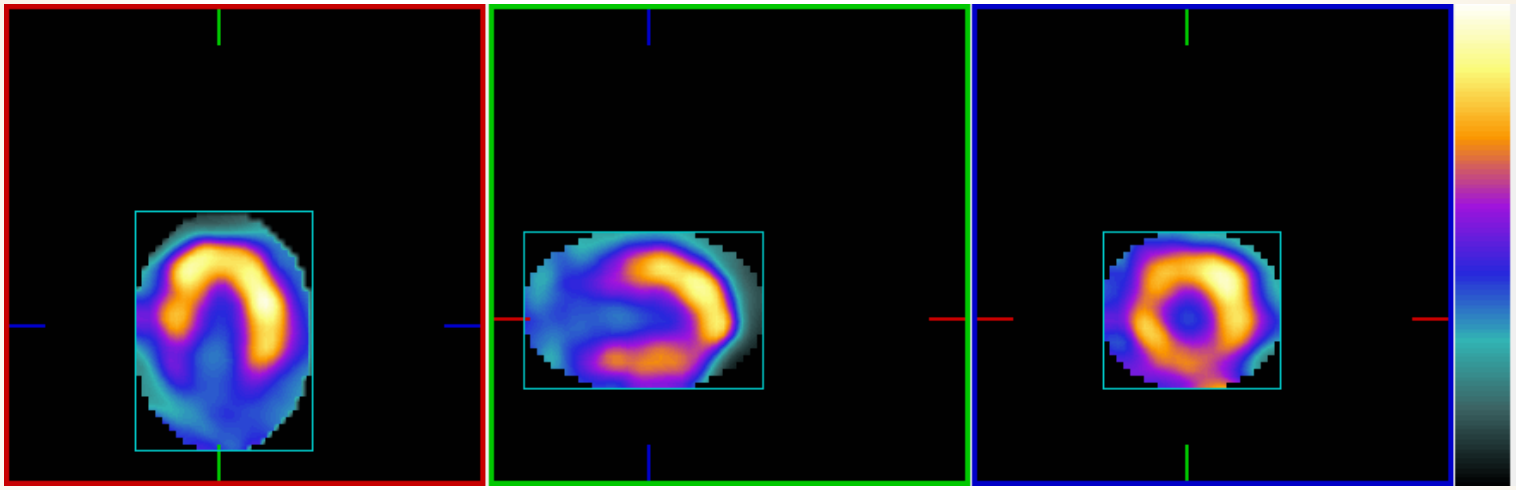
120'



Entrée vasculaire

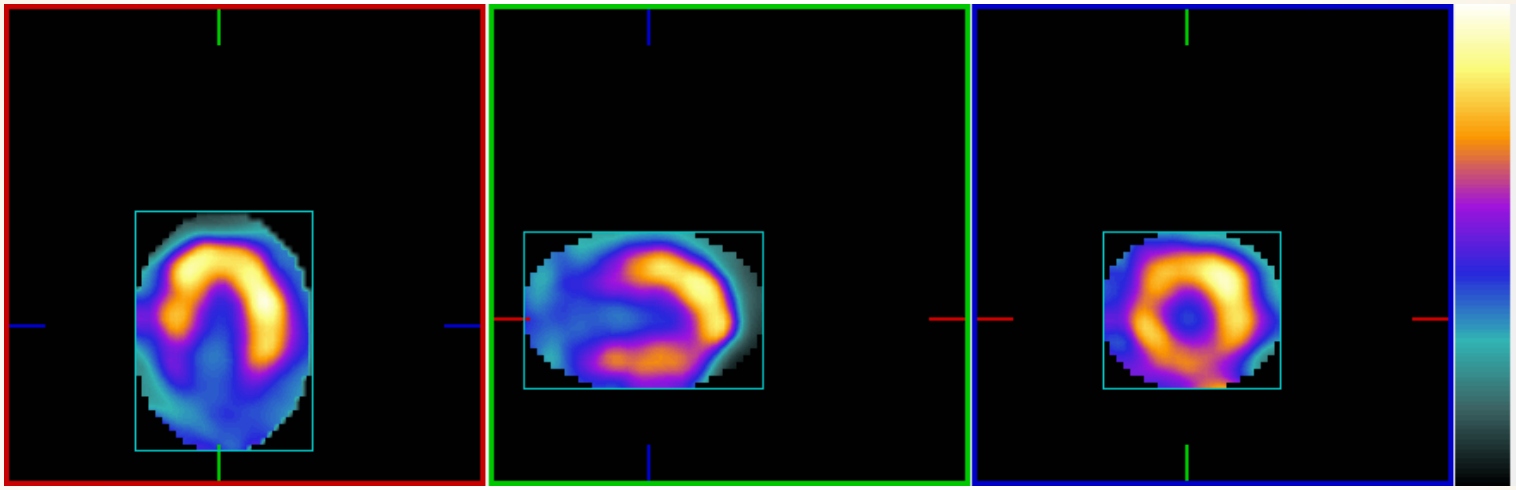
Protocole

Segmentation myocardique

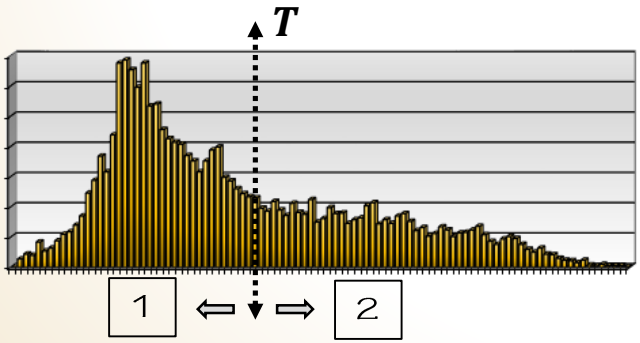


Protocole

Segmentation myocardique



Méthode d'Otsu

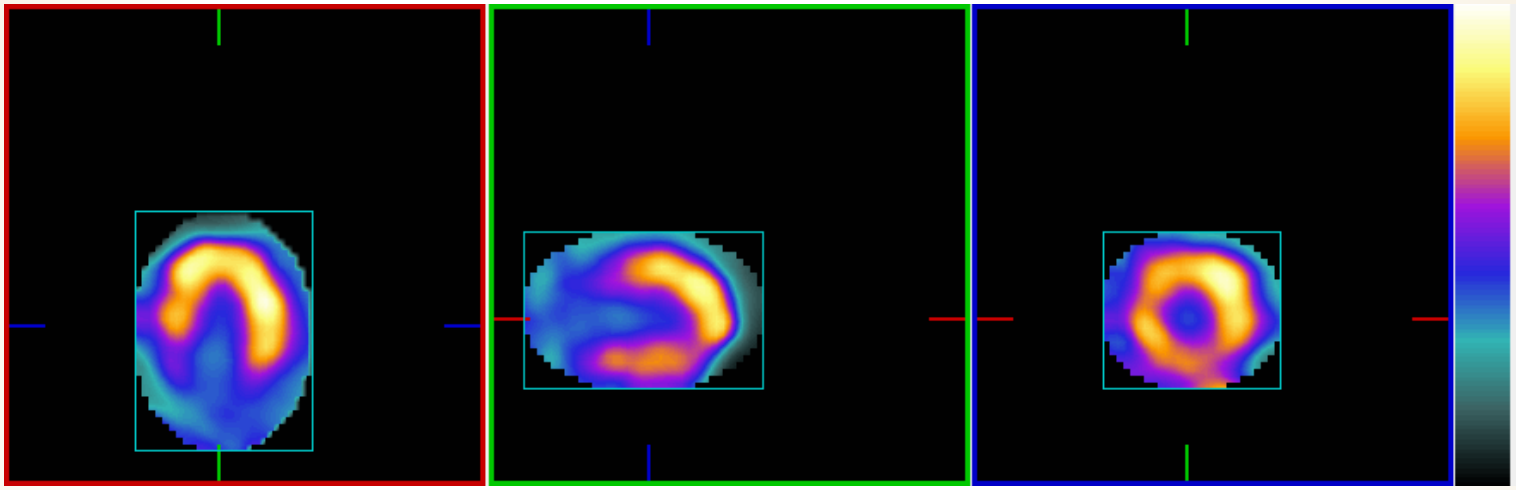


$$T = argmin\,(V_w)$$

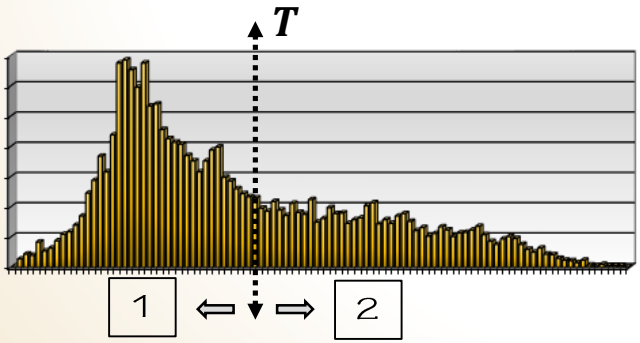
$$= argmin\,\{w_1V_1 + w_2V_2\}$$

Protocole

Segmentation myocardique



Méthode d'Otsu



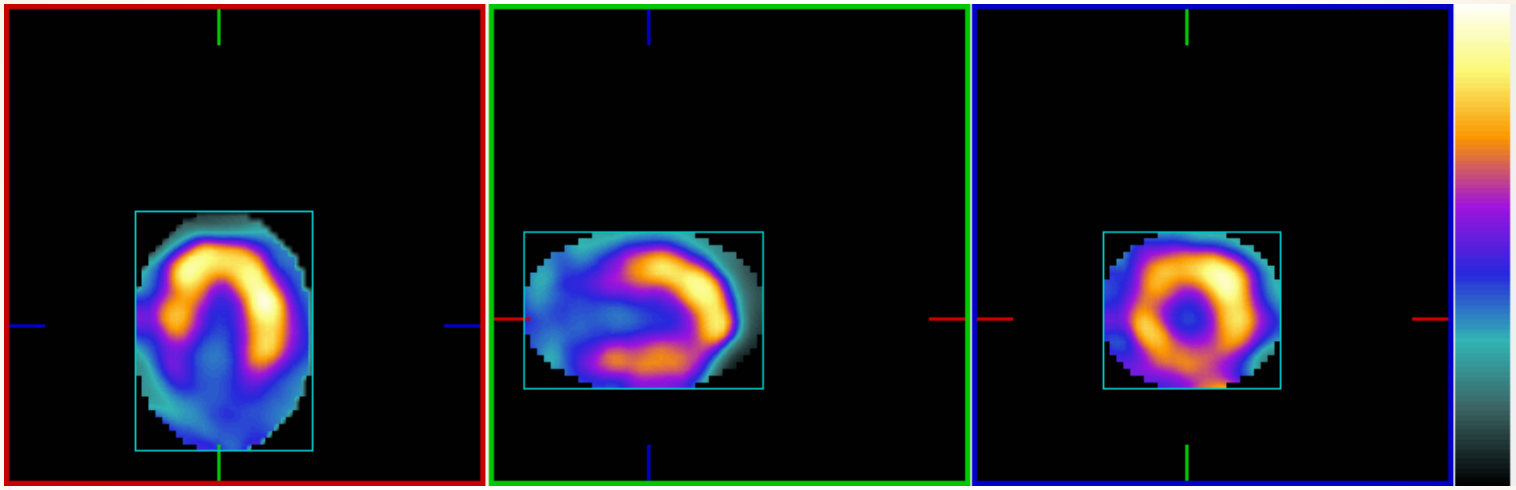
$$T = argmin\,(V_w)$$

$$= argmax\,(V_b)$$

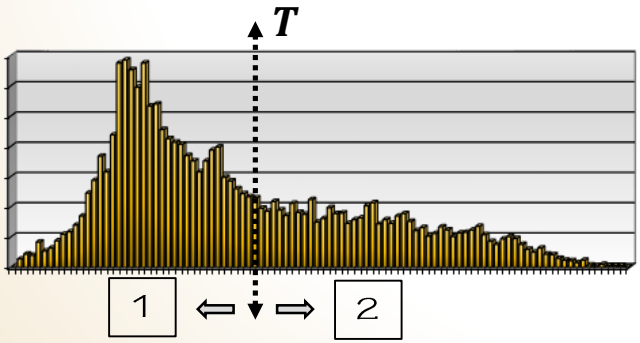
$$= argmax\,(V - V_w)$$

Protocole

Segmentation myocardique



Méthode d'Otsu



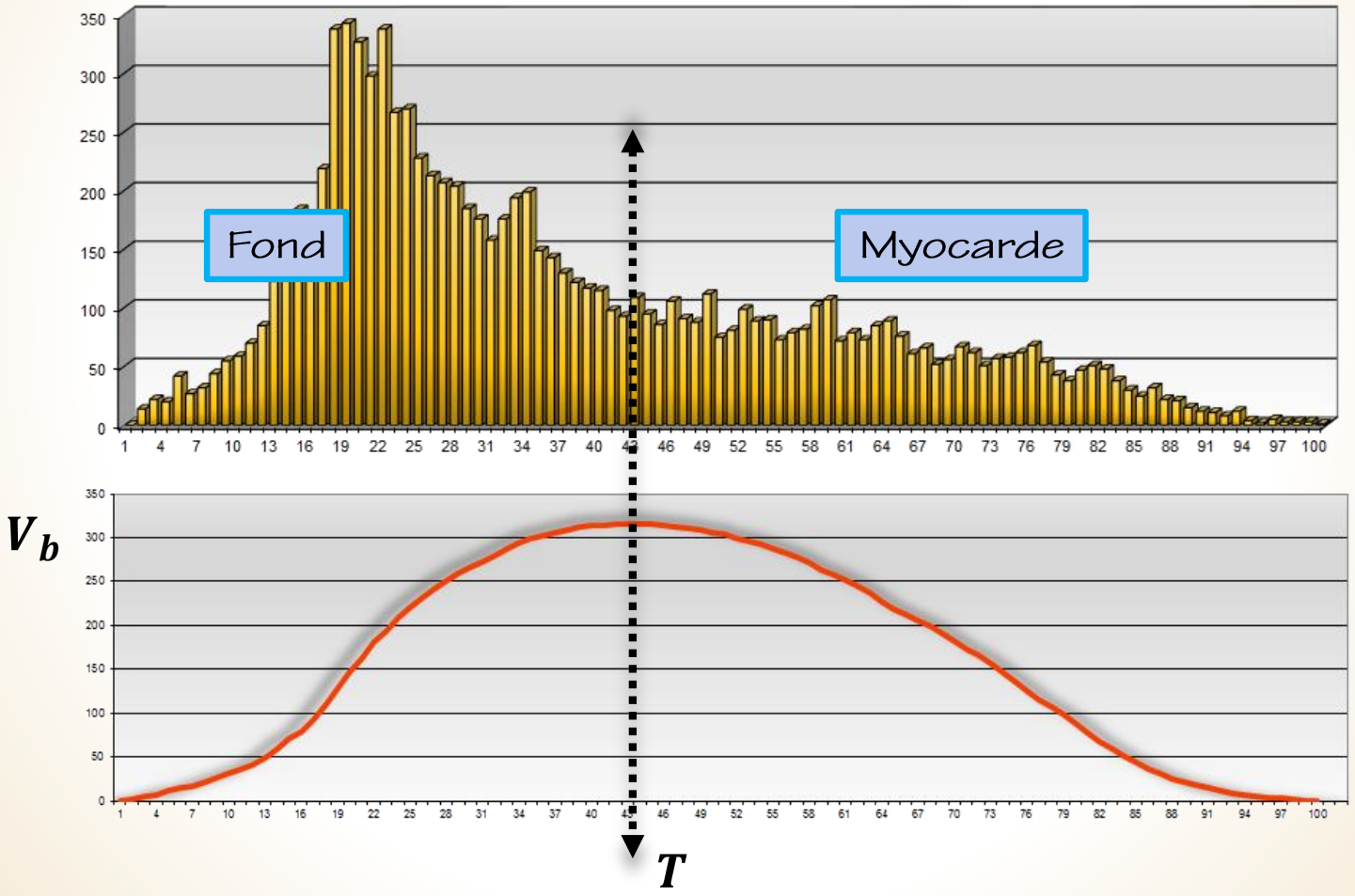
$$T = argmin\,(V_w)$$

$$= argmax\,(V_b)$$

$$= argmax\left\{w_1 w_2\,(\mu_2 - \mu_1)^2\right\}$$

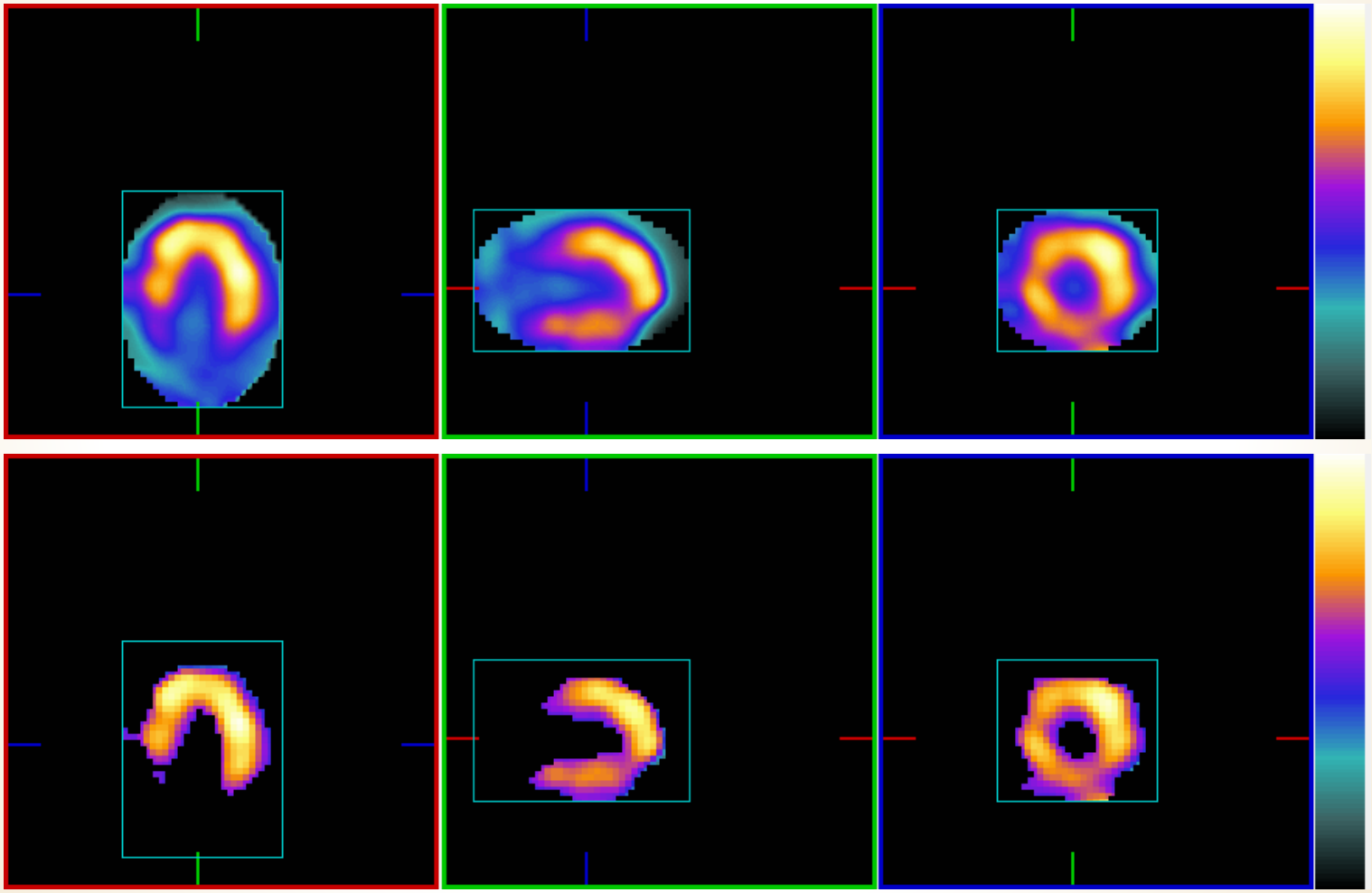
Protocole

Segmentation myocardique



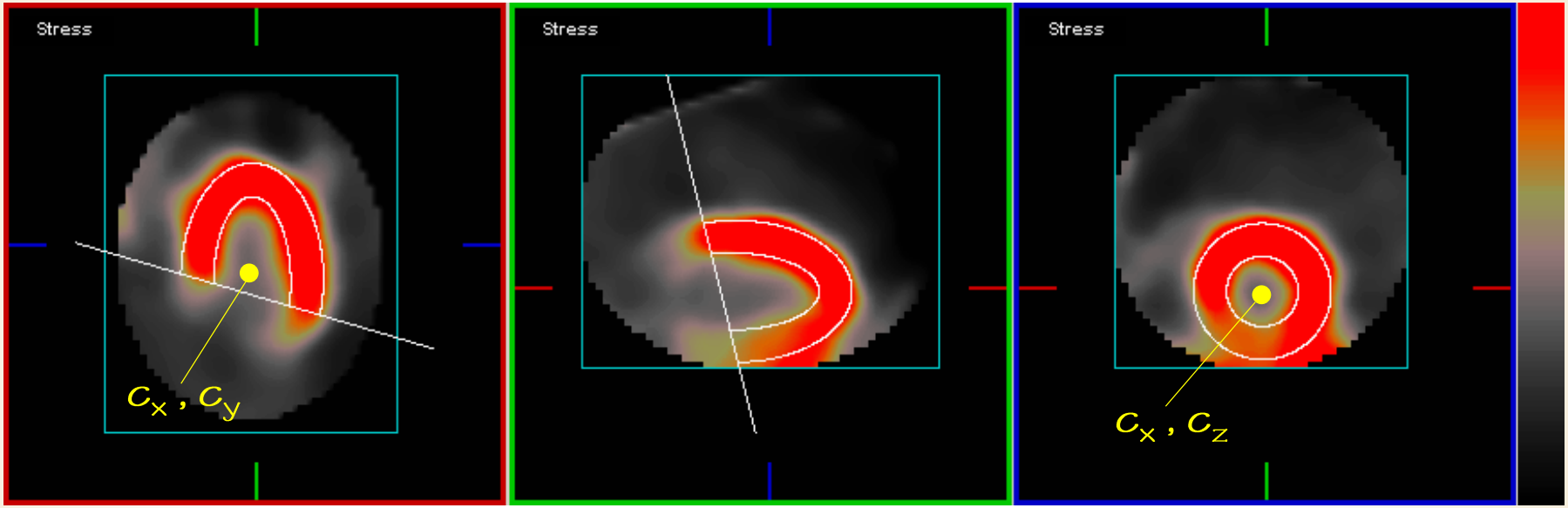
Protocole

Segmentation myocardique



Protocole

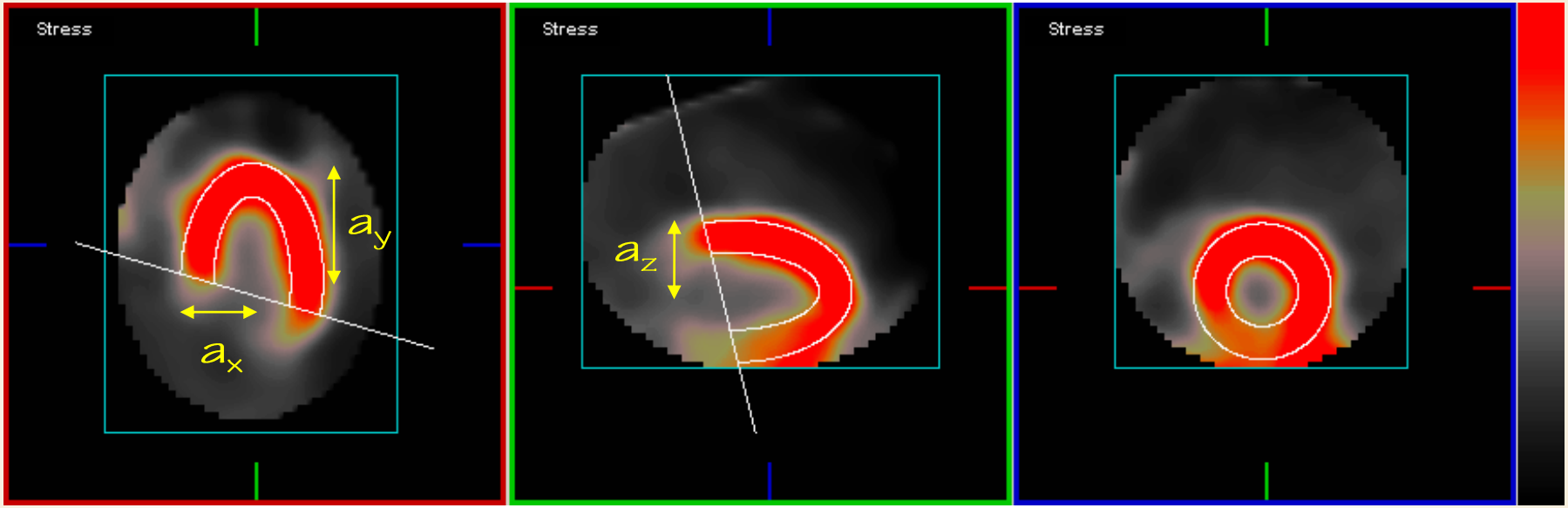
Segmentation myocardique



$$\Pi = \{c_x, c_y, c_z\}$$

Protocole

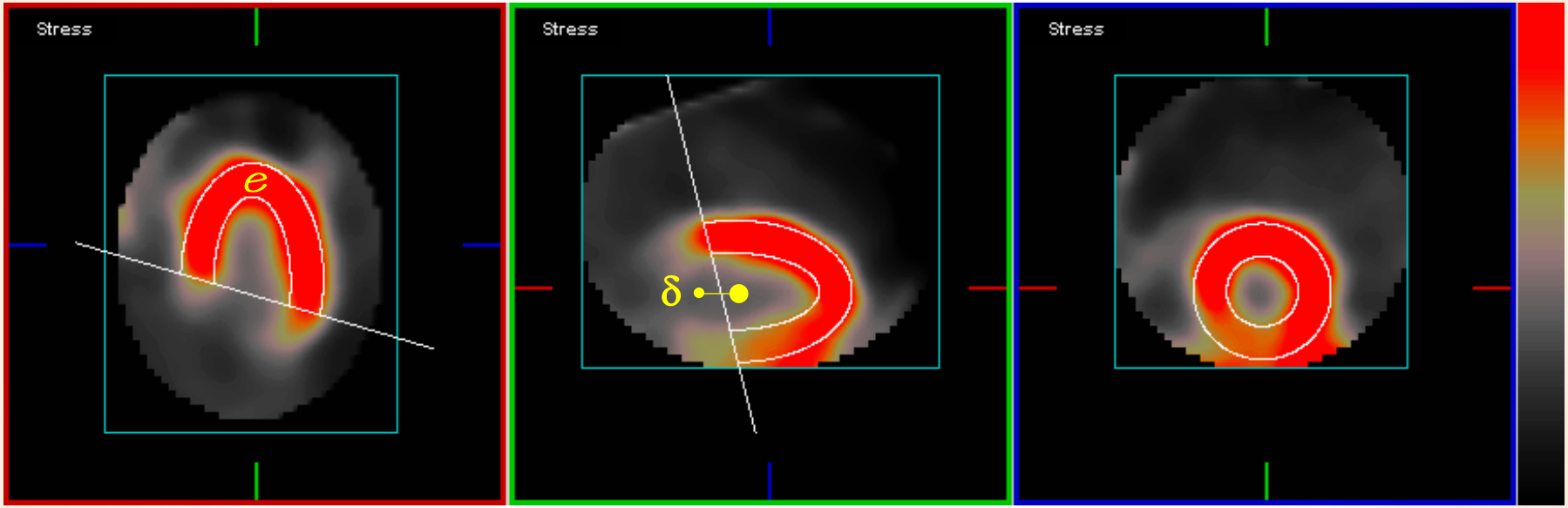
Segmentation myocardique



$$\Pi = \{c_x, c_y, c_z ; a_x, a_y, a_z\}$$

Protocole

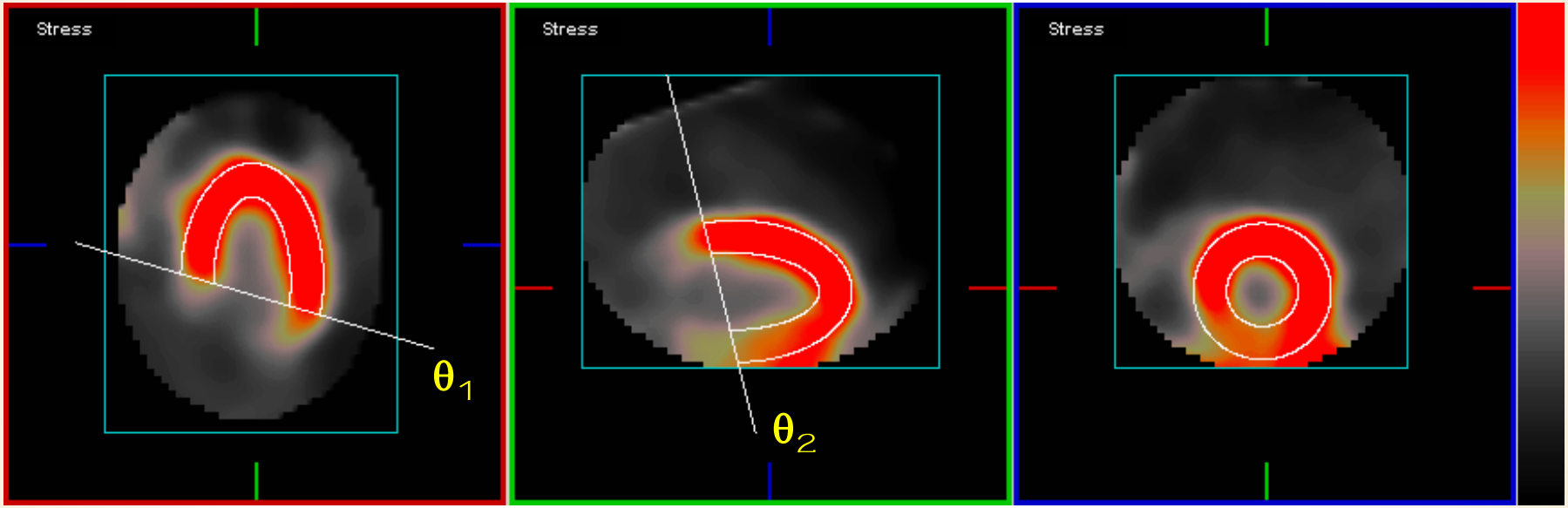
Segmentation myocardique



$$\Pi = \{c_x, c_y, c_z ; a_x, a_y, a_z; e, \delta\}$$

Protocole

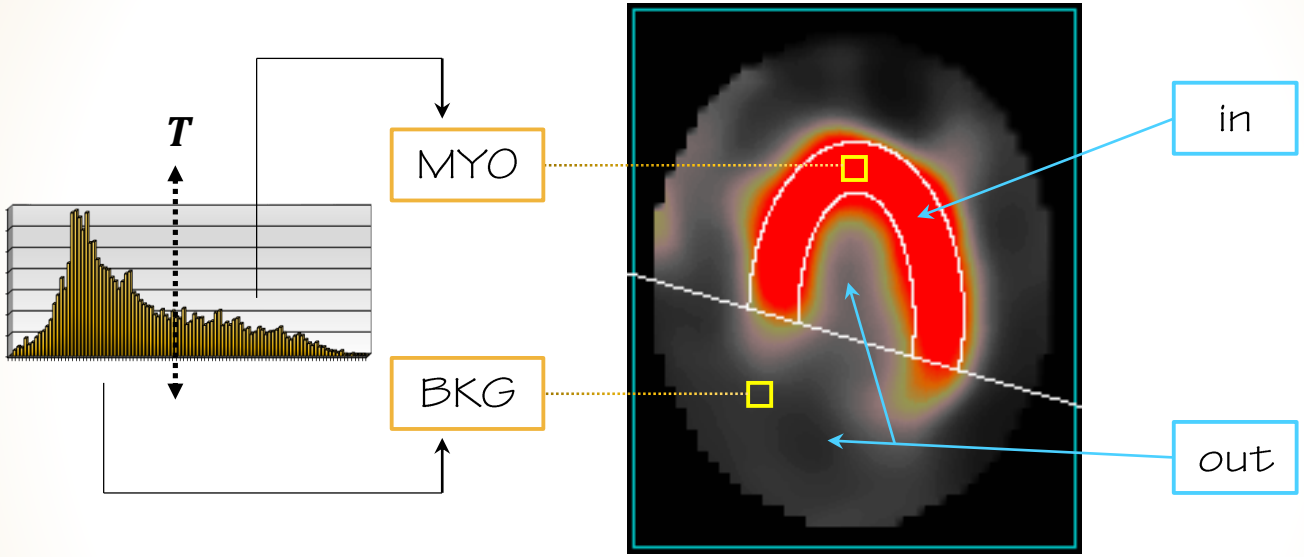
Segmentation myocardique



$$\Pi = \{c_x, c_y, c_z ;\ a_x, a_y, a_z;\ e, \delta;\ \theta_1, \theta_2\}$$

Protocole

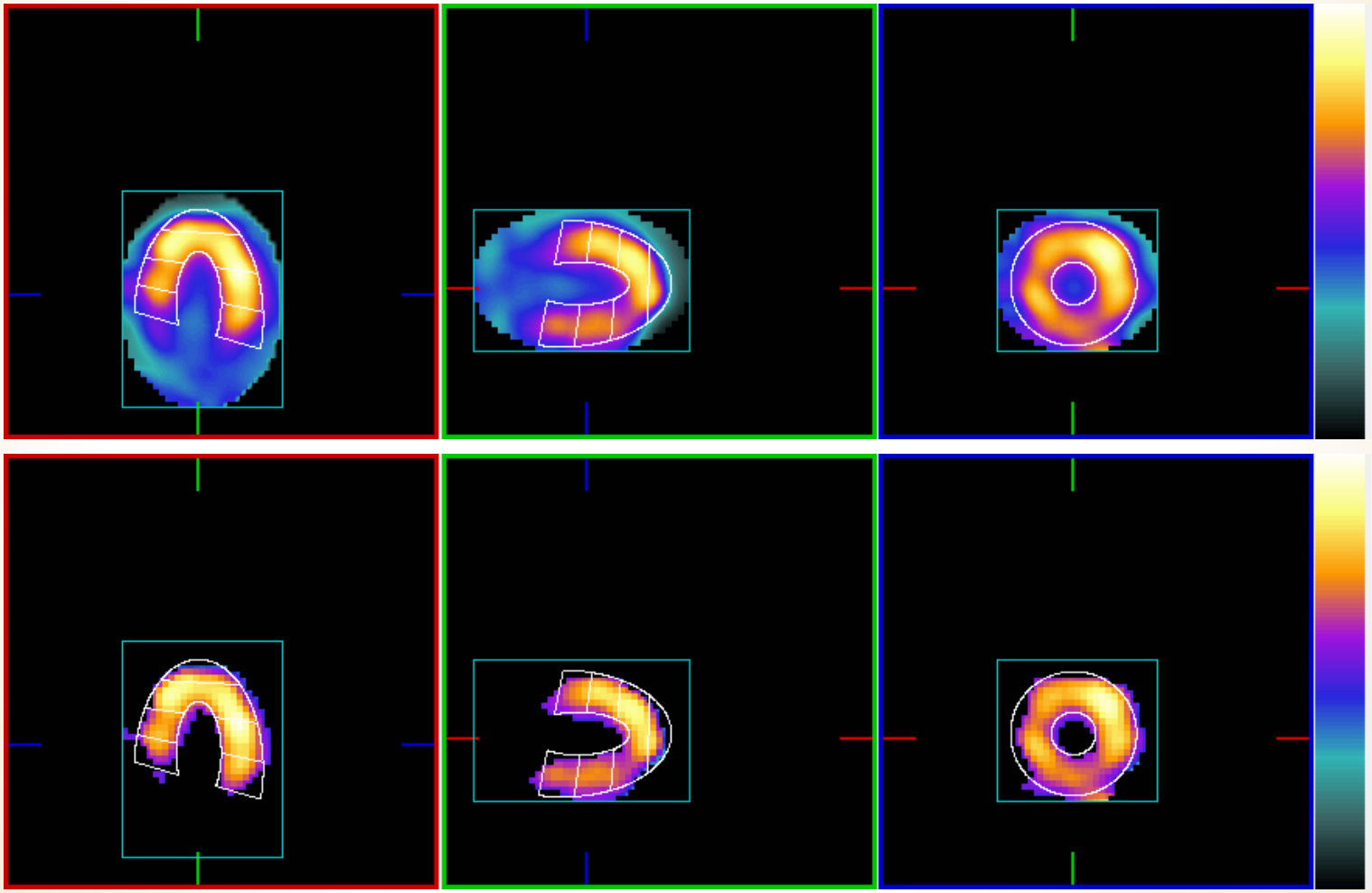
Segmentation myocardique



$$\Pi_{opt} = argmin\left\{\sum_{\Omega}(f - T)^2\right\} \qquad \Omega = \{\mathbf{BKG} \cap \mathbf{in}\} \cup \{\mathbf{MYO} \cap \mathbf{out}\}$$

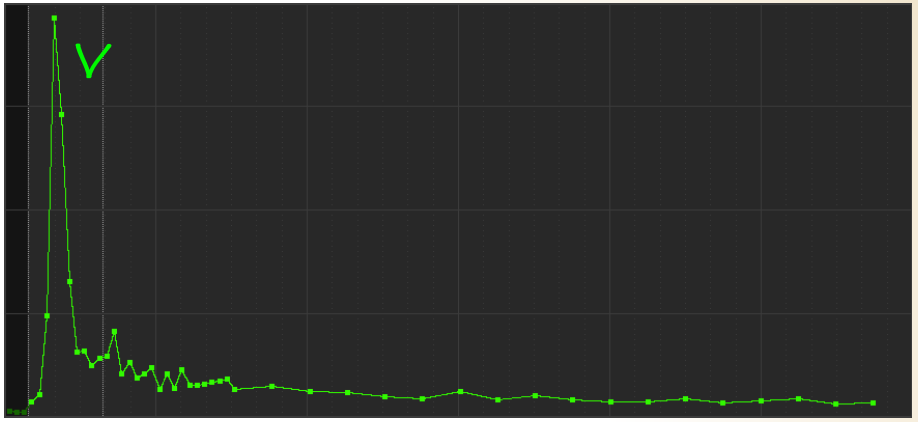
Protocole

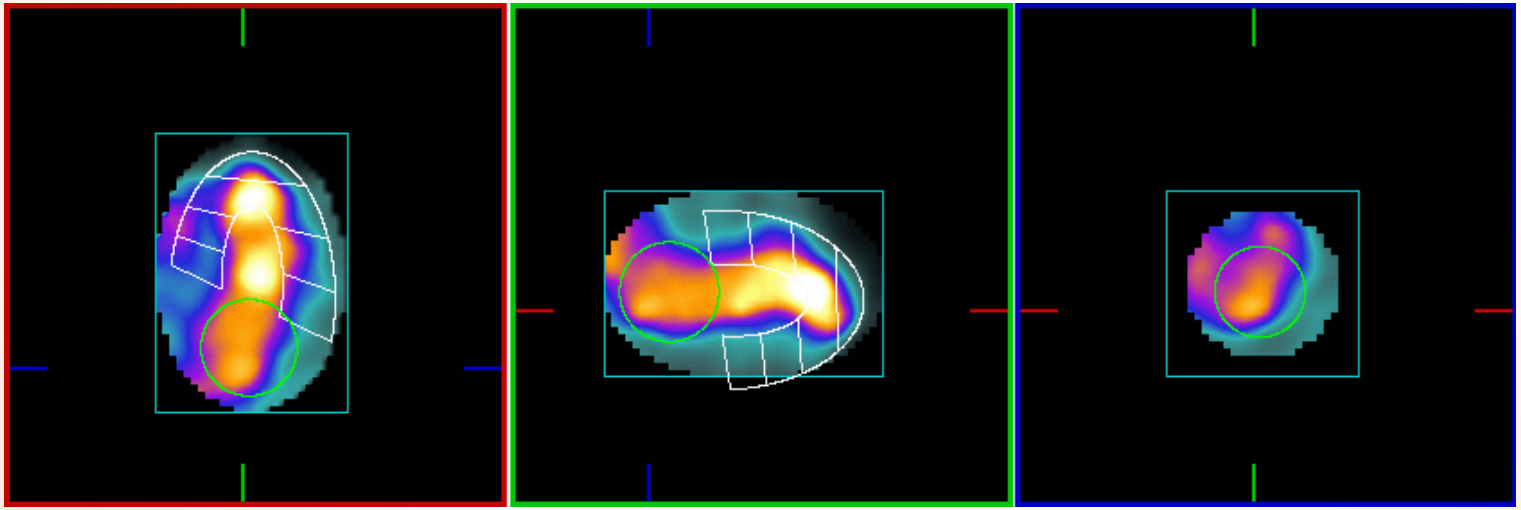
Segmentation myocardique



Protocole

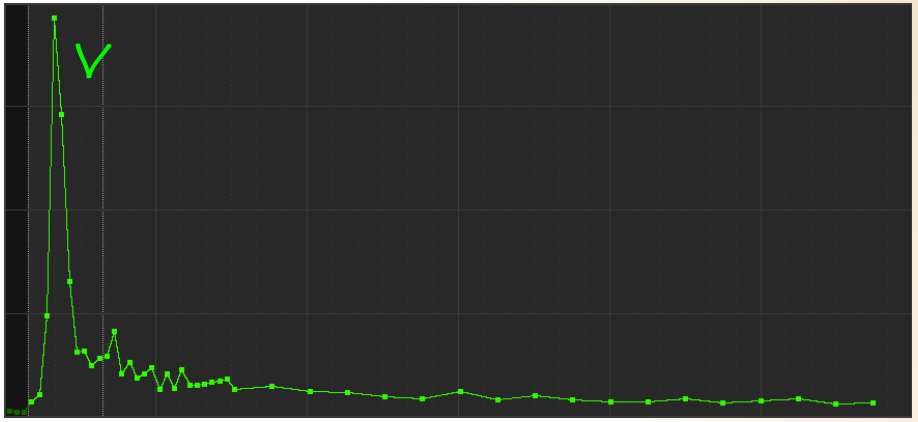
Entrée vasculaire

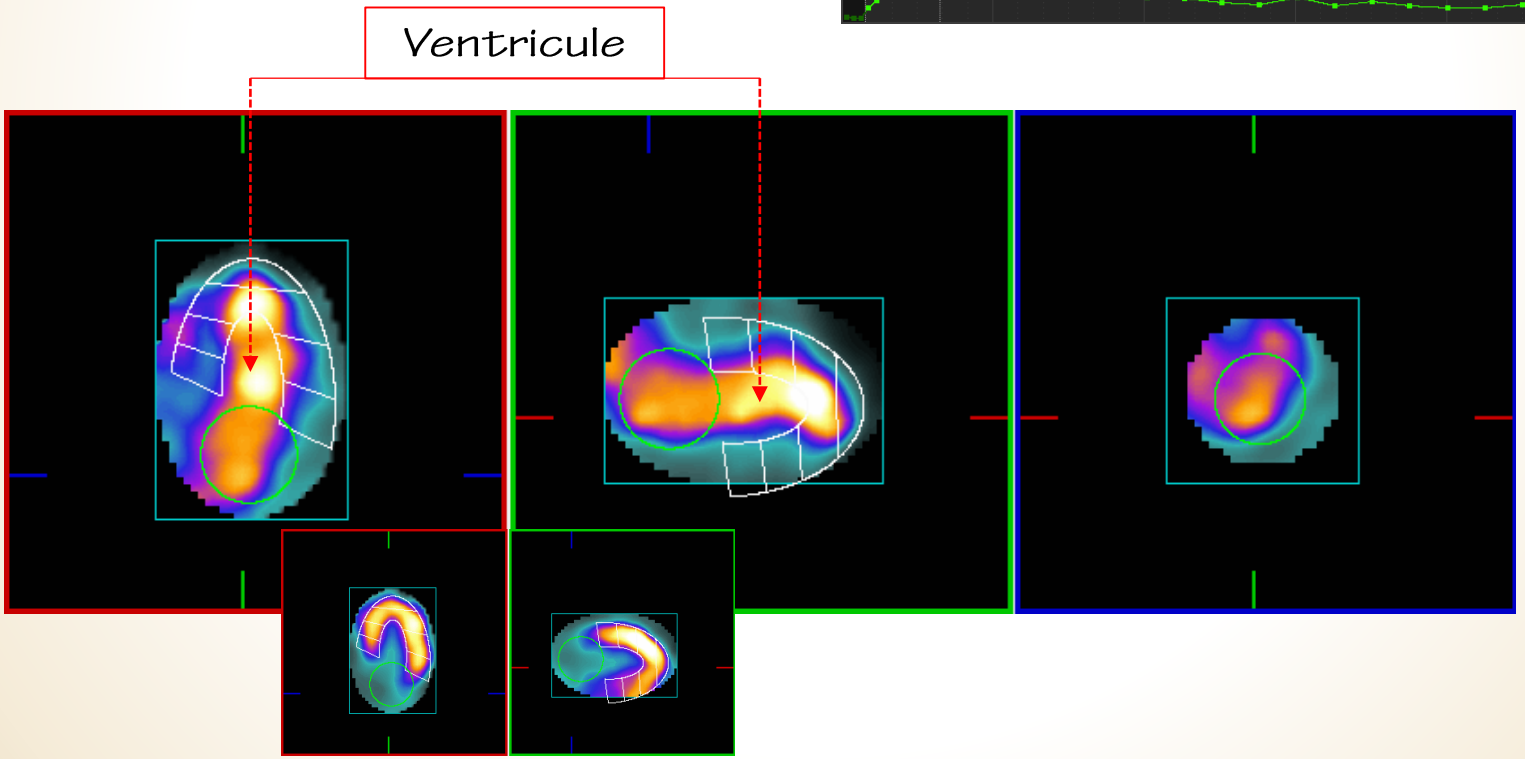




Protocole

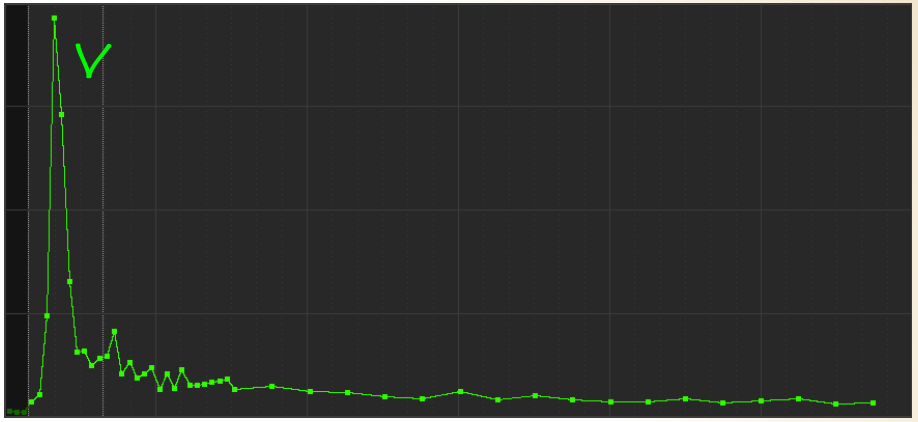
Entrée vasculaire

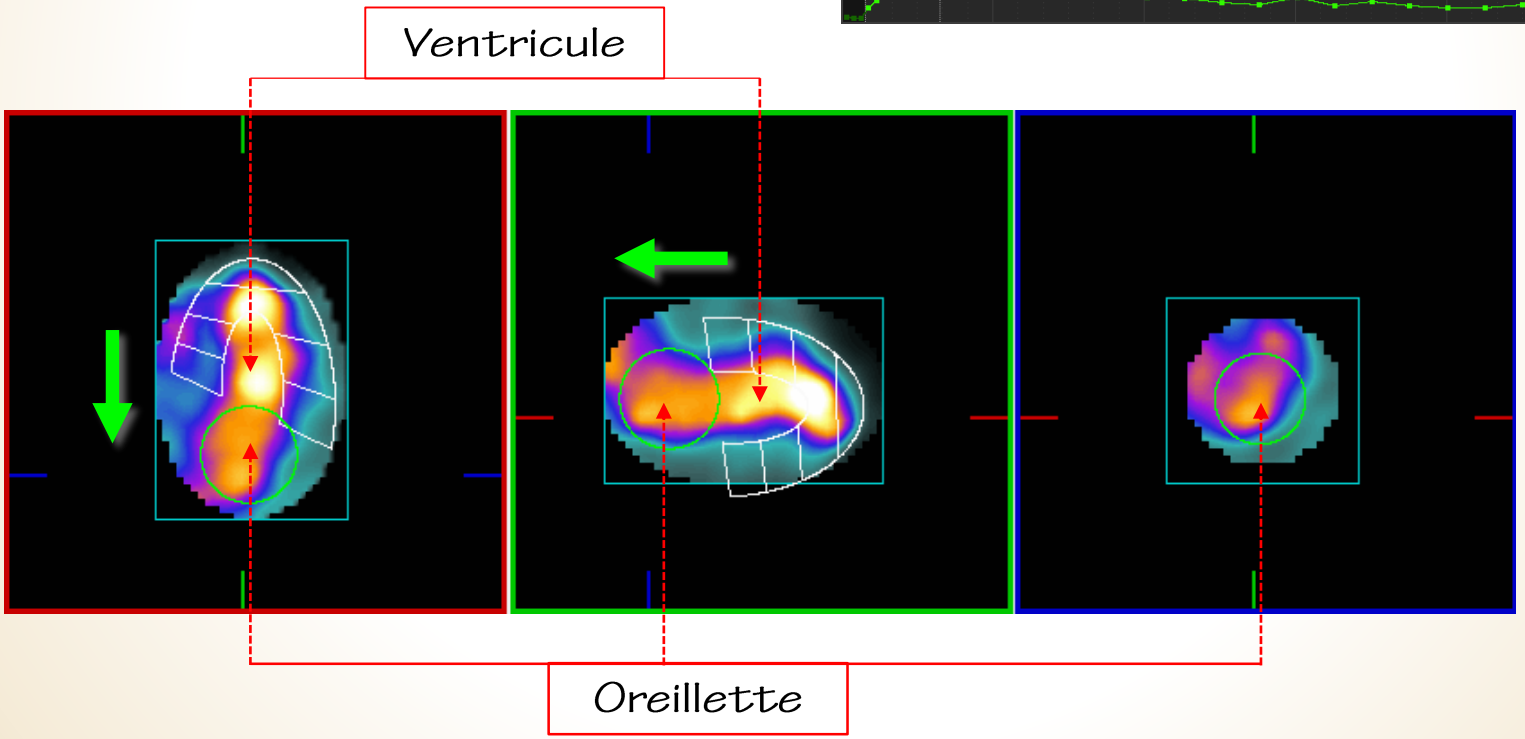




Protocole

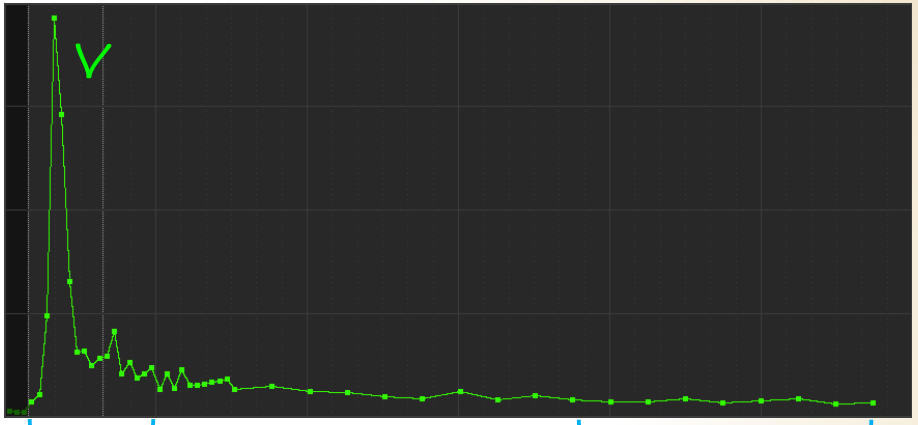
Entrée vasculaire





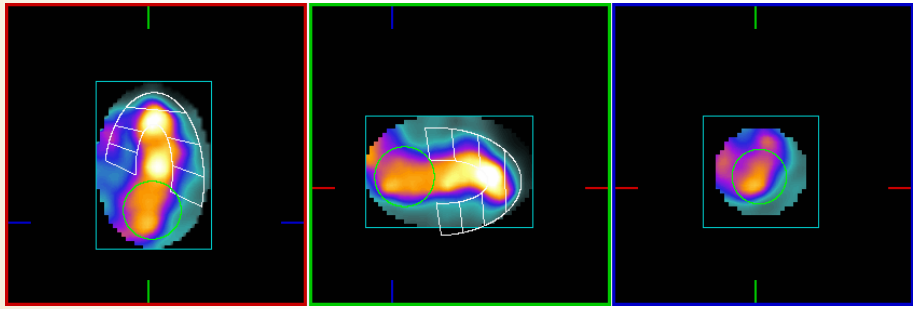
Protocole

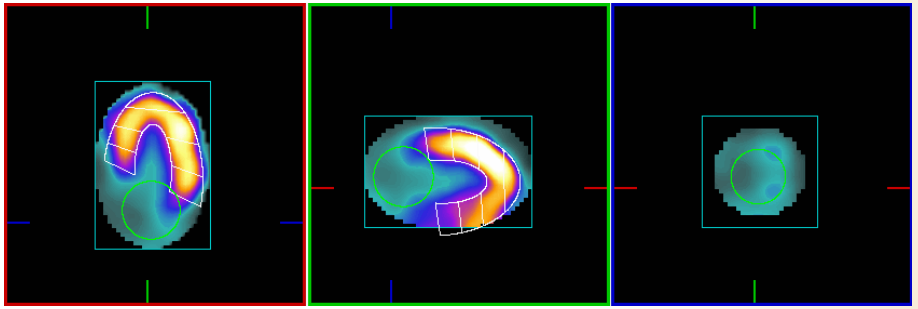
Entrée vasculaire



vasc

myoc

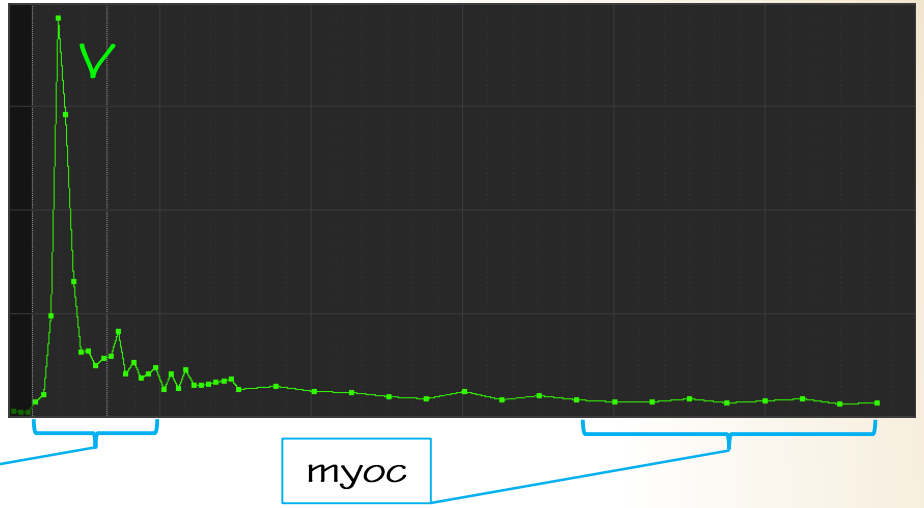


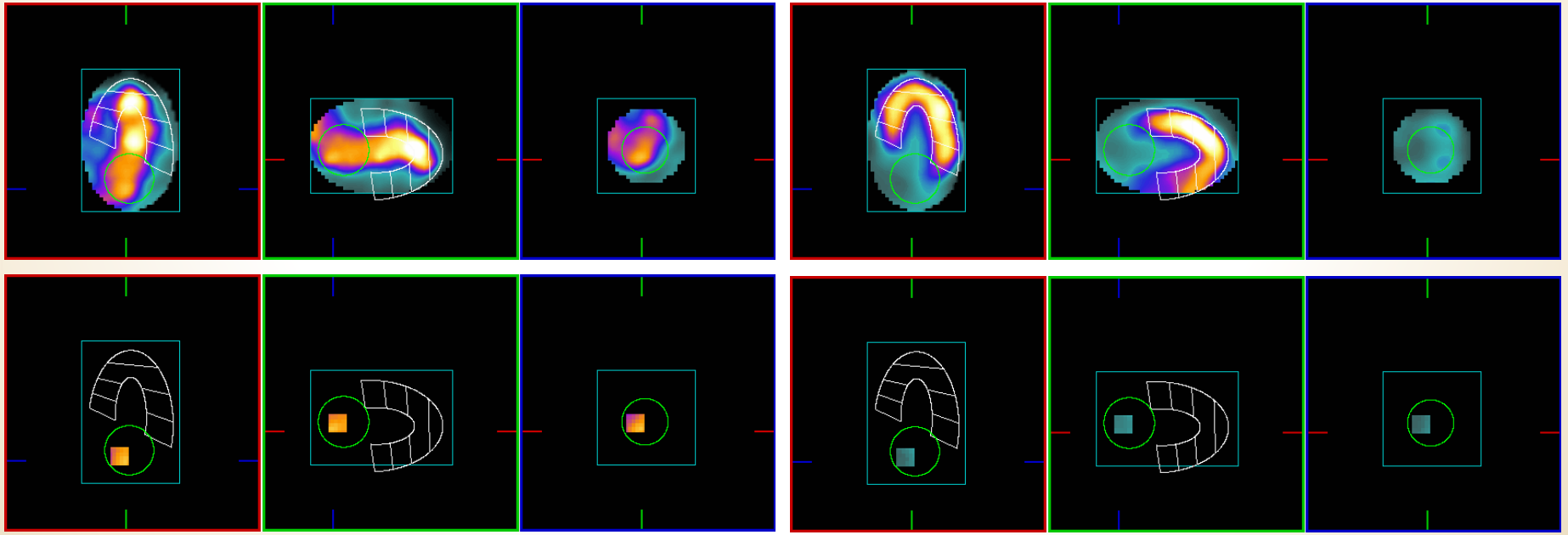


Protocole

Entrée vasculaire

$$C = \underset{5\times5\times5}{argmax}\left\{\frac{\sum_{vasc} f}{\sum_{myoc} f}\right\}$$

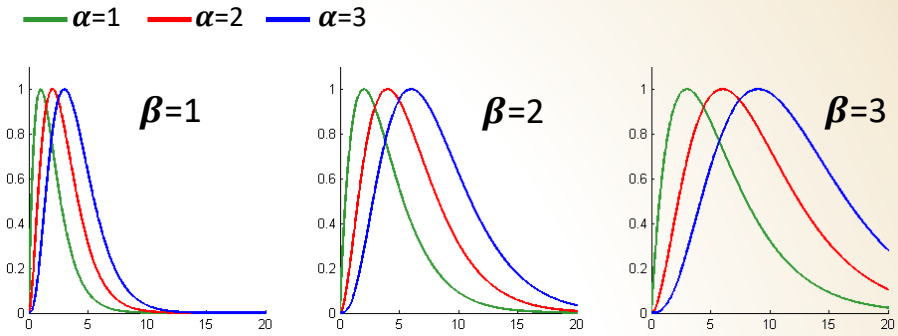




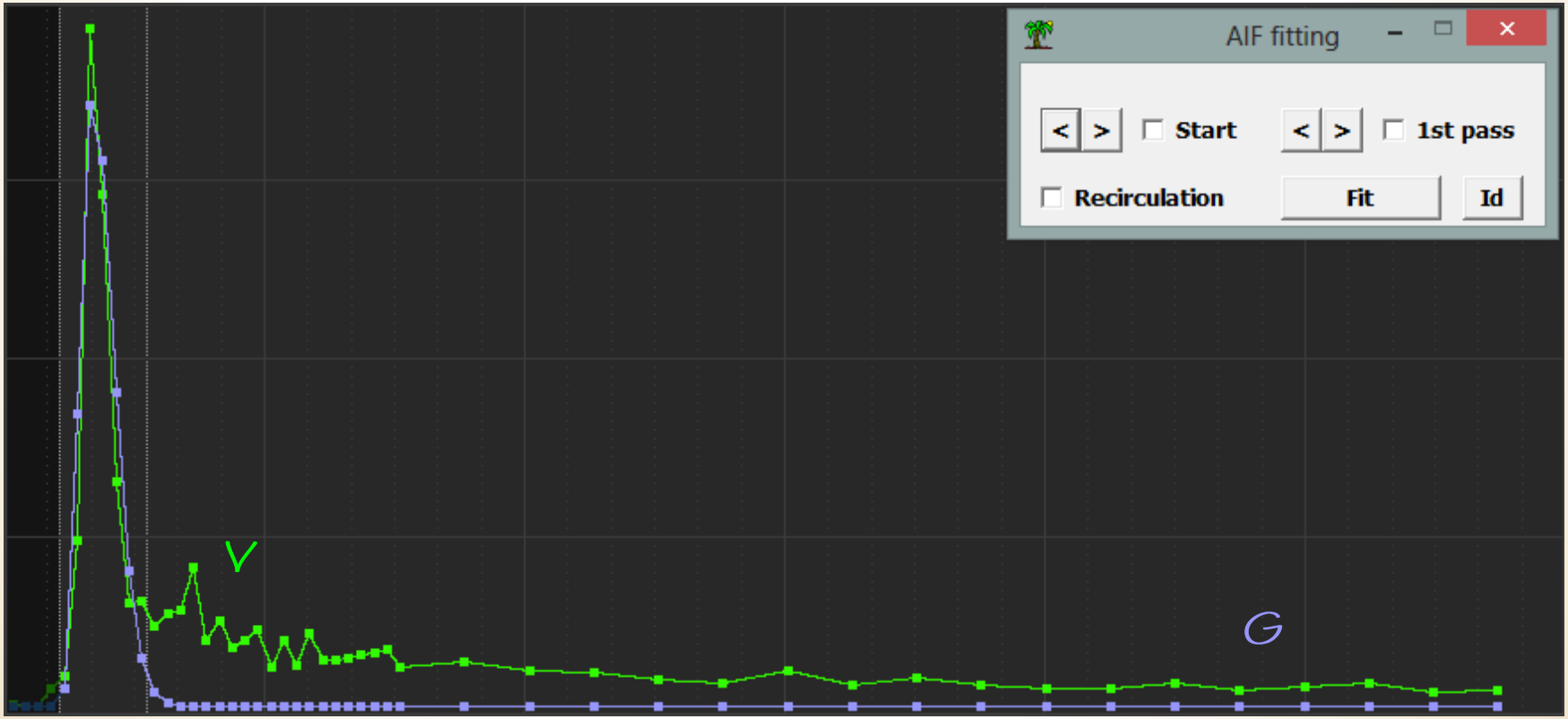
Protocole

Entrée vasculaire

$$V(t) \approx G(t) = A(t - t_0)^{\alpha}\, exp(-(t - t_0)/\beta)$$



t_0



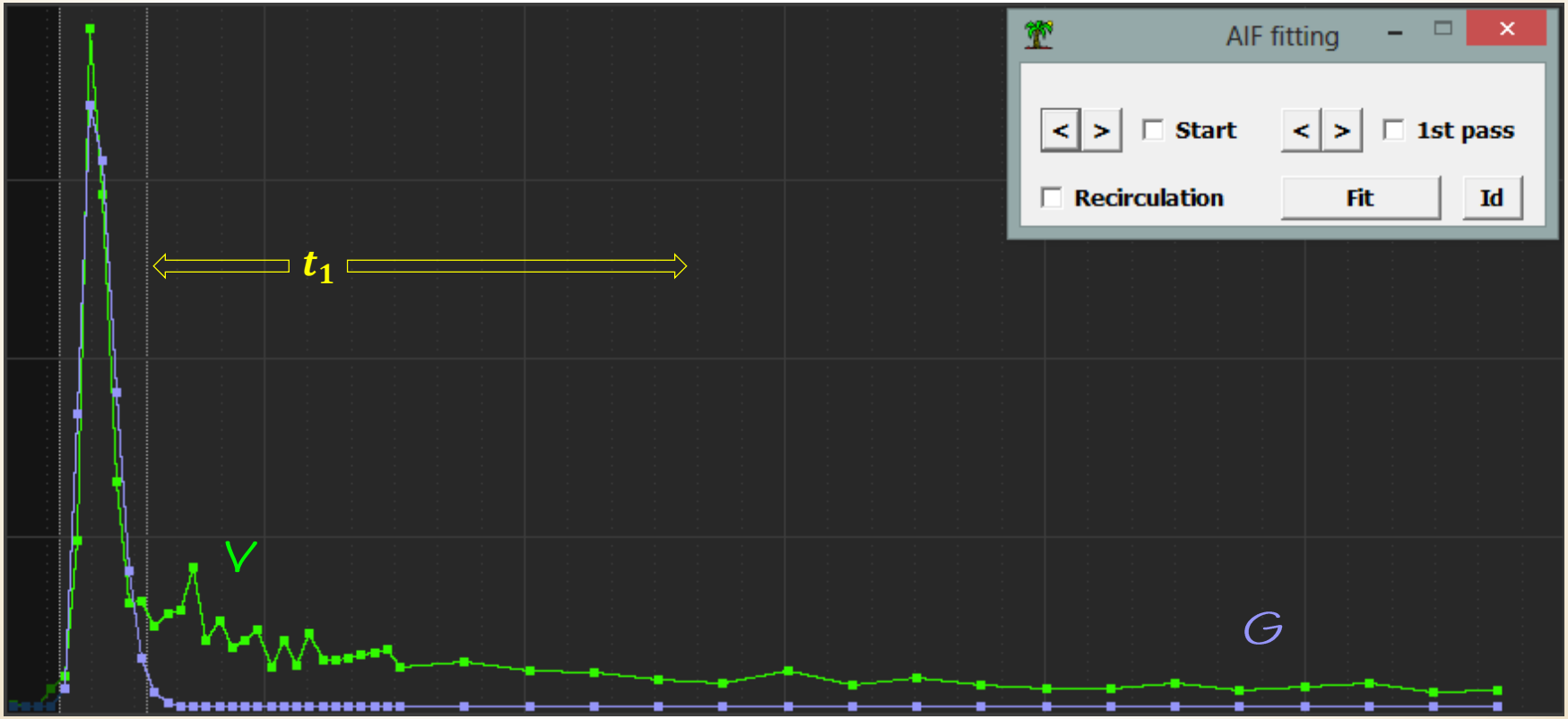
Protocole

Entrée vasculaire

$$V(t) \approx G(t) = A(t - t_0)^{\alpha}\, exp(-(t - t_0)/\beta)$$

$$ln\big(V(t)\big) \approx ln(A) + \alpha\, ln(t - t_0) - \frac{1}{\beta}(t - t_0)$$

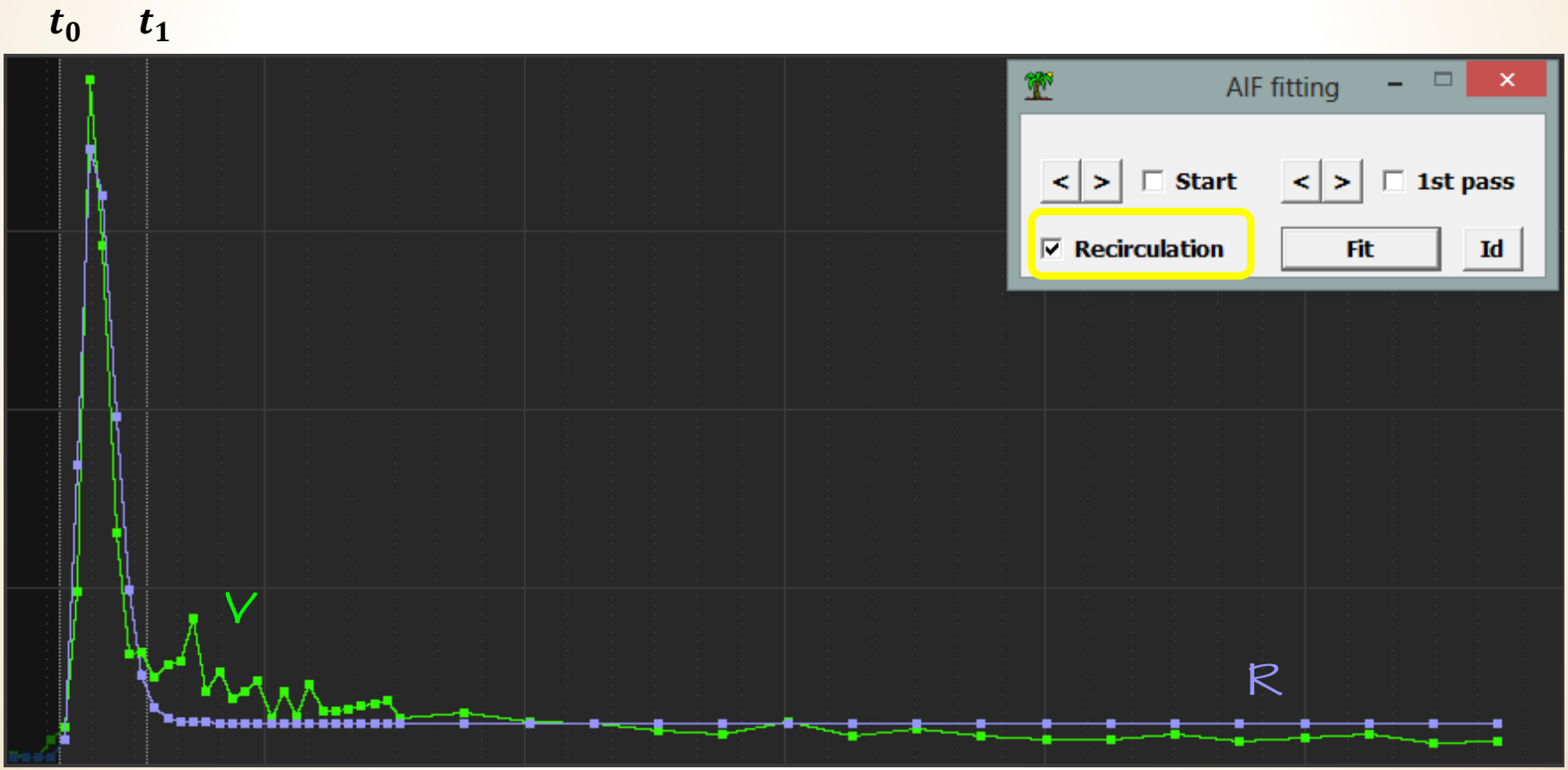
t_0 t_1



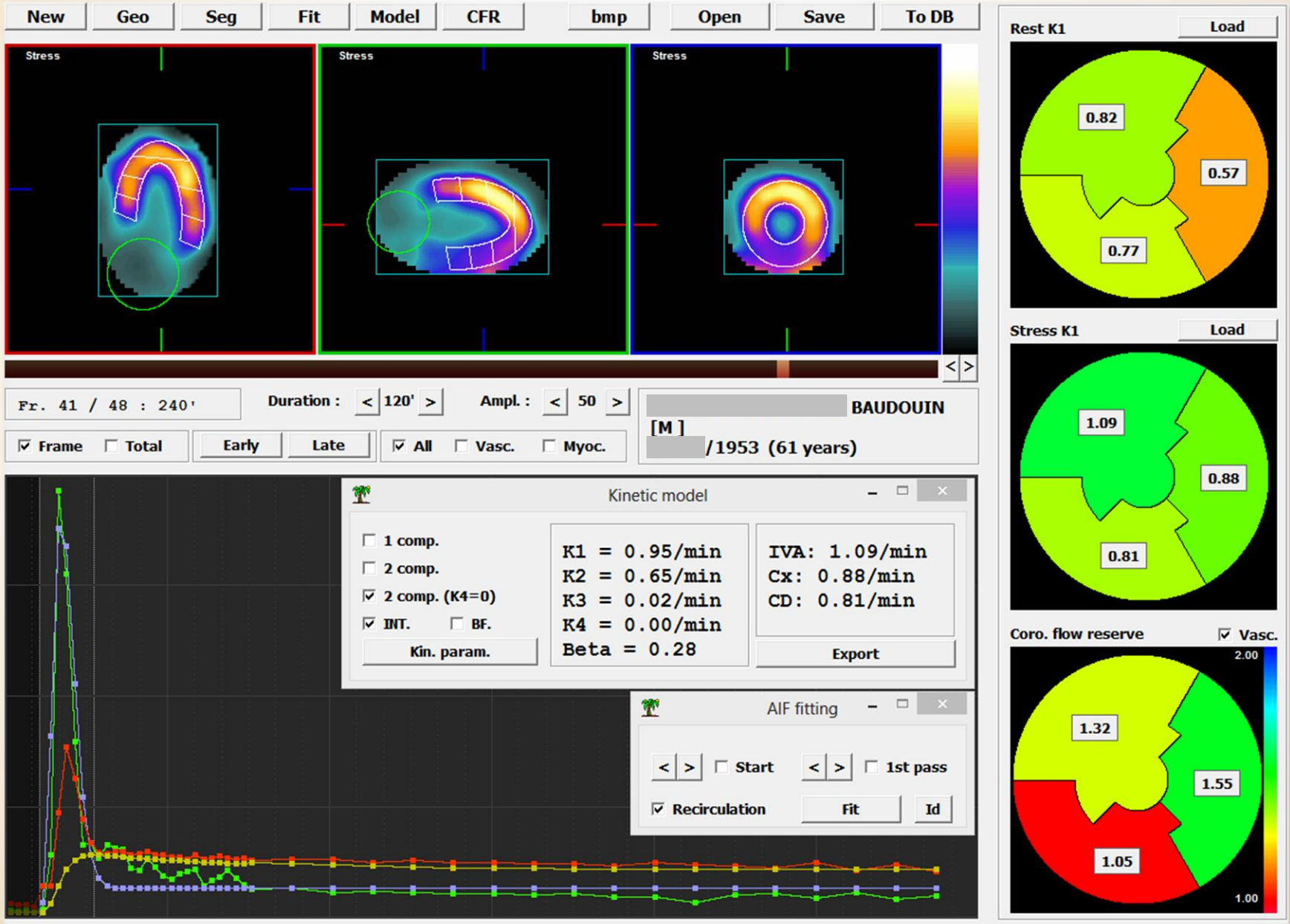
Protocole

Entrée vasculaire

$$V(t) \approx R(t) = G(t) + \kappa \int_0^t G(\tau)\, d\tau$$



Protocole


New
Geo
Seg
Fit
Model
CFR
bmp
Open
Save
To DB
Stress
Stress
Stress
Fr. 41 / 48 : 240'
Duration : < 120' >
Ampl. : < 50 >
Frame
Total
Early
Late
All
Vasc.
Myoc.
BAUDOUIN
[M]
/1953 (61 years)
Kinetic model
1 comp.
2 comp.
2 comp. (K4=0)
INT.
BF.
Kin. param.
K1 = 0.95/min
K2 = 0.65/min
K3 = 0.02/min
K4 = 0.00/min
Beta = 0.28
IVA: 1.09/min
Cx: 0.88/min
CD: 0.81/min
Export
AIF fitting
Start
1st pass
Recirculation
Fit
Id
Rest K1
Load
0.82
0.57
0.77
Stress K1
Load
1.09
0.88
0.81
Coro. flow reserve
Vasc.
2.00
1.32
1.55
1.05
1.00

Protocole

Exemple : Mme B

57 ans

Tabac
Diabète
Dyslipidémie

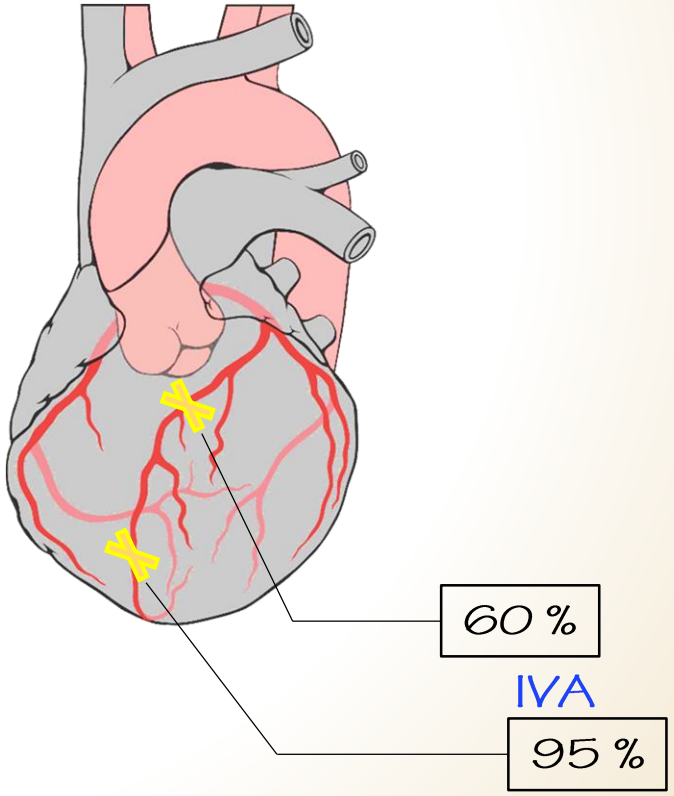
Infarctus inférieur

CORO à H3

Protocole

Exemple : Mme B

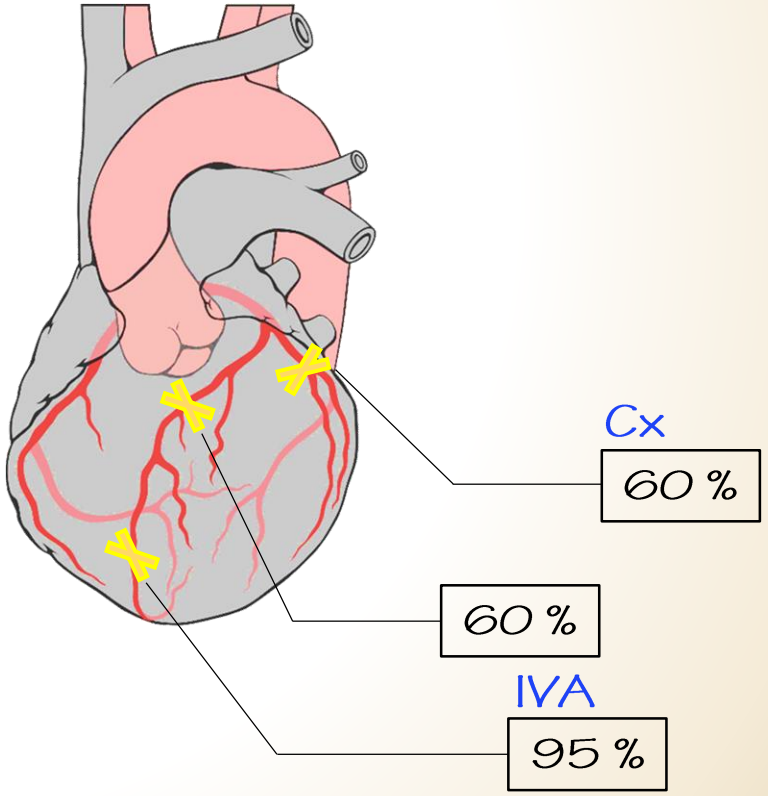
CORO à H3



Protocole

Exemple : Mme B

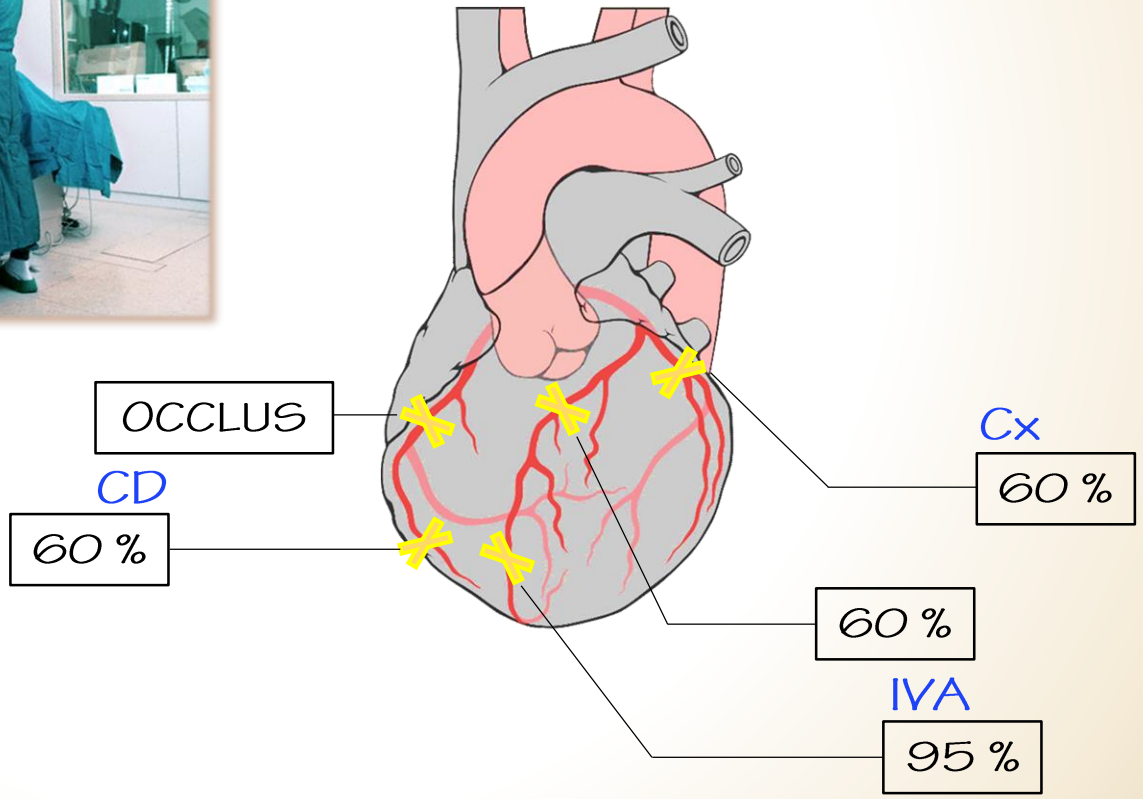
CORO à H3



Protocole

Exemple : Mme B

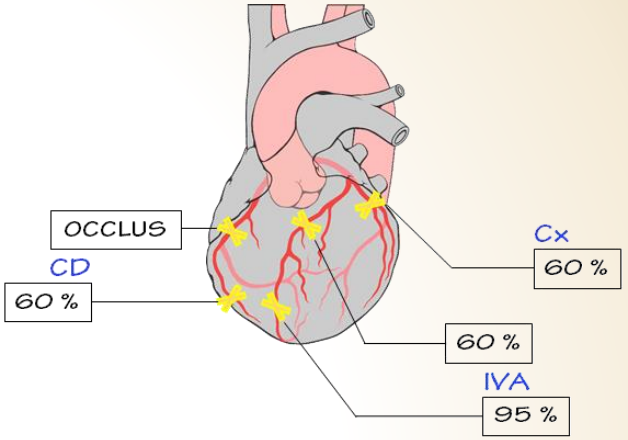
CORO à H3



Protocole

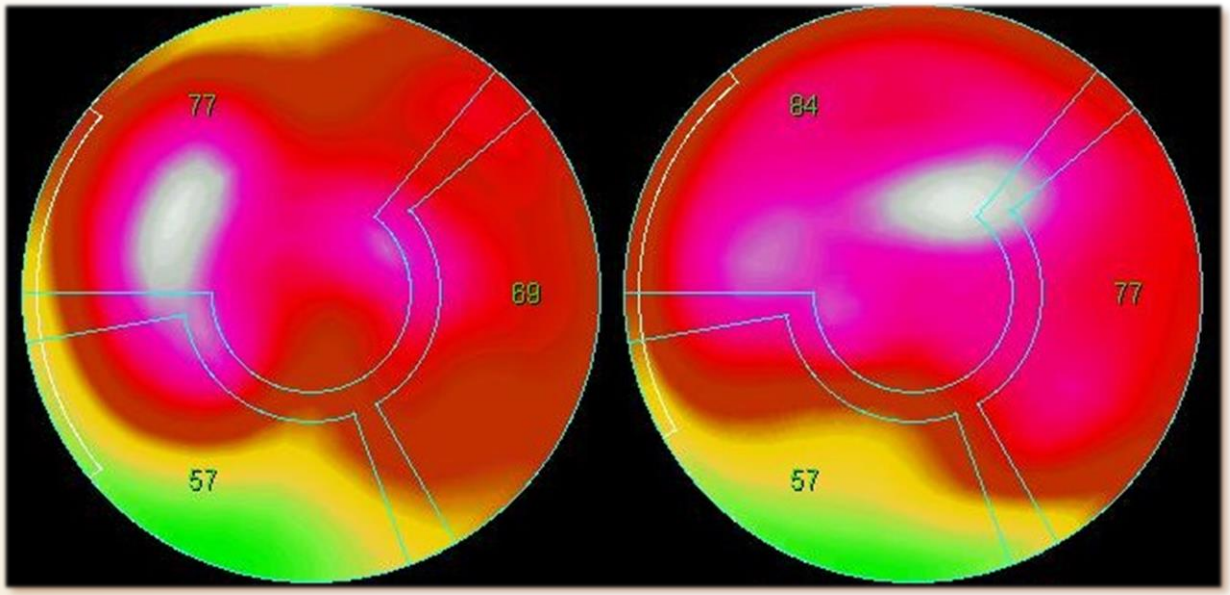
Exemple : Mme B

SCINTI à J4 :



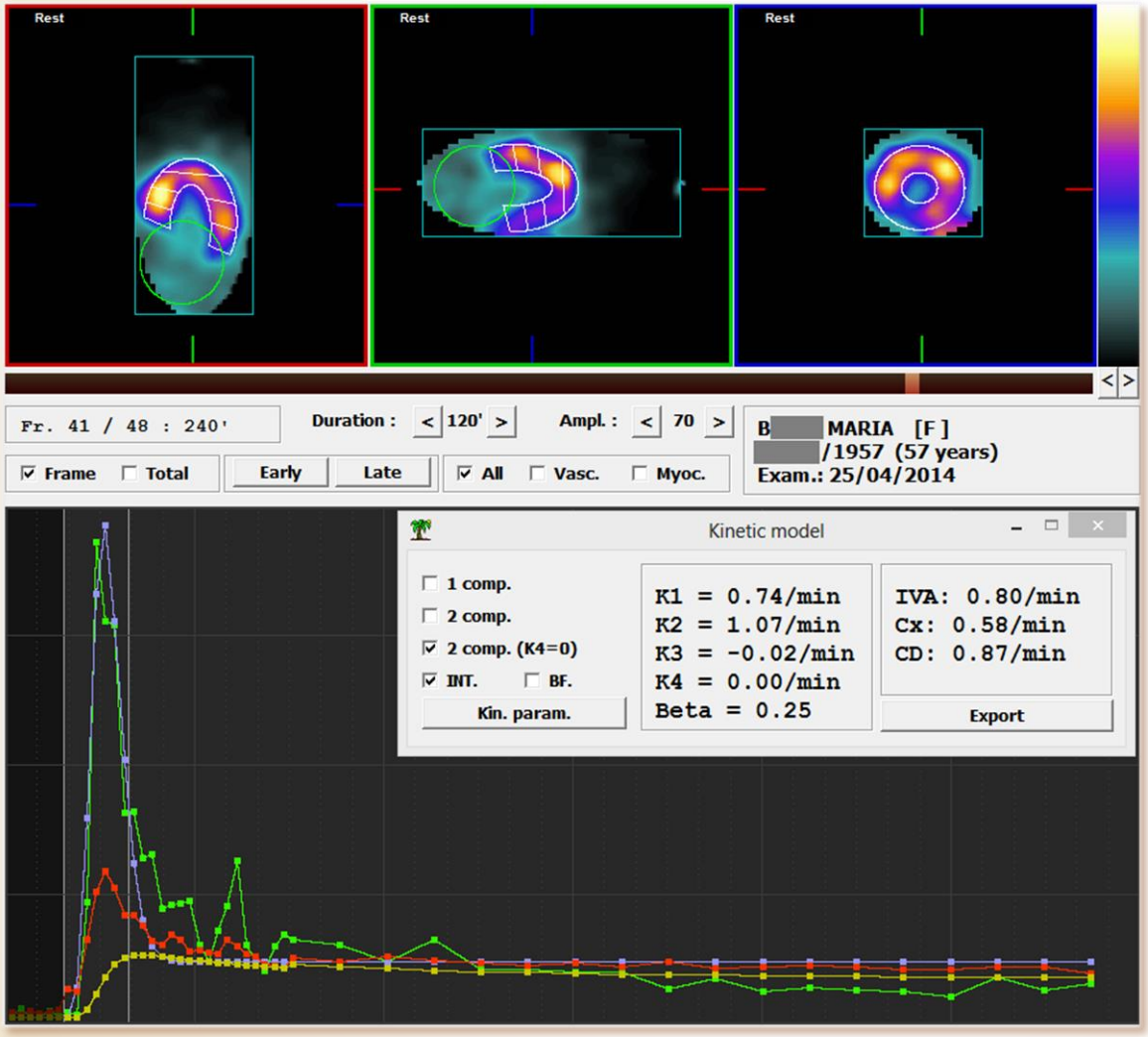
Effort

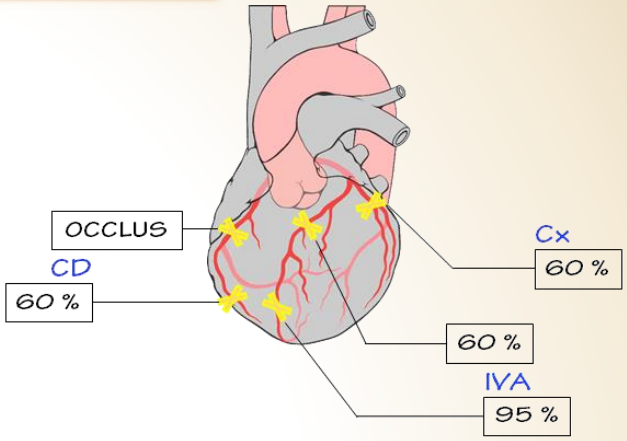
Repos



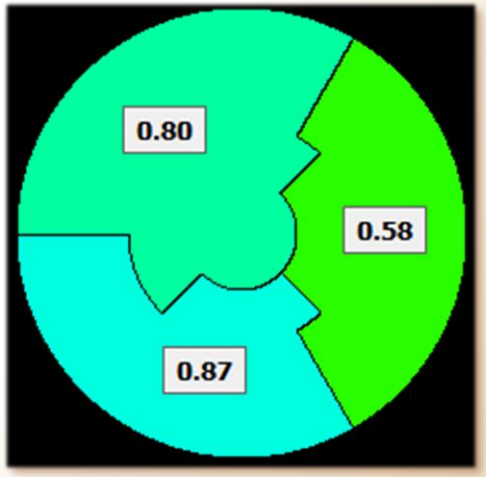
Protocole

Exemple : Mme B



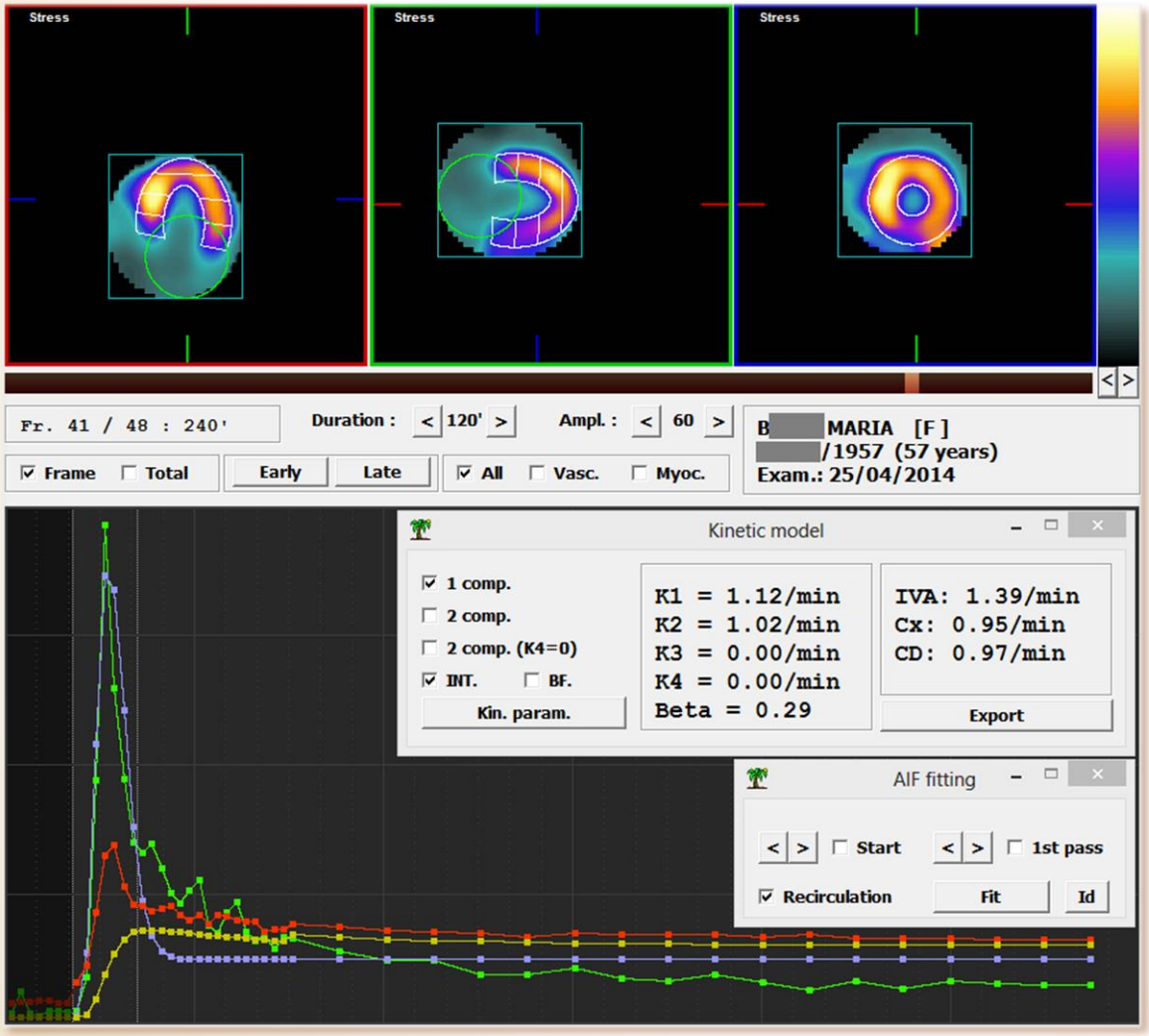


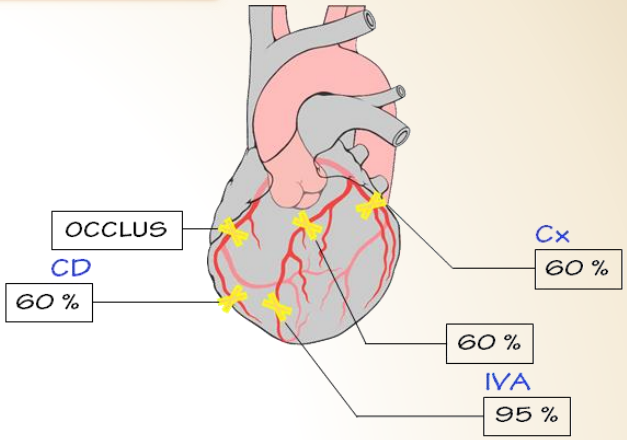
K1 repos



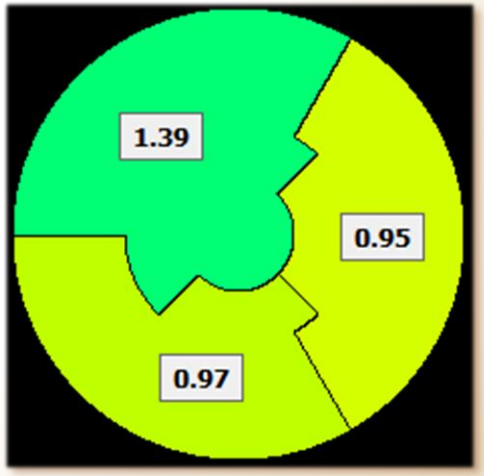
Protocole

Exemple : Mme B



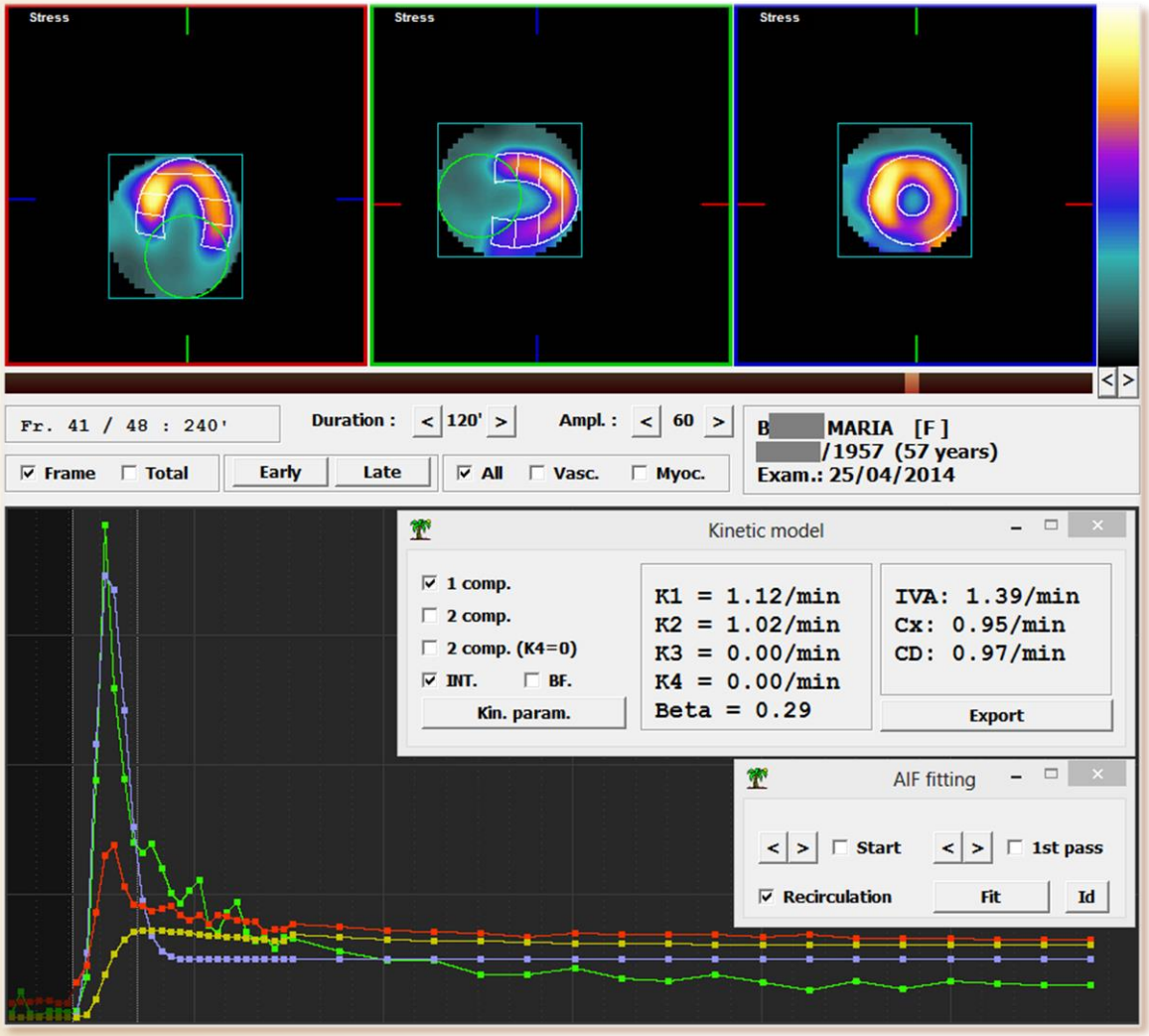


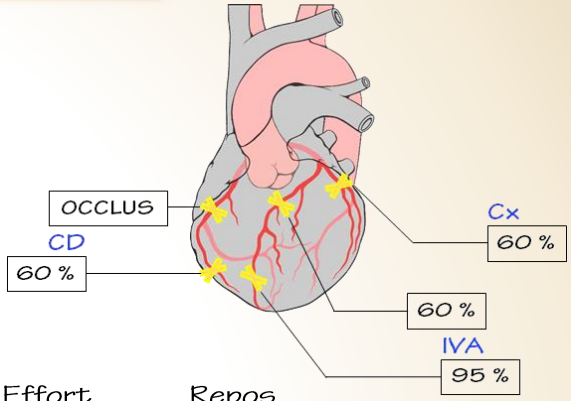
K1 effort

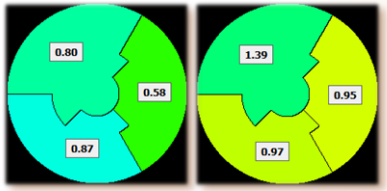


Protocole

Exemple : Mme B







Réserve coronaire