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

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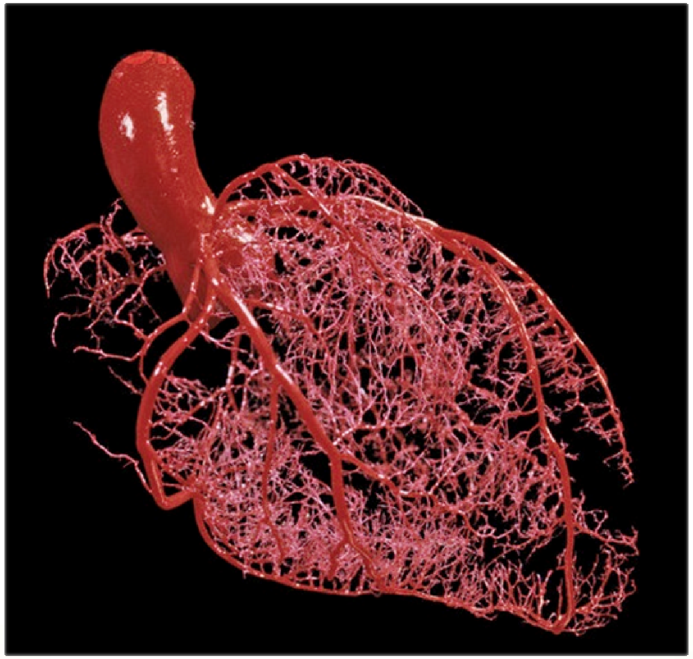
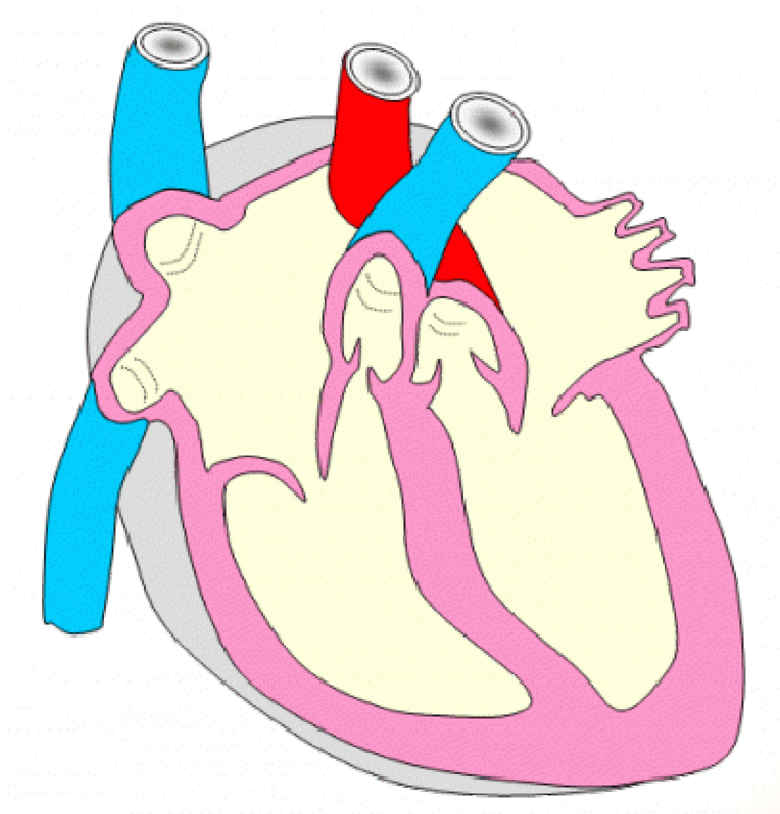


Fayçal Ben Bouallègue
CHU Montpellier – Service de Médecine Nucléaire

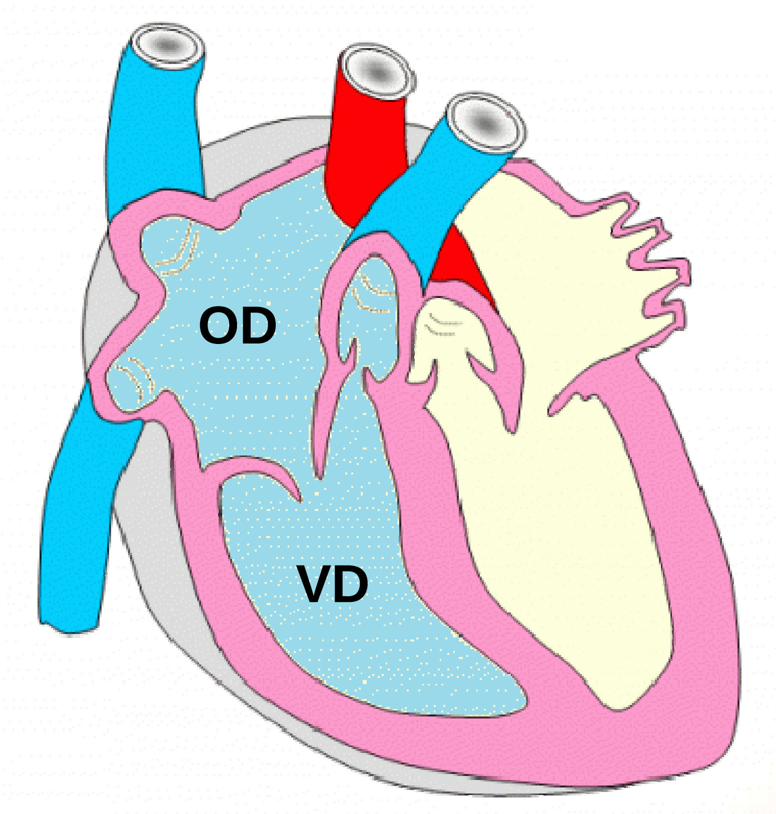
Pathologie coronarienne

Physiologie du cœur



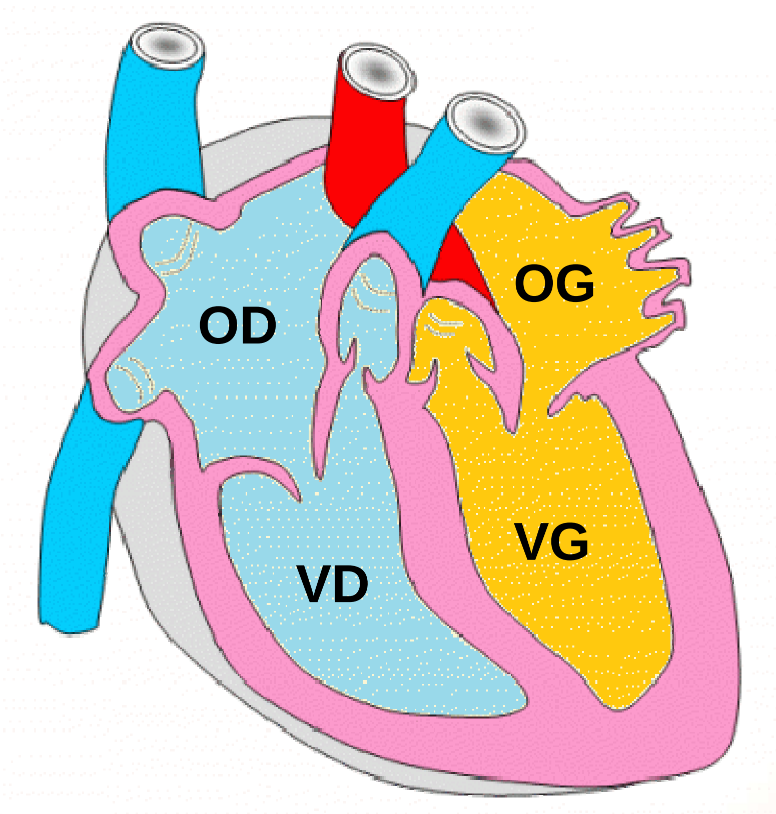
Pathologie coronarienne

Physiologie du cœur



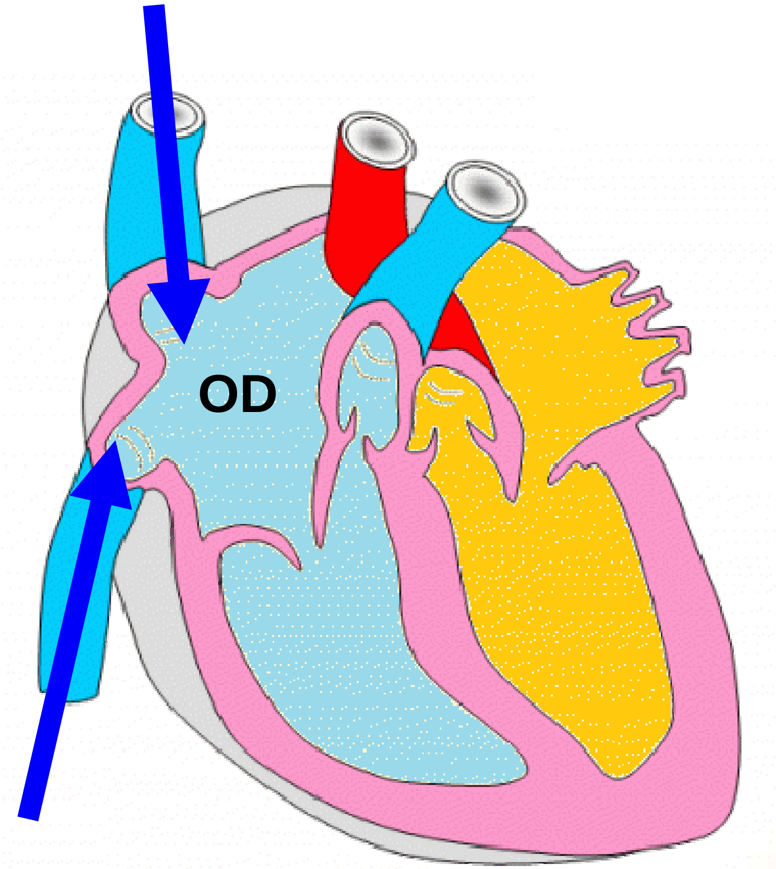
Pathologie coronarienne

Physiologie du cœur



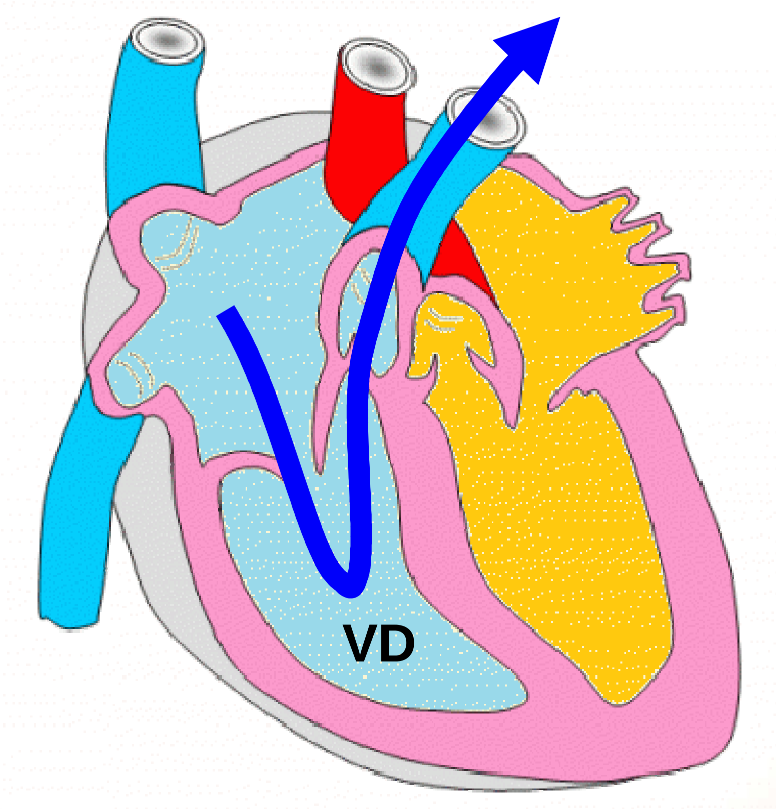
Pathologie coronarienne

Physiologie du cœur



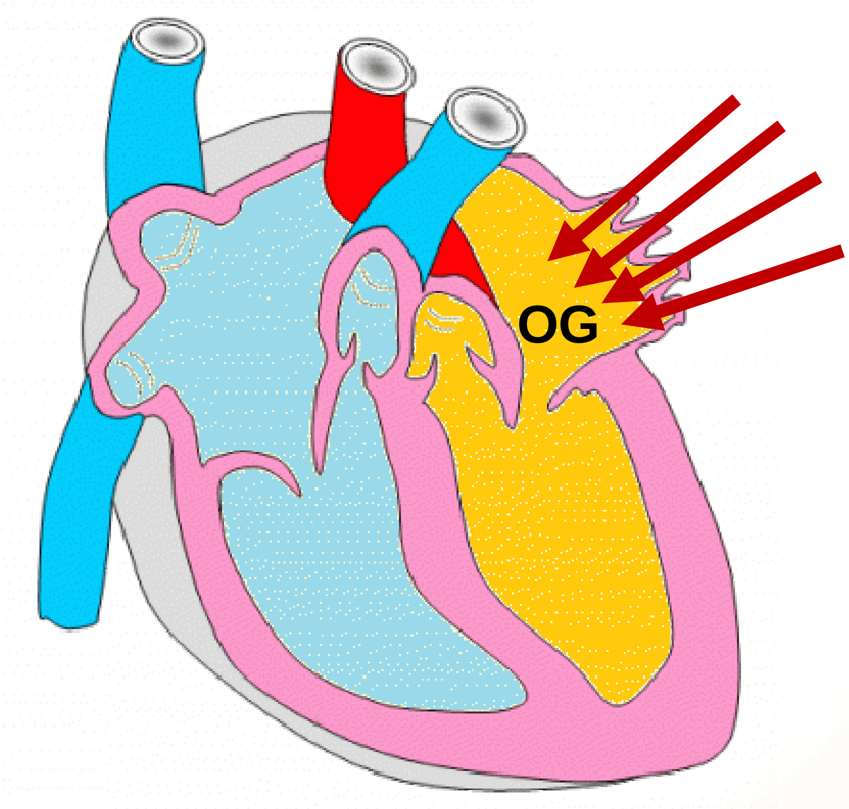
Pathologie coronarienne

Physiologie du cœur



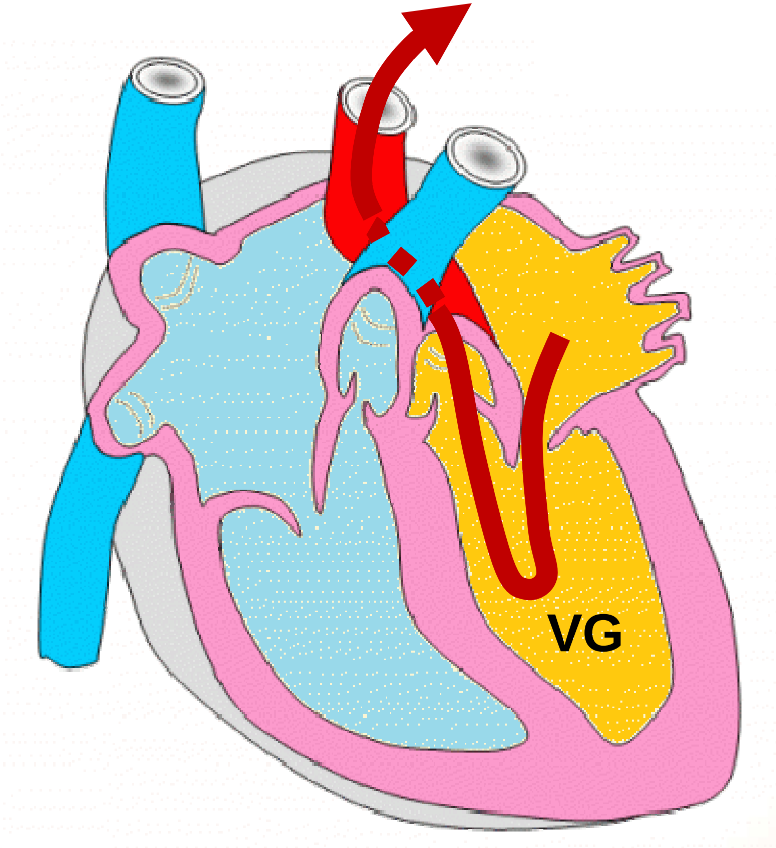
Pathologie coronarienne

Physiologie du cœur



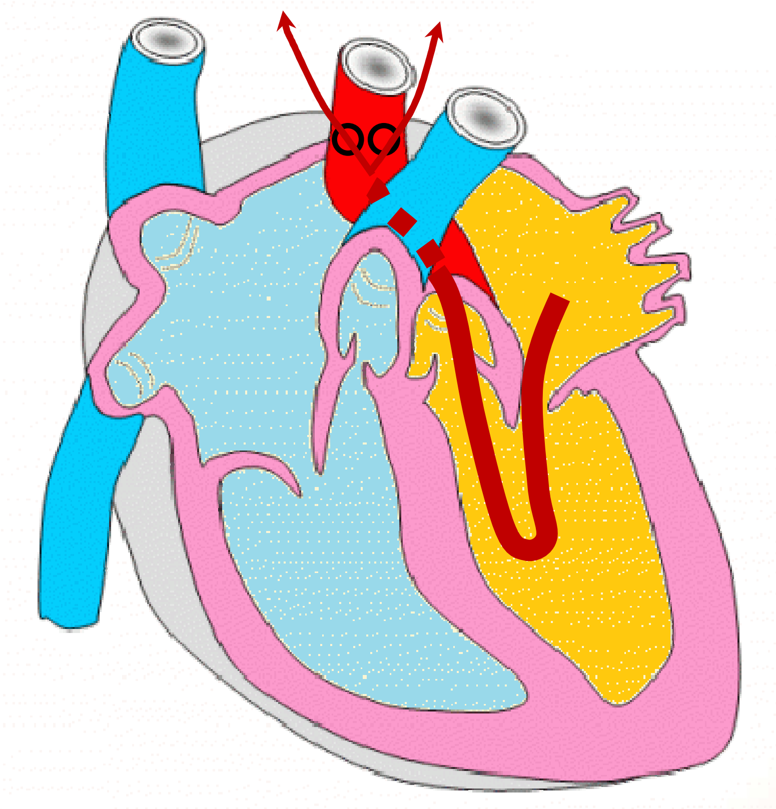
Pathologie coronarienne

Physiologie du cœur



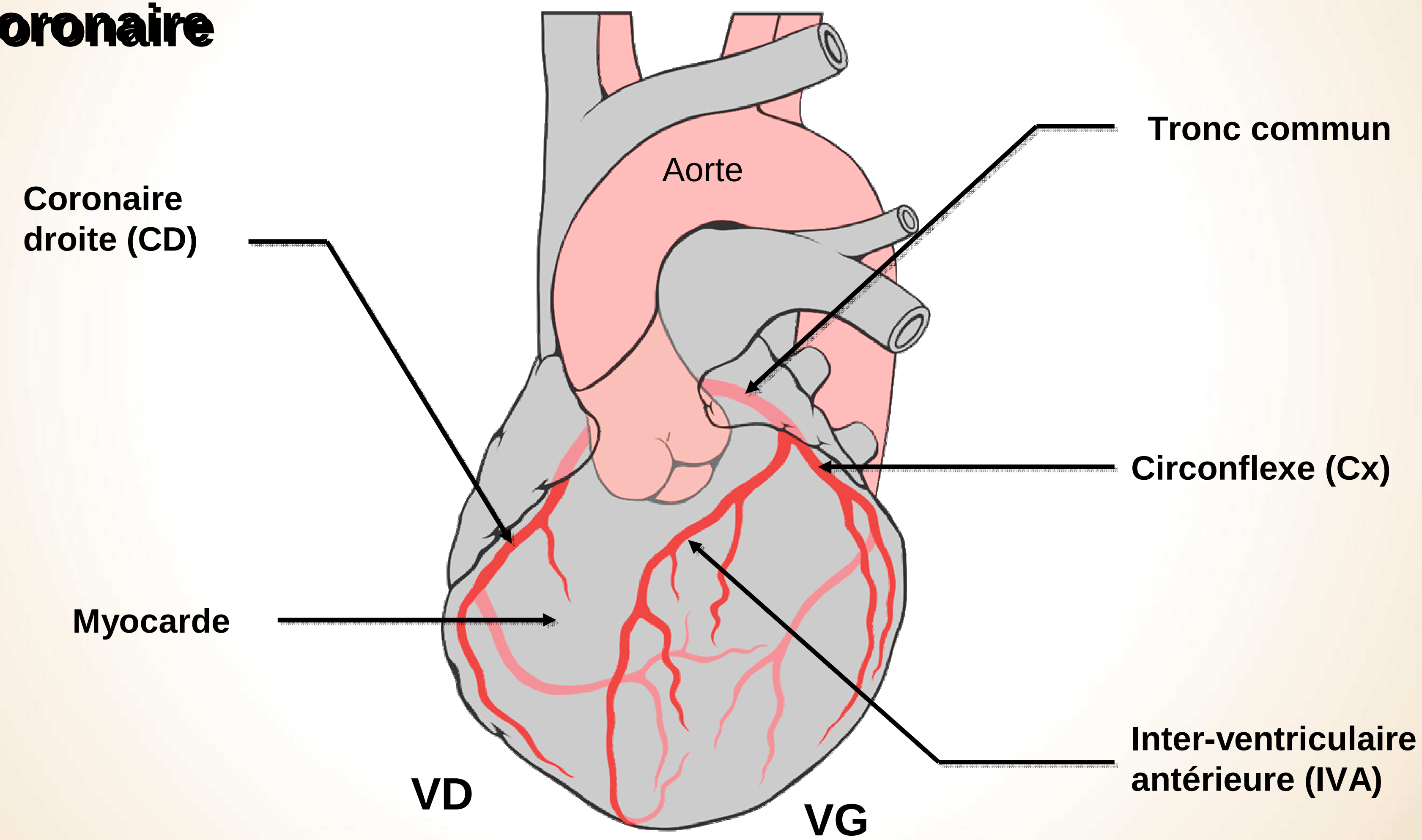
Pathologie coronarienne

Physiologie du cœur



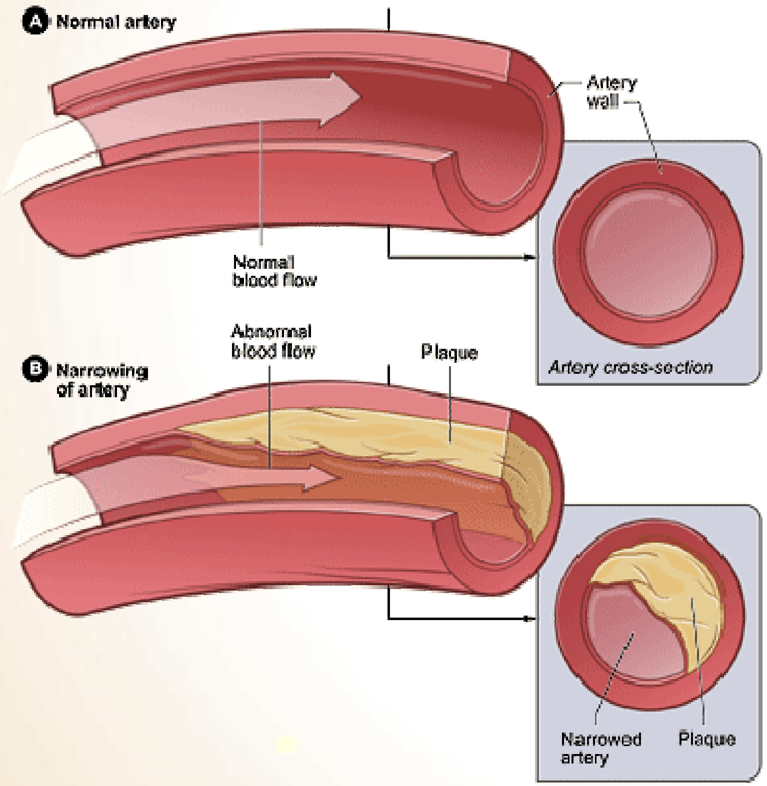
Pathologie coronarienne

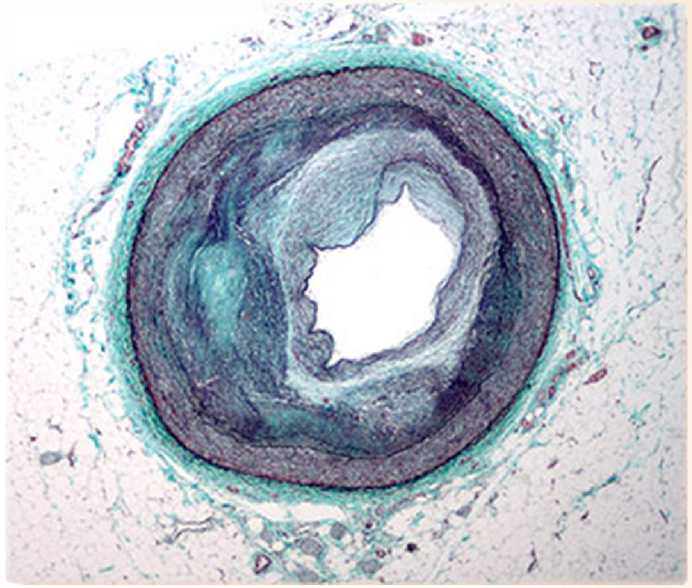
Vascularisation coronaire



Pathologie coronarienne

Ischémie myocardique

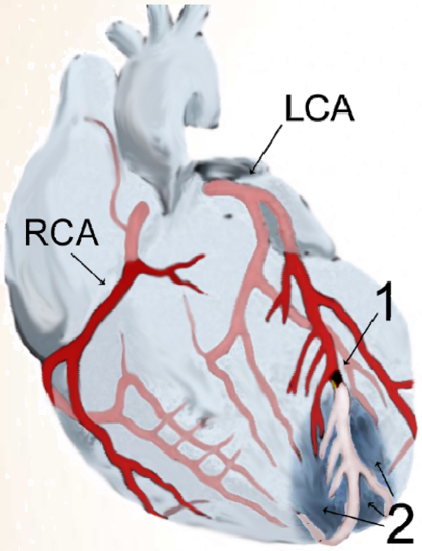


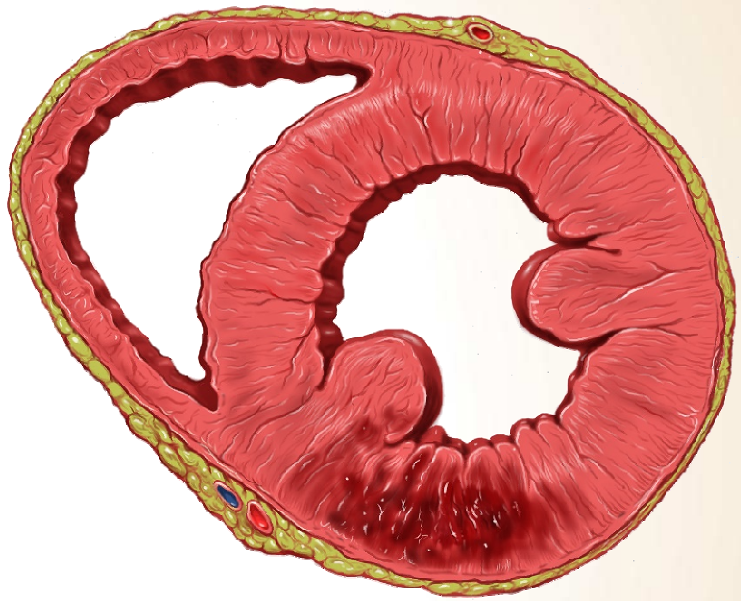


Sténose coronaire → **Ischémie myocardique**

Pathologie coronarienne

Ischémie myocardique





Sténose obstructive

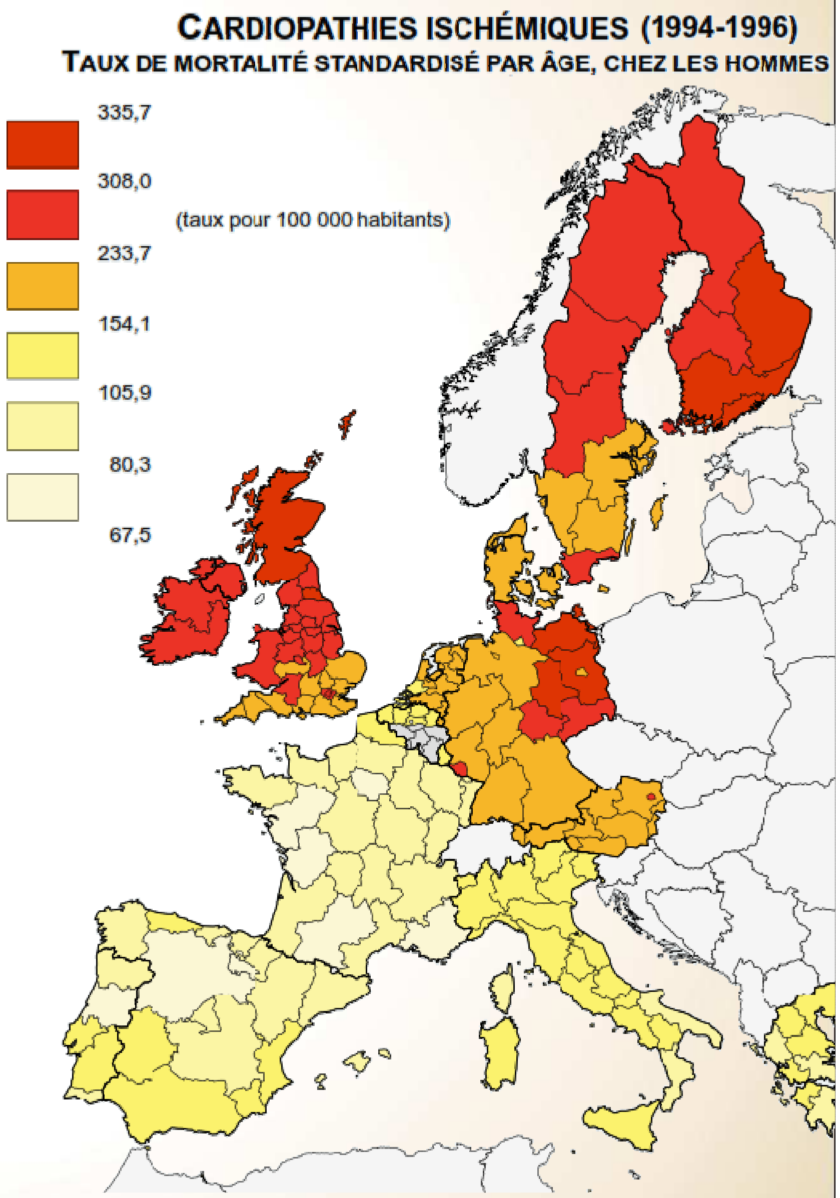
Infarctus

< 24h

Nécrose myocardique

Insuffisance cardiaque
Troubles du rythme
Mort subite

Pathologie coronarienne

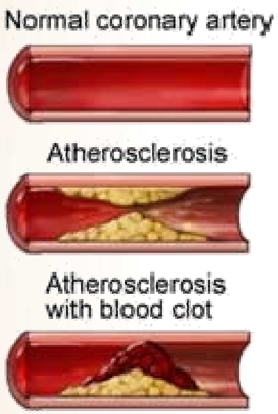


Statistiques
France 2008

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

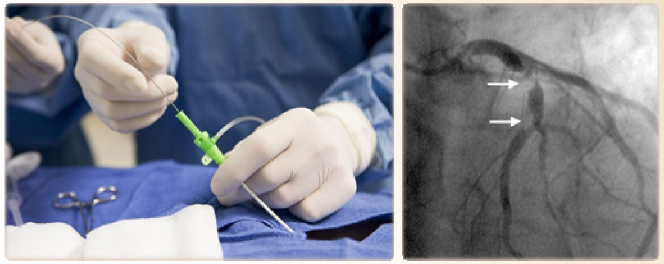
↓ Flux coronaire

Modifications métaboliques

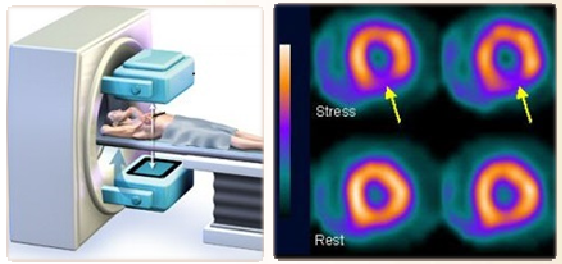
Dysfonction ventriculaire

Modifications électriques

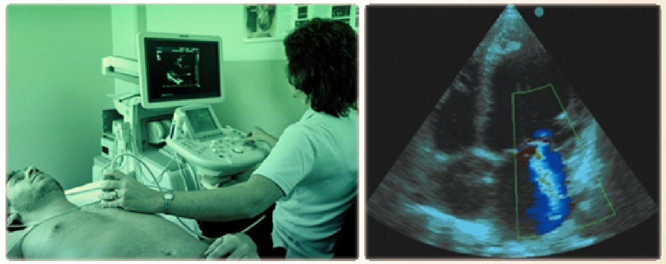
Douleur



coronarographie

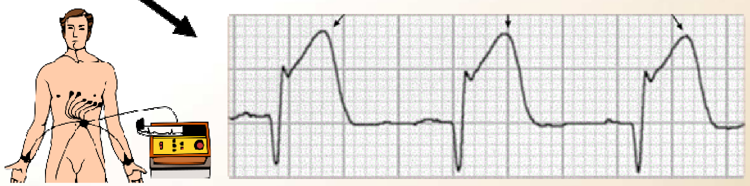


tomoscintigraphie



échocardiographie

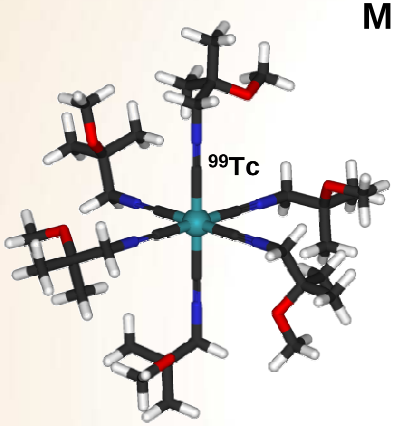
ECG



Scintigraphie myocardique

■ **Protocole**

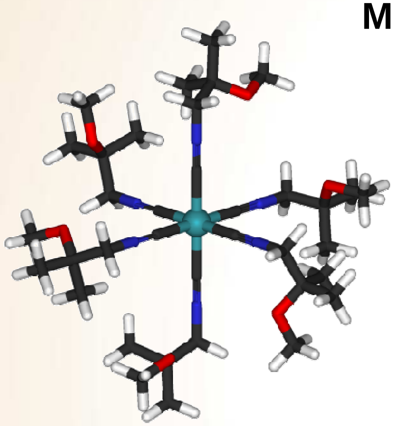
MIBI – 4 mCi



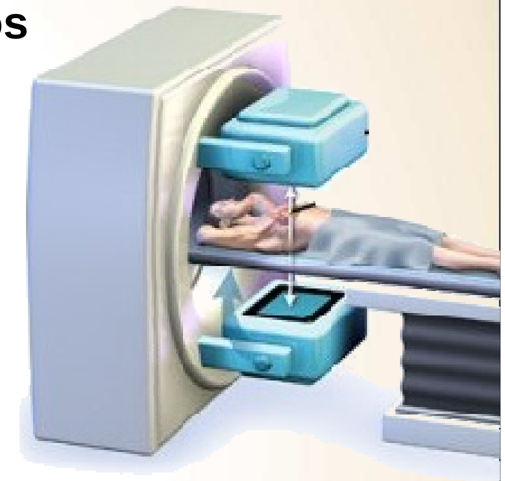
Scintigraphie myocardique

- **Protocole**

MIBI – 4 mCi



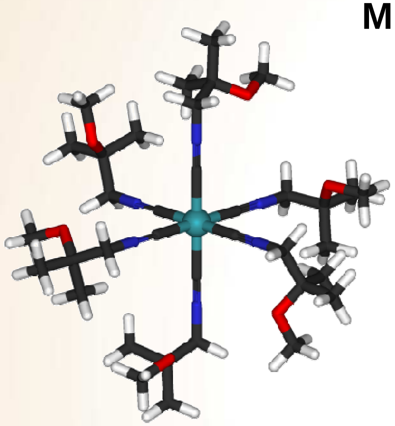
Repos

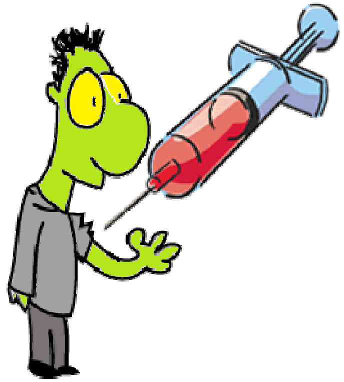


Scintigraphie myocardique

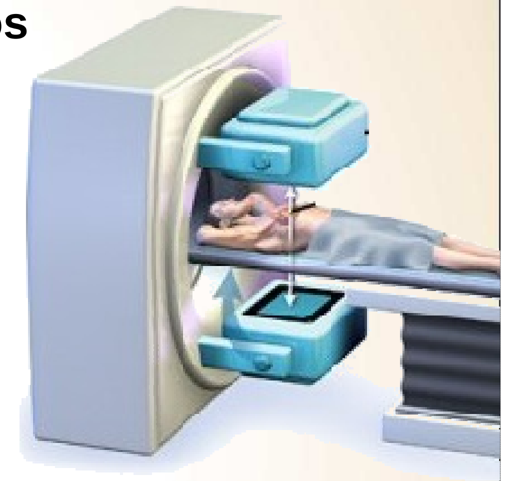
- **Protocole**

MIBI – 4 mCi





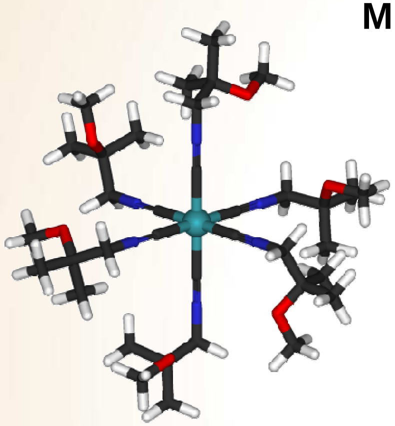
Repos

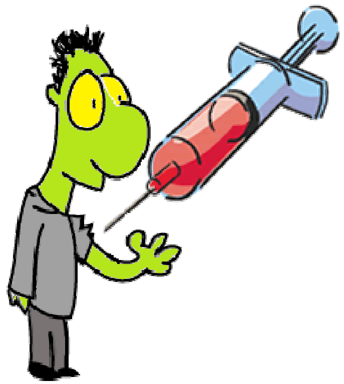


Scintigraphie myocardique

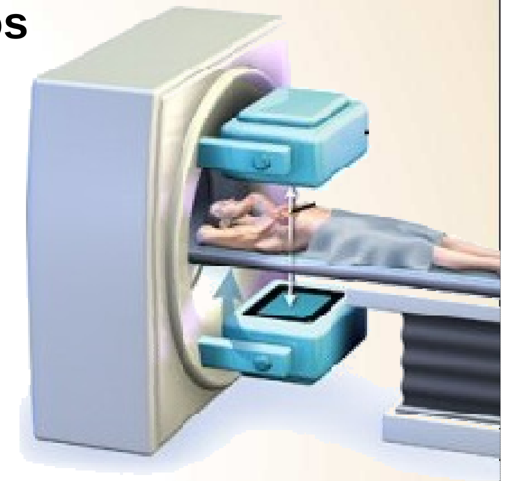
■ **Protocole**

MIBI – 4 mCi

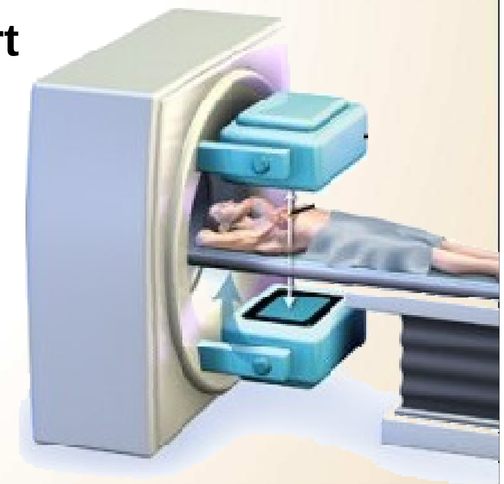




Repos



Effort



MIBI – 12 mCi

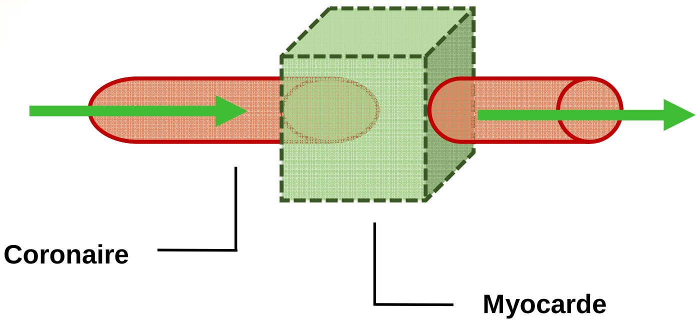
Scintigraphie myocardique

■ Physiologie

Repos

Effort

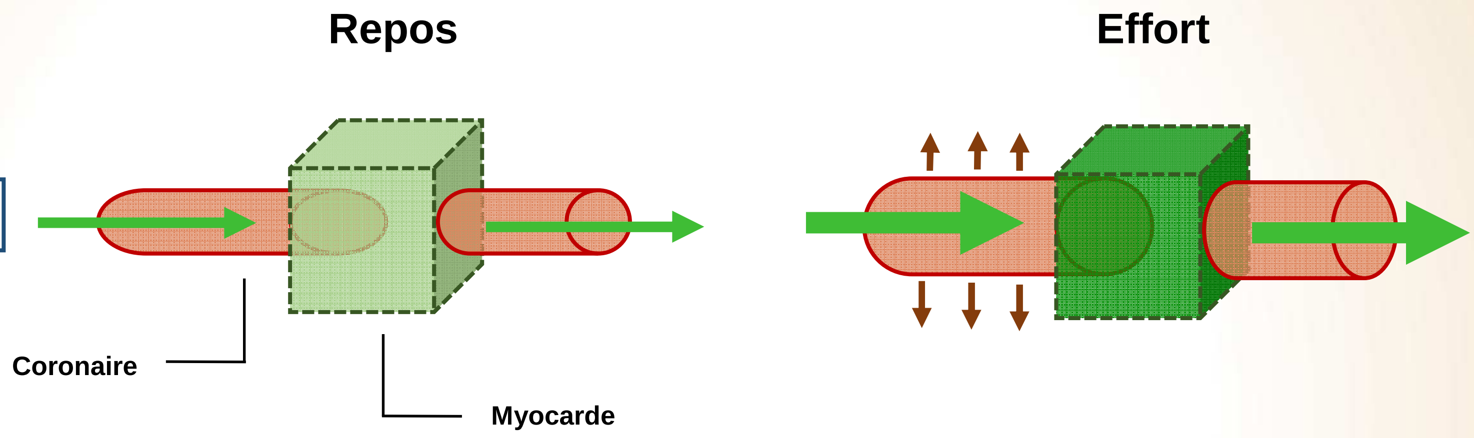
Cœur sain



Scintigraphie myocardique

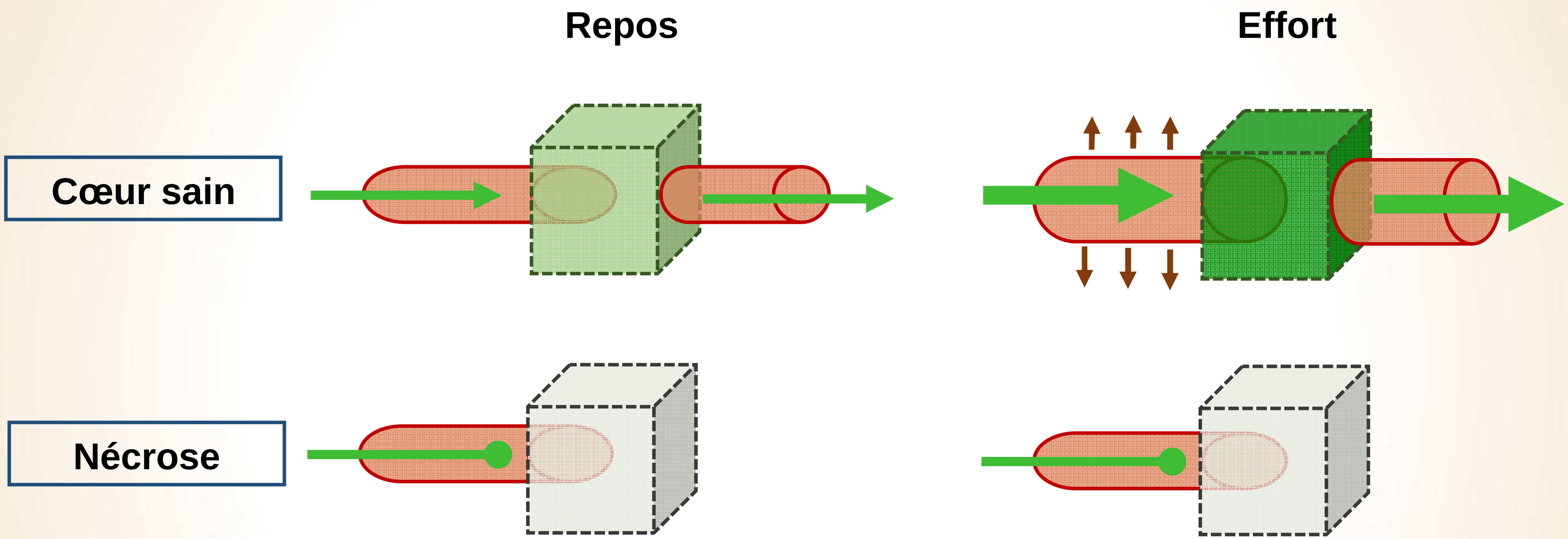
- Physiologie

Cœur sain



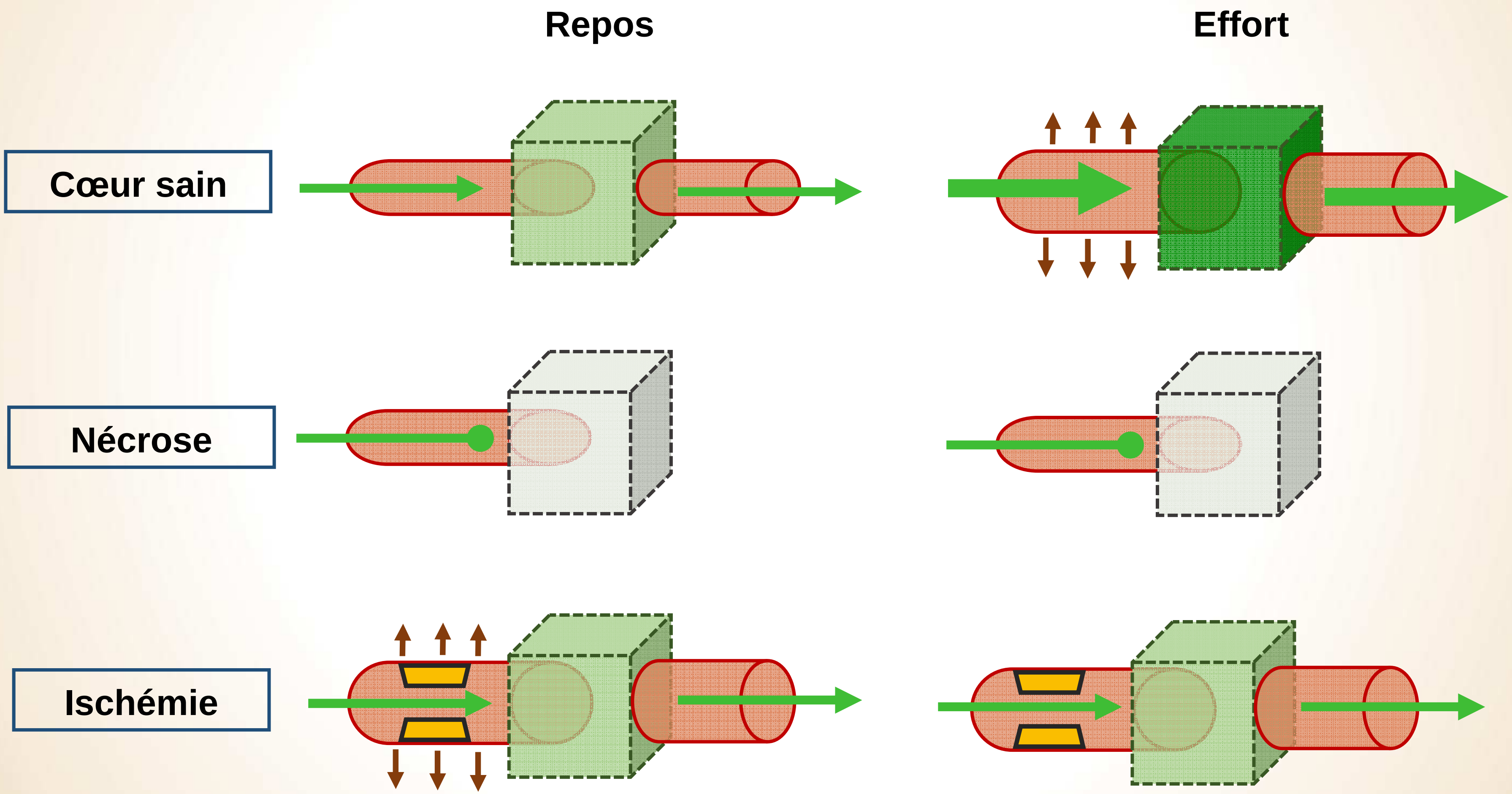
Scintigraphie myocardique

■ Physiologie



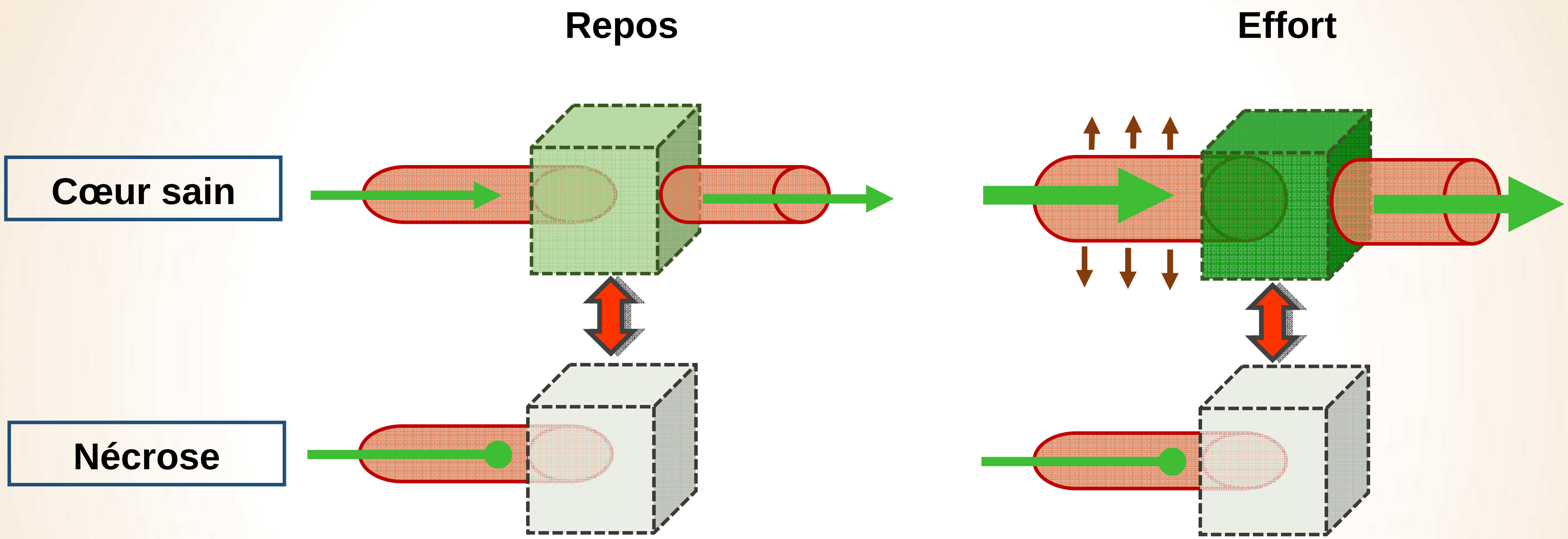
Scintigraphie myocardique

- Physiologie



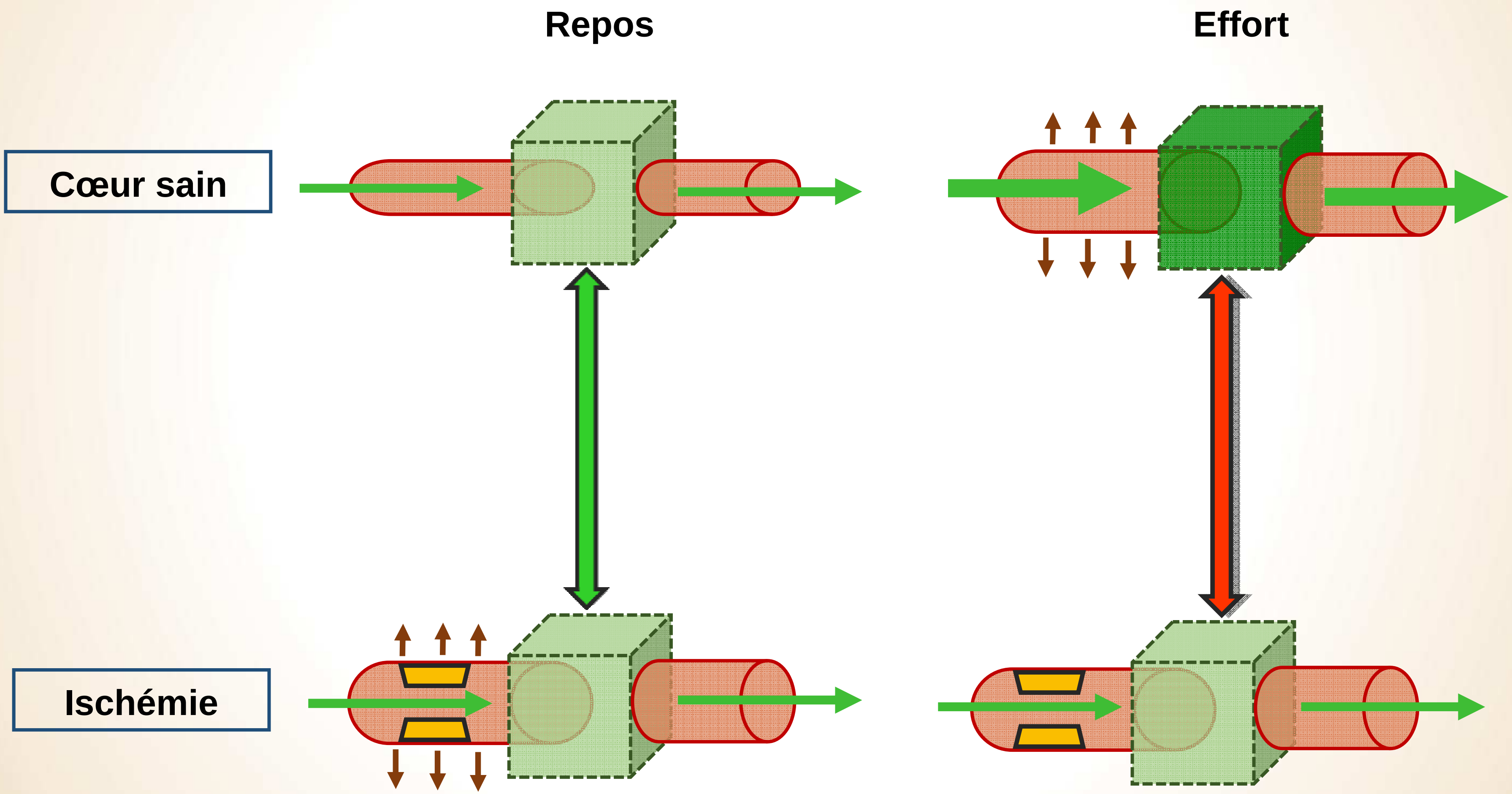
Scintigraphie myocardique

- Physiologie



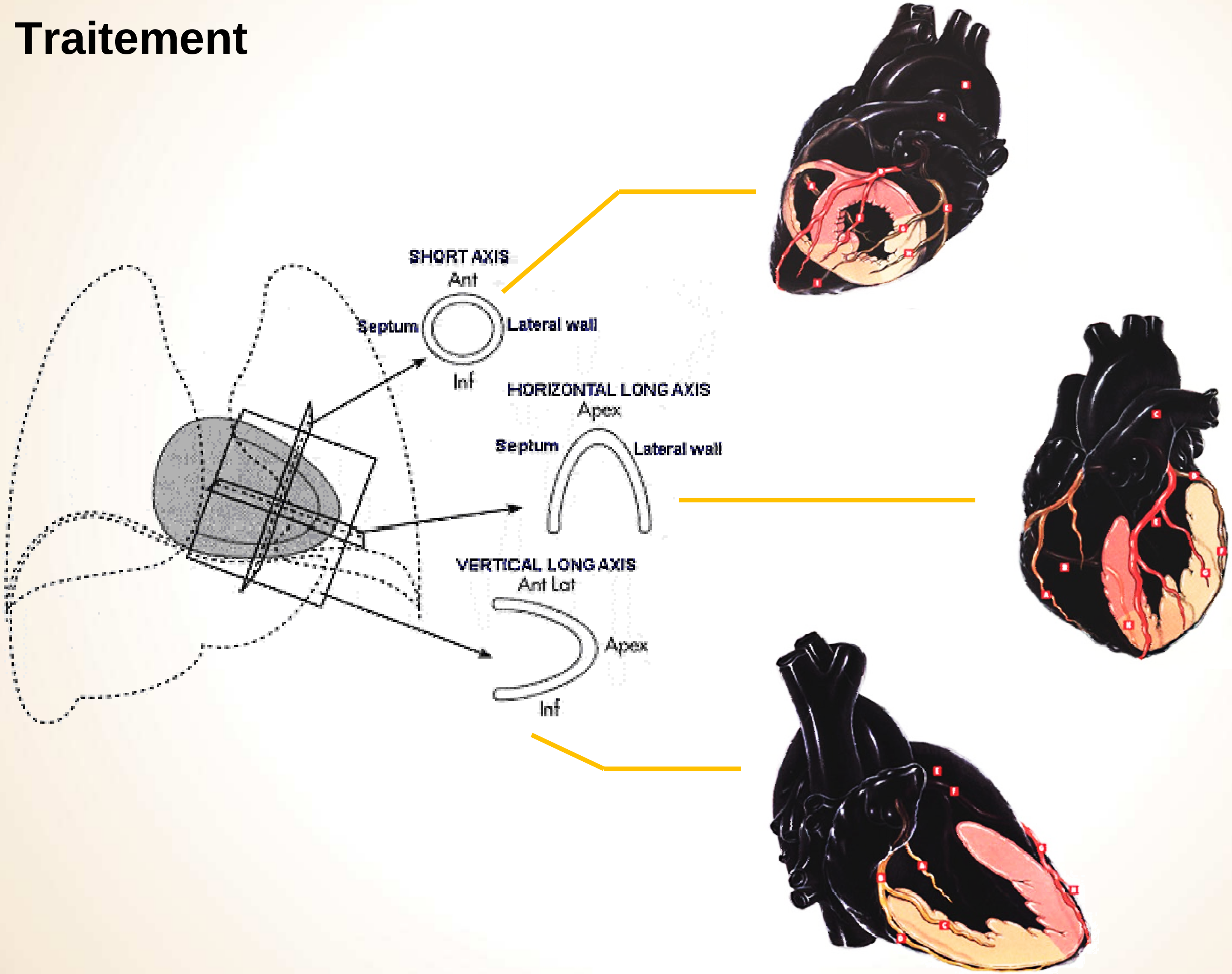
Scintigraphie myocardique

- Physiologie



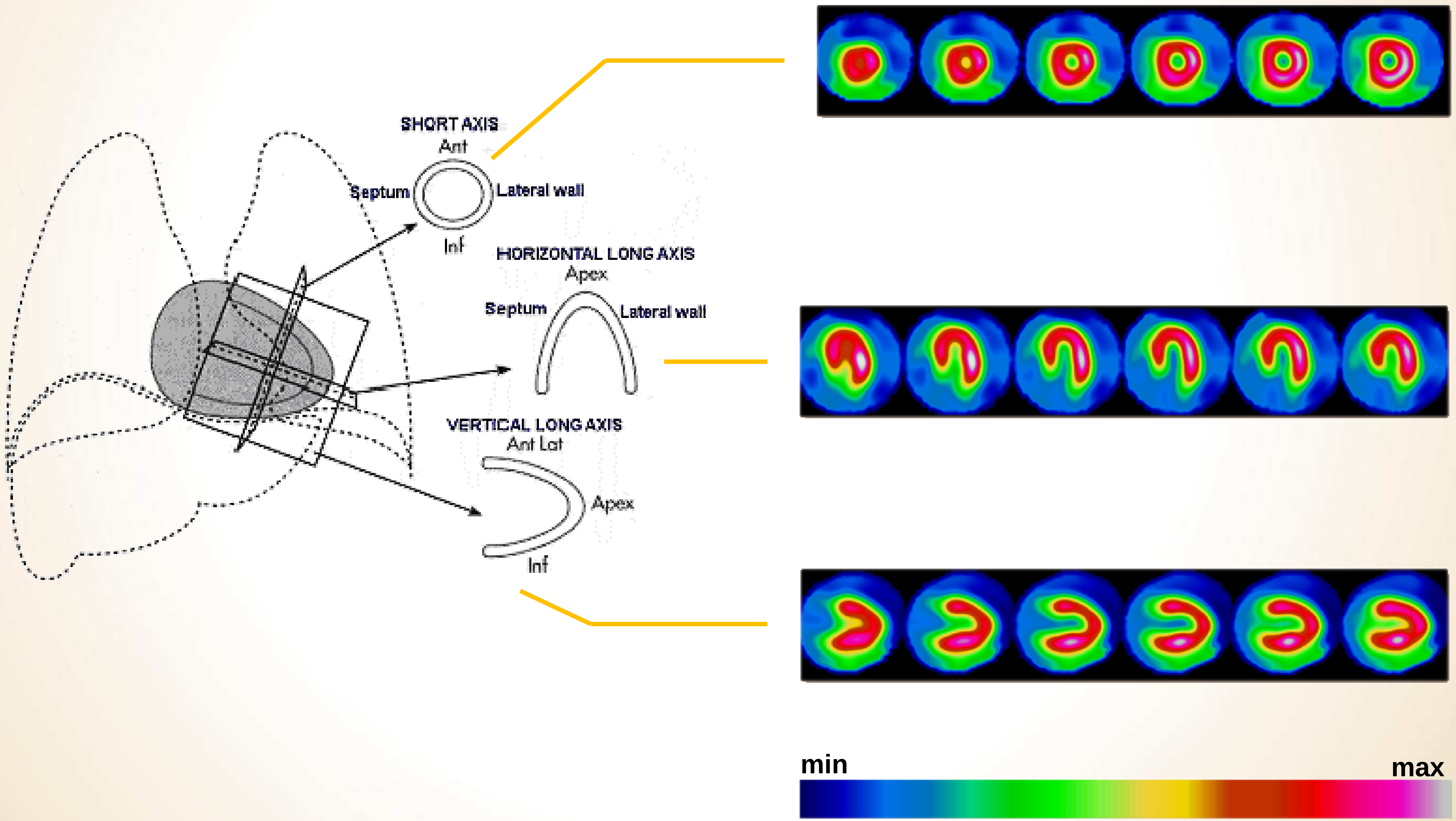
Scintigraphie myocardique

- Traitement



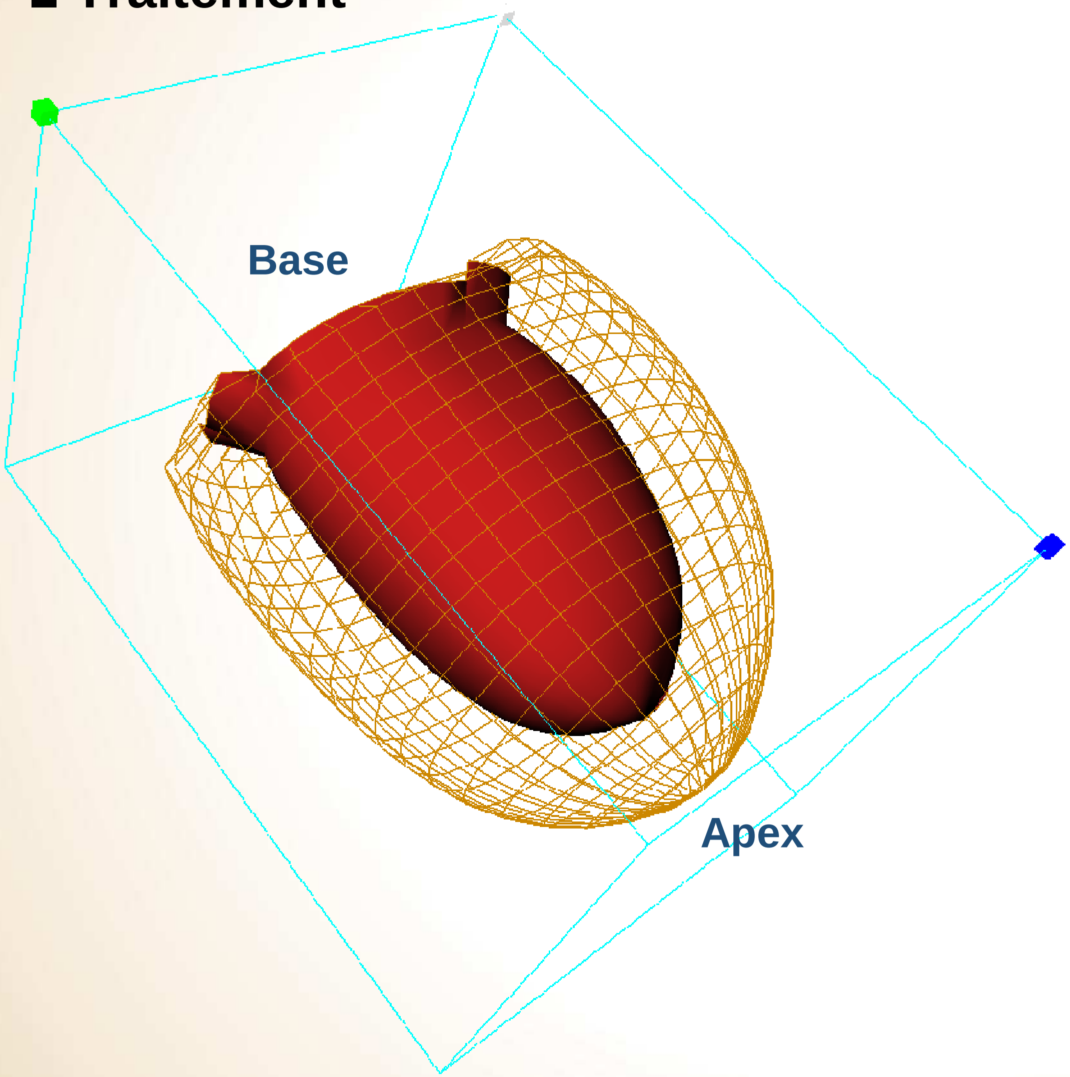
Scintigraphie myocardique

■ **Traitement**



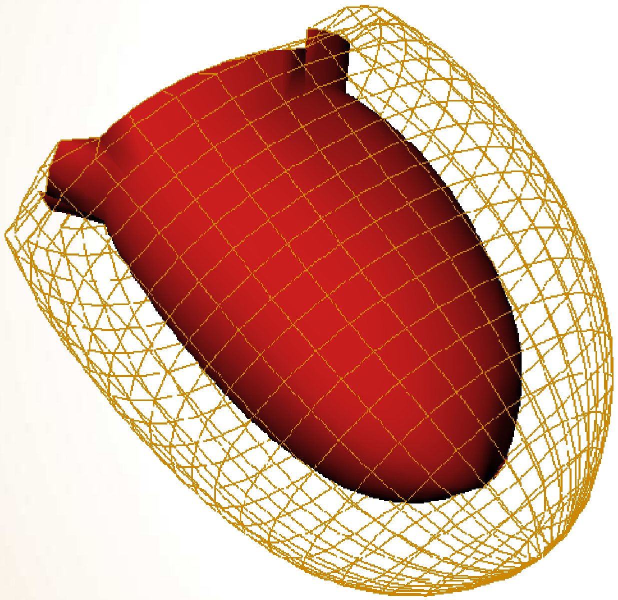
Scintigraphie myocardique

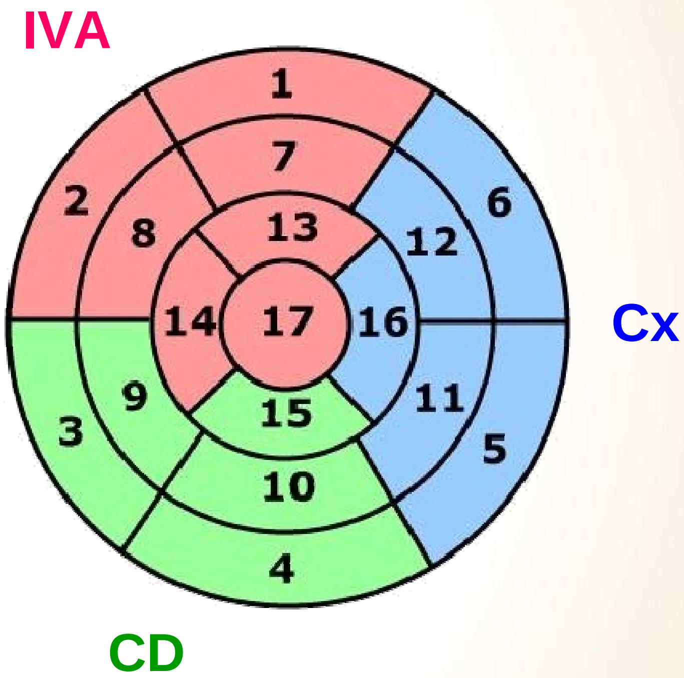
- **Traitement**



Scintigraphie myocardique

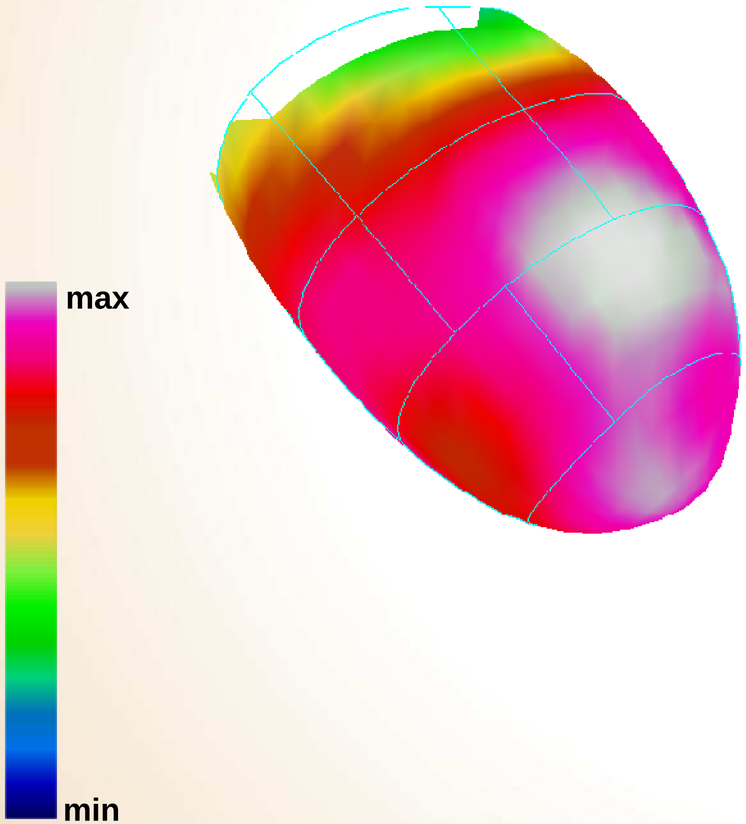
- Traitement

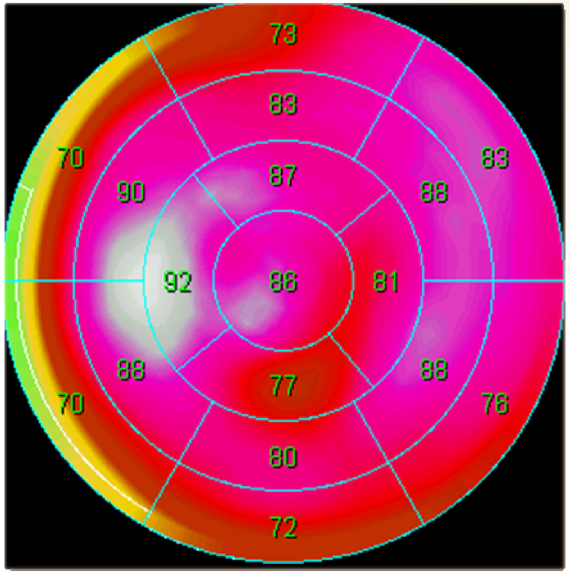


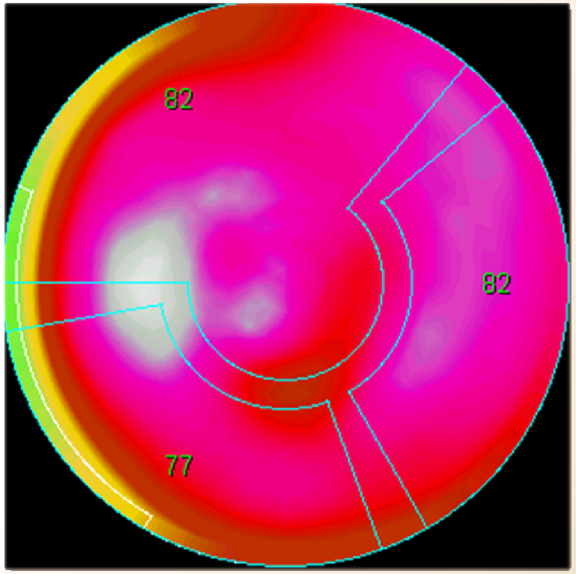


Scintigraphie myocardique

- Traitement





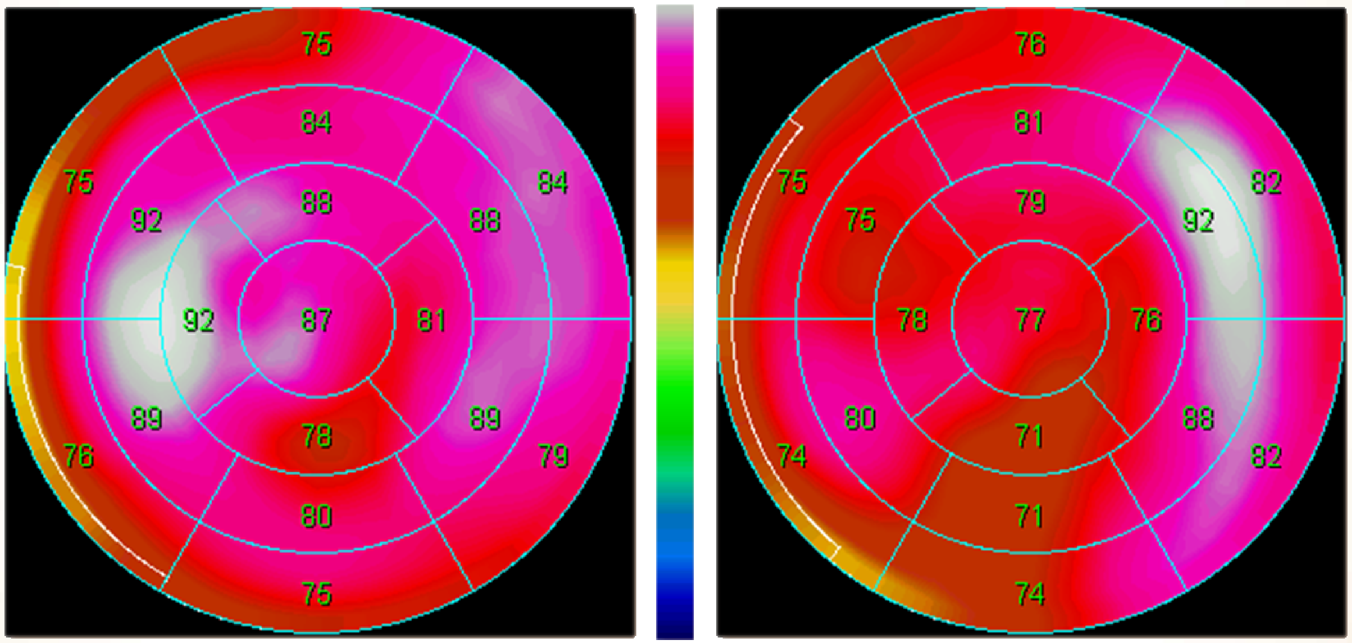


Scintigraphie myocardique

- Interprétation

Effort

Repos

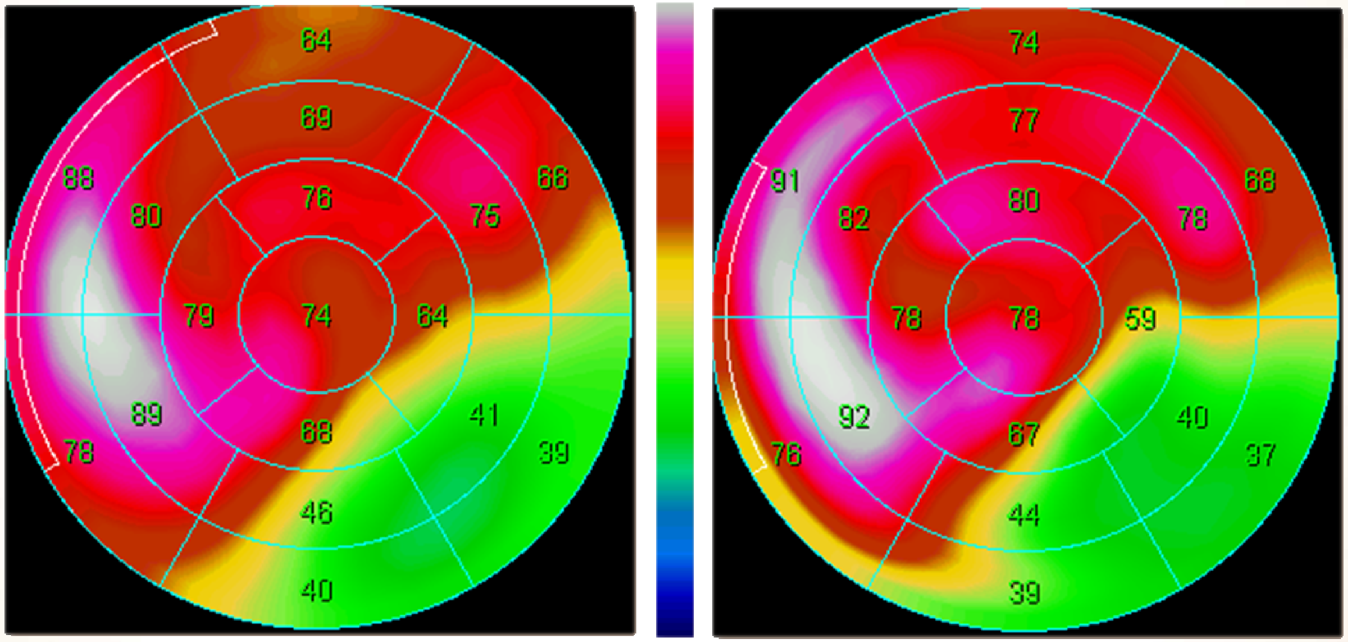


Scintigraphie normale

Scintigraphie myocardique

- **Interprétation**

Effort **Repos**

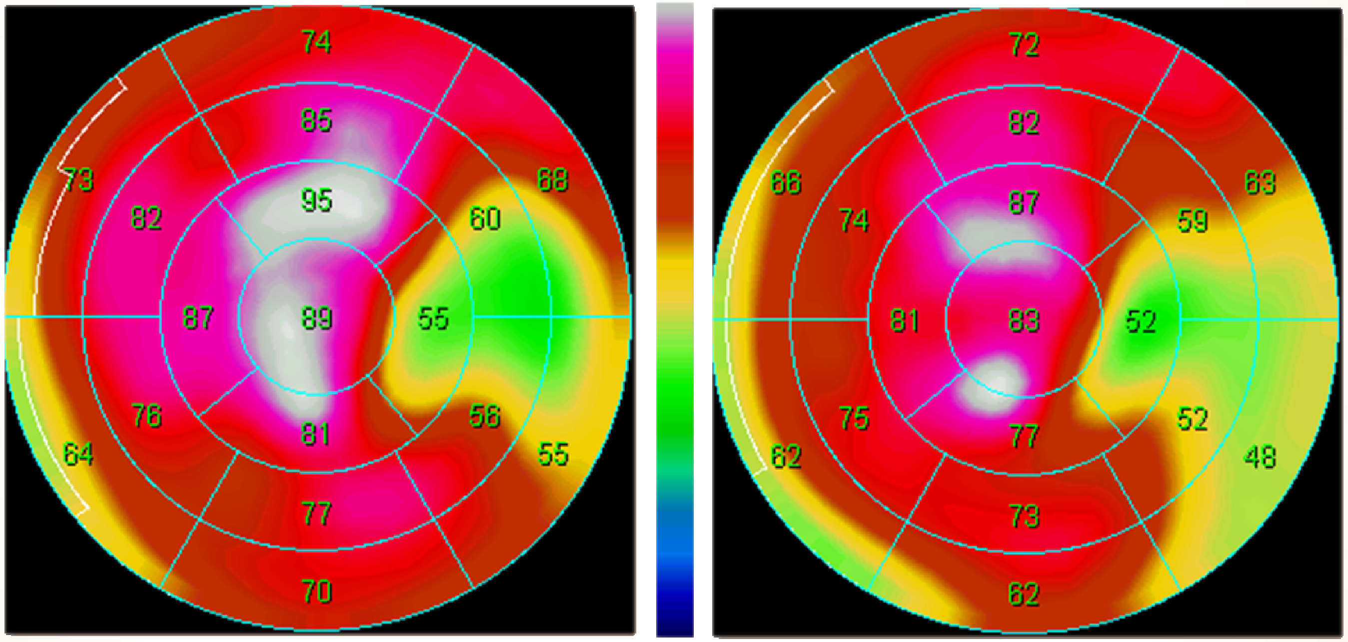


Séquelle d'infarctus

Scintigraphie myocardique

- **Interprétation**

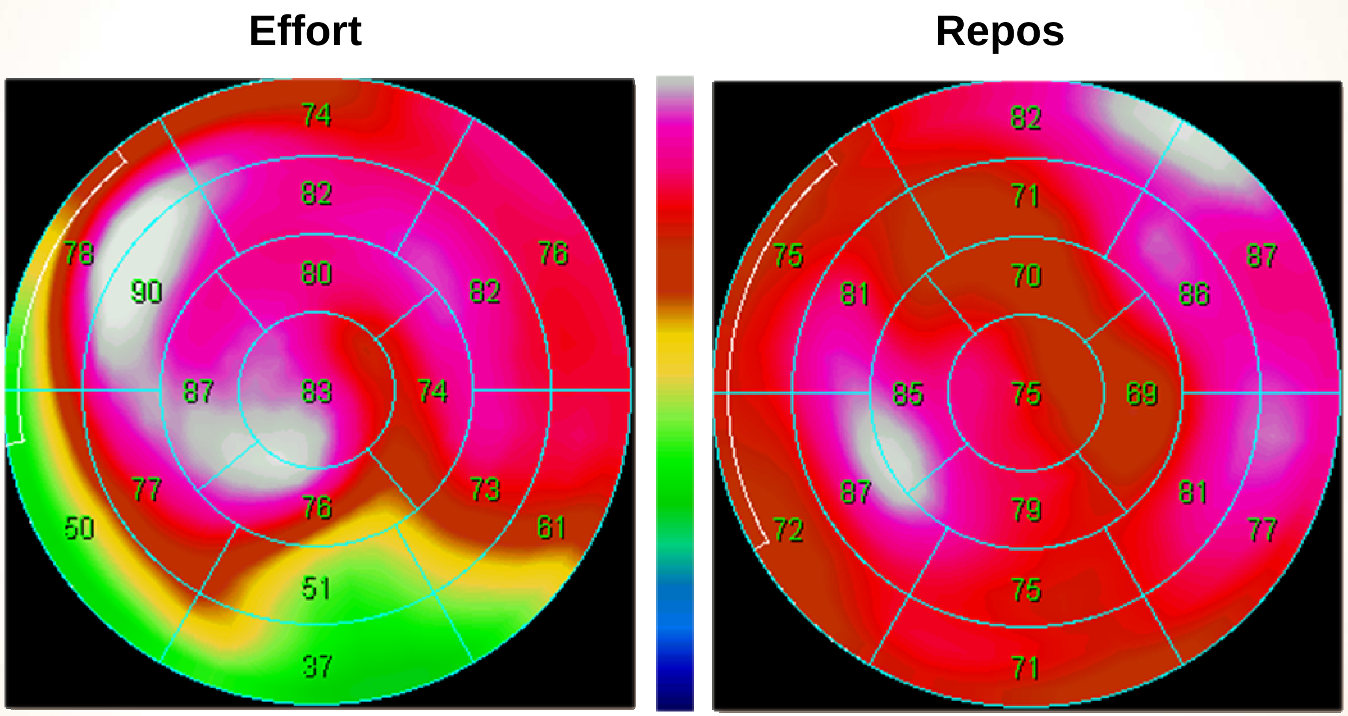
Effort **Repos**



Séquelle d'infarctus

Scintigraphie myocardique

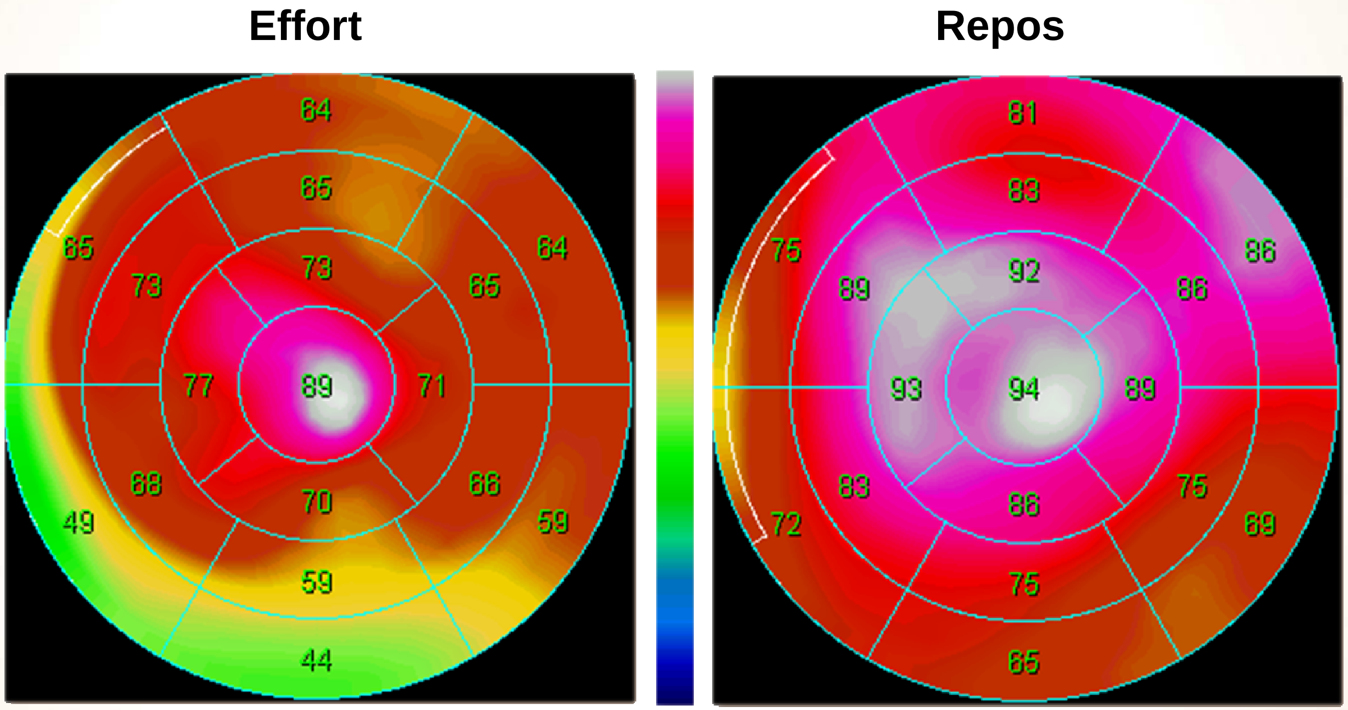
■ **Interprétation**



Ischémie myocardique

Scintigraphie myocardique

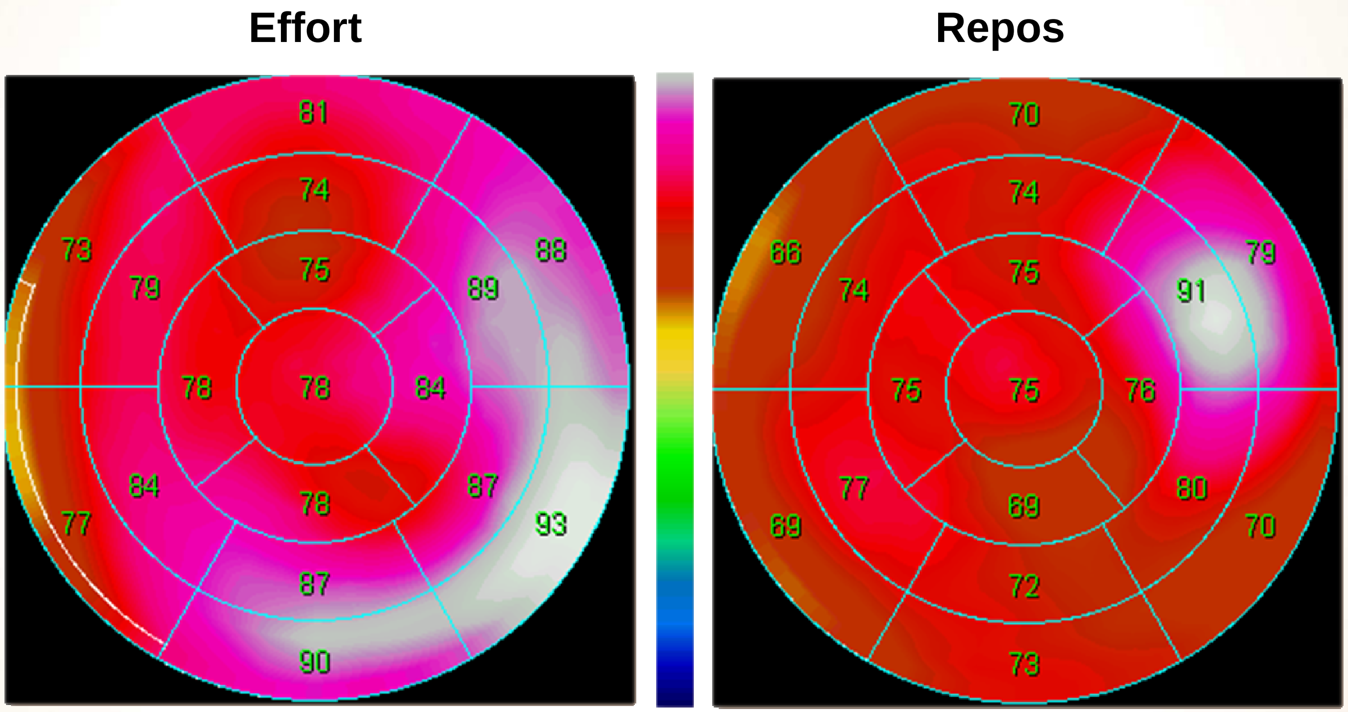
■ **Interprétation**



Ischémie myocardique

Scintigraphie myocardique

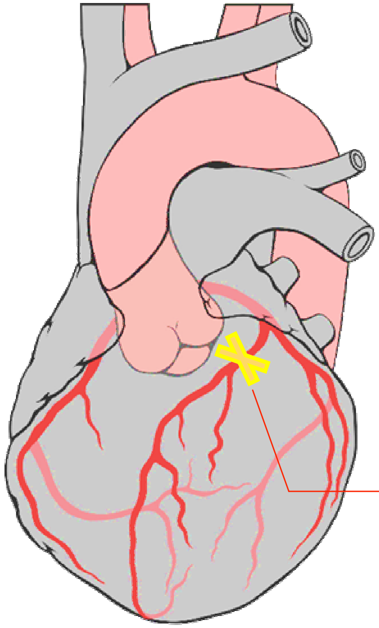
- Interprétation

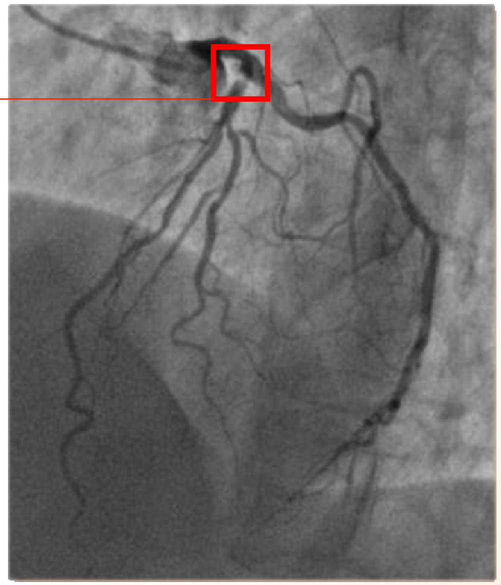


...???...

Scintigraphie myocardique

- **Interprétation**

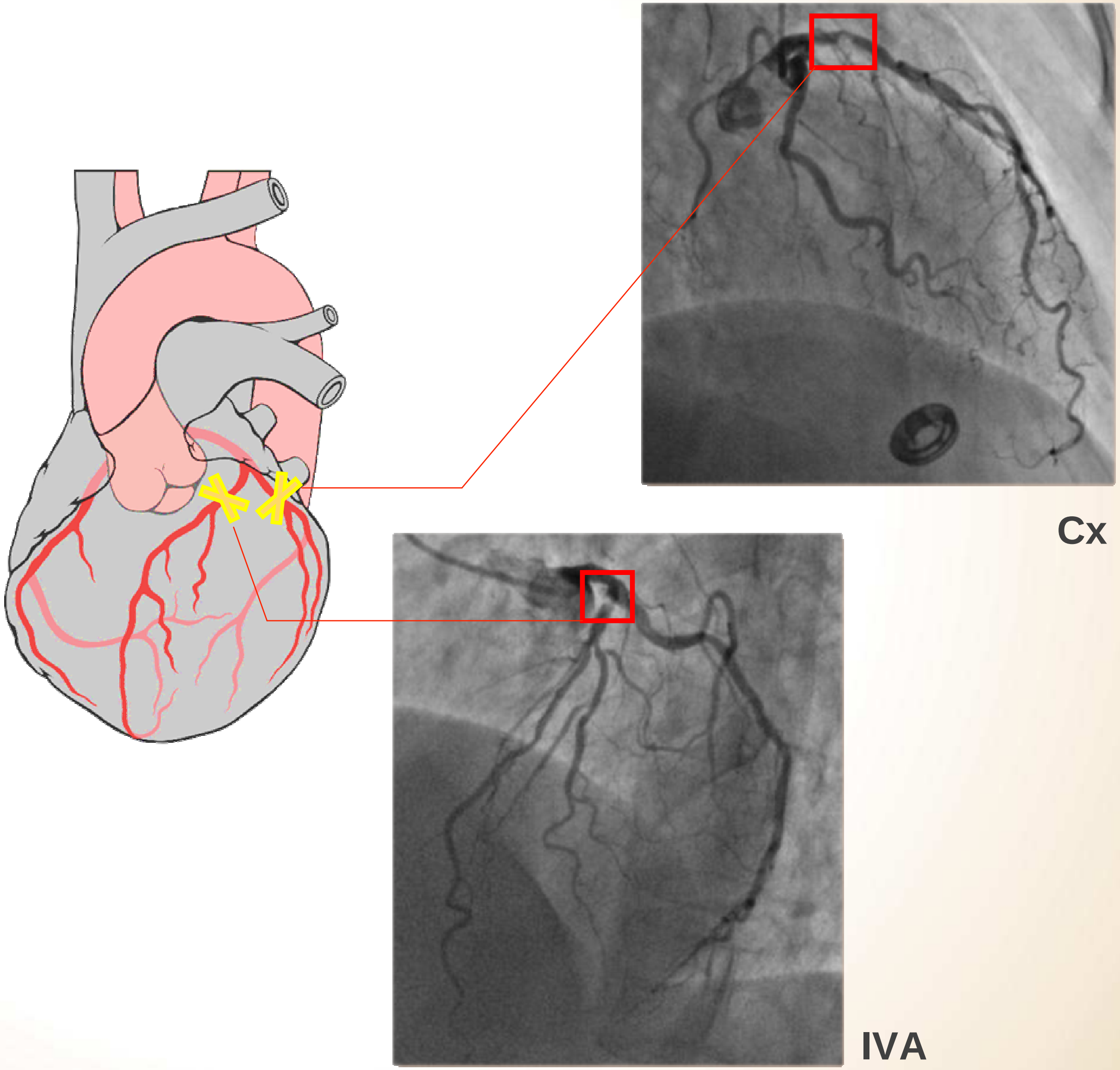




IVA

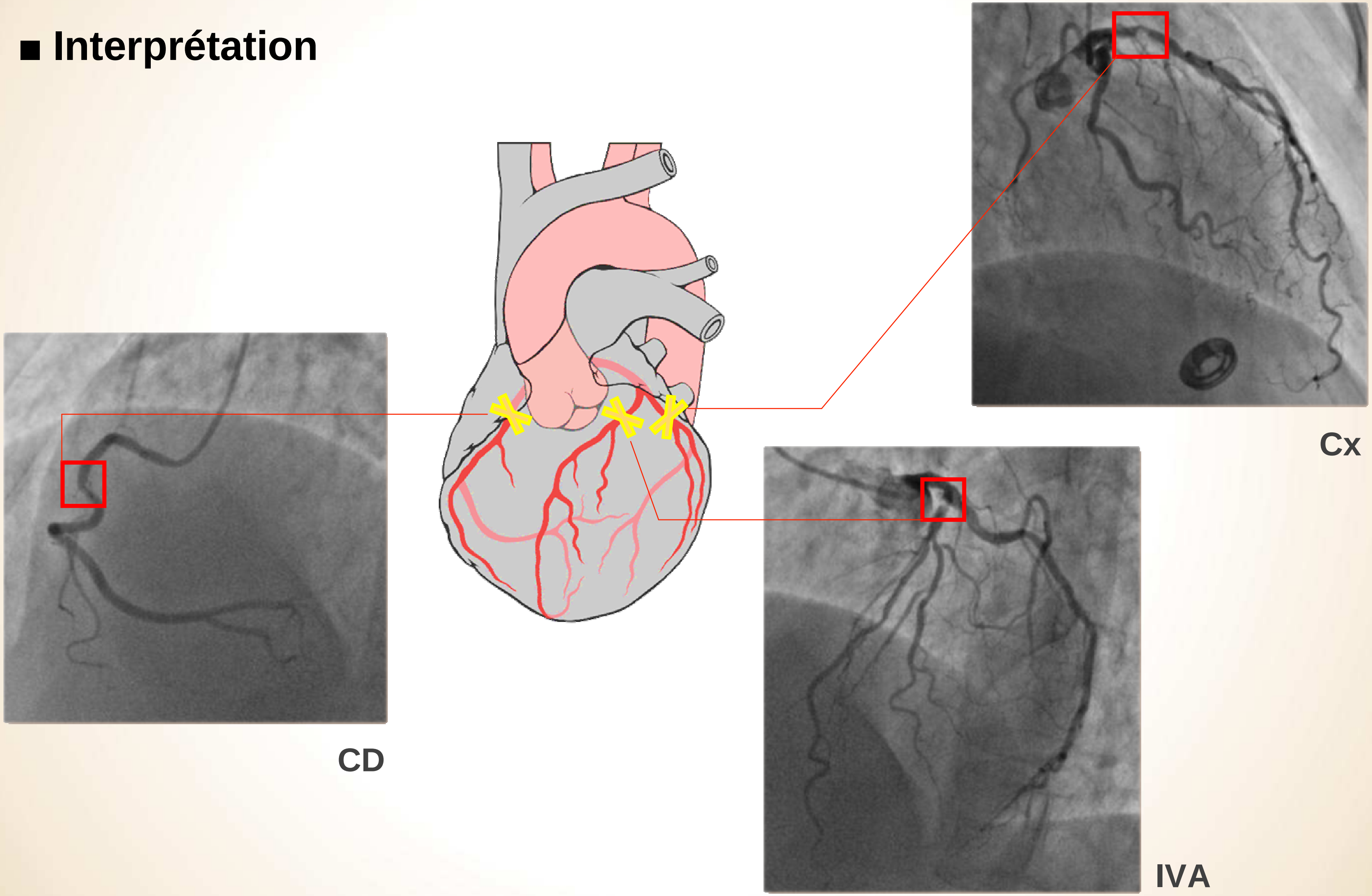
Scintigraphie myocardique

- **Interprétation**



Scintigraphie myocardique

- **Interprétation**



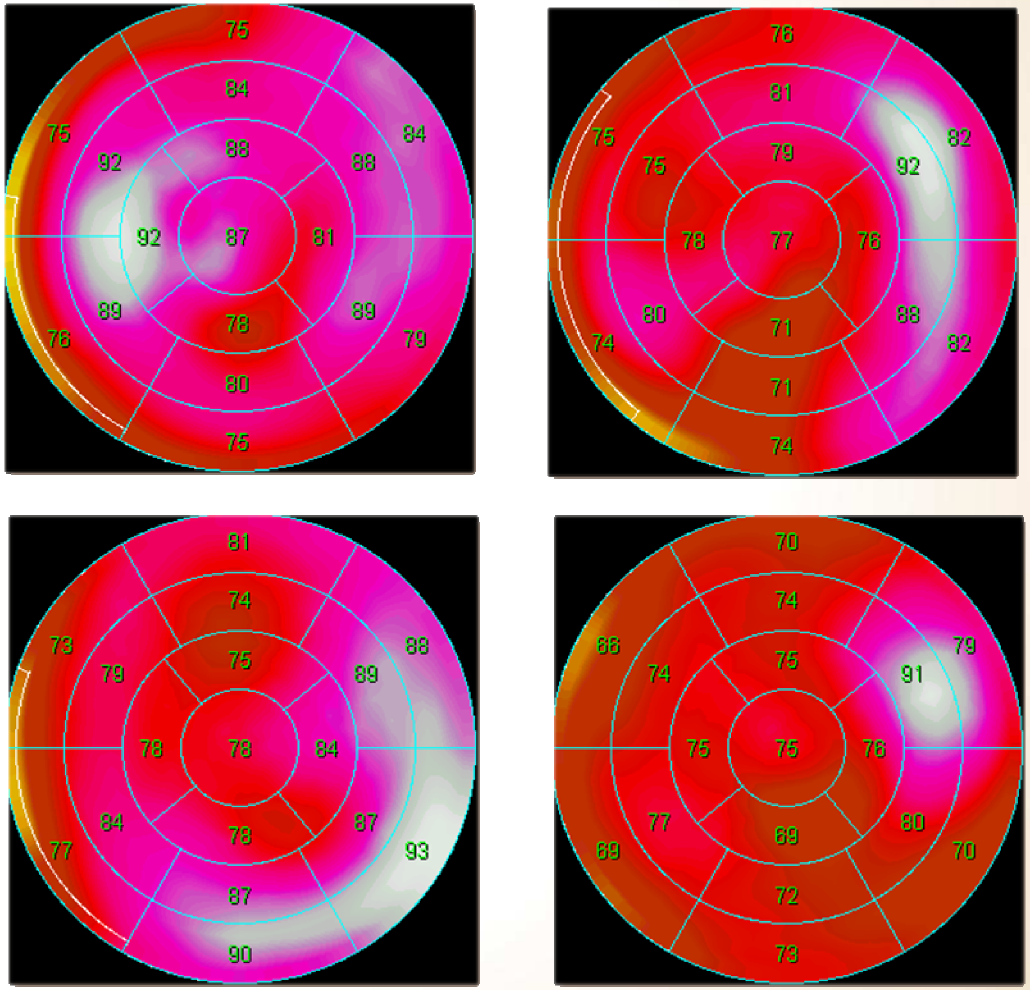
Scintigraphie myocardique

- Interprétation

Effort | Repos

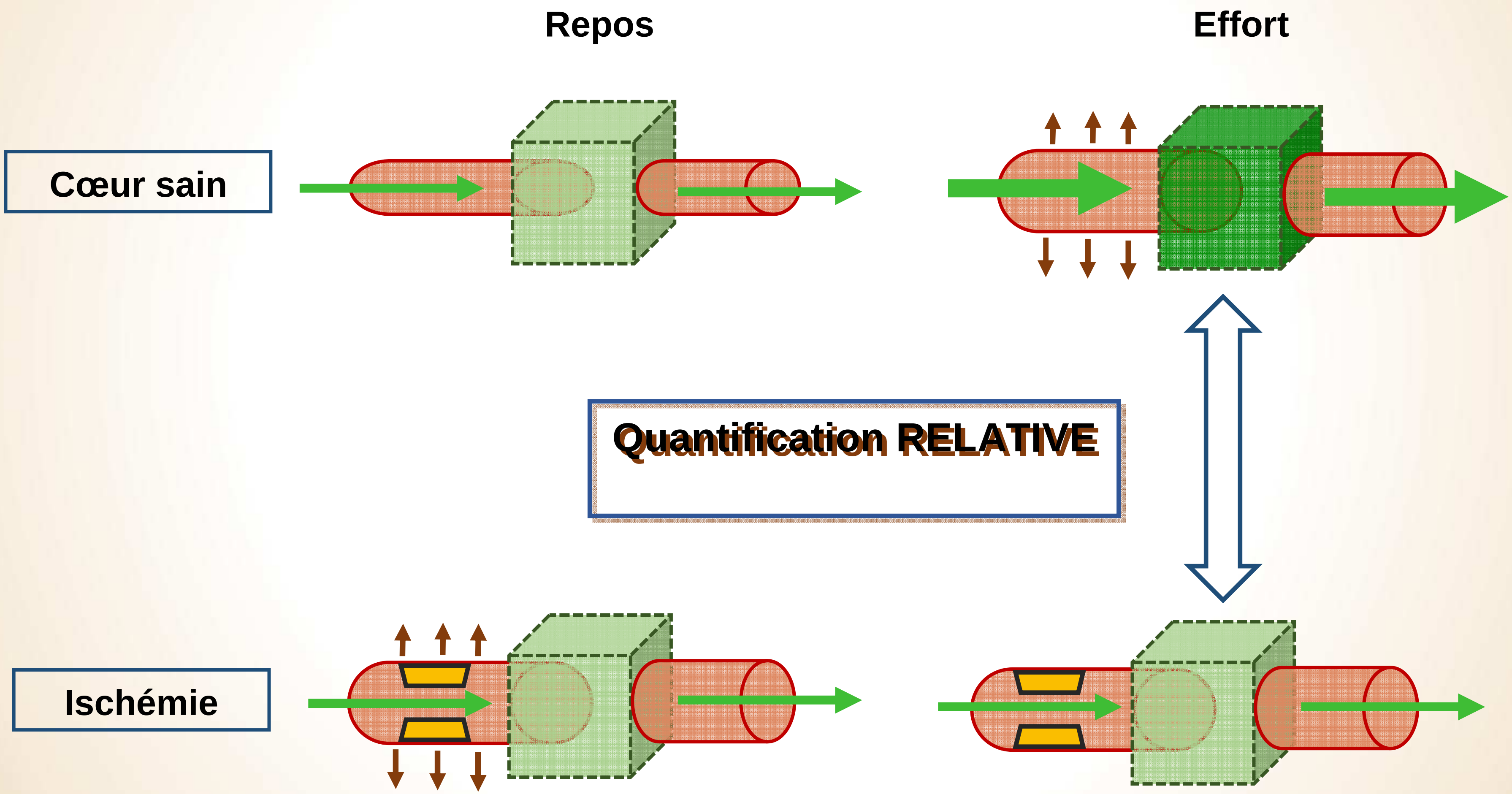
Scintigraphie normale

Pathologie tri-tronculaire « équilibrée »

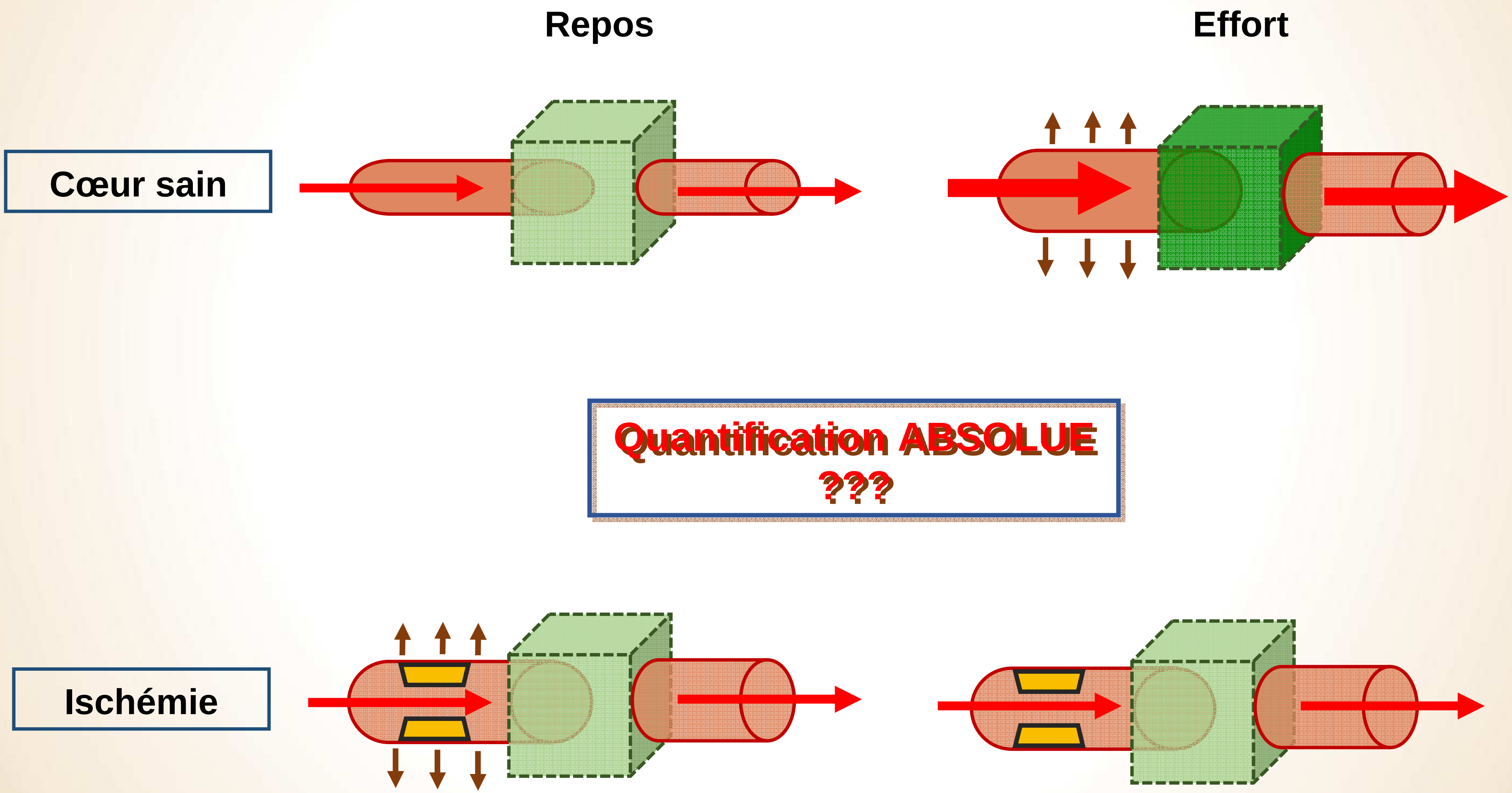


Scintigraphie myocardique

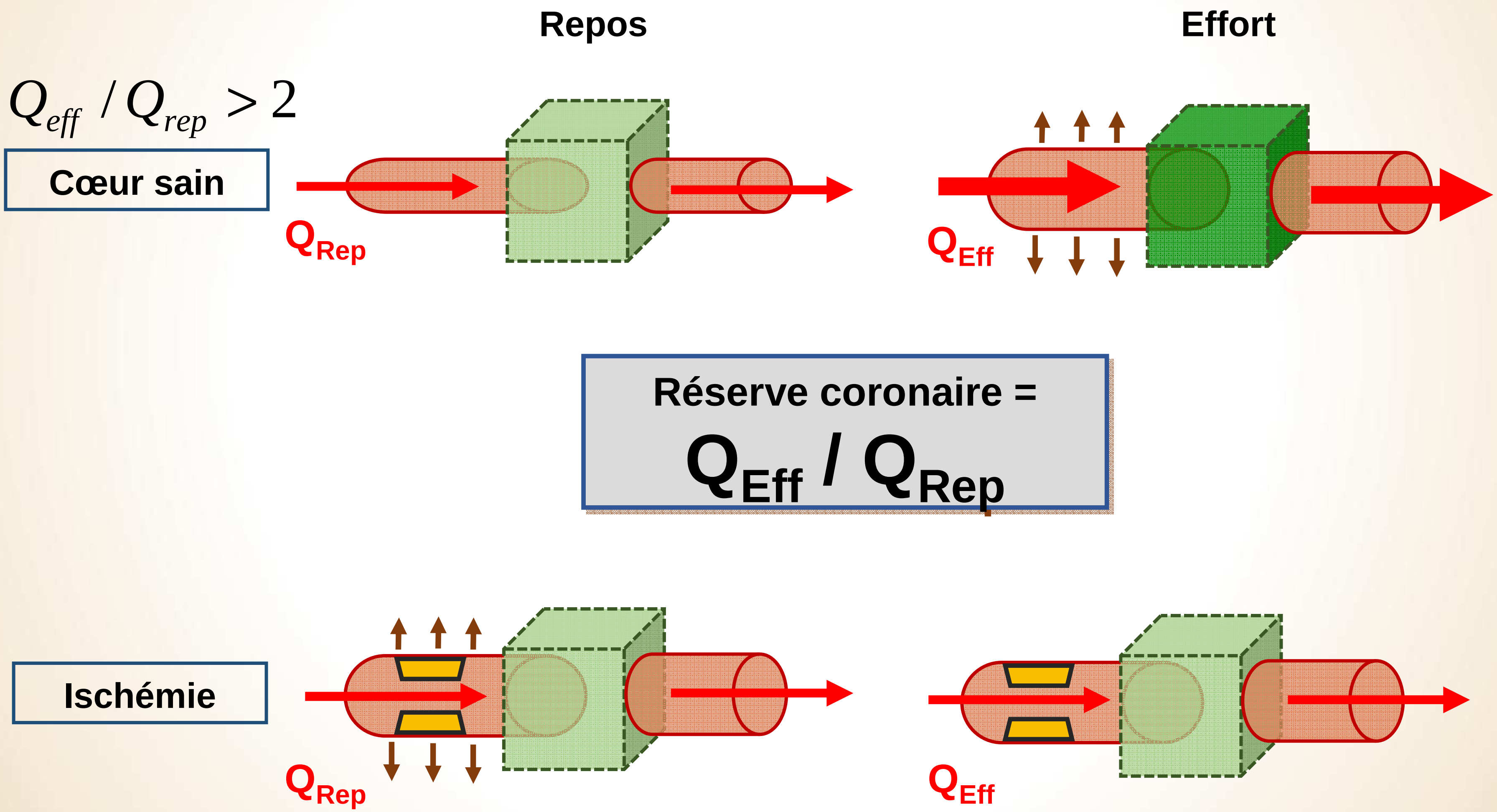
- Interprétation



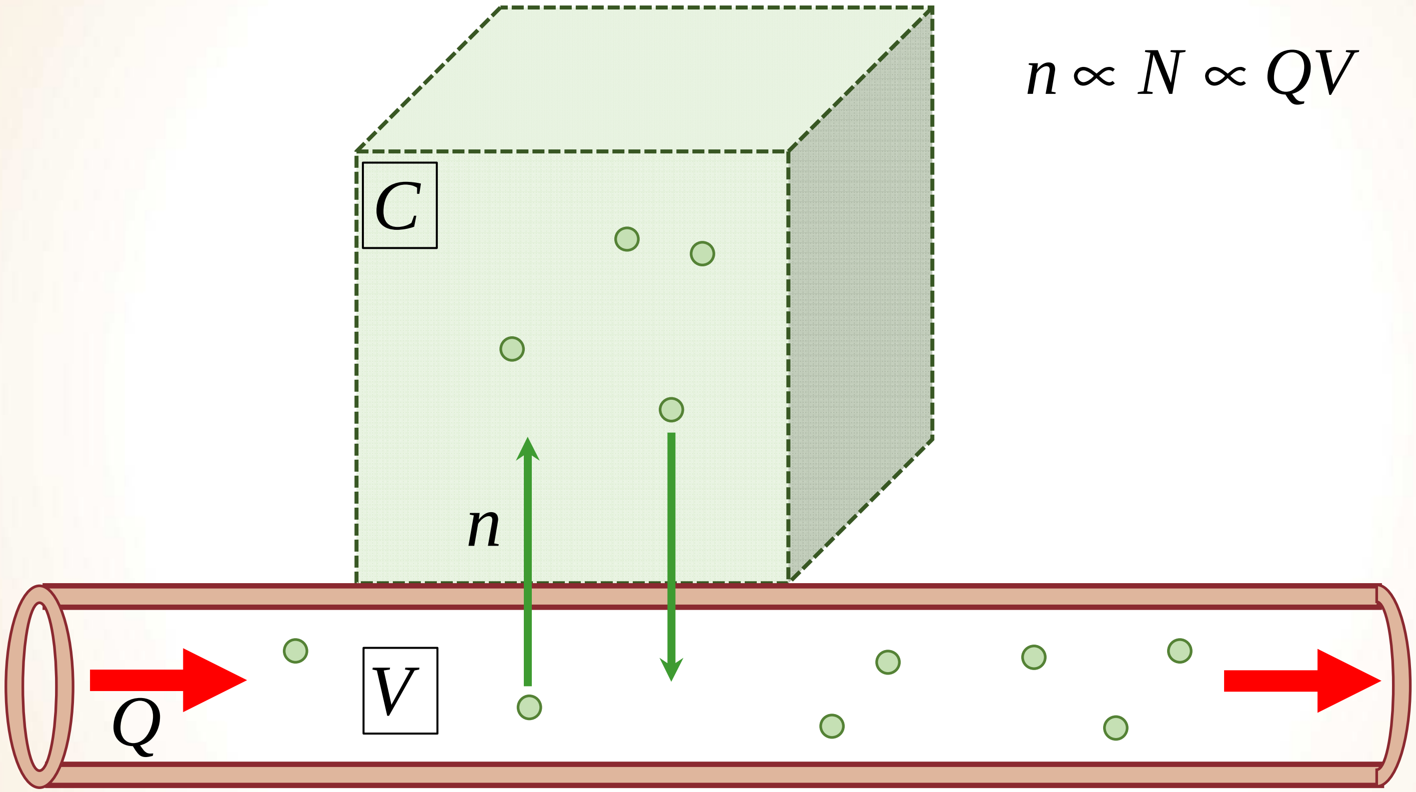
Scintigraphie myocardique



Réserve coronaire

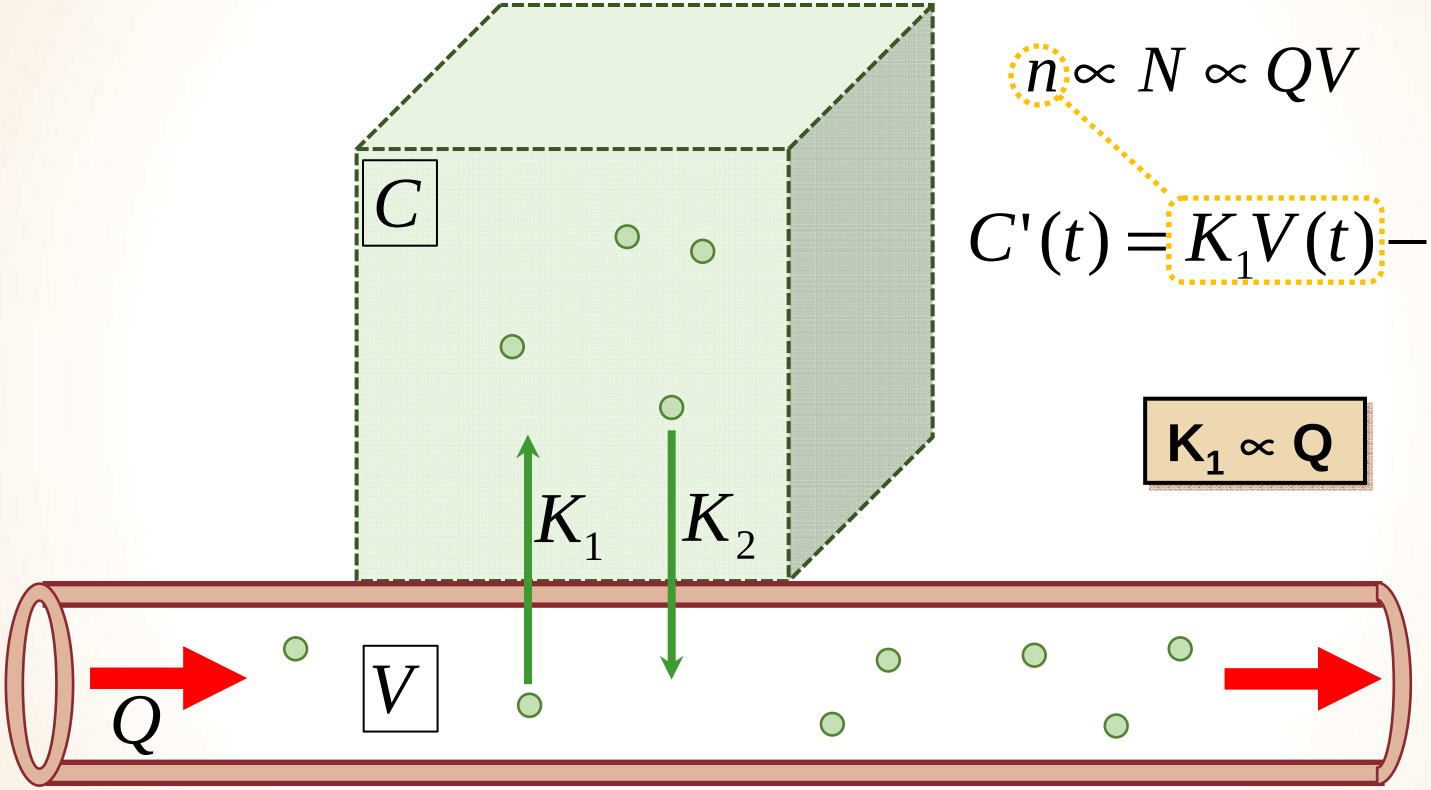


Réserve coronaire



$n \propto N \propto QV$

Réserve coronaire

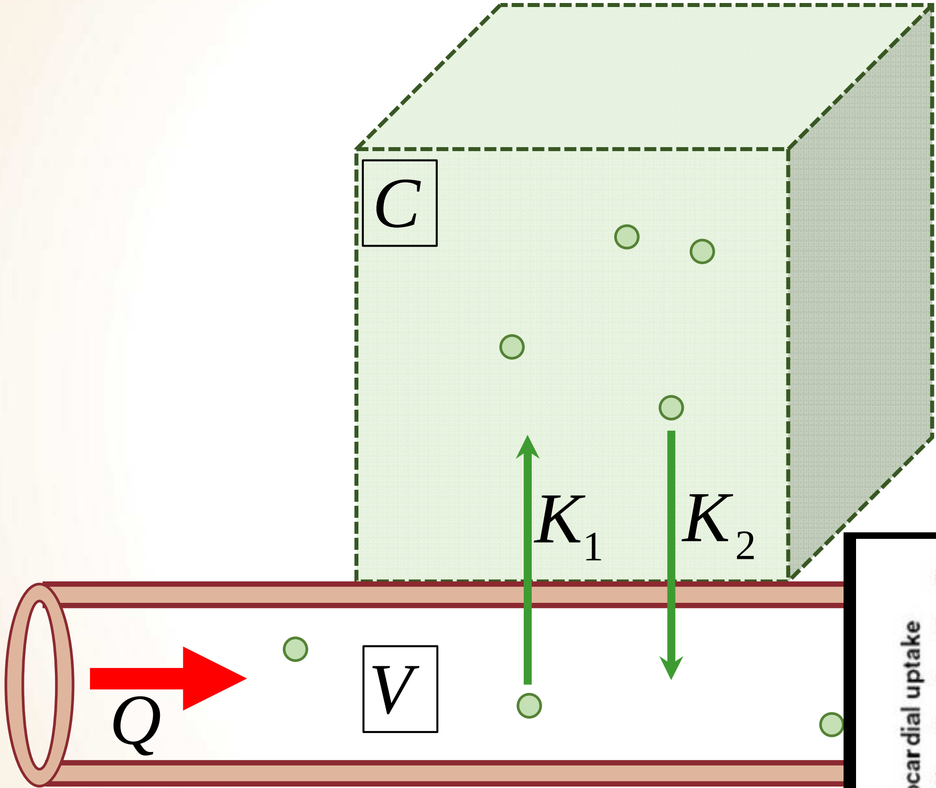


$$n \propto N \propto QV$$

$$C'(t) = \boxed{K_1 V(t)} - K_2 C(t)$$

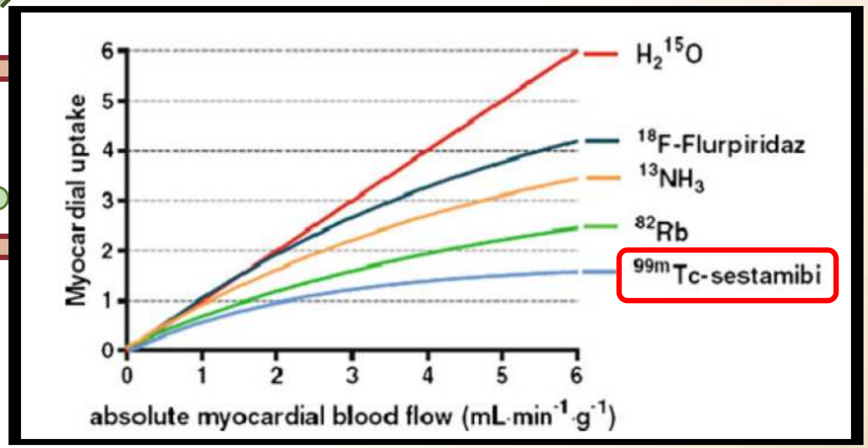
$$\boxed{\mathbf{K_1 \propto Q}}$$

Réserve coronaire

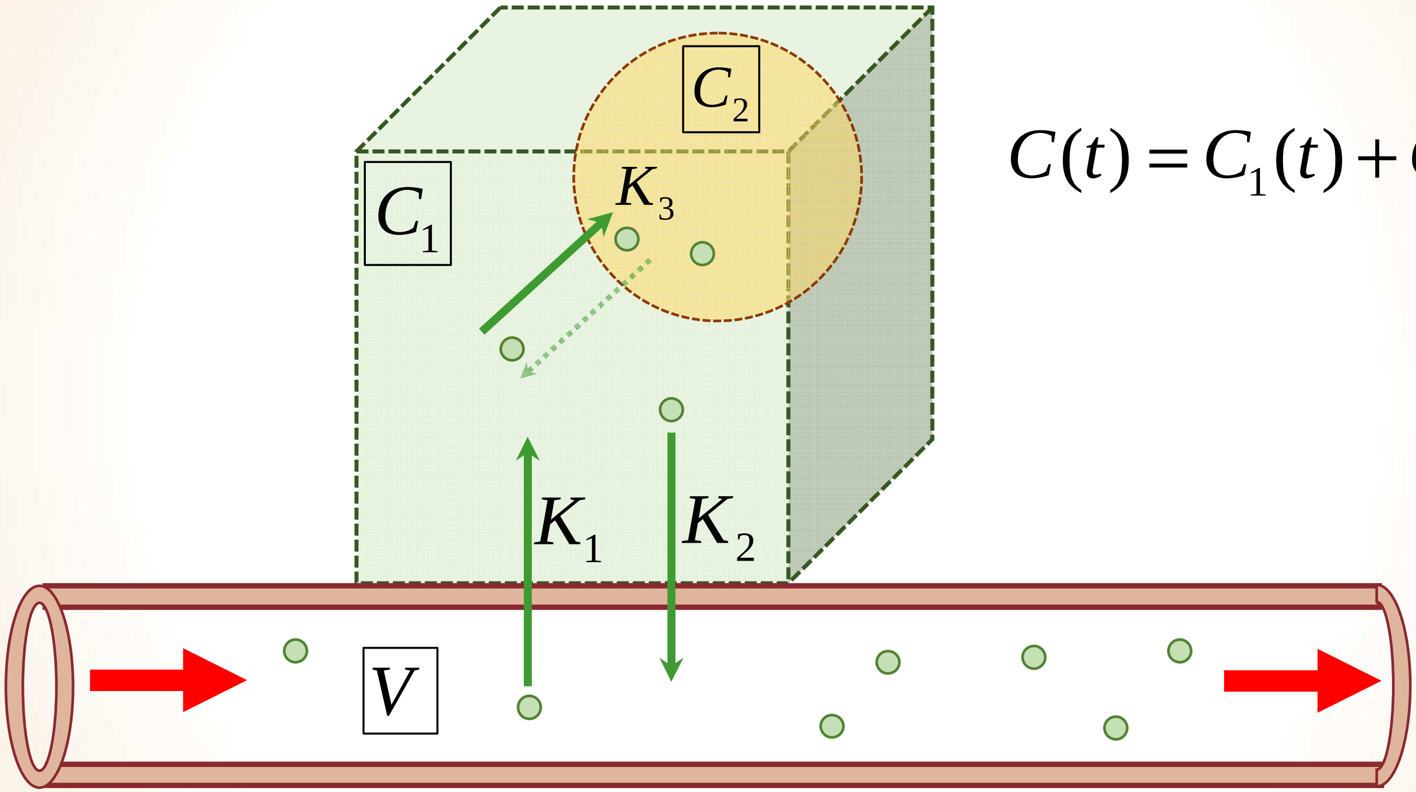


$$C'(t) = K_1 V(t) - K_2 C(t)$$

$\boxed{\mathbf{K_1 \propto Q}}$



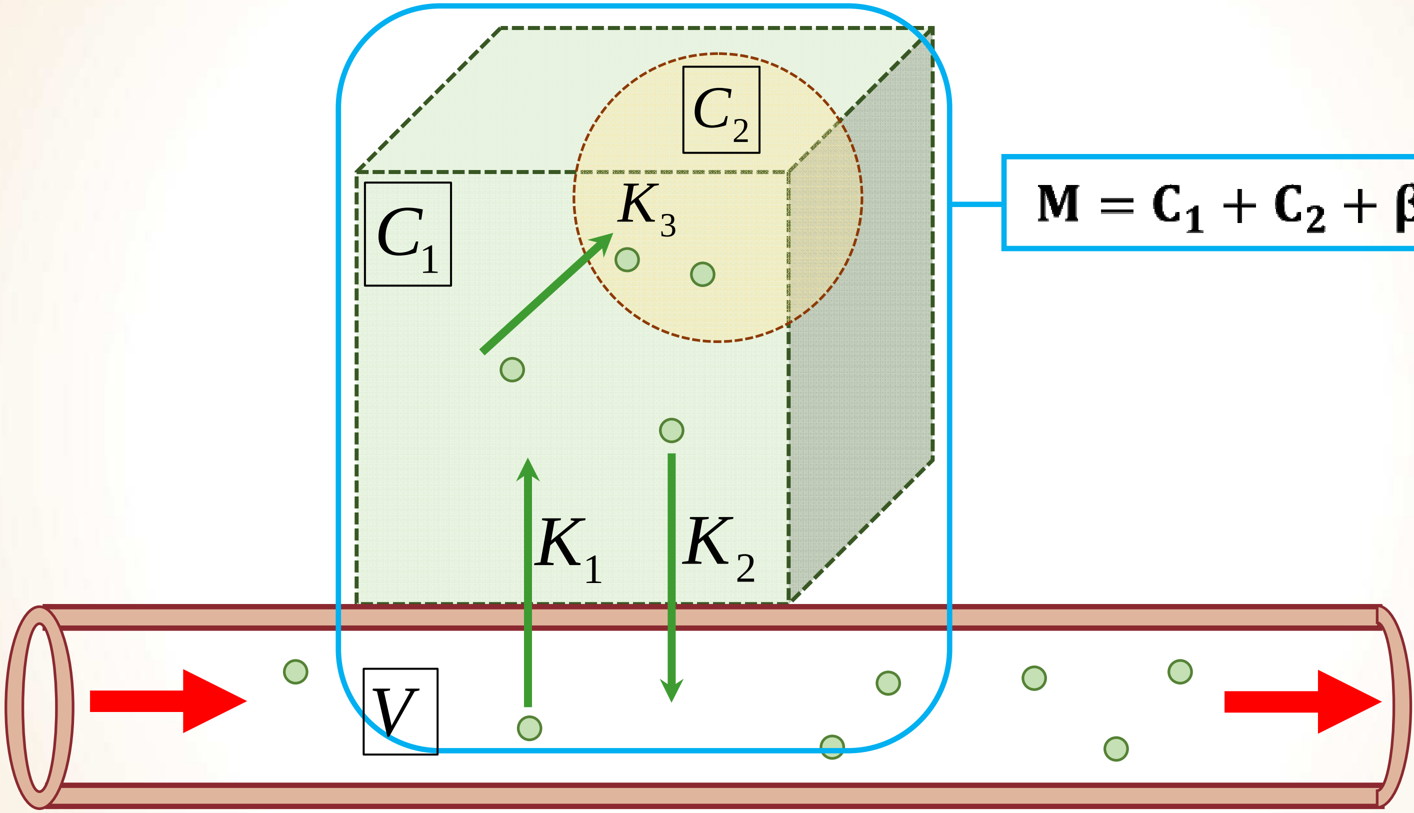
Réserve coronaire



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

$$C'' + \left(K_2 + K_3\right) C' = K_1\, V' + K_1 K_3\, V$$

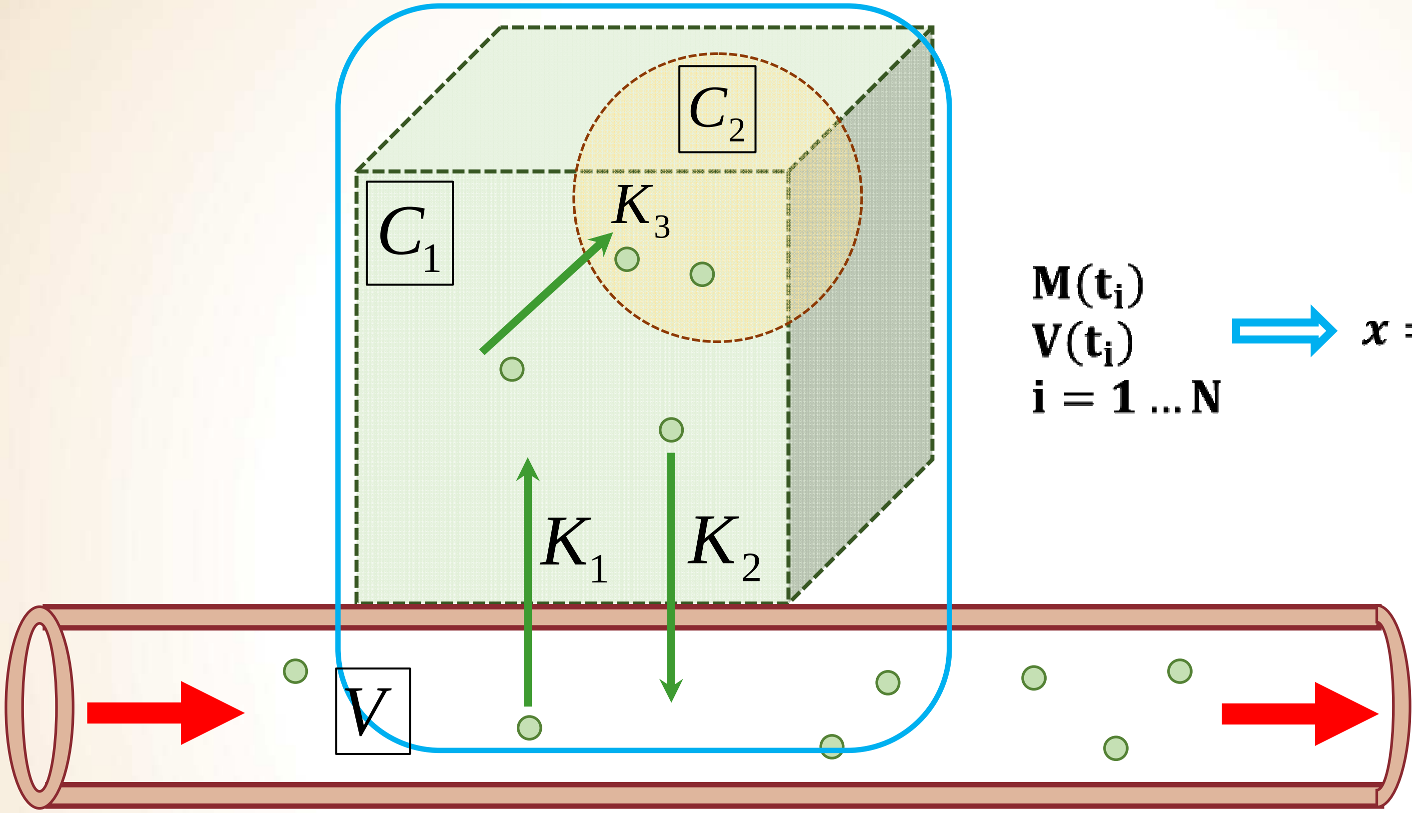
Réserve coronaire



$$M = C_1 + C_2 + \beta V$$

$$M'' + (K_2 + K_3)M' = \beta V'' + [K_1 + \beta(K_2 + K_3)]V' + K_1K_3 V$$

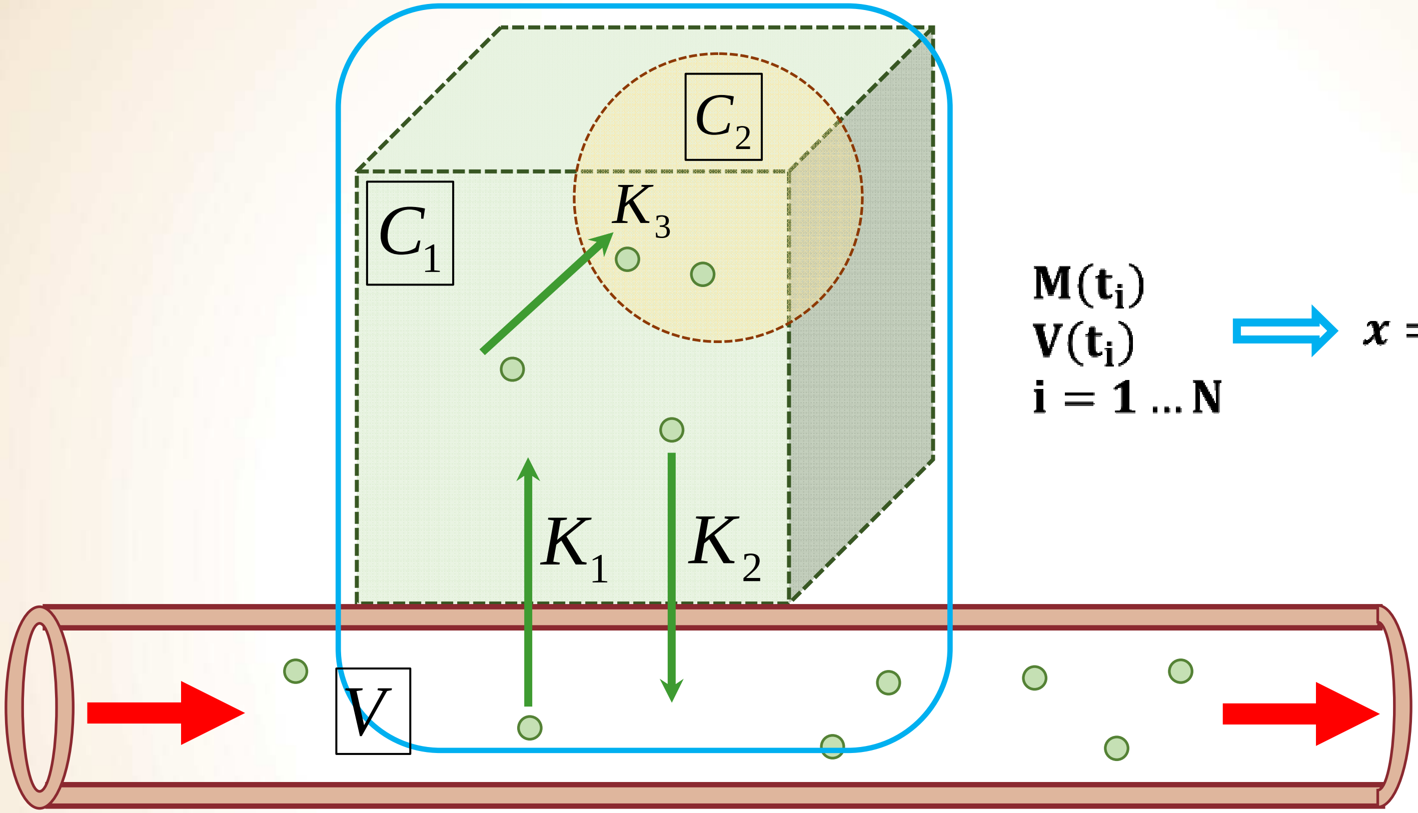
Réserve coronaire



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

$$M'' + (K_2 + K_3)M' = \beta V'' + [K_1 + \beta(K_2 + K_3)]V' + K_1K_3 V$$

Réserve coronaire



$$\begin{array}{l} M(t_i) \\ V(t_i) \\ i = 1 \dots N \end{array} \Rightarrow x = \begin{pmatrix} \boxed{K_1} \\ K_2 \\ K_3 \\ \beta \end{pmatrix} \Rightarrow \boxed{Q}$$

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

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

NLLS

Réserve coronaire

LLS

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

Réserve coronaire

LLS

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

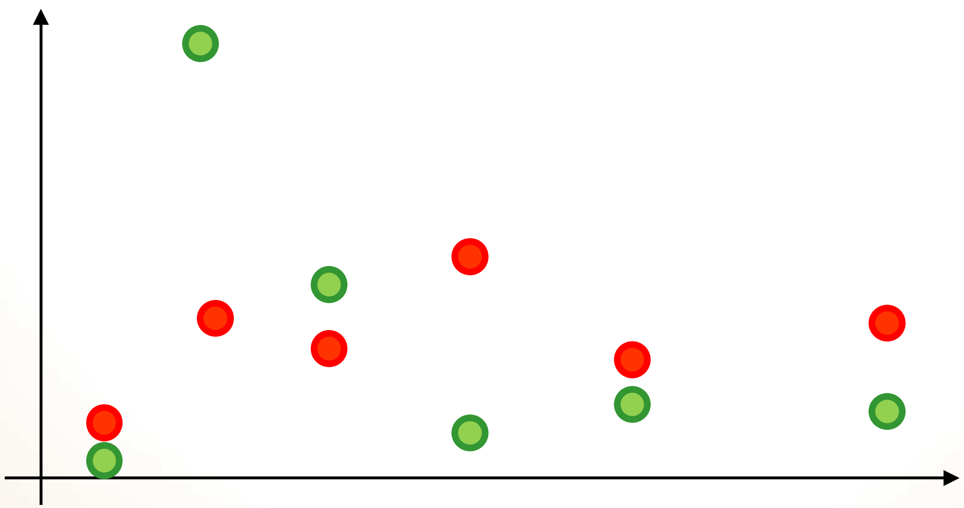
$$\mathbf{M''(t_i)} = \boldsymbol{a_1}\mathbf{M'(t_i)} + \boldsymbol{a_2}\mathbf{V''(t_i)} + \boldsymbol{a_3}\mathbf{V'(t_i)} + \boldsymbol{a_4}\mathbf{V(t_i)} \qquad \mathbf{i = 0 \ldots N}$$

Réserve coronaire

LLS

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

$$\mathbf{M''(t_i)} = a_1 \mathbf{M'(t_i)} + a_2 \mathbf{V''(t_i)} + a_3 \mathbf{V'(t_i)} + a_4 \mathbf{V(t_i)} \qquad \mathbf{i = 0 \ldots N}$$



Réserve coronaire

LLS

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

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

Réserve coronaire

$\boxed{\text{LLS}}$

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

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

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

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

Réserve coronaire

LLS

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

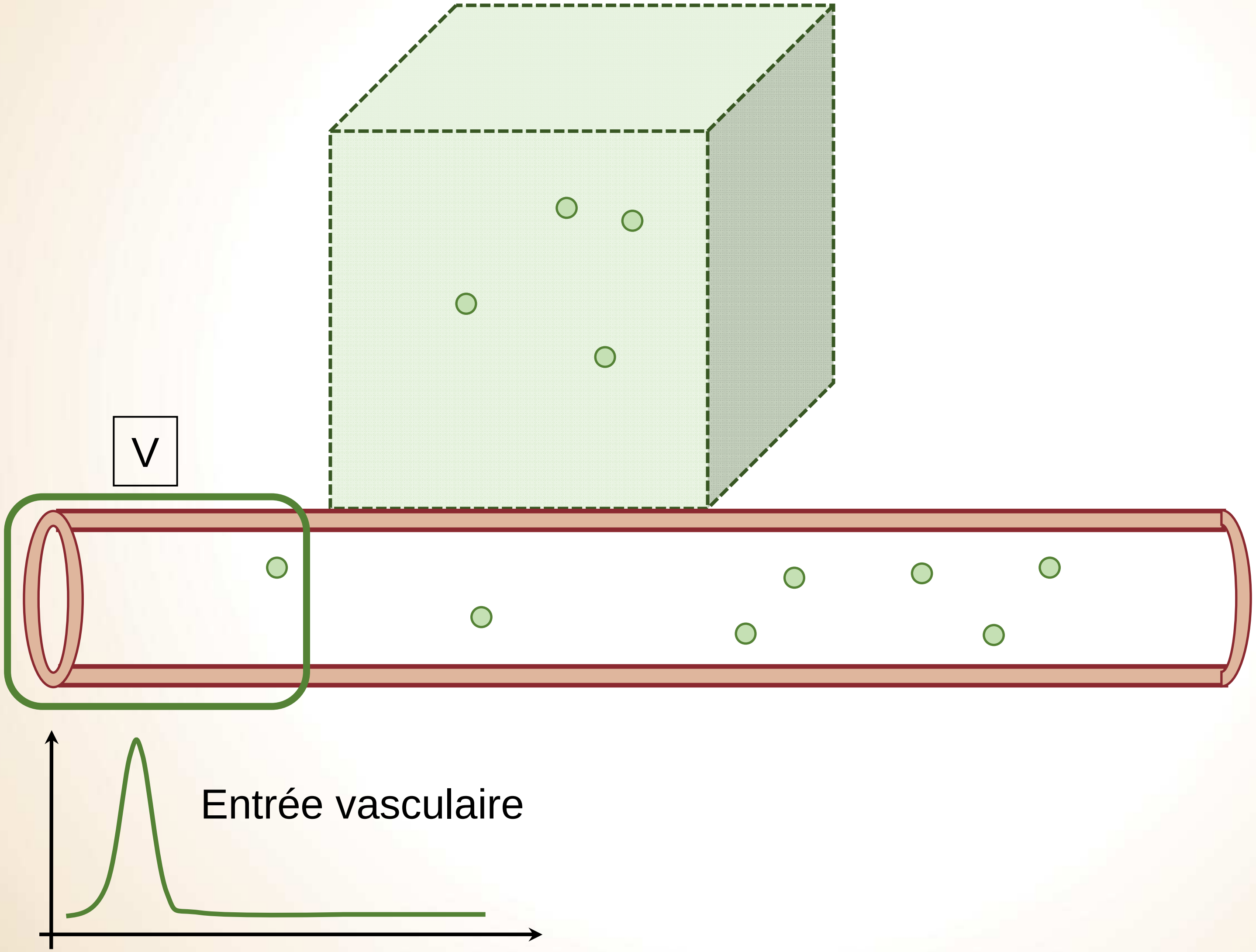
$$\mathbf{M(t_i)} = \boldsymbol{a_1} \int_0^{t_i} \mathbf{M} + \boldsymbol{a_2}\mathbf{V(t_i)} + \boldsymbol{a_3} \int_0^{t_i} \mathbf{V} + \boldsymbol{a_4} \int_0^{t_i} \int \mathbf{V}$$

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

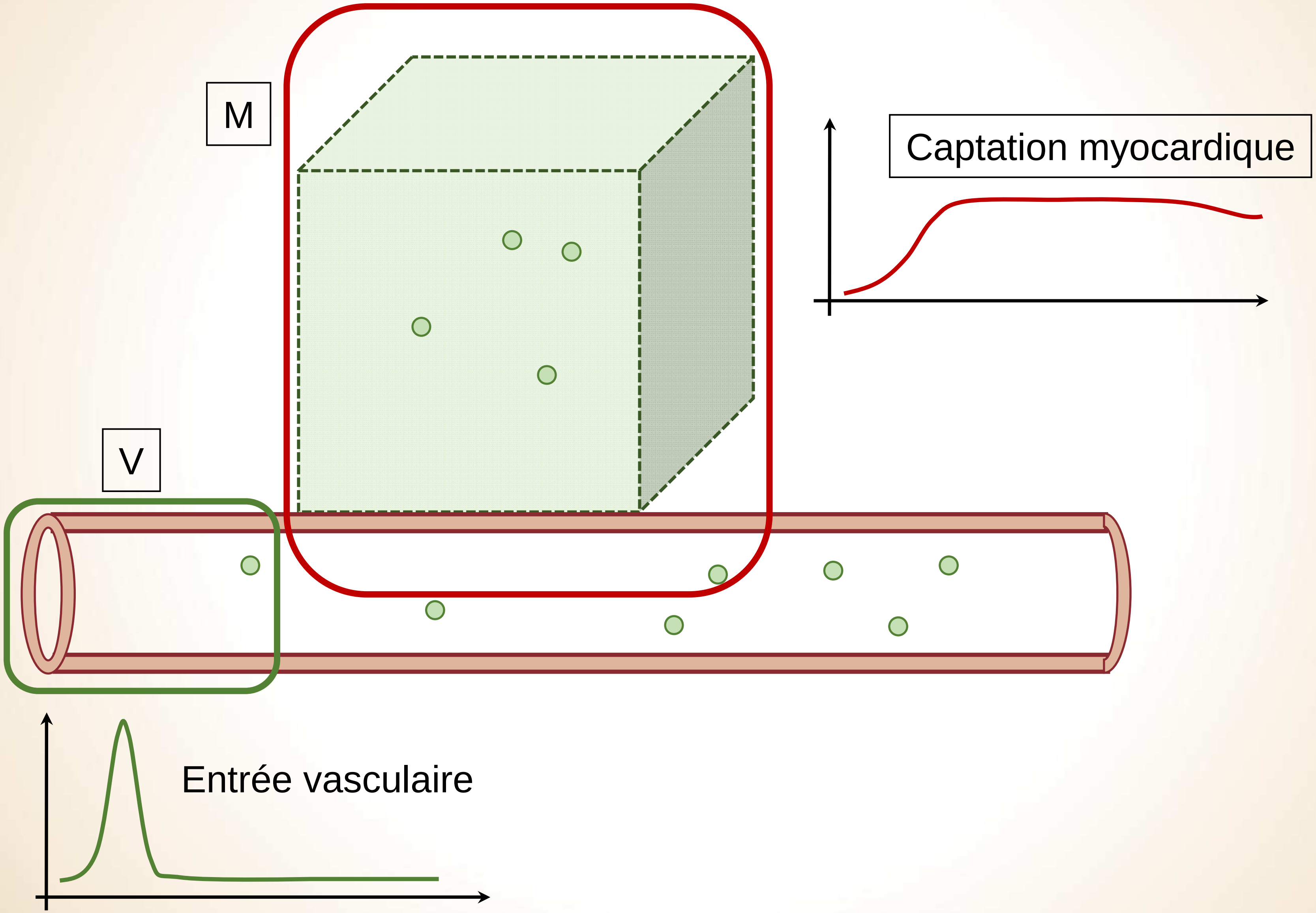
$$\boxed{\boldsymbol{a} = \left(\mathbf{H}^{\mathbf{T}}\mathbf{H}\right)^{-1}\mathbf{H}^{\mathbf{T}}\boldsymbol{b}}$$

$$\boxed{K_1 = a_3 + a_1 a_2}$$

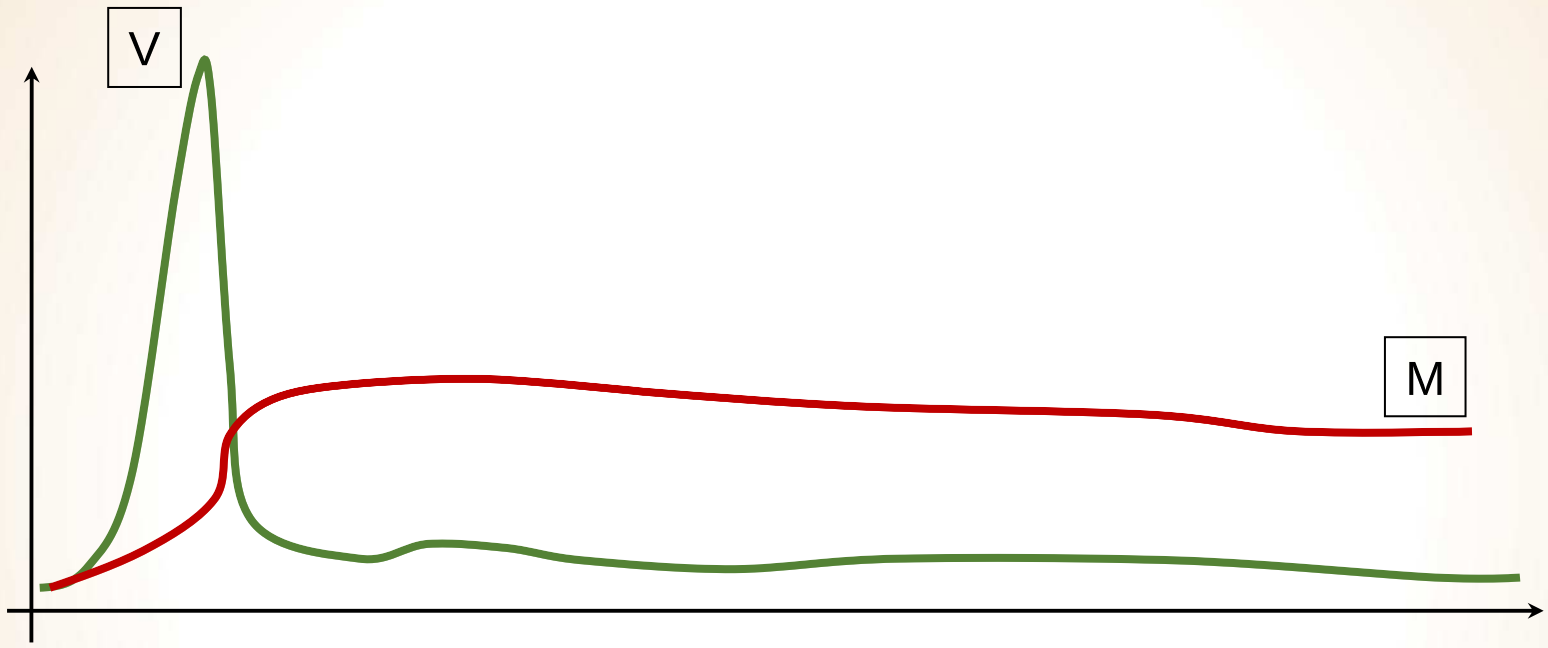
Réserve coronaire



Réserve coronaire

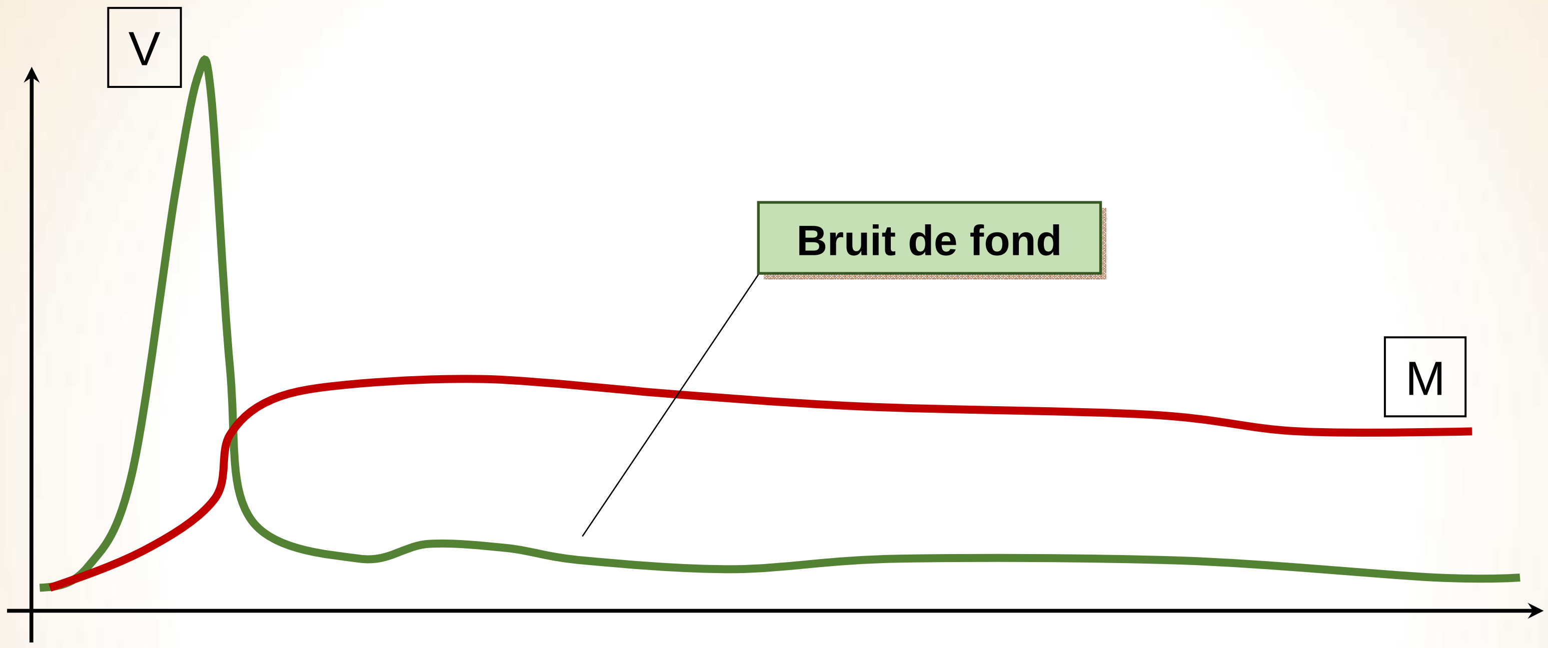


Réserve coronaire

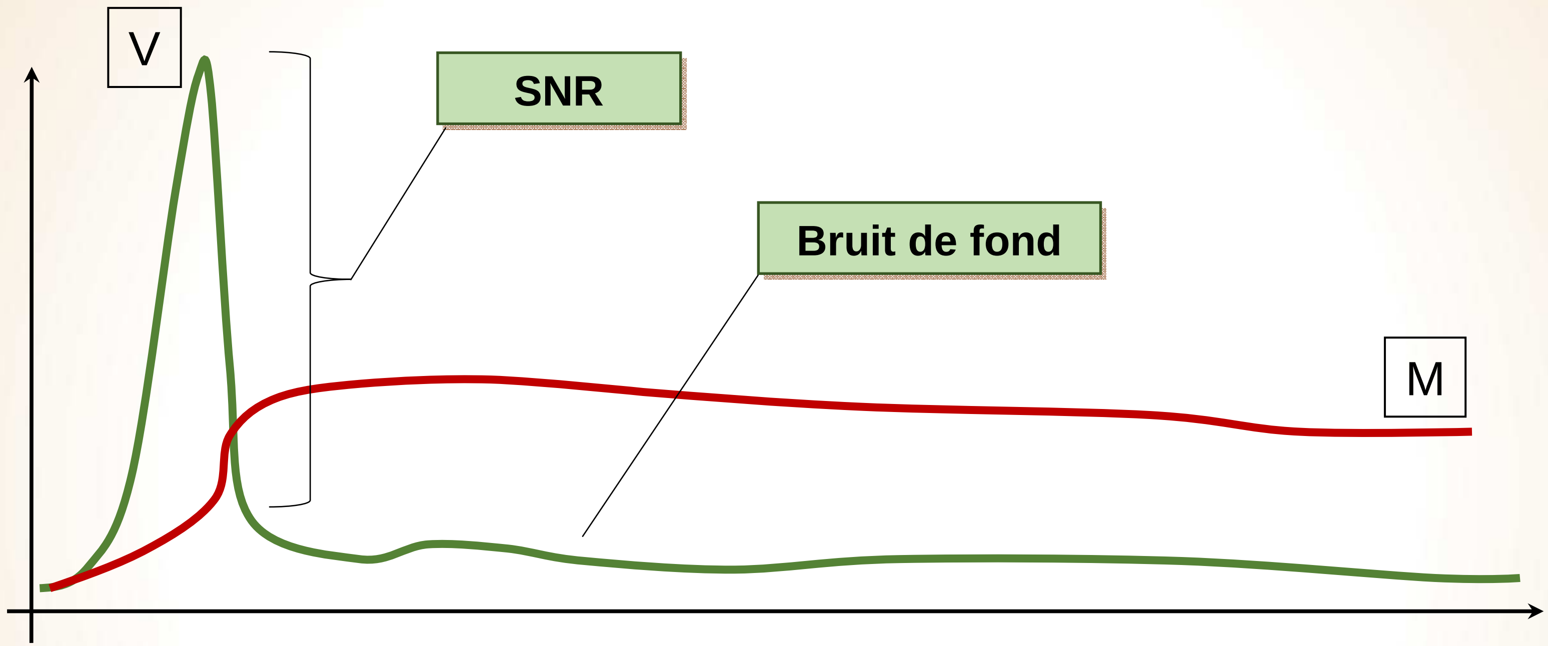


$$M'' + (K_2 + K_3)M' = \beta V'' + [K_1 + \beta(K_2 + K_3)]V' + K_1K_3 V$$

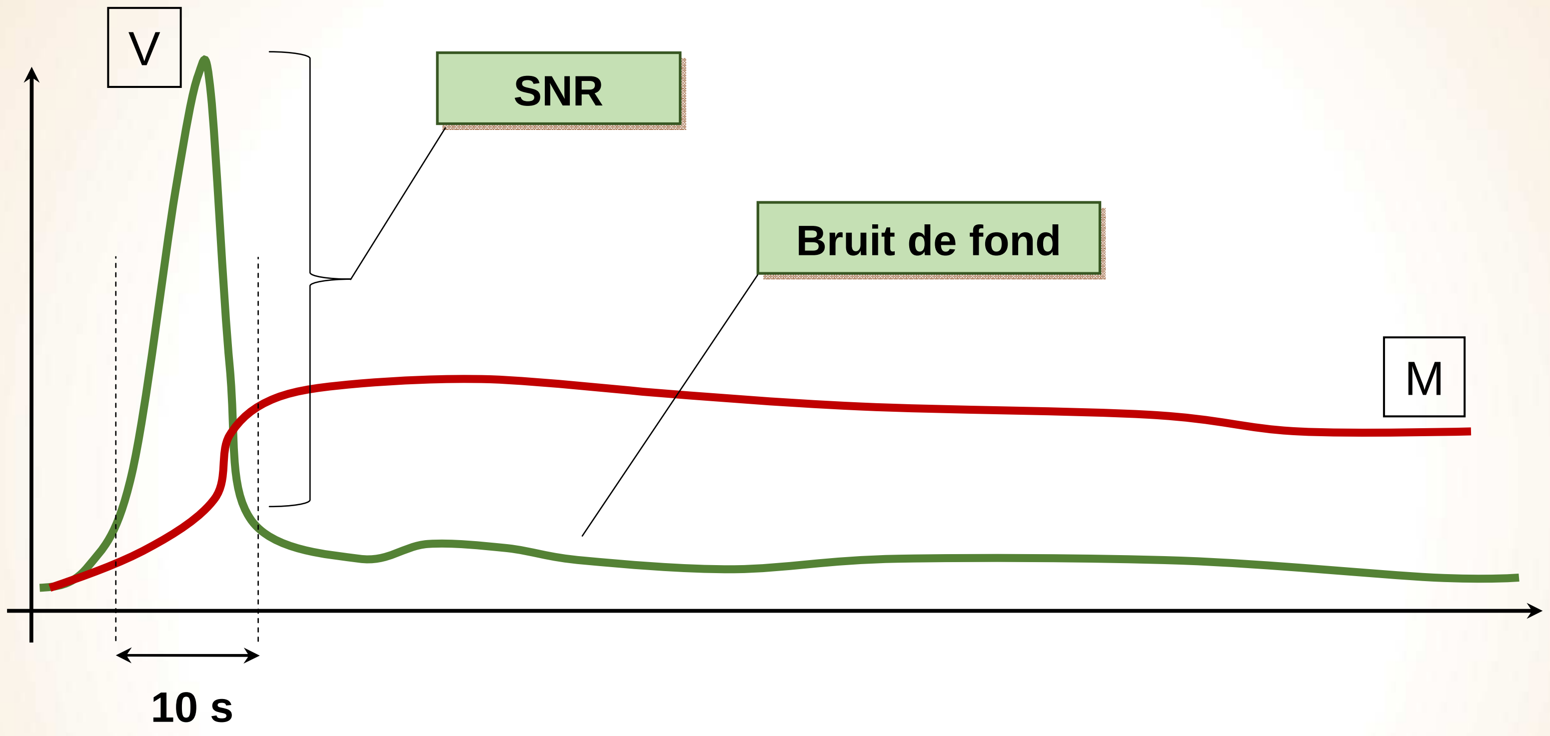
Réserve coronaire



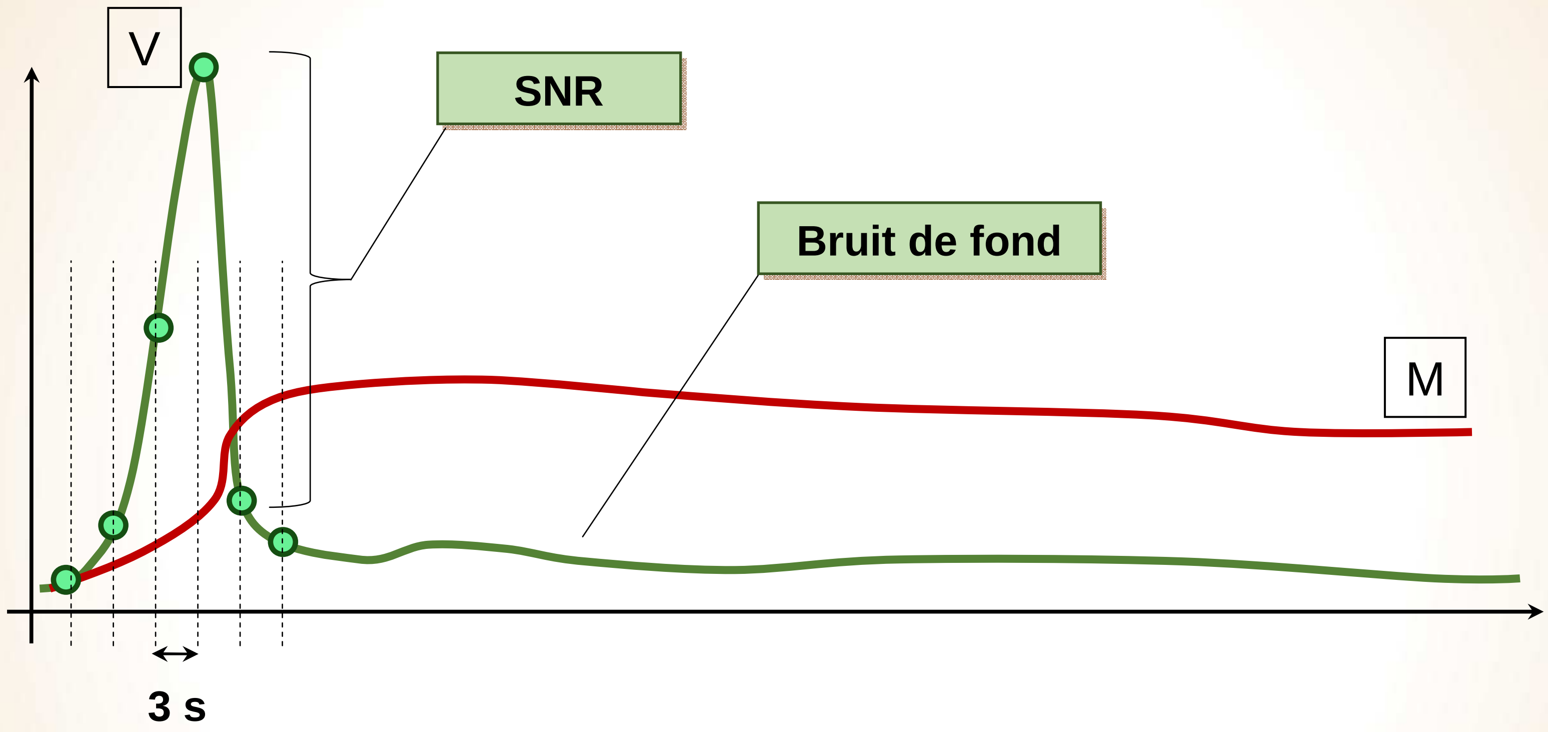
Réserve coronaire



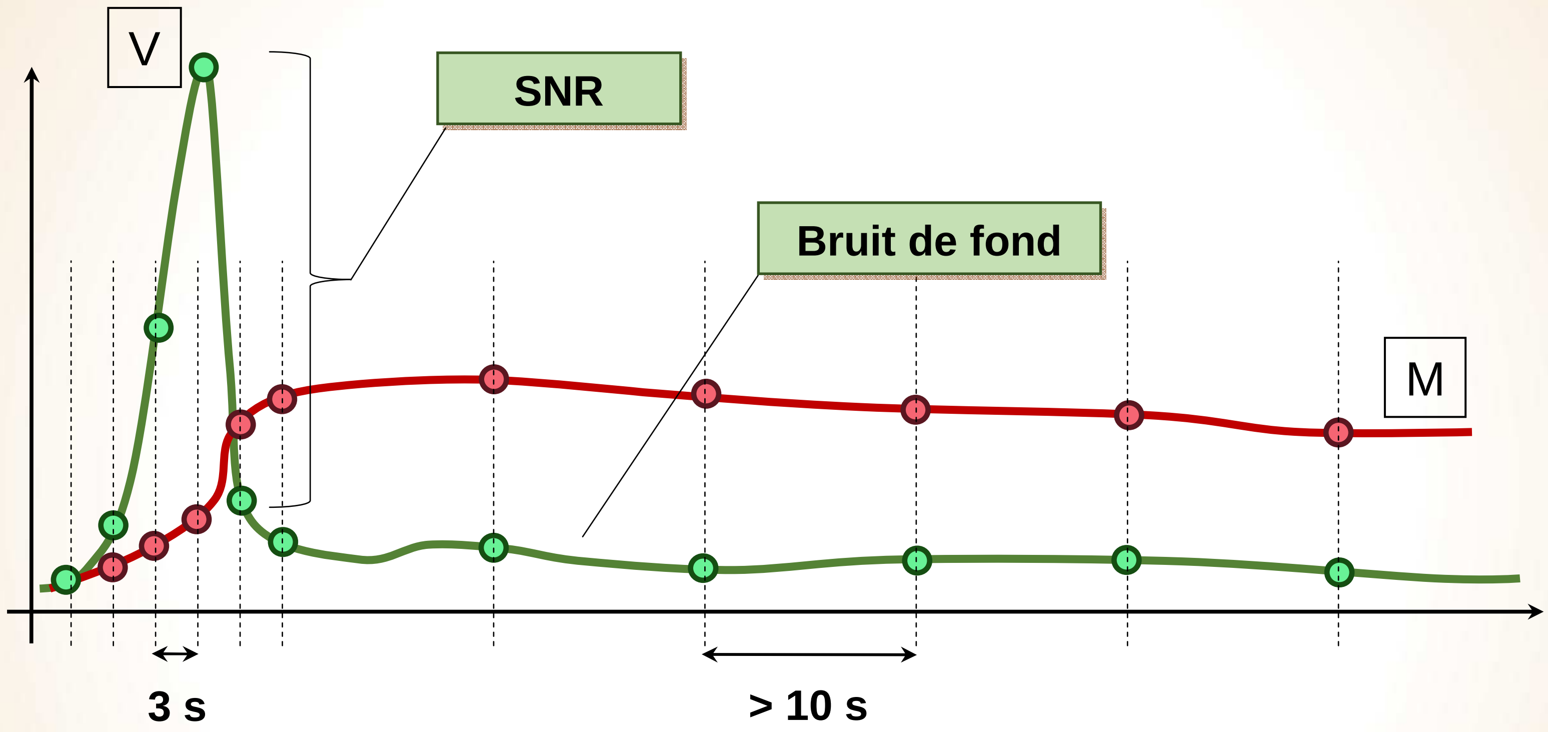
Réserve coronaire



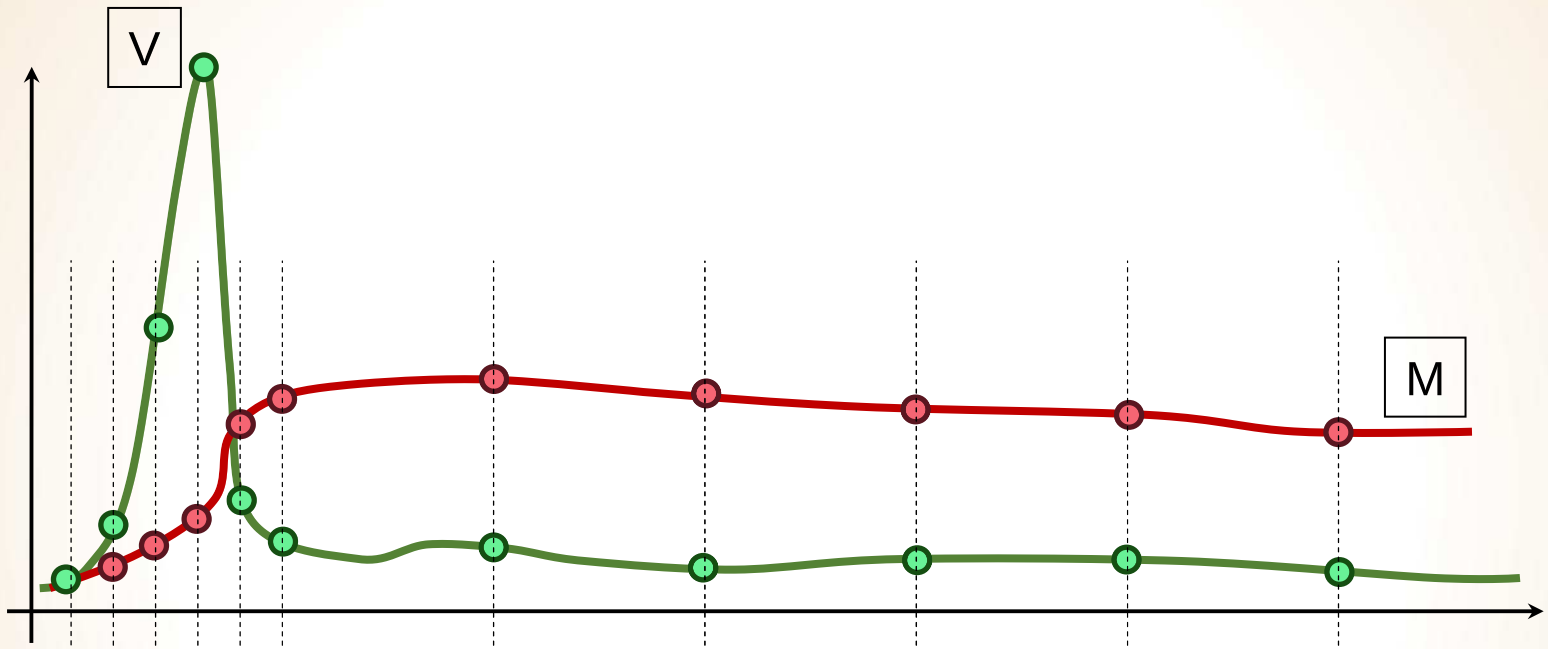
Réserve coronaire



Réserve coronaire



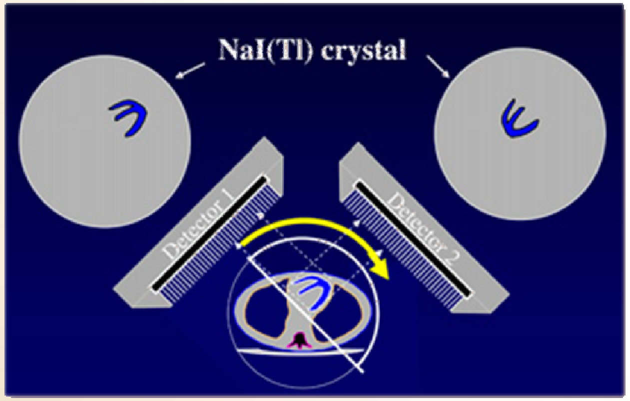
Réserve coronaire

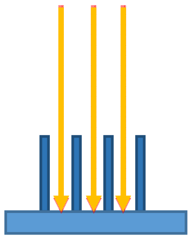


Tomographie dynamique

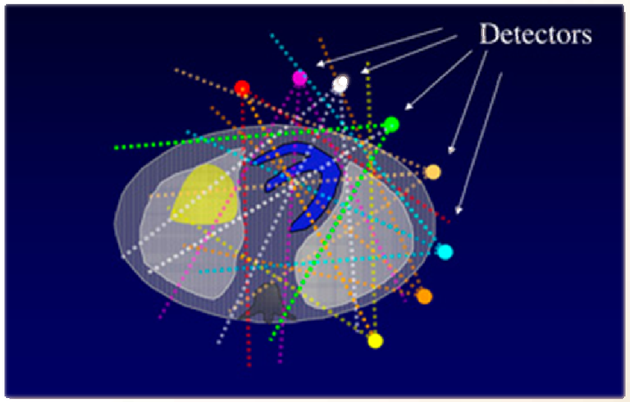
Caméra CZT

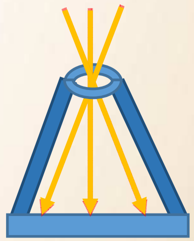
Anger



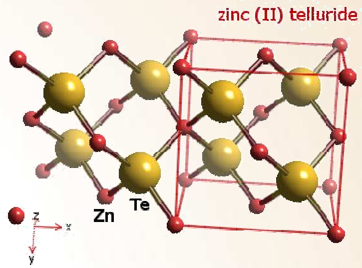


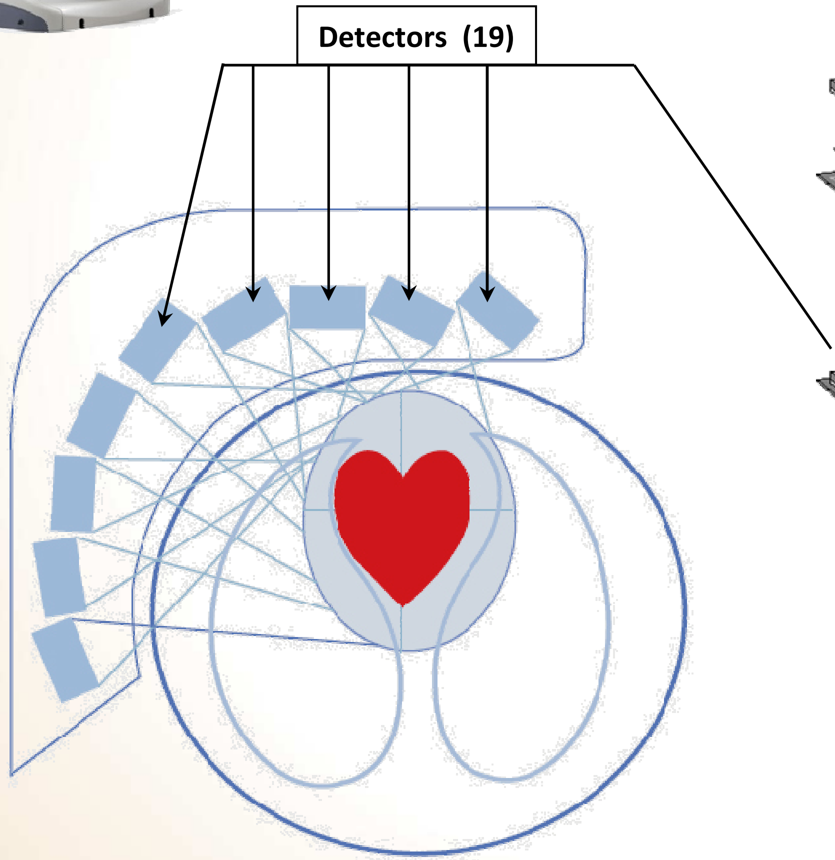
CZT

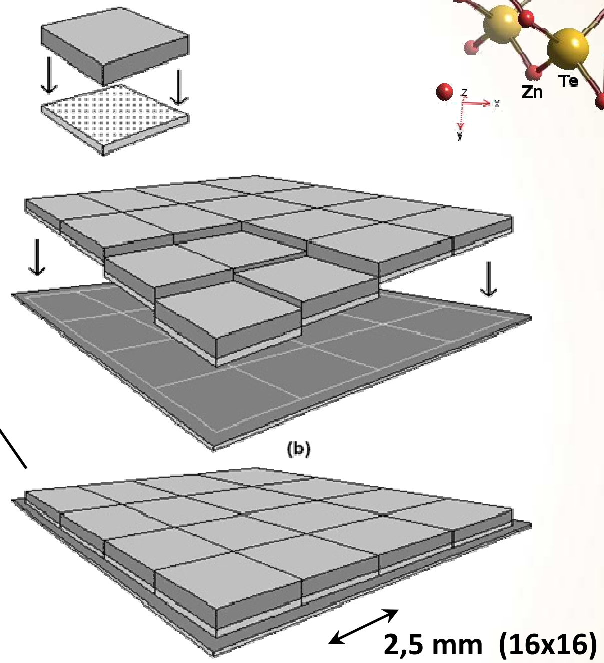


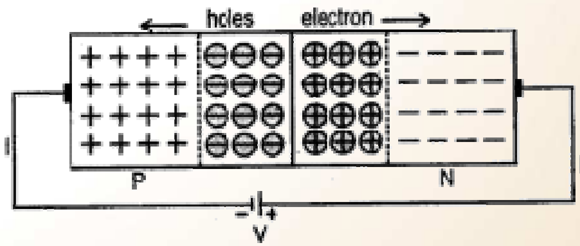


Caméra CZT

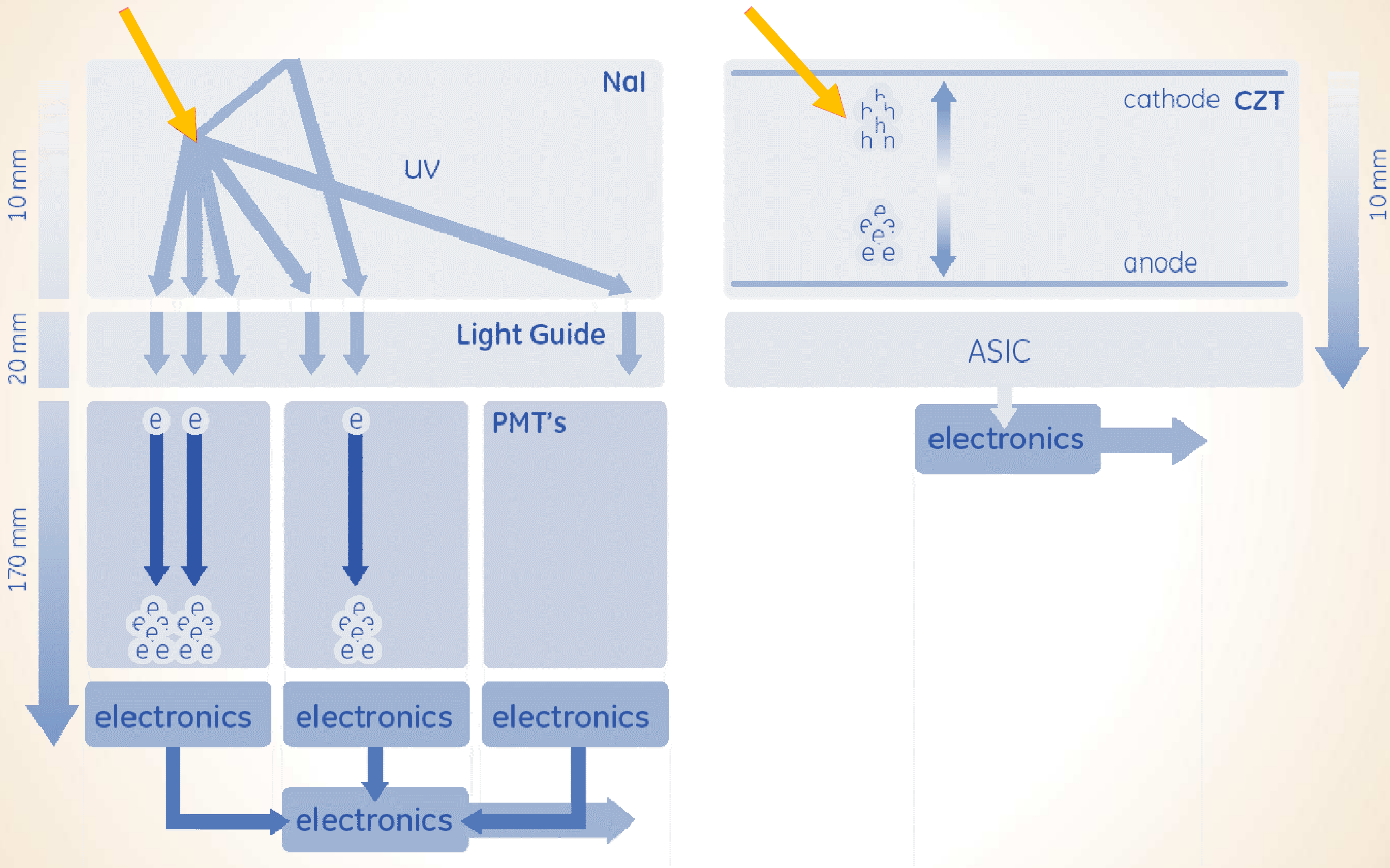

zinc (II) telluride
Zn
Te


Detectors (19)


(b)
2,5 mm (16x16)

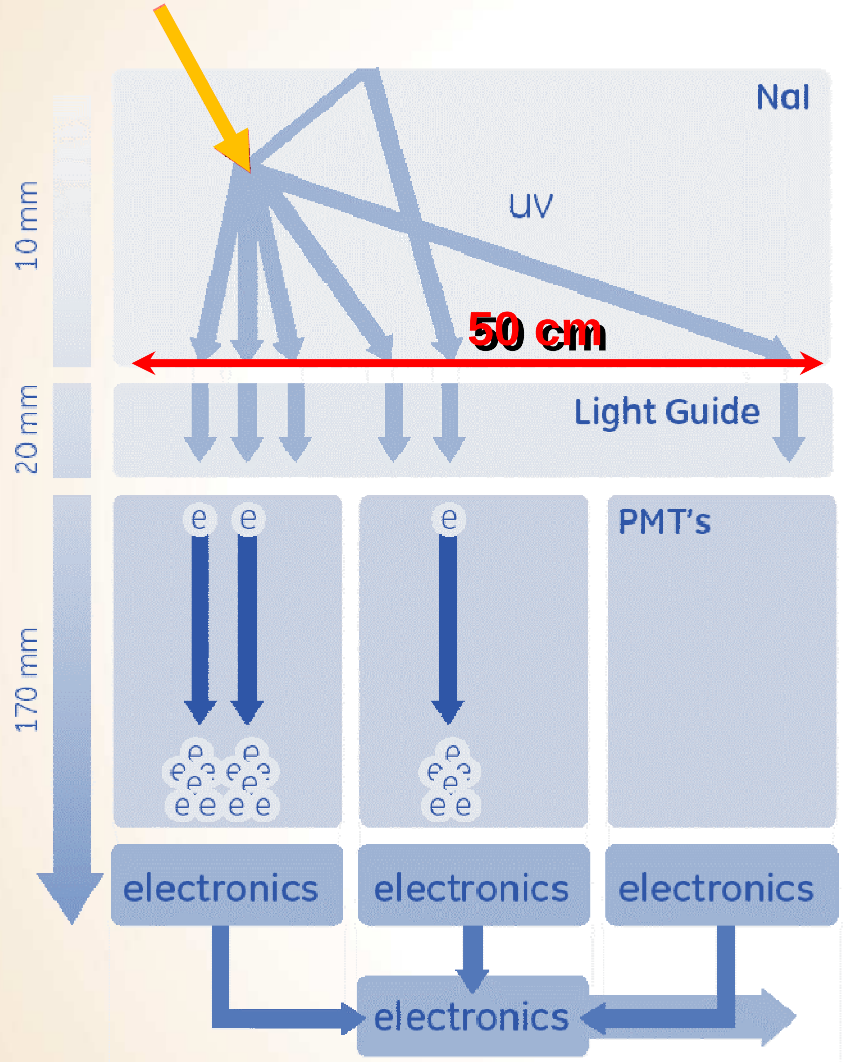

holes
electron
P
N
I
I
V

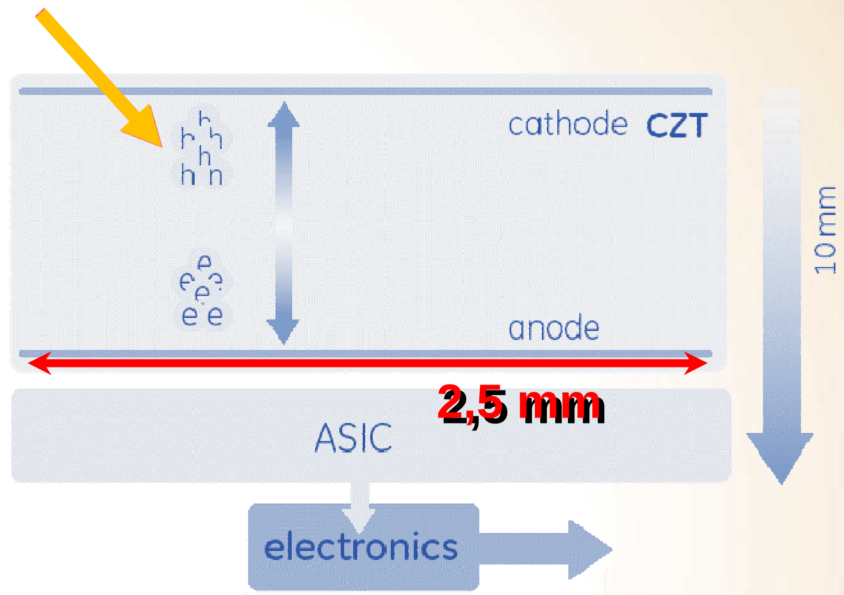
Caméra CZT

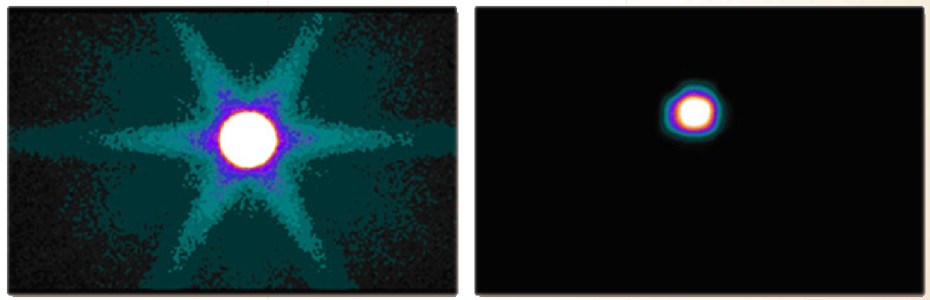


NaI
UV
Light Guide
PMT's
e e
e
electronics
electronics
electronics
electronics
10 mm
20 mm
170 mm
cathode CZT
anode
ASIC
electronics
10 mm

Caméra CZT

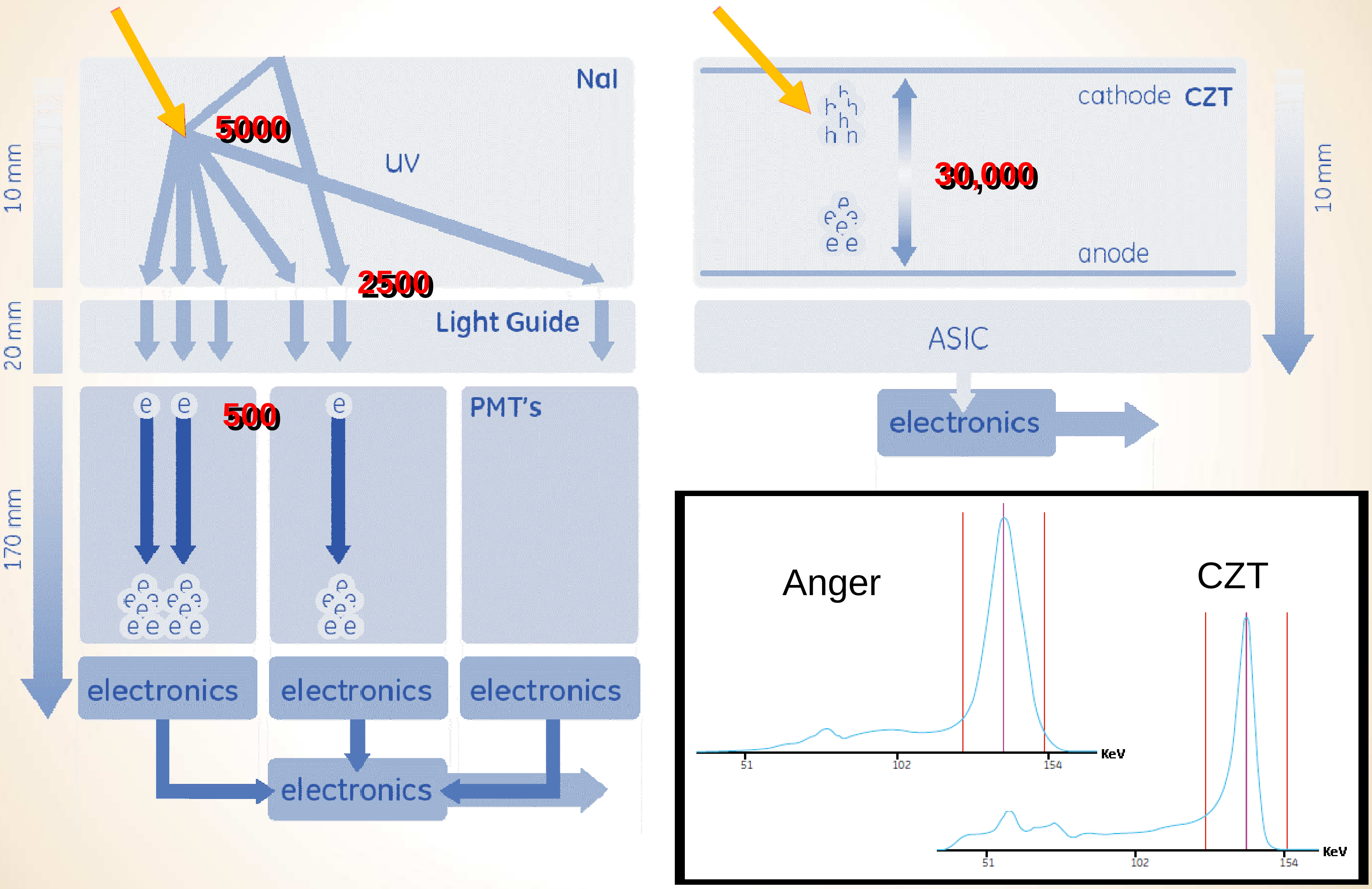




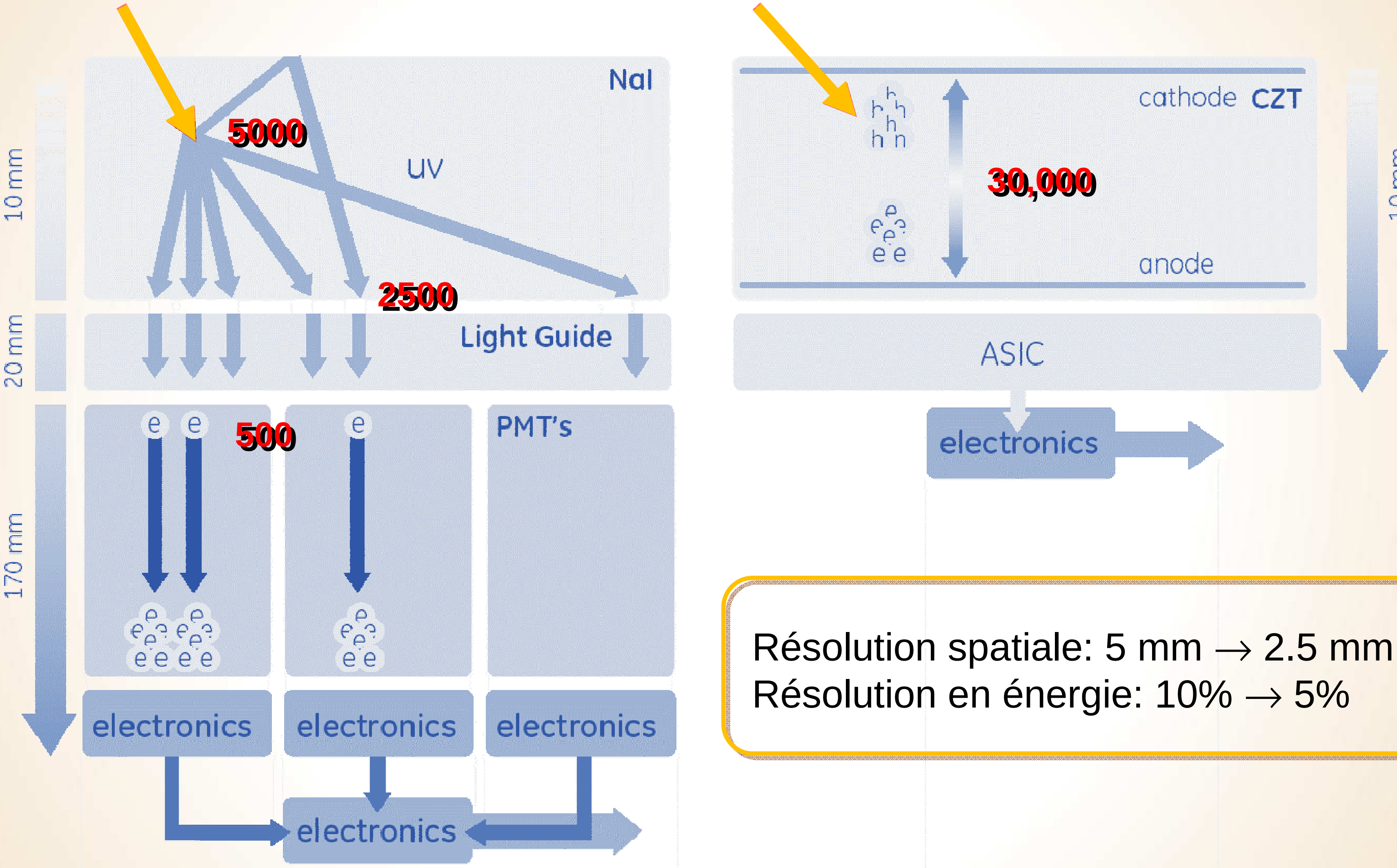


Résolution spatiale: 5 mm → 2.5 mm

Caméra CZT

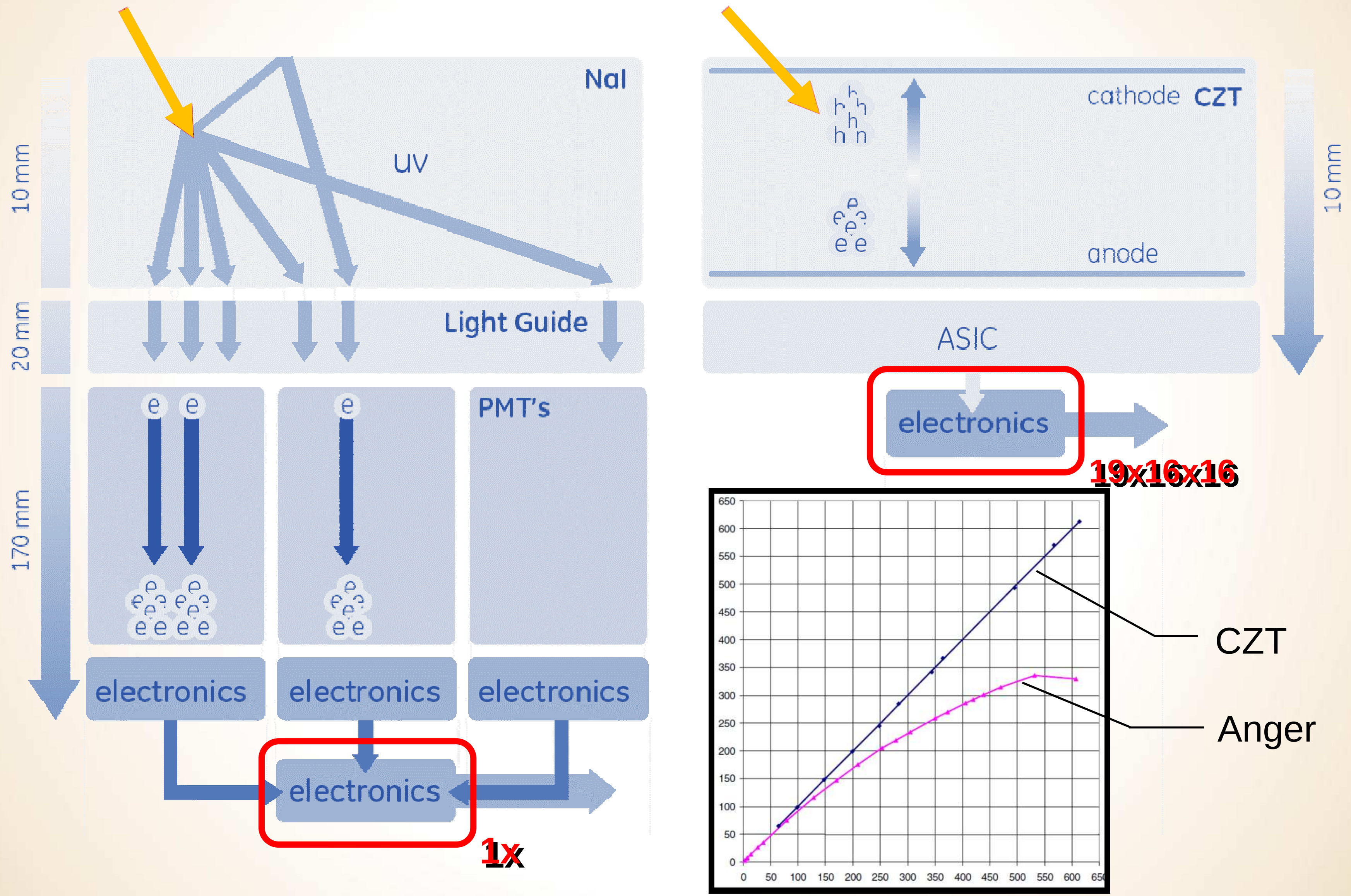

NaI
5000
UV
2500
Light Guide
10 mm
20 mm
170 mm
e e
500
e
PMT's
electronics
electronics
electronics
electronics
cathode CZT
h h h h h h
30,000
e e e e e
anode
10 mm
ASIC
electronics
Anger
CZT
KeV
51
102
154
KeV
51
102
154

Caméra CZT

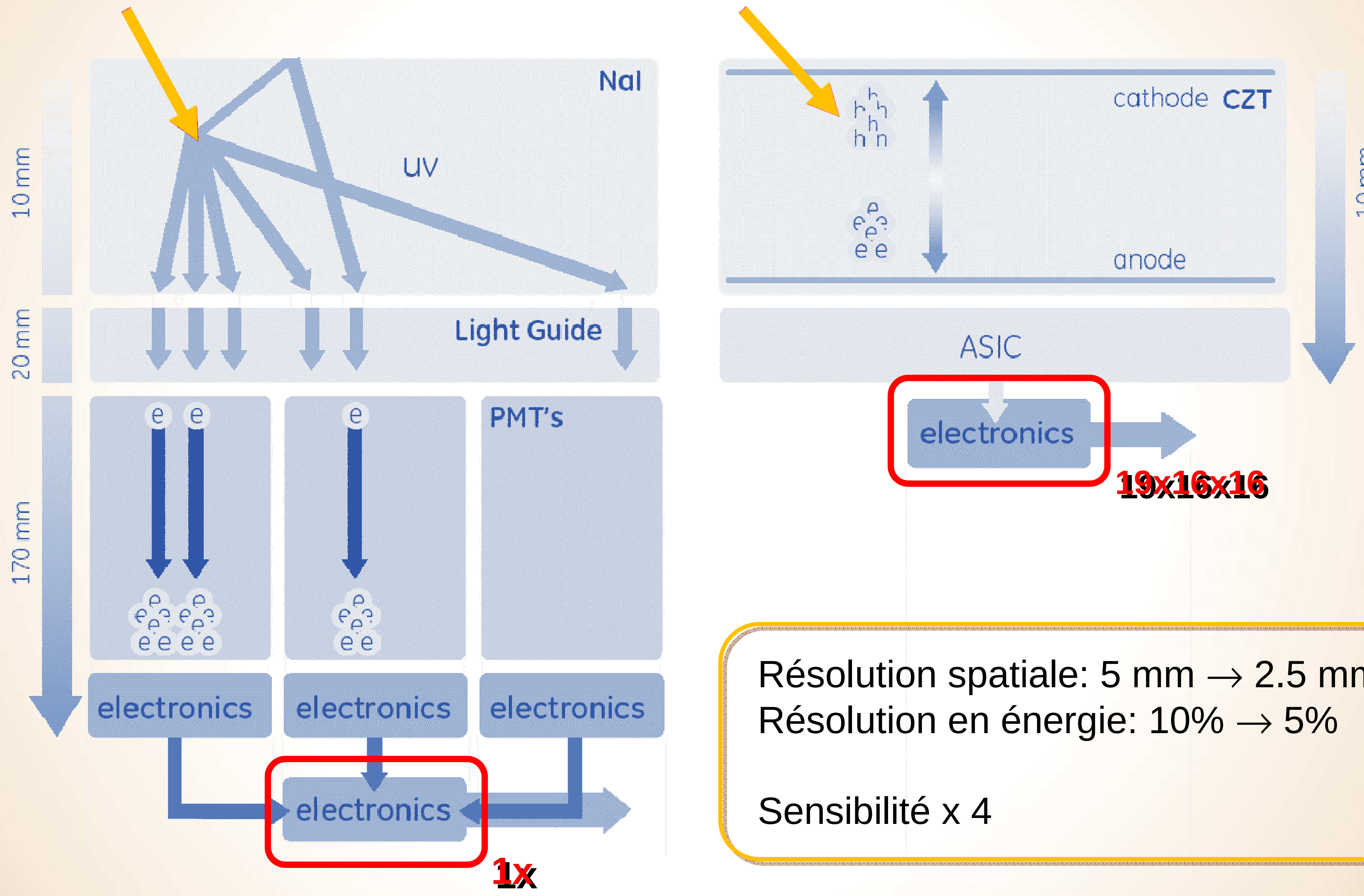


Résolution spatiale: 5 mm → 2.5 mm
Résolution en énergie: 10% → 5%

Caméra CZT


NaI
UV
Light Guide
10 mm
20 mm
170 mm
PMT's
e e
e
electronics
electronics
electronics
electronics
1x
cathode
CZT
anode
ASIC
10 mm
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



Résolution spatiale: 5 mm → 2.5 mm
Résolution en énergie: 10% → 5%

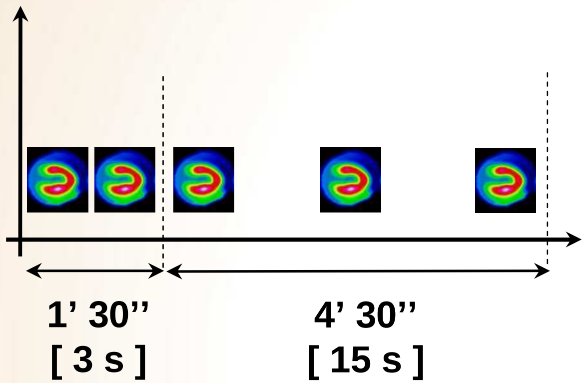
Sensibilité x 4

Protocole

REPOS

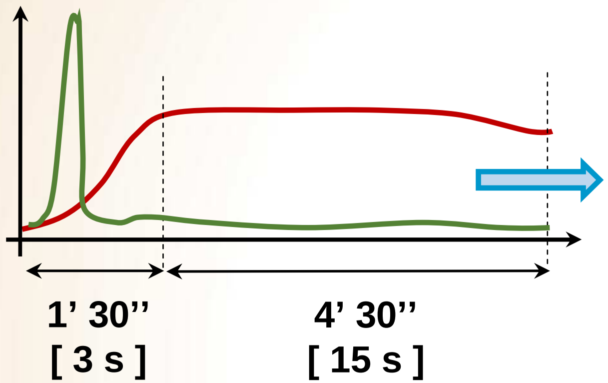
Protocole

REPOS



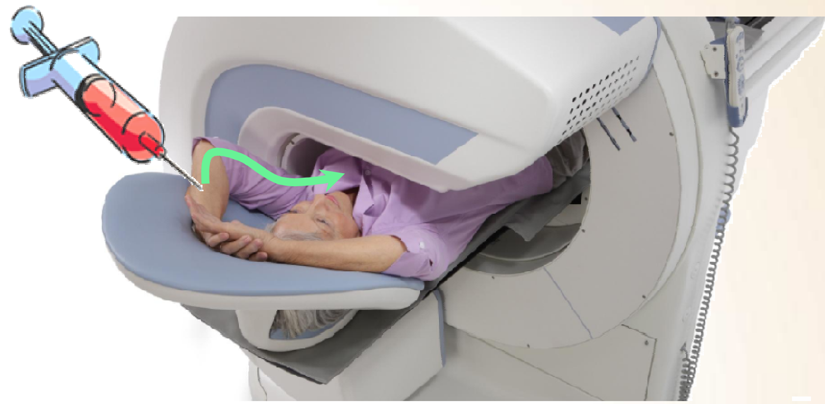
Protocole

REPOS



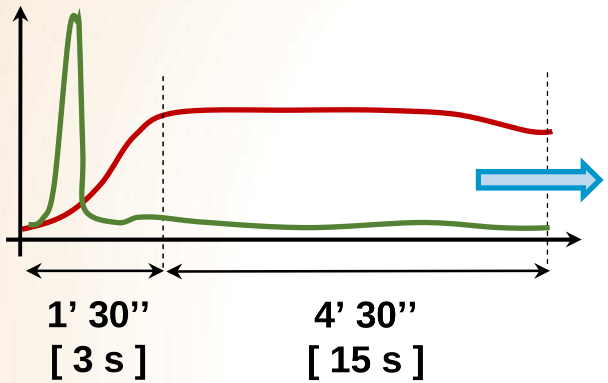
$K_1 \propto Q_{repos}$

MIBI
5 mCi



Protocole

REPOS

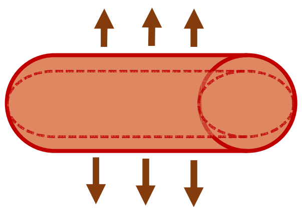


$K_1 \propto Q_{repos}$

MIBI
5 mCi

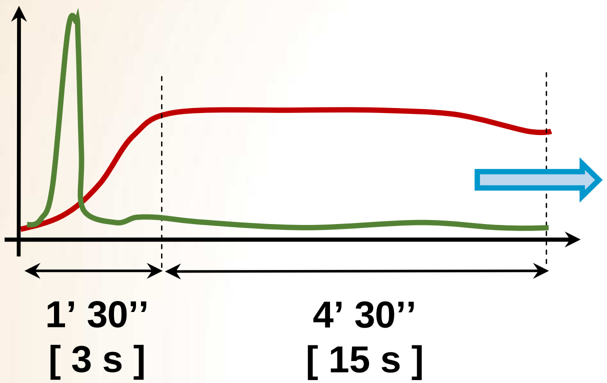
STRESS

Dipyridamole



Protocole

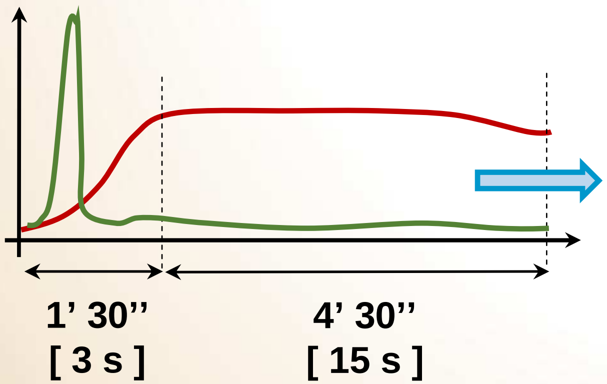
REPOS



$K_1 \propto Q_{repos}$

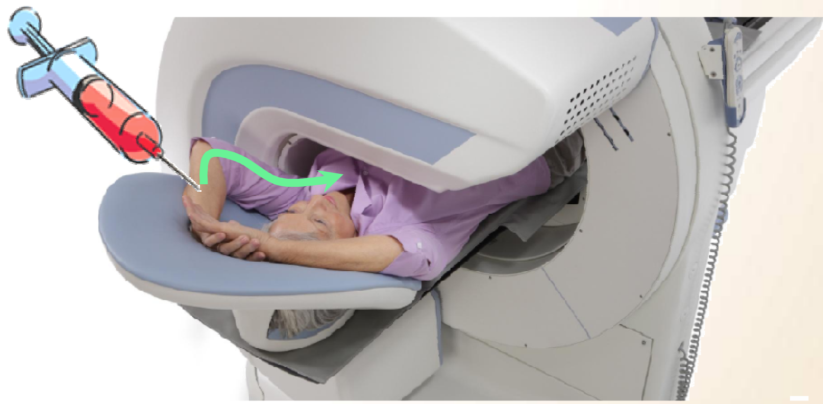
MIBI
5 mCi

STRESS

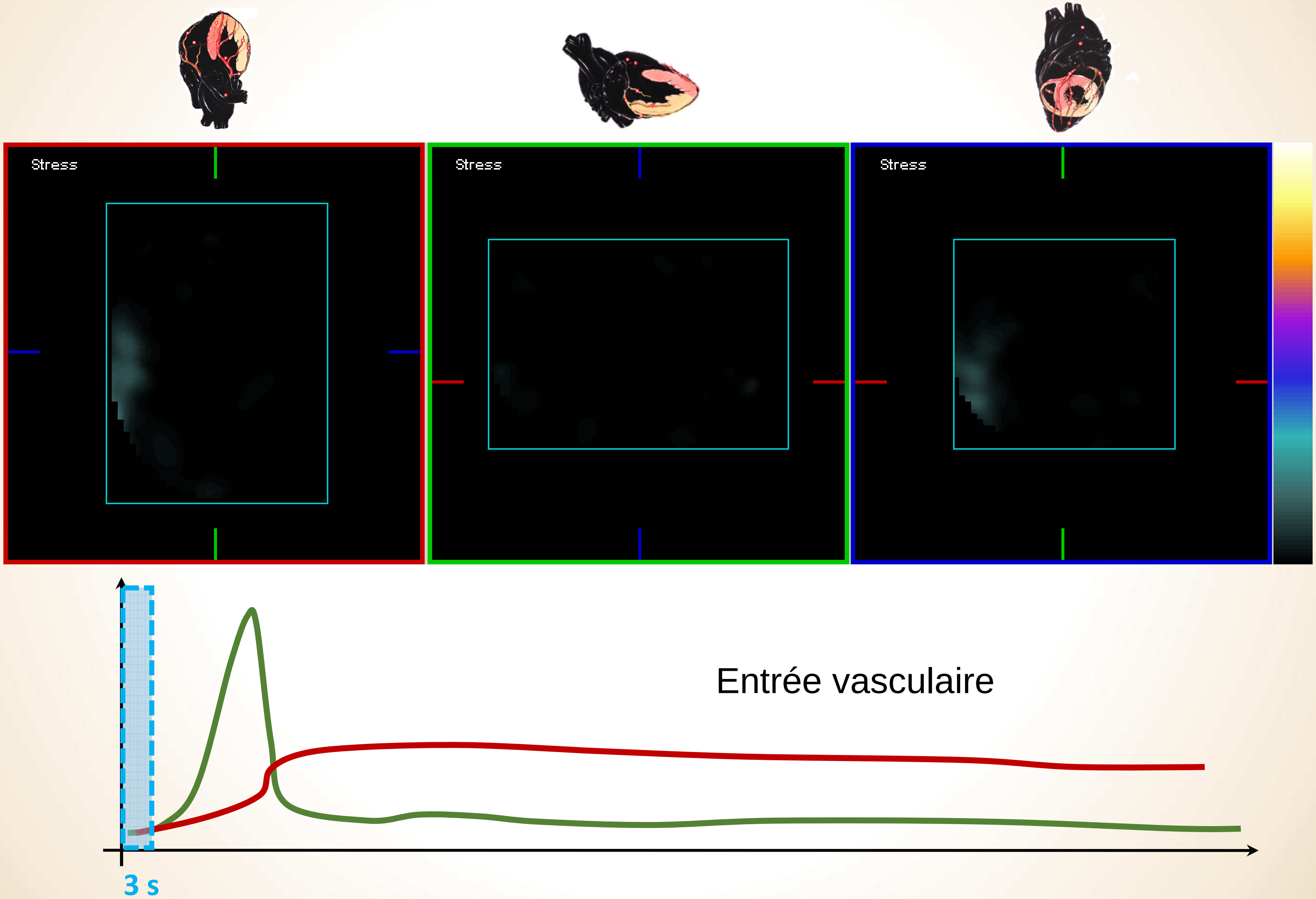


$K_1 \propto Q_{stress}$

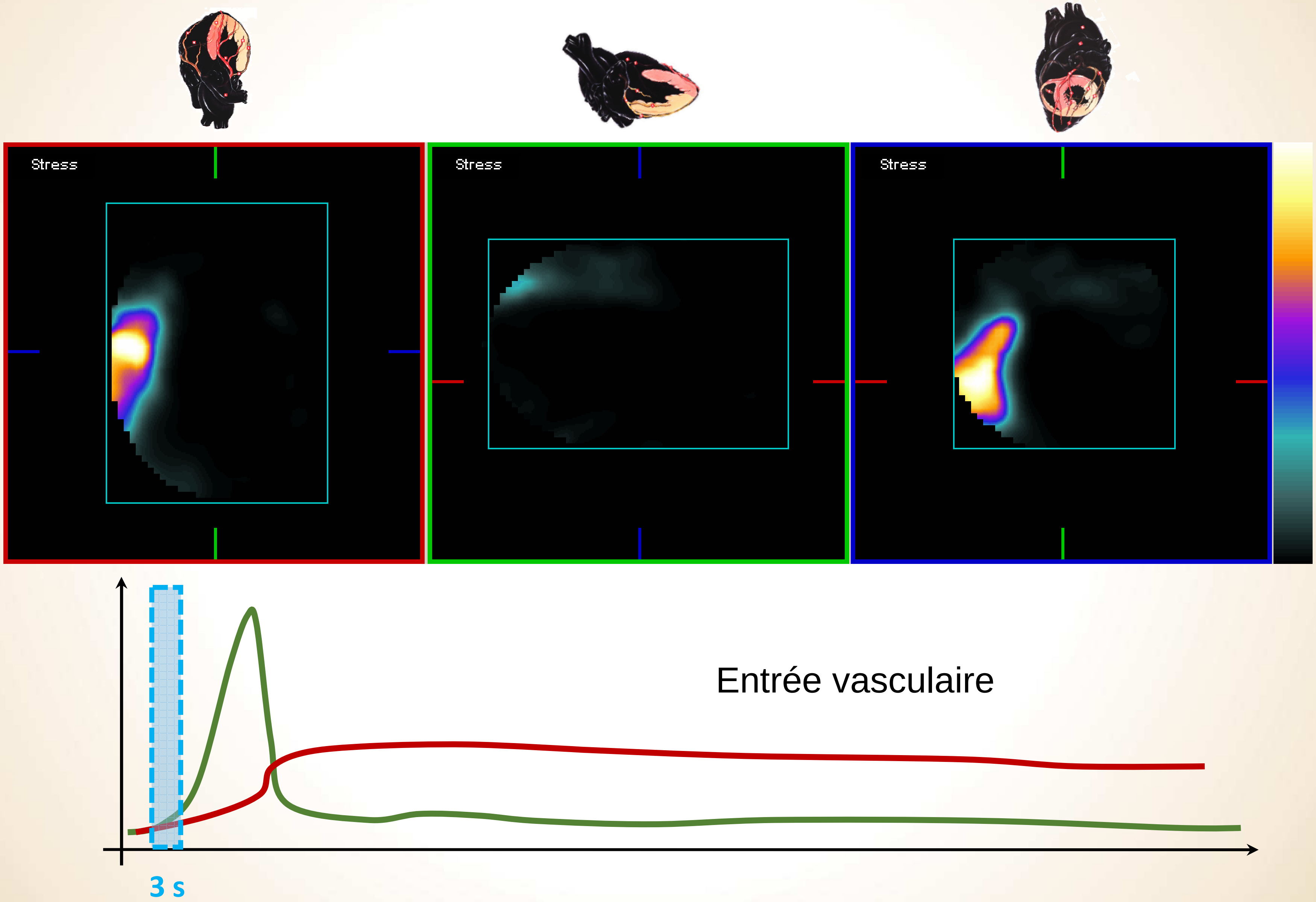
MIBI
20 mCi



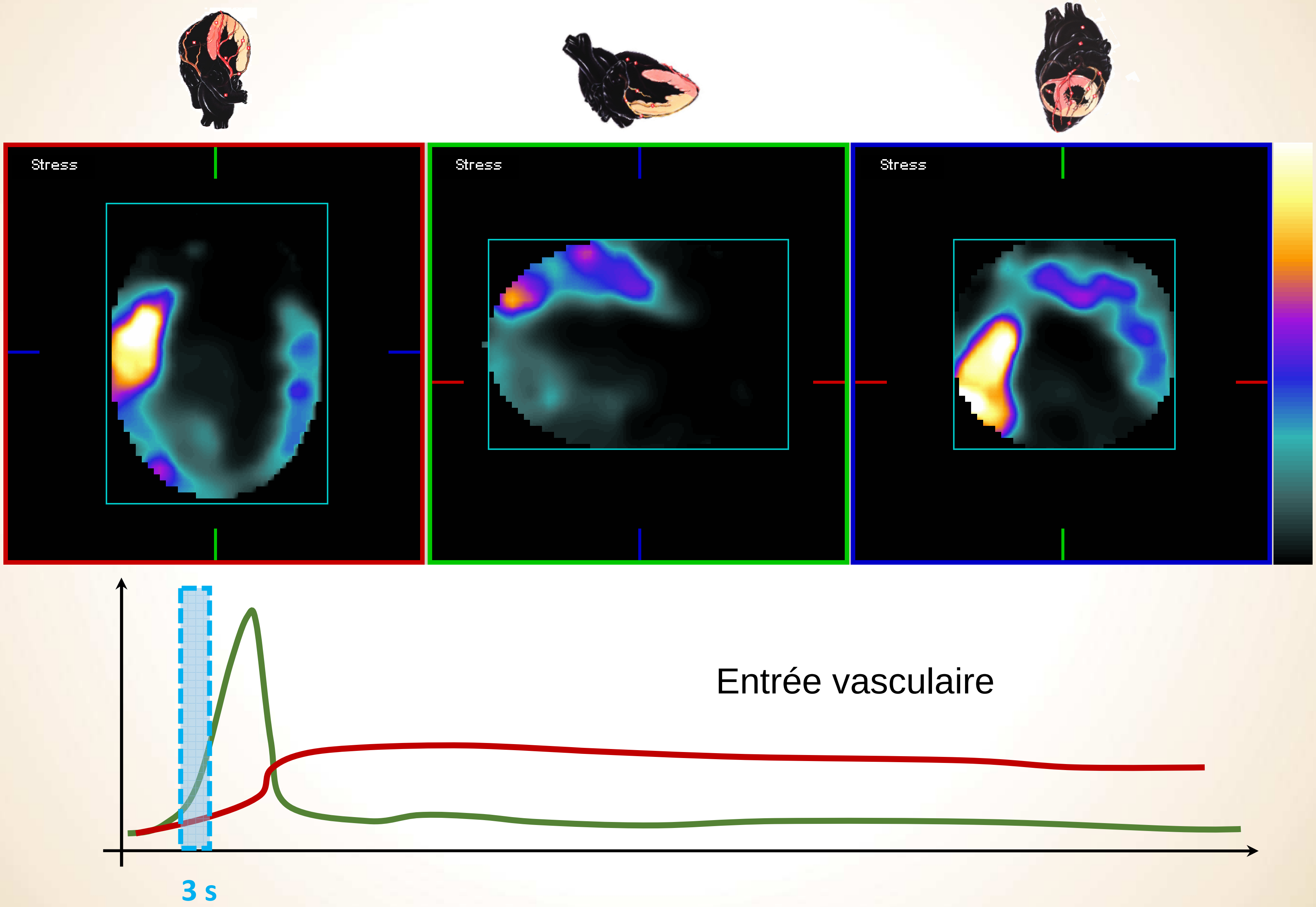
Protocole



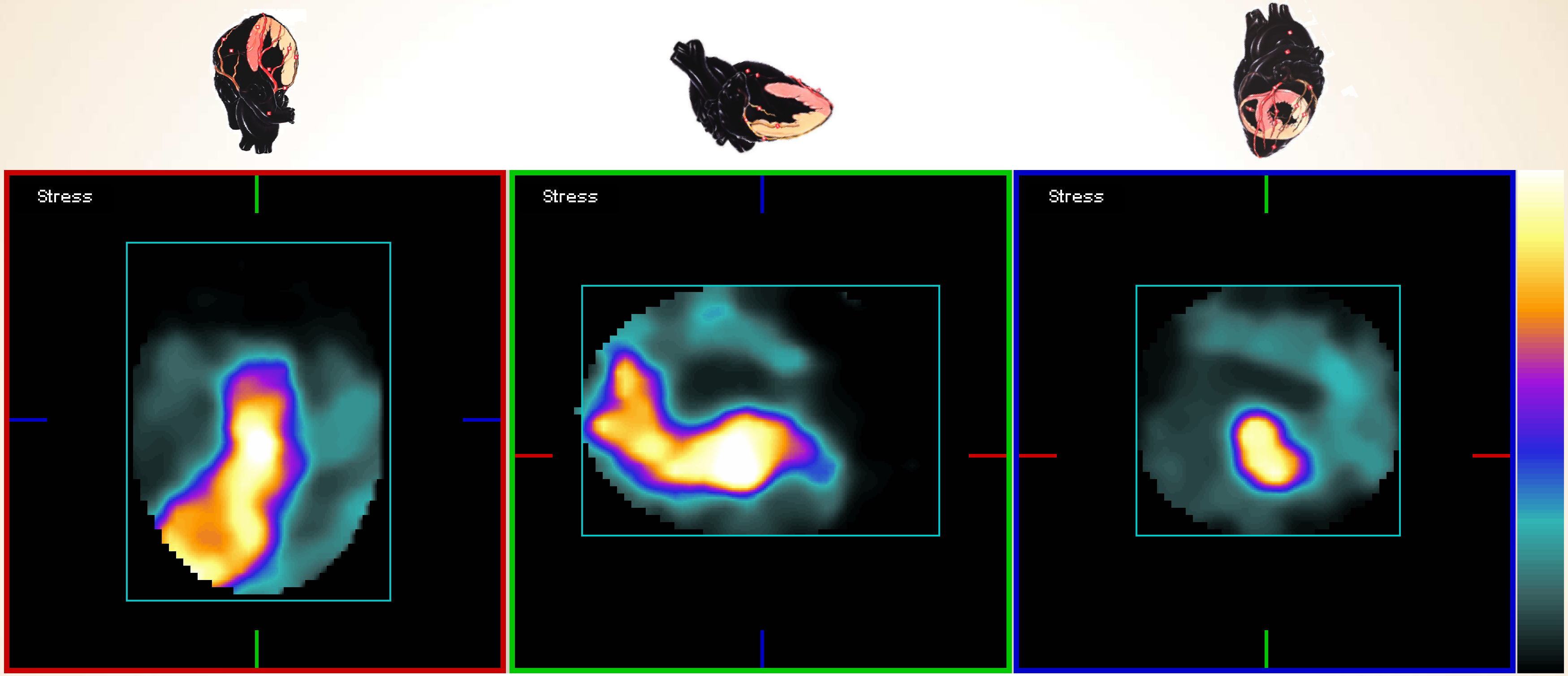
Protocole

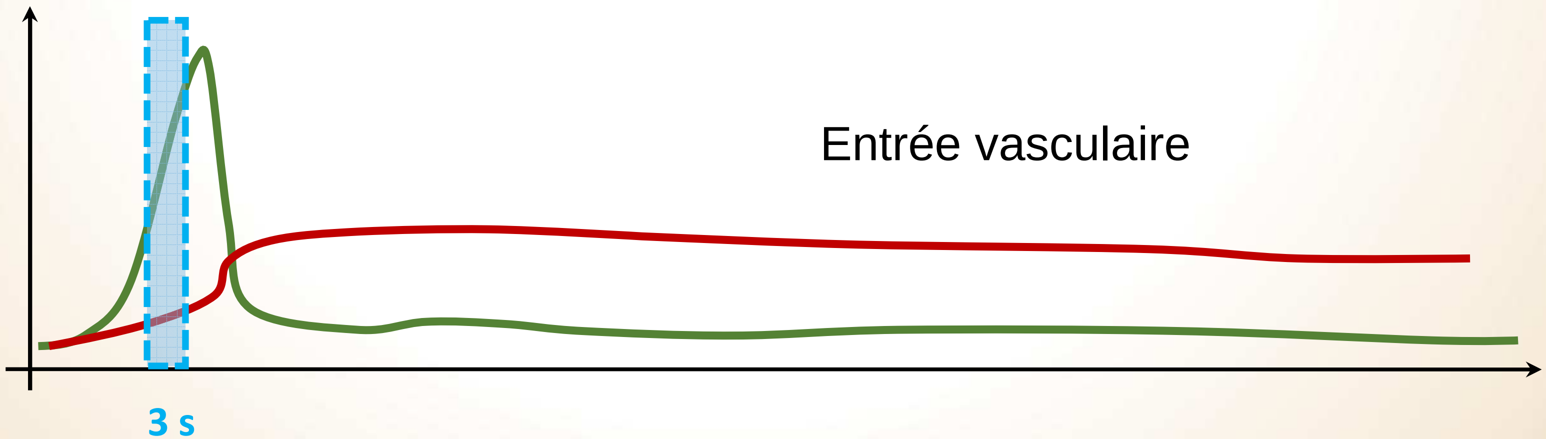


Protocole

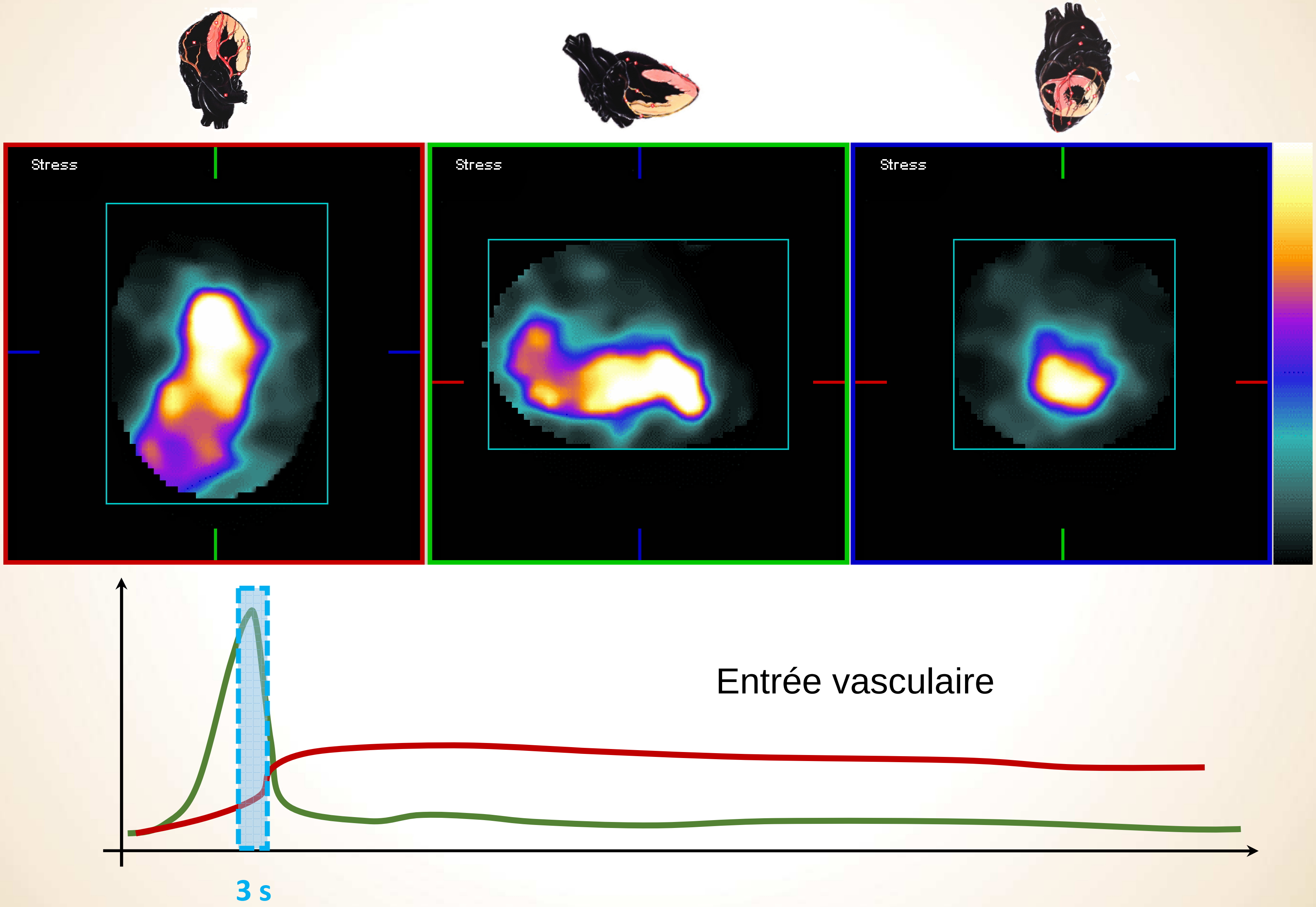


Protocole

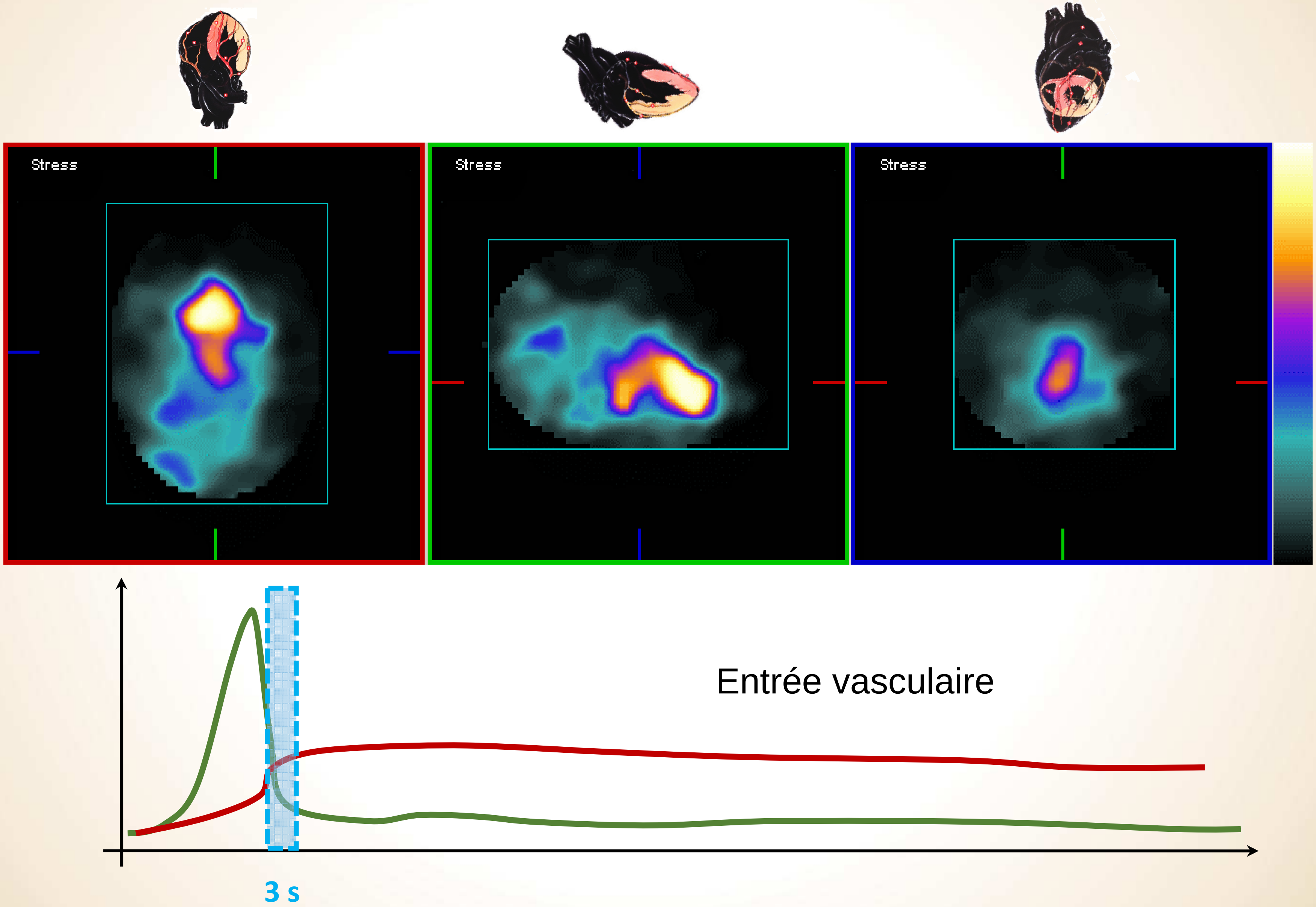




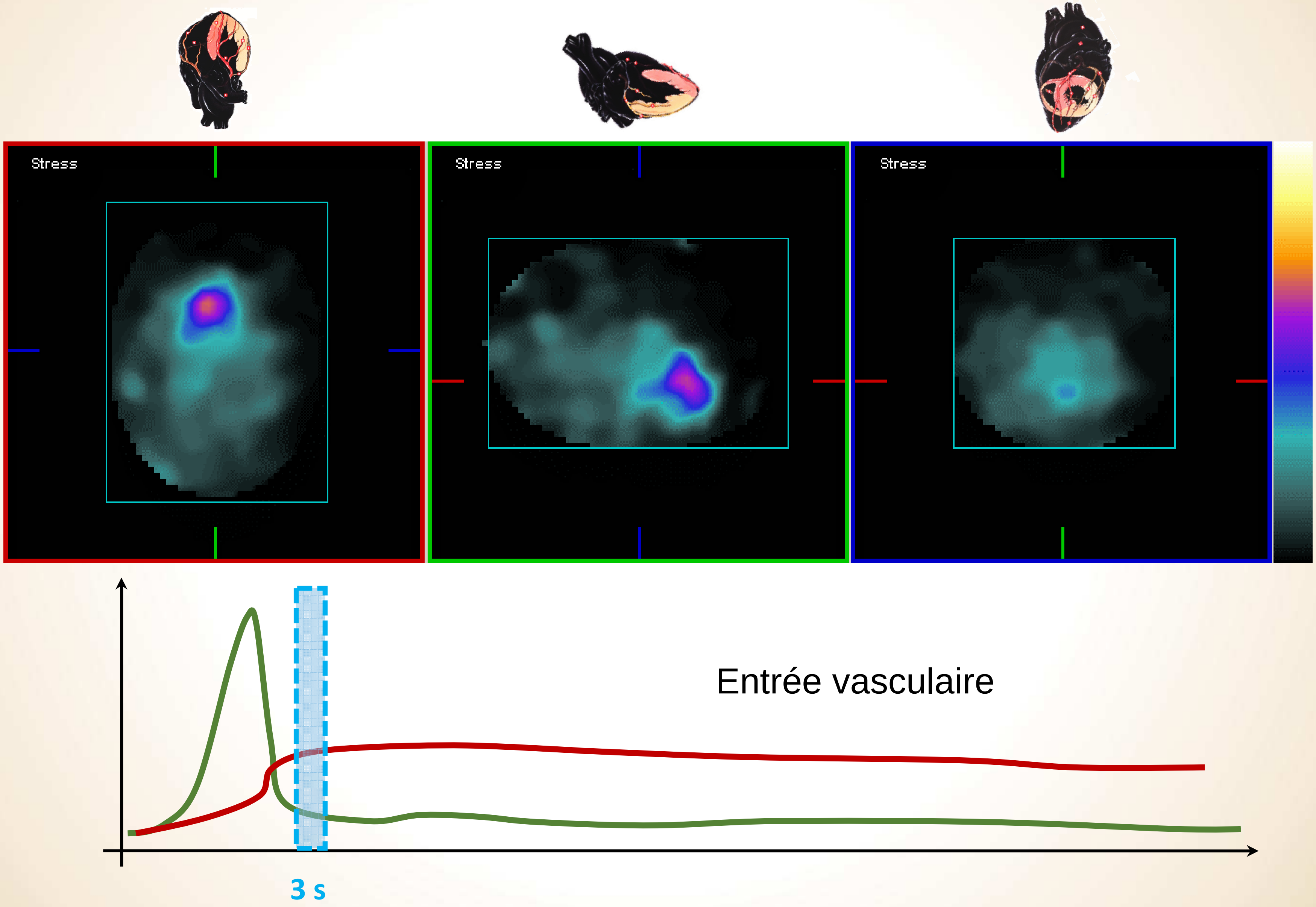
Protocole



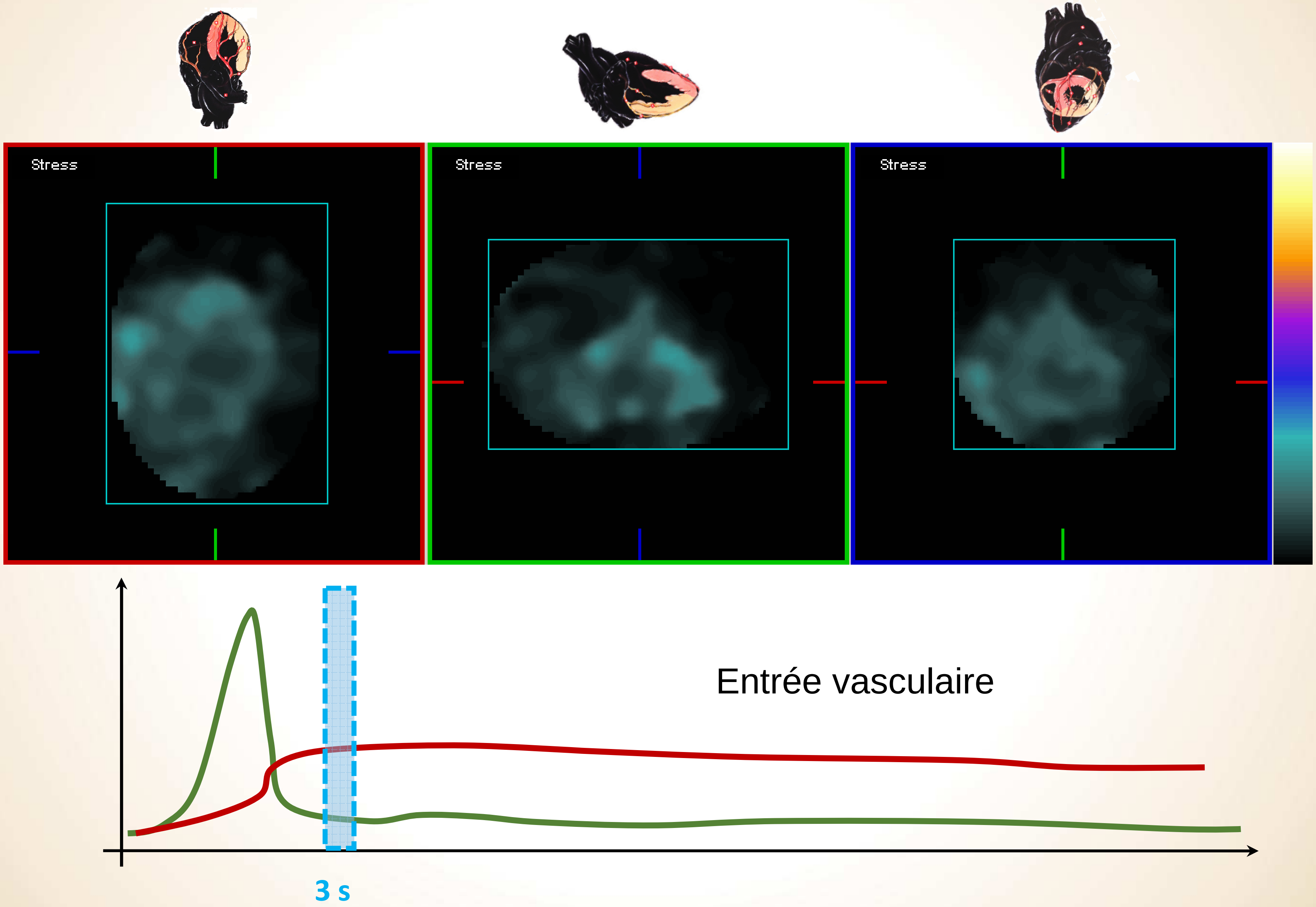
Protocole



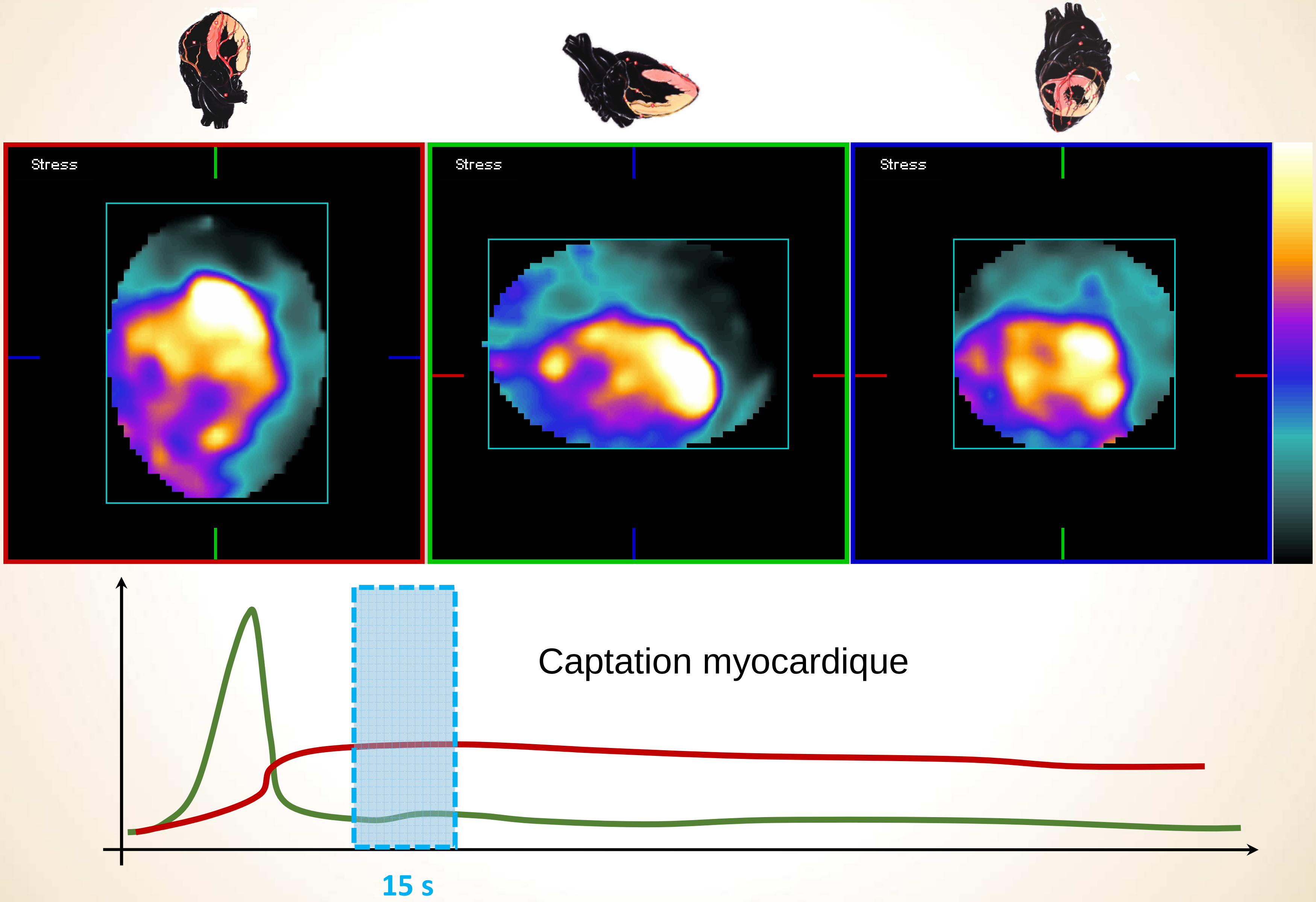
Protocole



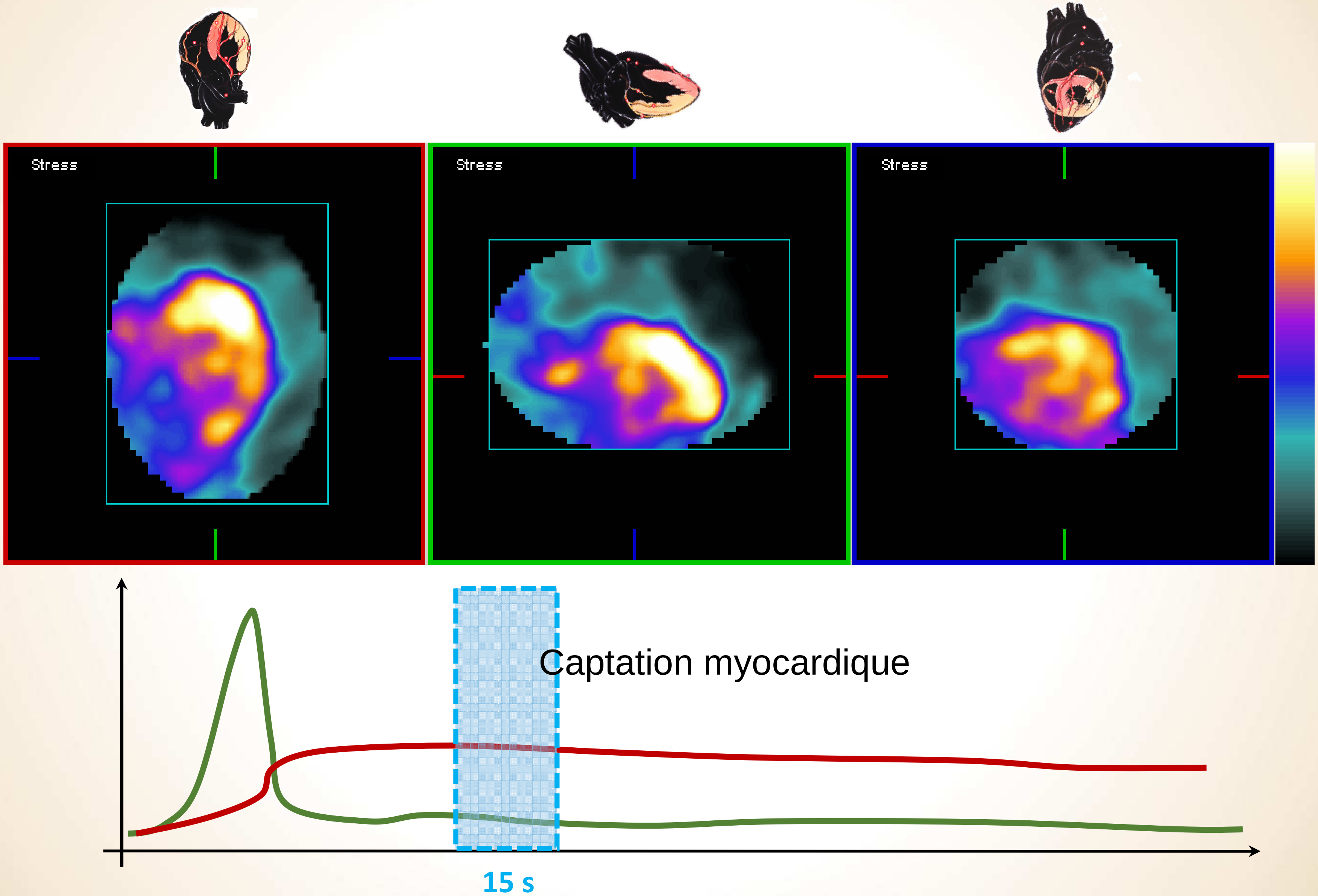
Protocole



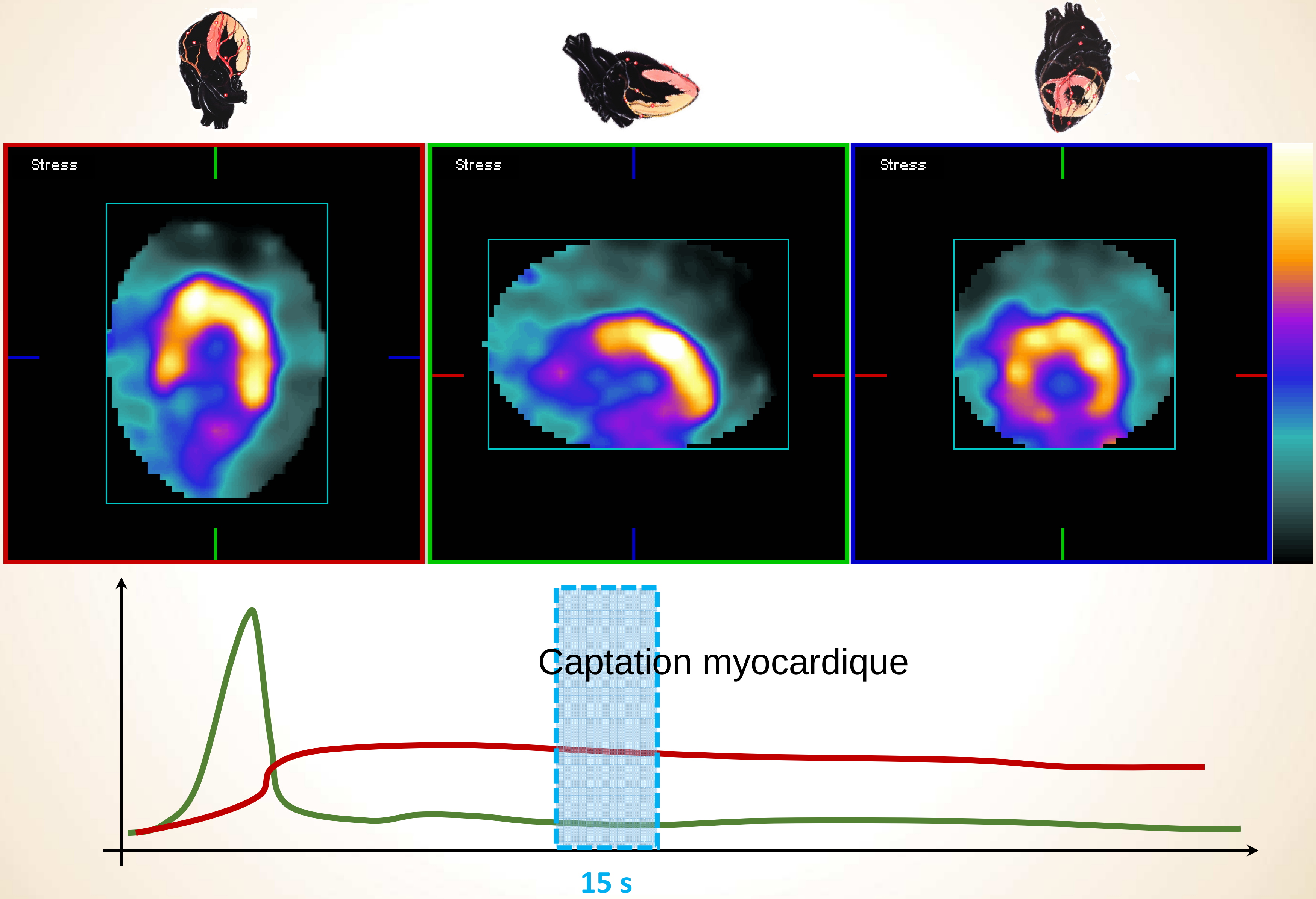
Protocole



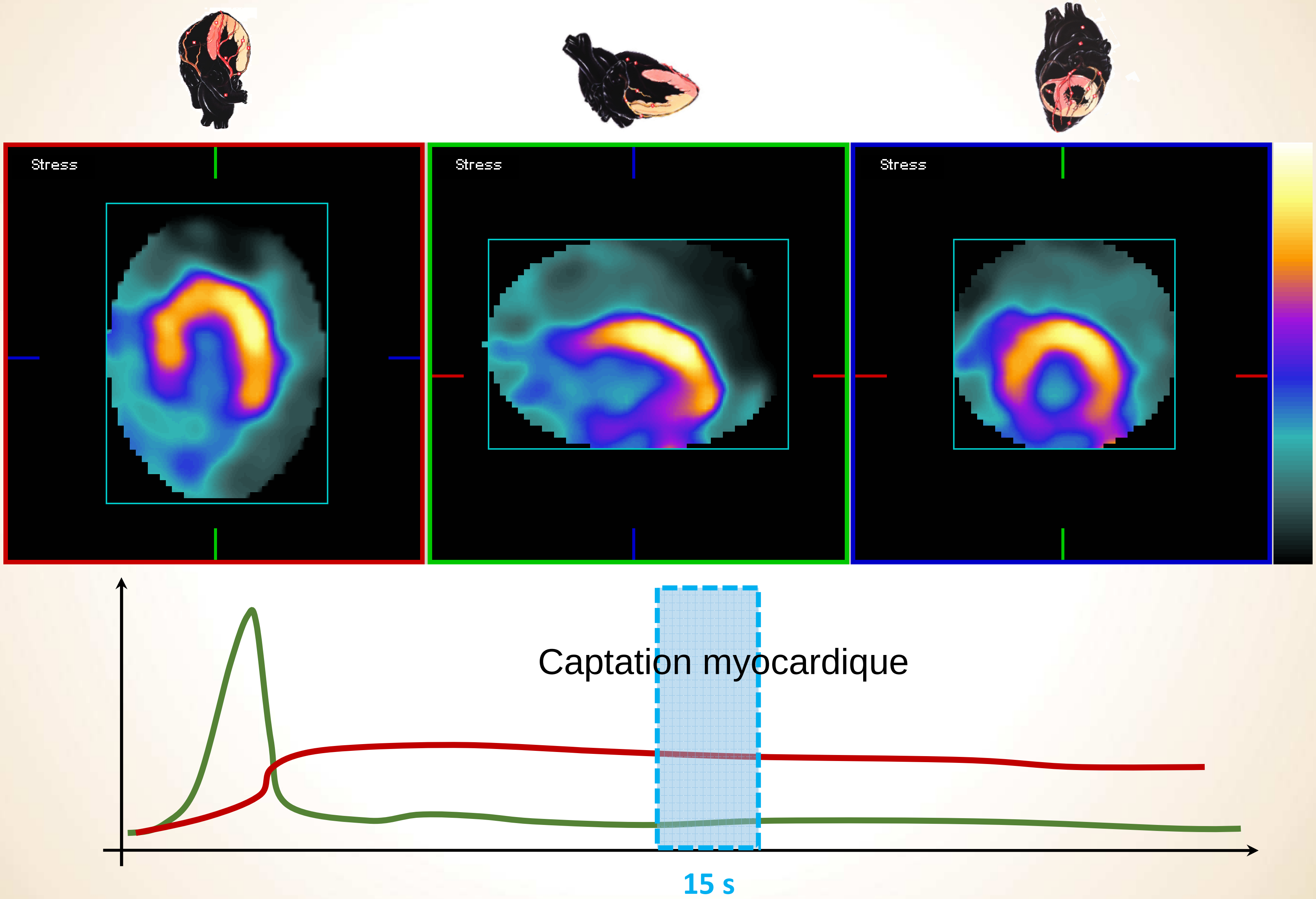
Protocole



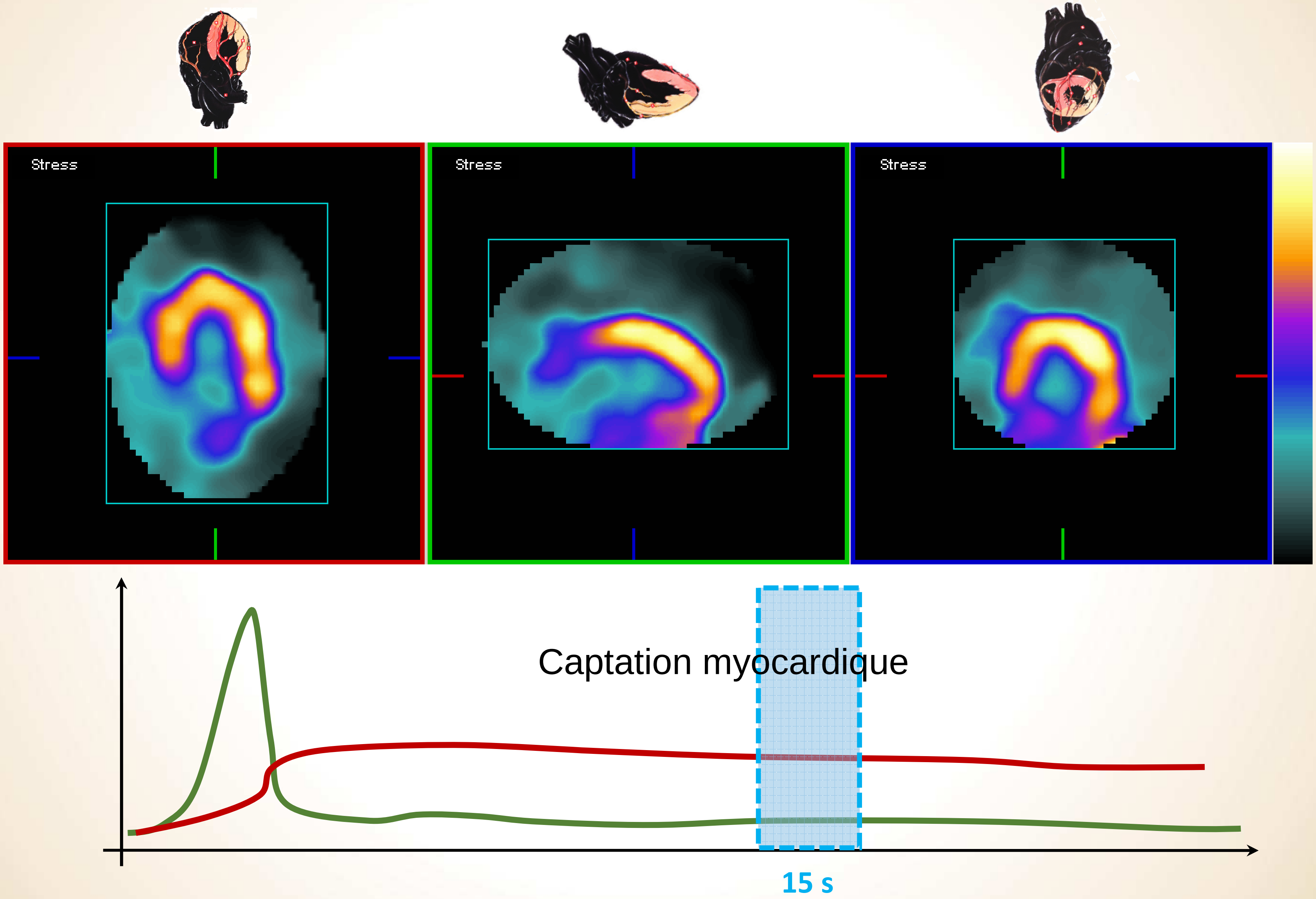
Protocole



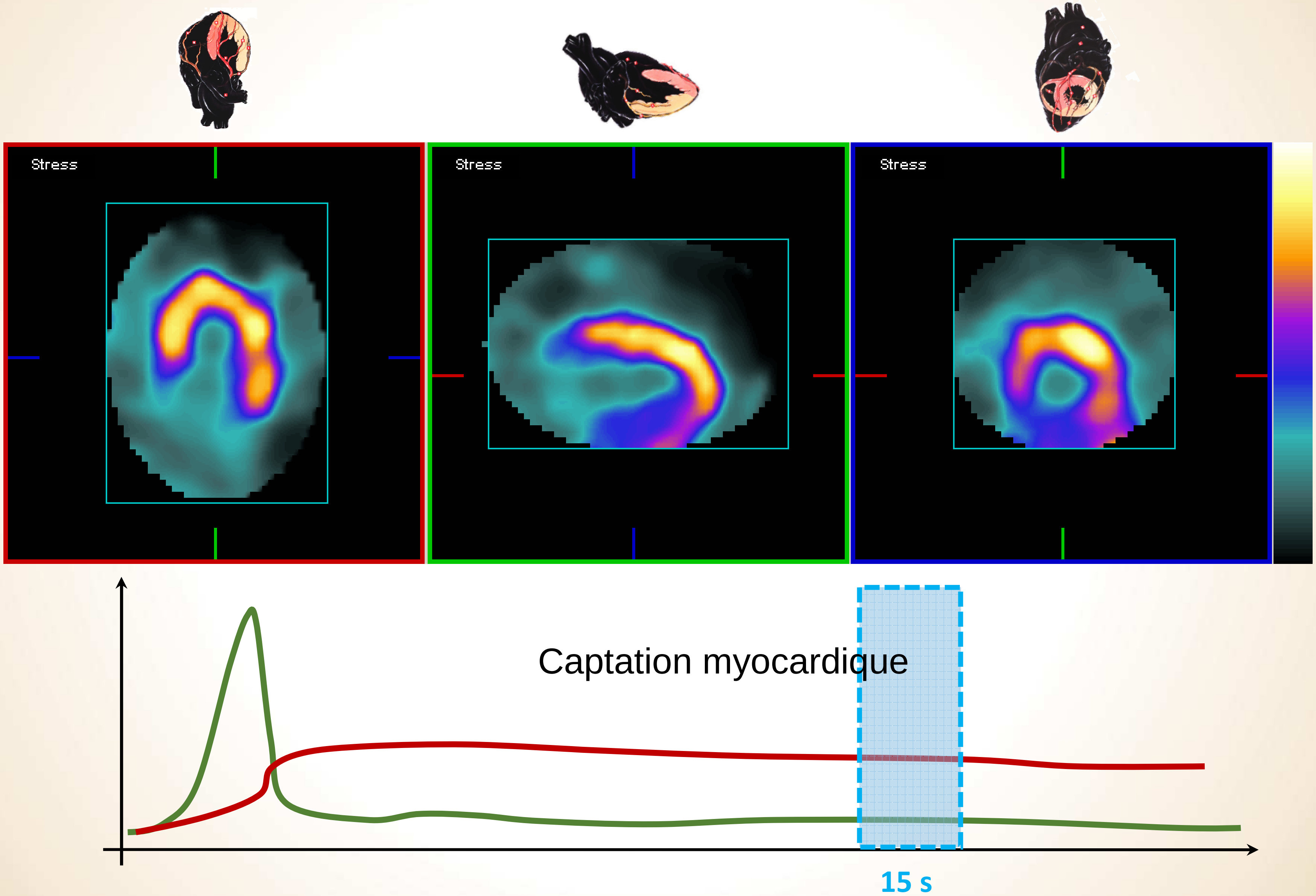
Protocole



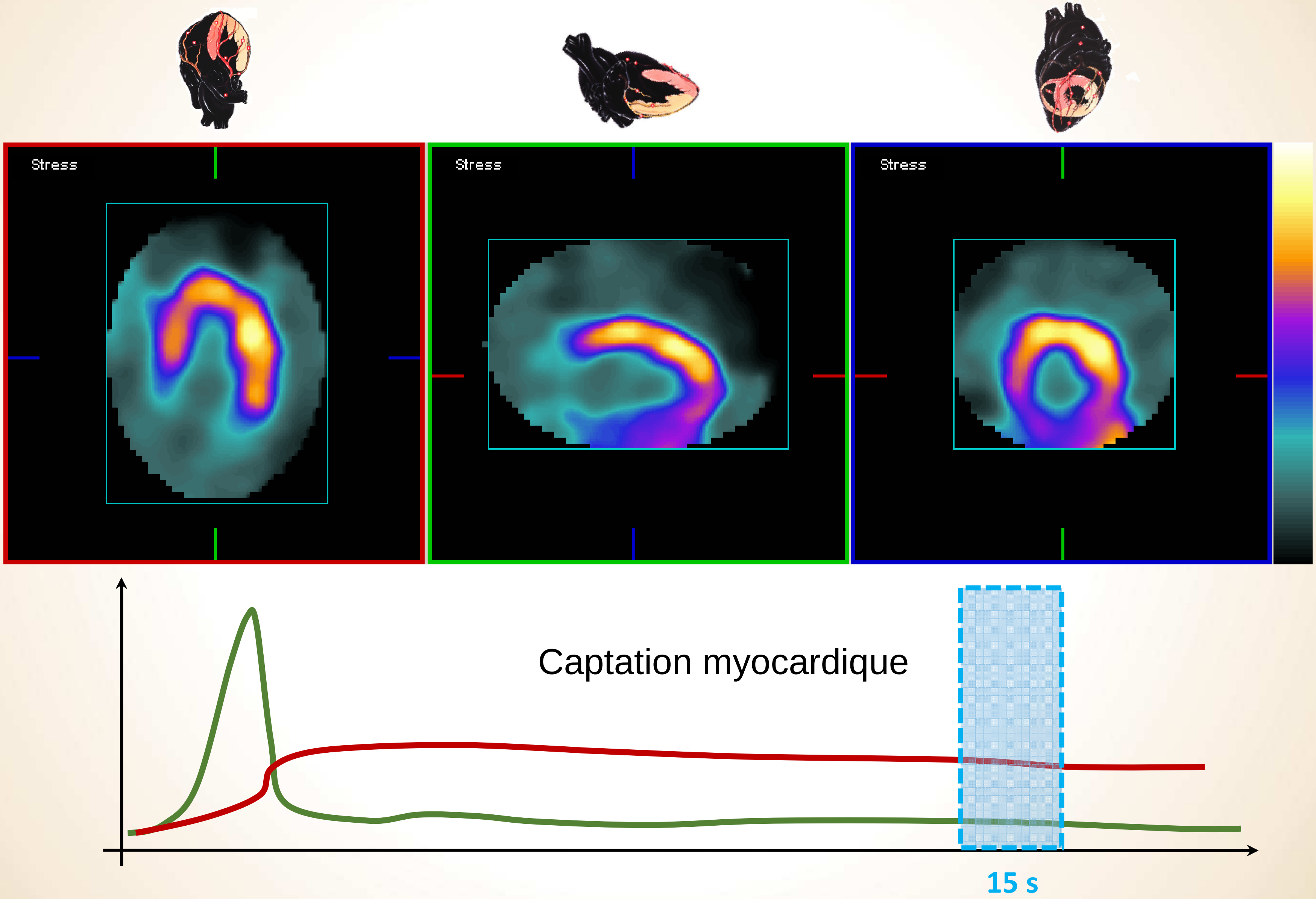
Protocole



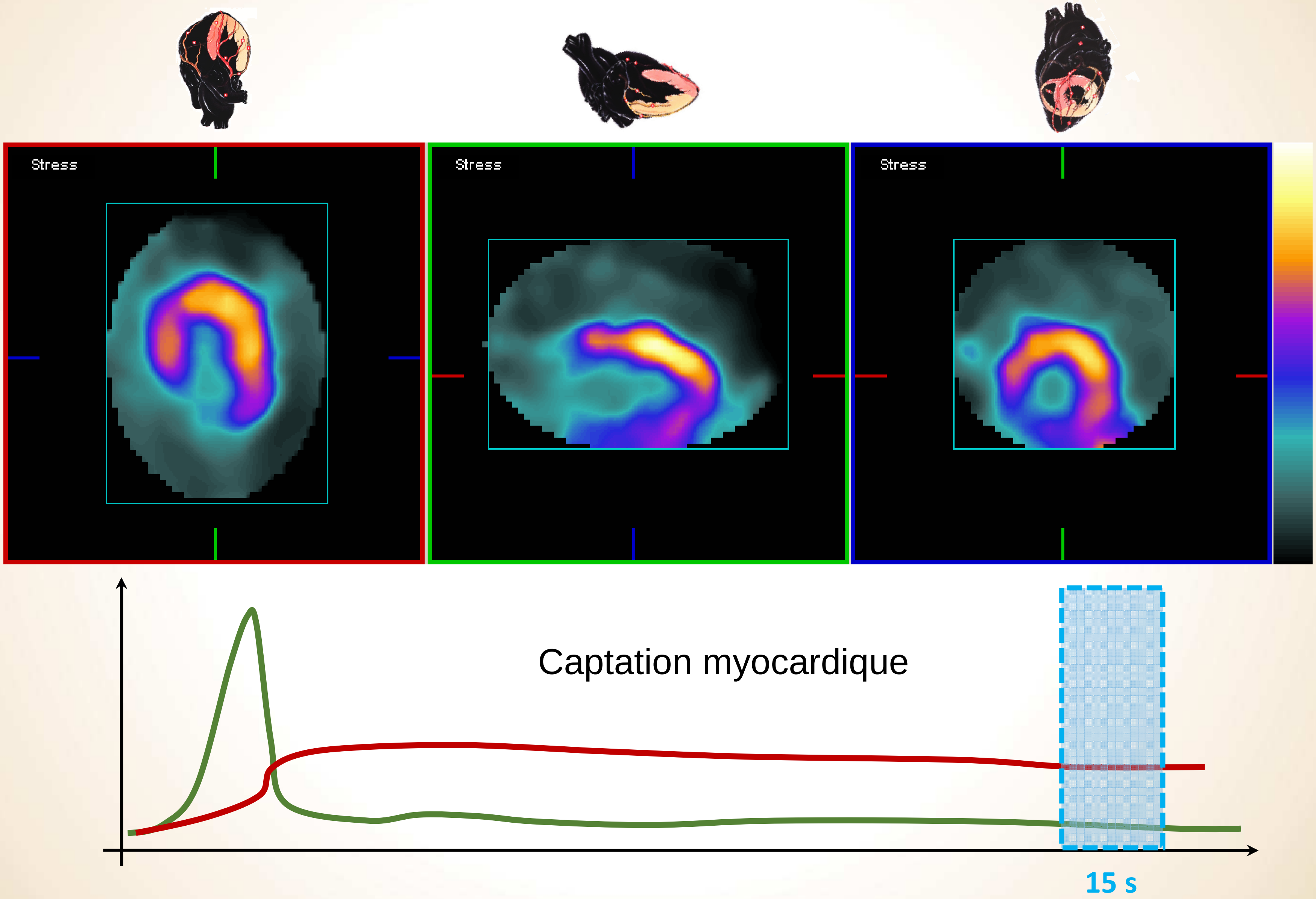
Protocole



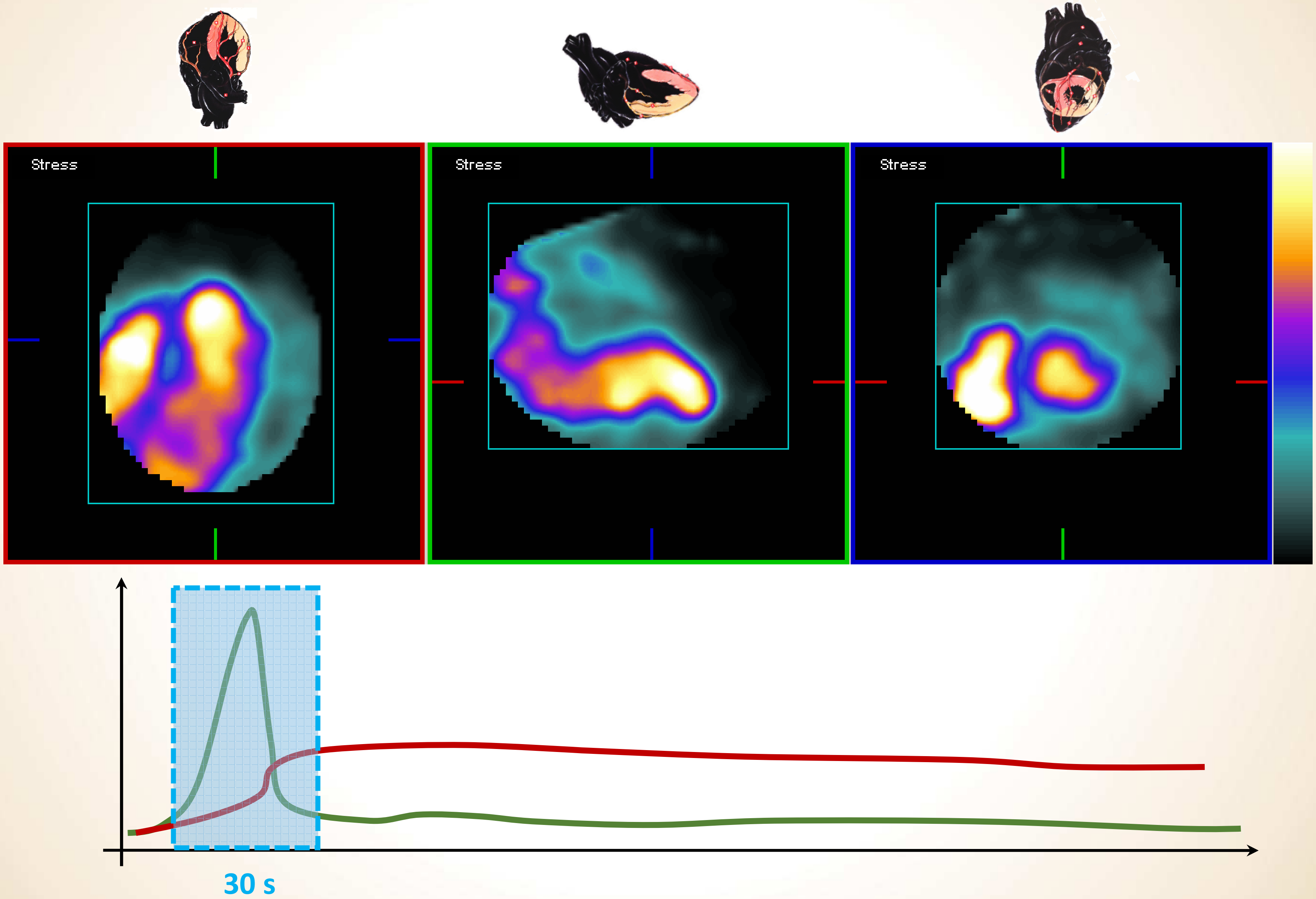
Protocole



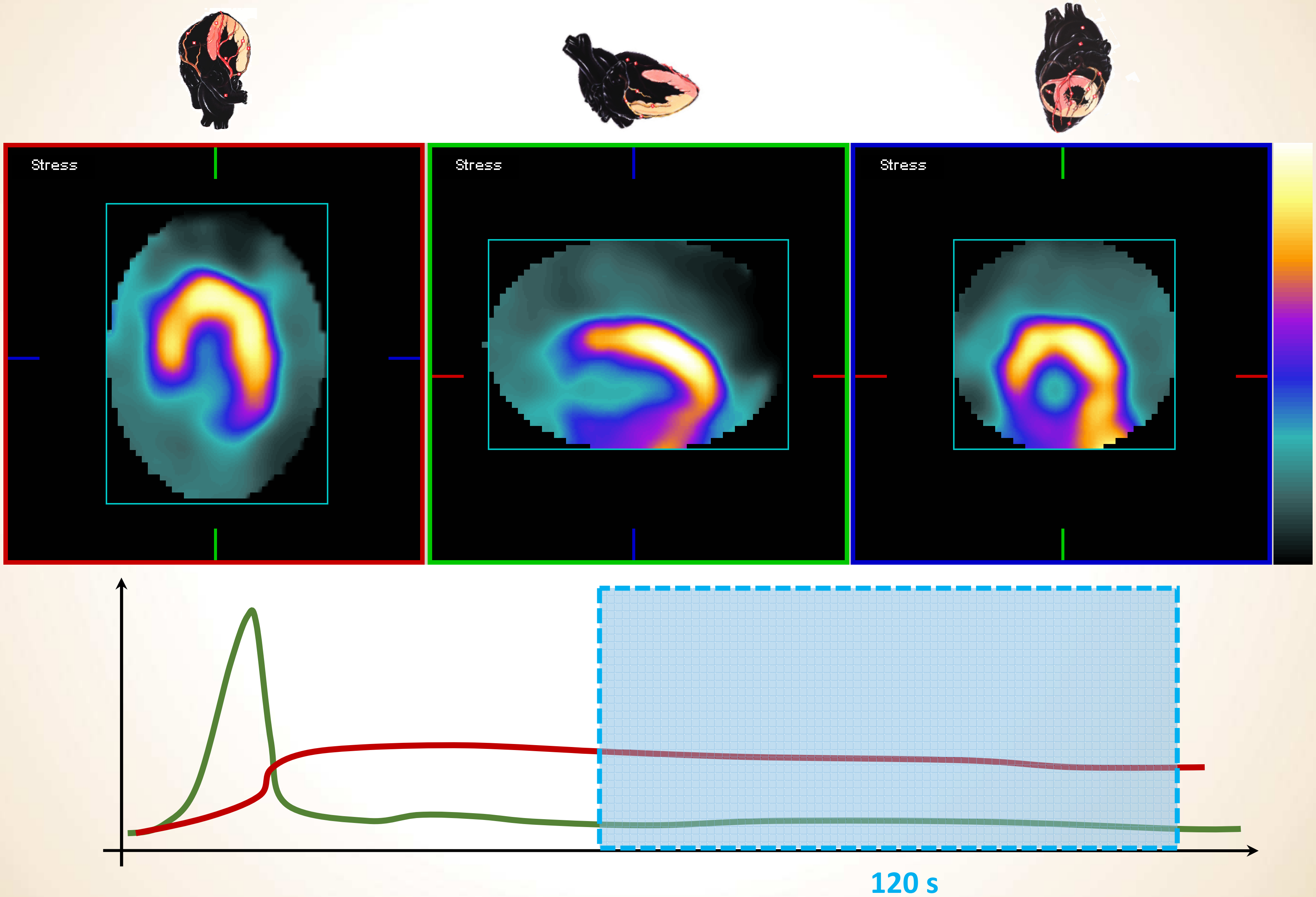
Protocole



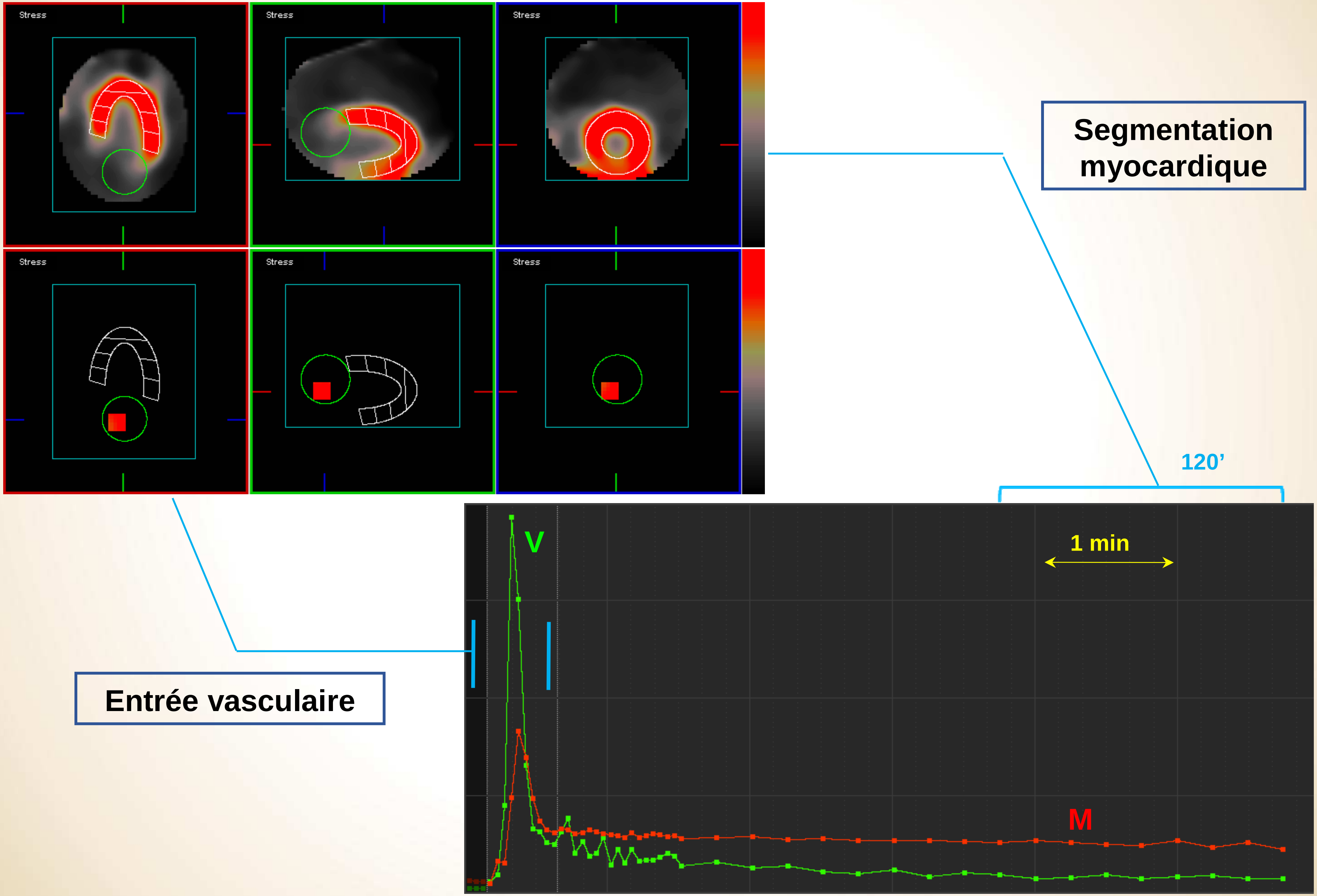
Protocole



Protocole



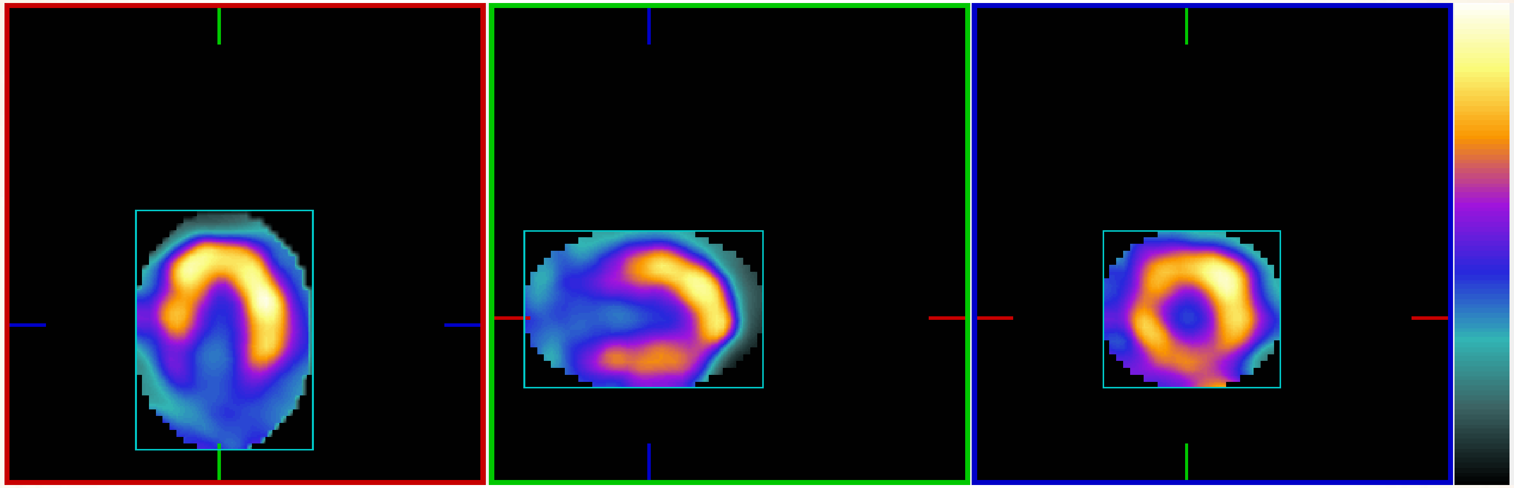
Protocole



Stress
Stress
Stress
Stress
Stress
Stress
Segmentation myocardique
120'
1 min
V
M
Entrée vasculaire

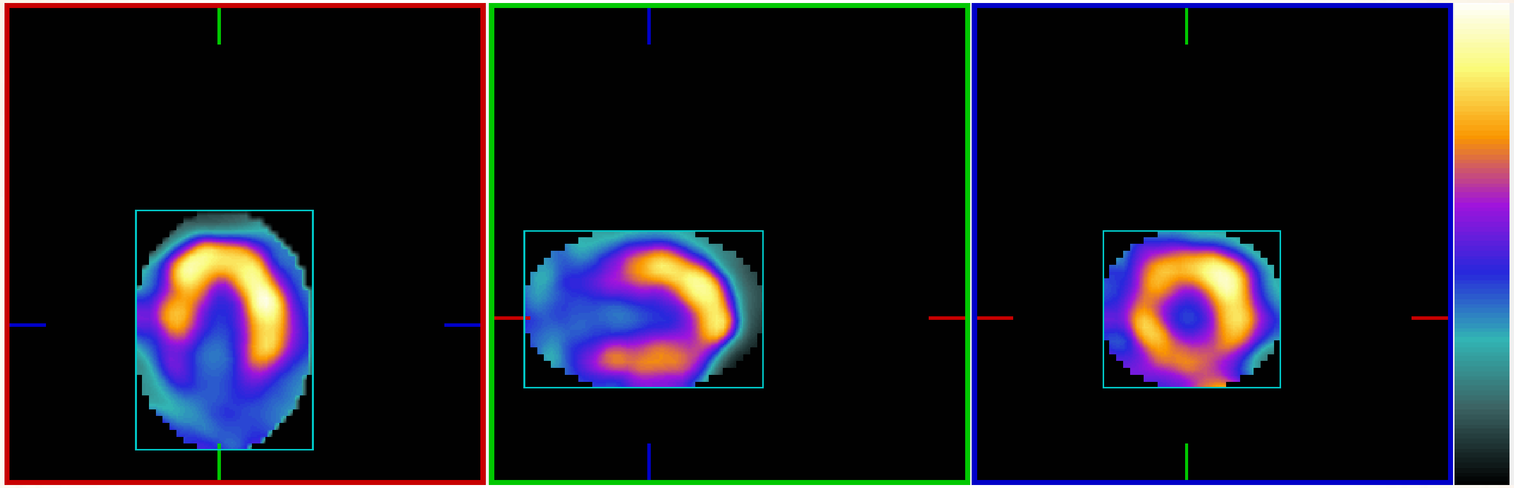
Protocole

Segmentation myocardique

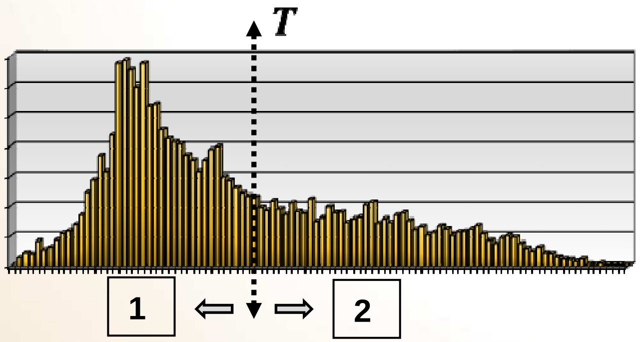


Protocole

Segmentation myocardique



Méthode d'Otsu

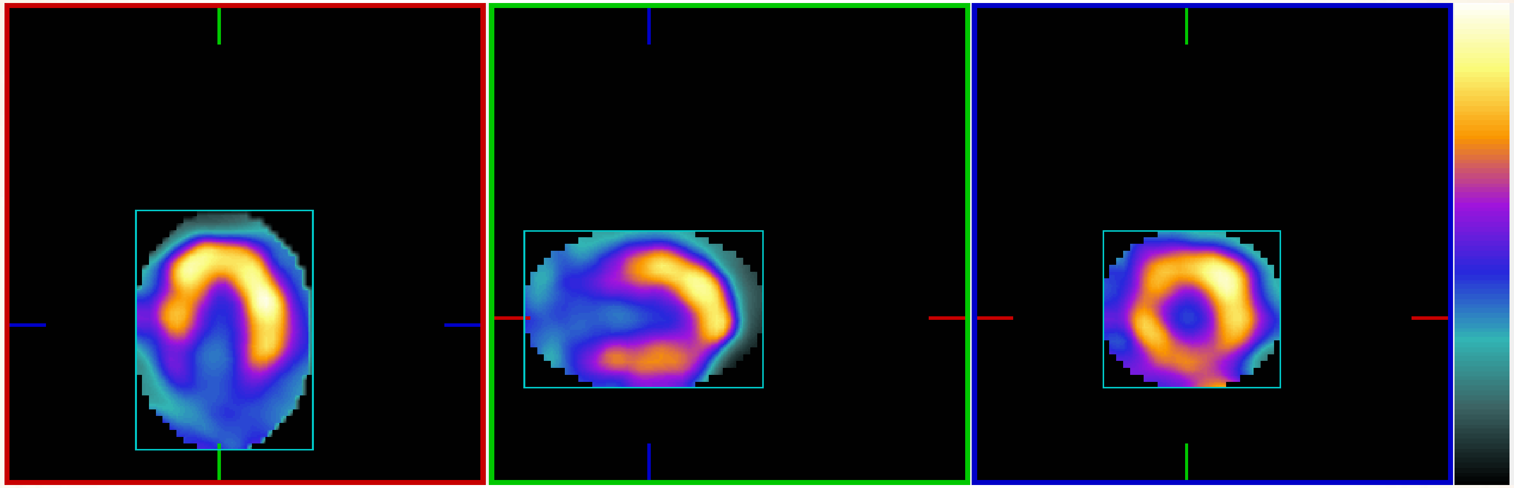


$$T = argmin\,(V_w)$$

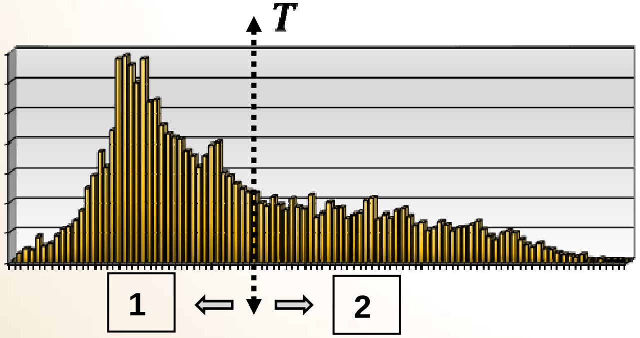
$$= argmin\,\{w_1 V_1 + w_2 V_2\}$$

Protocole

Segmentation myocardique



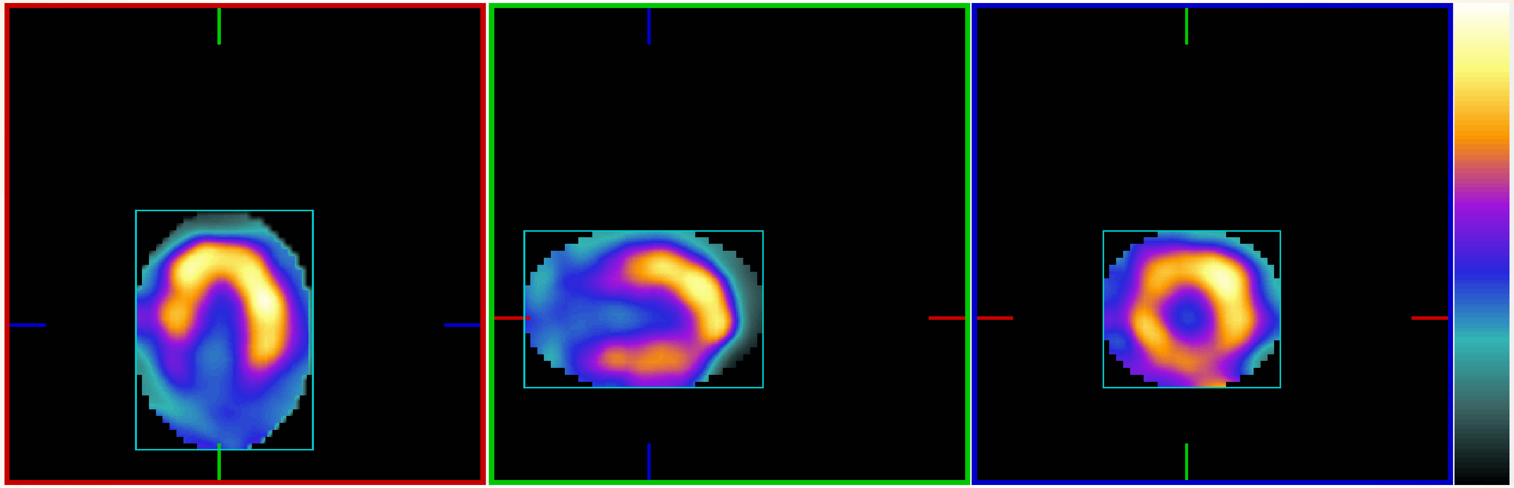
Méthode d'Otsu



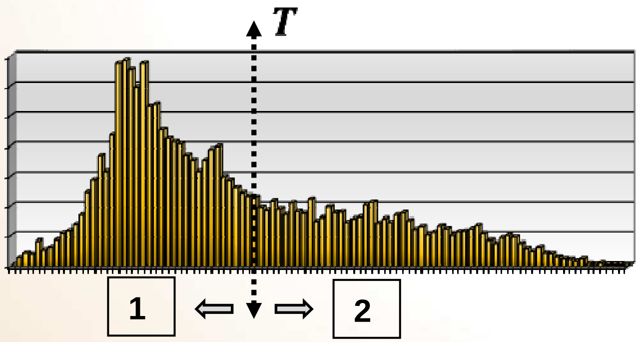
$$T = argmin\,(V_w)$$
$$= argmax\,(V_b)$$
$$= argmax\,(V - V_w)$$

Protocole

Segmentation myocardique



Méthode d'Otsu



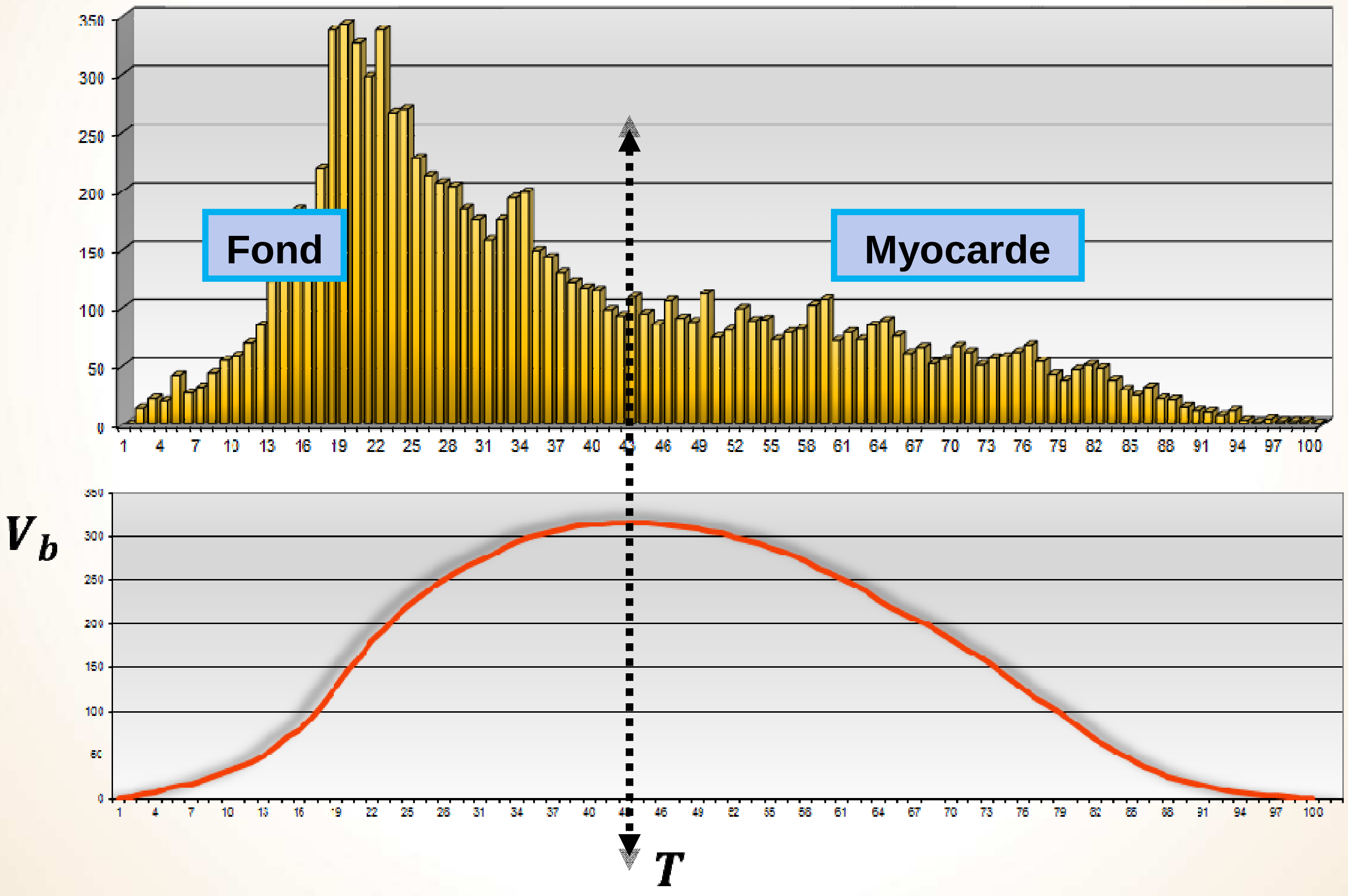
$$T = argmin\,(V_w)$$

$$= argmax\,(V_b)$$

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

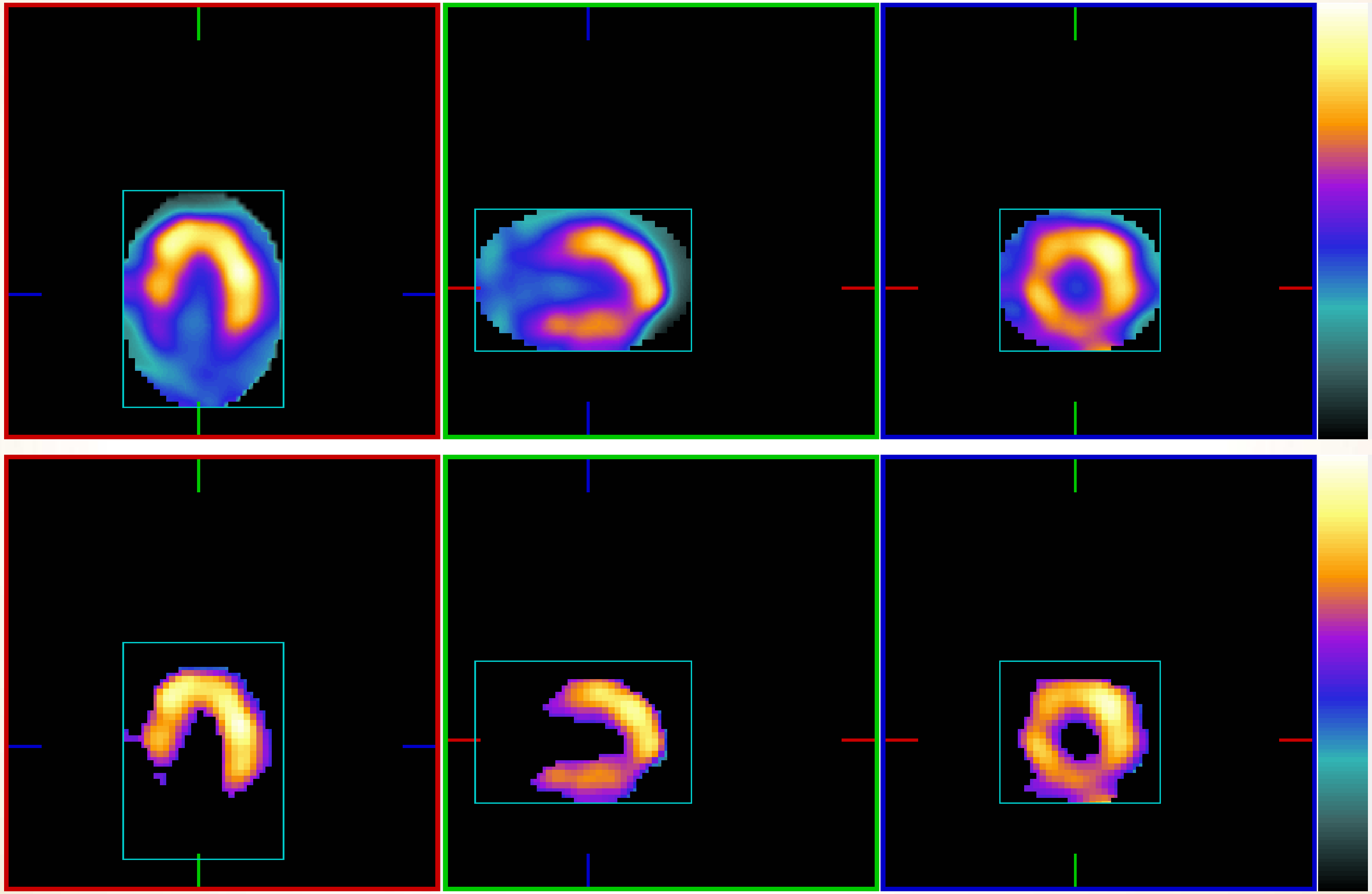
Protocole

Segmentation myocardique



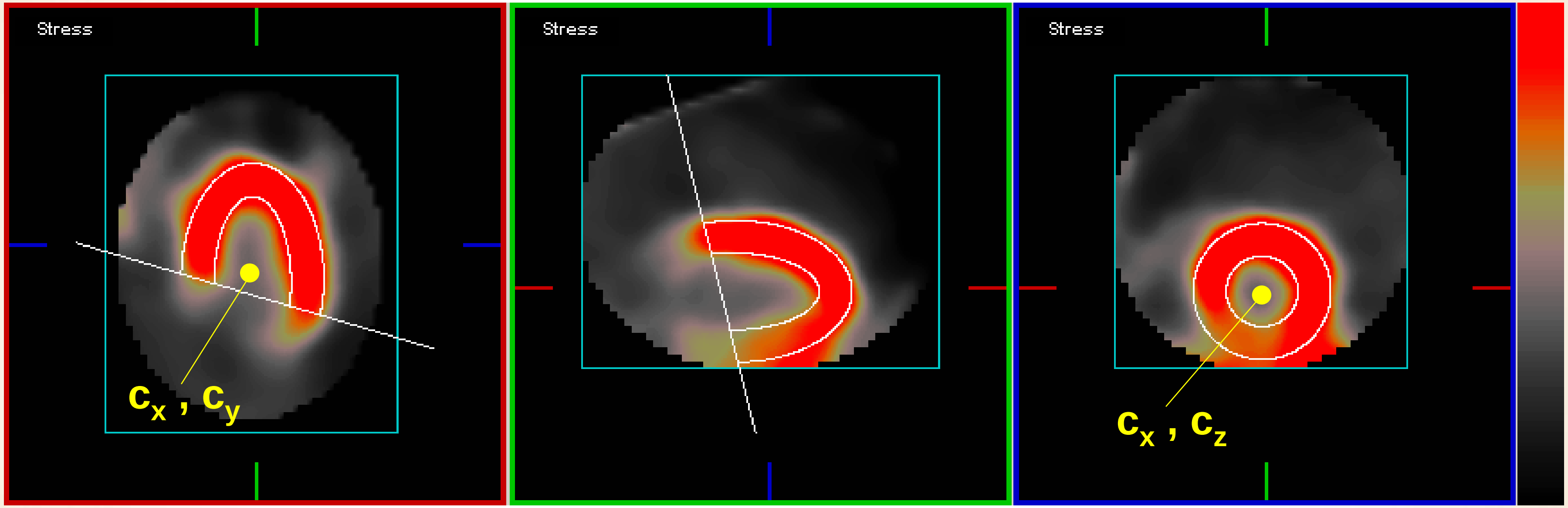
Protocole

Segmentation myocardique



Protocole

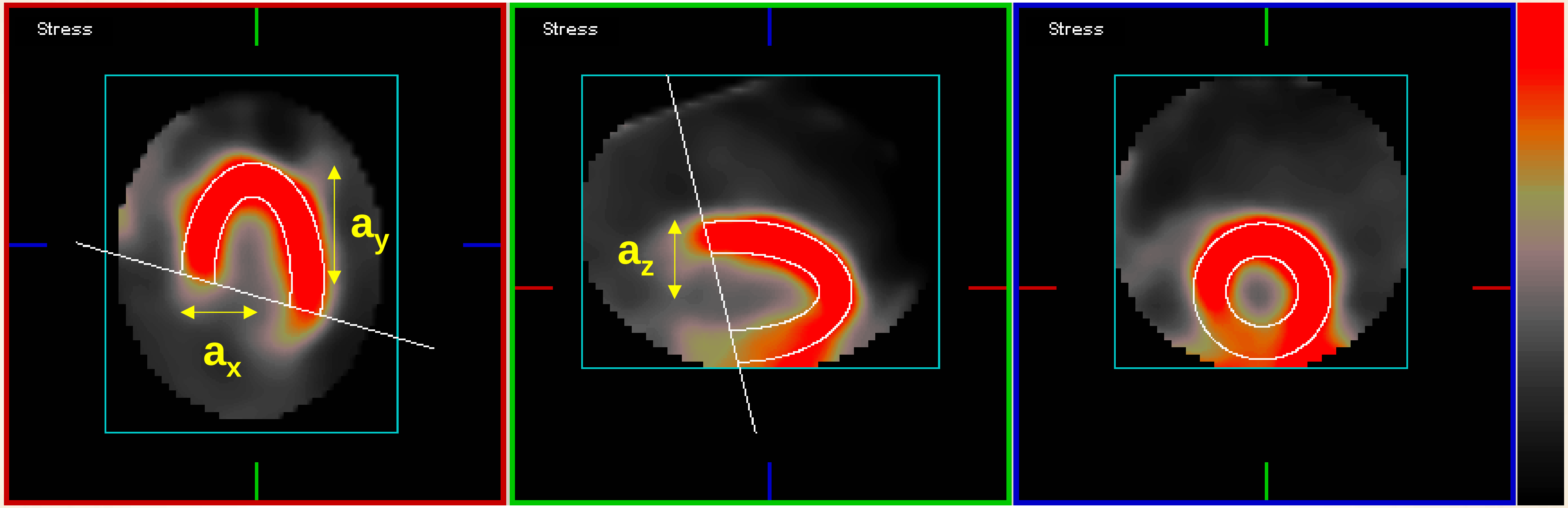
Segmentation myocardique



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

Protocole

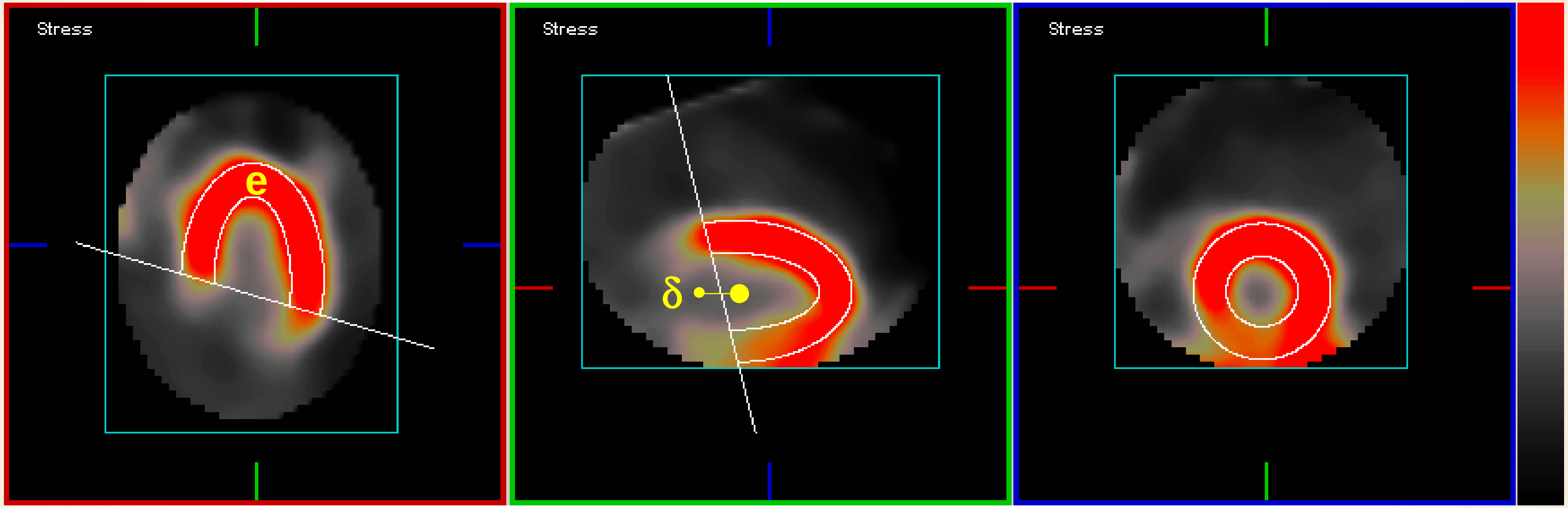
Segmentation myocardique



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

Protocole

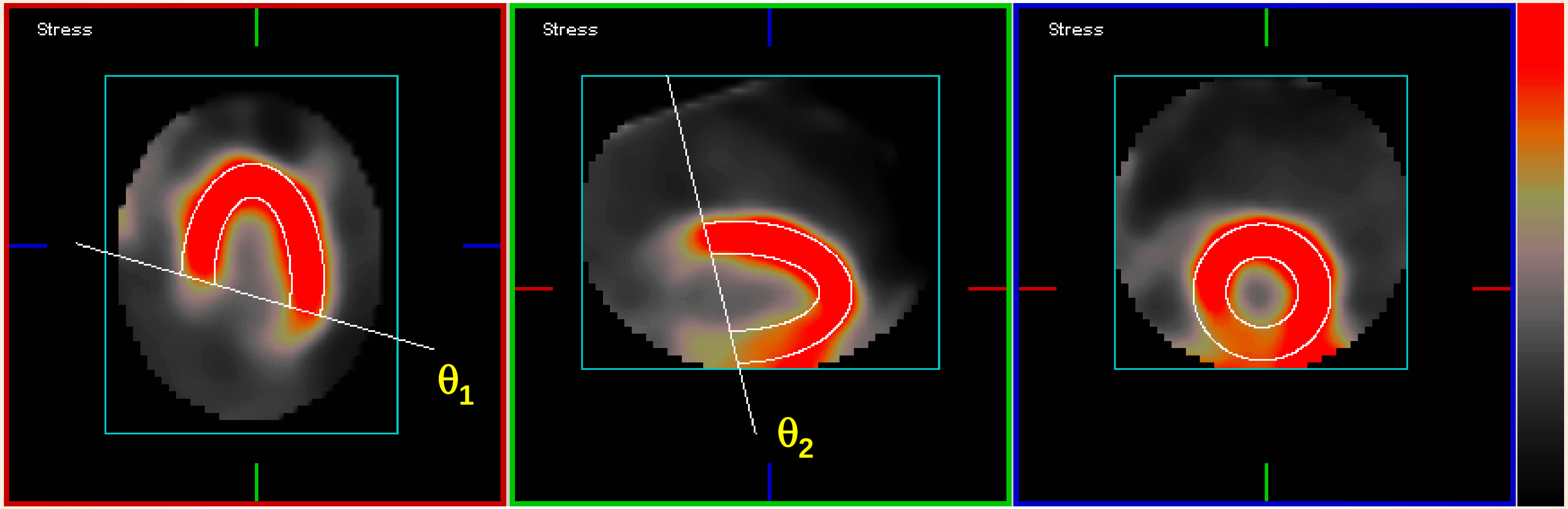
Segmentation myocardique



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

Protocole

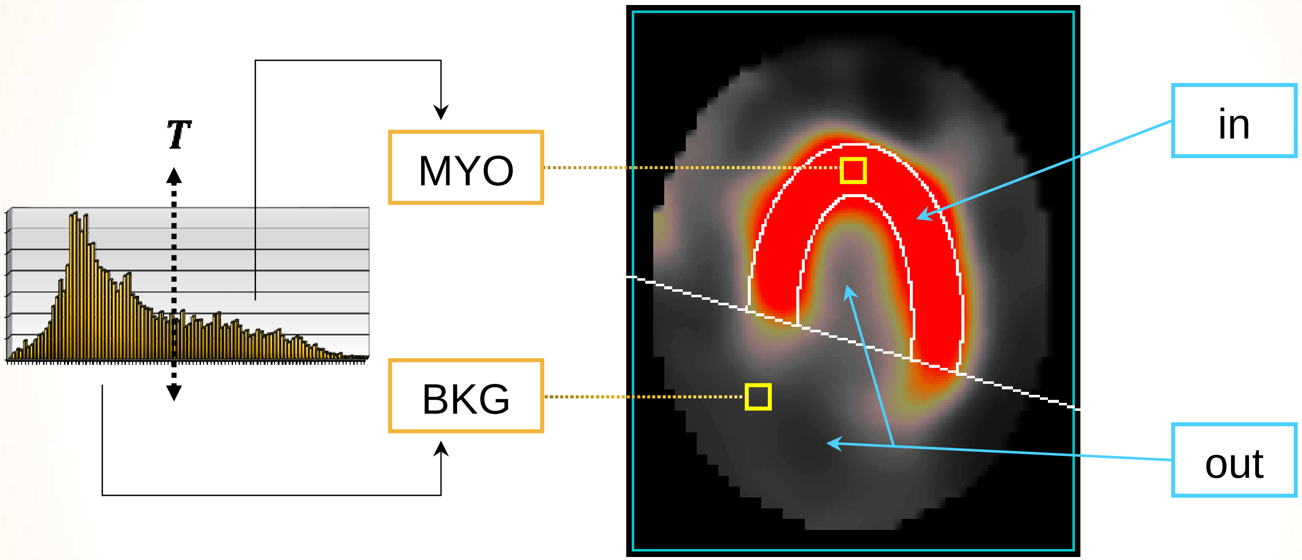
Segmentation myocardique



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

Protocole

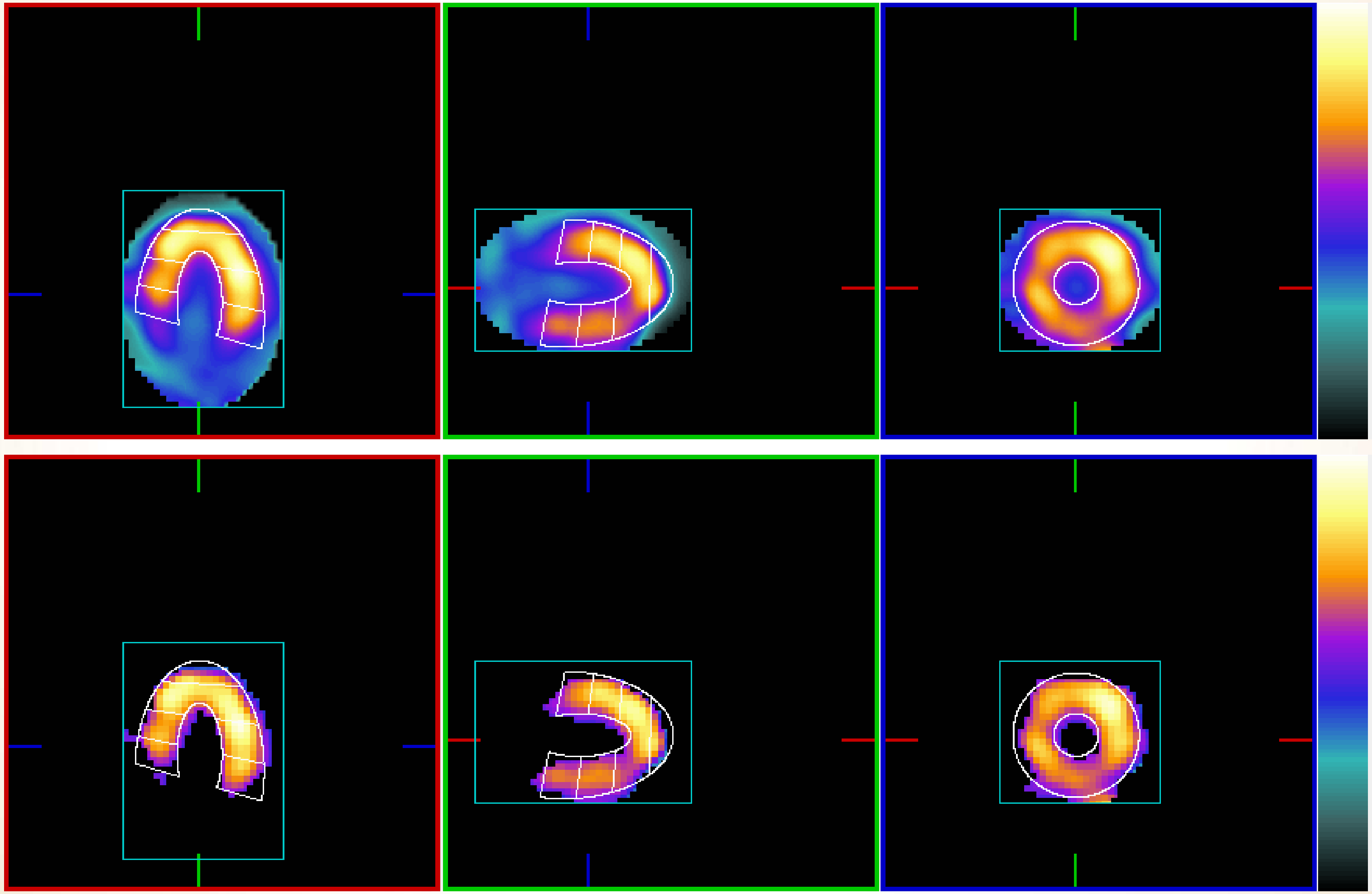
Segmentation myocardique



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

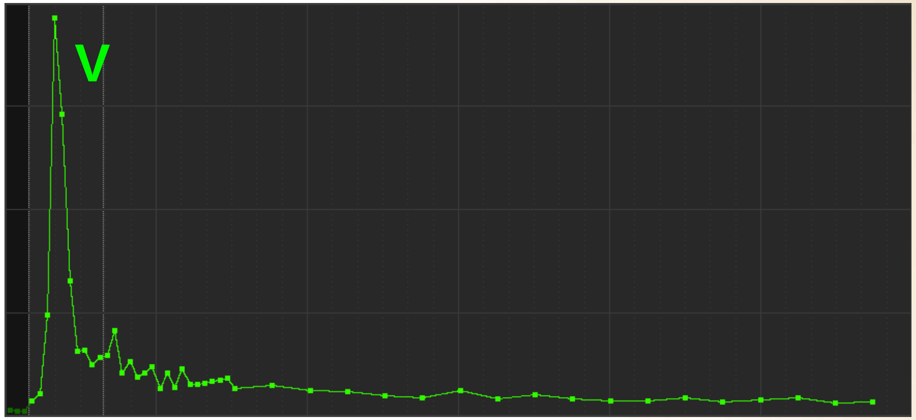
Protocole

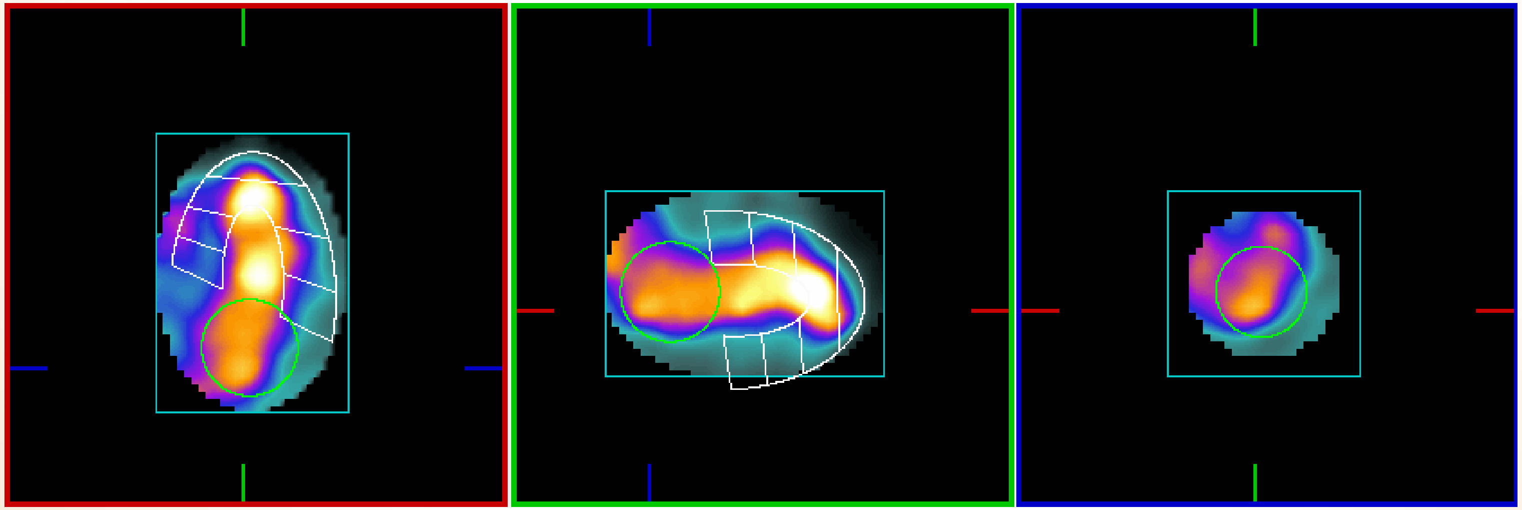
Segmentation myocardique



Protocole

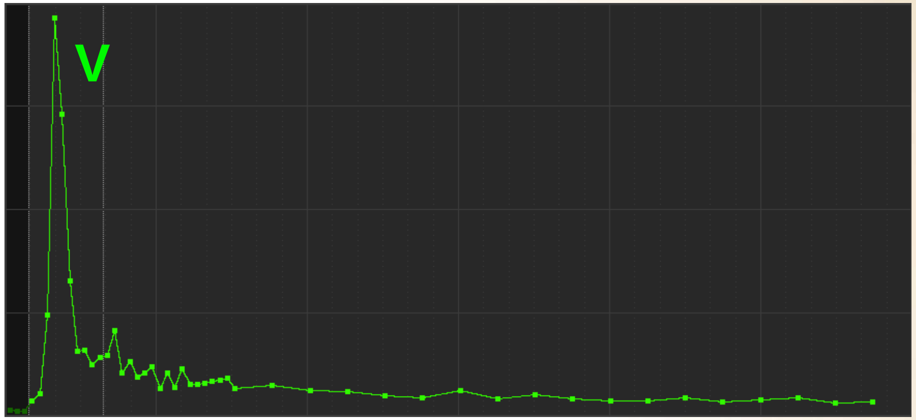
Entrée vasculaire

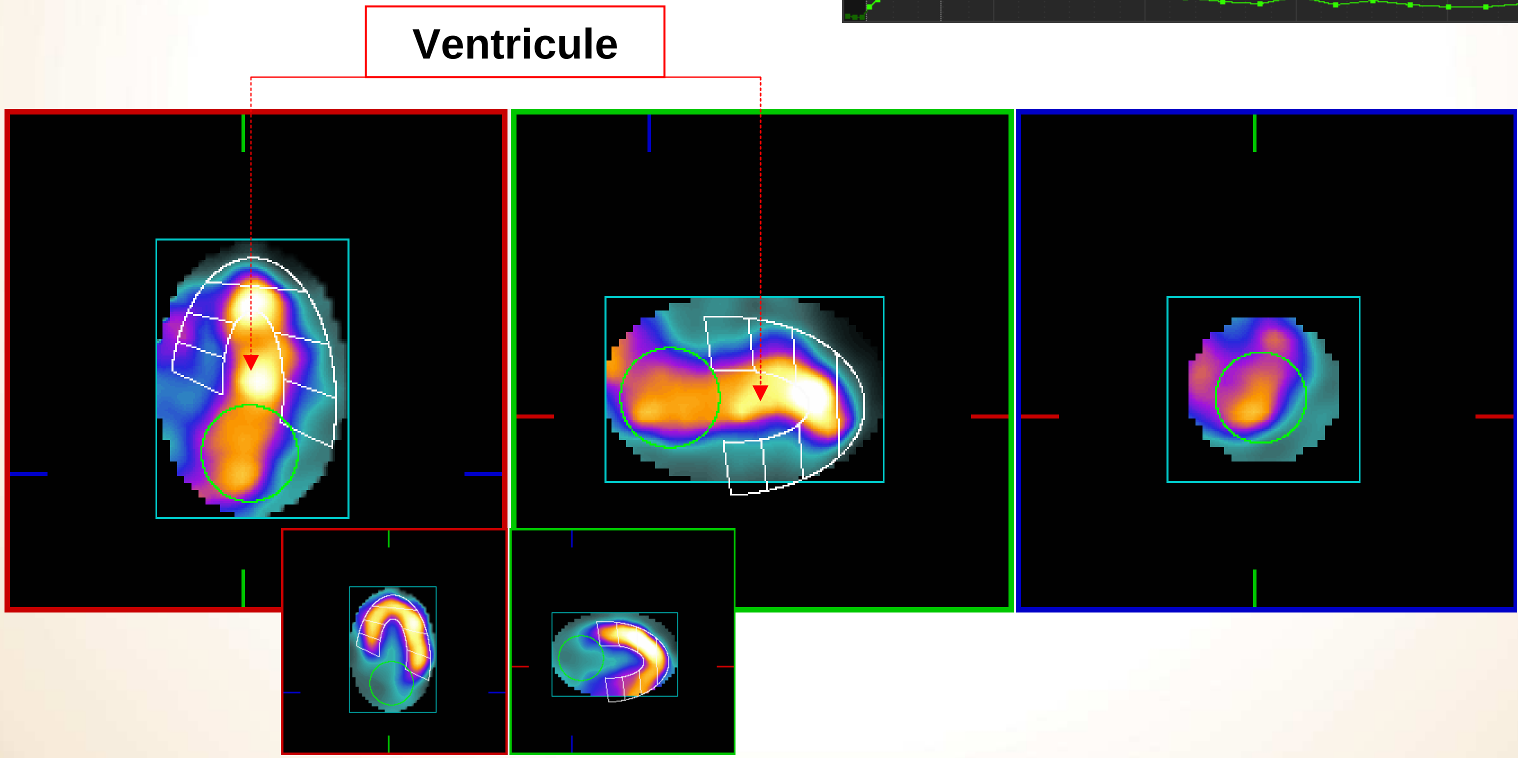




Protocole

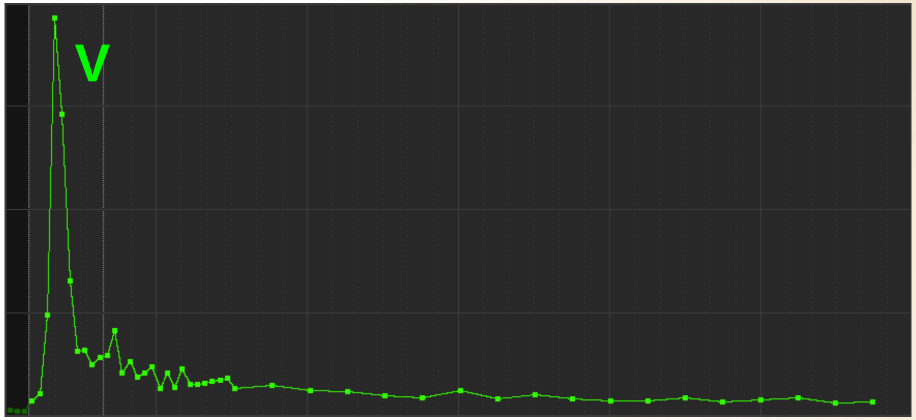
Entrée vasculaire

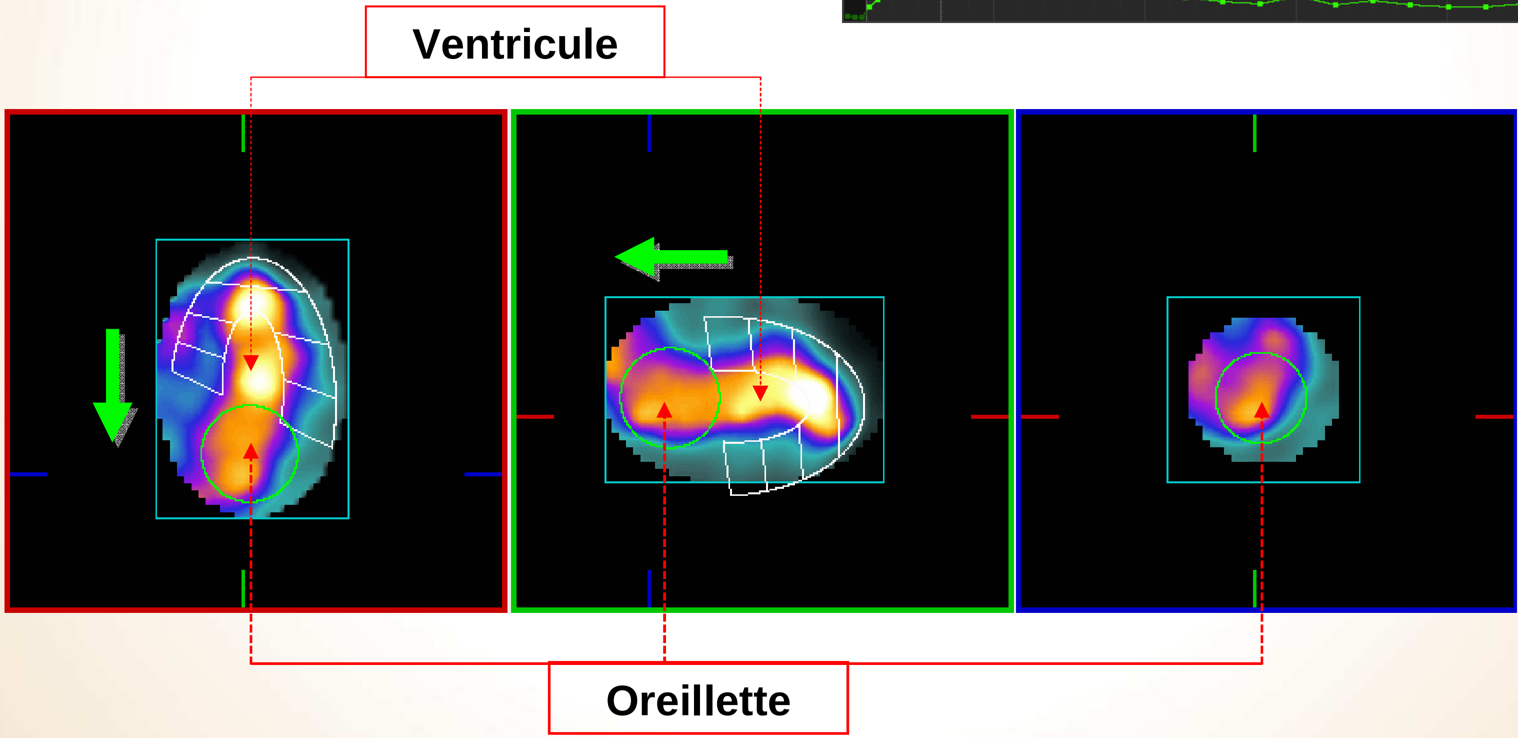




Protocole

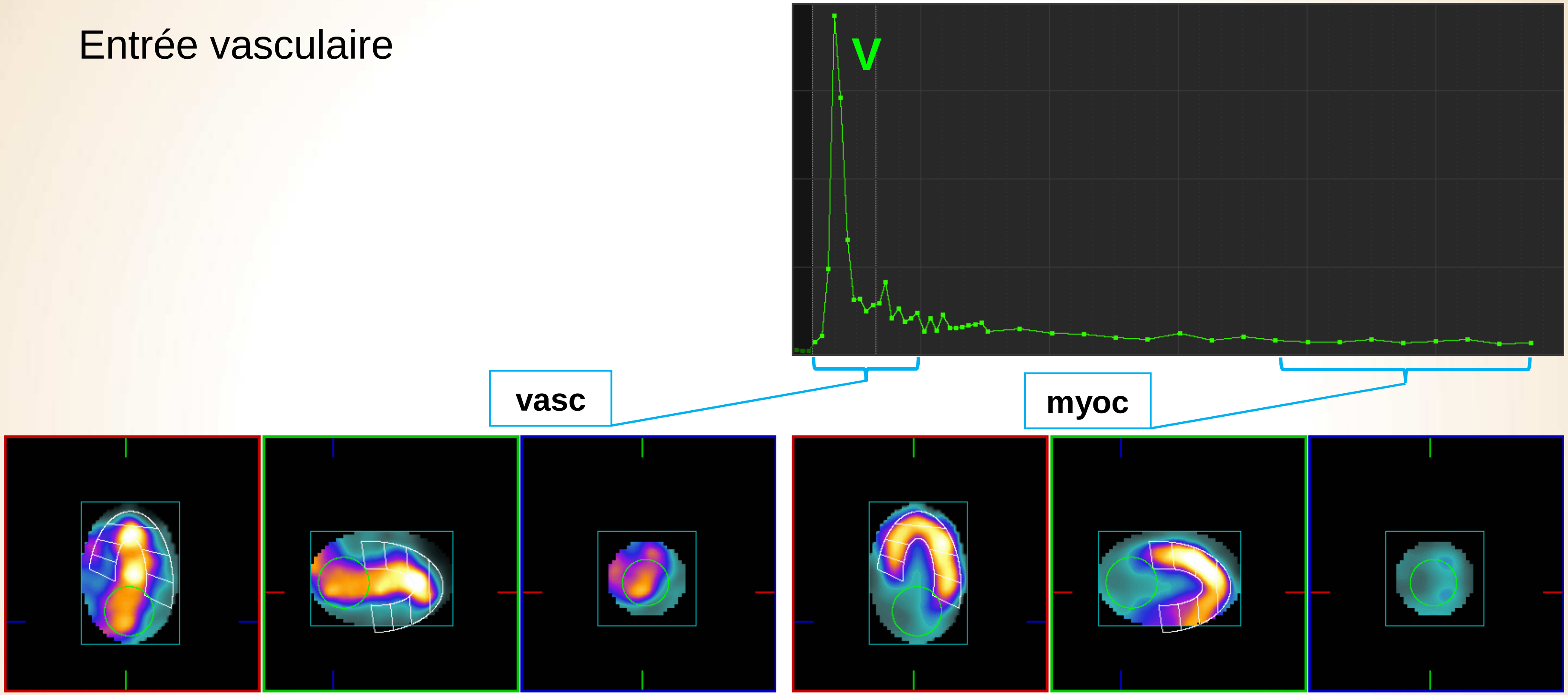
Entrée vasculaire





Protocole

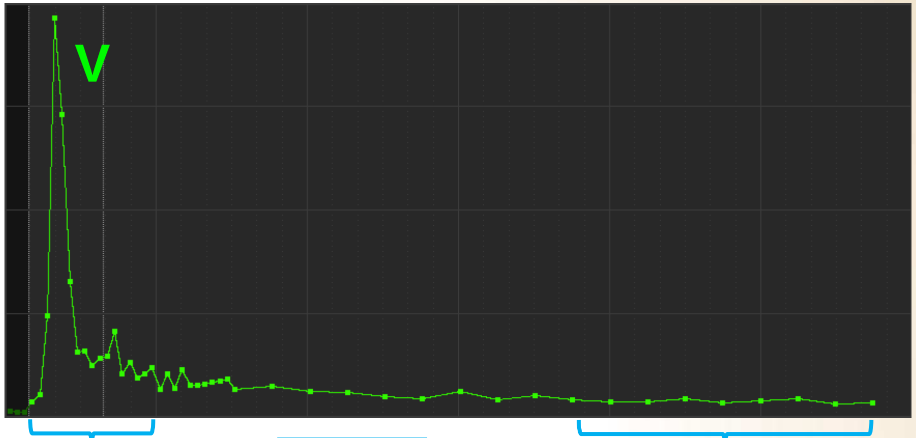
Entrée vasculaire

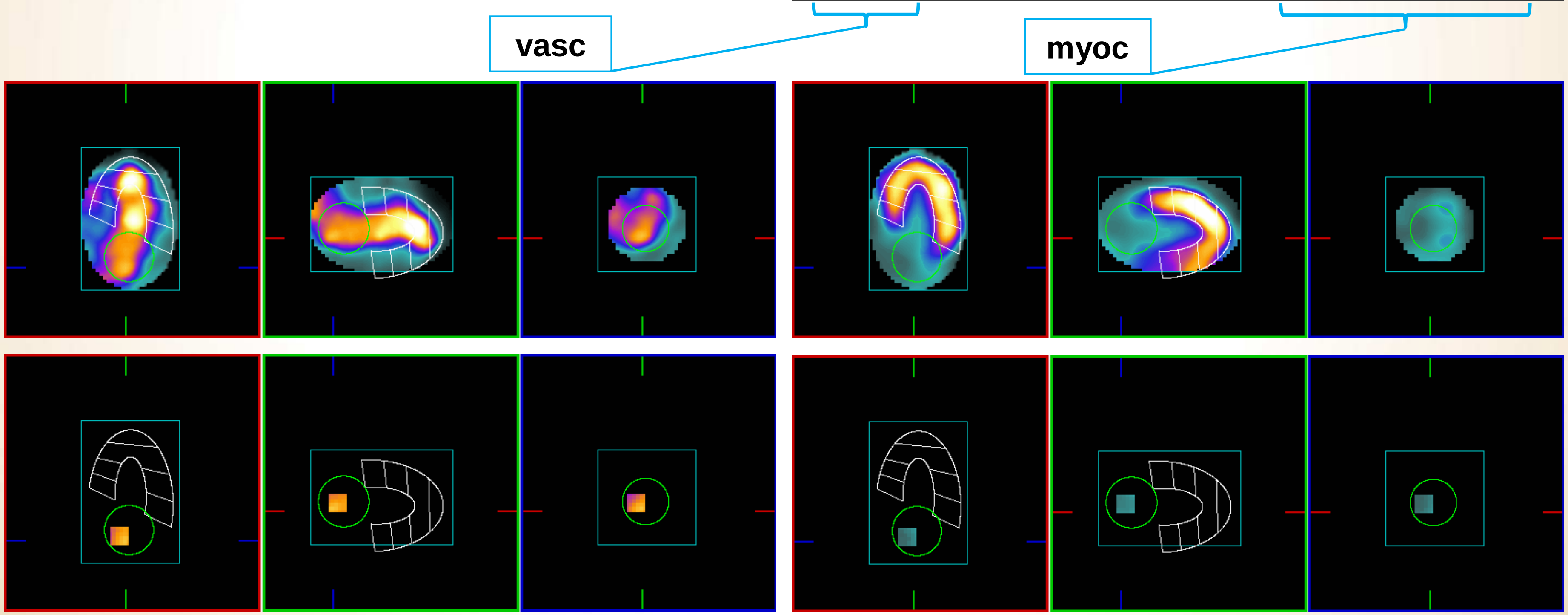


Protocole

Entrée vasculaire

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

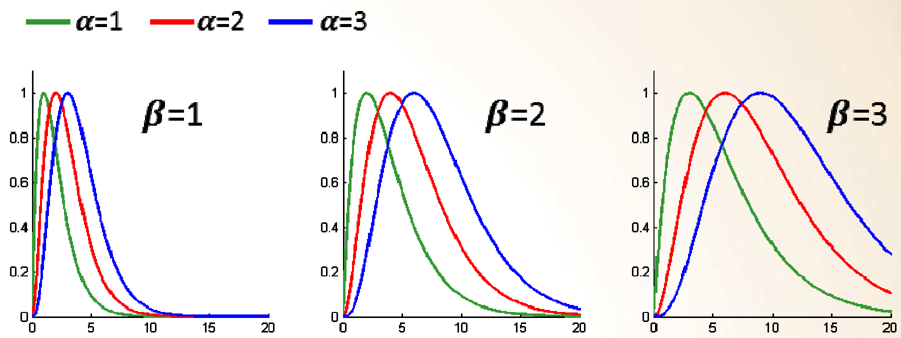


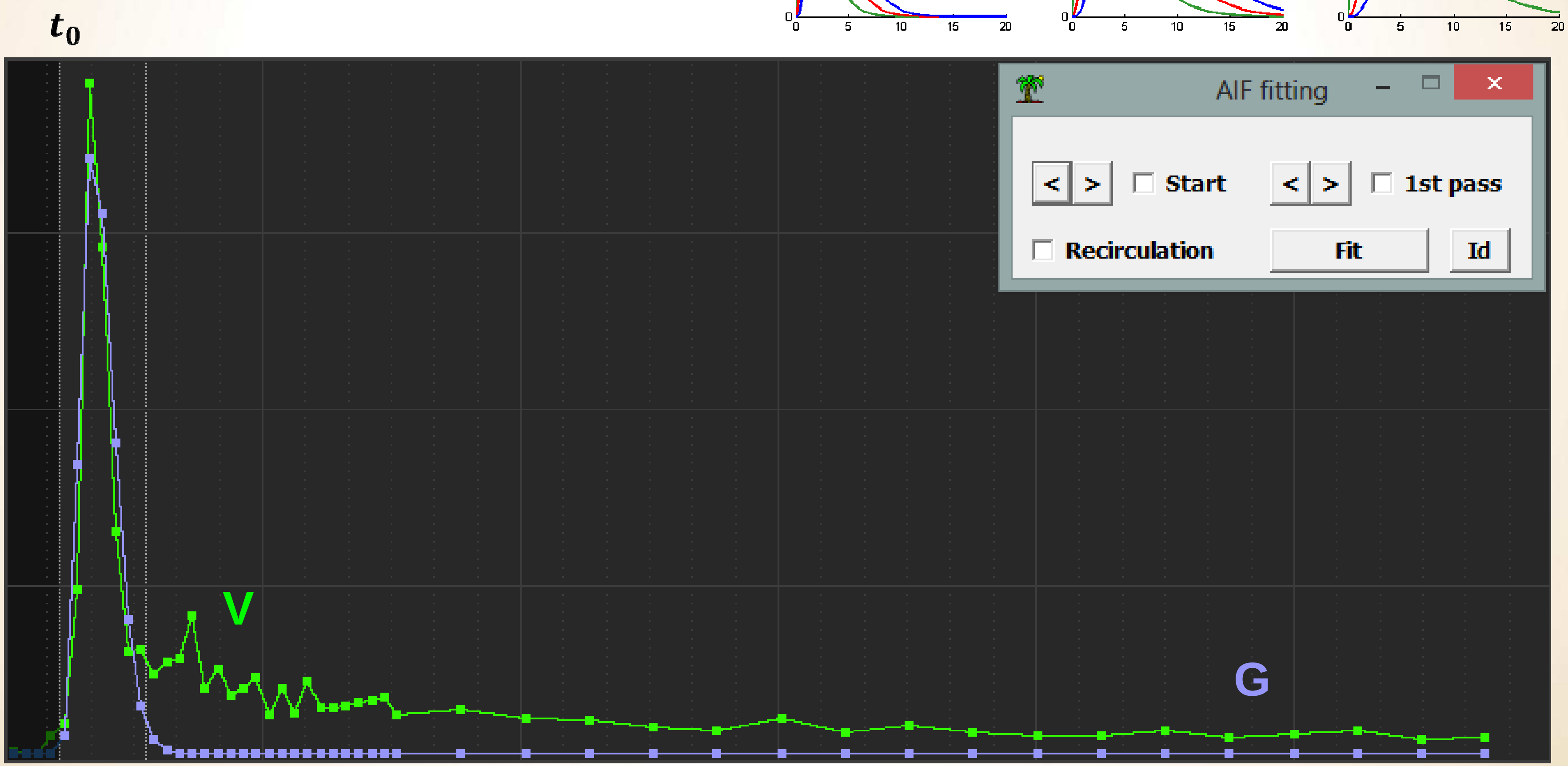


Protocole

Entrée vasculaire

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





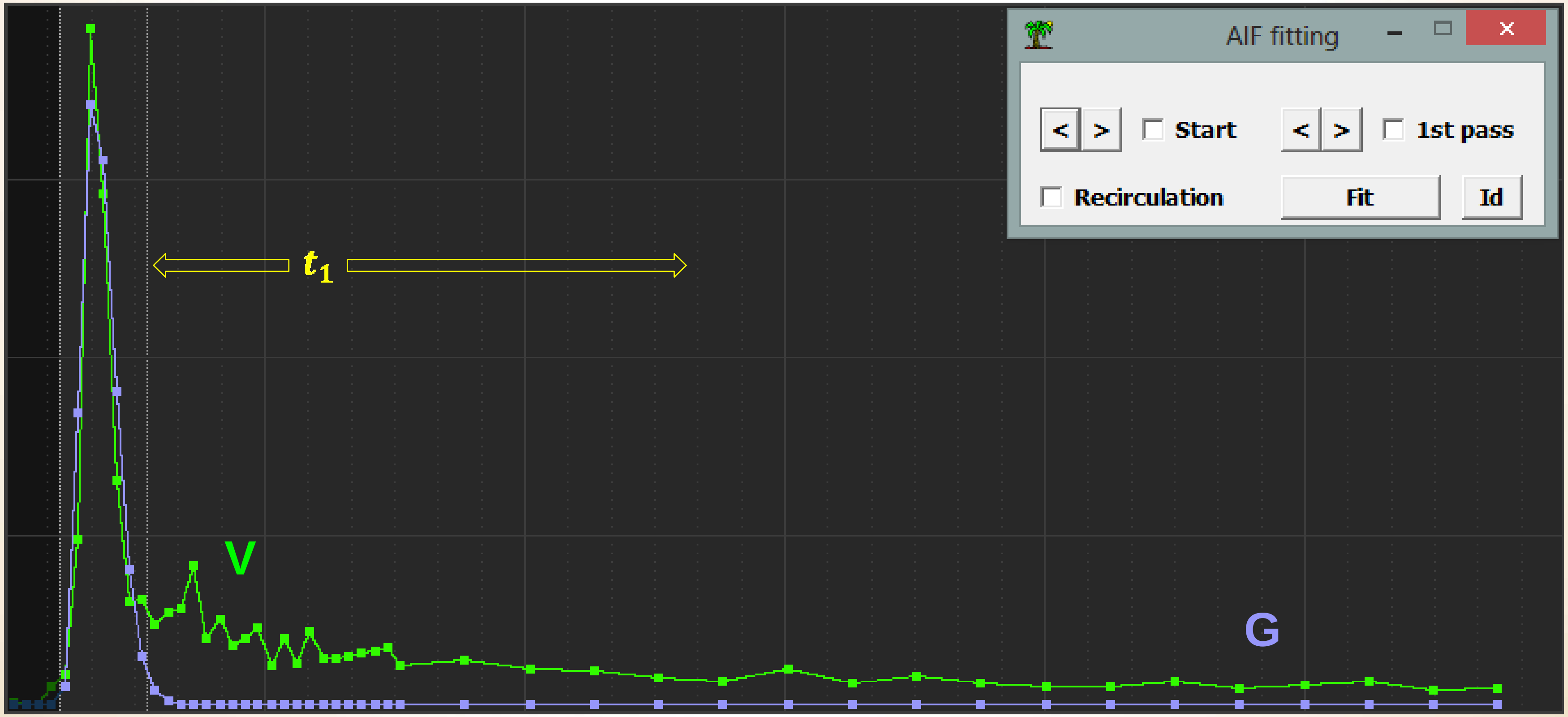
Protocole

Entrée vasculaire

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

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

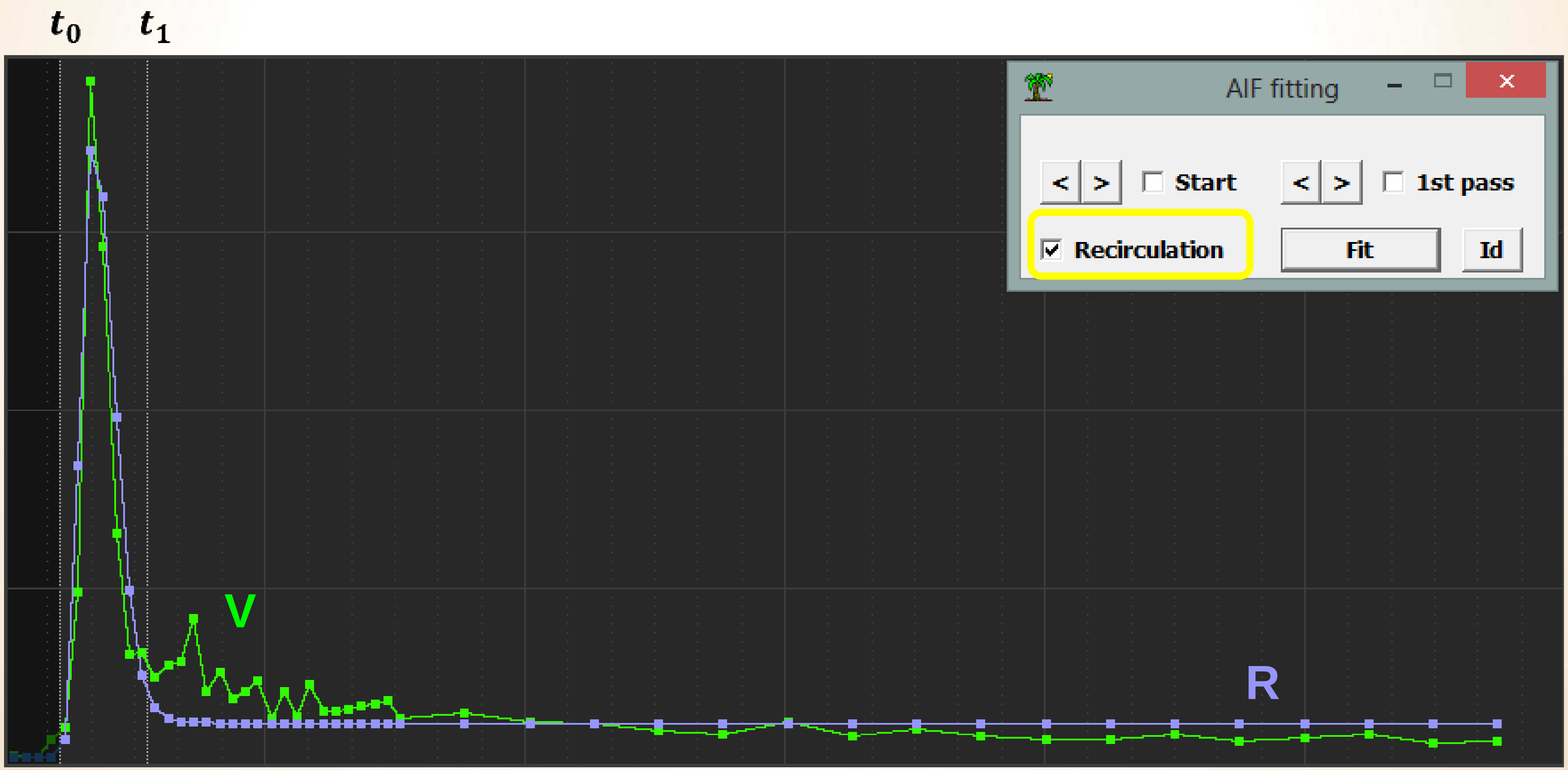
t_0 t_1



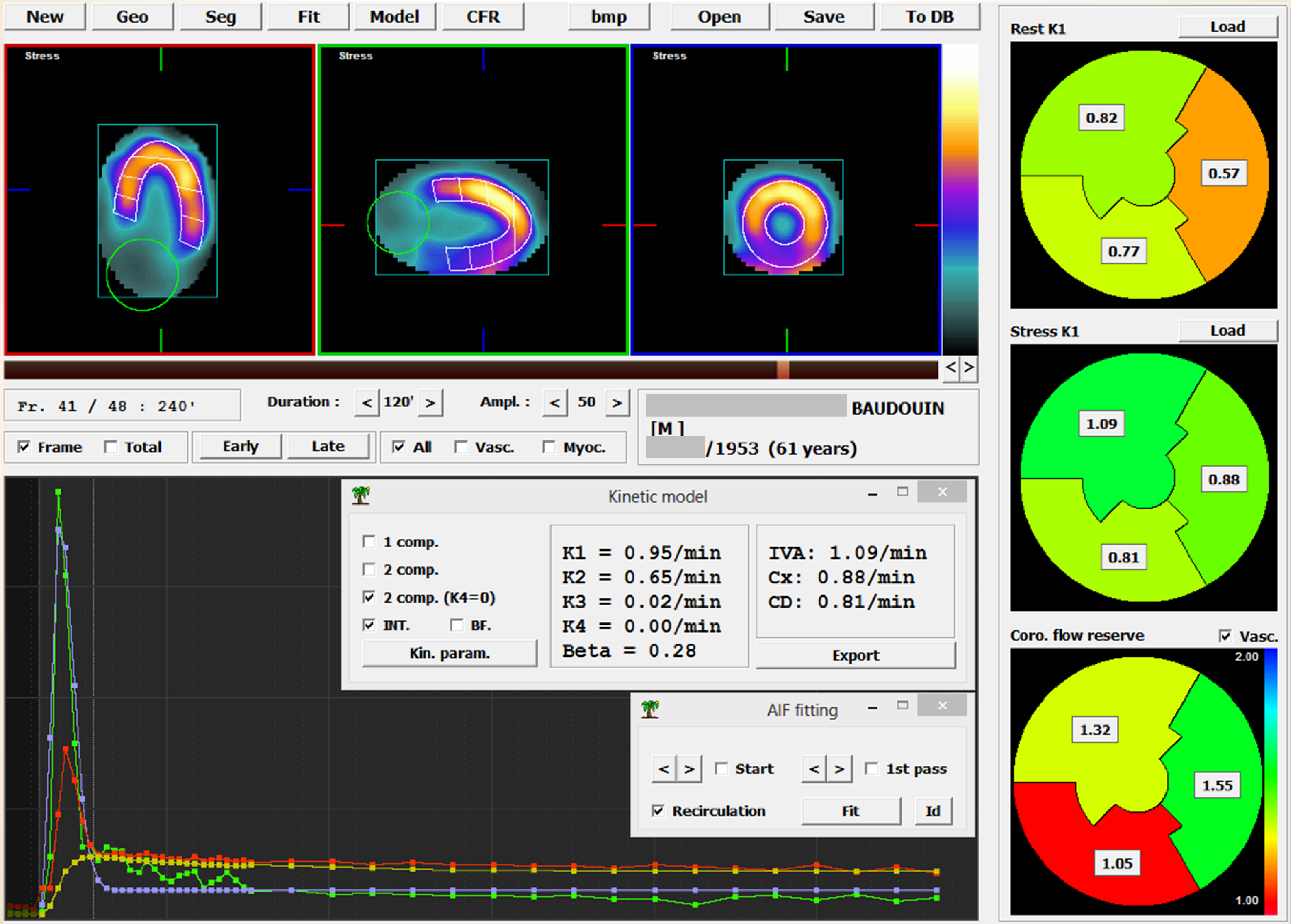
Protocole

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 >
BAUDOUIN
[M]
/1953 (61 years)
Frame
Total
Early
Late
All
Vasc.
Myoc.
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

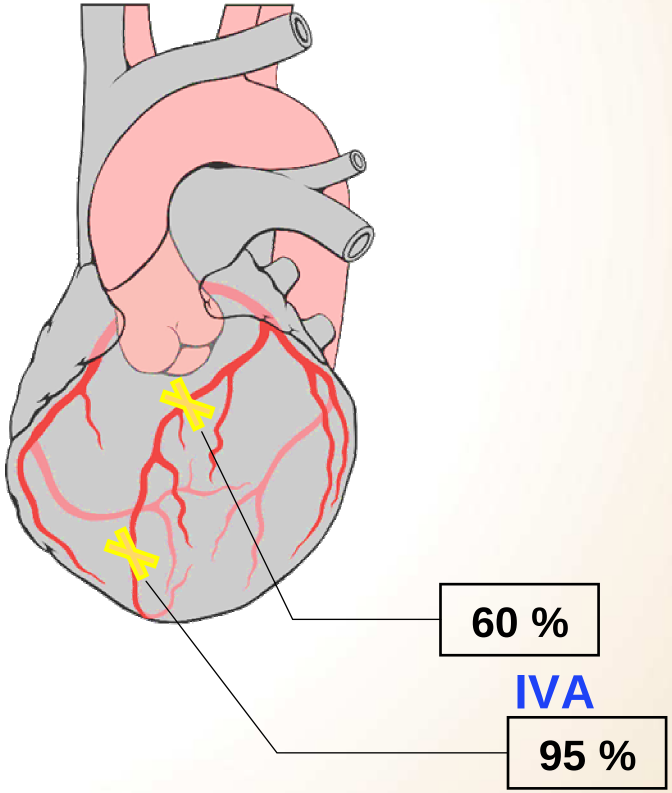
Infarctus inférieur

CORO à H3

Protocole

Exemple : Mme B

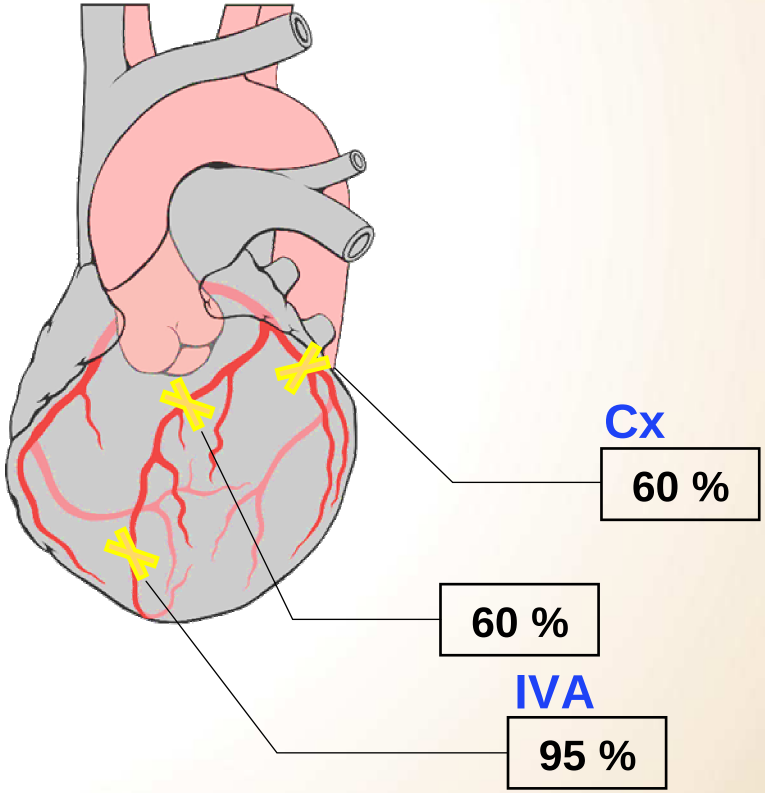
CORO à H3



Protocole

Exemple : Mme B

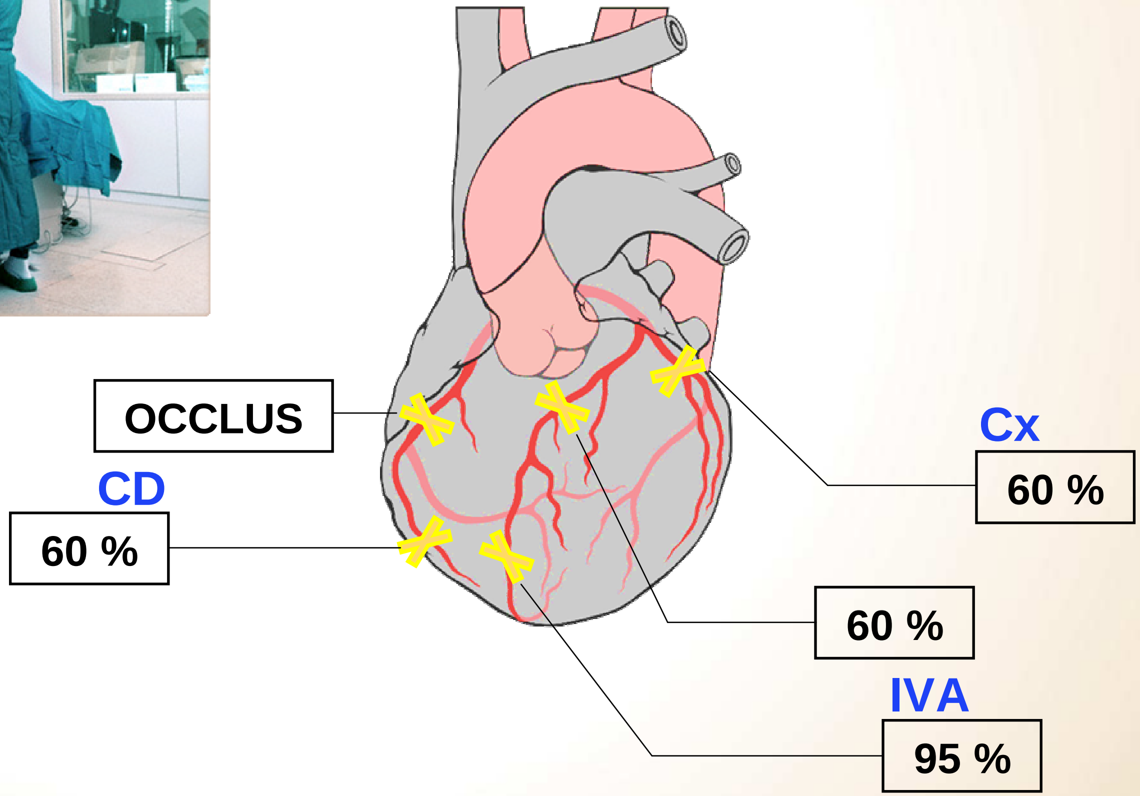
CORO à H3



Protocole

Exemple : Mme B

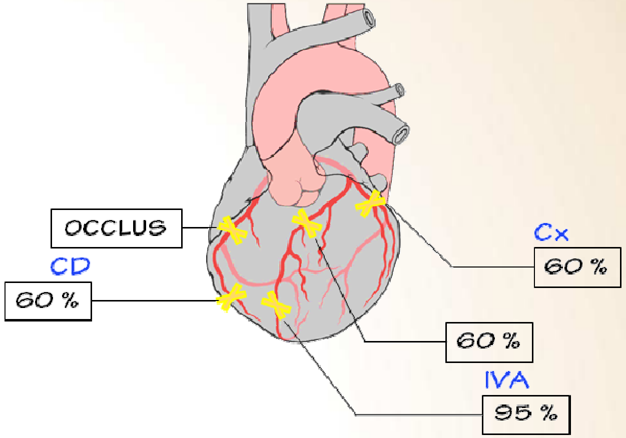
CORO à H3



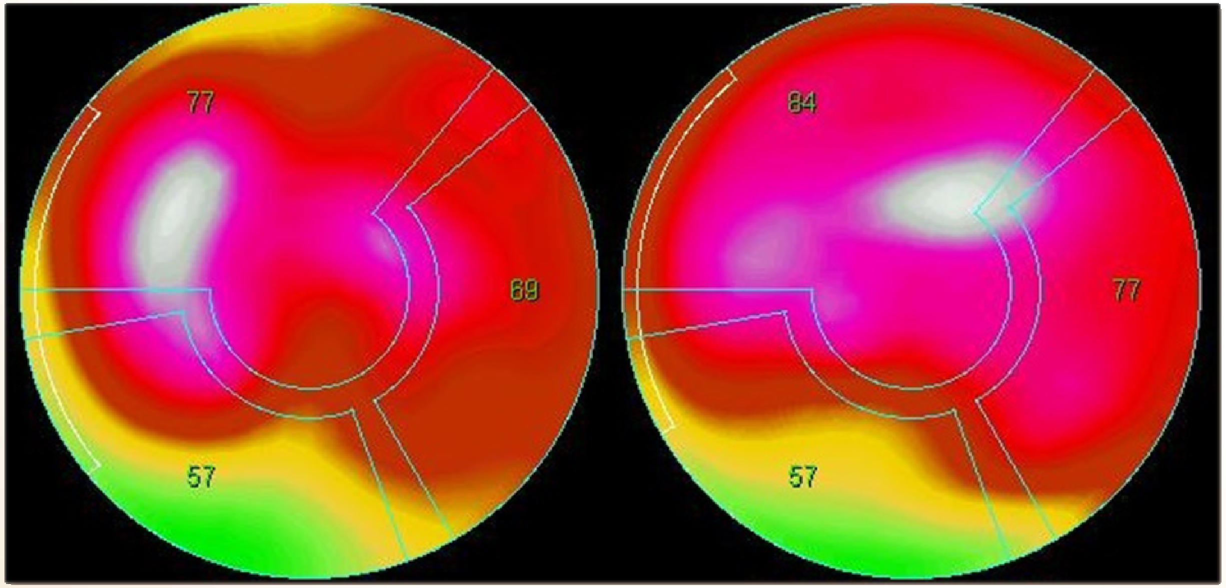
Protocole

Exemple : Mme B

SCINTI à J4 :

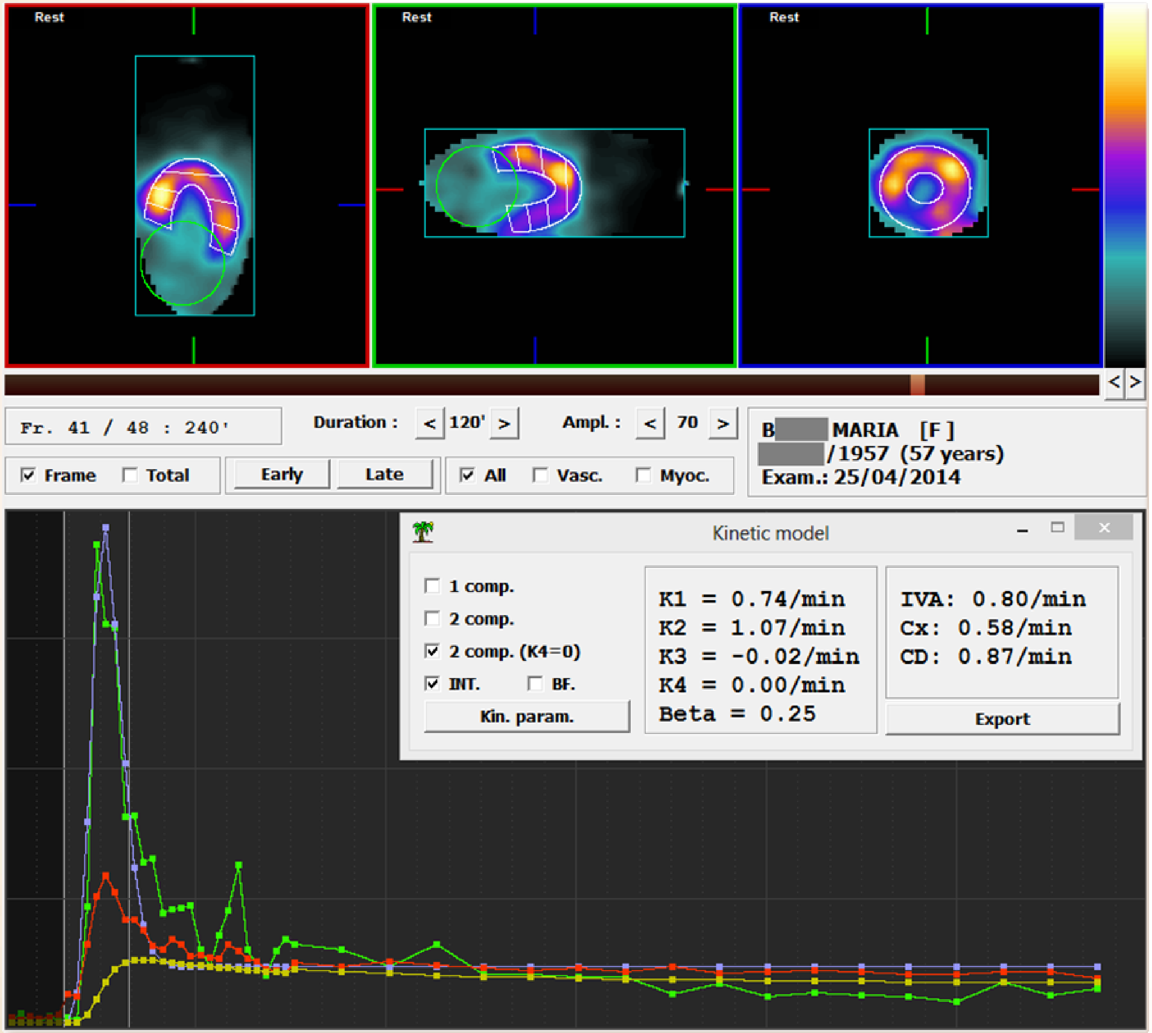


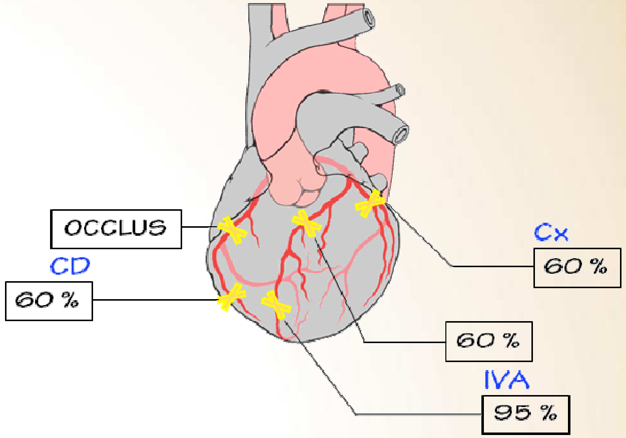
Effort **Repos**



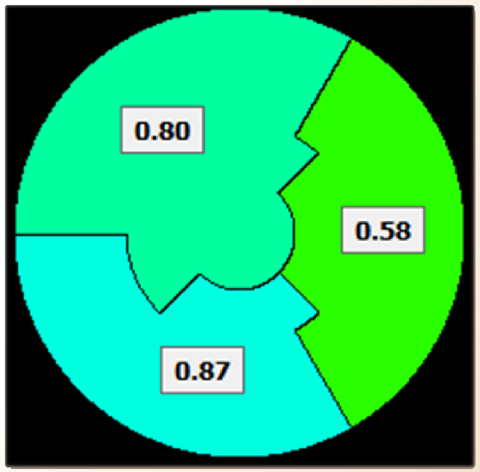
Protocole

Exemple : Mme B



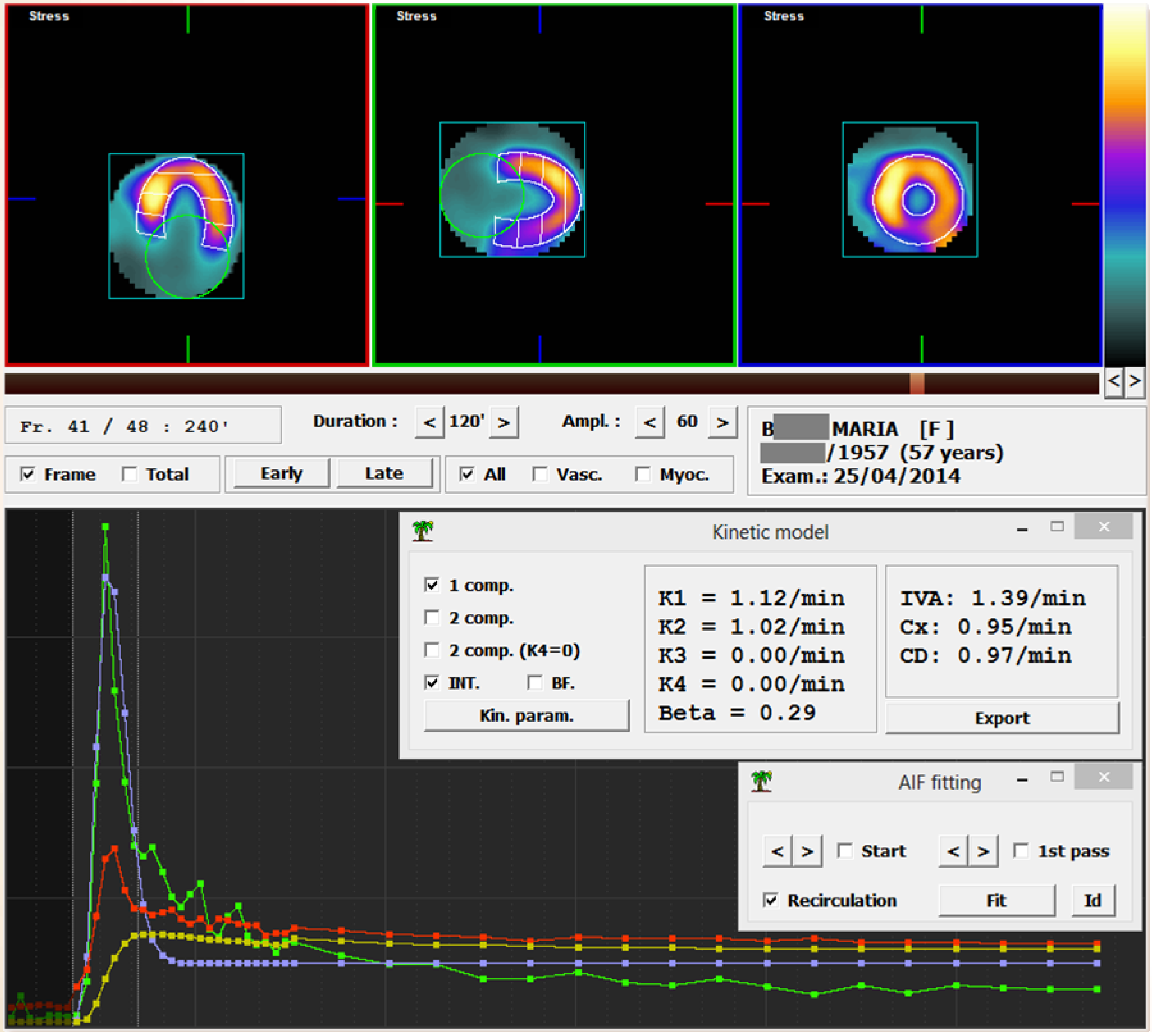


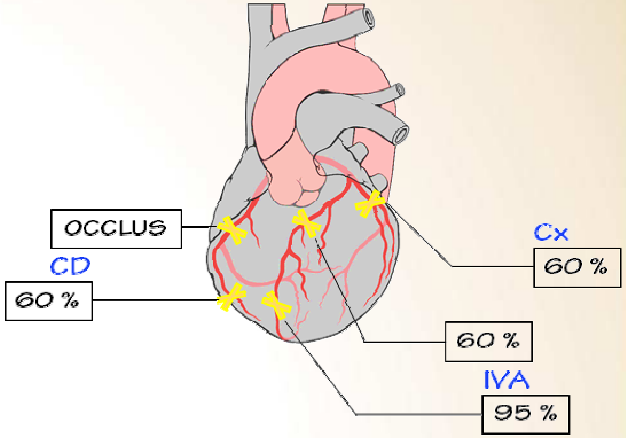
K1 repos



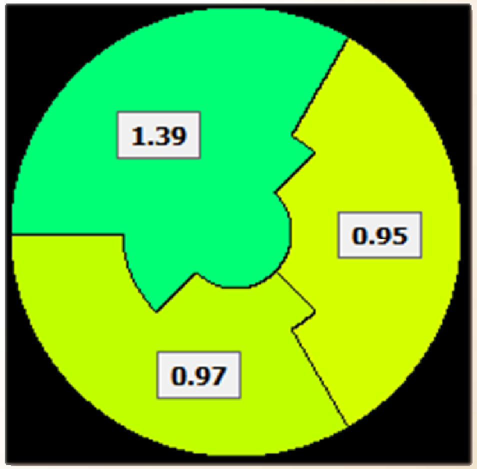
Protocole

Exemple : Mme B



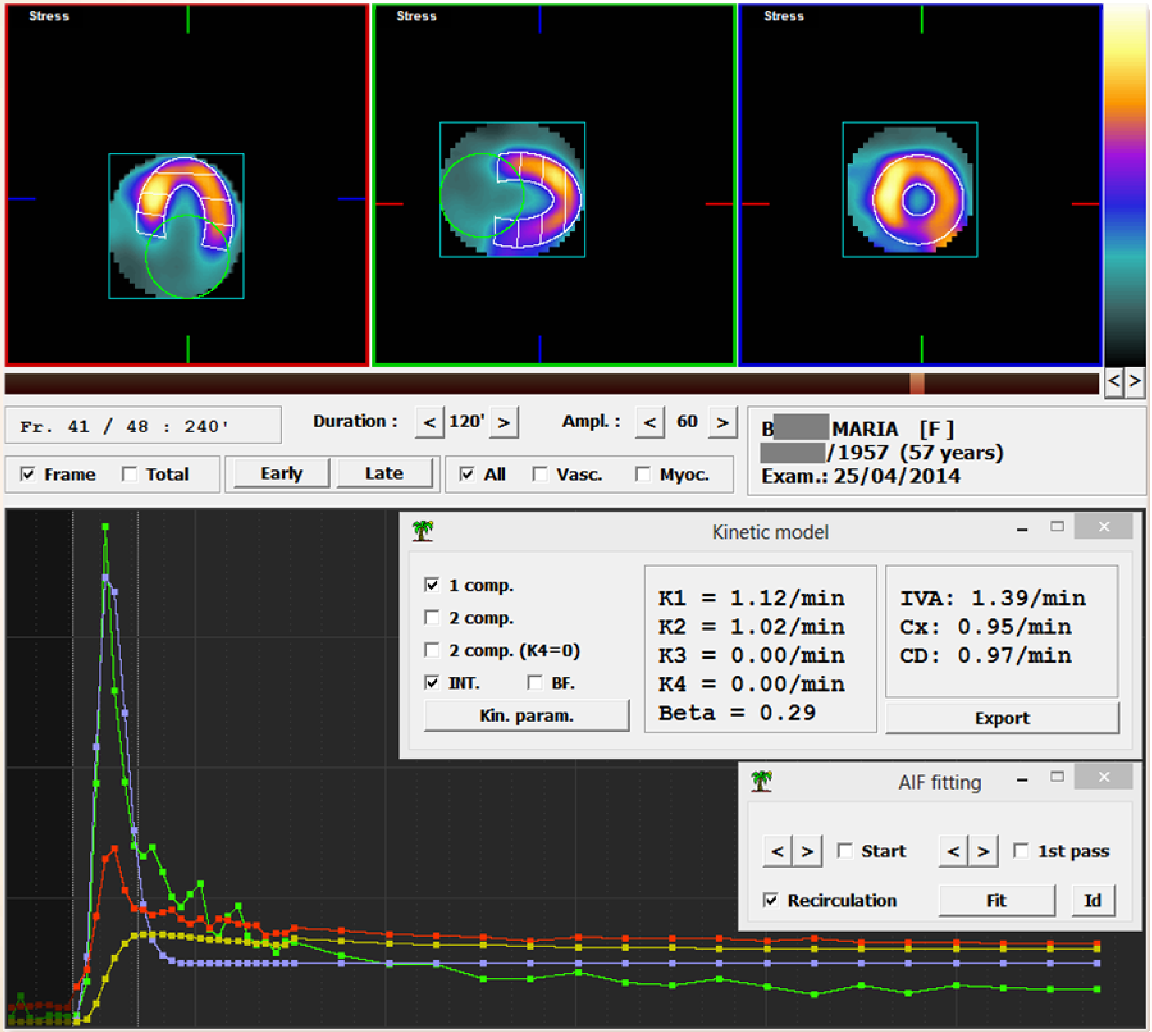


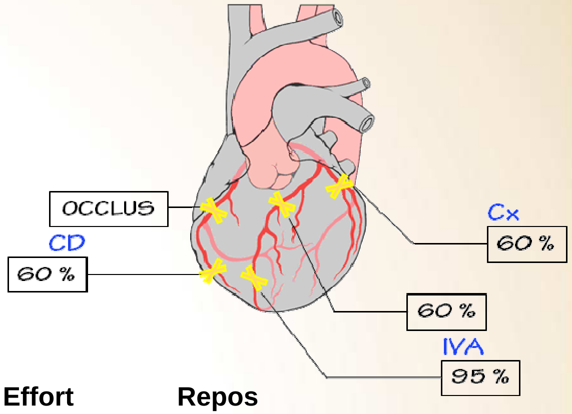
K1 effort



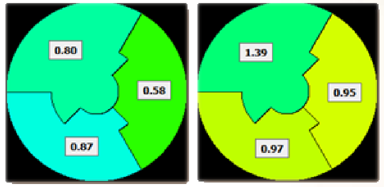
Protocole

Exemple : Mme B





Effort Repos



Réserve coronaire