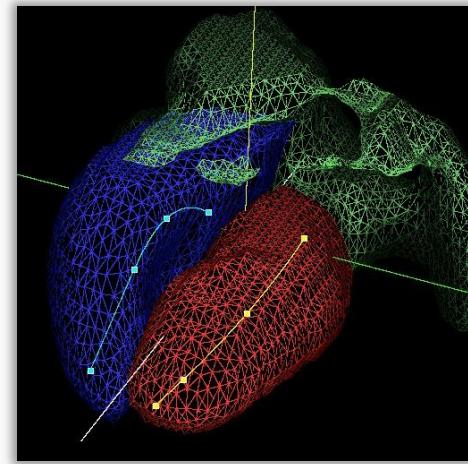


# MASTER PhyMed

## GMPH308 - Physique de l'imagerie médicale

### ANALYSE d'IMAGES MÉDICALES

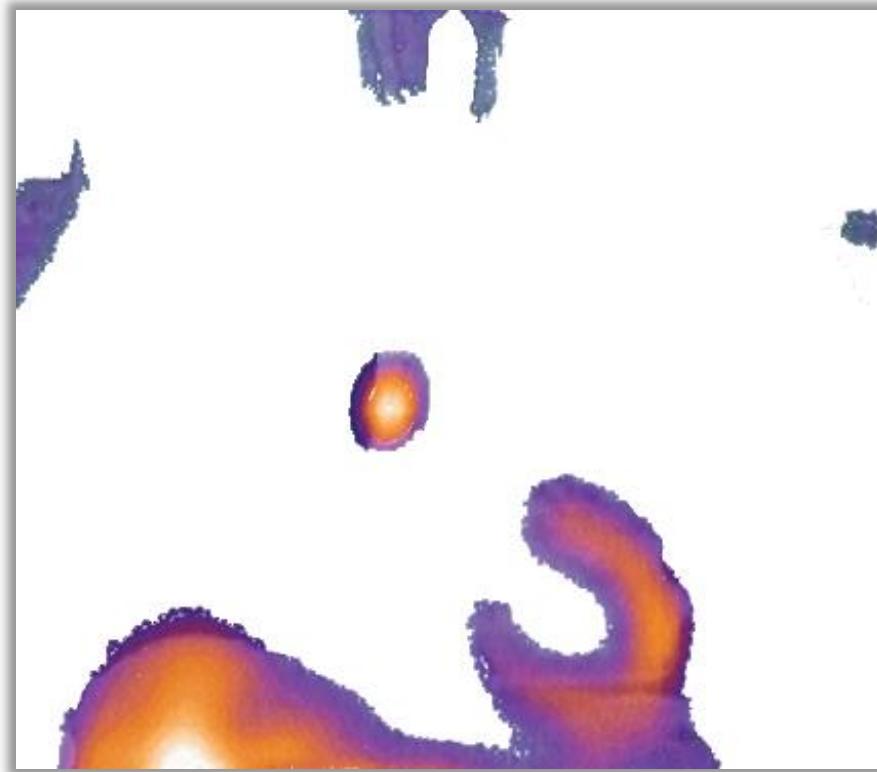
Quelques solutions logicielles



Fayçal Ben Bouallègue  
[faycal.ben-bouallegue@umontpellier.fr](mailto:faycal.ben-bouallegue@umontpellier.fr)  
<http://scinti.edu.umontpellier.fr>

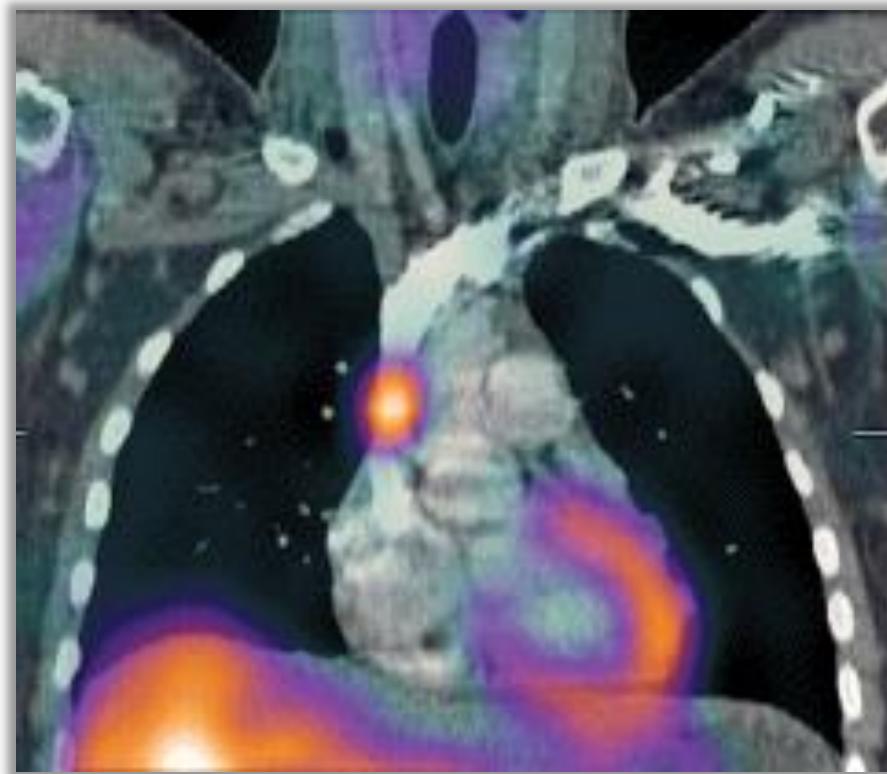
# Recalage d'images multimodales

- Localisation anatomique des anomalies fonctionnelles



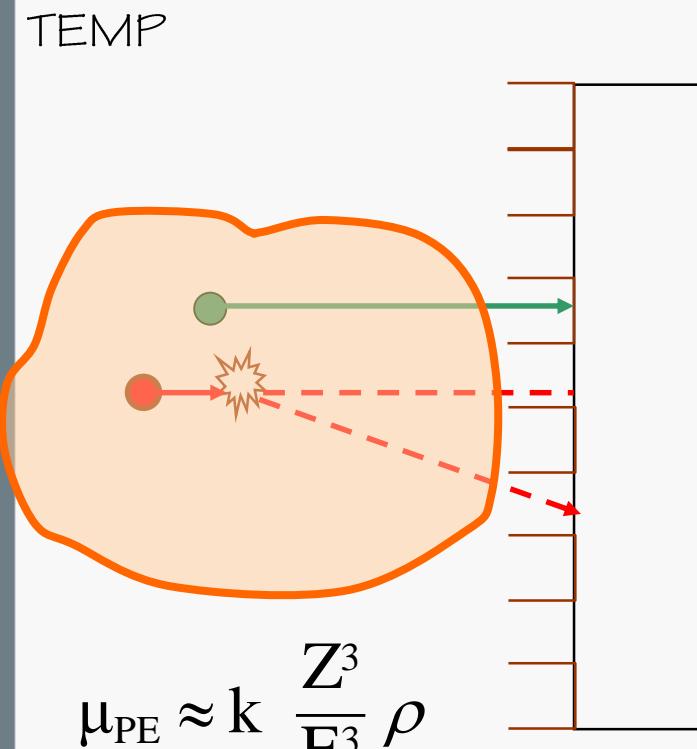
# Recalage d'images multimodales

- Localisation anatomique des anomalies fonctionnelles

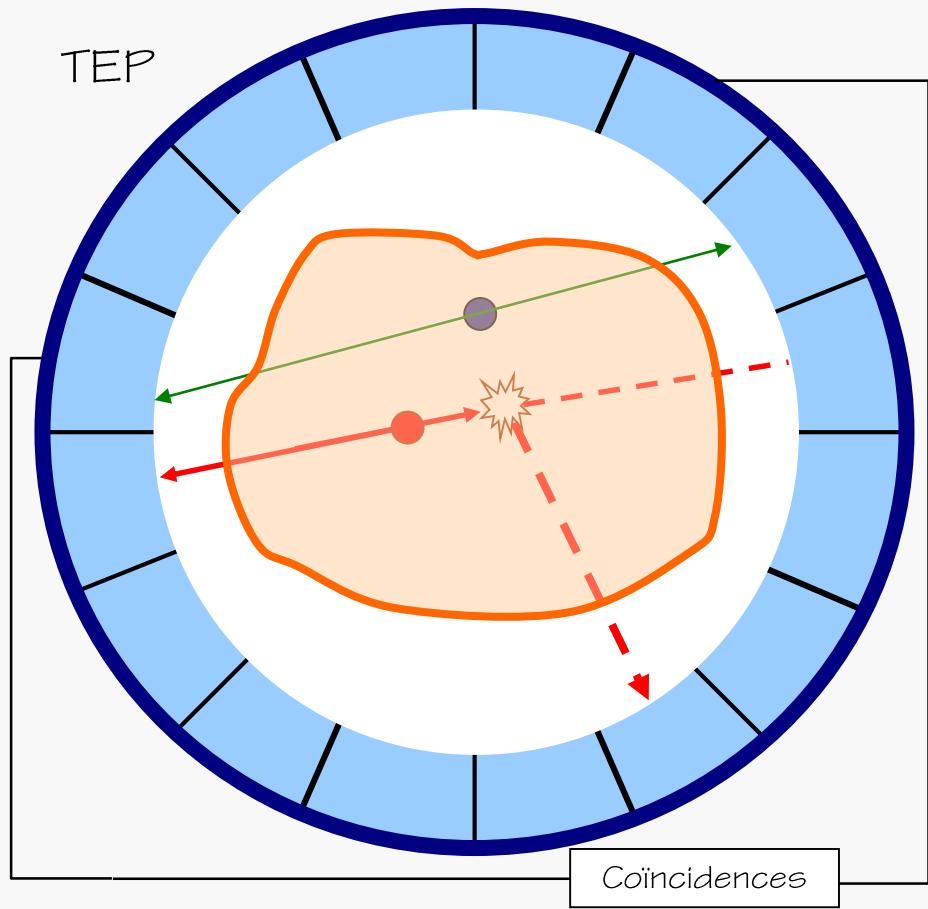


# Recalage d'images multimodales

- Localisation anatomique des anomalies fonctionnelles
- Correction d'atténuation

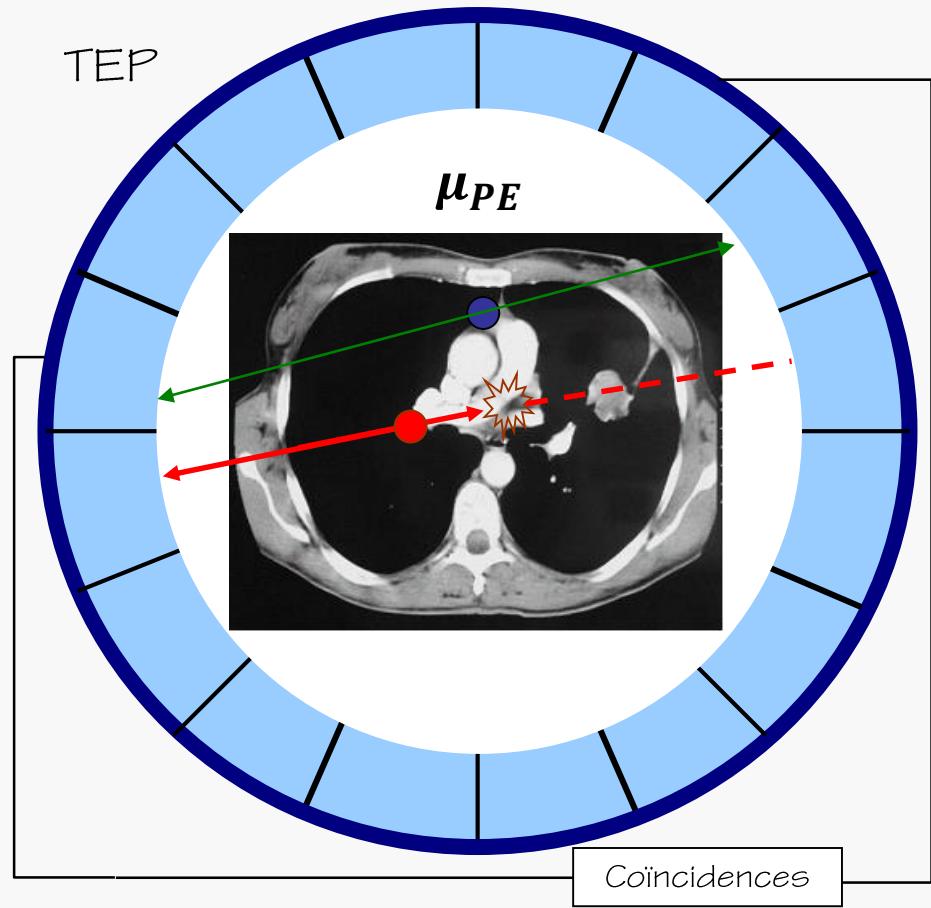
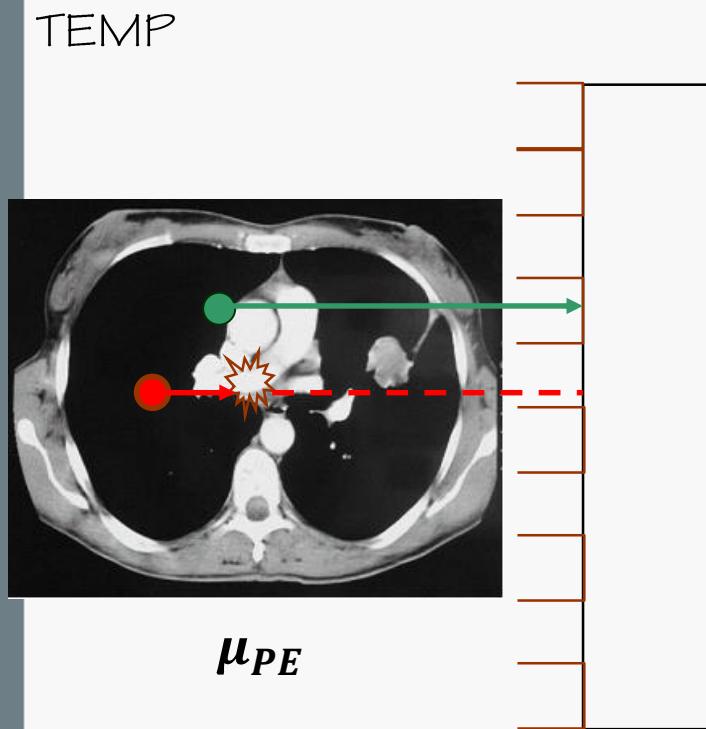


$$\mu_C \approx k' \rho$$



# Recalage d'images multimodales

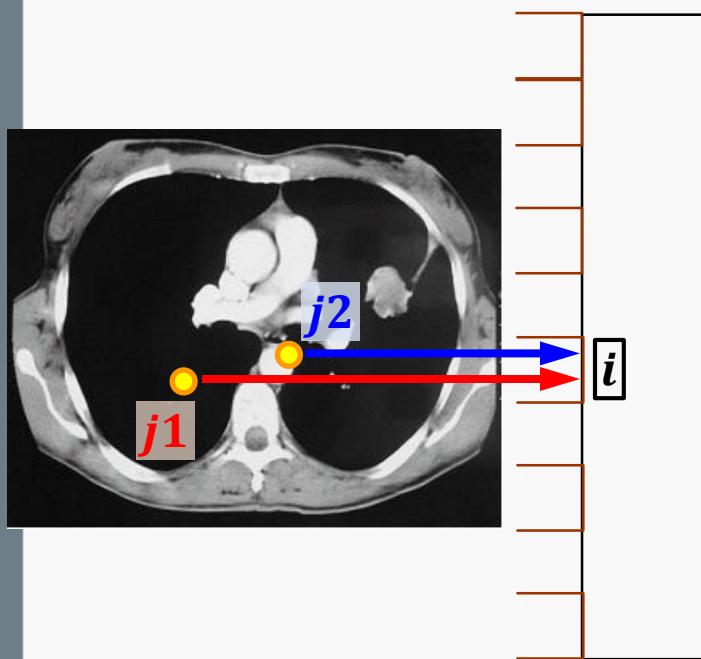
- Localisation anatomique des anomalies fonctionnelles
- Correction d'atténuation



# Recalage d'images multimodales

- Localisation anatomique des anomalies fonctionnelles
- Correction d'atténuation

TEMP



$$p = \mathbf{R}f$$

$$\mathbf{R}_{i,j1} = \wp(j1 \rightarrow i) = \lambda e^{-\int \mu dx}$$
$$\neq$$

$$\mathbf{R}_{i,j2} = \wp(j2 \rightarrow i) = \lambda e^{-\int \mu dx}$$

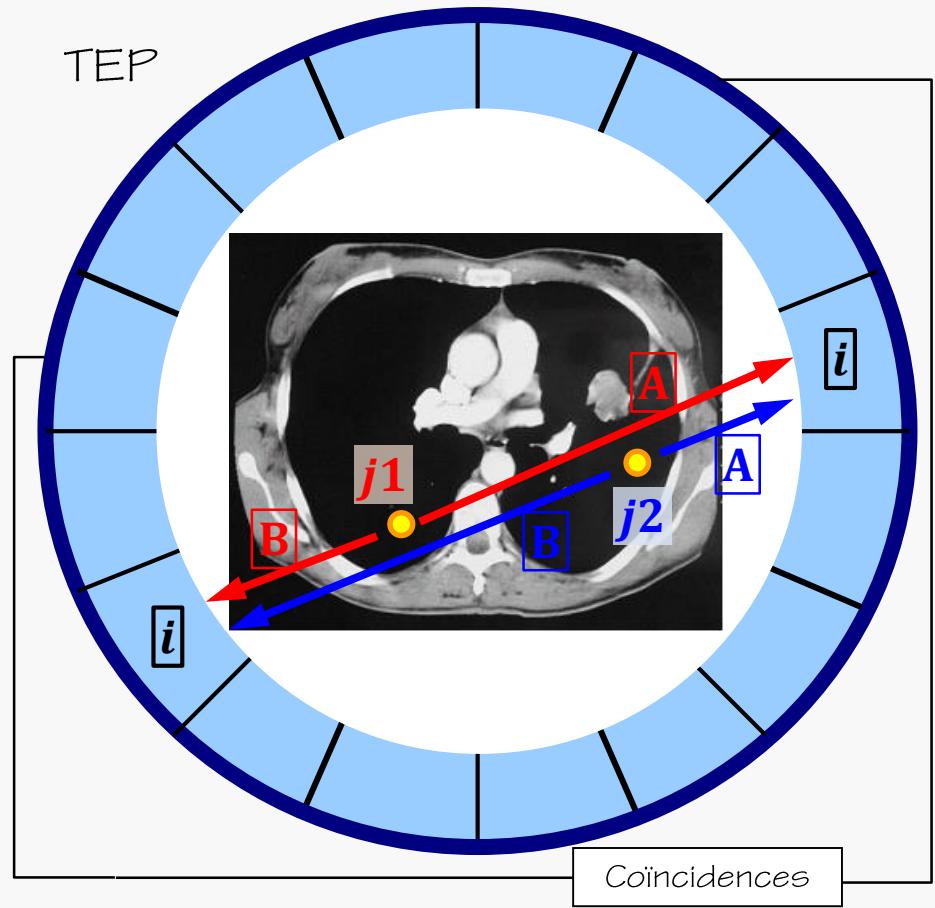
# Recalage d'images multimodales

- Localisation anatomique des anomalies fonctionnelles
- Correction d'atténuation

$$p = \mathbf{R}f$$

$$R_{i,j1} = \wp(j1 \rightarrow i) = \lambda [e^{-\int_A \mu dx} e^{-\int_B \mu dx}]$$

$$R_{i,j2} = \wp(j2 \rightarrow i) = \lambda [e^{-\int_A \mu dx} e^{-\int_B \mu dx}]$$



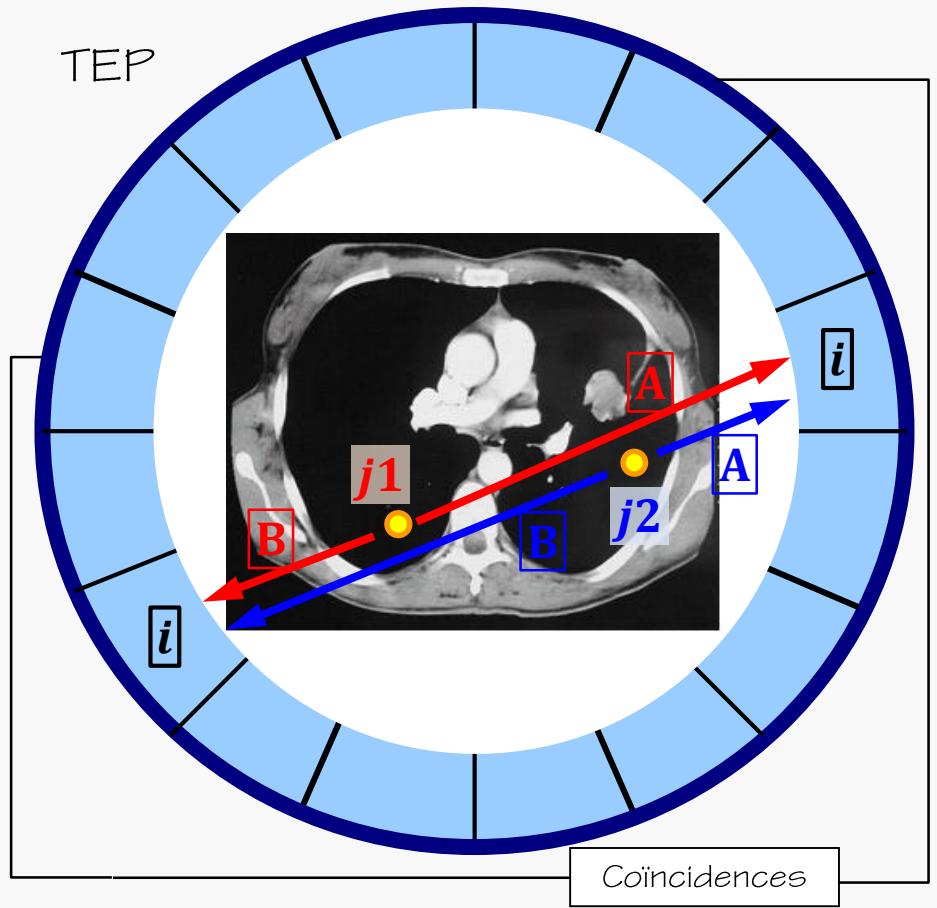
# Recalage d'images multimodales

- Localisation anatomique des anomalies fonctionnelles
- Correction d'atténuation

$$p = \mathbf{R}f$$

$$\begin{aligned} R_{i,j1} &= \wp(j1 \rightarrow i) = \lambda [e^{-\int_A \mu dx} e^{-\int_B \mu dx}] \\ &= \lambda e^{-\int_{A+B} \mu dx} = \lambda \gamma_i \end{aligned}$$

$$R_{i,j2} = \wp(j2 \rightarrow i) = \lambda [e^{-\int_A \mu dx} e^{-\int_B \mu dx}]$$



# Recalage d'images multimodales

- Localisation anatomique des anomalies fonctionnelles
- Correction d'atténuation

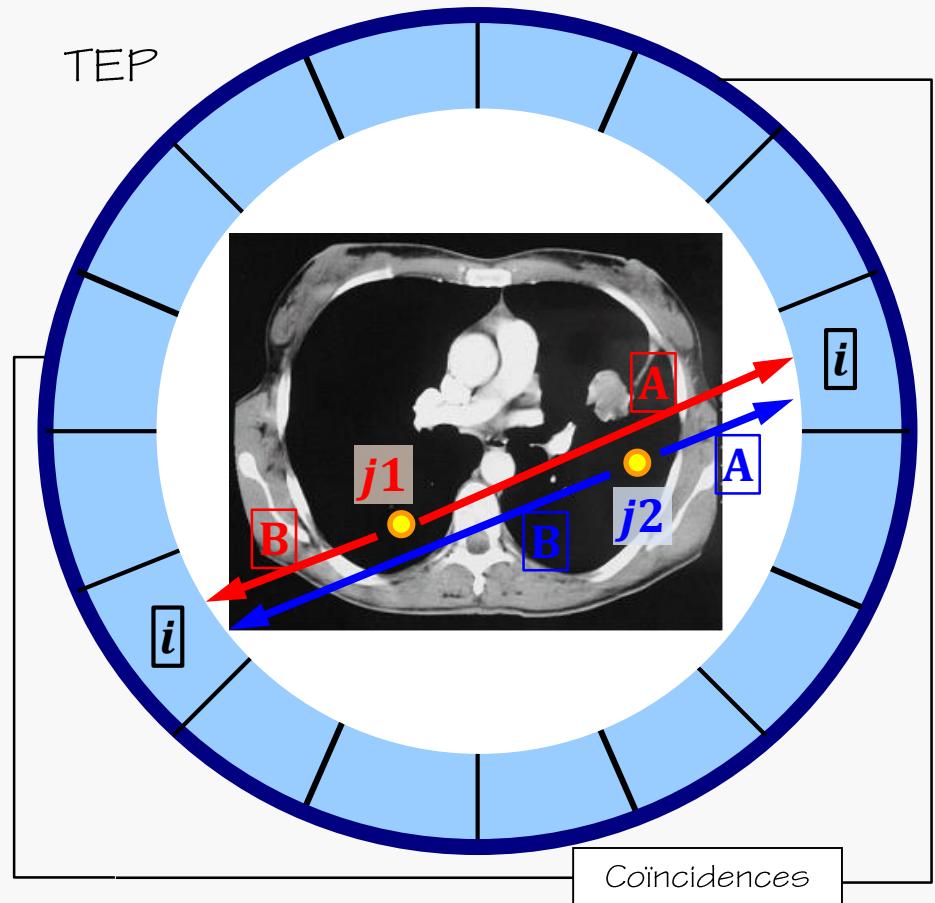
$$p = \mathbf{R}f$$

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$$R_{i,j2} = \wp(j2 \rightarrow i) = \lambda [e^{-\int_A \mu dx} e^{-\int_B \mu dx}]$$

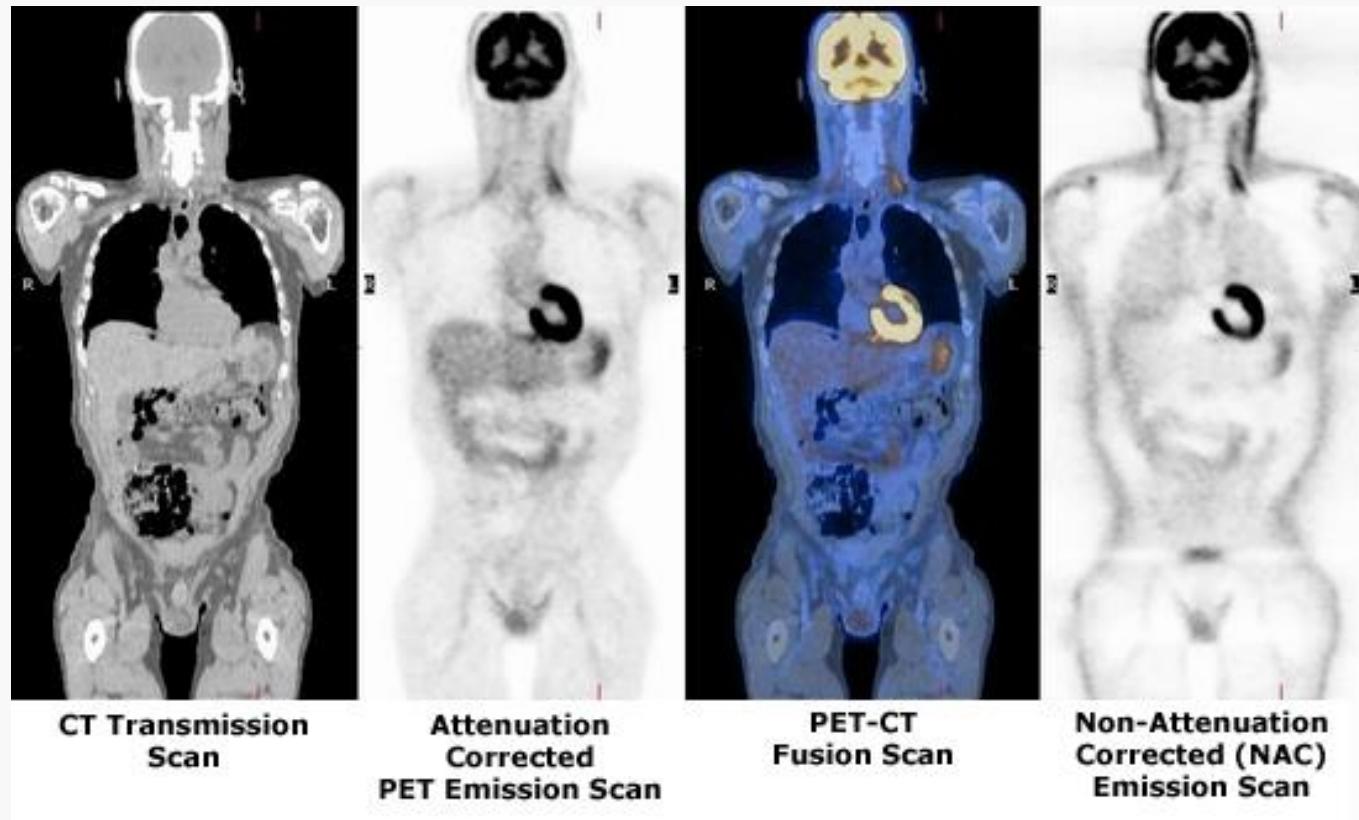
$$\bar{\bar{p}}_i = p_i / \gamma_i$$

$$\bar{\bar{p}} = \mathbf{R}f$$



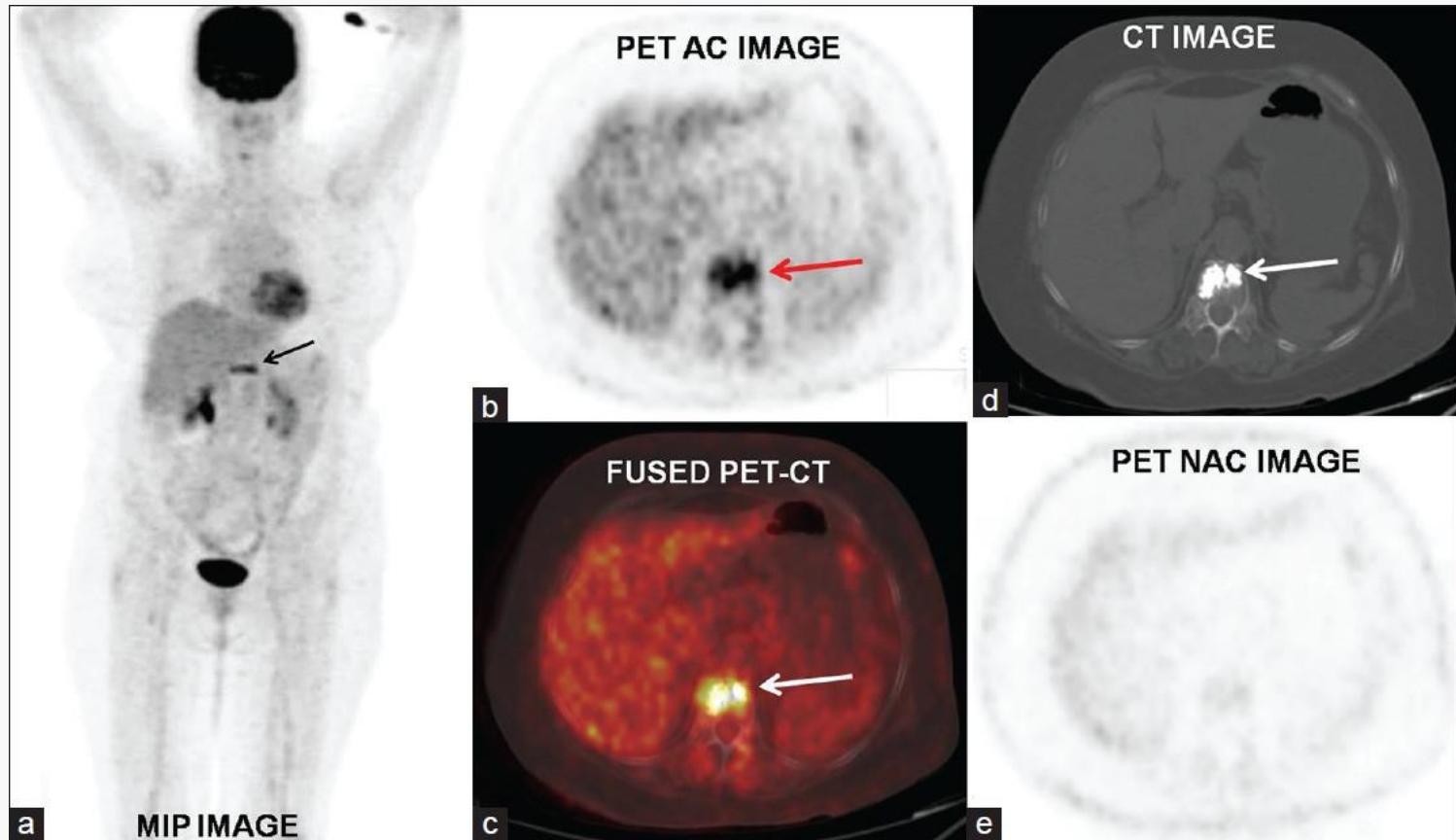
# Recalage d'images multimodales

- Localisation anatomique des anomalies fonctionnelles
- Correction d'atténuation



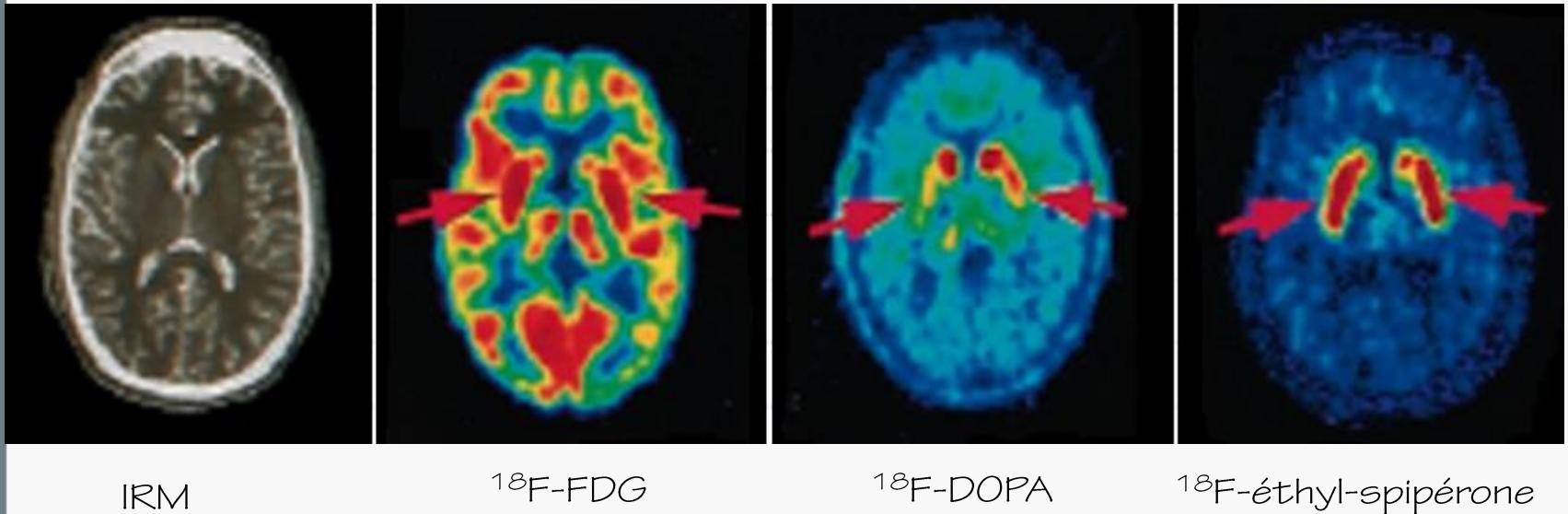
# Recalage d'images multimodales

- Localisation anatomique des anomalies fonctionnelles
- Correction d'atténuation



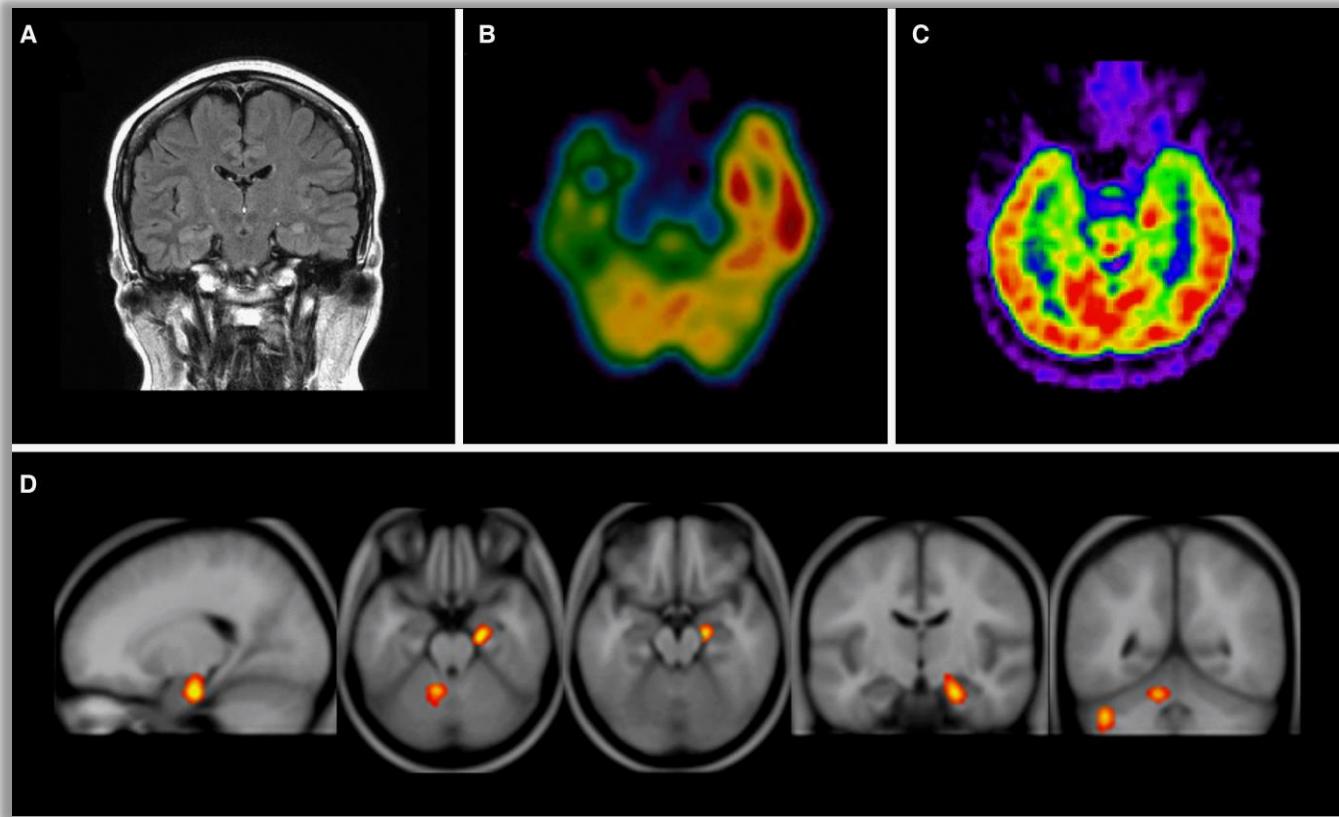
# Recalage d'images multimodales

- Localisation anatomique des anomalies fonctionnelles
- Correction d'atténuation
- Interprétation multimodale

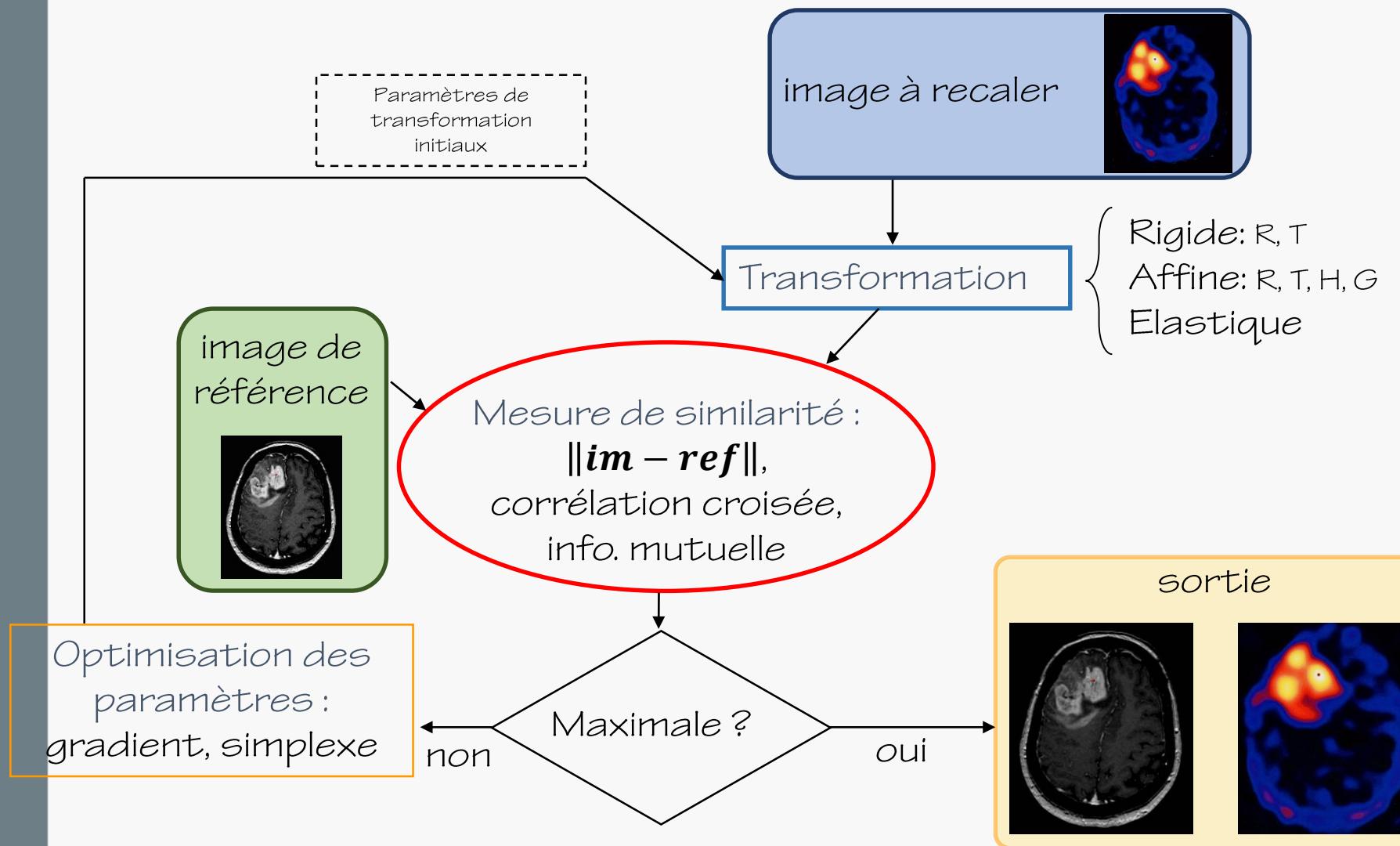


# Recalage d'images multimodales

- Localisation anatomique des anomalies fonctionnelles
- Correction d'atténuation
- Interprétation multimodale
- Cartographie statistiques (SPM)



# Recalage d'images multimodales



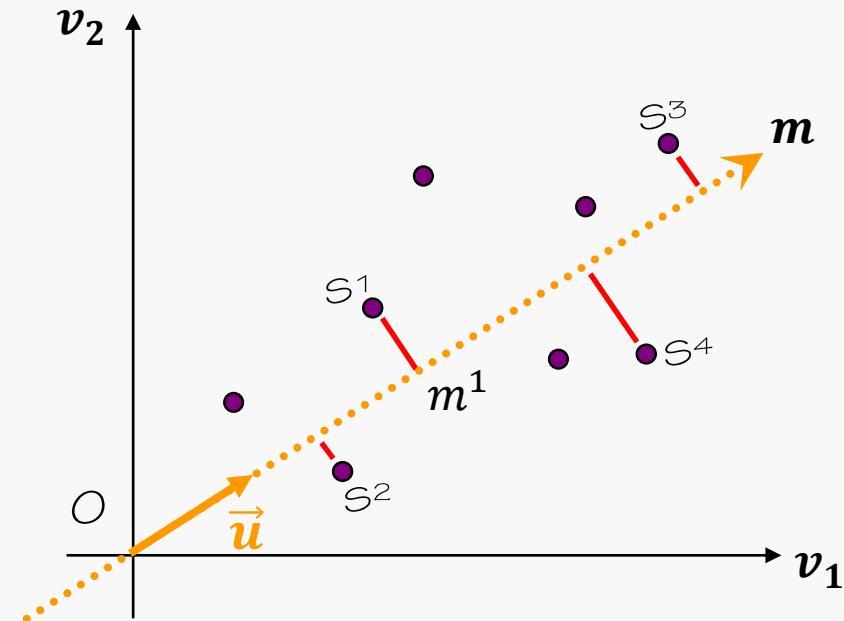
# Analyse factorielle

Analyse de 2 variables  $v_k$  (ex: taille et poids) sur N sujets  $S^n$

$$\mathbf{M} = \begin{bmatrix} v_1^1 & v_2^1 \\ v_1^2 & v_2^2 \\ v_1^3 & v_2^3 \\ v_1^4 & v_2^4 \\ \vdots & \vdots \end{bmatrix} \rightarrow \text{sujet } S^2$$

variable      variable

$v_1$              $v_2$

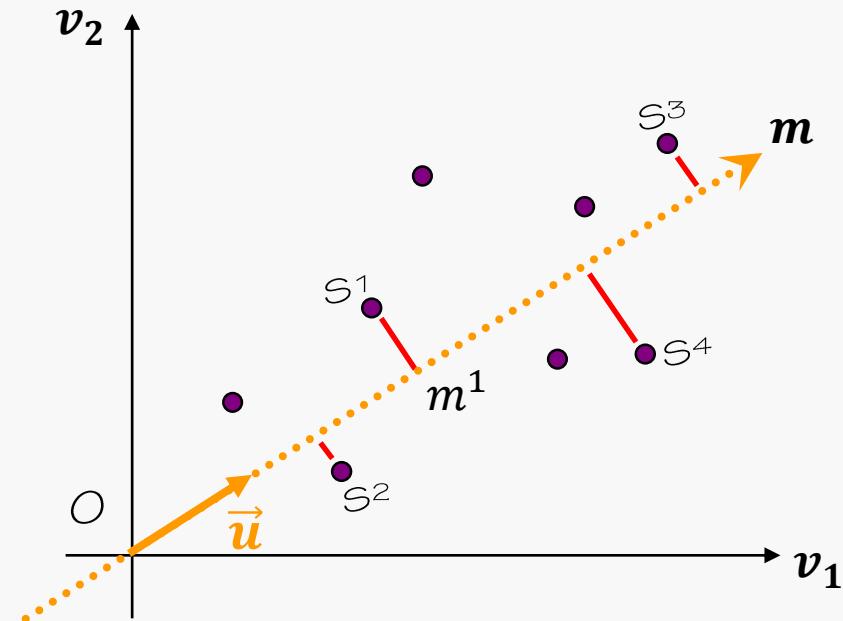


Idée : isoler les caractéristiques principales de chaque sujet  $S^n$  en ne le décrivant que par le point  $m^n$  (ex: « corpulence »)

# Analyse factorielle

Analyse de 2 variables  $\boldsymbol{v}_k$  (ex: taille et poids) sur N sujets  $S^n$

$$\boldsymbol{m} = \mathbf{M}\boldsymbol{u}$$
$$Var(\boldsymbol{m}) = \frac{1}{N} \boldsymbol{m}^T \boldsymbol{m} = \frac{1}{N} \boldsymbol{u}^T \mathbf{M}^T \mathbf{M} \boldsymbol{u} = \boldsymbol{u}^T \mathbf{C} \boldsymbol{u}$$



# Analyse factorielle

Analyse de 2 variables  $\boldsymbol{v}_k$  (ex: taille et poids) sur N sujets  $S^n$

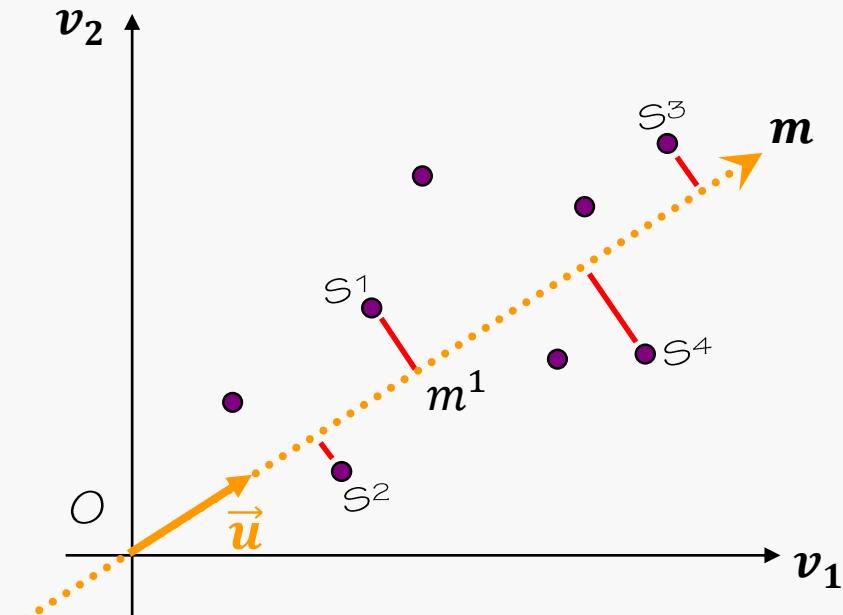
$$\boldsymbol{m} = \mathbf{M}\boldsymbol{u}$$

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$$\boldsymbol{u} = \sum \alpha_n \boldsymbol{c}_n$$

$$Var(\boldsymbol{m}) = \sum \alpha_n^2 \boldsymbol{c}_n^T \mathbf{C} \boldsymbol{c}_n$$

$$= \sum \alpha_n^2 \lambda_n \boldsymbol{c}_n^T \boldsymbol{c}_n = \sum \alpha_n^2 \lambda_n$$



# Analyse factorielle

Analyse de 2 variables  $\mathbf{v}_k$  (ex: taille et poids) sur N sujets  $S^n$

$$\mathbf{m} = \mathbf{Mu}$$

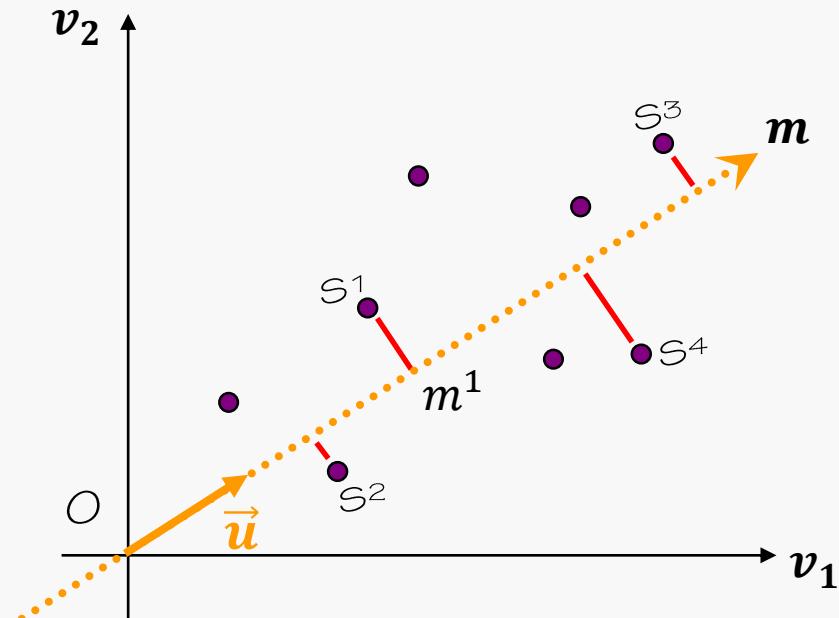
$$Var(\mathbf{m}) = \frac{1}{N} \mathbf{m}^T \mathbf{m} = \frac{1}{N} \mathbf{u}^T \mathbf{M}^T \mathbf{M} \mathbf{u} = \mathbf{u}^T \mathbf{C} \mathbf{u}$$

$$\mathbf{u} = \sum \alpha_n \mathbf{c}_n$$

$$Var(\mathbf{m}) = \sum \alpha_n^2 \mathbf{c}_n^T \mathbf{C} \mathbf{c}_n$$

$$= \sum \alpha_n^2 \lambda_n \mathbf{c}_n^T \mathbf{c}_n = \sum \alpha_n^2 \lambda_n$$

$$\max \{Var(\mathbf{m})\} = \lambda_1 : \mathbf{u} = \mathbf{c}_1$$



$\mathbf{u}$  est le vecteur propre de  $\mathbf{C}$  de valeur propre maximale

# Analyse factorielle

Analyse de 2 variables  $\mathbf{v}_k$  (ex: taille et poids) sur N sujets  $S^n$

$$\mathbf{m} = \mathbf{Mu}$$

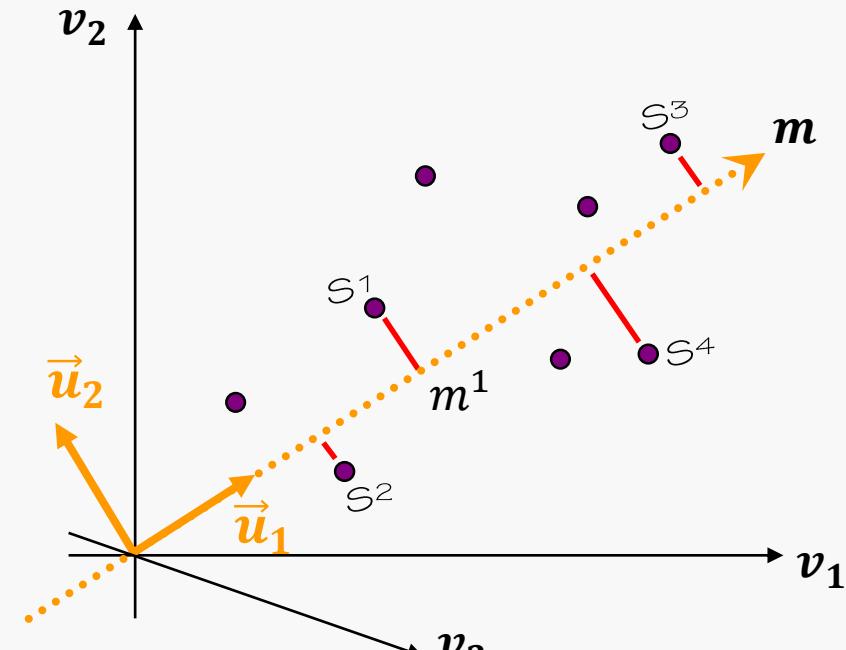
$$Var(\mathbf{m}) = \frac{1}{N} \mathbf{m}^T \mathbf{m} = \frac{1}{N} \mathbf{u}^T \mathbf{M}^T \mathbf{M} \mathbf{u} = \mathbf{u}^T \mathbf{C} \mathbf{u}$$

$$\mathbf{u} = \sum \alpha_n \mathbf{c}_n$$

$$Var(\mathbf{m}) = \sum \alpha_n^2 \mathbf{c}_n^T \mathbf{C} \mathbf{c}_n$$

$$= \sum \alpha_n^2 \lambda_n \mathbf{c}_n^T \mathbf{c}_n = \sum \alpha_n^2 \lambda_n$$

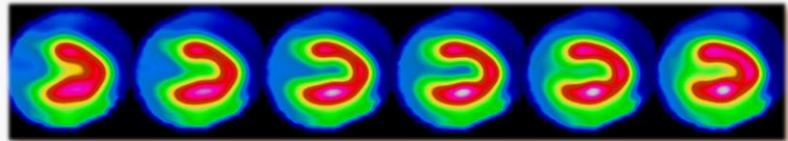
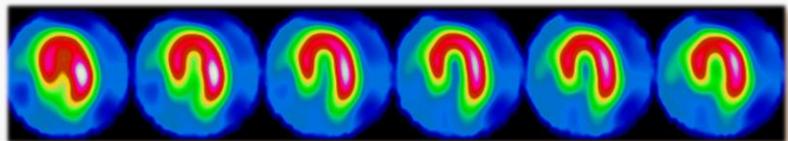
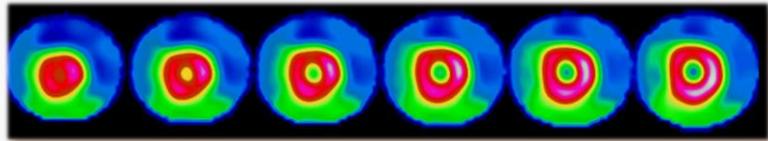
$$\max \{Var(\mathbf{m})\} = \lambda_1 + \lambda_2 + \dots$$
$$\mathbf{u}_1 = \mathbf{c}_1 ; \mathbf{u}_2 = \mathbf{c}_2 ; \dots$$



Les  $\mathbf{u}_n$  sont les vecteurs propres de  $\mathbf{C}$  de valeurs propres maximales

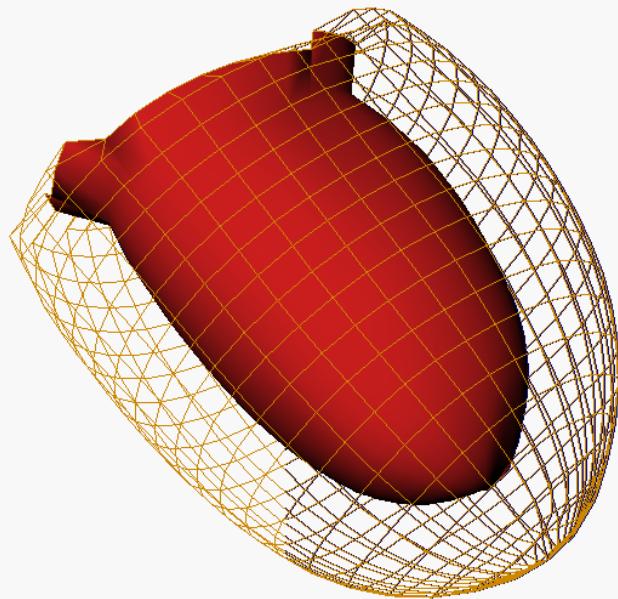
# Analyse factorielle

SPECT dynamique

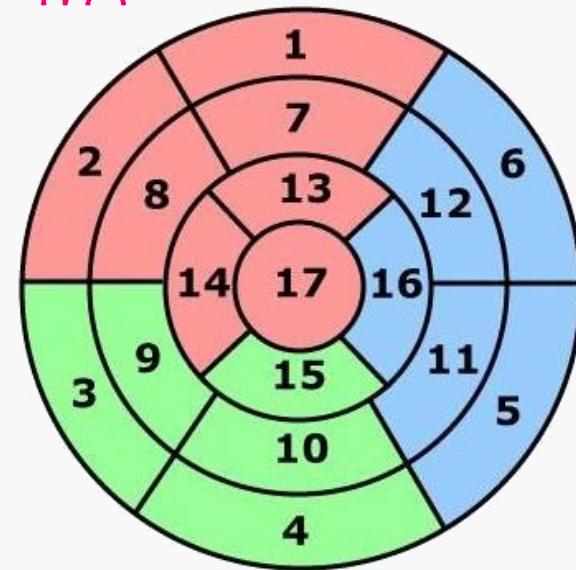


# Analyse factorielle

SPECT dynamique



IVA



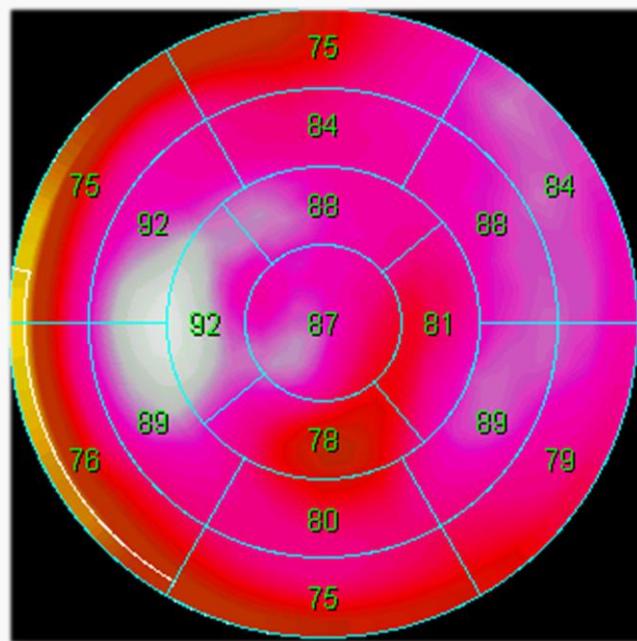
Cx

CD

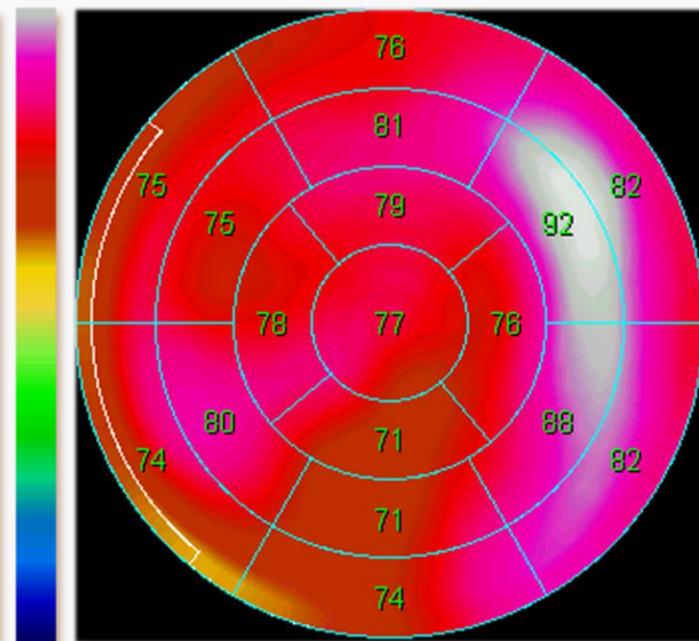
# Analyse factorielle

SPECT dynamique

Effort



Repos

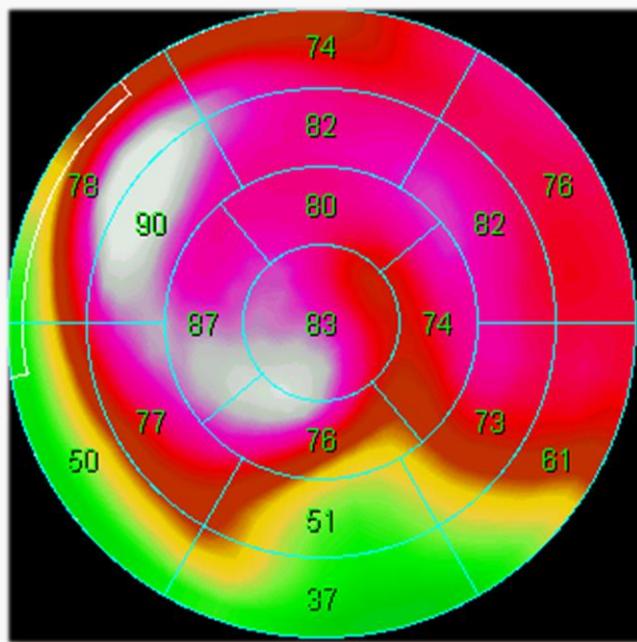


Scintigraphie normale

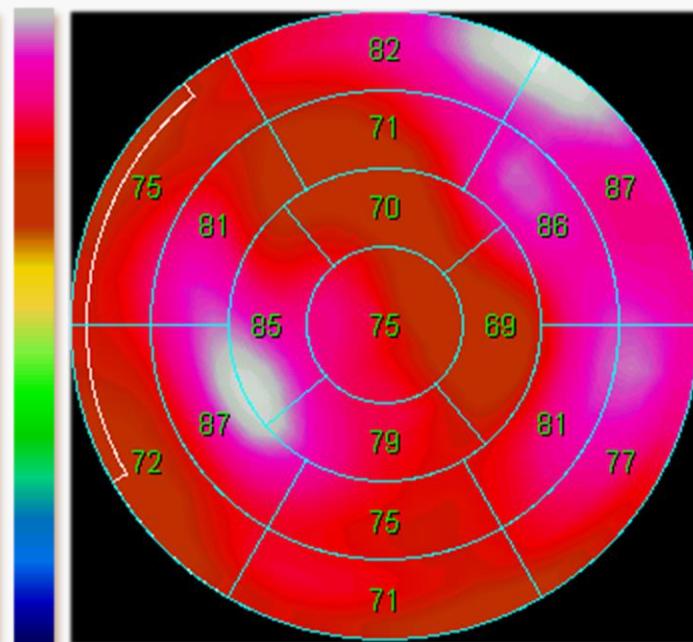
# Analyse factorielle

SPECT dynamique

Effort



Repos



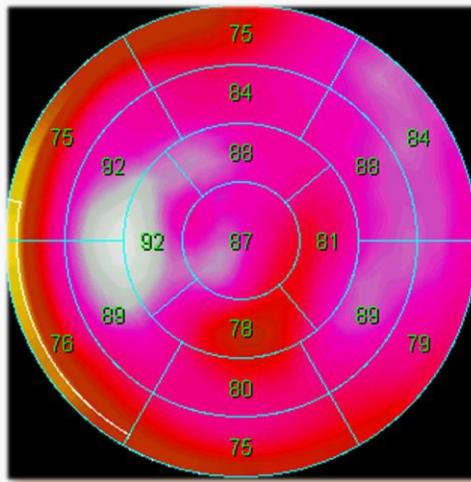
Ischémie myocardique

# Analyse factorielle

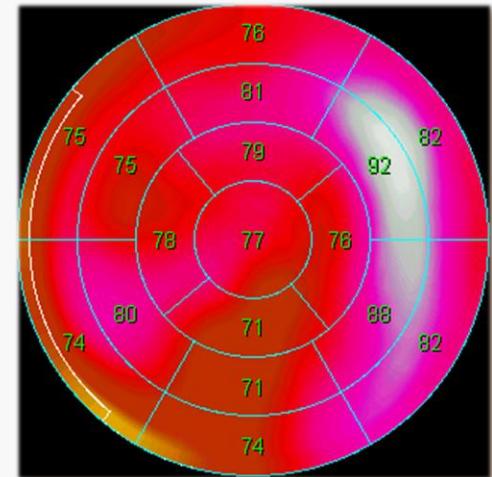
SPECT dynamique

Scintigraphie normale

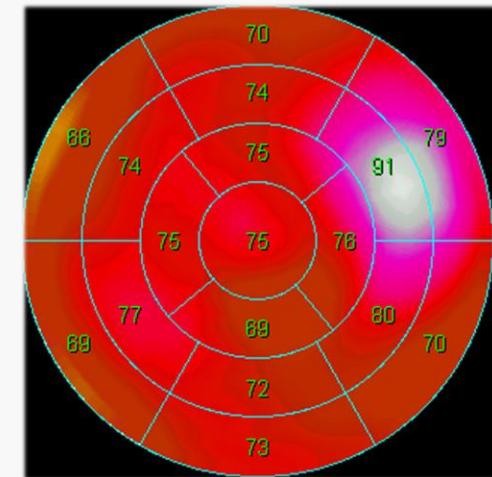
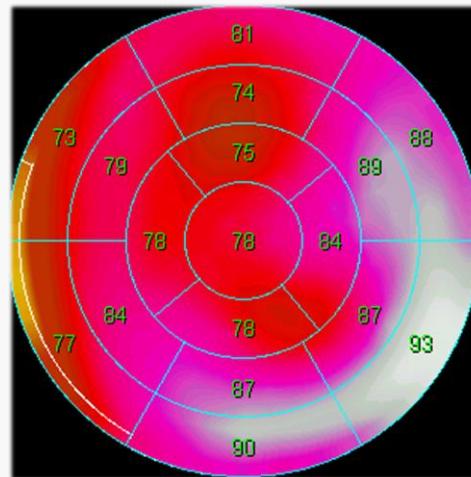
Effort



Repos



Pathologie  
tri-tronculaire  
« équilibrée »



# Analyse factorielle

SPECT dynamique

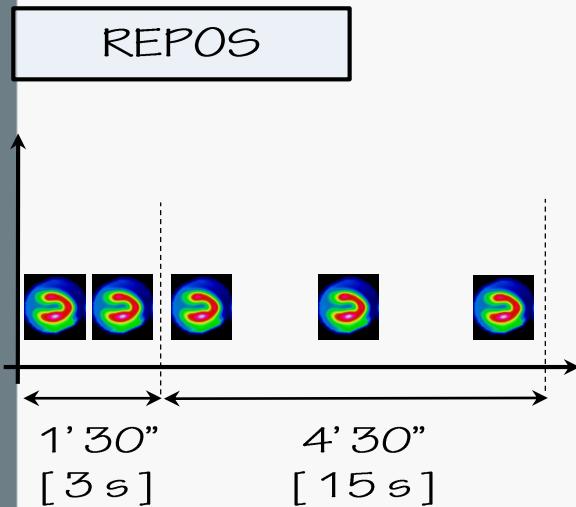
REPOS

MIBI  
5 mCi



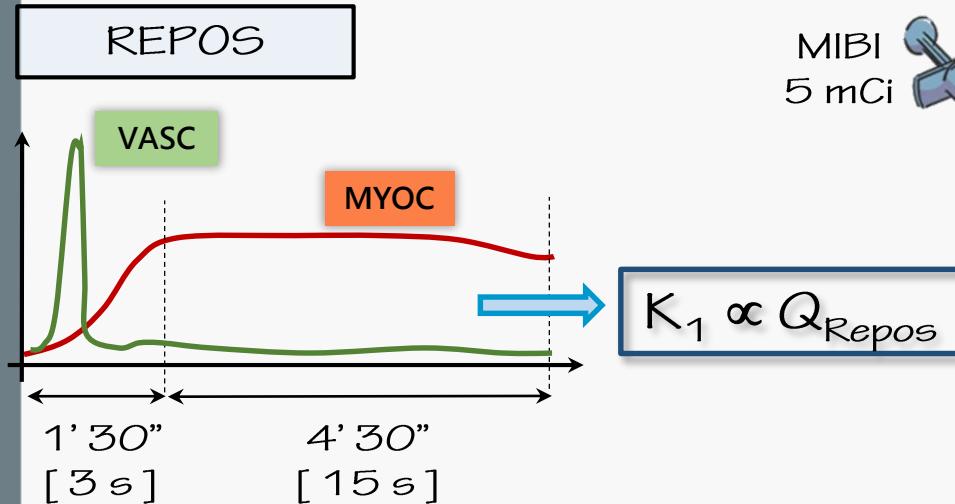
# Analyse factorielle

SPECT dynamique



# Analyse factorielle

SPECT dynamique

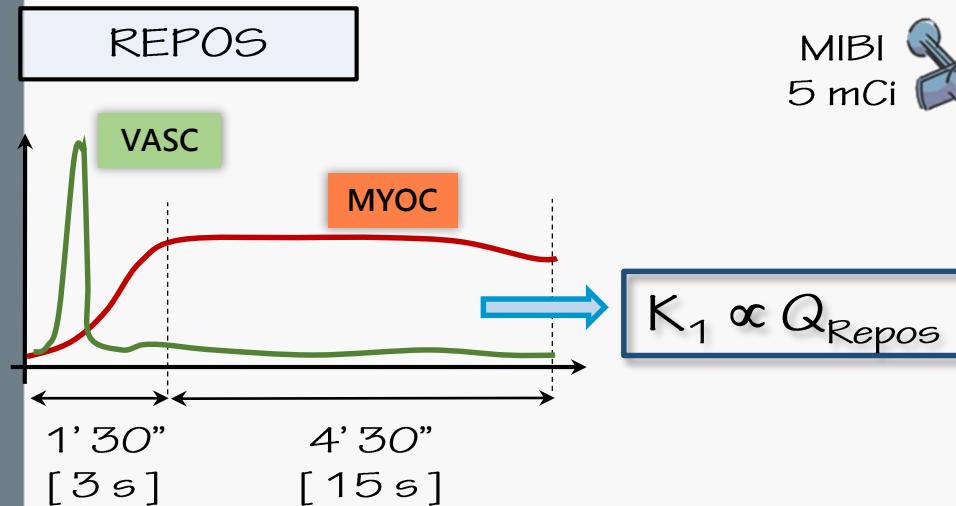


MIBI  
5 mCi



# Analyse factorielle

SPECT dynamique



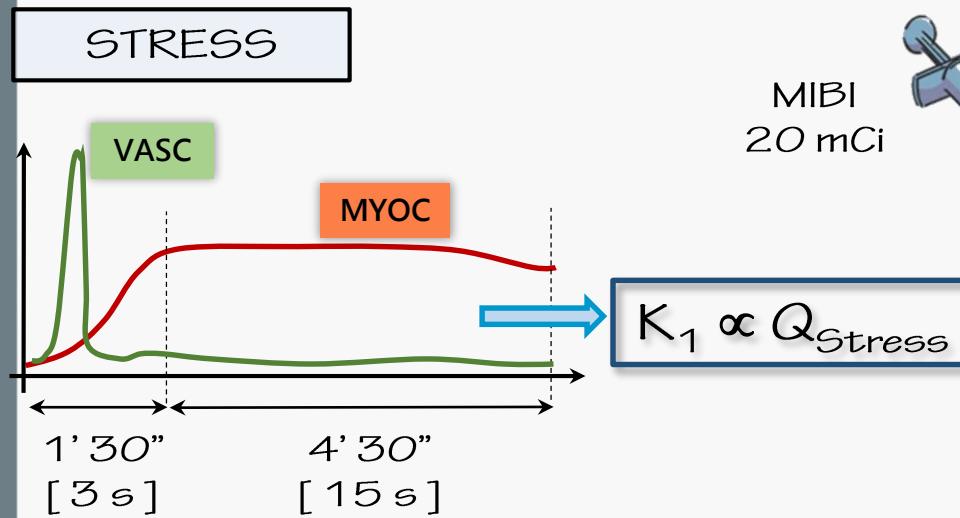
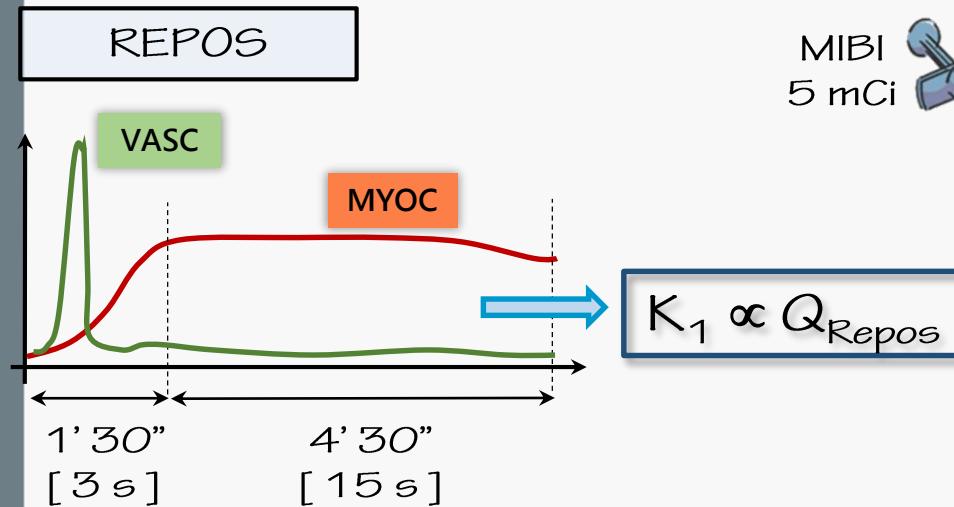
STRESS



Dipyridamole

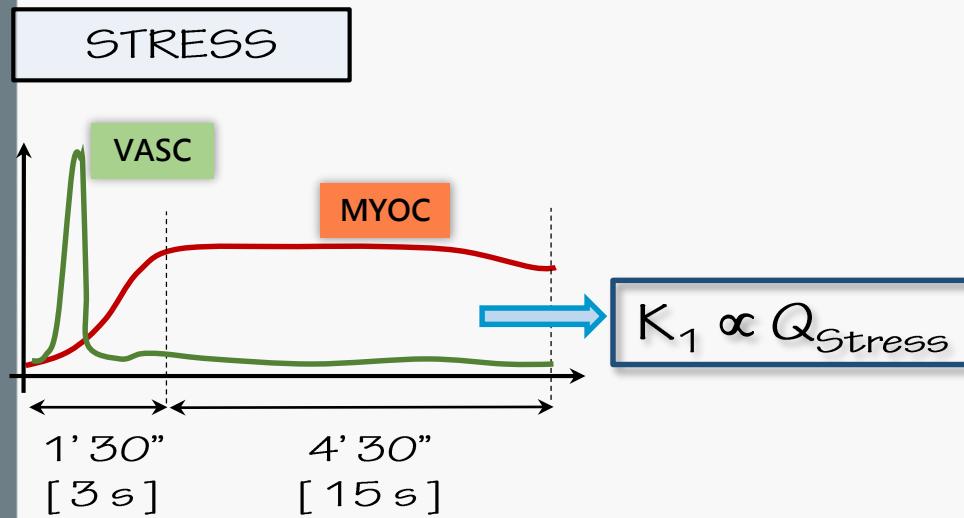
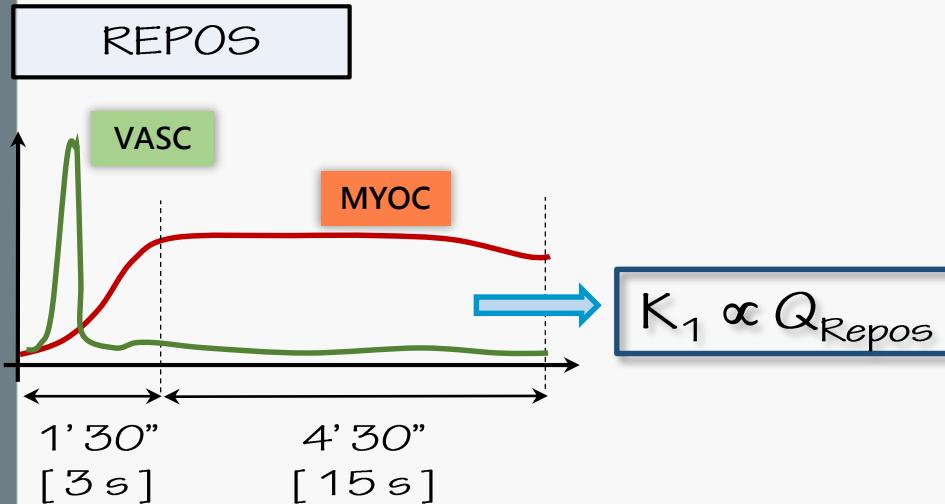
# Analyse factorielle

SPECT dynamique



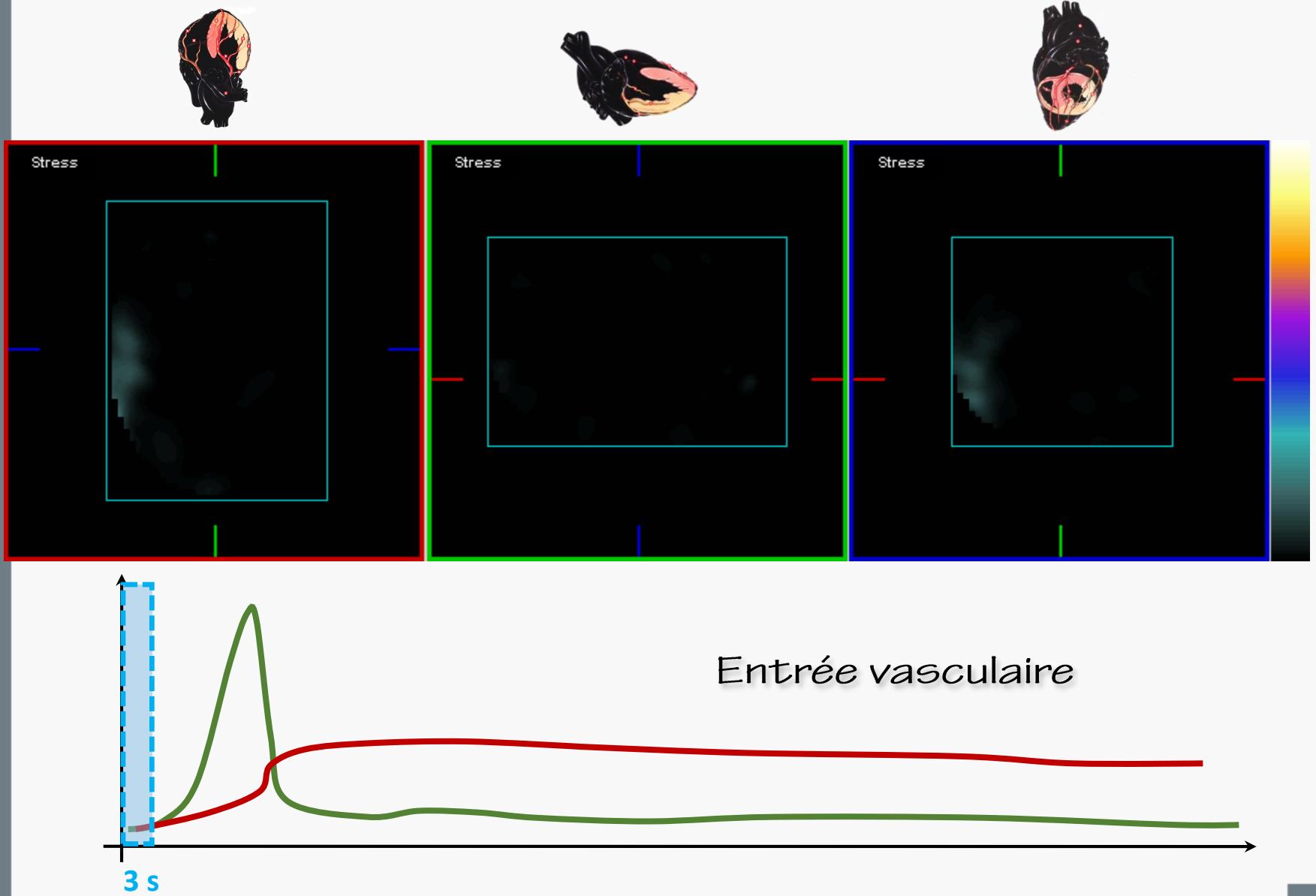
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SPECT dynamique

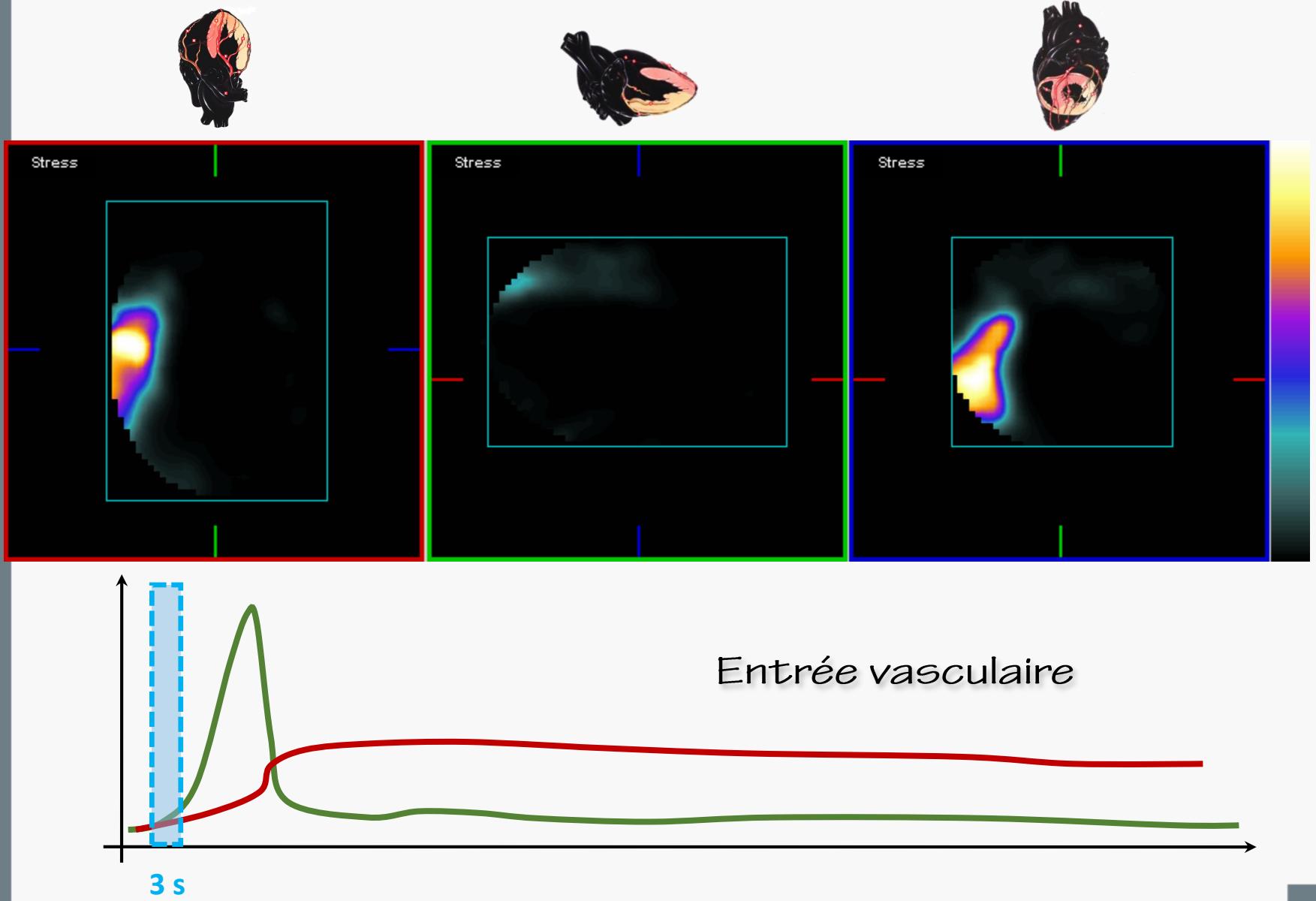


Réserve coronaire =  
 $Q_{\text{Stress}} / Q_{\text{Repos}}$

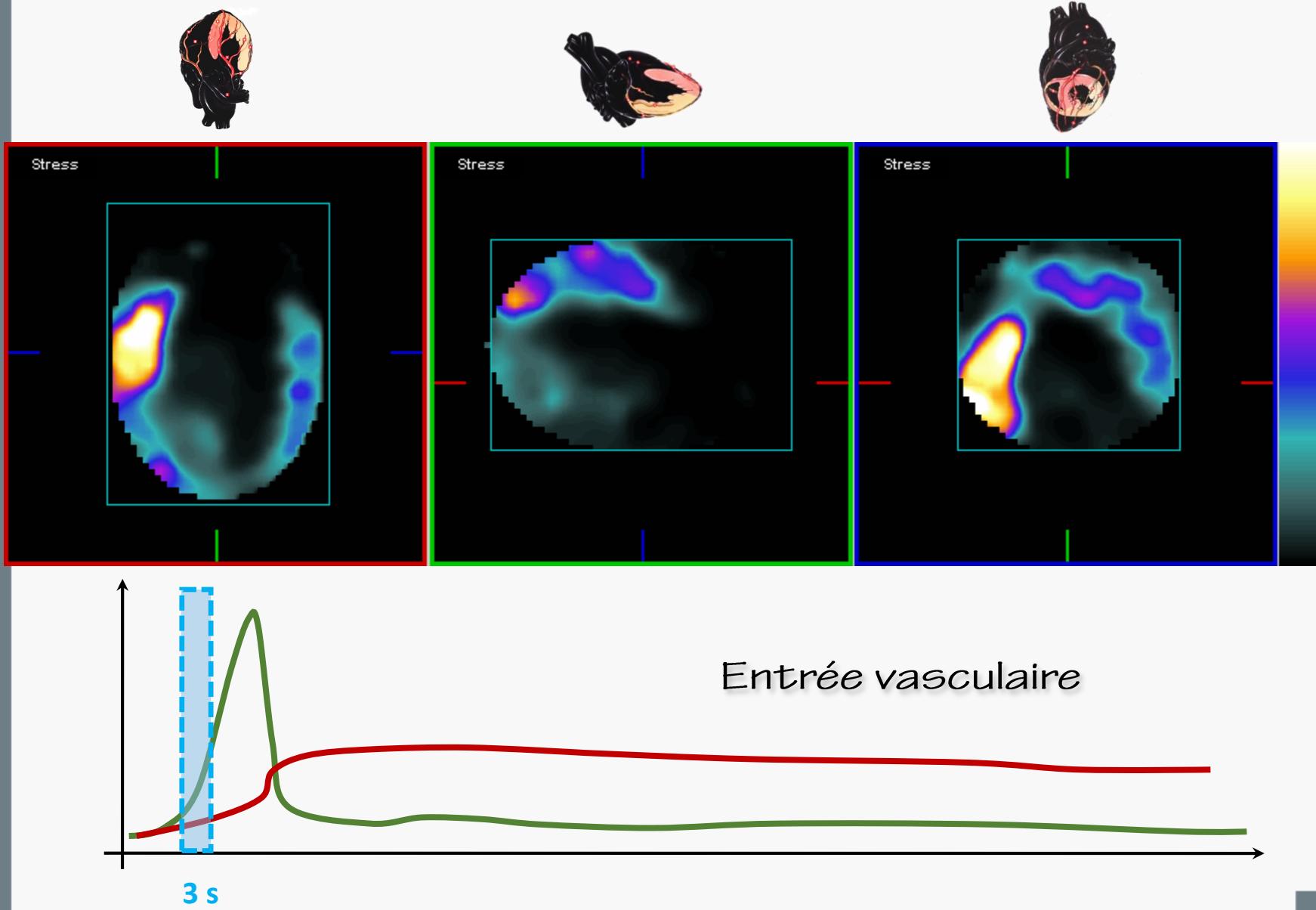
# Analyse factorielle



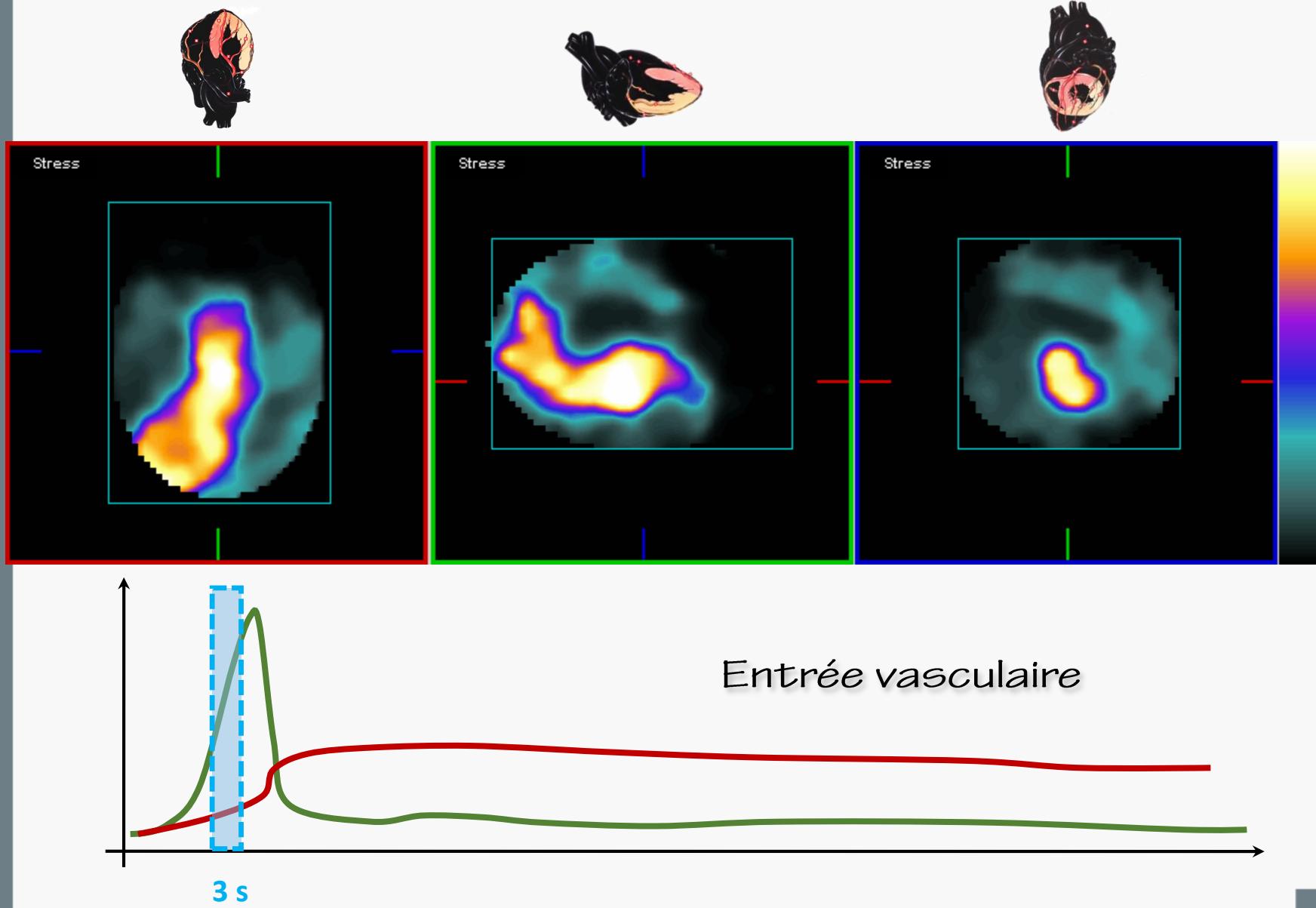
# Analyse factorielle



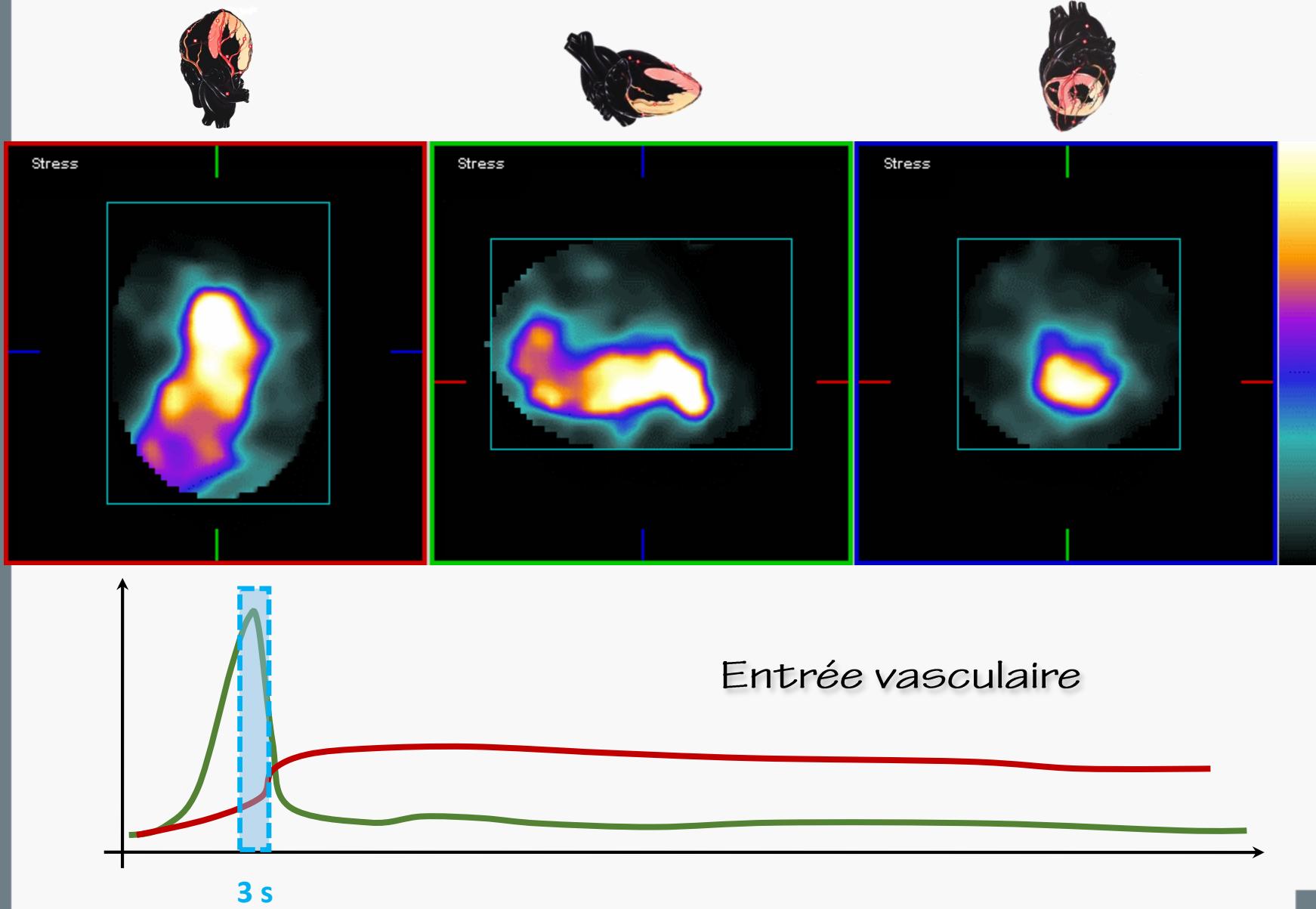
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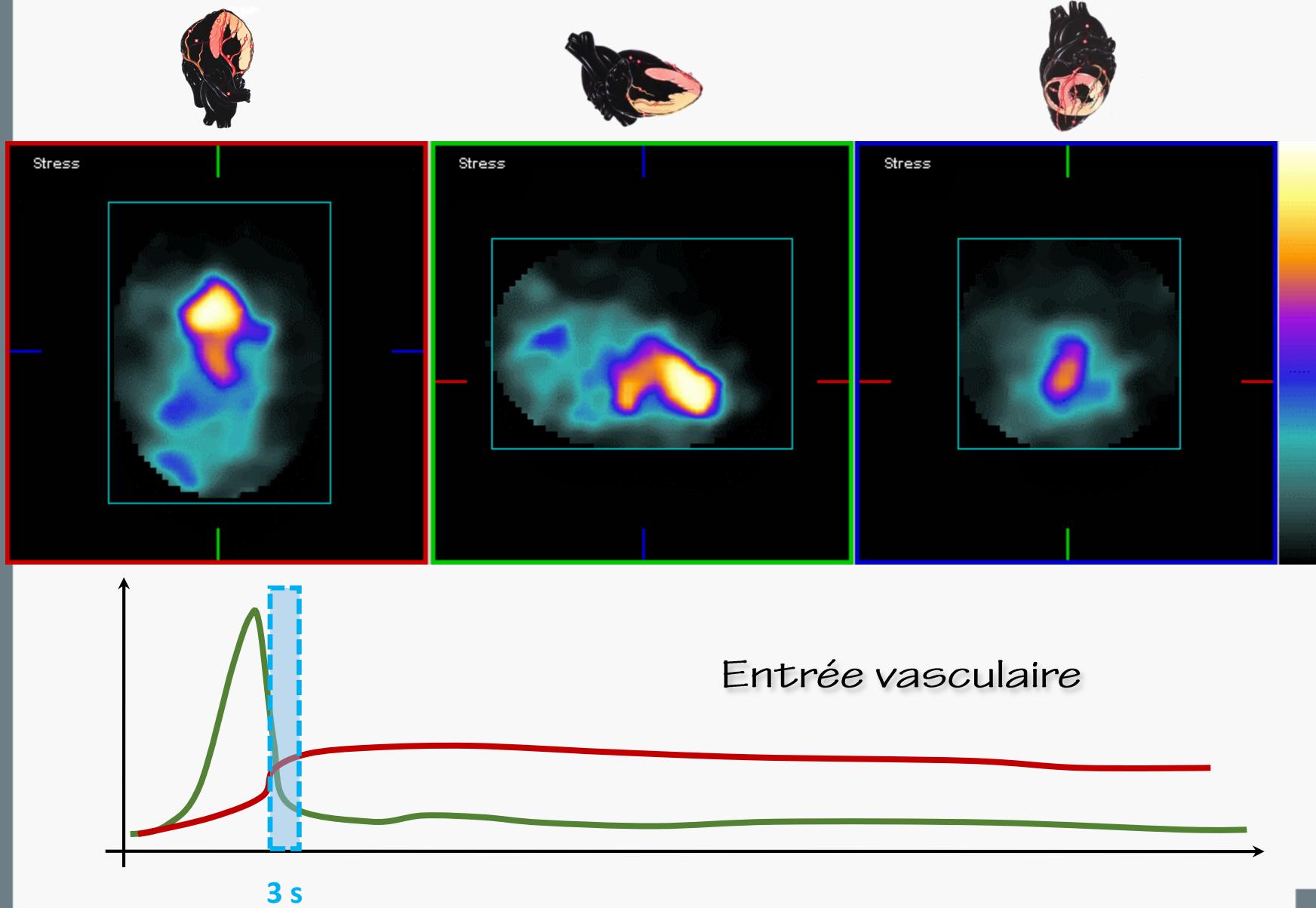
# Analyse factorielle



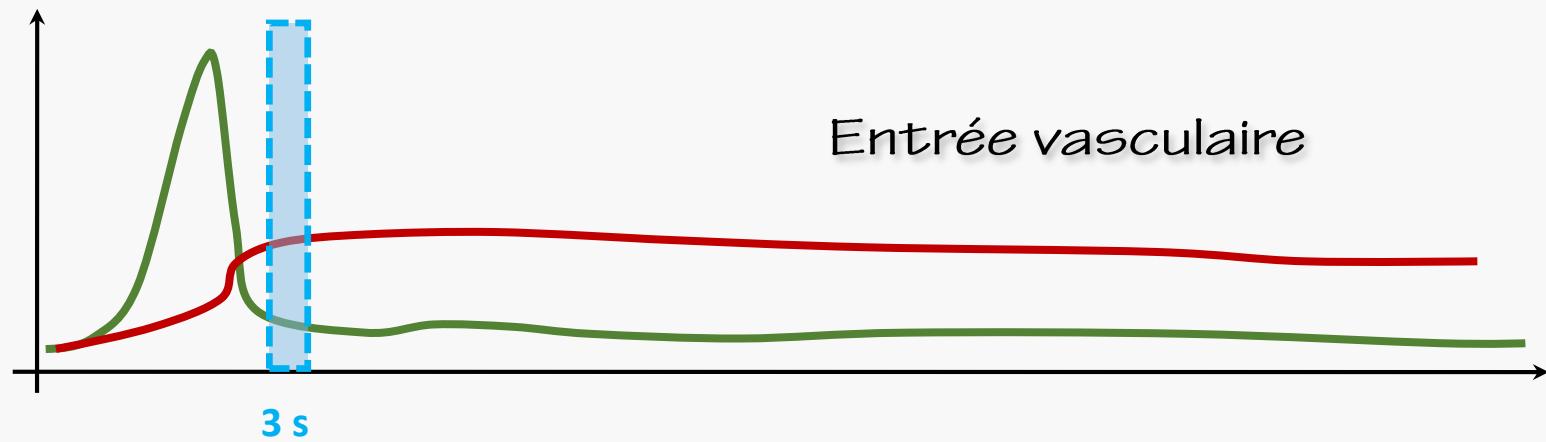
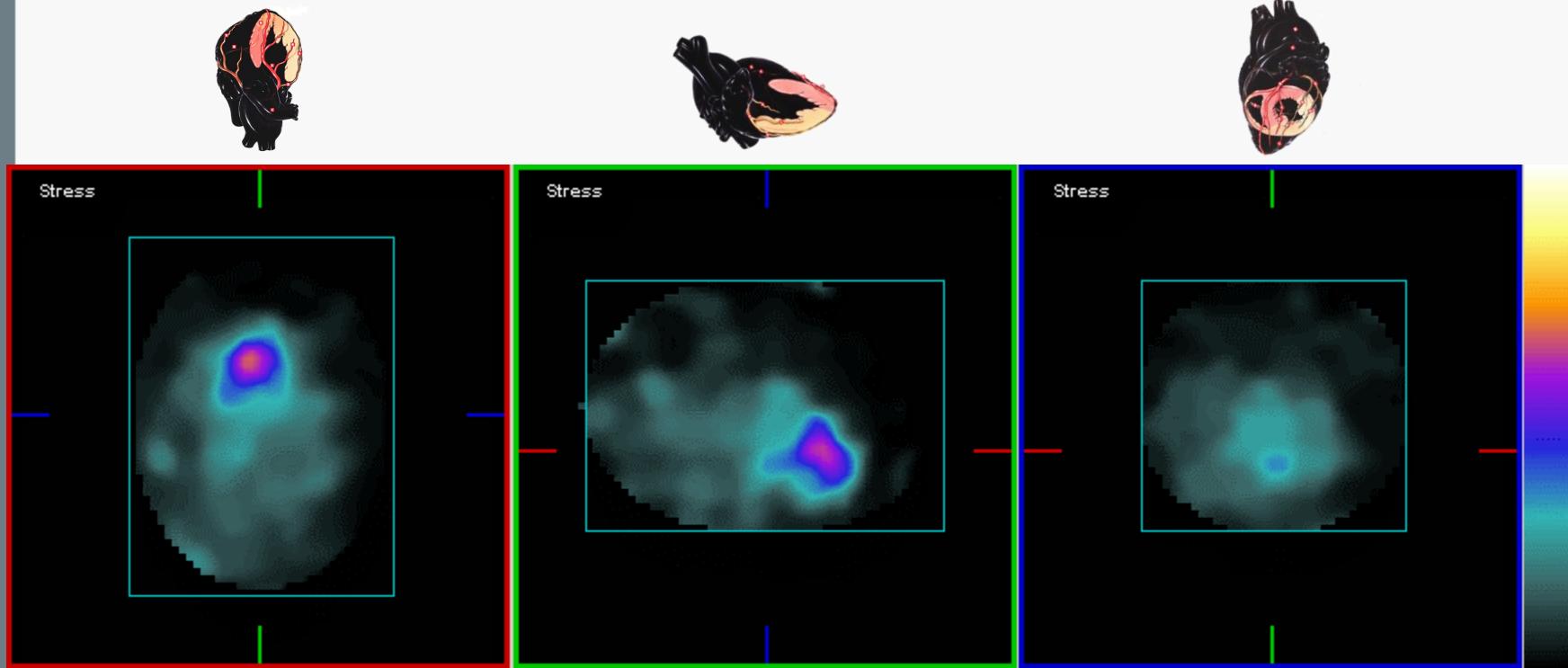
# Analyse factorielle



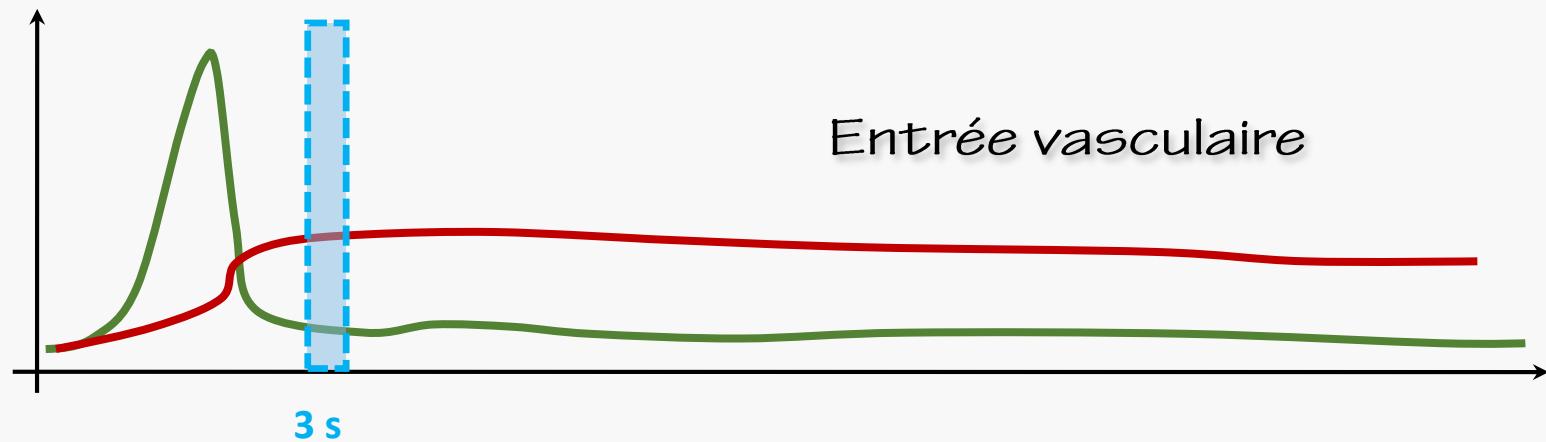
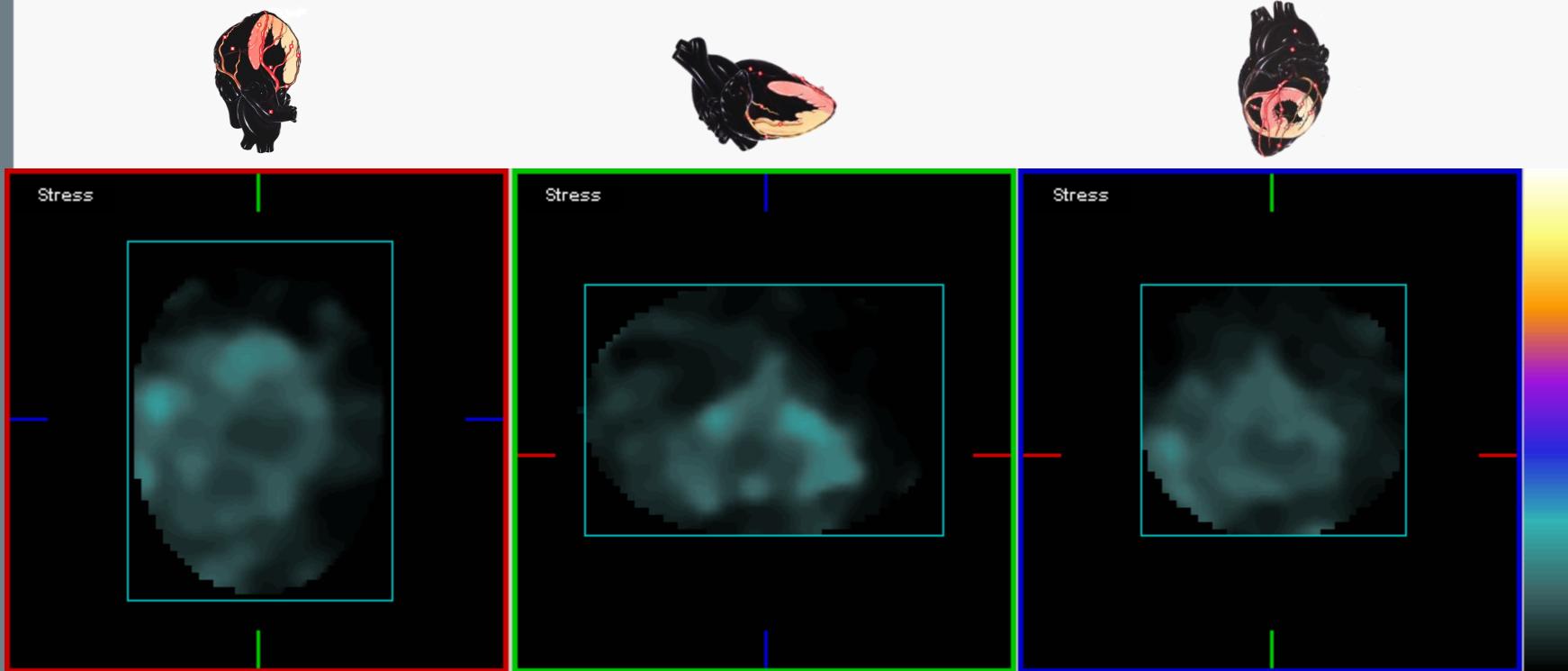
# Analyse factorielle



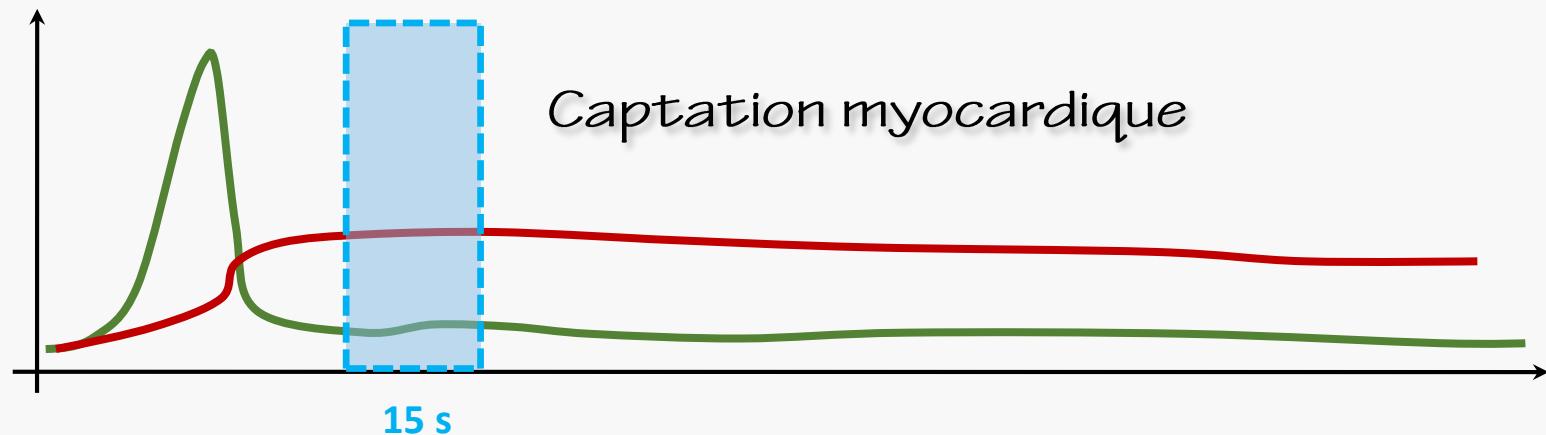
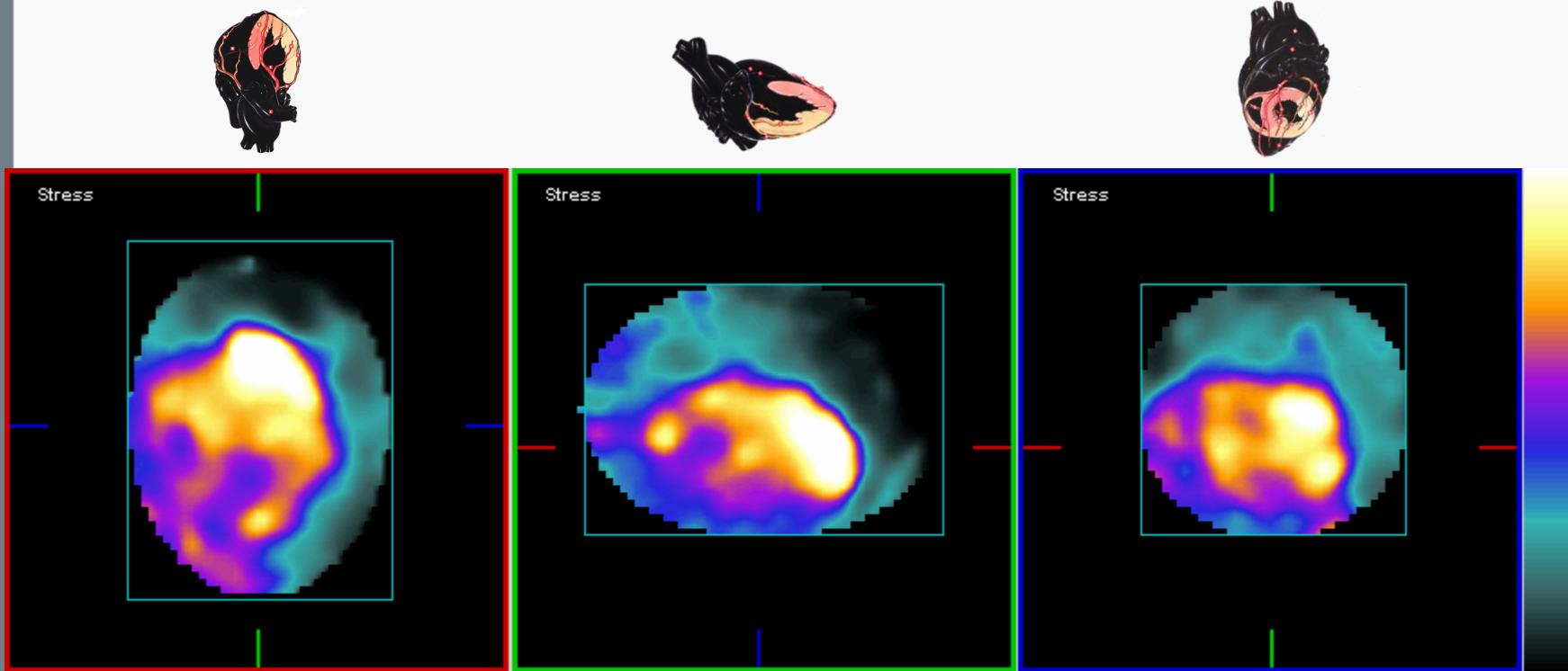
# Analyse factorielle



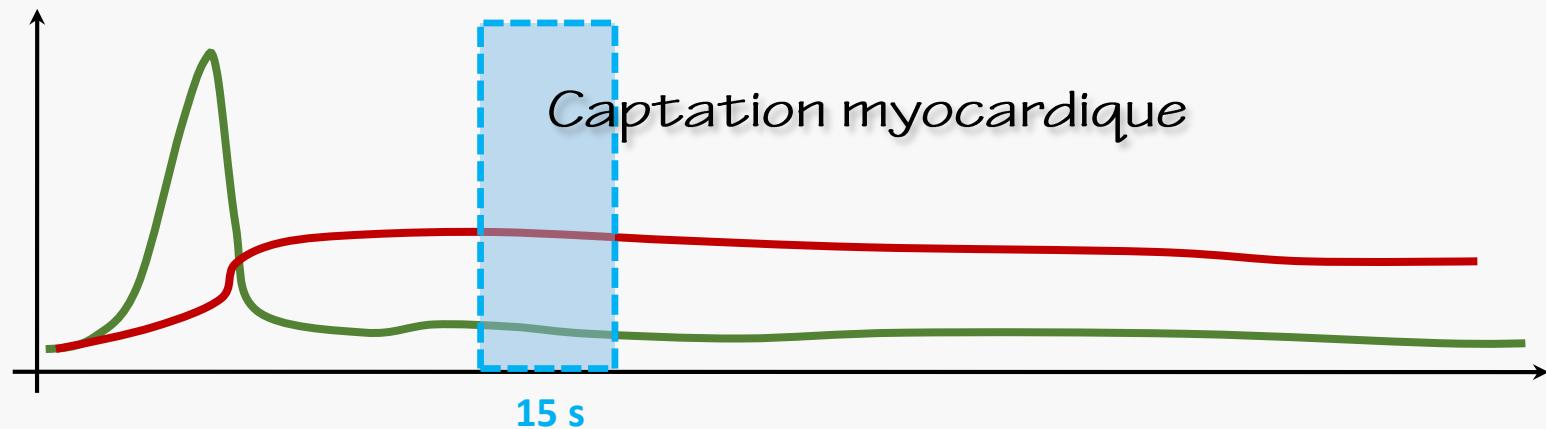
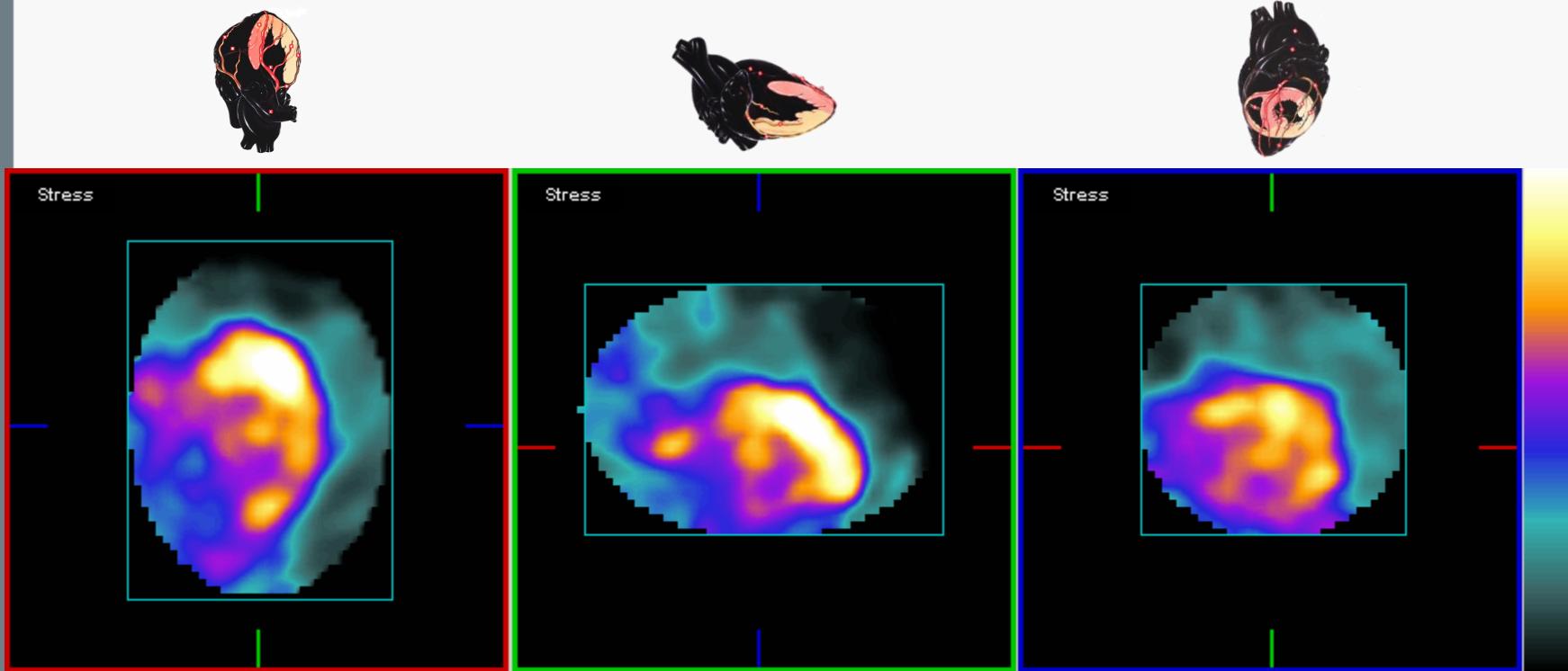
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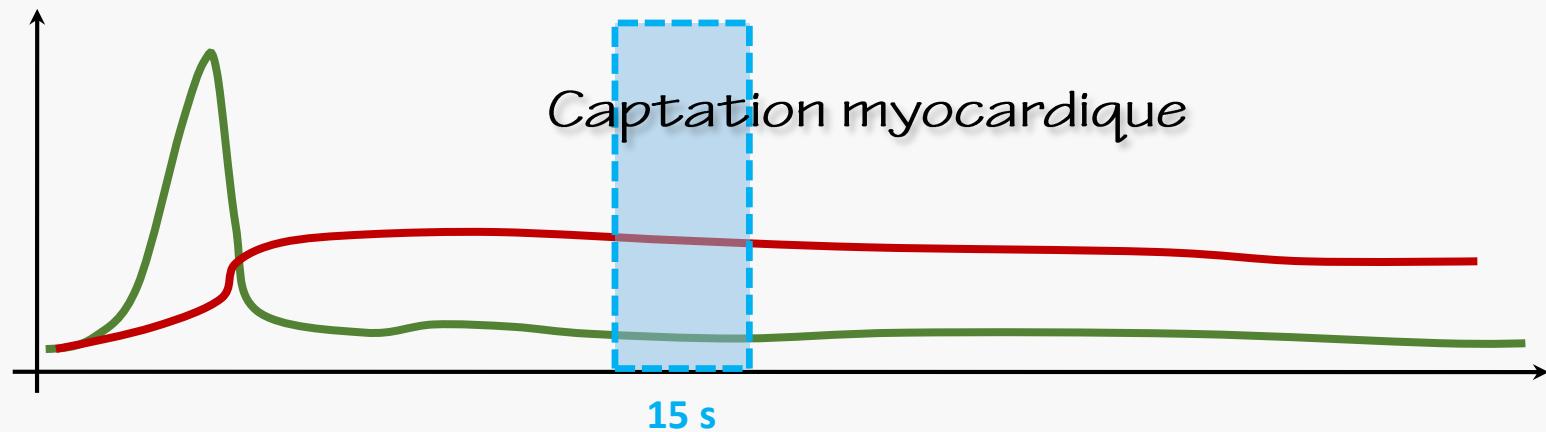
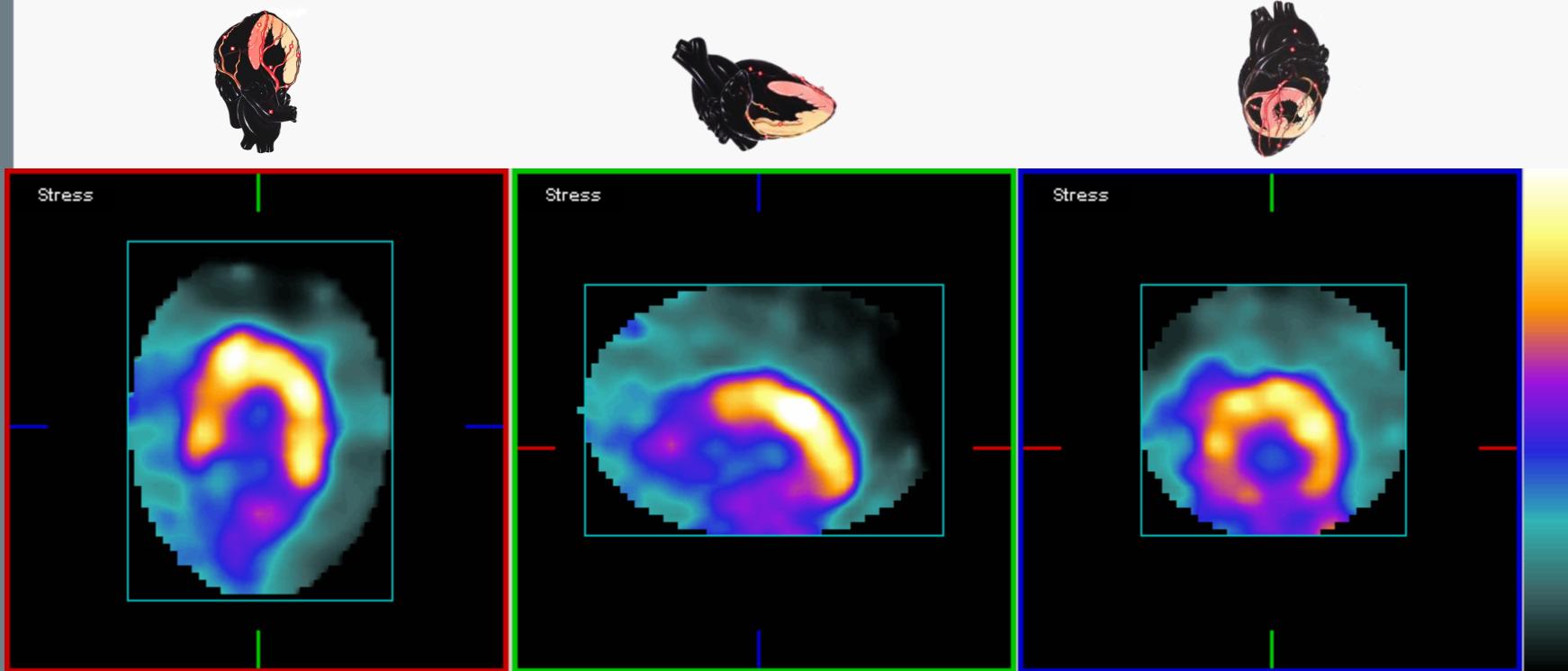
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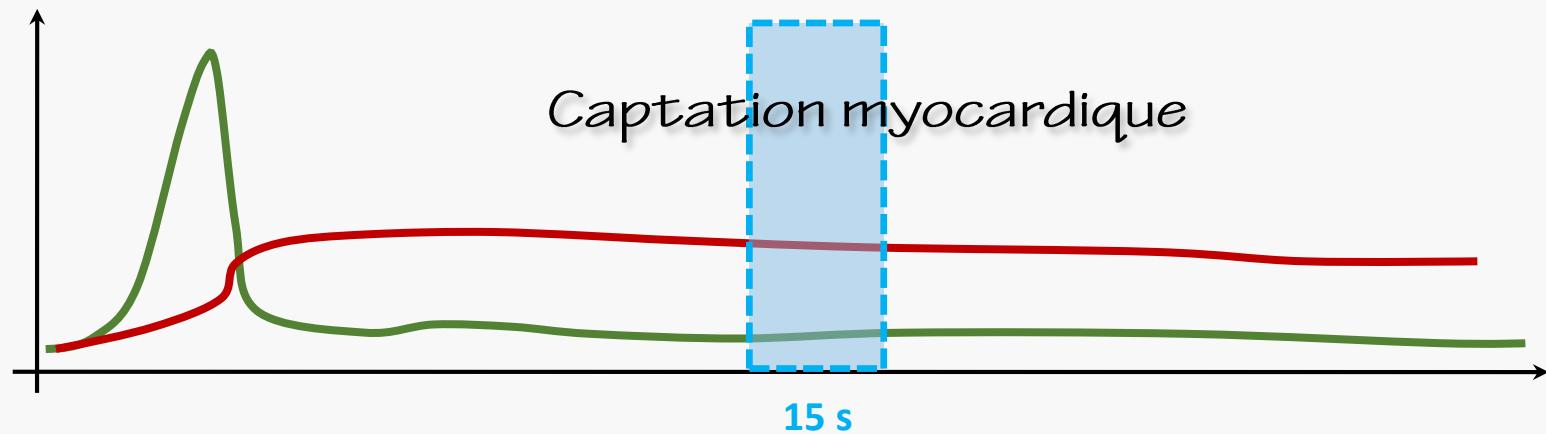
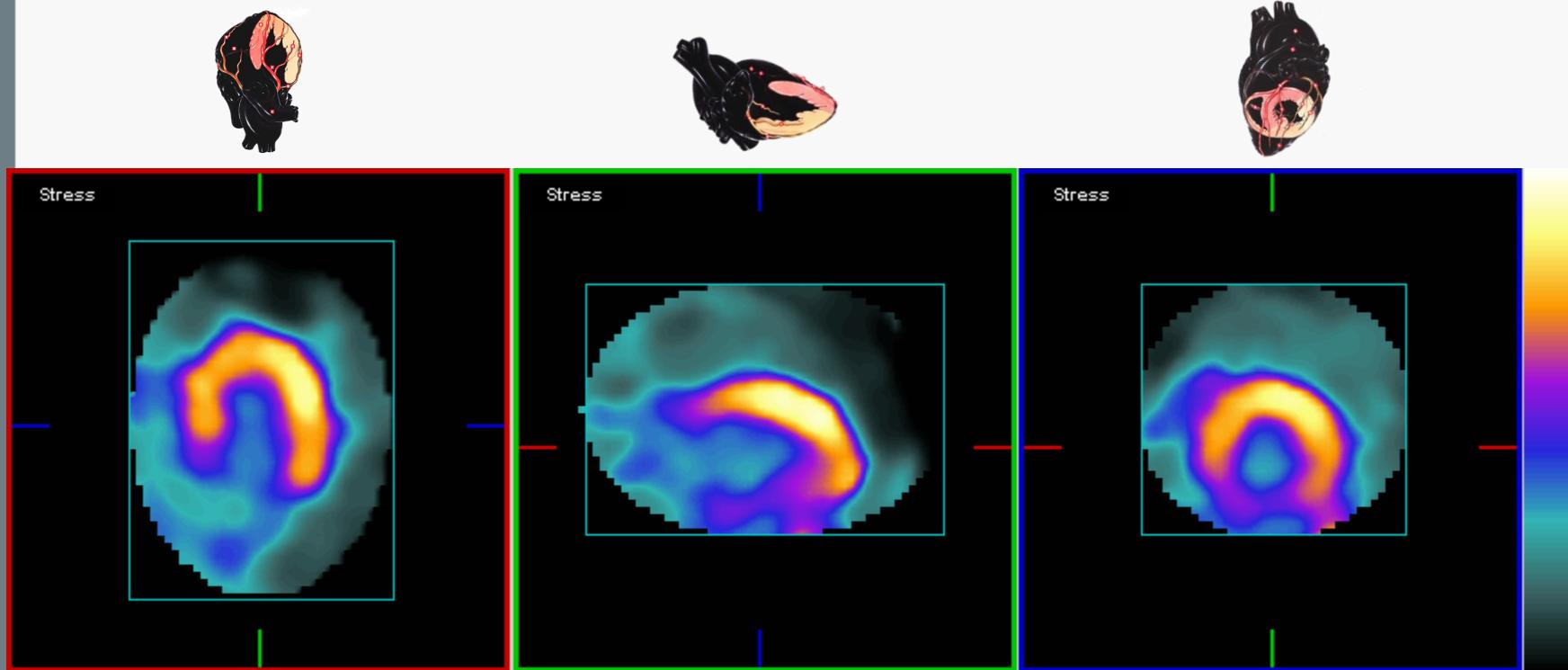
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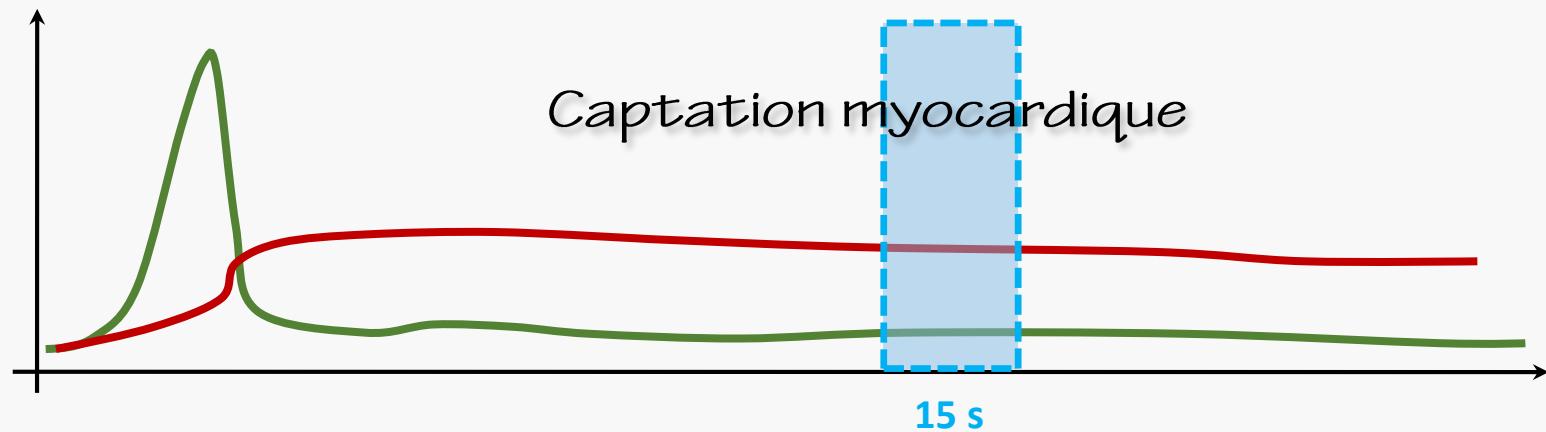
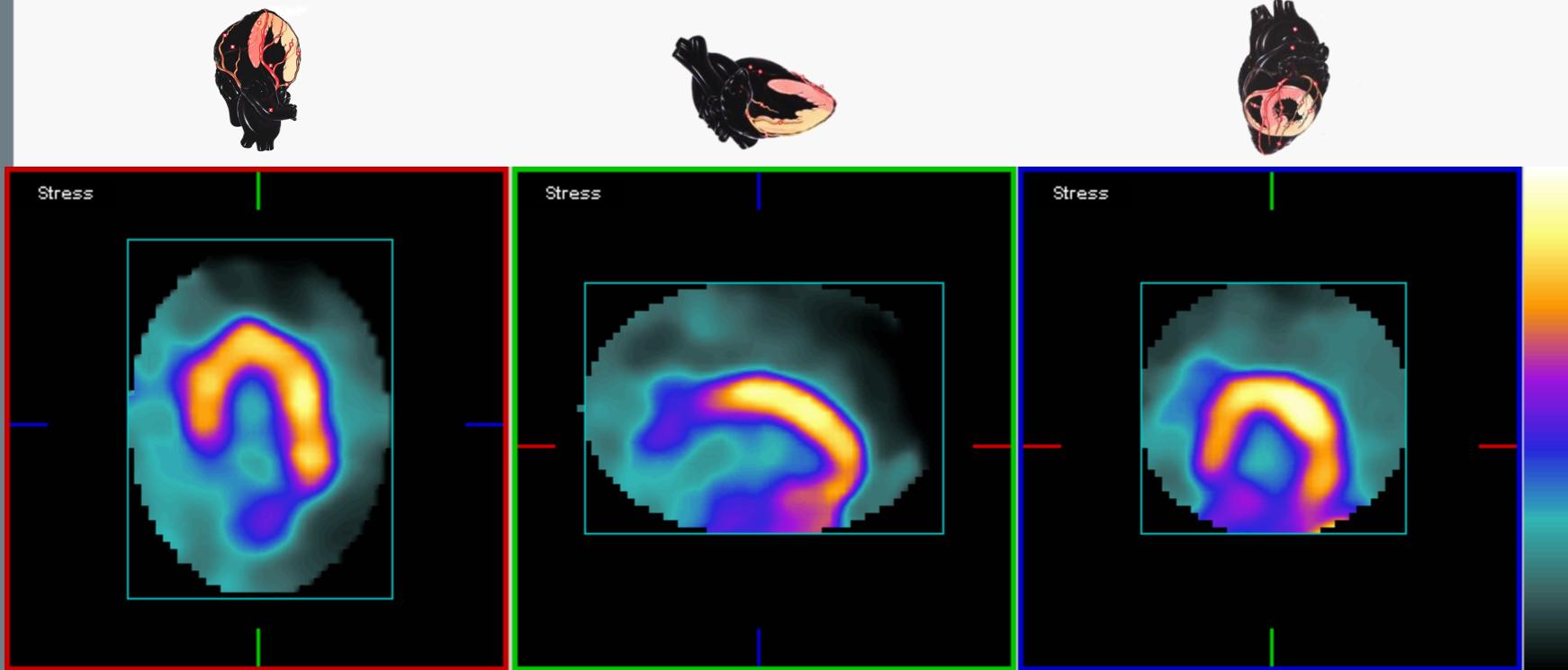
# Analyse factorielle



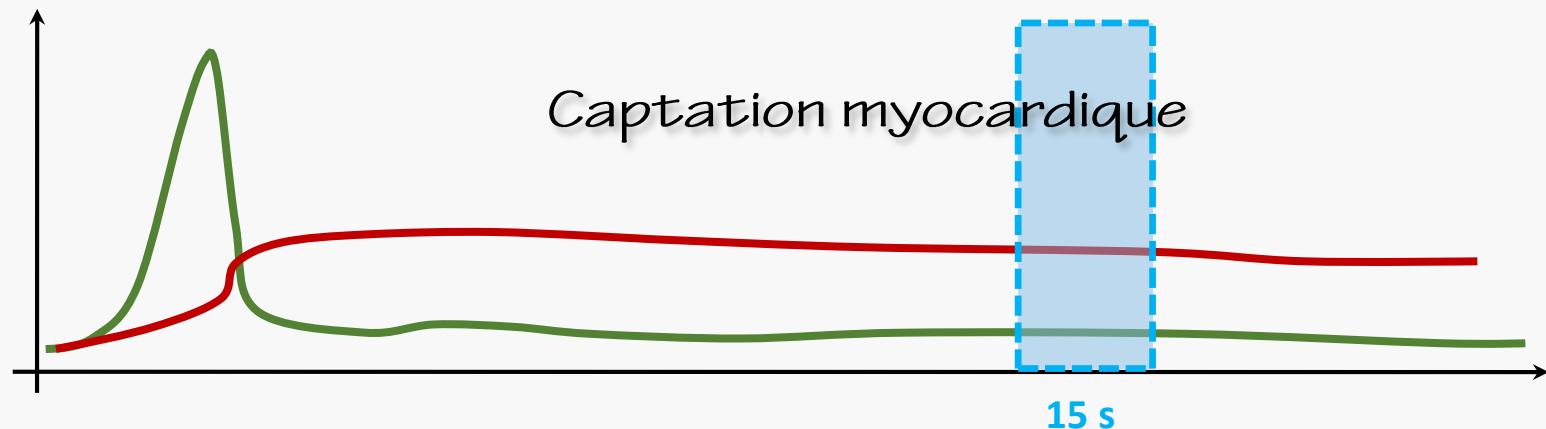
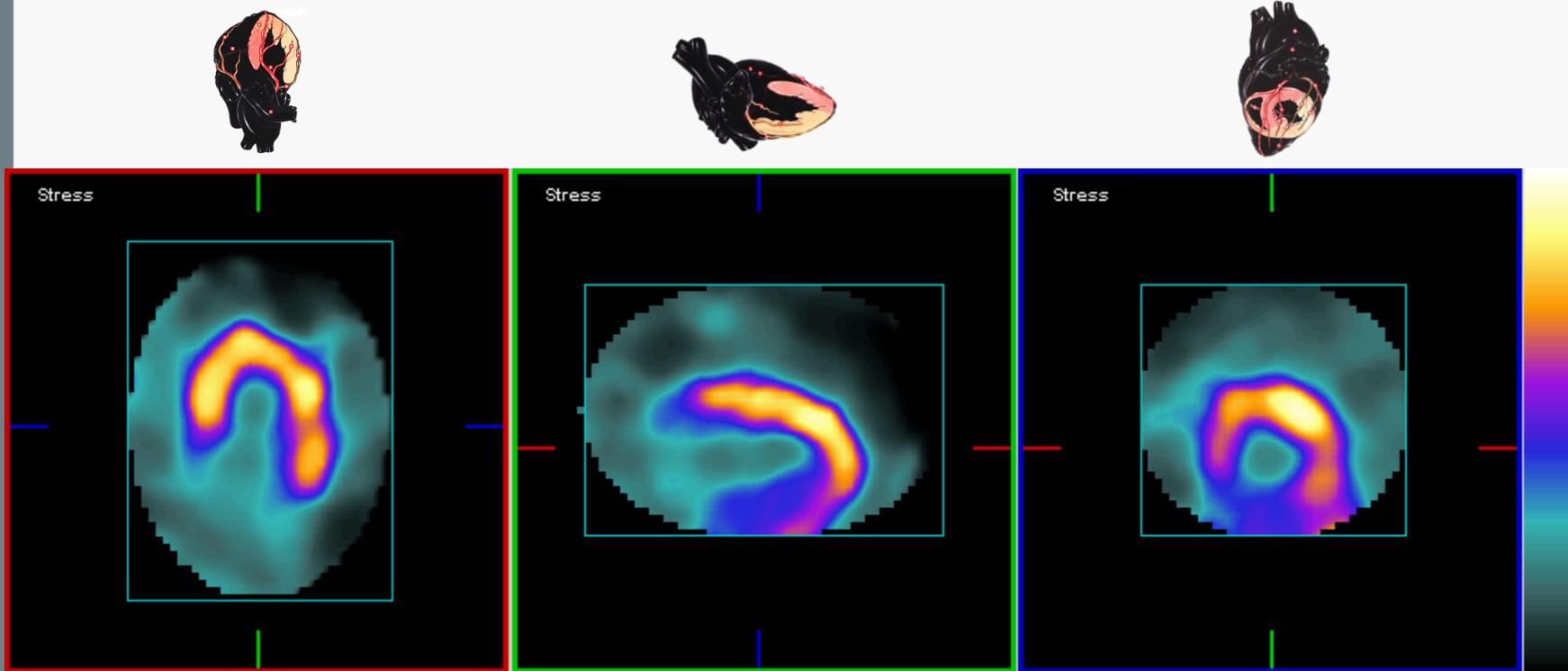
# Analyse factorielle



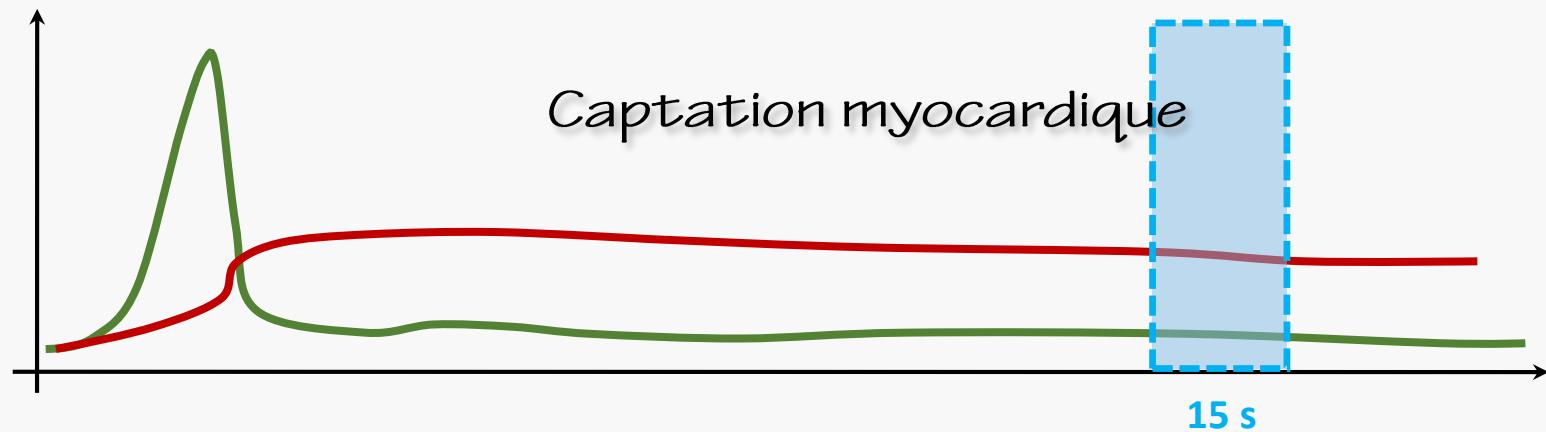
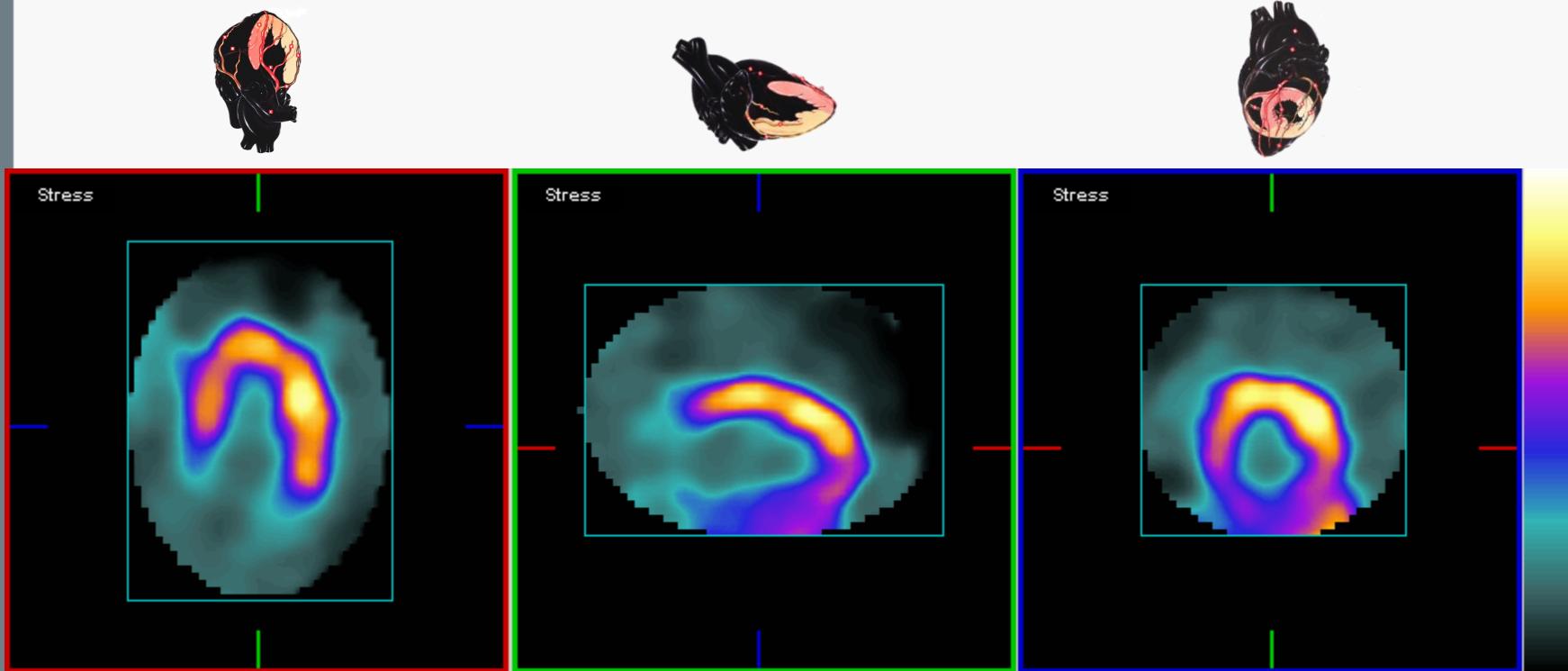
# Analyse factorielle



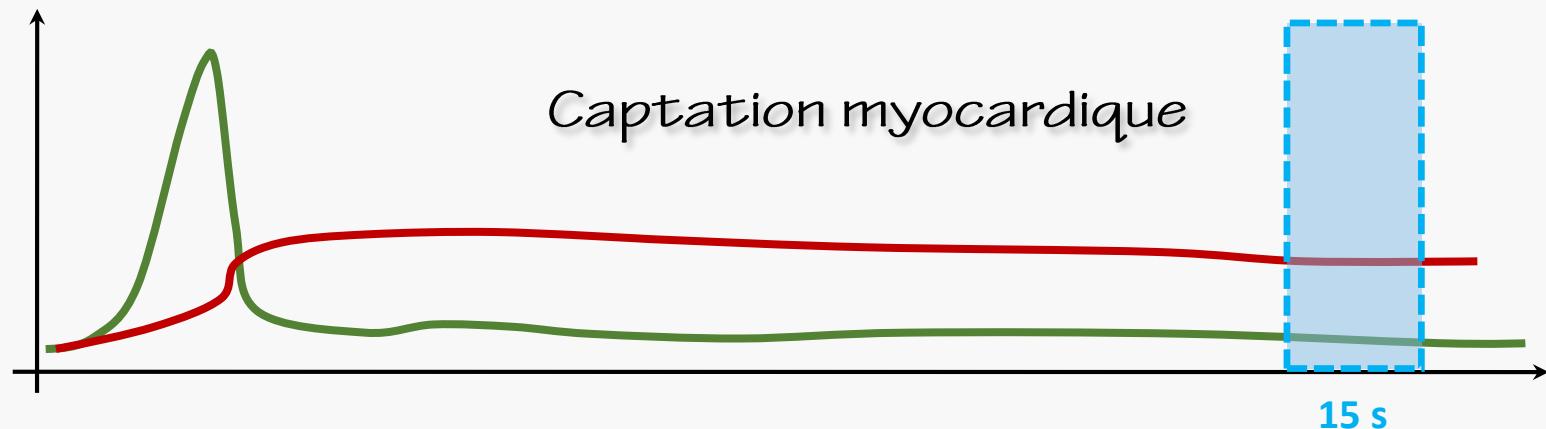
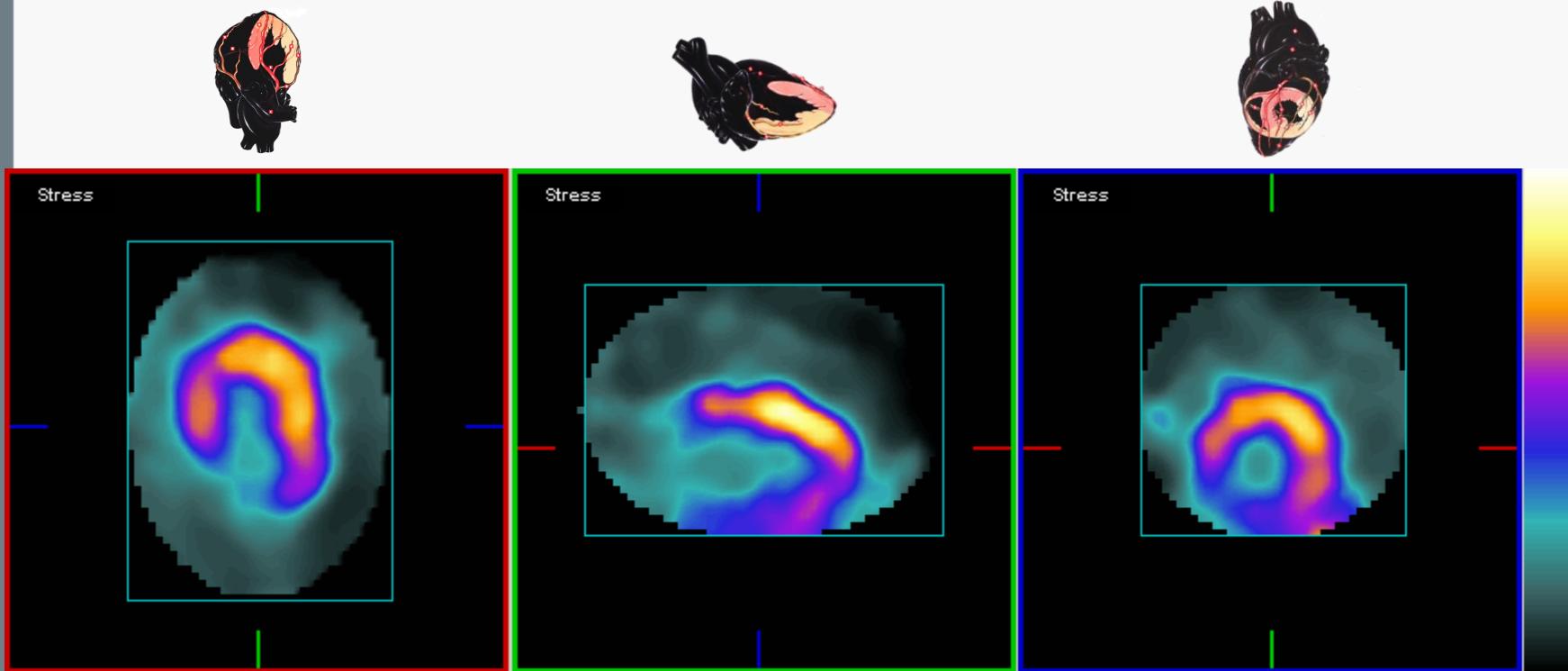
# Analyse factorielle



# Analyse factorielle

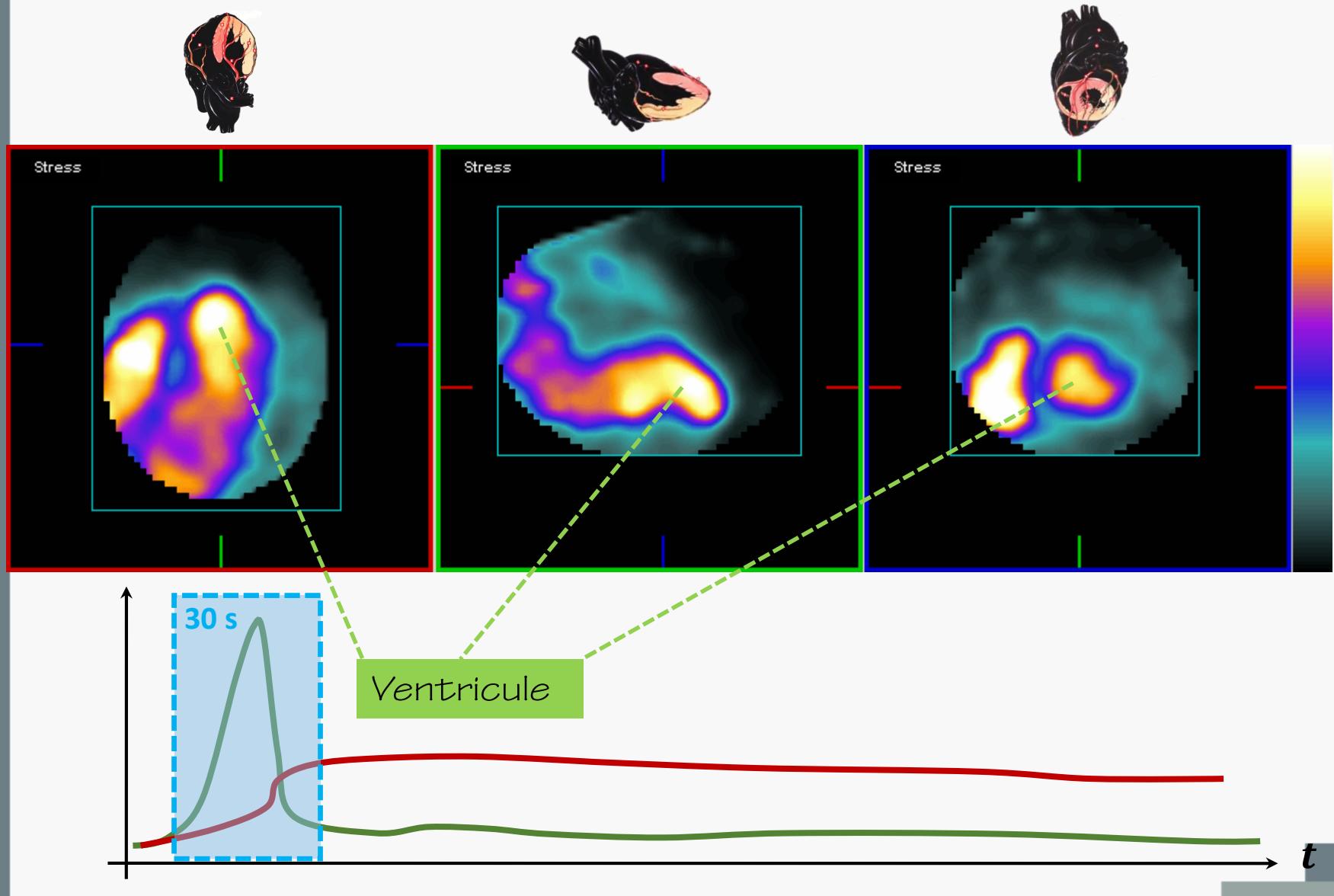


# Analyse factorielle



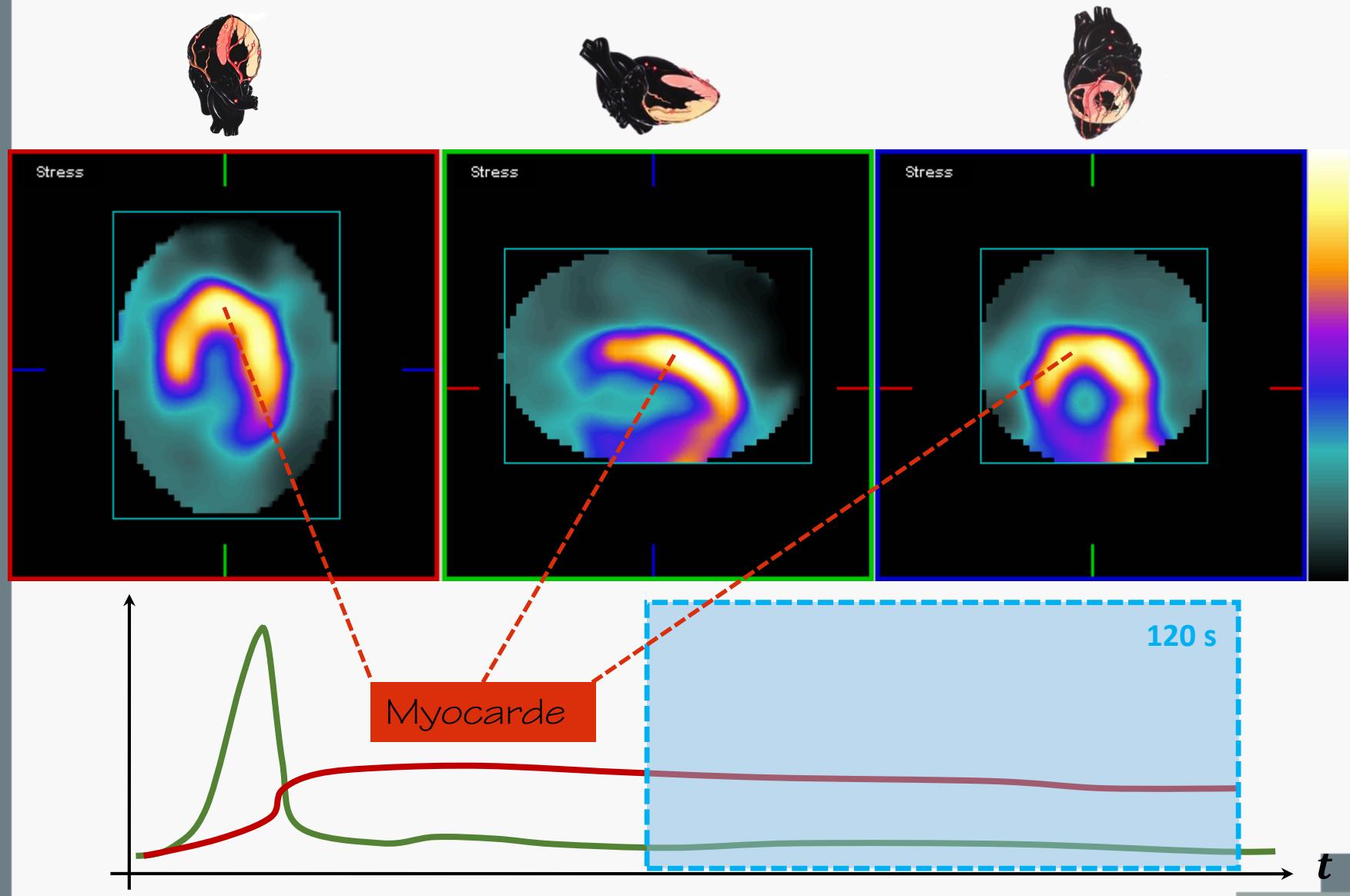
# Analyse factorielle

## SPECT dynamique



# Analyse factorielle

## SPECT dynamique

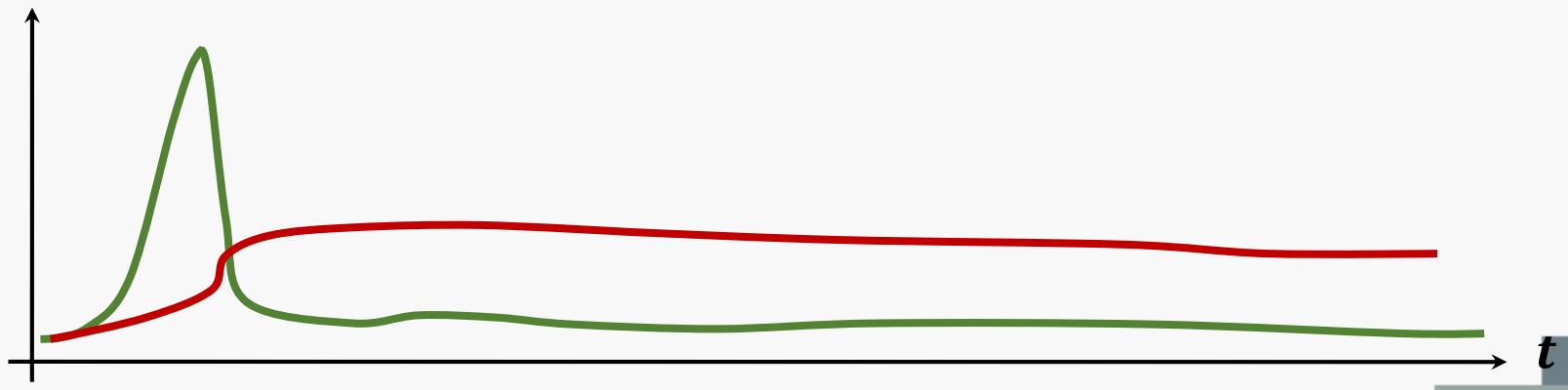
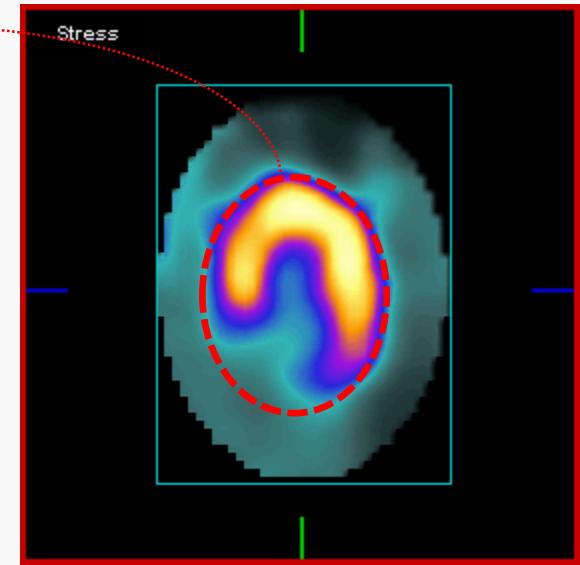


# Analyse factorielle

SPECT dynamique

$$\mathbf{M} = \begin{bmatrix} \blacksquare & \blacksquare & \blacksquare \\ \blacksquare & \blacksquare & \blacksquare \\ \blacksquare & \blacksquare & \blacksquare \end{bmatrix} \quad \downarrow \quad \begin{array}{l} \text{voxels} \\ \text{"sujets"} \end{array}$$

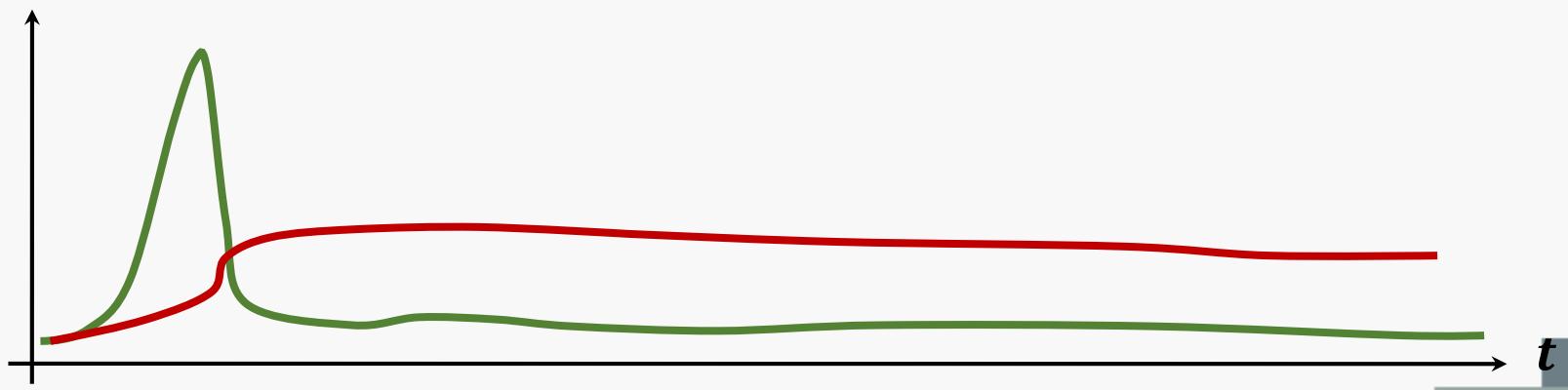
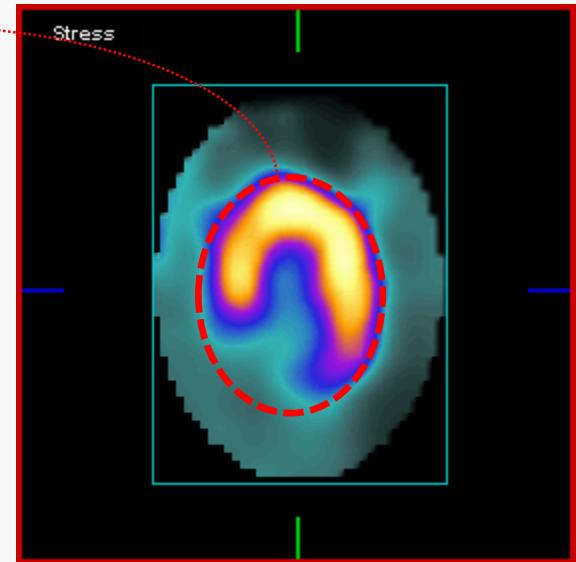
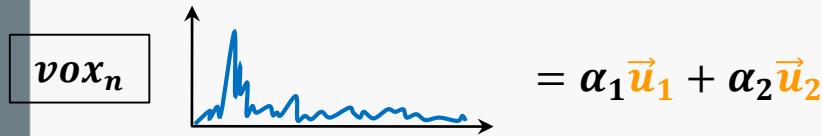
$t$



# Analyse factorielle

SPECT dynamique

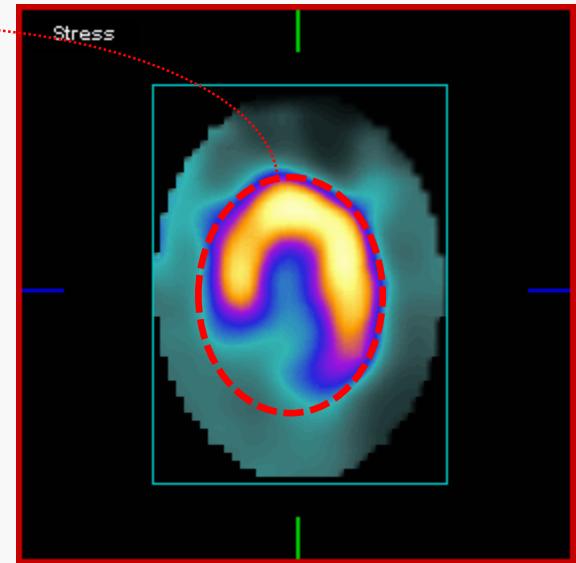
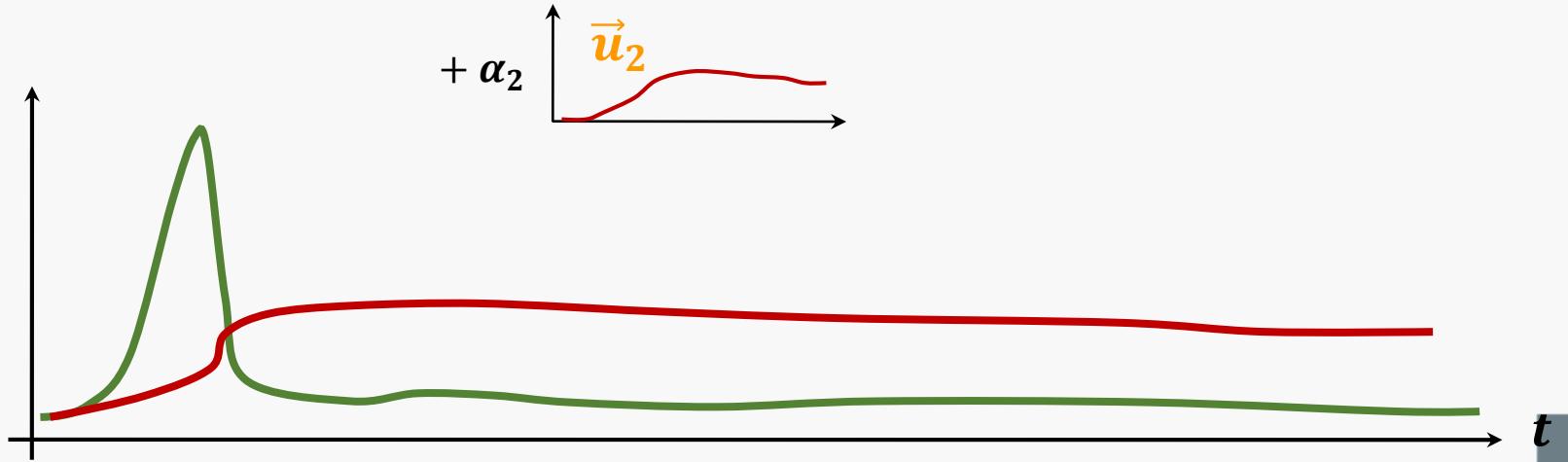
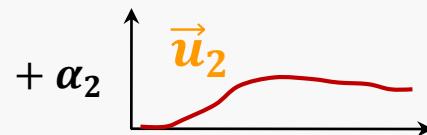
$$\mathbf{M} = \begin{bmatrix} \blacksquare & \blacksquare & \blacksquare \\ \blacksquare & \blacksquare & \blacksquare \\ \blacksquare & \blacksquare & \blacksquare \end{bmatrix} \xrightarrow[t]{} \boxed{\text{voxels}} \quad \text{"sujets"}$$



# Analyse factorielle

SPECT dynamique

$$\mathbf{M} = \begin{bmatrix} \blacksquare & \blacksquare & \blacksquare \\ \blacksquare & \blacksquare & \blacksquare \\ \blacksquare & \blacksquare & \blacksquare \end{bmatrix} \quad \downarrow \quad \boxed{\text{voxels}} \quad \text{"sujets"} \quad \xrightarrow{t}$$

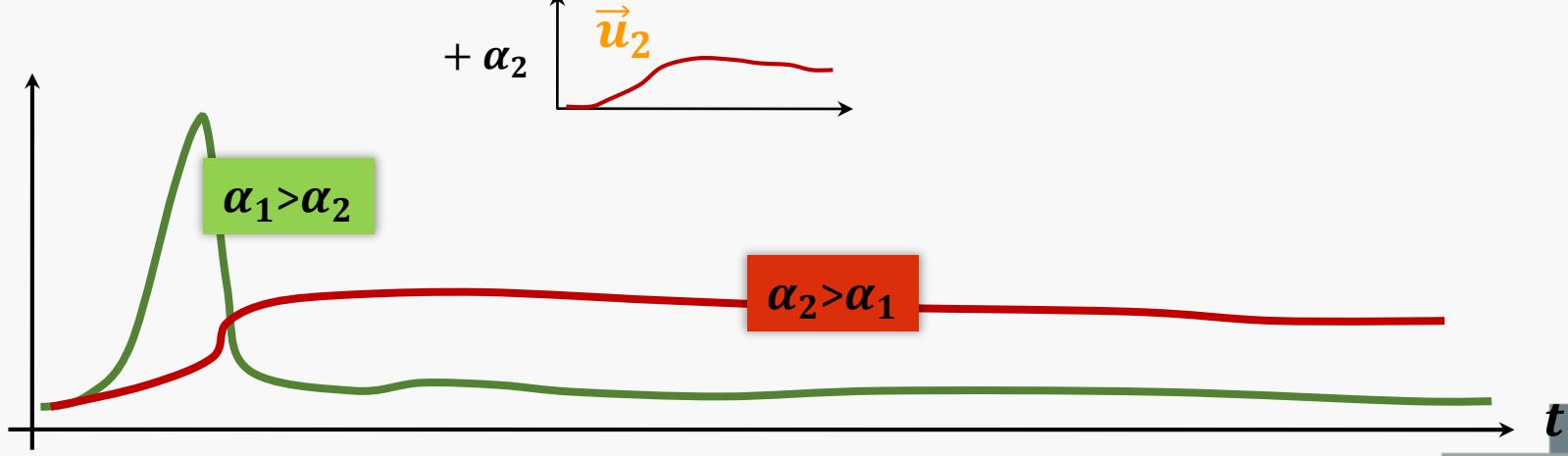
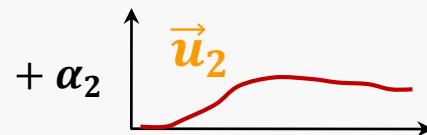
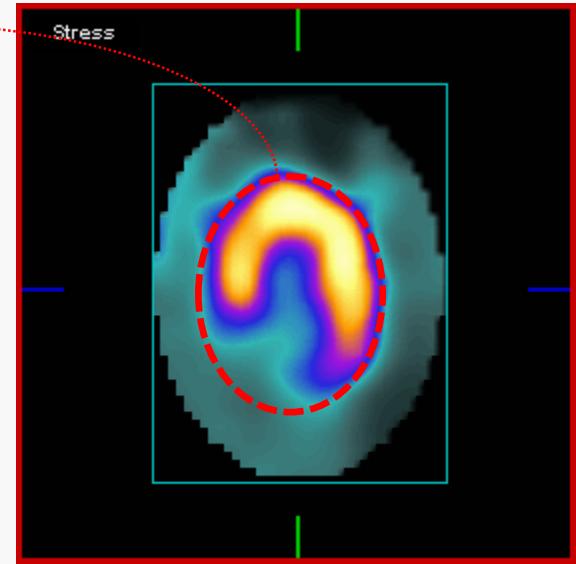


# Analyse factorielle

SPECT dynamique

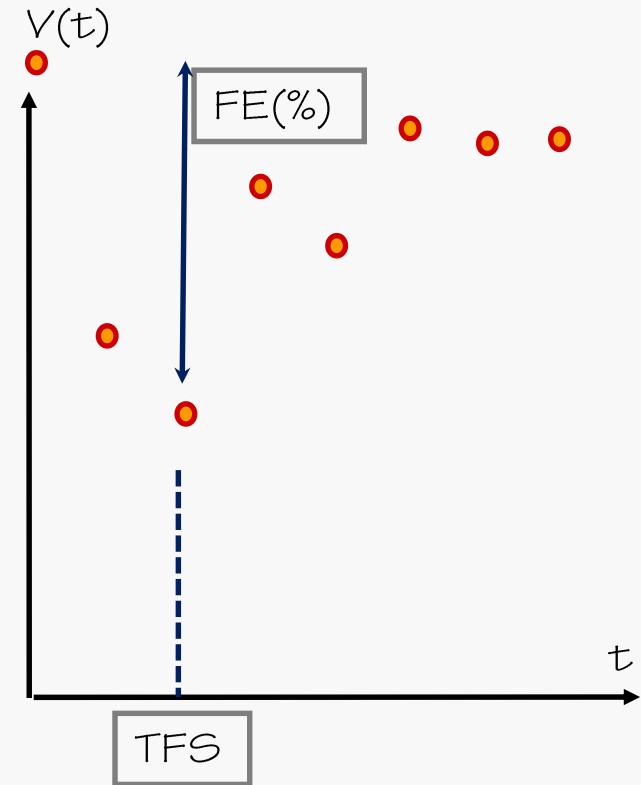
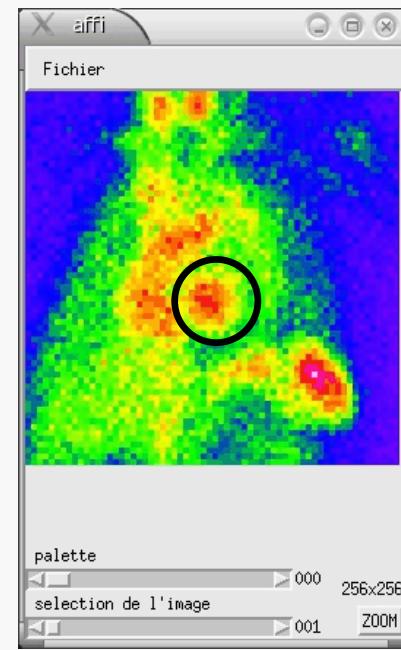
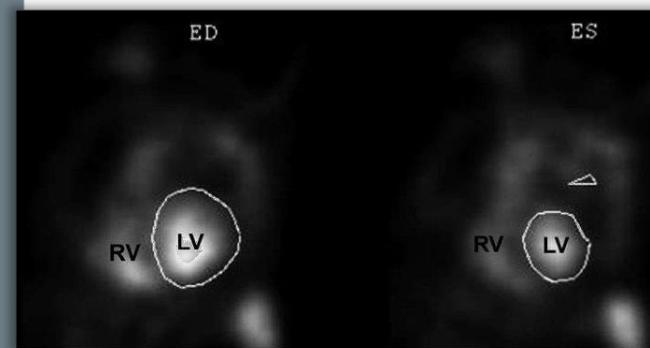
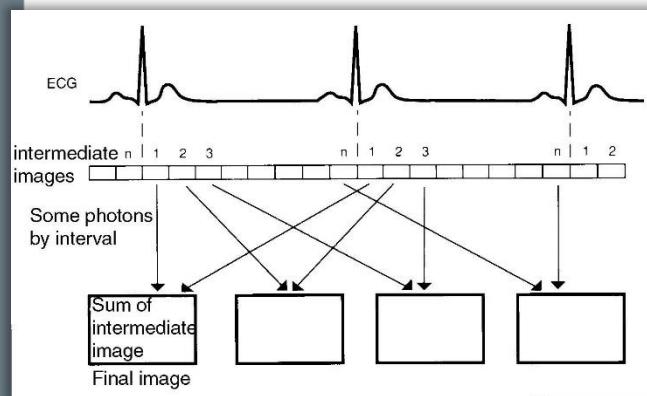
$$\mathbf{M} = \begin{bmatrix} \blacksquare & \blacksquare & \blacksquare \\ \blacksquare & \blacksquare & \blacksquare \\ \blacksquare & \blacksquare & \blacksquare \end{bmatrix} \quad \downarrow \quad \begin{array}{l} \text{voxels} \\ \text{"sujets"} \end{array}$$

$\xrightarrow{t}$



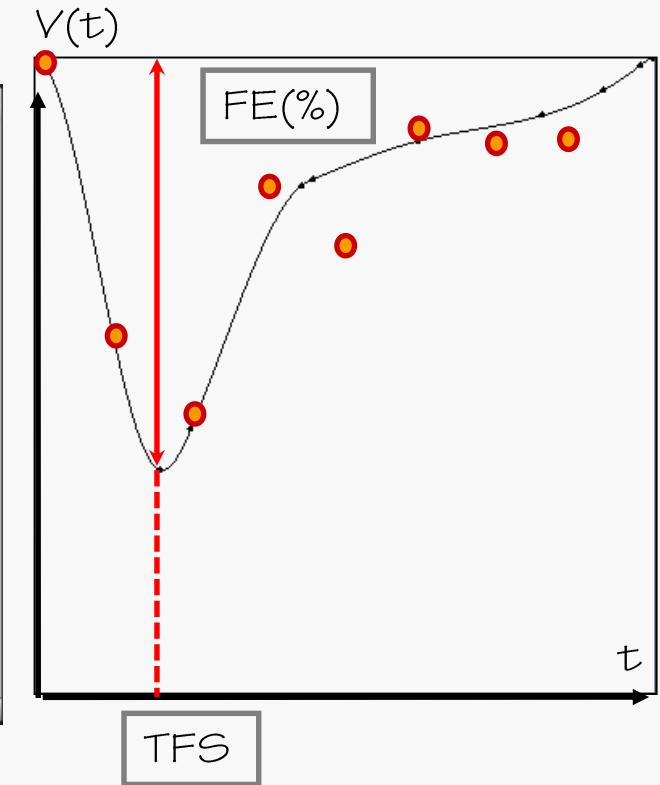
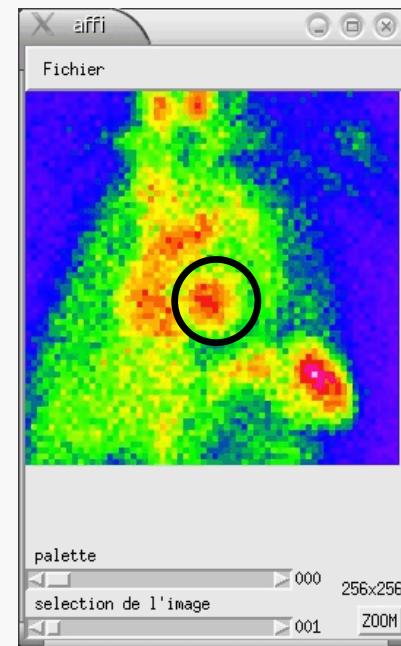
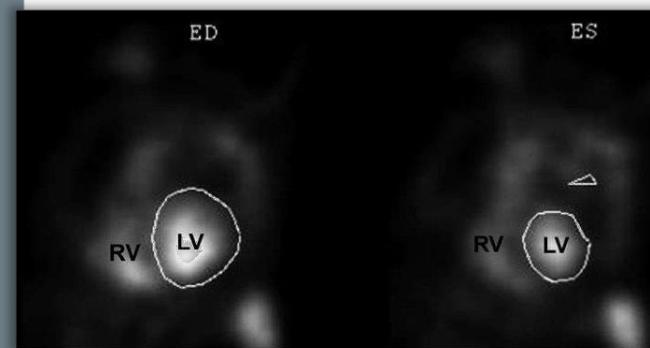
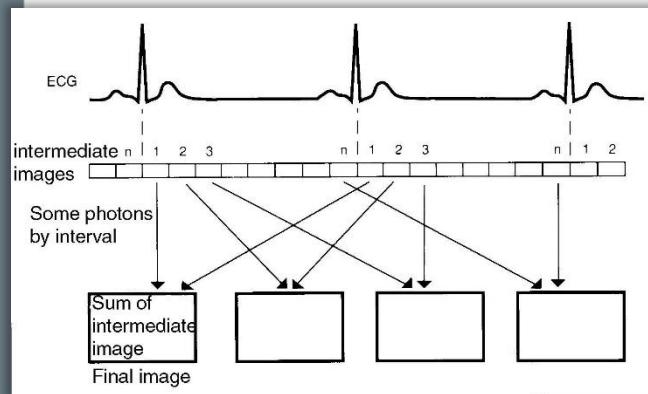
# Ventriculographie isotopique

- Marquage des GR au  $^{99m}\text{Tc}$
- Synchronisation ECG
- Analyse de CTA globale / locale



# Ventriculographie isotopique

- Marquage des GR au  $^{99m}\text{Tc}$
- Synchronisation ECG
- Analyse de CTA globale / locale

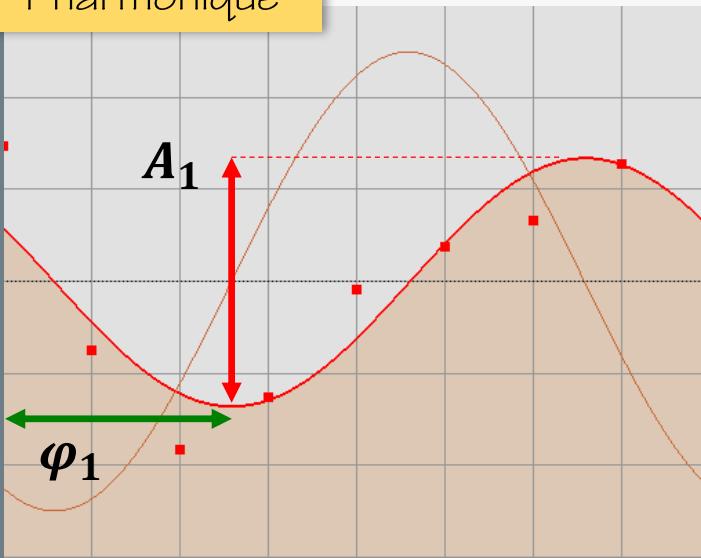


# Ventriculographie isotopique

## FIT HARMONIQUE

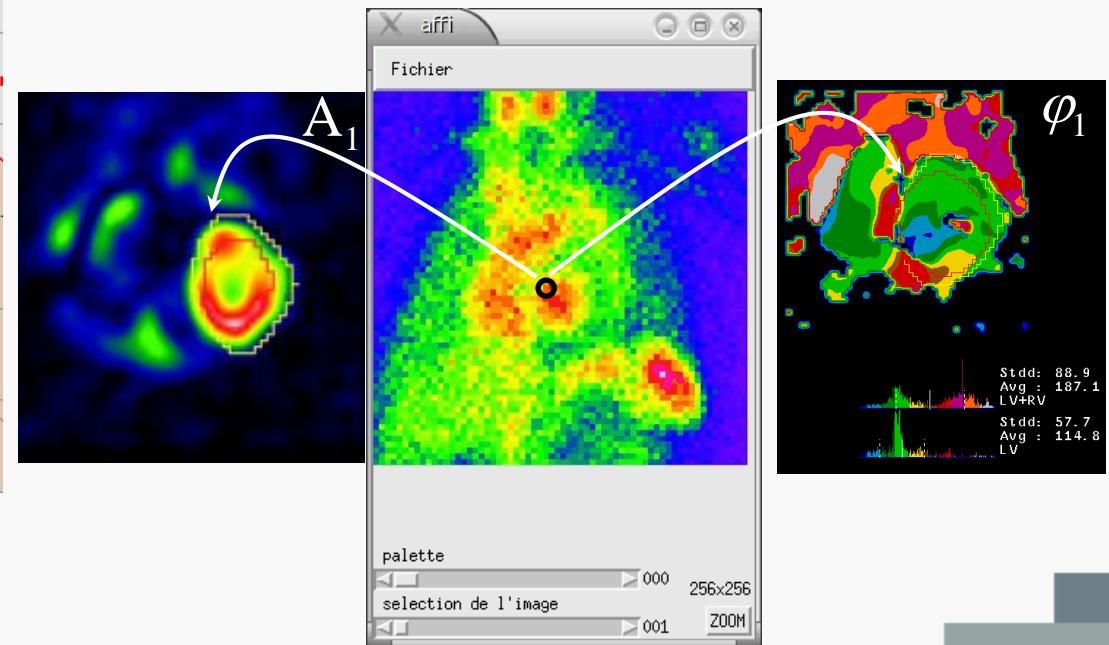
$$s(t) = \frac{1}{N} \sum_{k=0}^{N-1} \hat{s}(k) \cdot e^{j \cdot (k \cdot \omega_0) t} = \sum_{k=0}^{N-1} A_k \cdot e^{j \cdot \varphi_k} \cdot e^{j \cdot (k \cdot \omega_0) t} \approx A_0 + A_1 e^{j \cdot (\omega_0 t + \varphi_1)}$$

1 harmonique



Ampitude  
↳ hypokinésies ?

Phase  
↳ dyskinésies ?

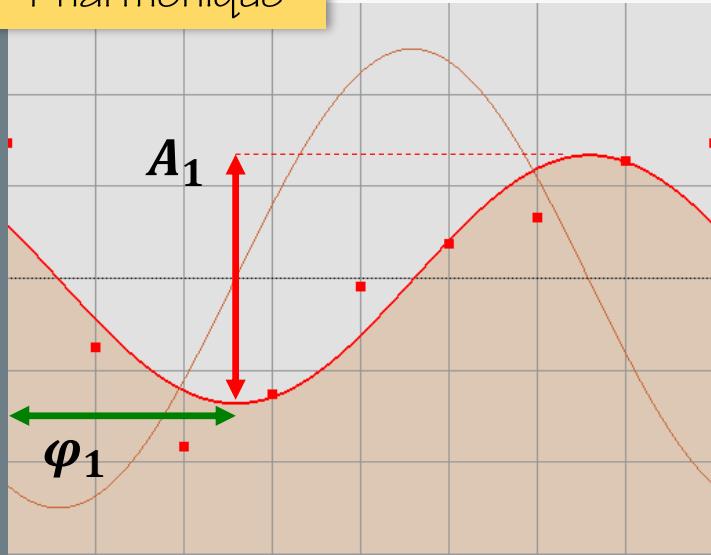


# Ventriculographie isotopique

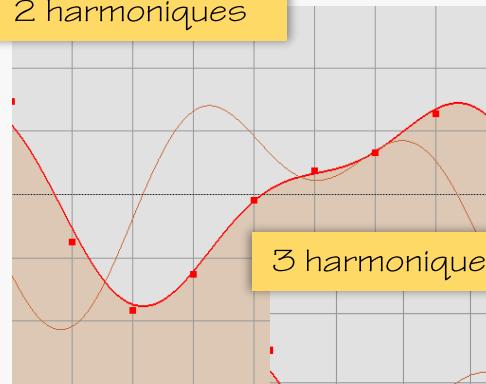
## FIT HARMONIQUE

$$s(t) = \frac{1}{N} \sum_{k=0}^{N-1} \hat{s}(k) \cdot e^{j \cdot (k \cdot \omega_0) t} = \sum_{k=0}^{N-1} A_k \cdot e^{j \cdot \varphi_k} \cdot e^{j \cdot (k \cdot \omega_0) t} \approx A_0 + A_1 e^{j \cdot (\omega_0 t + \varphi_1)}$$

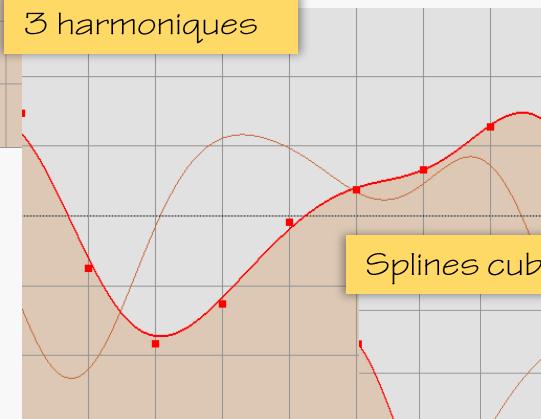
1 harmonique



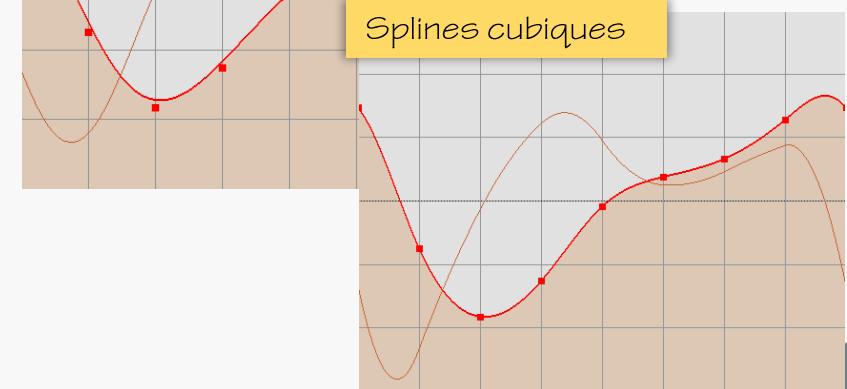
2 harmoniques



3 harmoniques

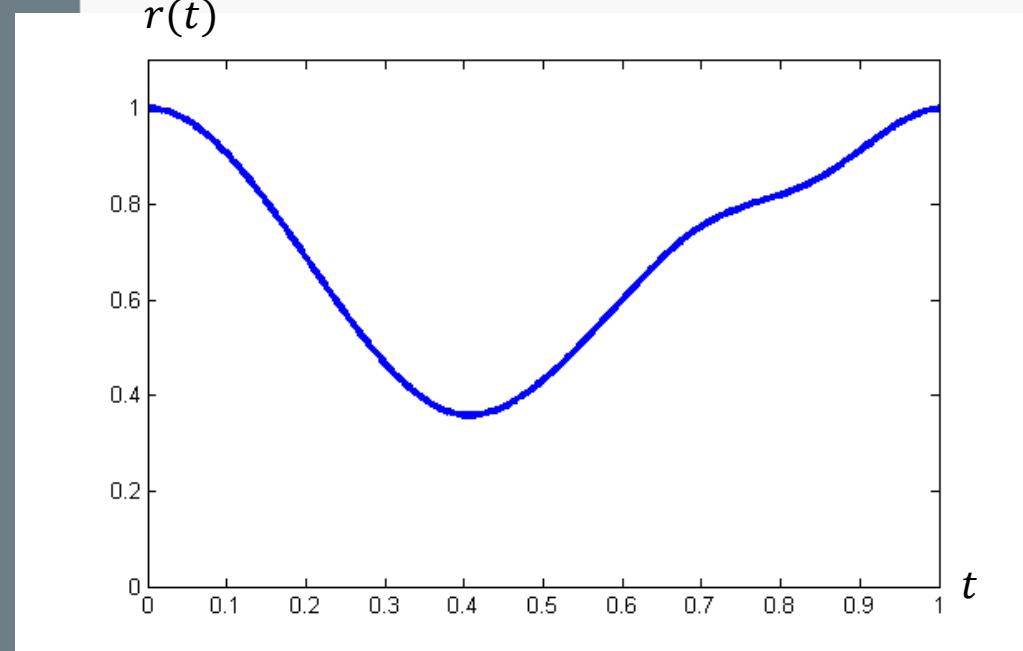


Splines cubiques



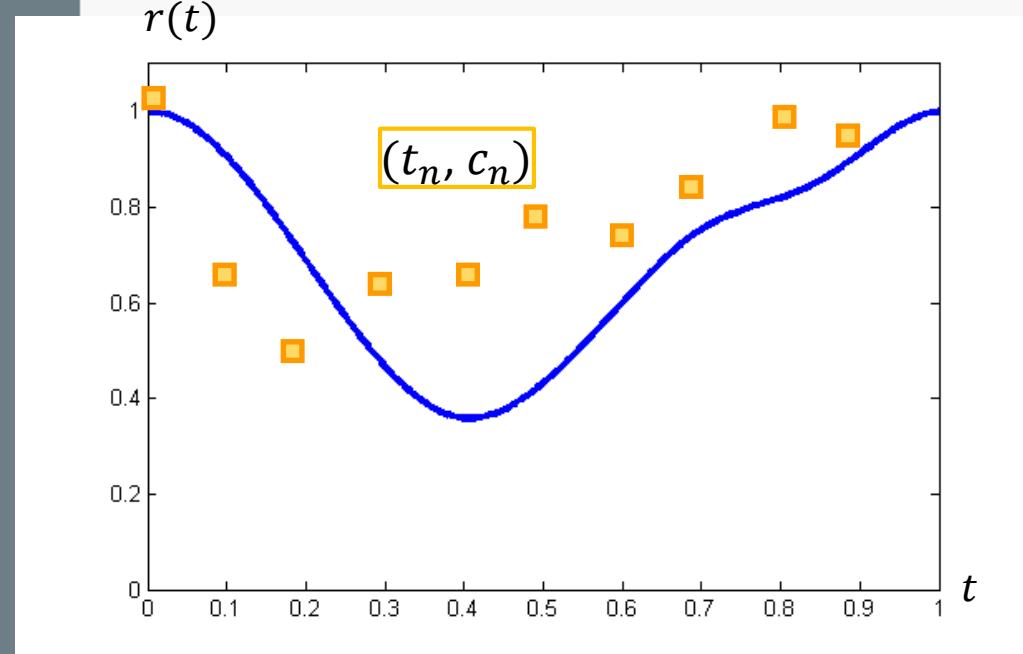
# Ventriculographie isotopique

COURBE de REFERENCE



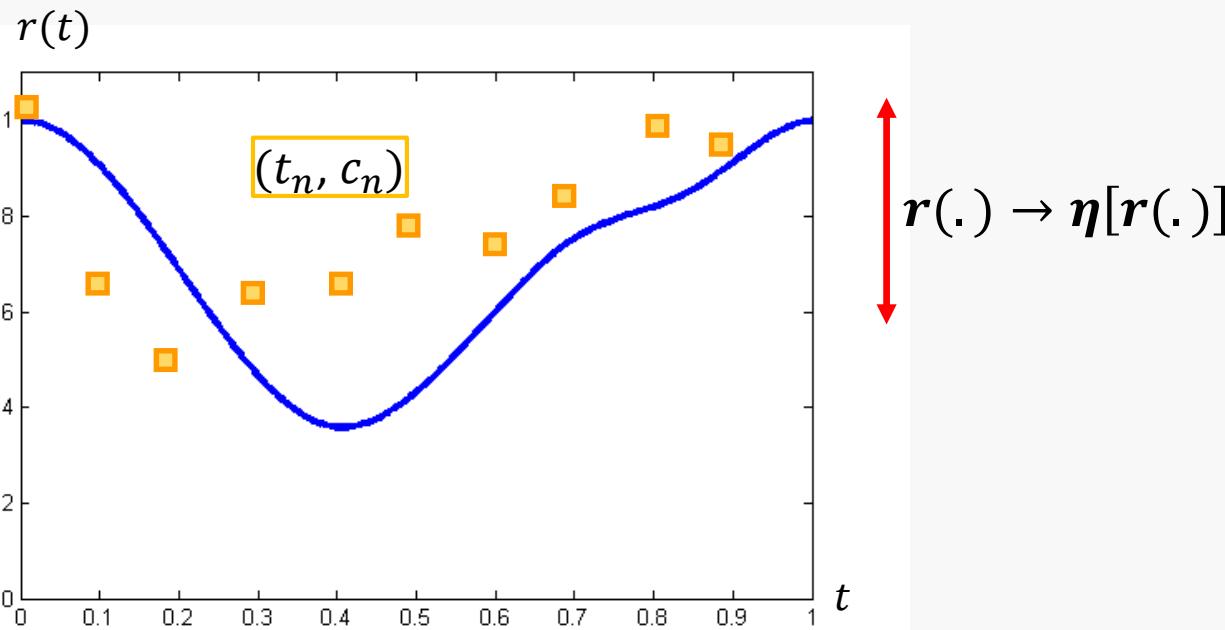
# Ventriculographie isotopique

COURBE de REFERENCE



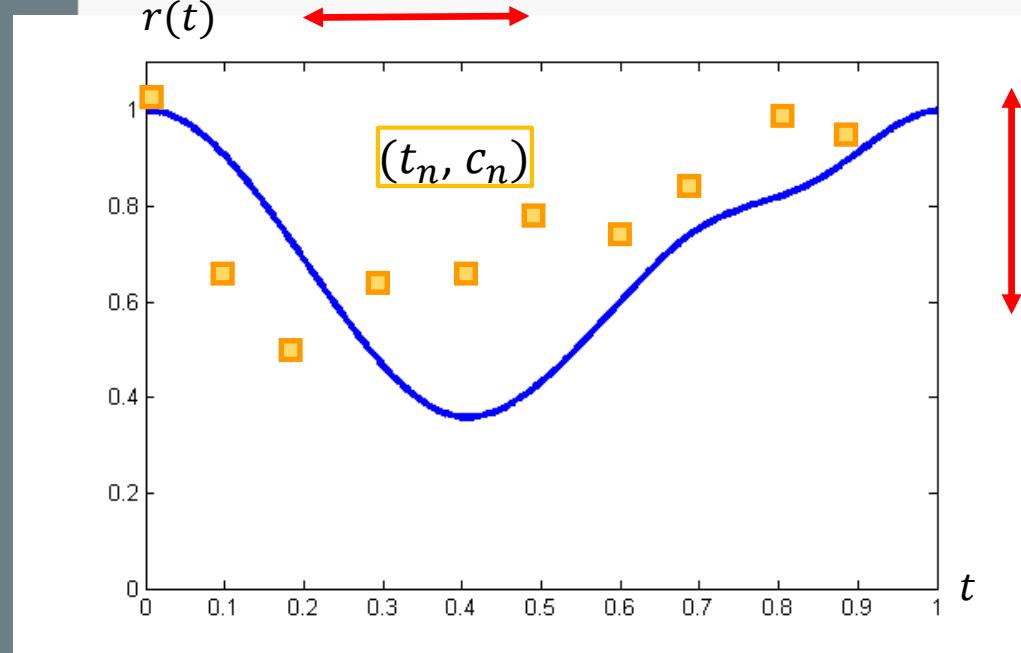
# Ventriculographie isotopique

COURBE de REFERENCE



# Ventriculographie isotopique

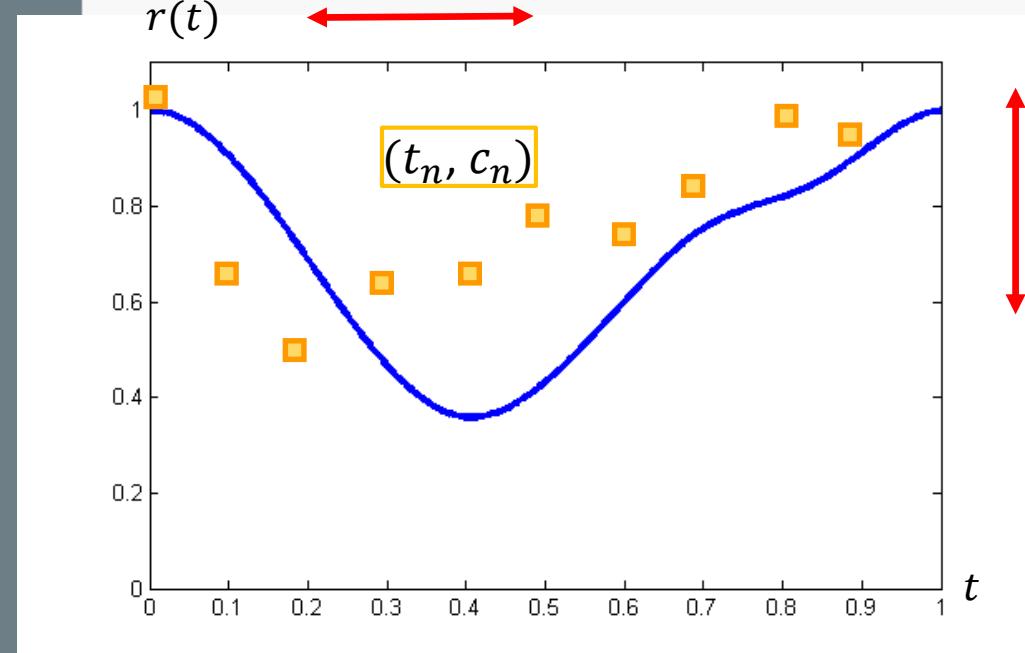
COURBE de REFERENCE



# Ventriculographie isotopique

COURBE de REFERENCE

$$c_n = \eta[r(\tau(t_n))]$$



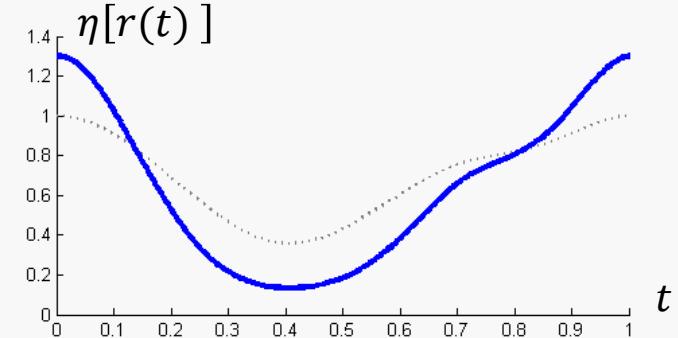
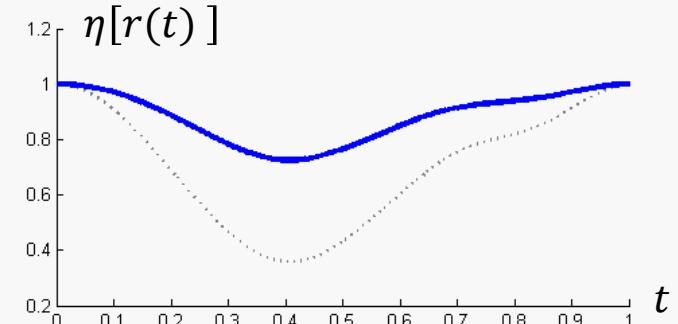
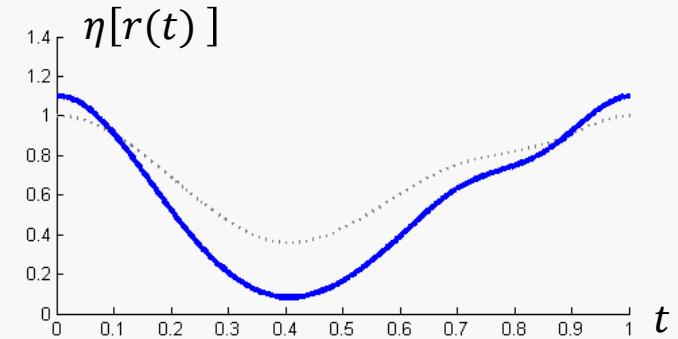
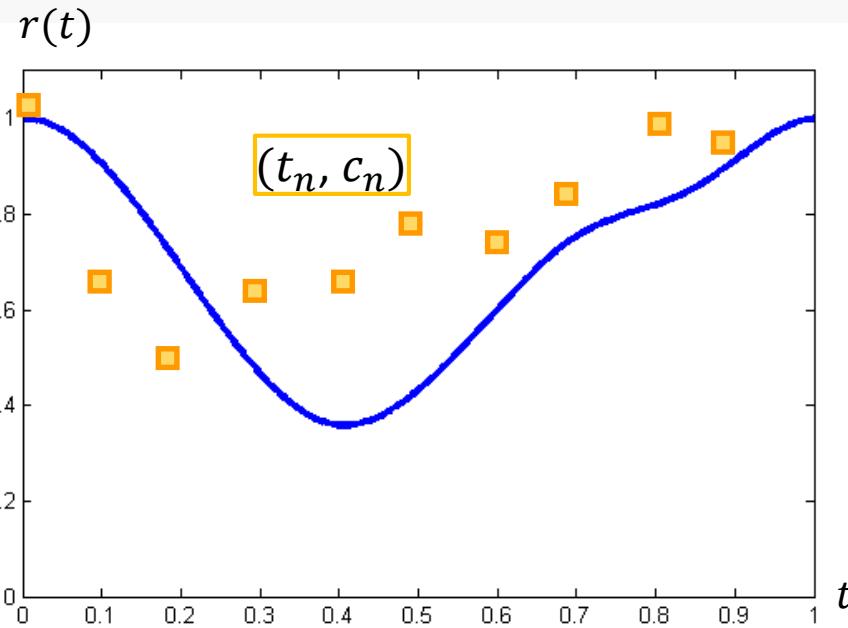
$$r(\cdot) \rightarrow \eta[r(\cdot)]$$

# Ventriculographie isotopique

COURBE de REFERENCE

$$c_n = \eta[r(\tau(t_n))]$$

$$\eta(\cdot) = P_2(\cdot)$$



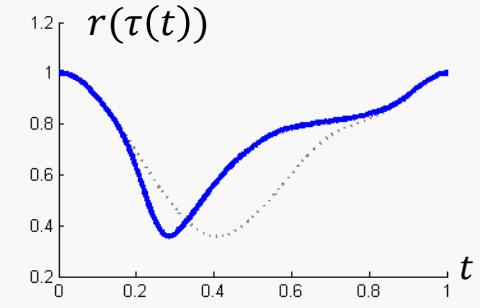
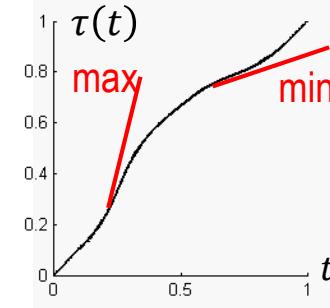
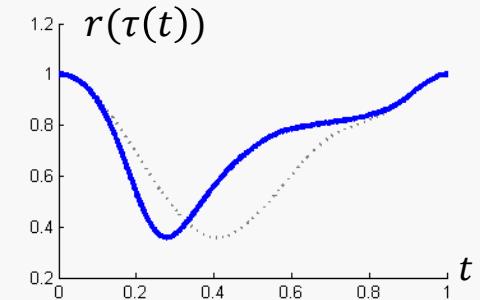
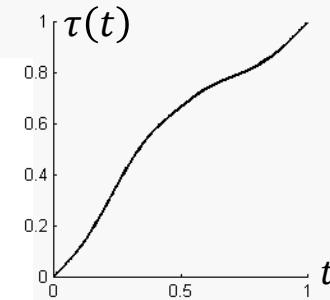
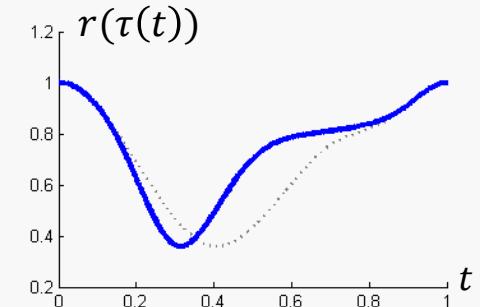
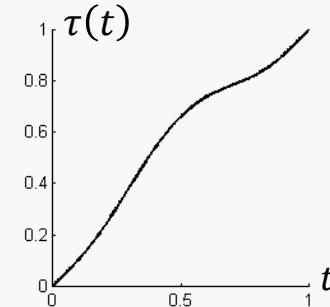
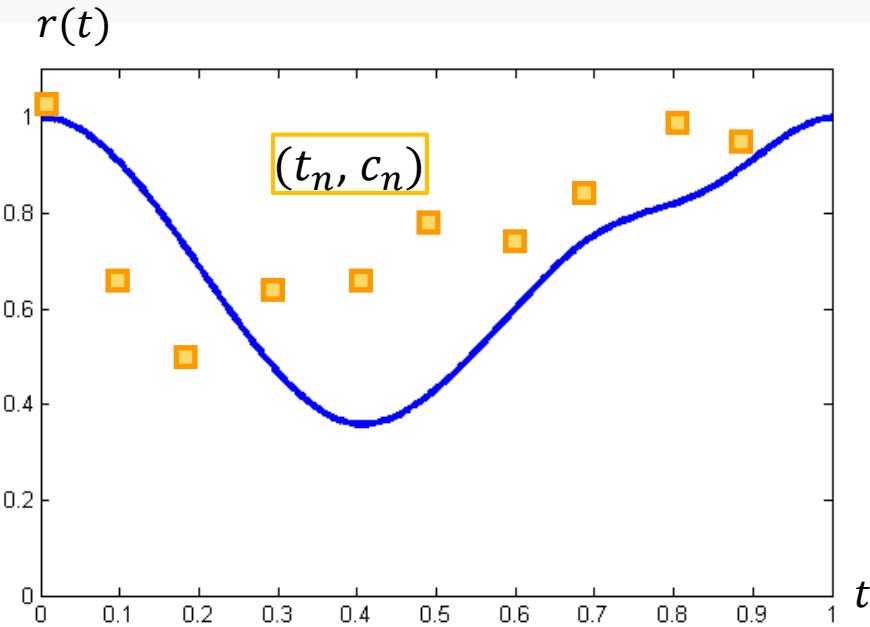
# Ventriculographie isotopique

COURBE de REFERENCE

$$c_n = \eta[r(\tau(t_n))]$$

$$\eta(\cdot) = P_2(\cdot)$$

$$\tau(t) = t + \sum_i \alpha_i \{1 + \cos[2\pi\omega_i(t - \mu_i)]\}$$



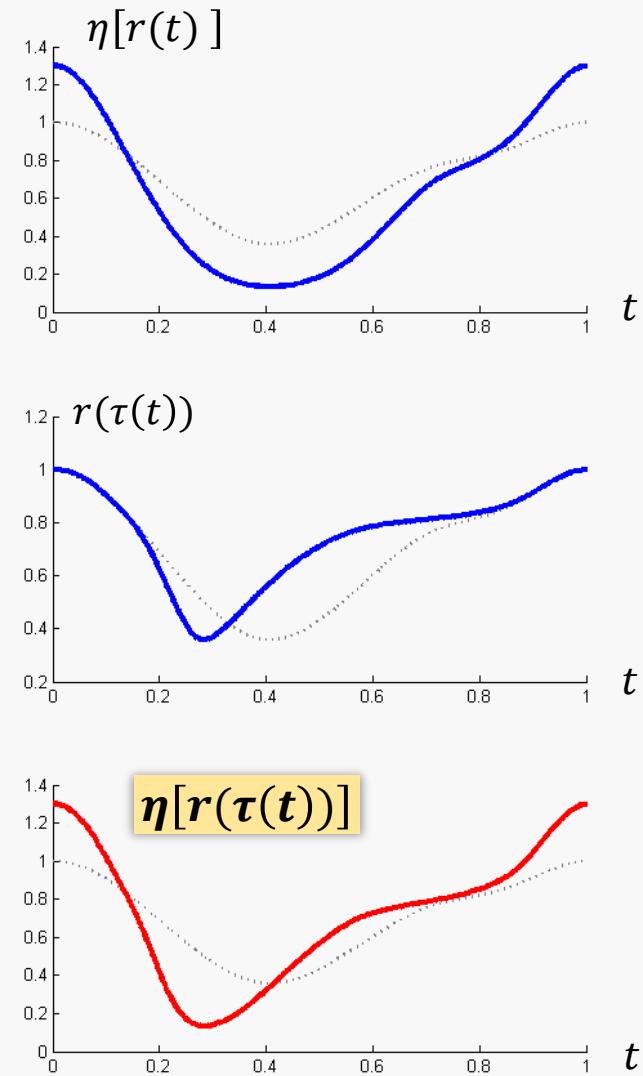
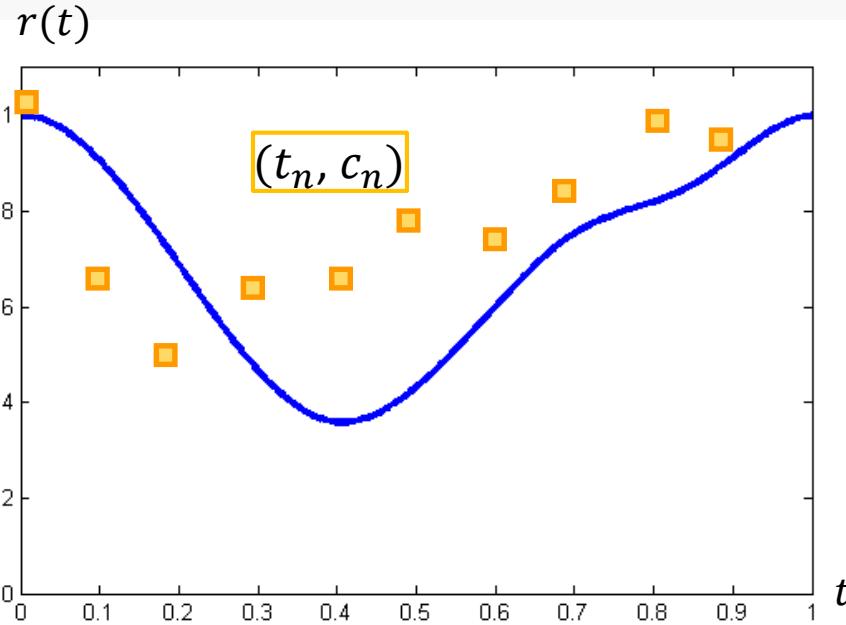
# Ventriculographie isotopique

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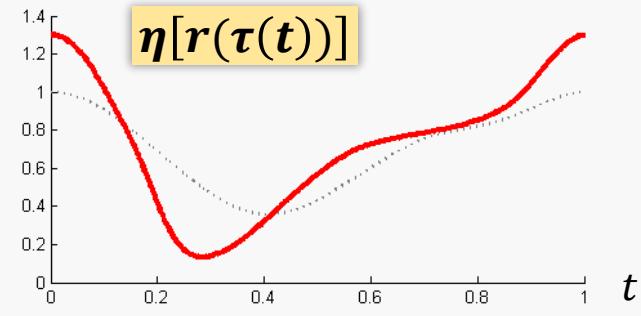
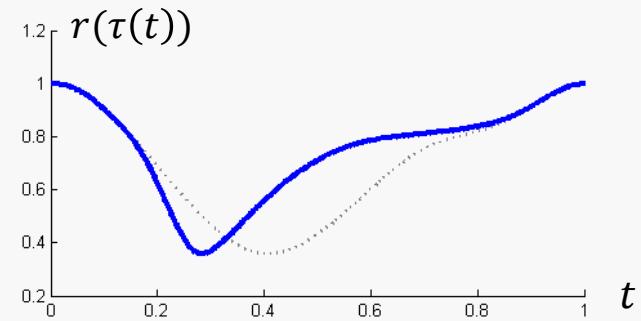
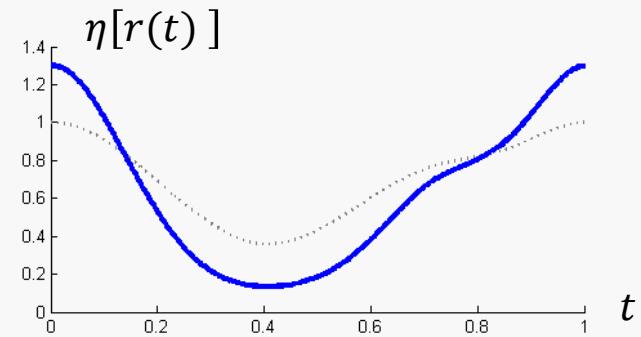
# Ventriculographie isotopique

COURBE de REFERENCE

$$c_n = \eta[r(\tau(t_n))]$$

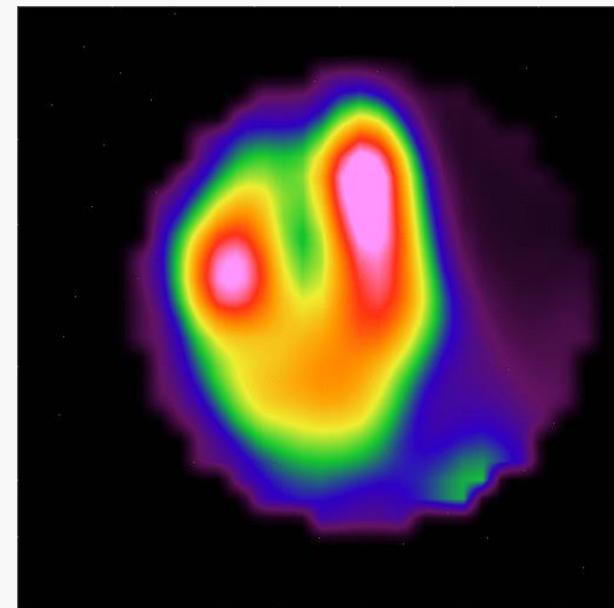
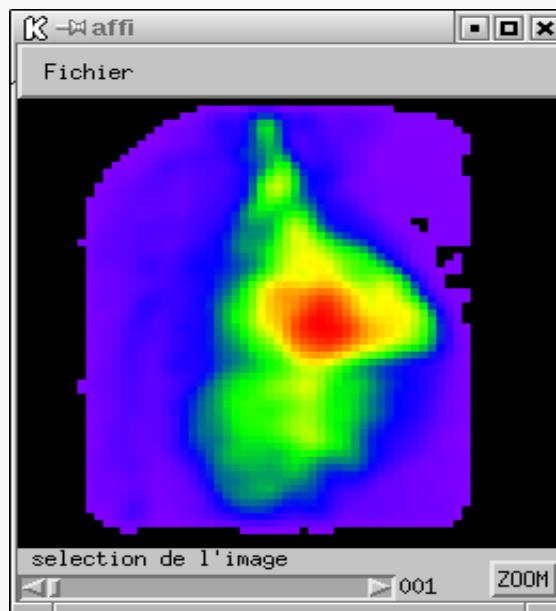
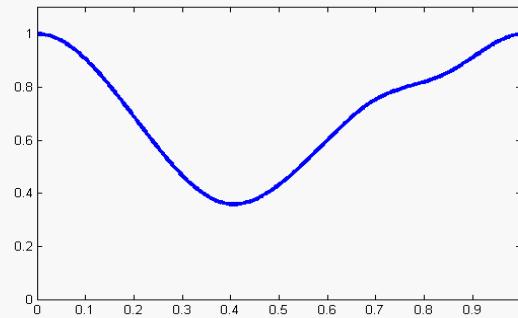
$$\eta(\cdot) = P_2(\cdot)$$

$$\tau(t) = t + \sum_i \alpha_i \{1 + \cos[2\pi\omega_i(t - \mu_i)]\}$$



# Tomo-ventriculographie

## ACQUISITION TOMOGRAPHIQUE

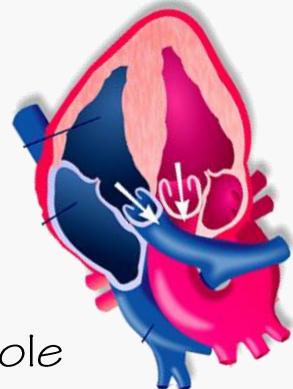
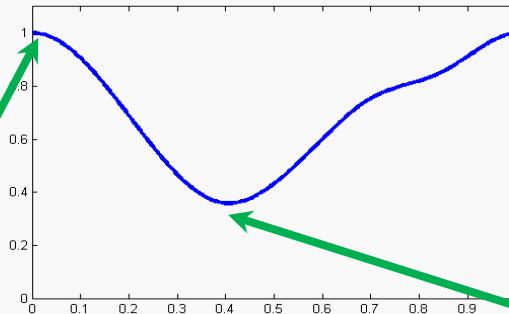


# Tomo-ventriculographie

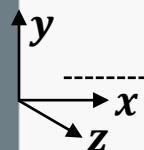
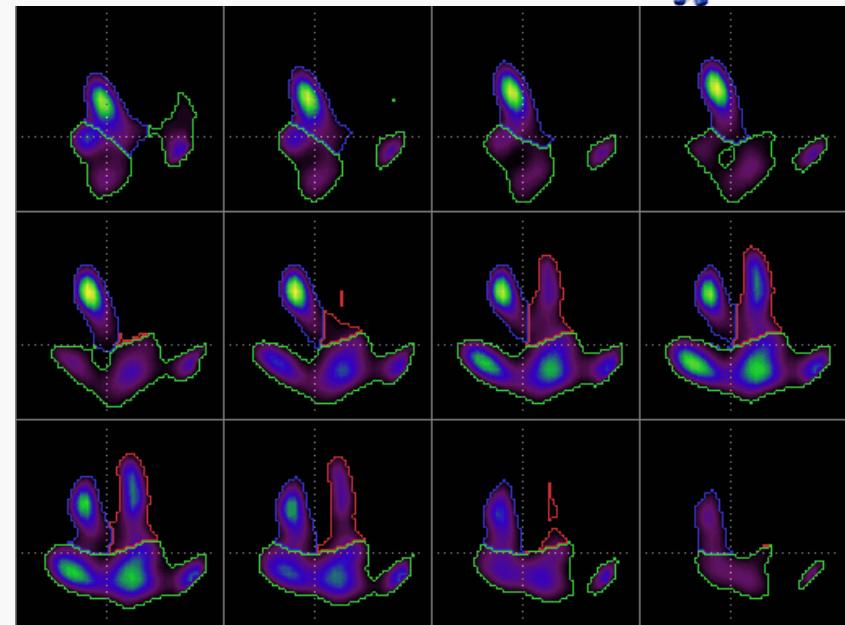
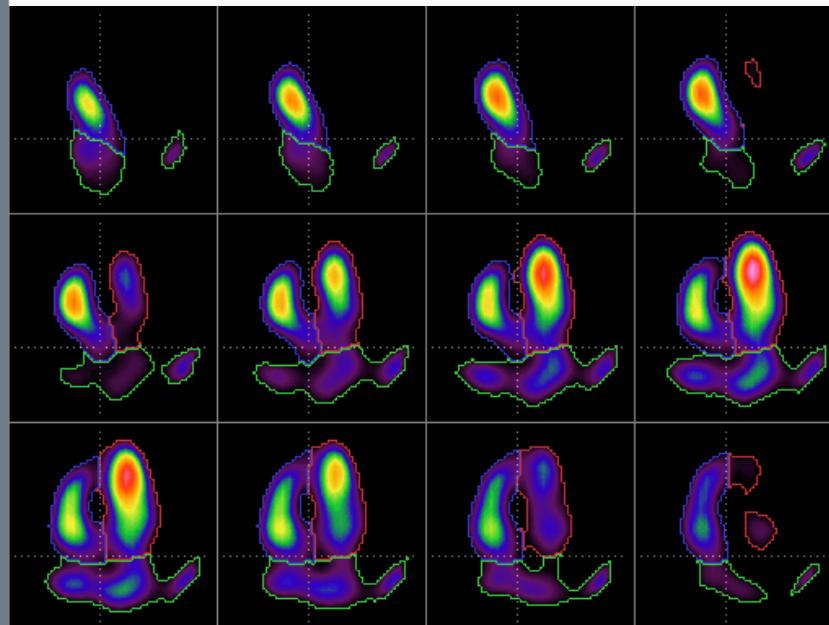
## SEGMENTATION



Fin de diastole



Fin de systole



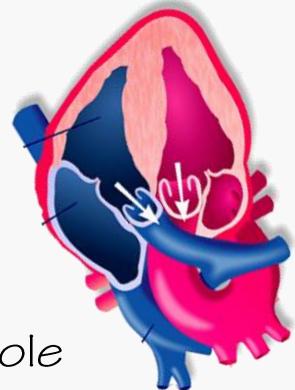
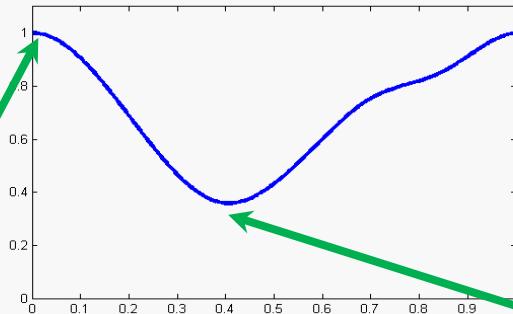
*t*

# Tomo-ventriculographie

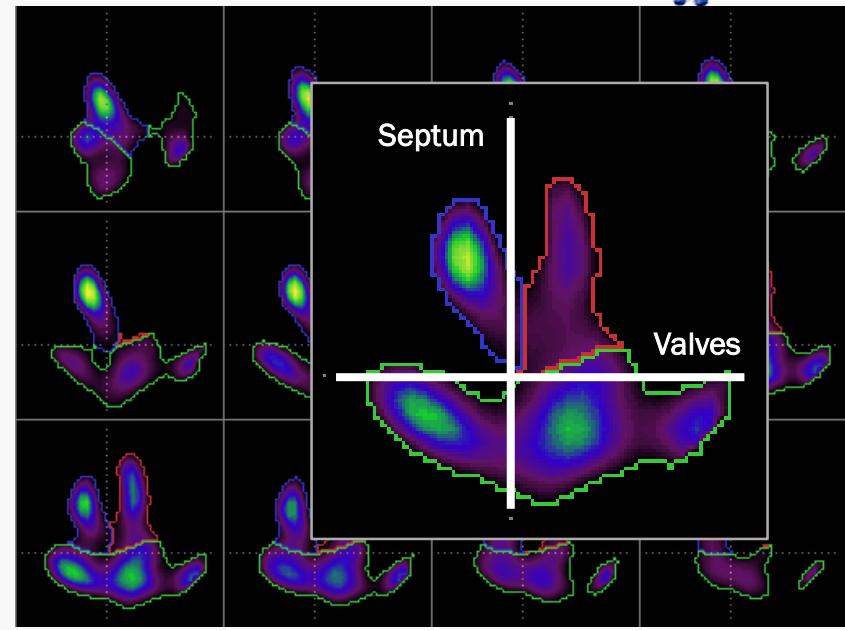
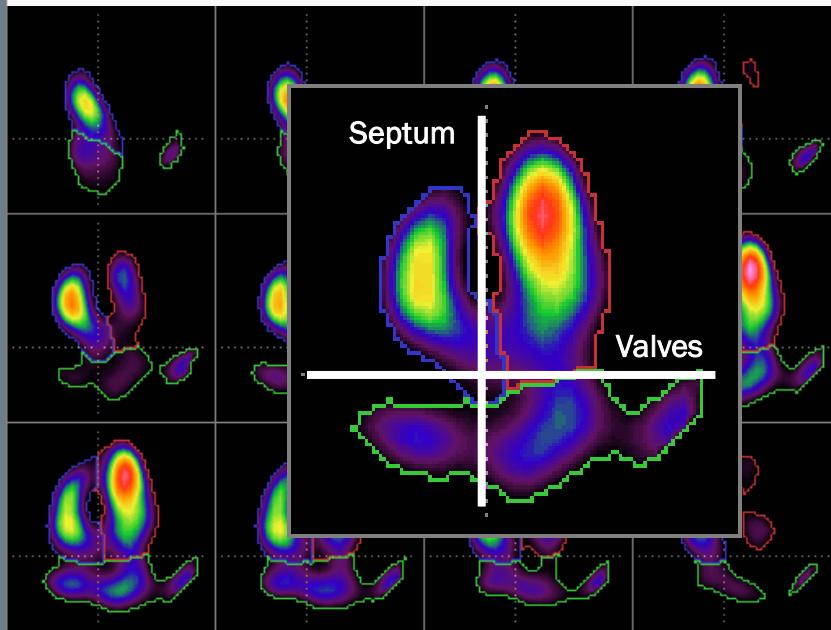
## SEGMENTATION



Fin de diastole



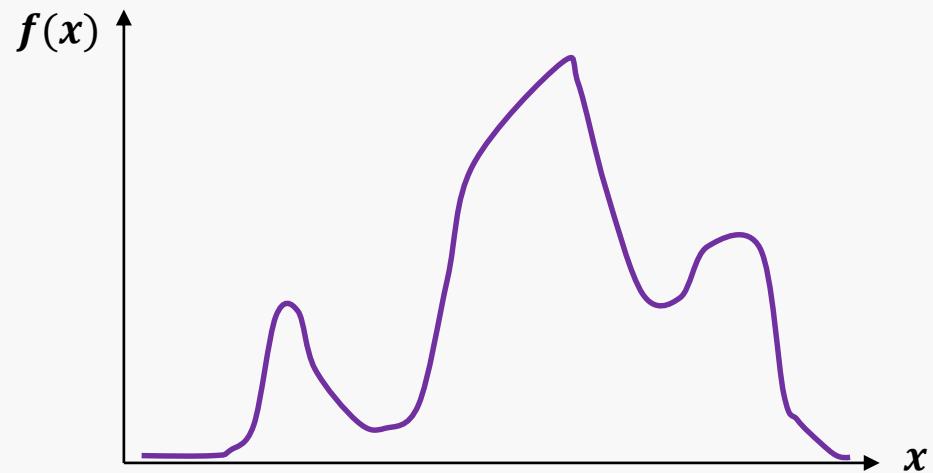
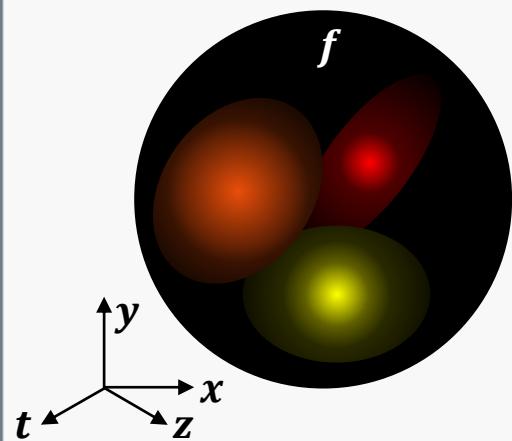
Fin de systole



# Tomo-ventriculographie

## SEGMENTATION

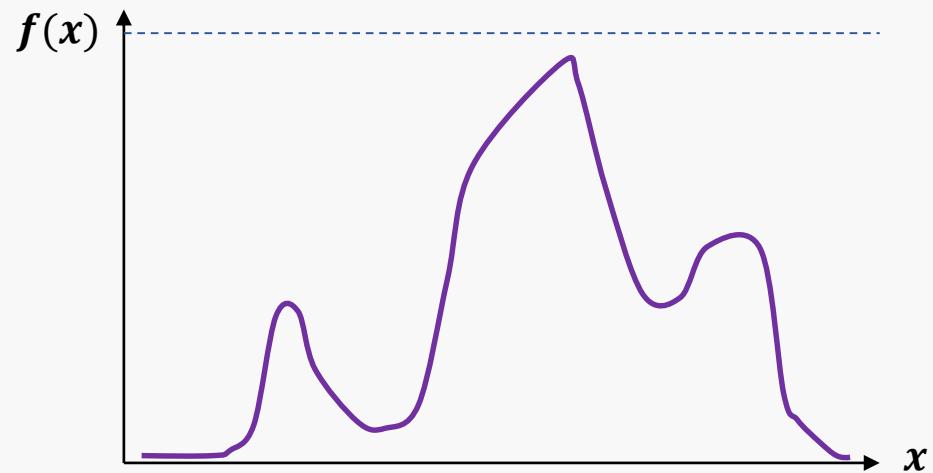
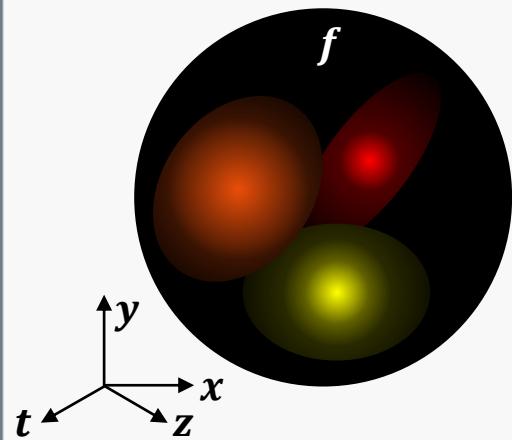
Immersion / ligne de partage des eaux



# Tomo-ventriculographie

## SEGMENTATION

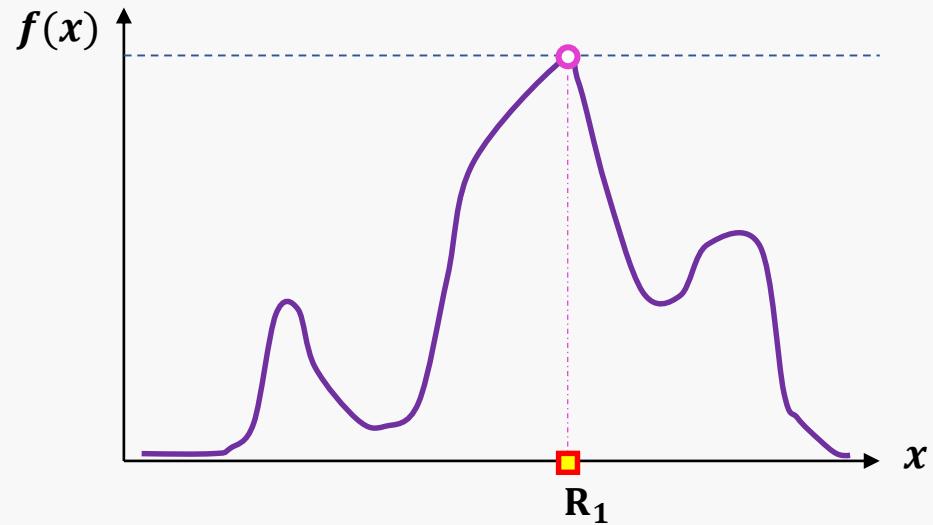
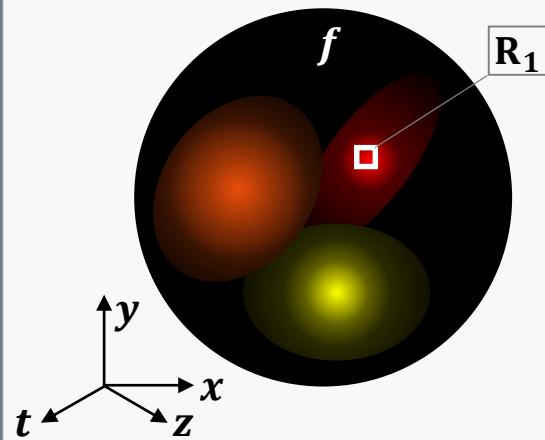
Immersion / ligne de partage des eaux



# Tomo-ventriculographie

## SEGMENTATION

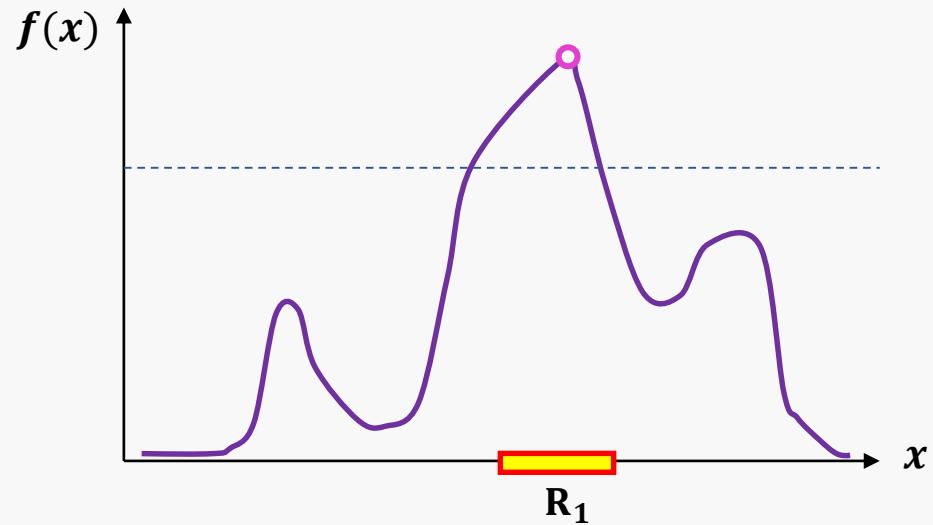
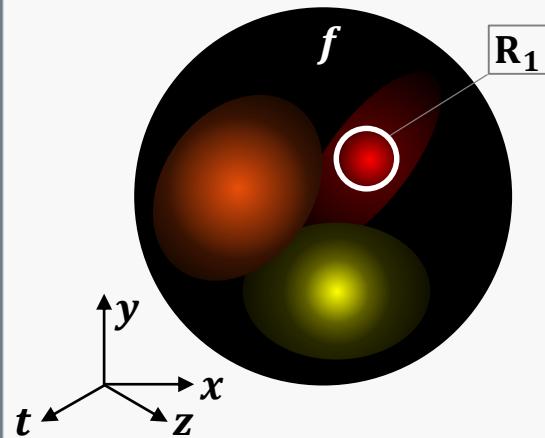
Immersion / ligne de partage des eaux



# Tomo-ventriculographie

## SEGMENTATION

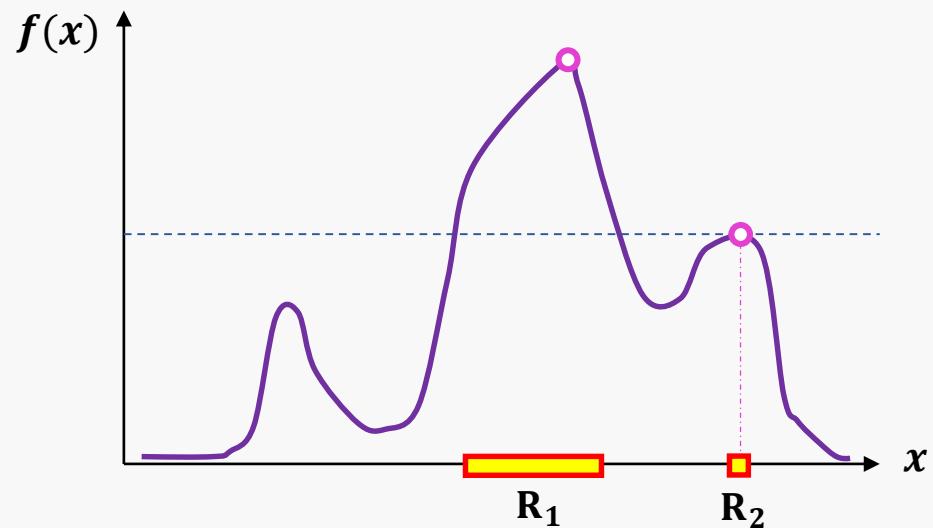
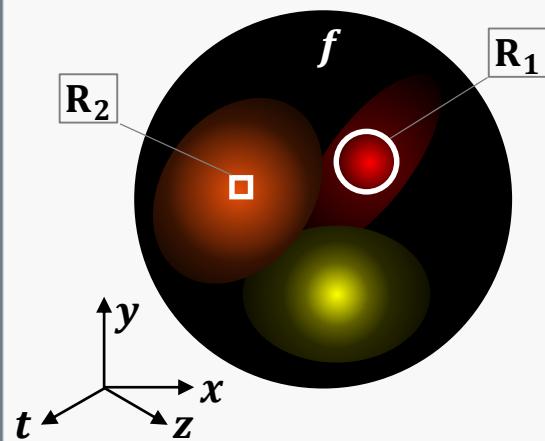
Immersion / ligne de partage des eaux



# Tomo-ventriculographie

## SEGMENTATION

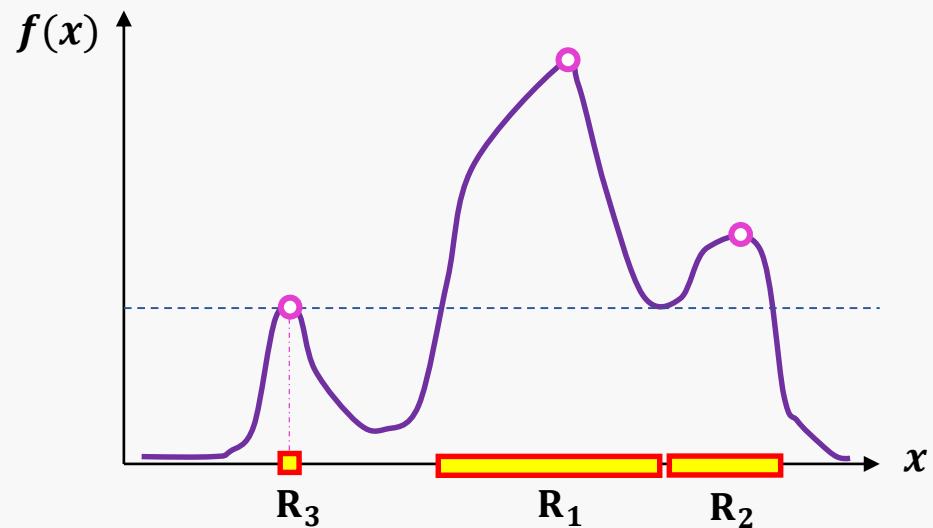
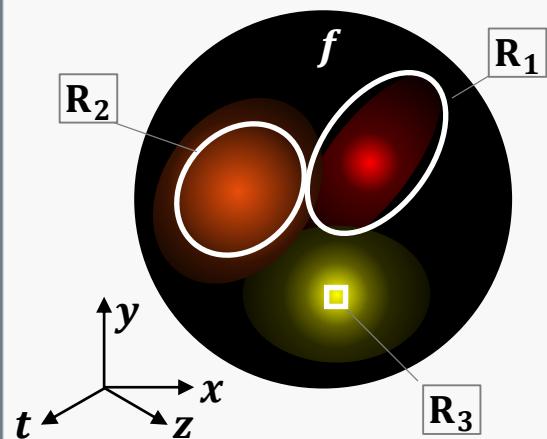
Immersion / ligne de partage des eaux



# Tomo-ventriculographie

## SEGMENTATION

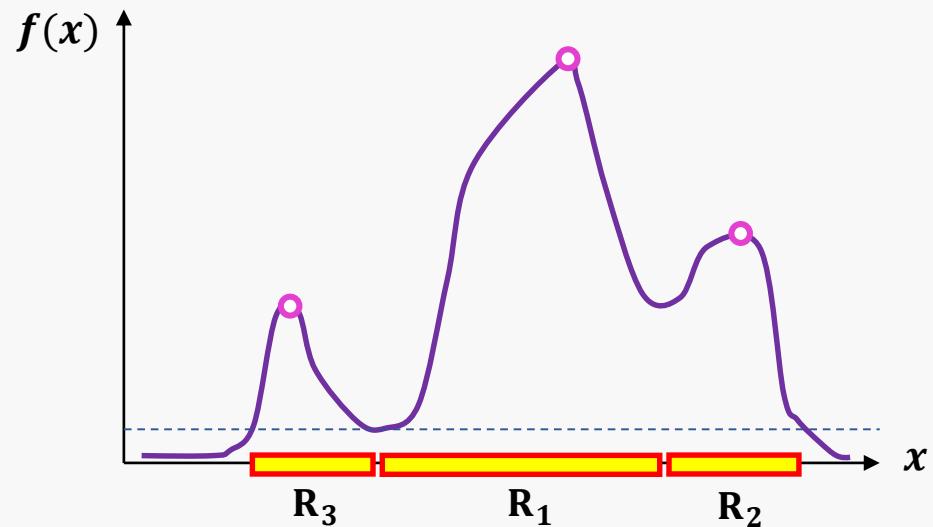
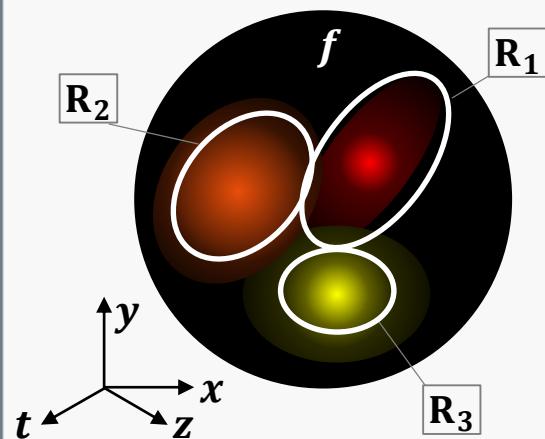
Immersion / ligne de partage des eaux



# Tomo-ventriculographie

## SEGMENTATION

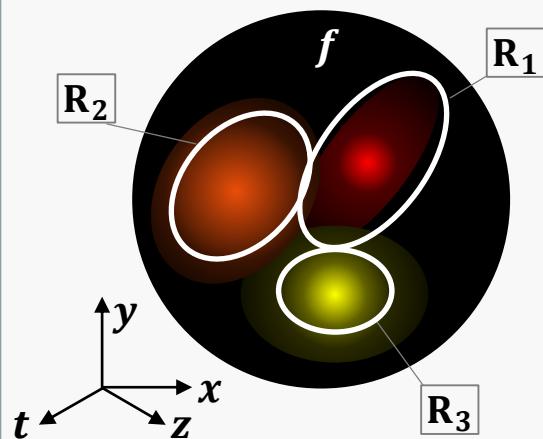
Immersion / ligne de partage des eaux



# Tomo-ventriculographie

## SEGMENTATION

Immersion / ligne de partage des eaux



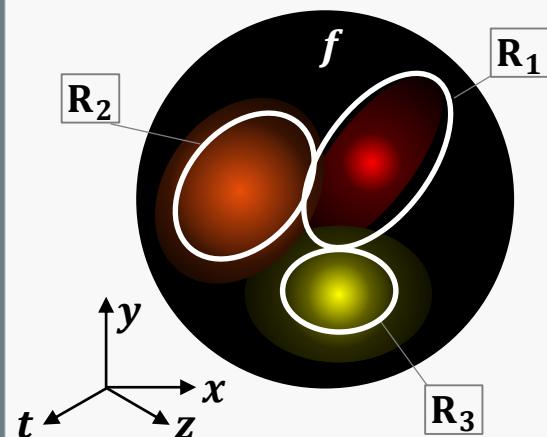
$$\Pi = \{\mathbf{R}_1, \mathbf{R}_2, \dots, \mathbf{R}_K\}$$

$$\begin{cases} \mathbf{g}_{k,x} = \text{barycentre}_x(\mathbf{R}_k) \\ \mathbf{g}_{k,y} = \text{barycentre}_y(\mathbf{R}_k) \end{cases}$$

# Tomo-ventriculographie

## SEGMENTATION

Immersion / ligne de partage des eaux

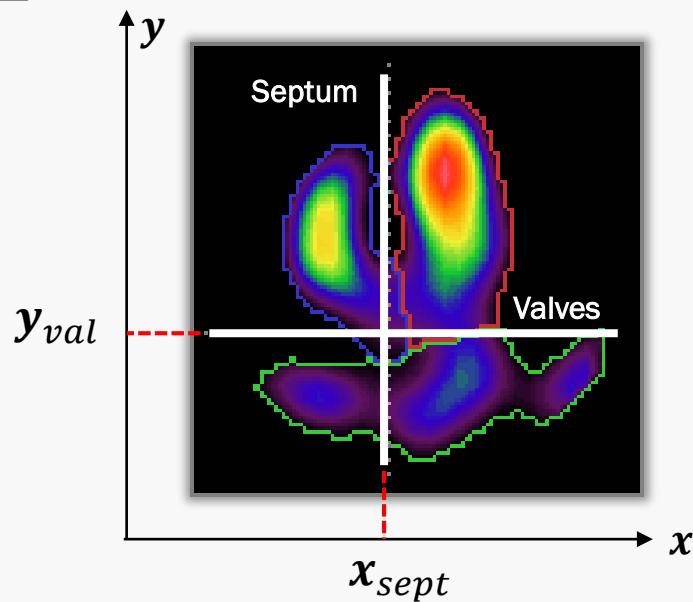


$$\Pi = \{\mathbf{R}_1, \mathbf{R}_2, \dots, \mathbf{R}_K\}$$

$$\begin{cases} \mathbf{g}_{k,x} = \text{barycentre}_x(\mathbf{R}_k) \\ \mathbf{g}_{k,y} = \text{barycentre}_y(\mathbf{R}_k) \end{cases}$$

$$\mathbf{g}_{k,y} < y_{val}$$

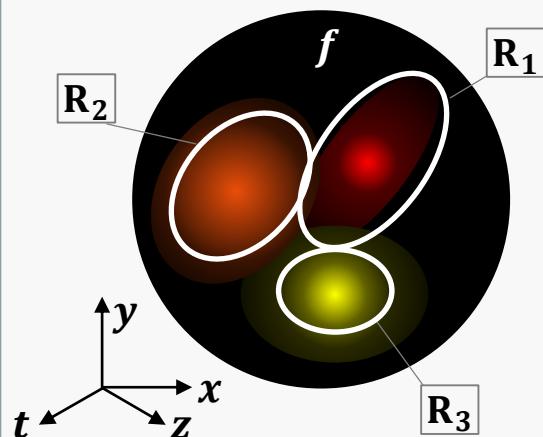
$$\mathbf{R}_k \subset \text{atria}$$



# Tomo-ventriculographie

## SEGMENTATION

Immersion / ligne de partage des eaux



$$\Pi = \{\mathbf{R}_1, \mathbf{R}_2, \dots, \mathbf{R}_K\}$$

$$\begin{cases} \mathbf{g}_{k,x} = \text{barycentre}_x(\mathbf{R}_k) \\ \mathbf{g}_{k,y} = \text{barycentre}_y(\mathbf{R}_k) \end{cases}$$

$$\mathbf{g}_{k,y} < y_{val}$$

$$\mathbf{R}_k \subset \text{atria}$$

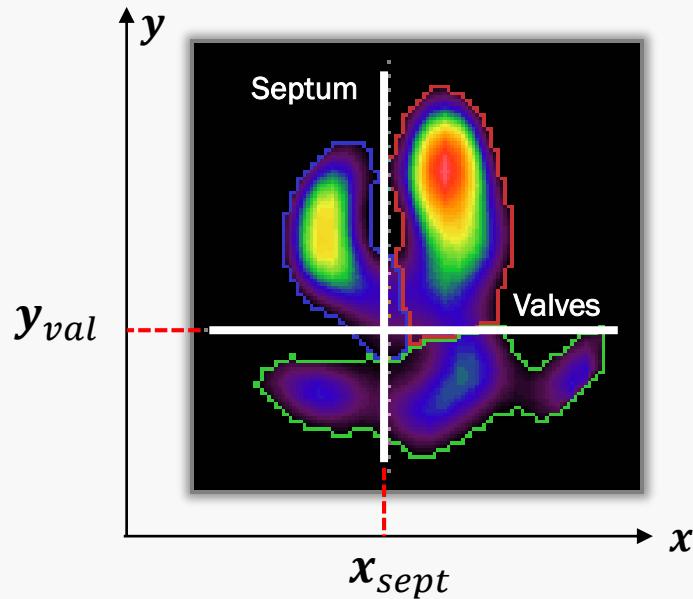
$$\mathbf{g}_{k,y} \geq y_{val}$$

$$\mathbf{g}_{k,y} < x_{sept}$$

$$\mathbf{R}_k \subset \text{VD}$$

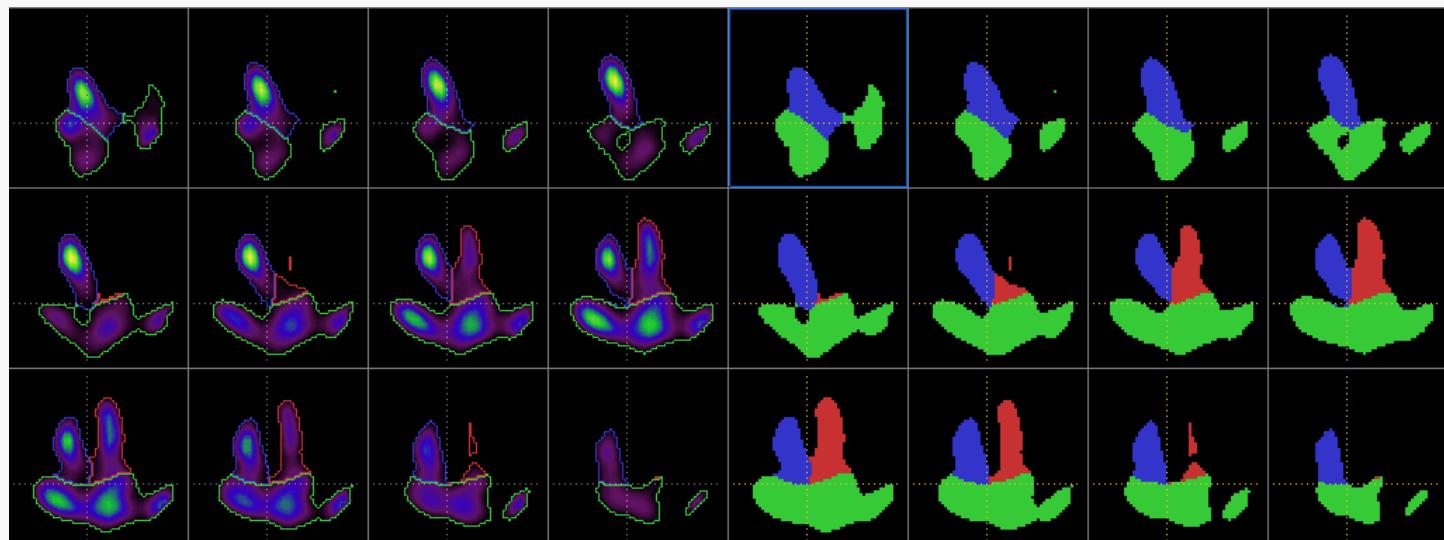
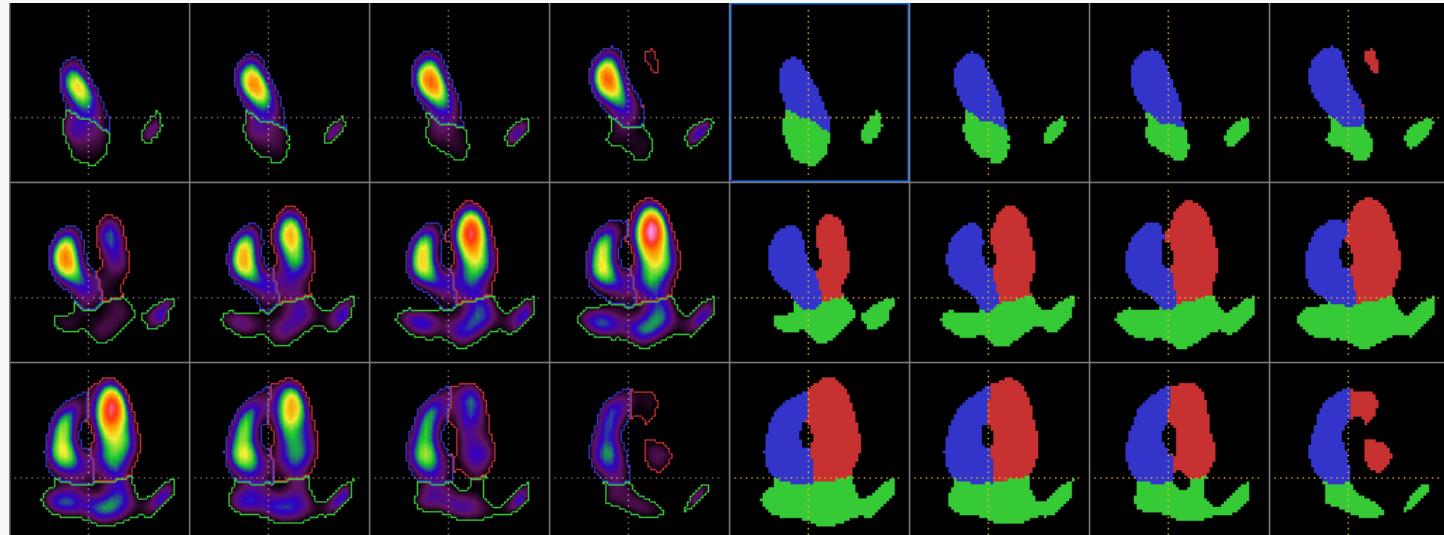
$$\mathbf{g}_{k,y} \geq x_{sept}$$

$$\mathbf{R}_k \subset \text{VG}$$



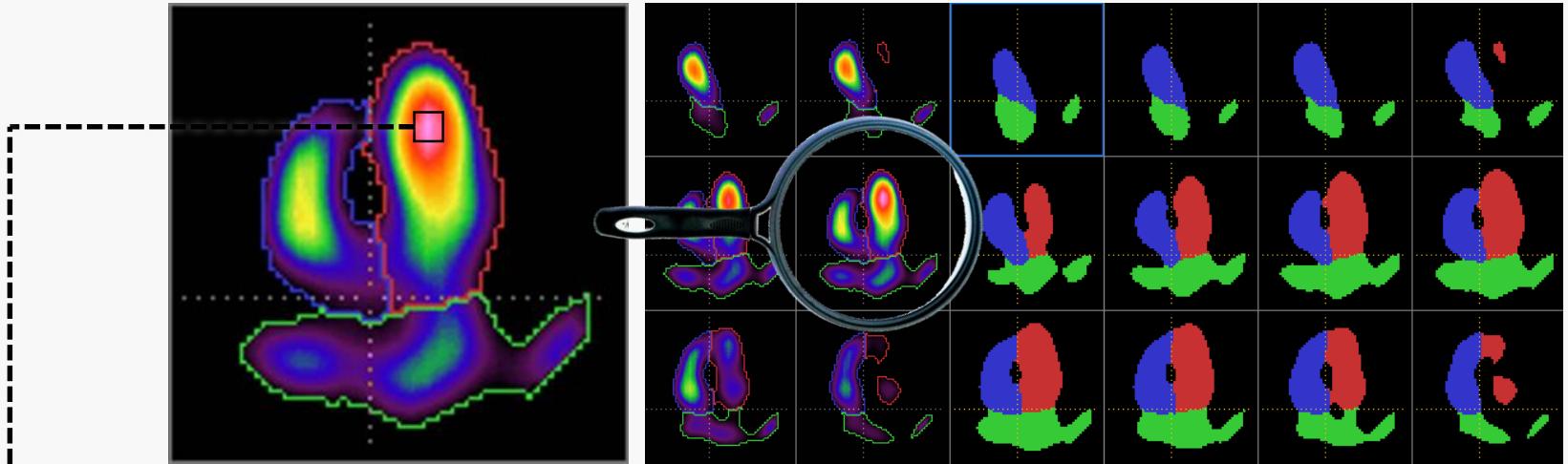
# Tomo-ventriculographie

## SEGMENTATION



# Tomo-ventriculographie

## MESURES DE VOLUMES



A = activité max

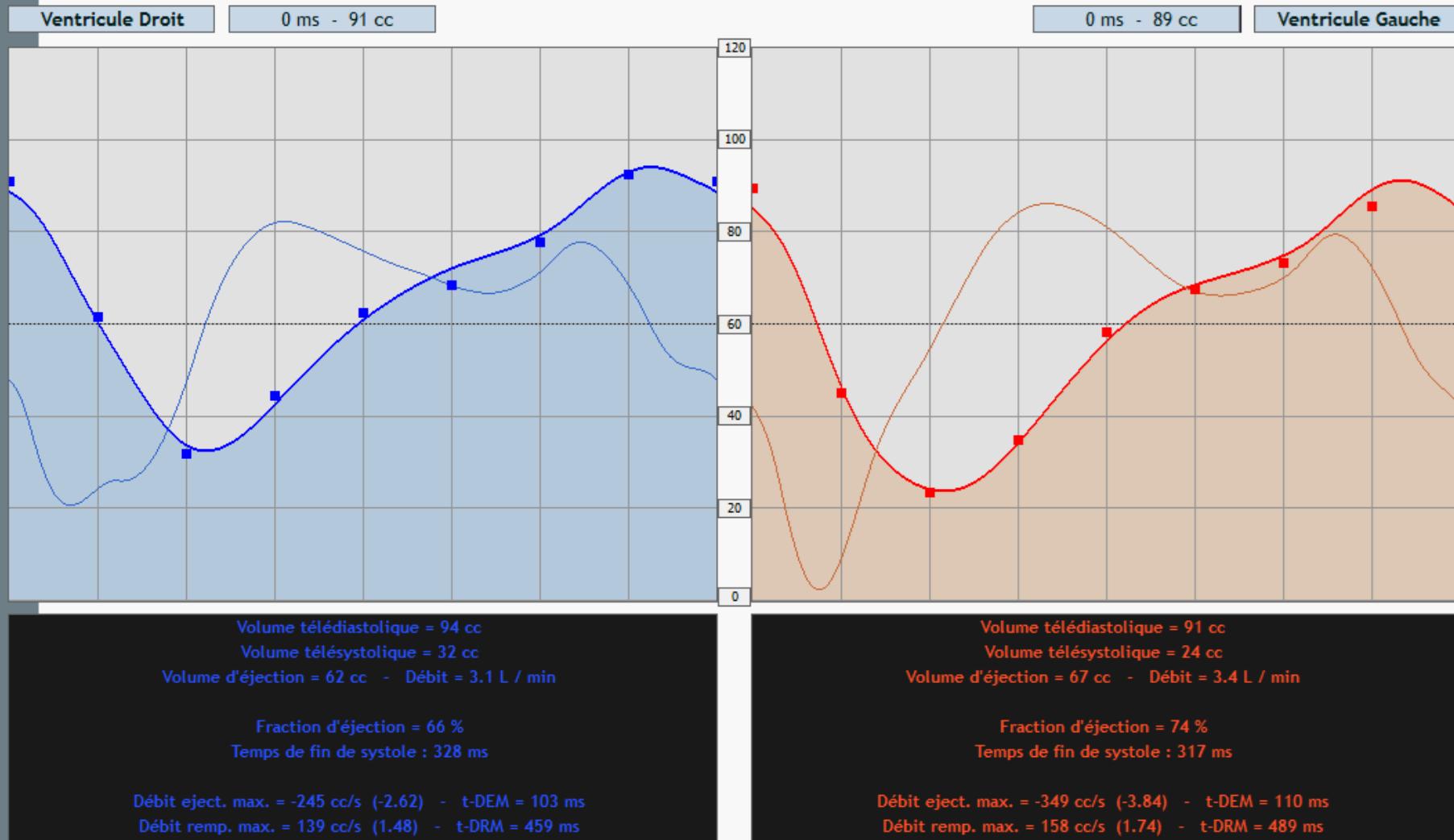
v = volume du voxel en cc

$$\text{Vol VG} = \sum v \times \frac{\text{activité}}{A}$$

$$\text{Vol VD} = \sum v \times \frac{\text{activité}}{A}$$

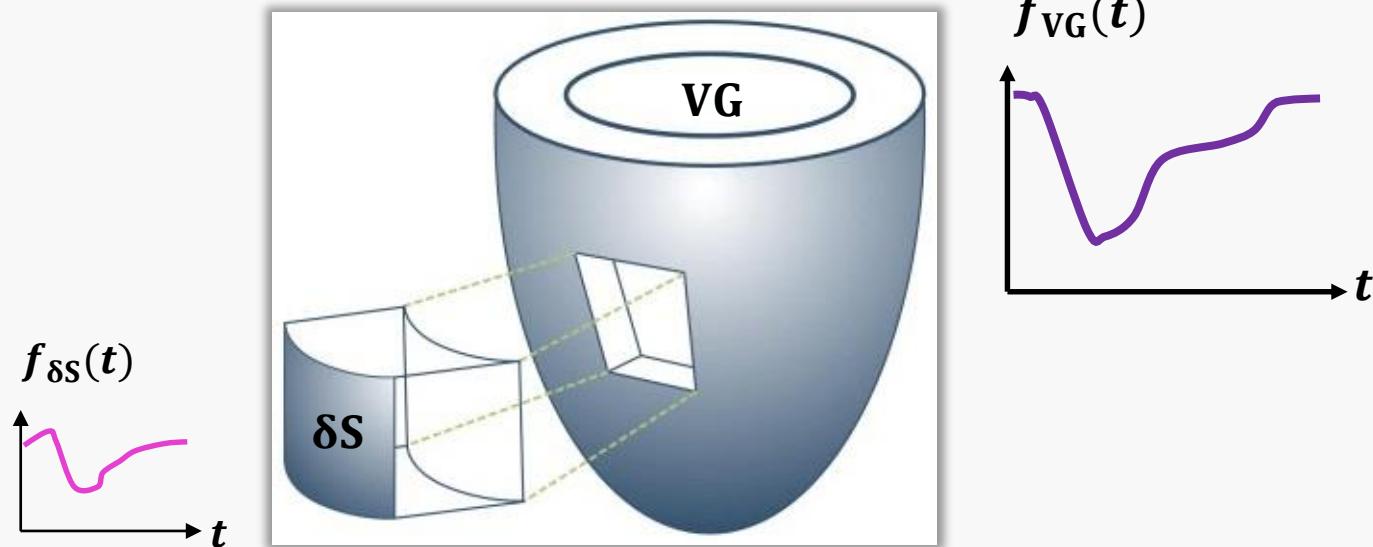
# Tomo-ventriculographie

## CINETIQUE GLOBALE



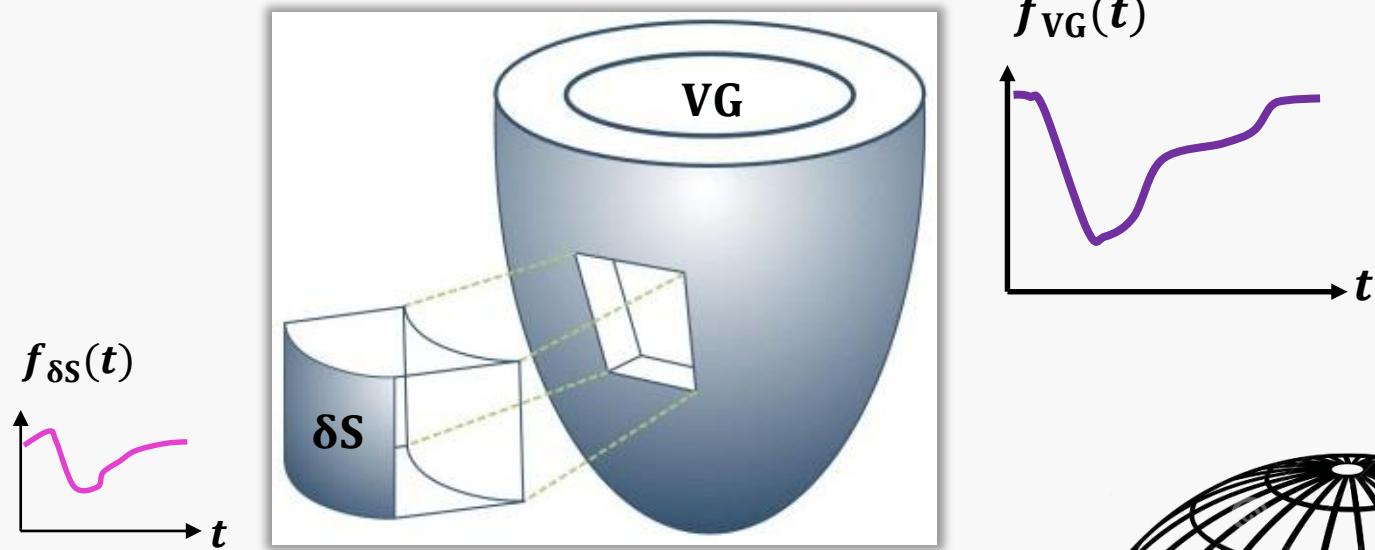
# Tomo-ventriculographie

## CINETIQUE LOCALE

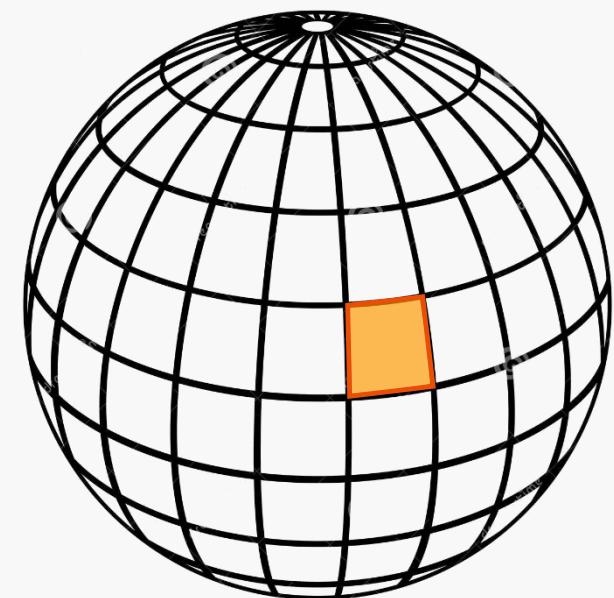


# Tomo-ventriculographie

## CINETIQUE LOCALE

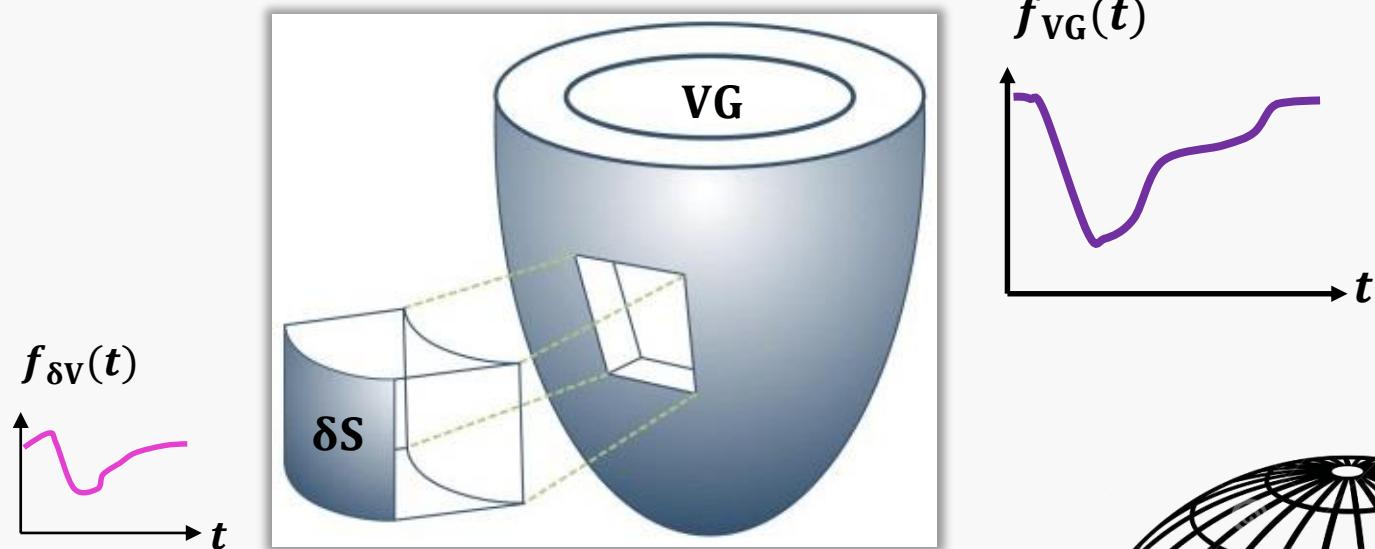


$$\delta S(\theta_i, \varphi_j)$$

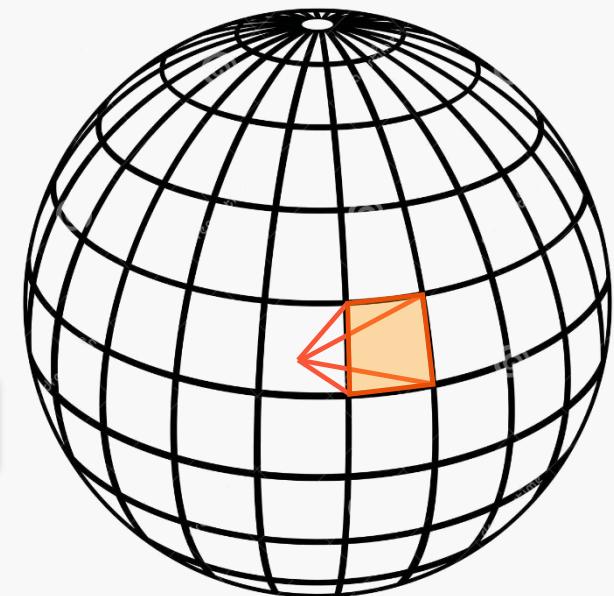


# Tomo-ventriculographie

## CINETIQUE LOCALE

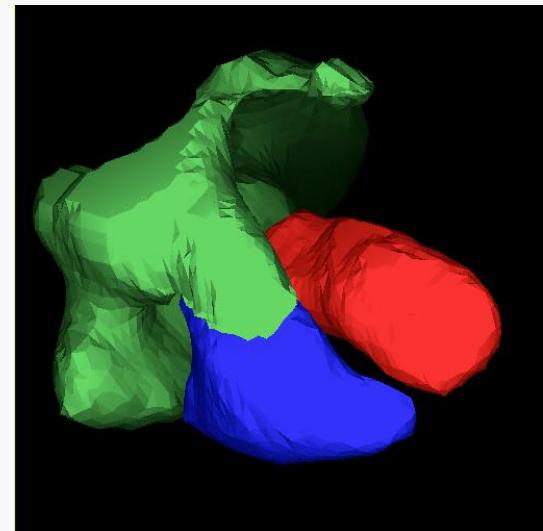
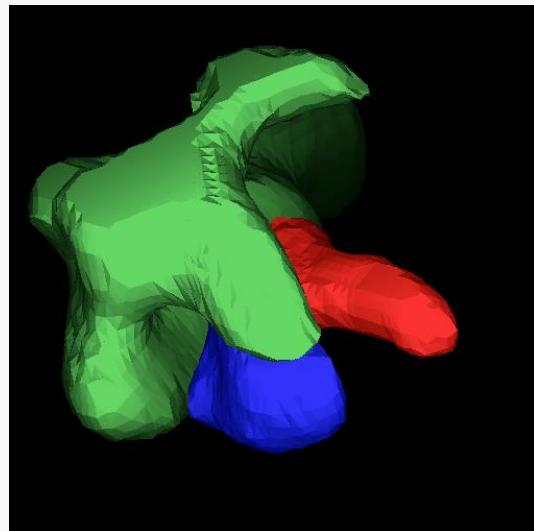
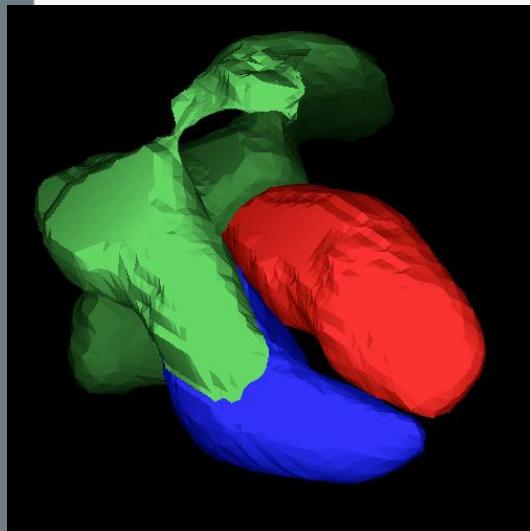
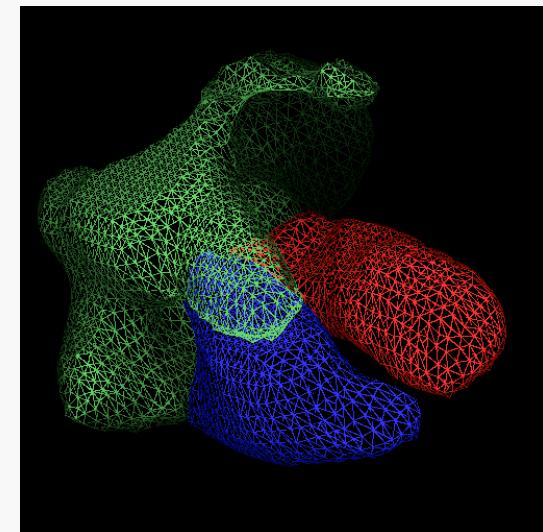
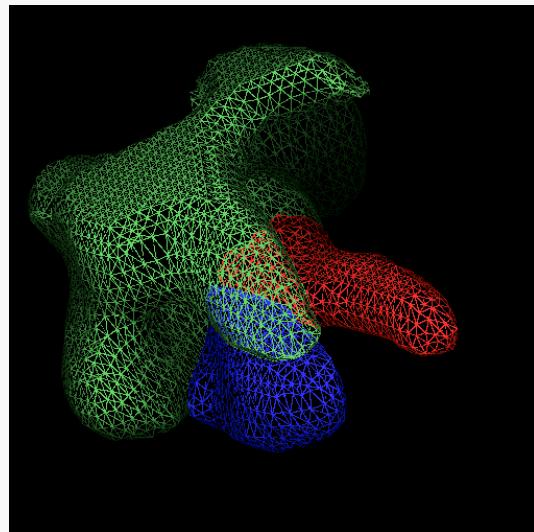
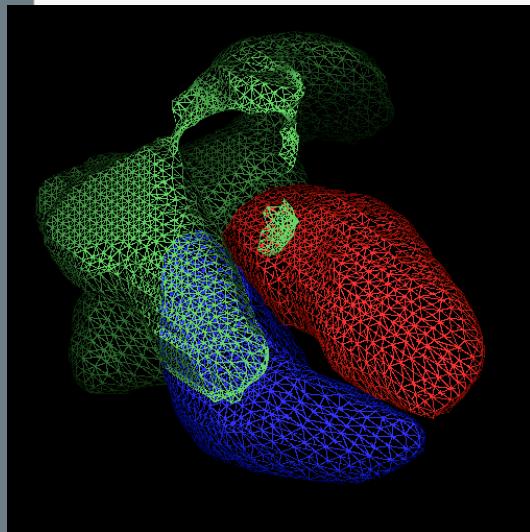


$$\begin{array}{l} \boxed{\delta S(\theta_i, \varphi_j)} \\ \boxed{\delta V(\theta_i, \varphi_j)} \end{array}$$



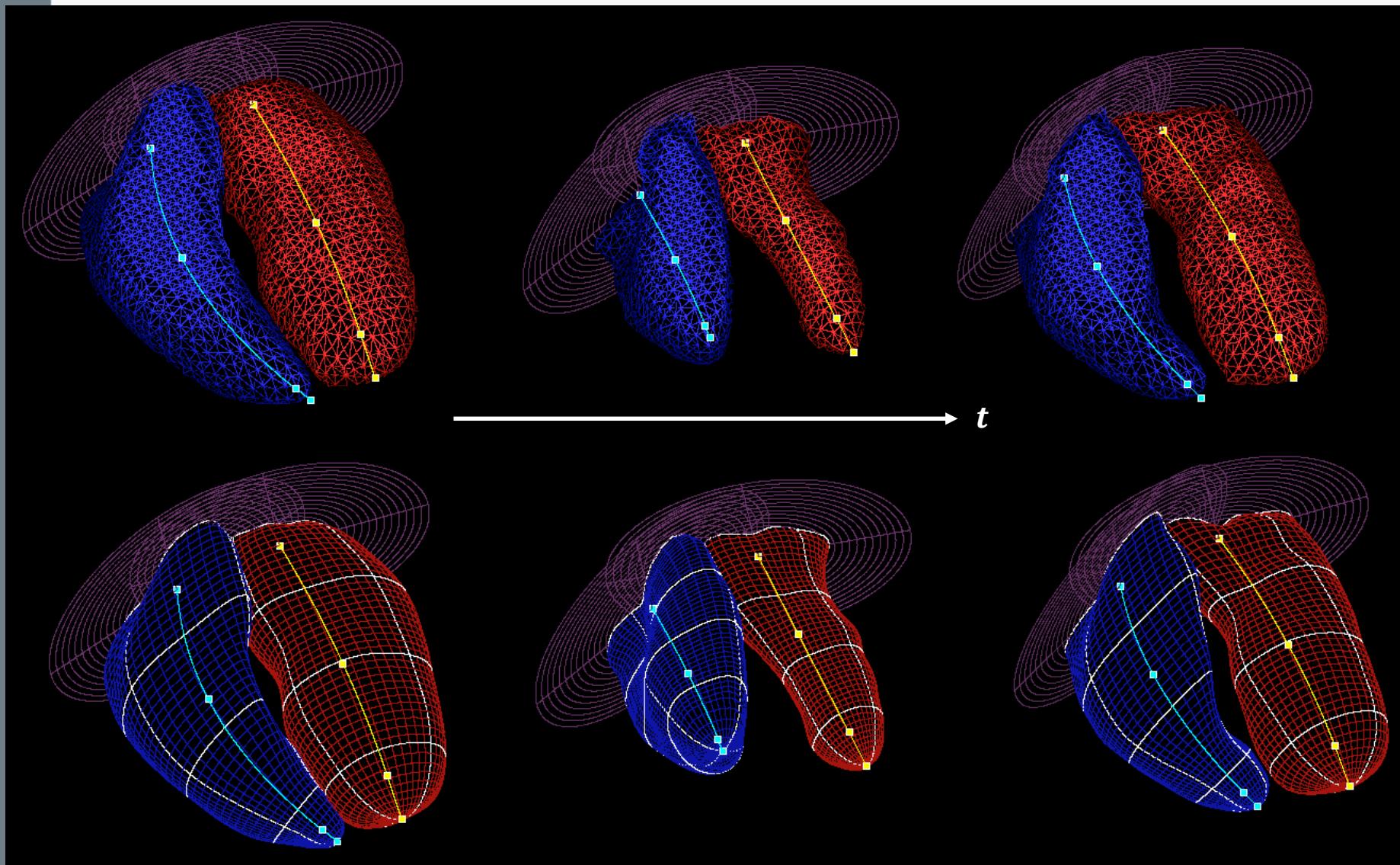
# Tomo-ventriculographie

## PARAMETRISATION 3D



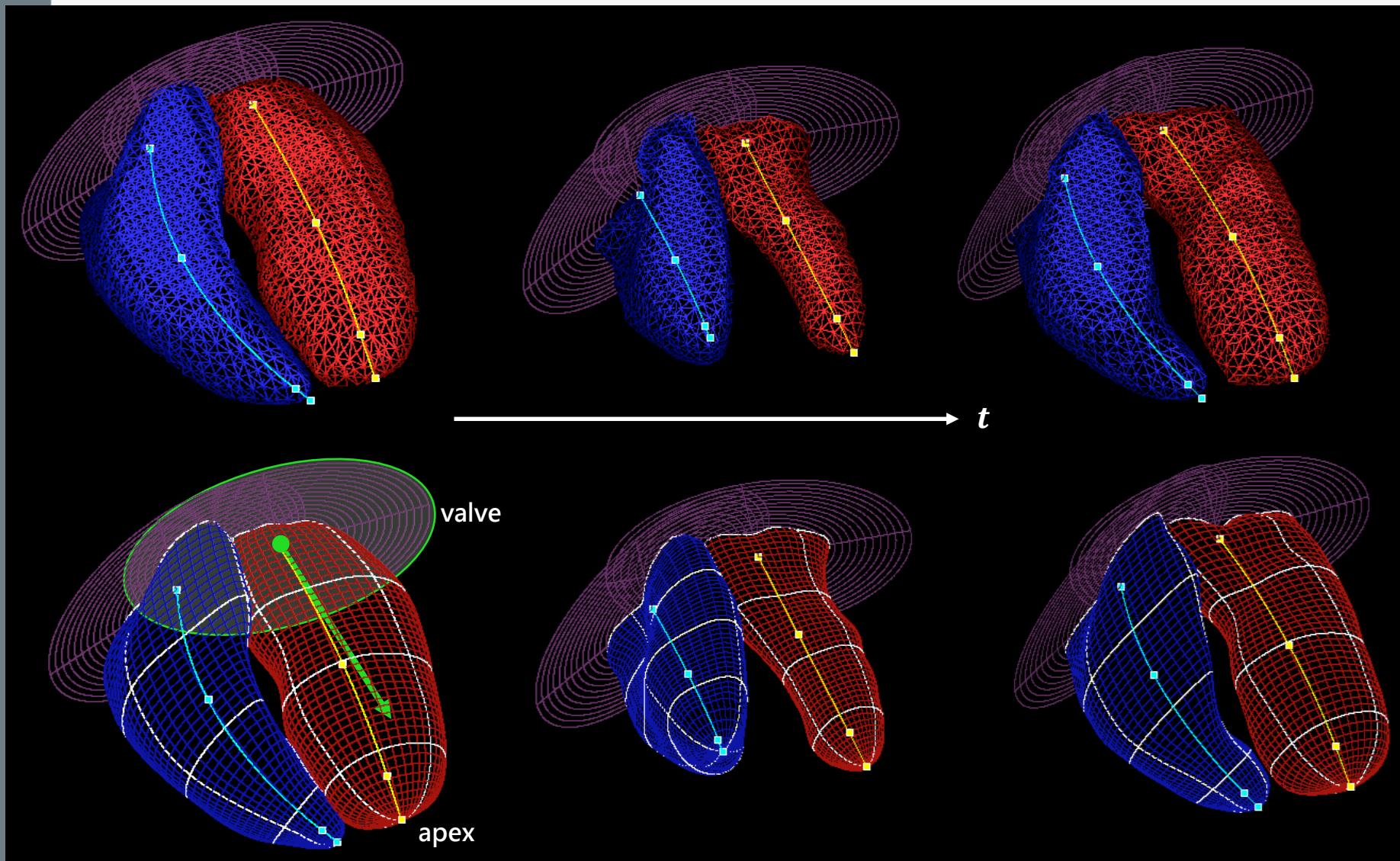
# Tomo-ventriculographie

## PARAMETRISATION 3D



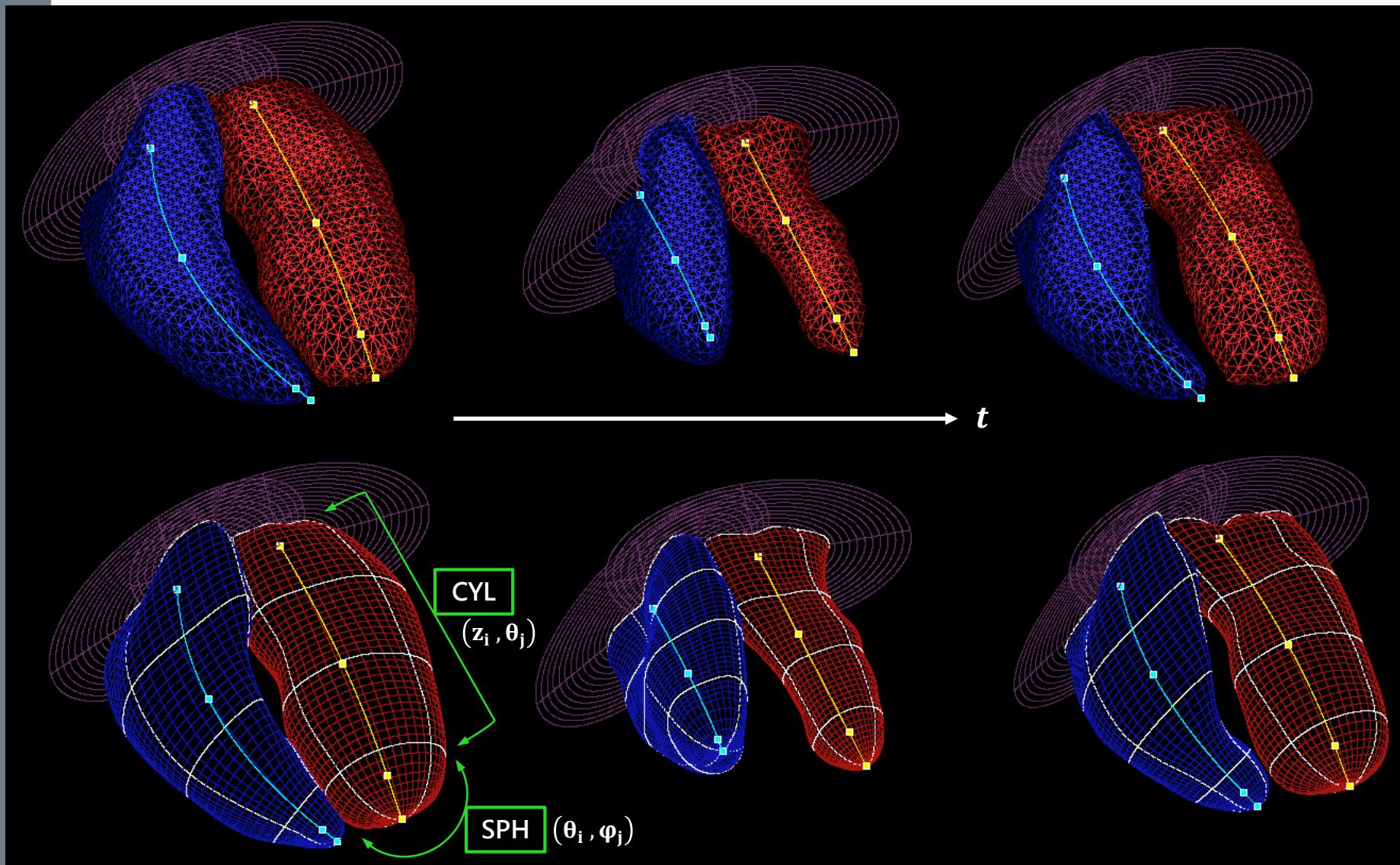
# Tomo-ventriculographie

## PARAMETRISATION 3D



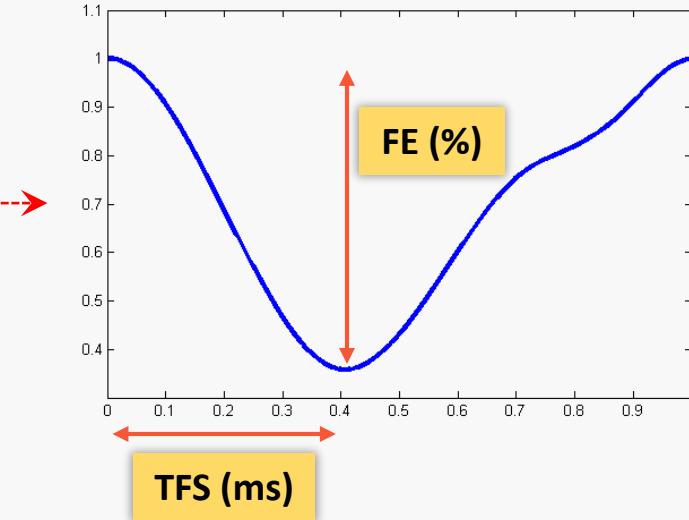
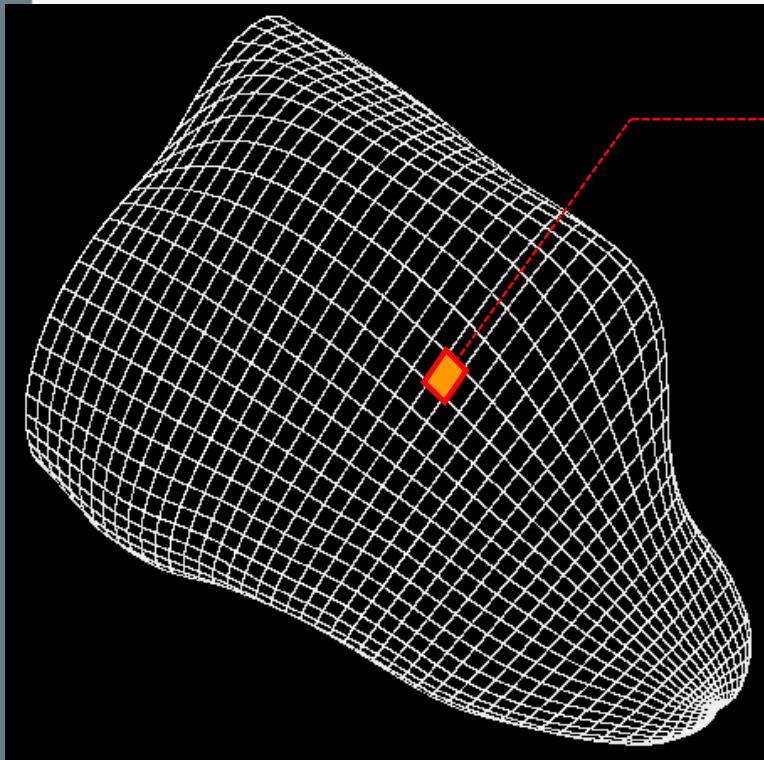
# Tomo-ventriculographie

## PARAMETRISATION 3D

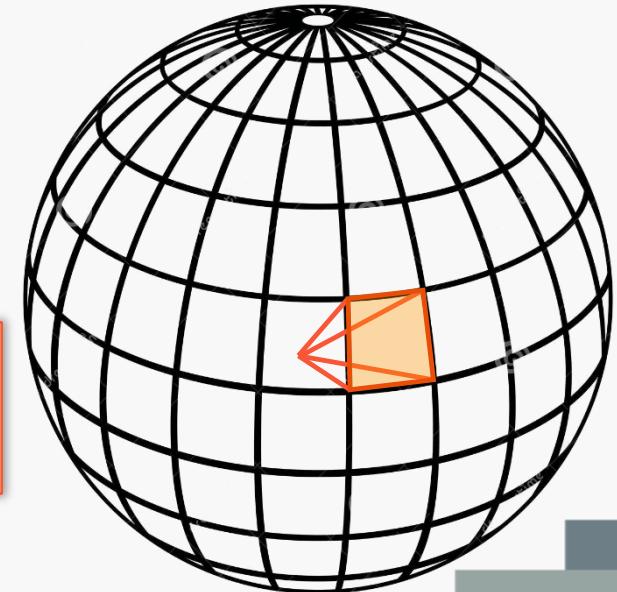


# Tomo-ventriculographie

## CINETIQUE LOCALE



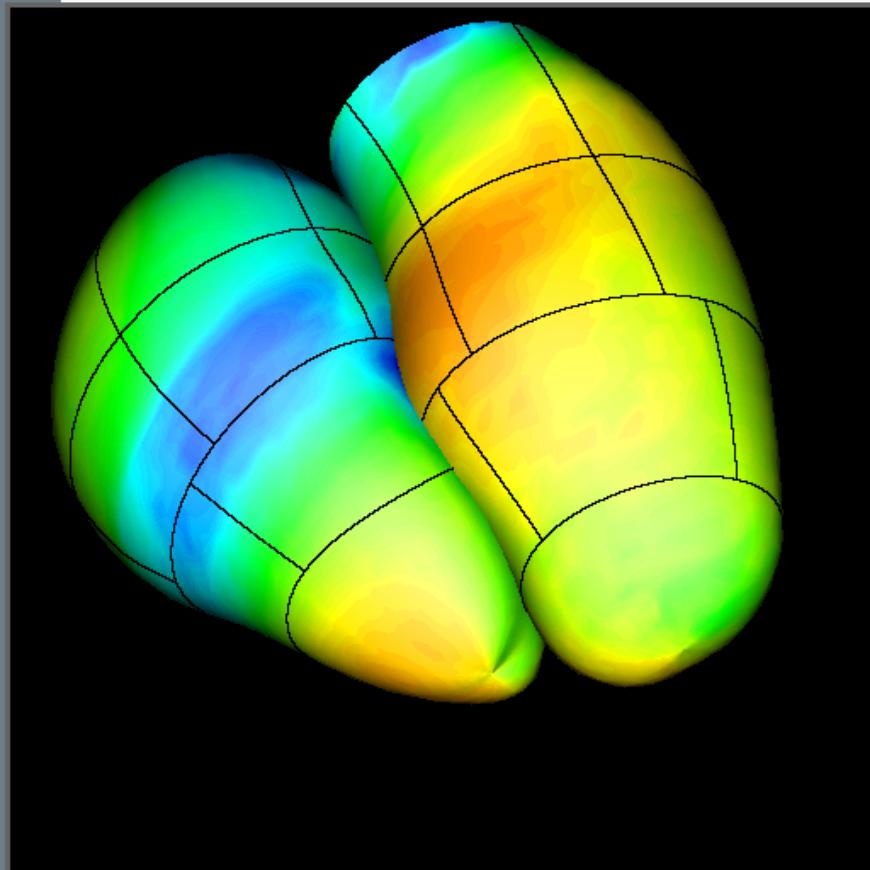
$$\delta V(z_i, \theta_i)$$
$$\delta V(\theta_i, \varphi_j)$$



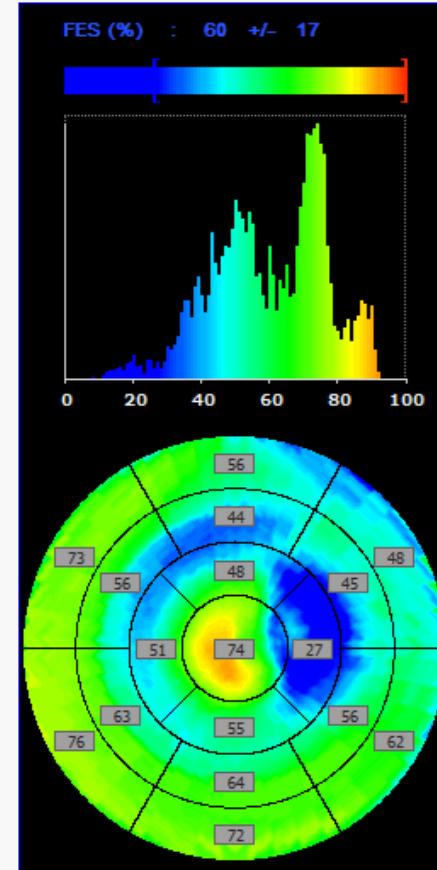
# Tomo-ventriculographie

## CINETIQUE LOCALE

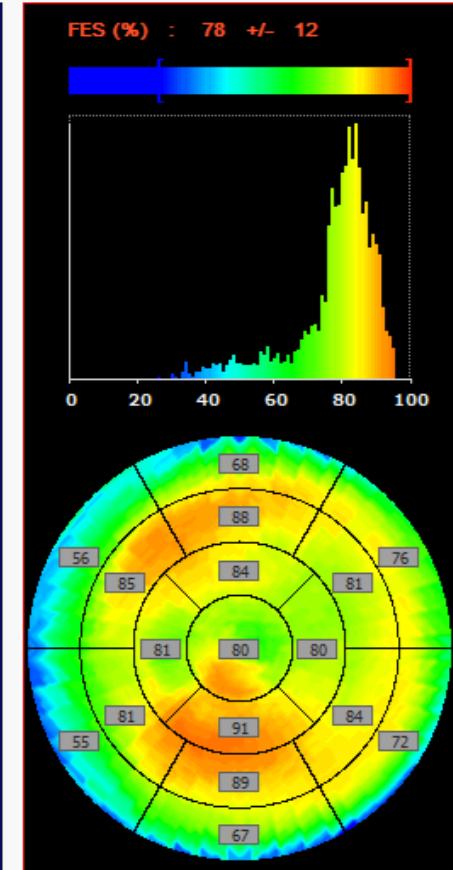
Fraction d'éjection systolique (%)



Vent. droit



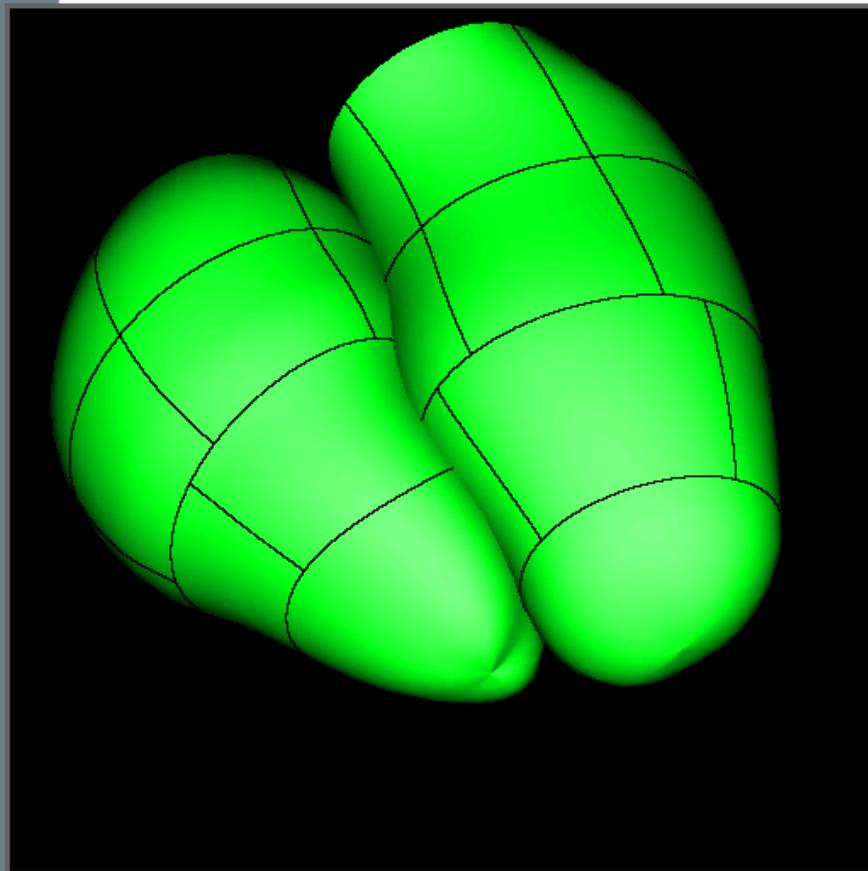
Vent. gauche



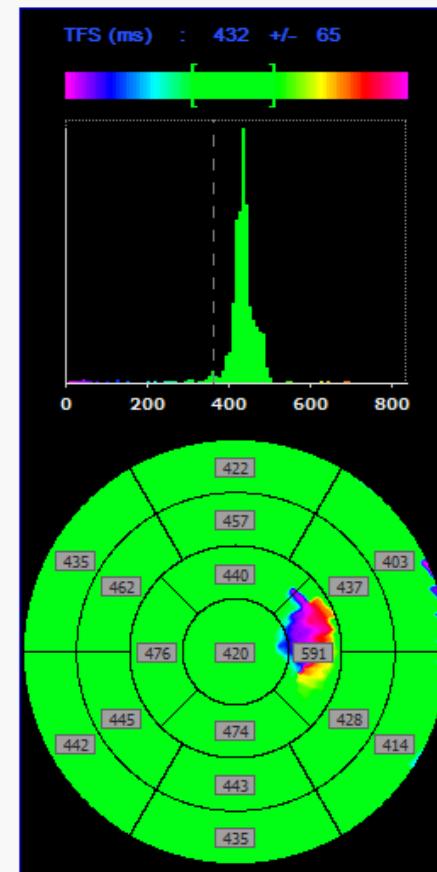
# Tomo-ventriculographie

## CINETIQUE LOCALE

Temps de fin de systole (ms)



Vent. droit



Vent. gauche

