# MODULE BIOCLINIQUE CARDIOVASCULAIRE

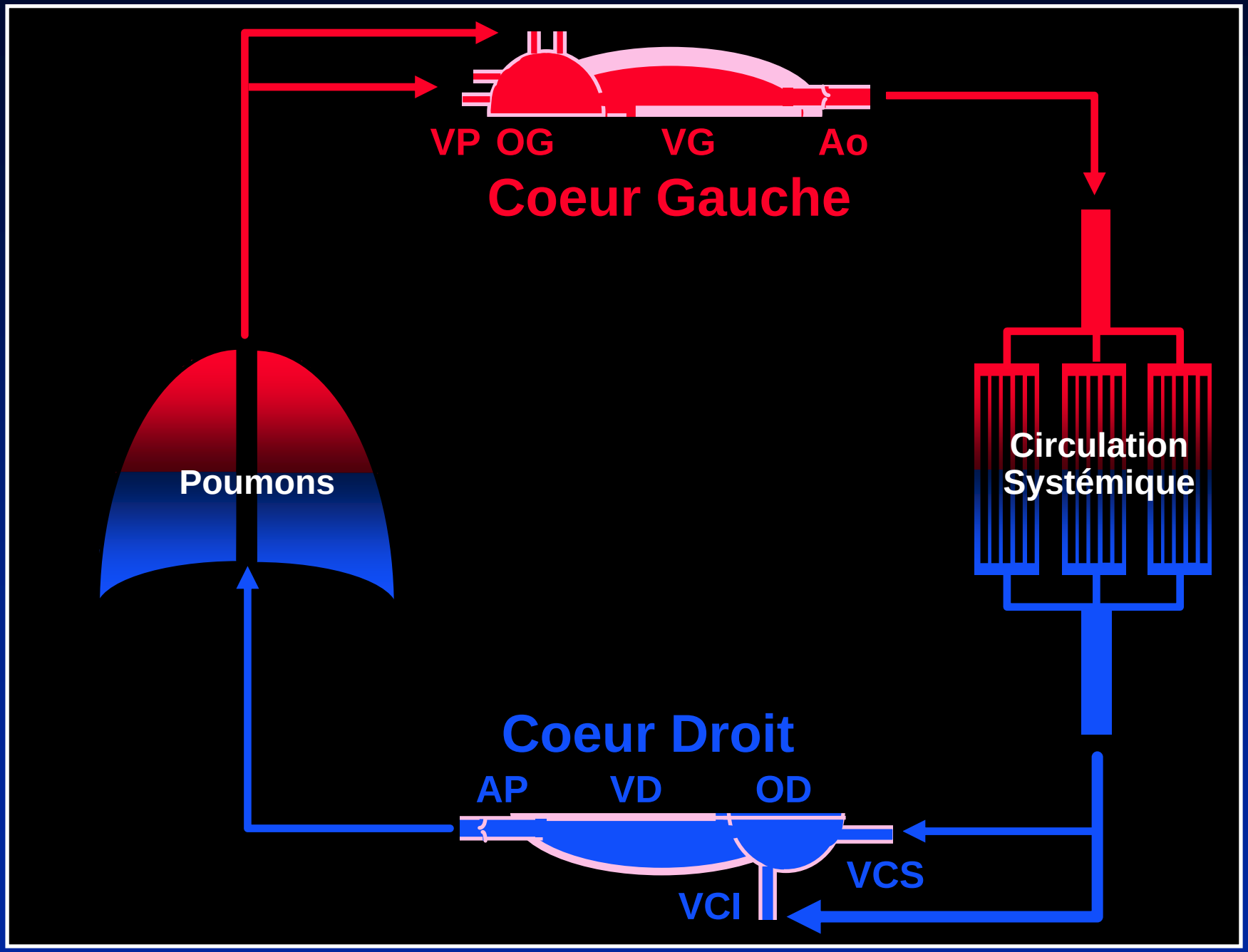
# PCEM2

## Cours N°1 :

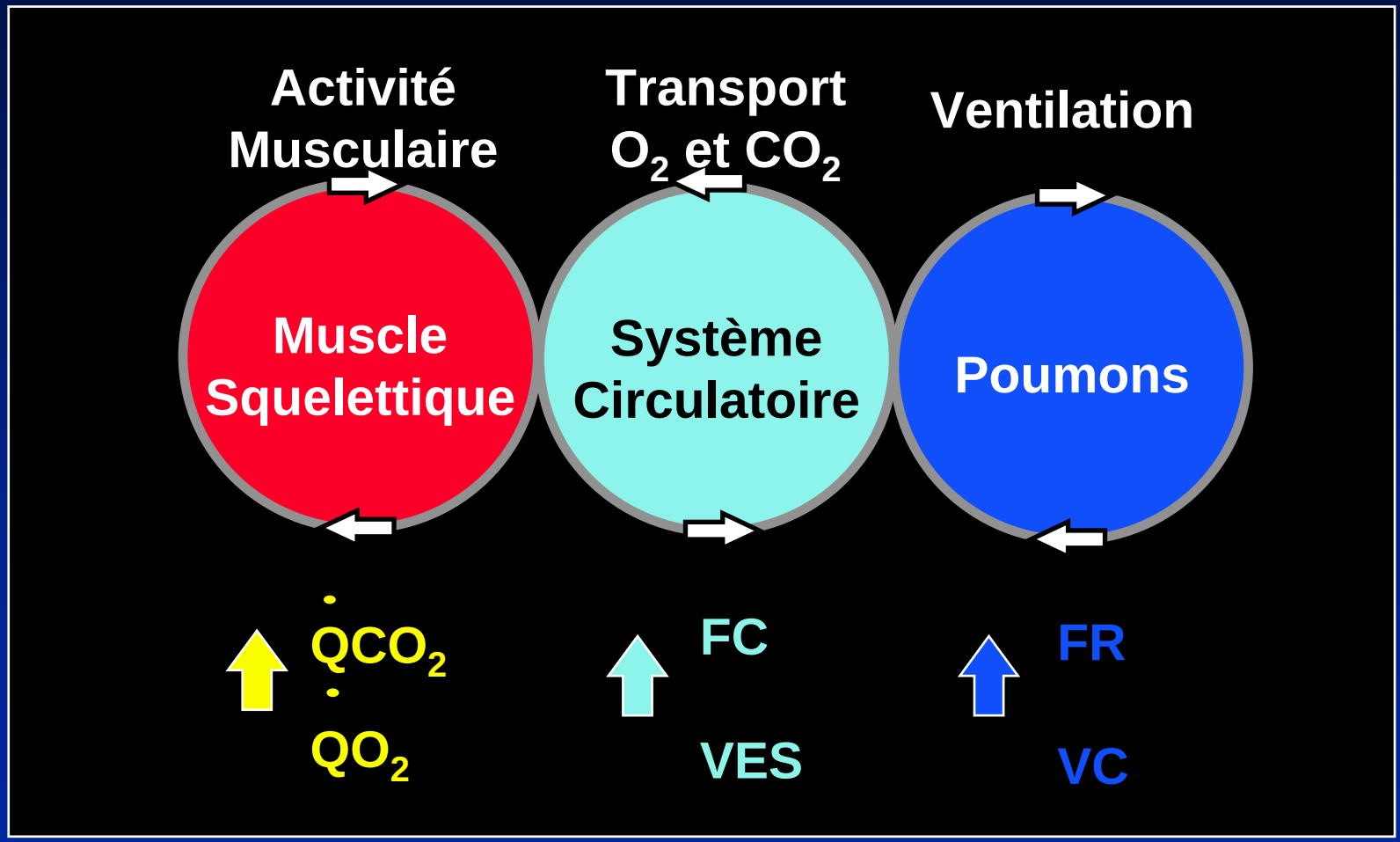
## Hémodynamique cardiaque

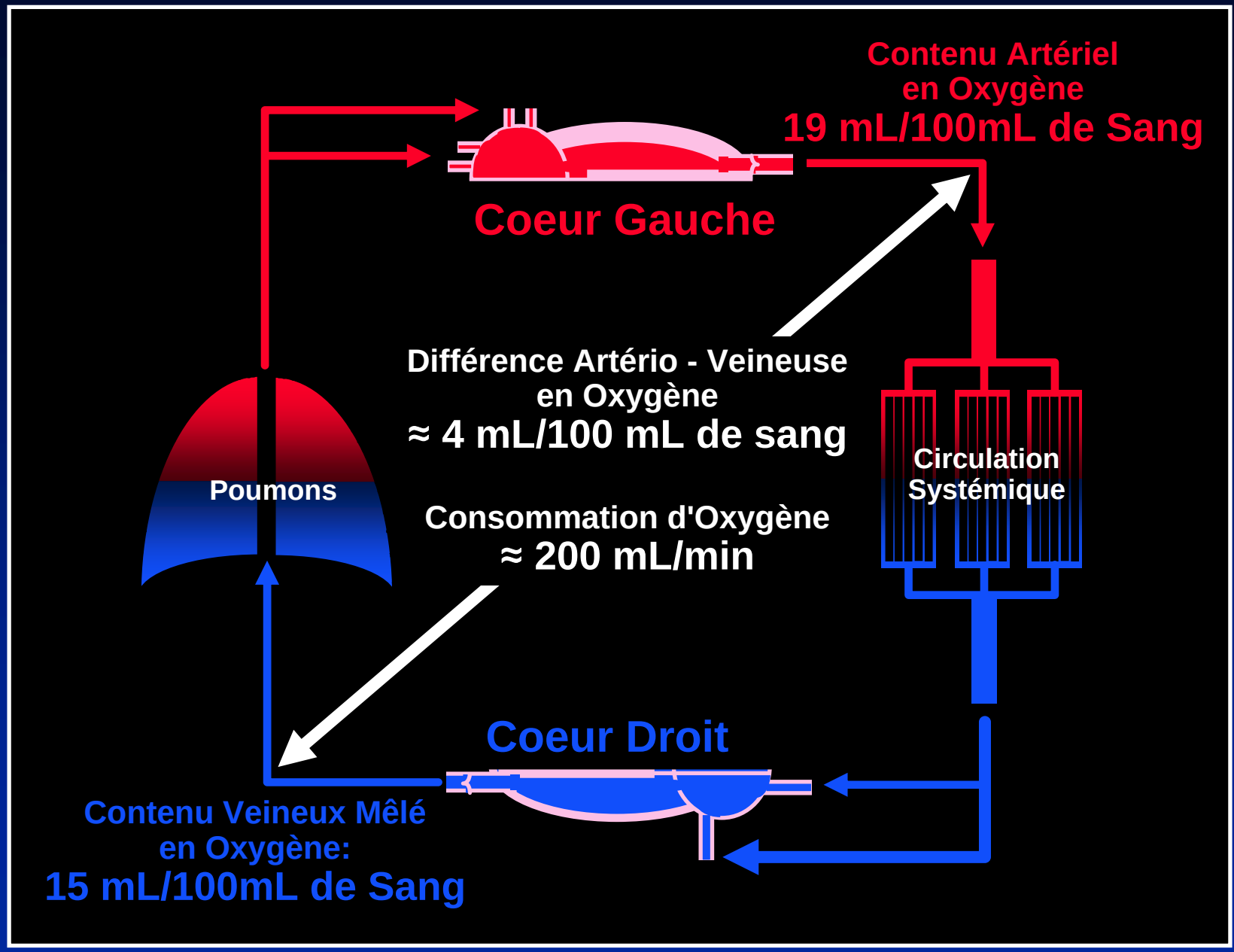
## Régulation de la performance cardiaque

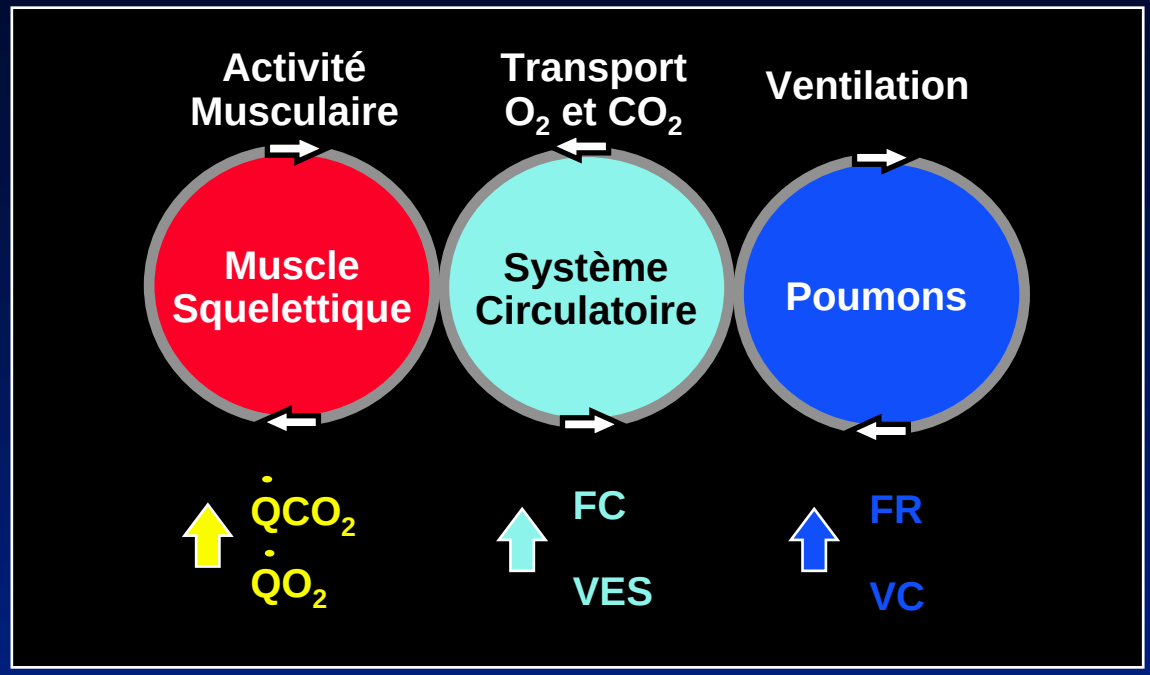
Prs J.-J. Mercadier, A. Nitenberg et M. Eugène

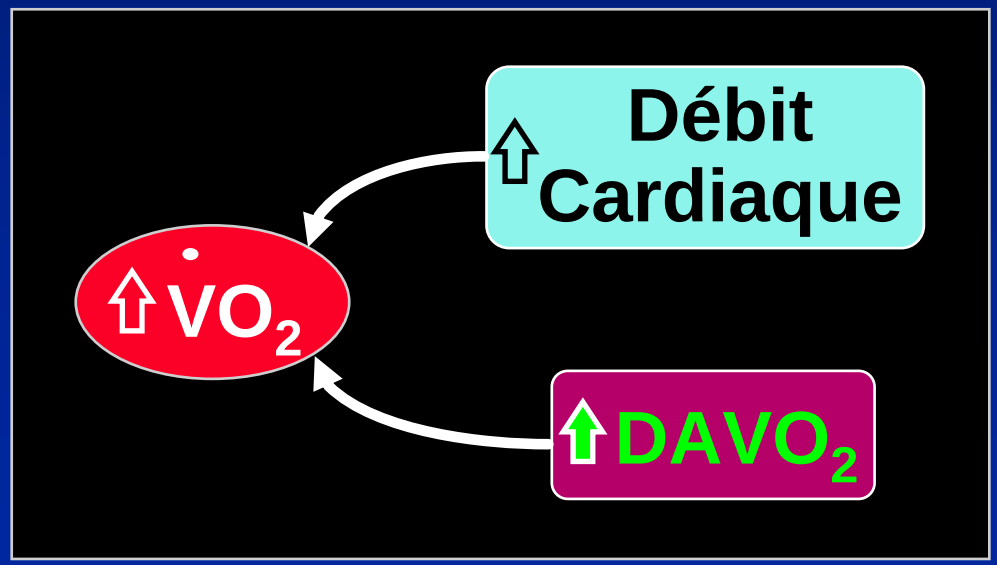

VP
OG
VG
Ao
Coeur Gauche
Poumons
Circulation
Systémique
Coeur Droit
AP
VD
OD
VCS
VCI

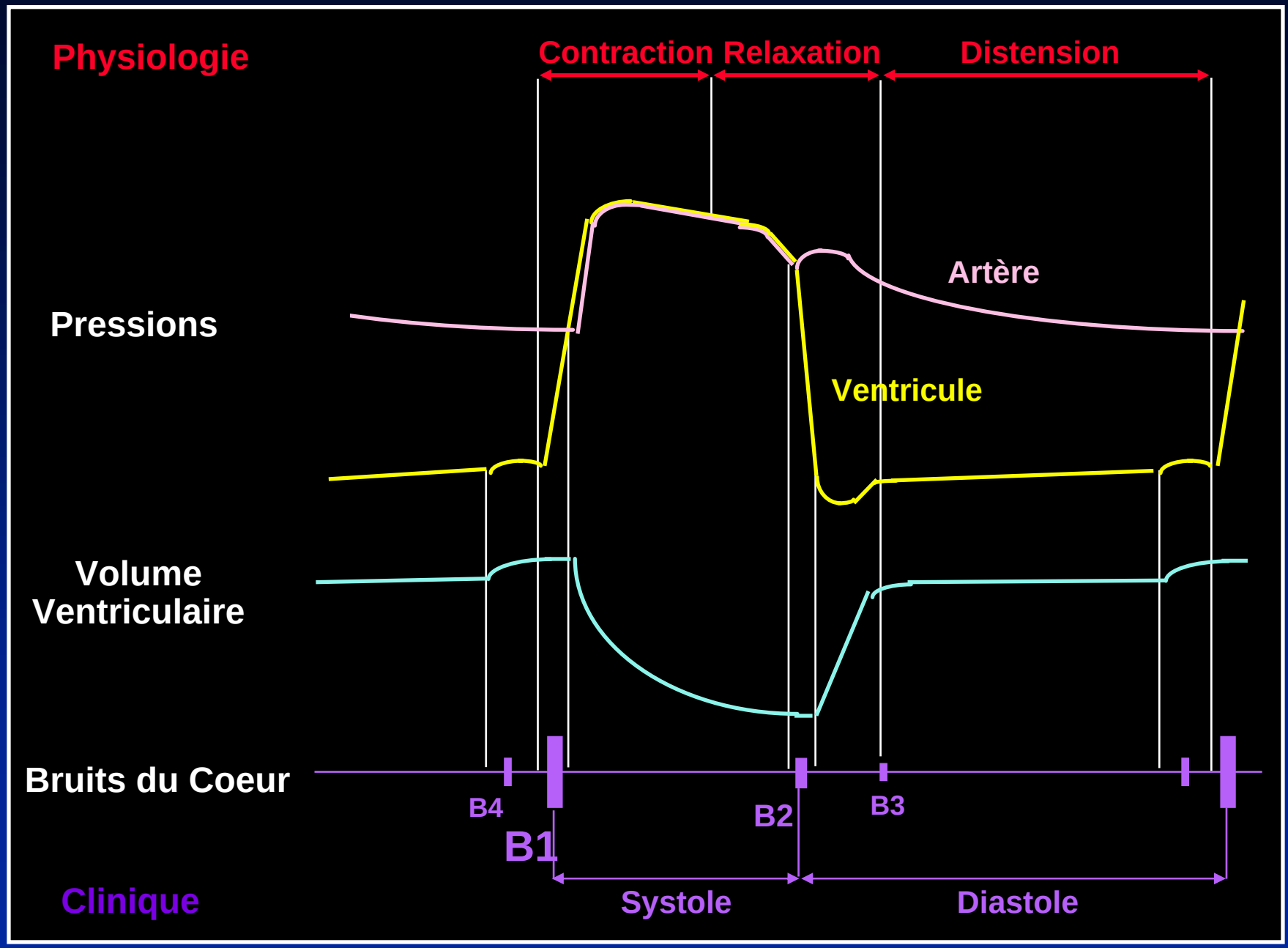
# Exercice Musculaire



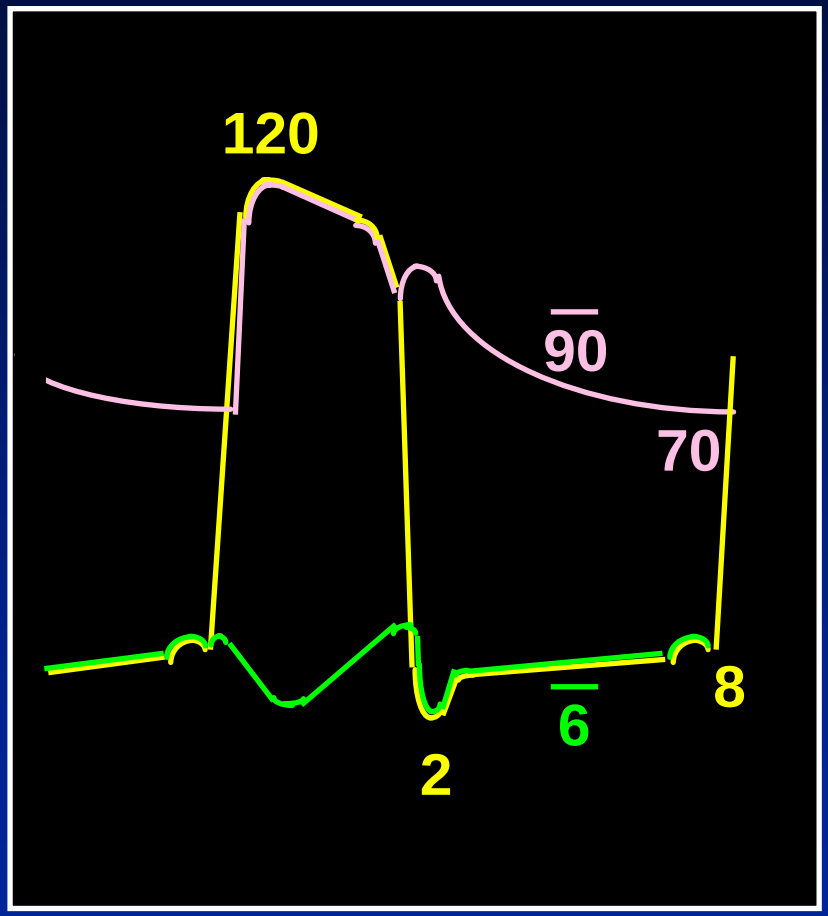

Contenu Artériel
en Oxygène
19 mL/100mL de Sang
Coeur Gauche
Différence Artério - Veineuse
en Oxygène
≈ 4 mL/100 mL de sang
Consommation d'Oxygène
≈ 200 mL/min
Poumons
Circulation
Systémique
Coeur Droit
Contenu Veineux Mêlé
en Oxygène:
15 mL/100mL de Sang


Activité Musculaire
Transport $O_2$ et $CO_2$
Ventilation
Muscle Squelettique
Système Circulatoire
Poumons
$\dot{Q}CO_2$
$\dot{Q}O_2$
FC
VES
FR
VC

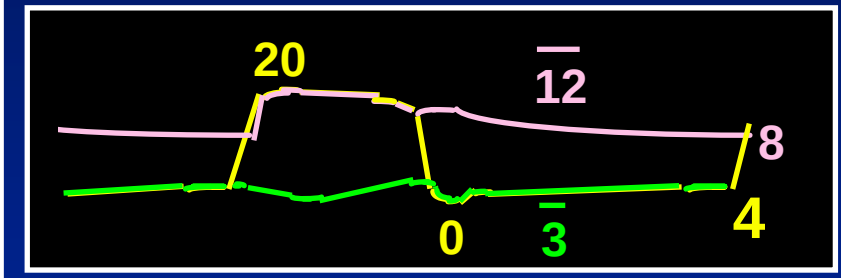

Débit Cardiaque
$\dot{V}O_2$
$DAVO_2$


Physiologie
Contraction Relaxation
Distension
Pressions
Artère
Ventricule
Volume
Ventriculaire
Bruits du Coeur
B4
B1
B2
B3
Clinique
Systole
Diastole

# Pressions



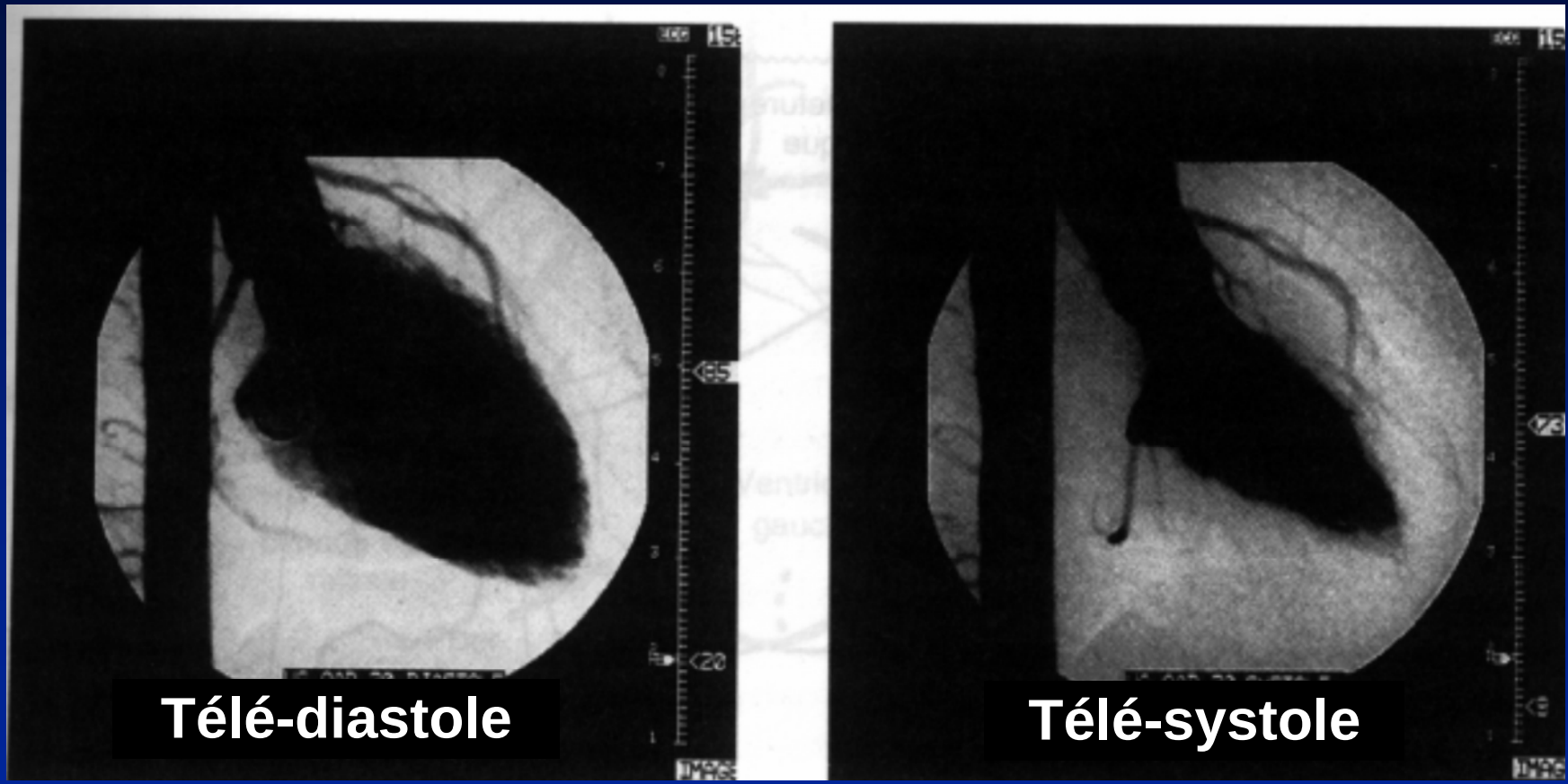

Cavités Gauches



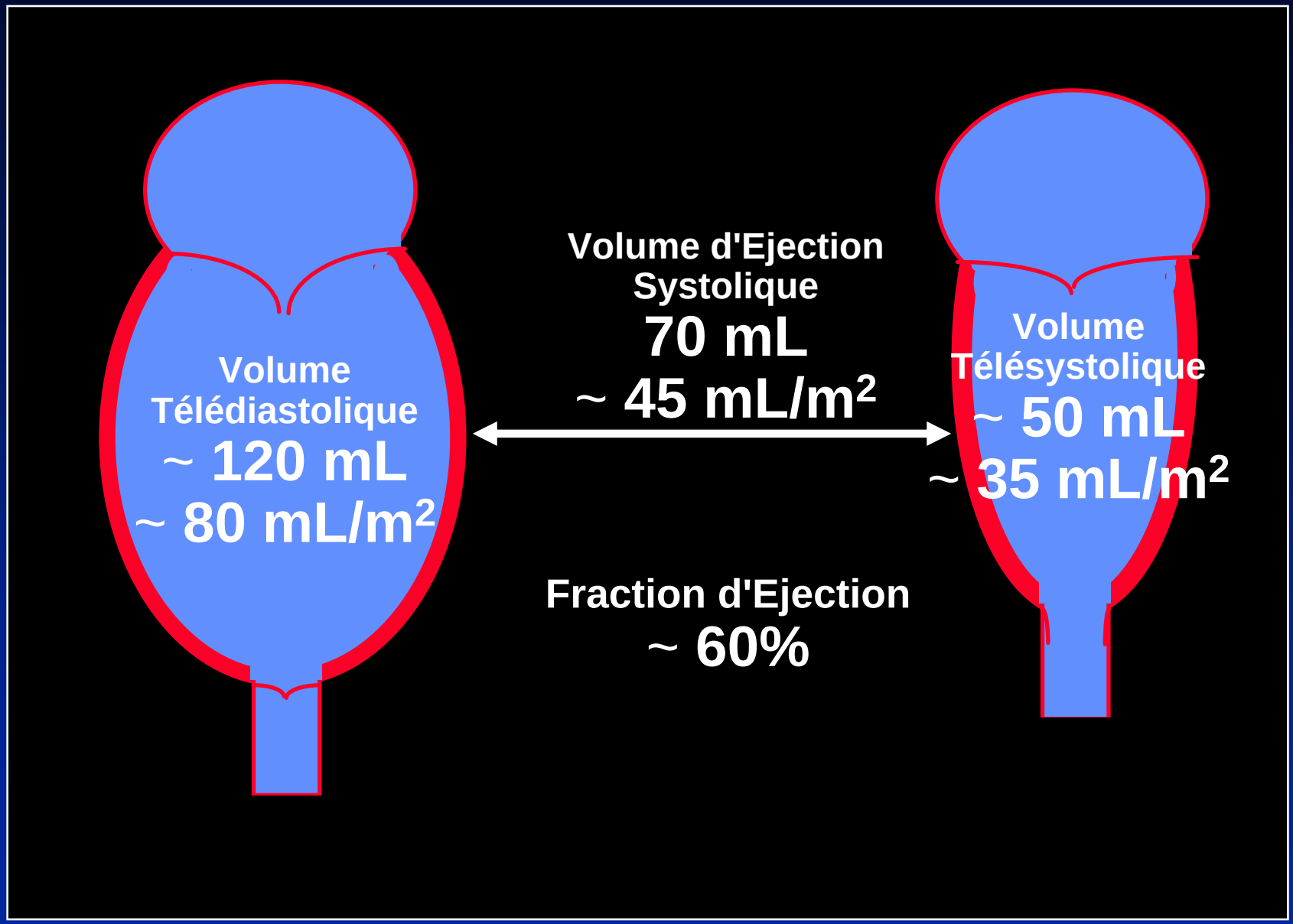

Cavités Droites

# Déterminants du Débit cardiaque

# Ventriculographie Gauche




**VTD – VTS = VES**


Volume
Télédiastolique
~ 120 mL
~ 80 mL/m²
Volume d'Ejection
Systolique
70 mL
~ 45 mL/m²
Volume
Télésystolique
~ 50 mL
~ 35 mL/m²
Fraction d'Ejection
~ 60%

# Débit Cardiaque

**Volume d'Ejection Systolique x Fréquence Cardiaque**

**70 mL x 70 batt/min**

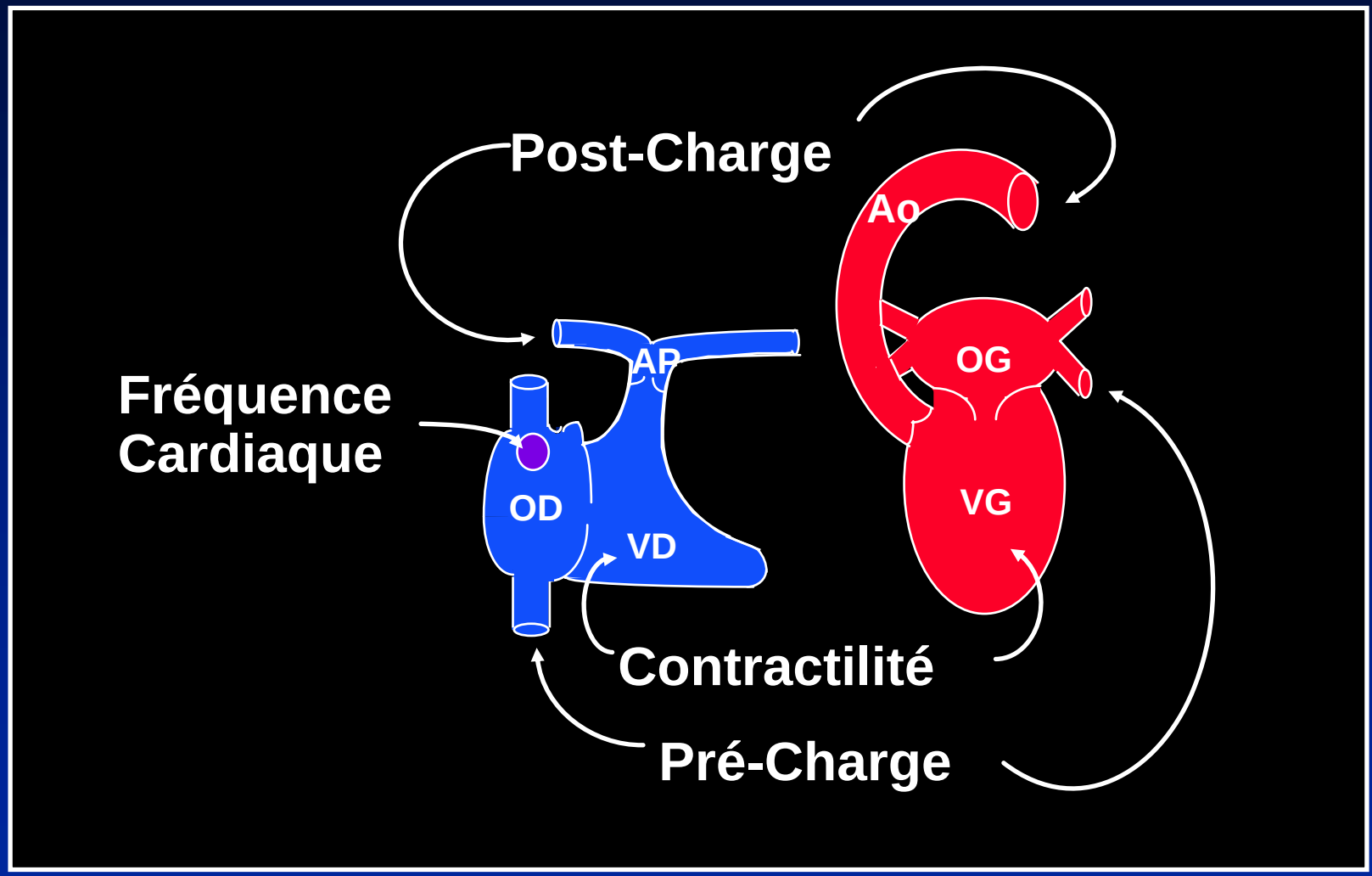
**~ 5 ± 1 L/min**

# Index Cardiaque

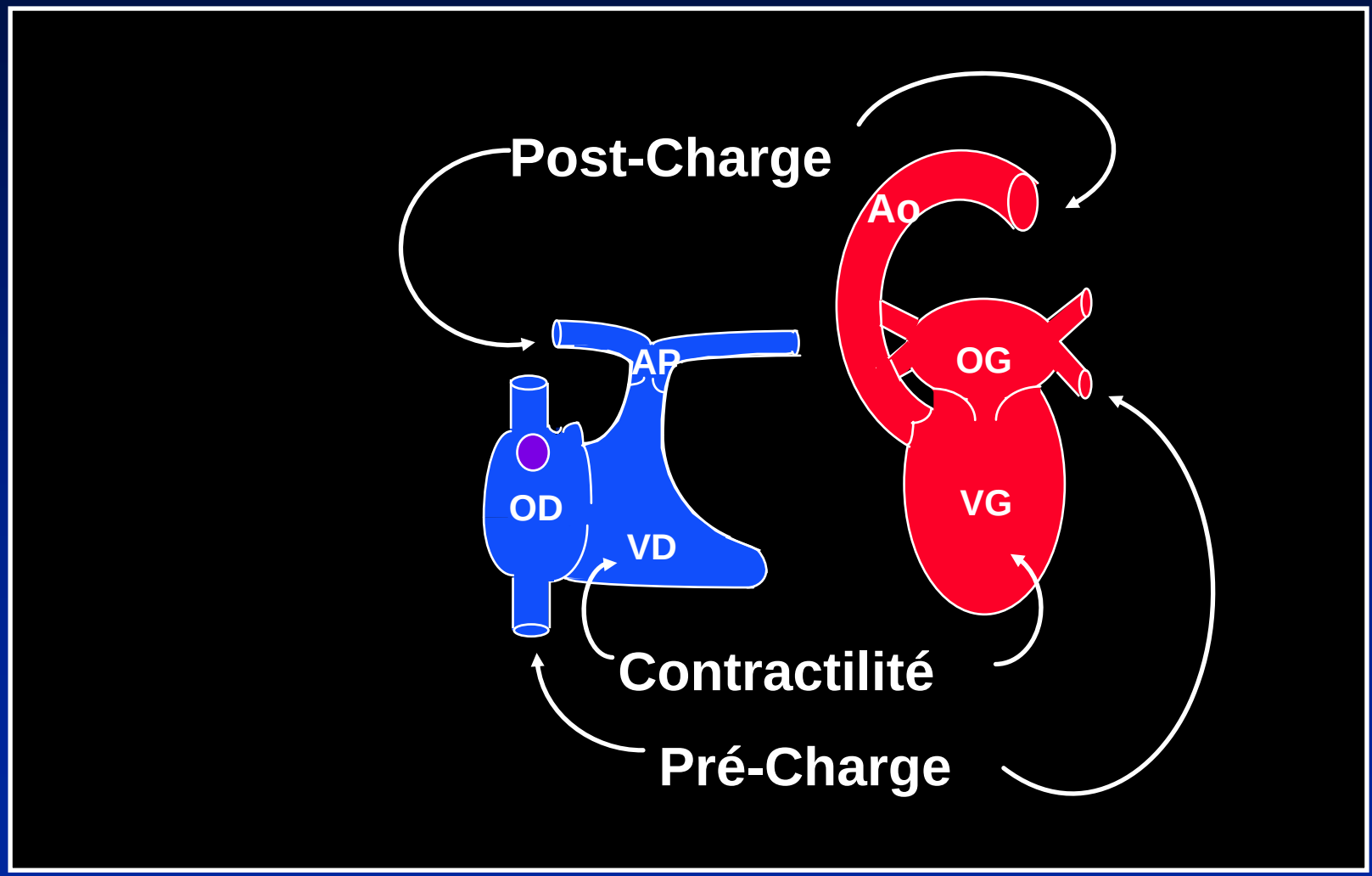
**Débit Cardiaque / Surface Corporelle**

**3,3 ± 0,3 L/min/$m^2$**

# Déterminants du débit cardiaque



# Déterminants de la performance ventriculaire (du volume d'éjection systolique=VES)



# Déterminants de la performance contractile du myocarde isolé

## Muscle papillaire isolé

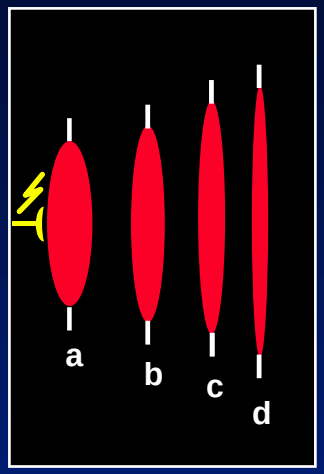
Effet de la

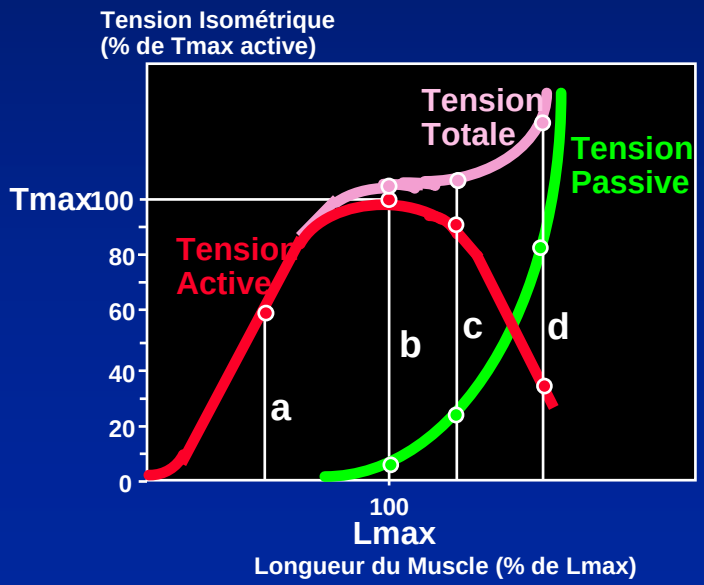
# Précharge

Etudié en

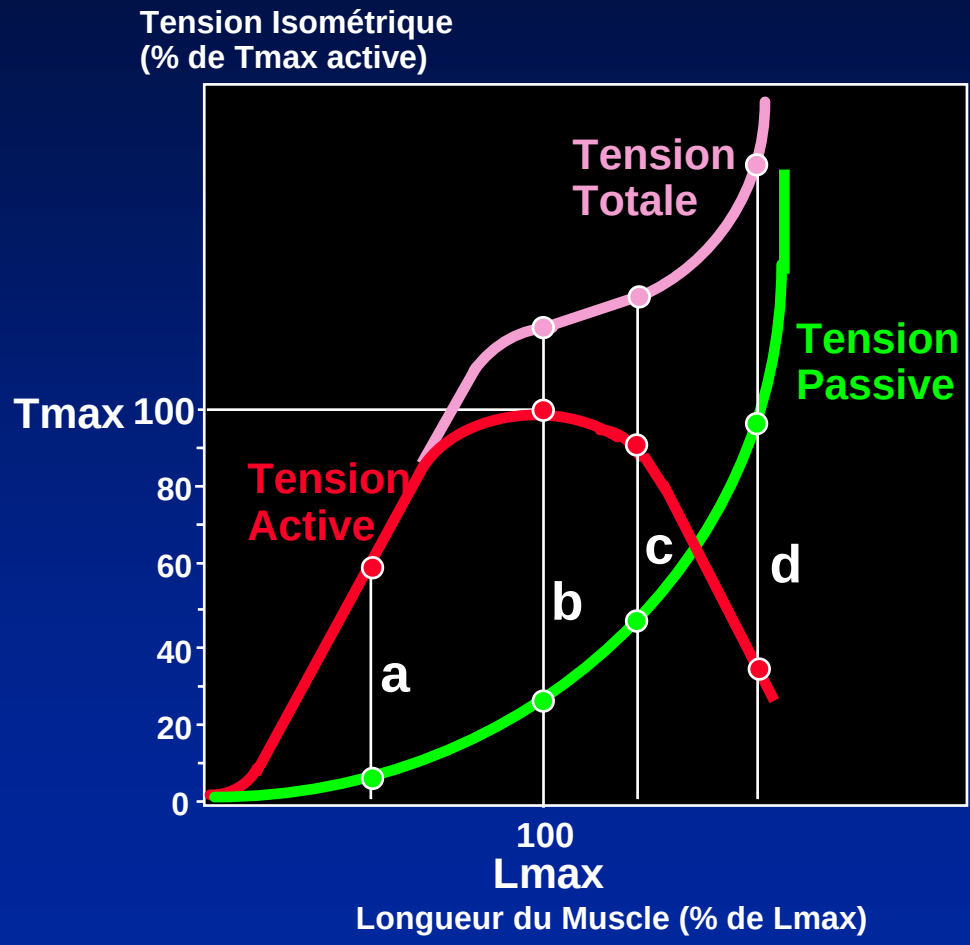
# Isométrie

# Effet de la longueur initiale du muscle (précharge) :
# Relation Tension-Longueur
# (Contractions Isométriques)



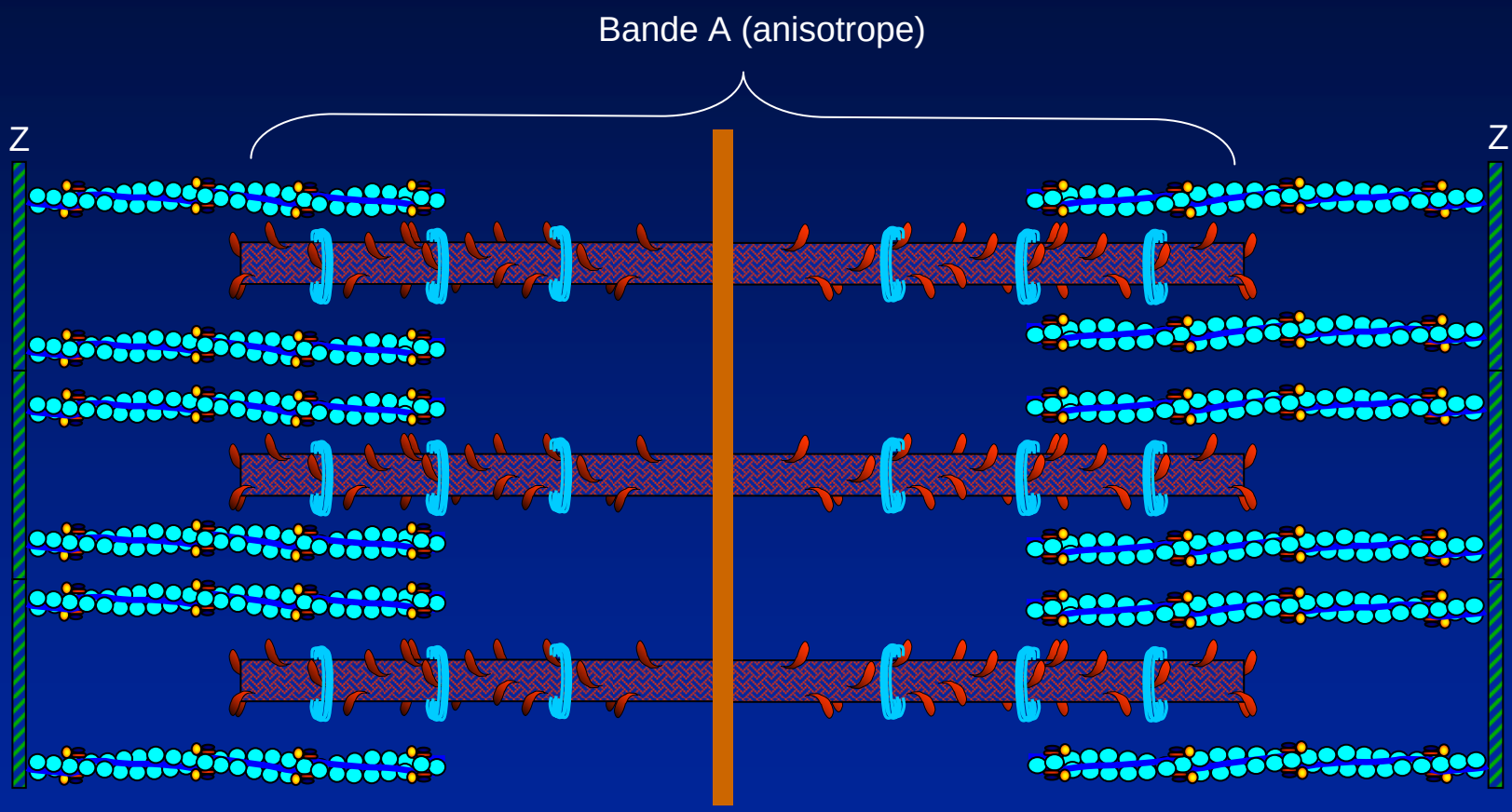




**Muscle Squelettique**

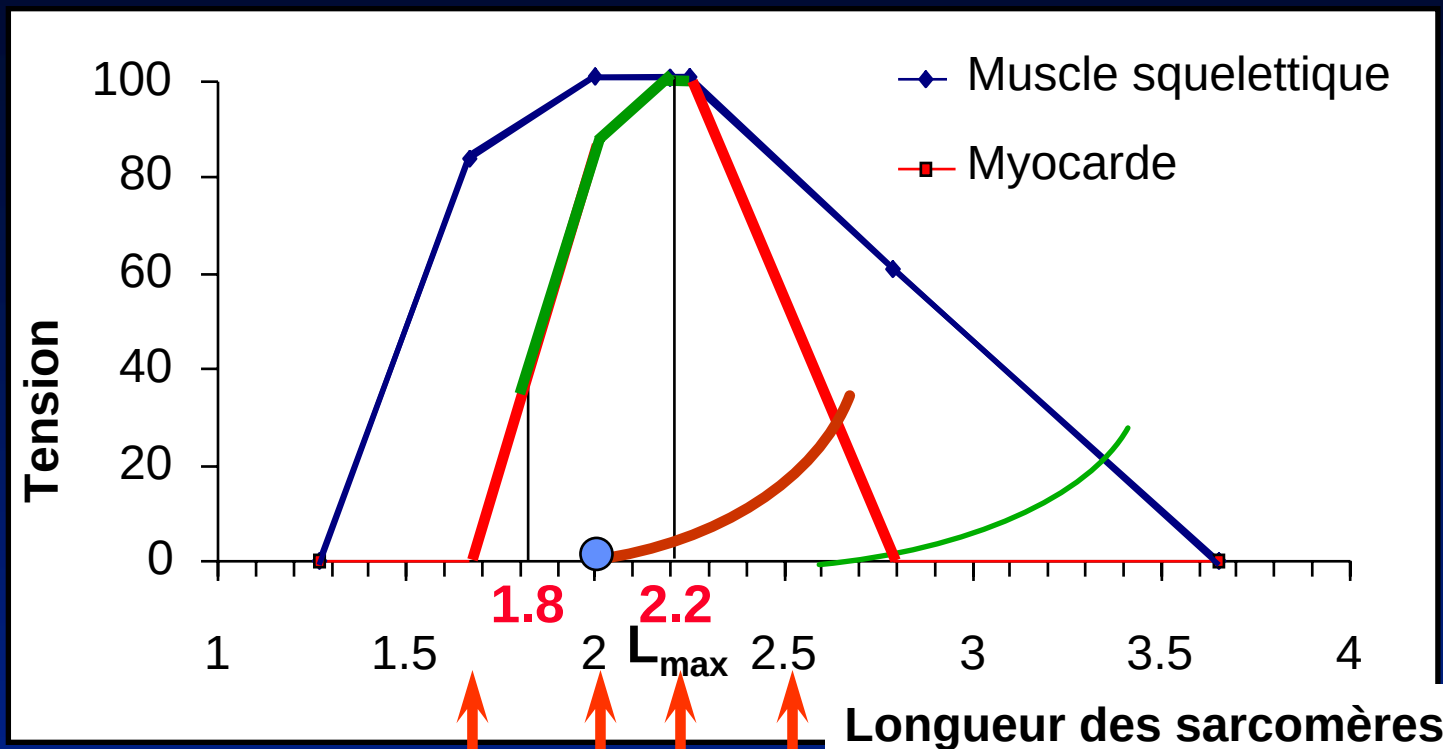


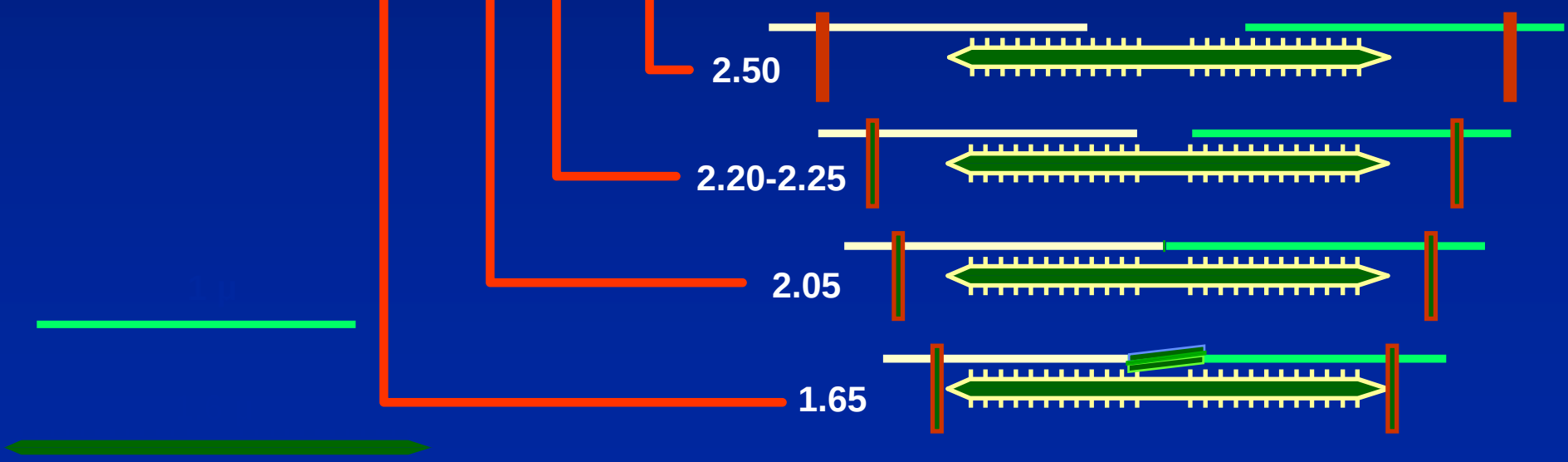

**Myocarde**

# Le sarcomère



# Relation tension-longueur



Effet de la

# Postcharge

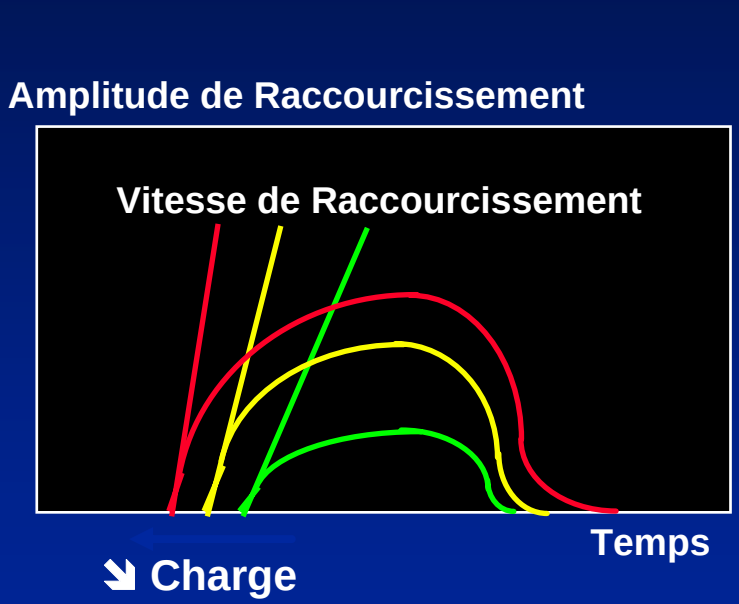
et de la

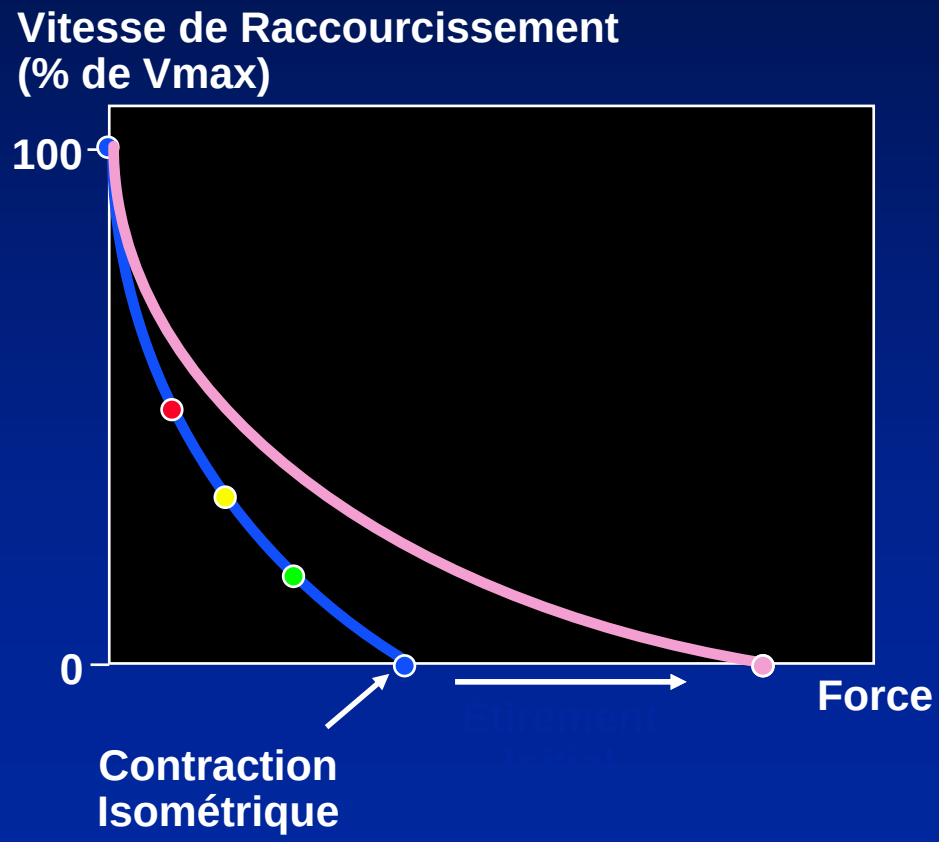
# Contractilité

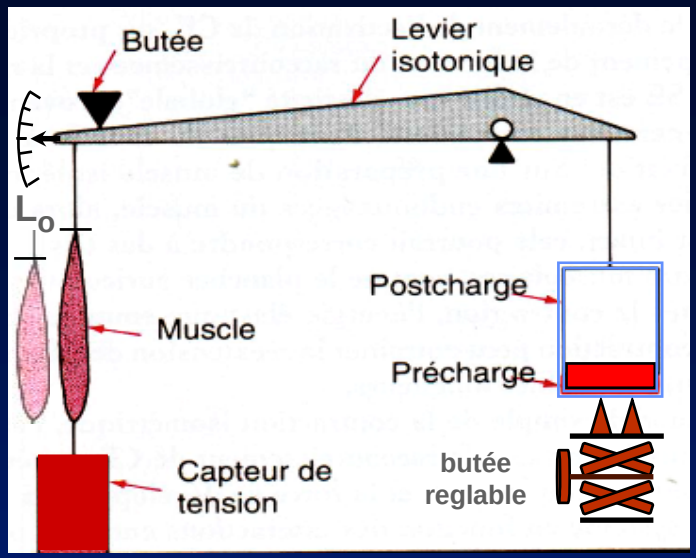
étudié en

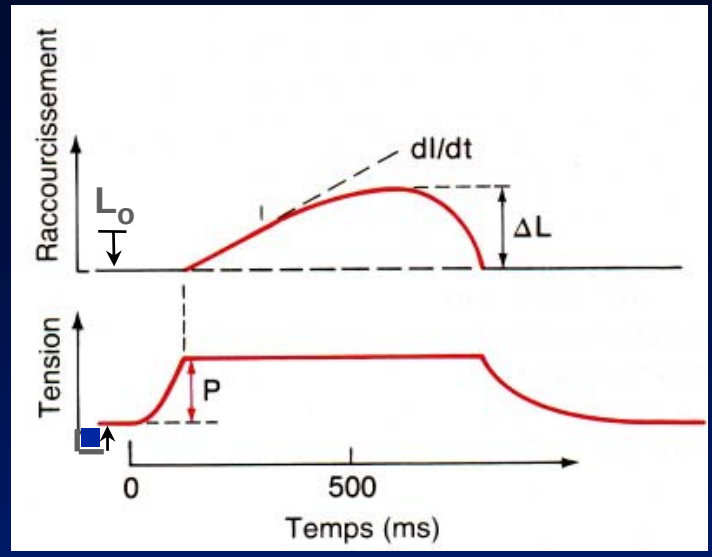
# isotonie

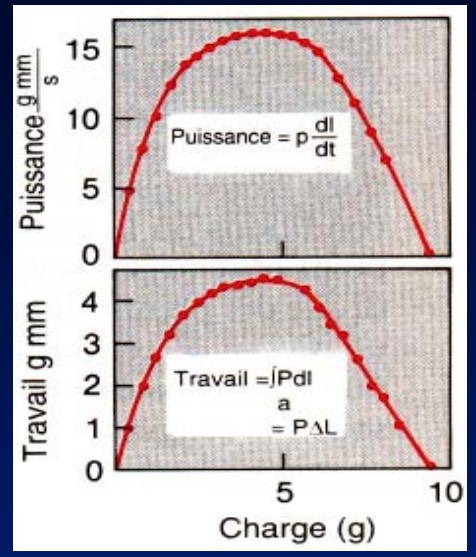
# Relation Force-Vitesse
# (Contractions Isotoniques)

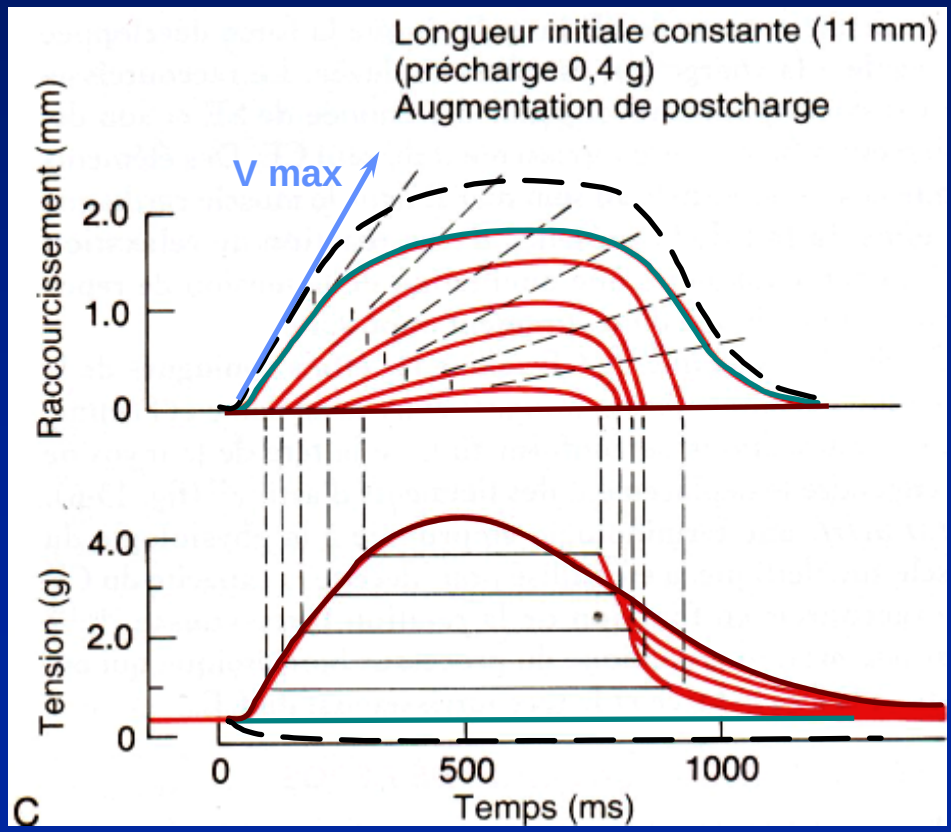


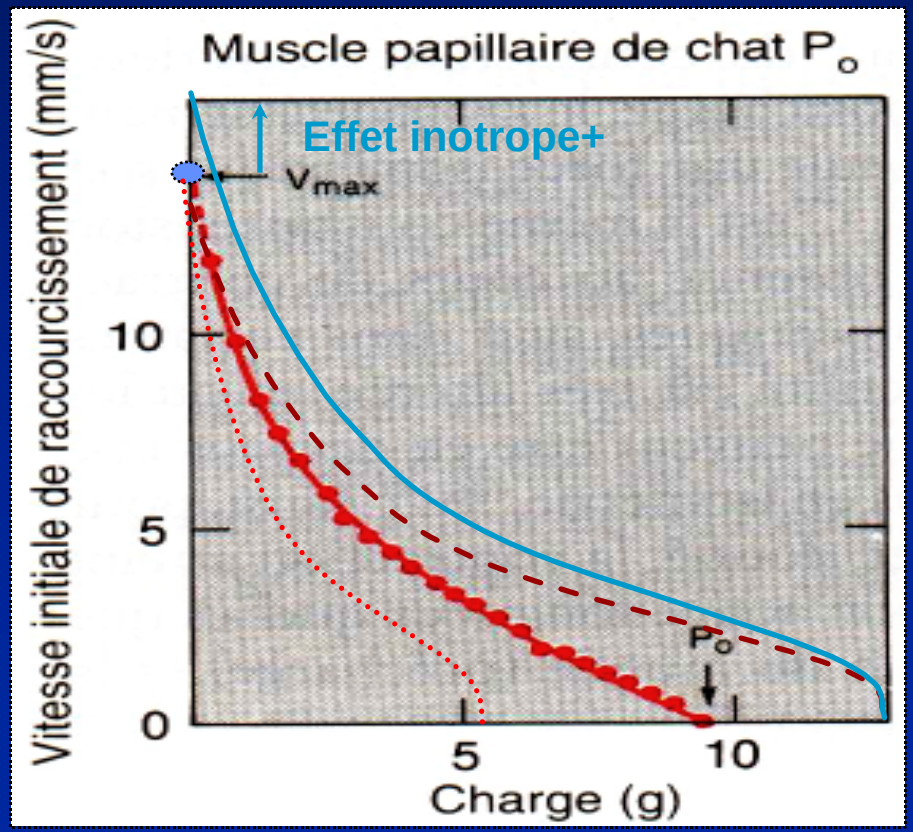




Butée
Levier isotonique
$L_o$
Muscle
Postcharge
Précharge
Capteur de tension
butée reglable

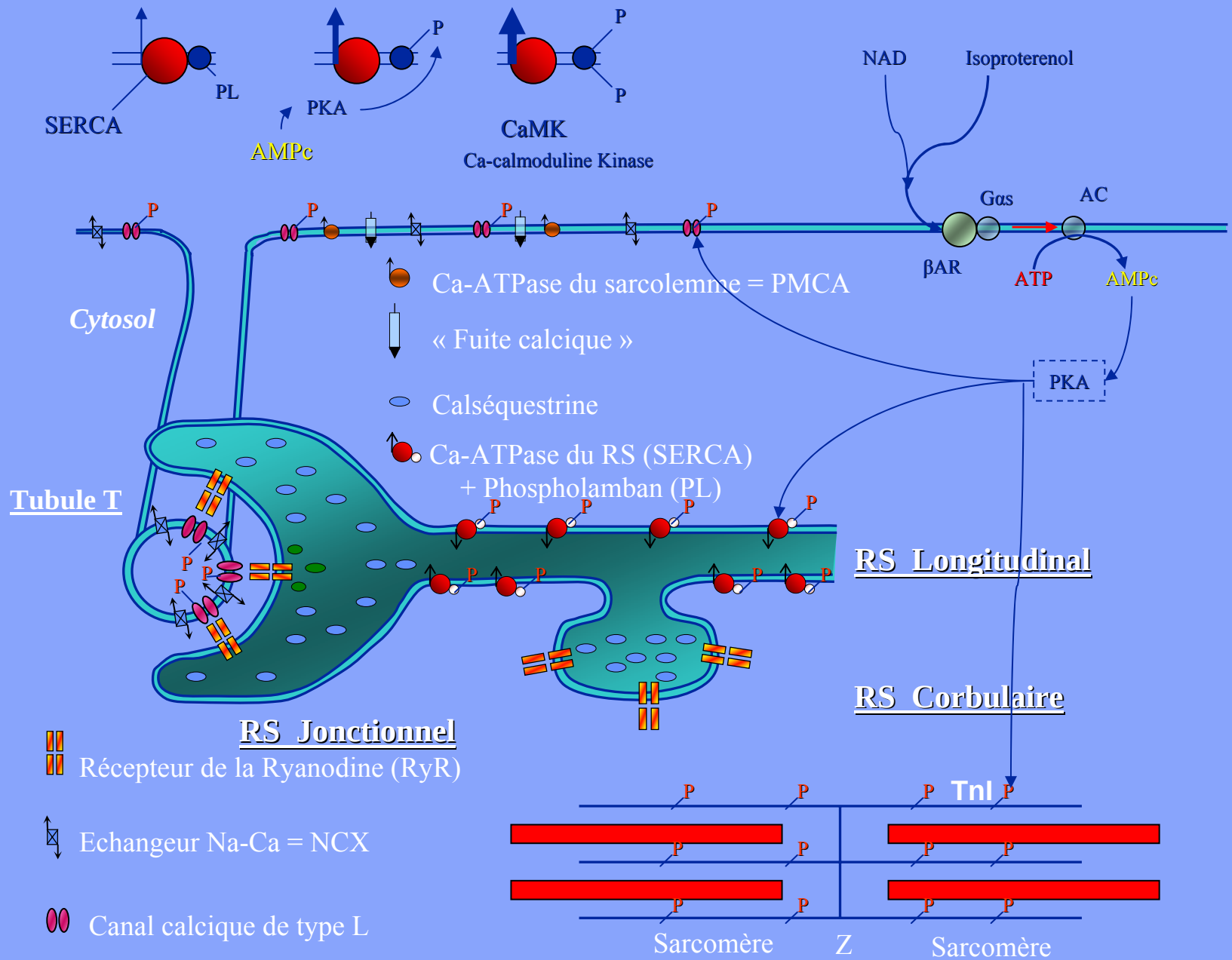

Raccourcissement
dl/dt
$L_o$
ΔL
Tension
P
0
500
Temps (ms)


Puissance $\frac{g\ mm}{s}$
Puissance = $p\frac{dl}{dt}$
Travail g mm
Travail = $\int_a P dl$ = PΔL
Charge (g)


Longueur initiale constante (11 mm)
(précharge 0,4 g)
Augmentation de postcharge
V max
Raccourcissement (mm)
Tension (g)
Temps (ms)
C


Muscle papillaire de chat $P_o$
Effet inotrope+
$V_{max}$
$P_o$
Vitesse initiale de raccourcissement (mm/s)
Charge (g)

# Effet de la stimulation sympathique sur les principales protéines du myocyte cardiaque



# Déterminants de la performance contractile du ventricule (G)

**Précharge**

**Postcharge**

**Contractilité**

# Précharge
## du ventricule

# Transposition de la relation force – longueur initiale (effet d'une variation de précharge) au niveau du cœur entier

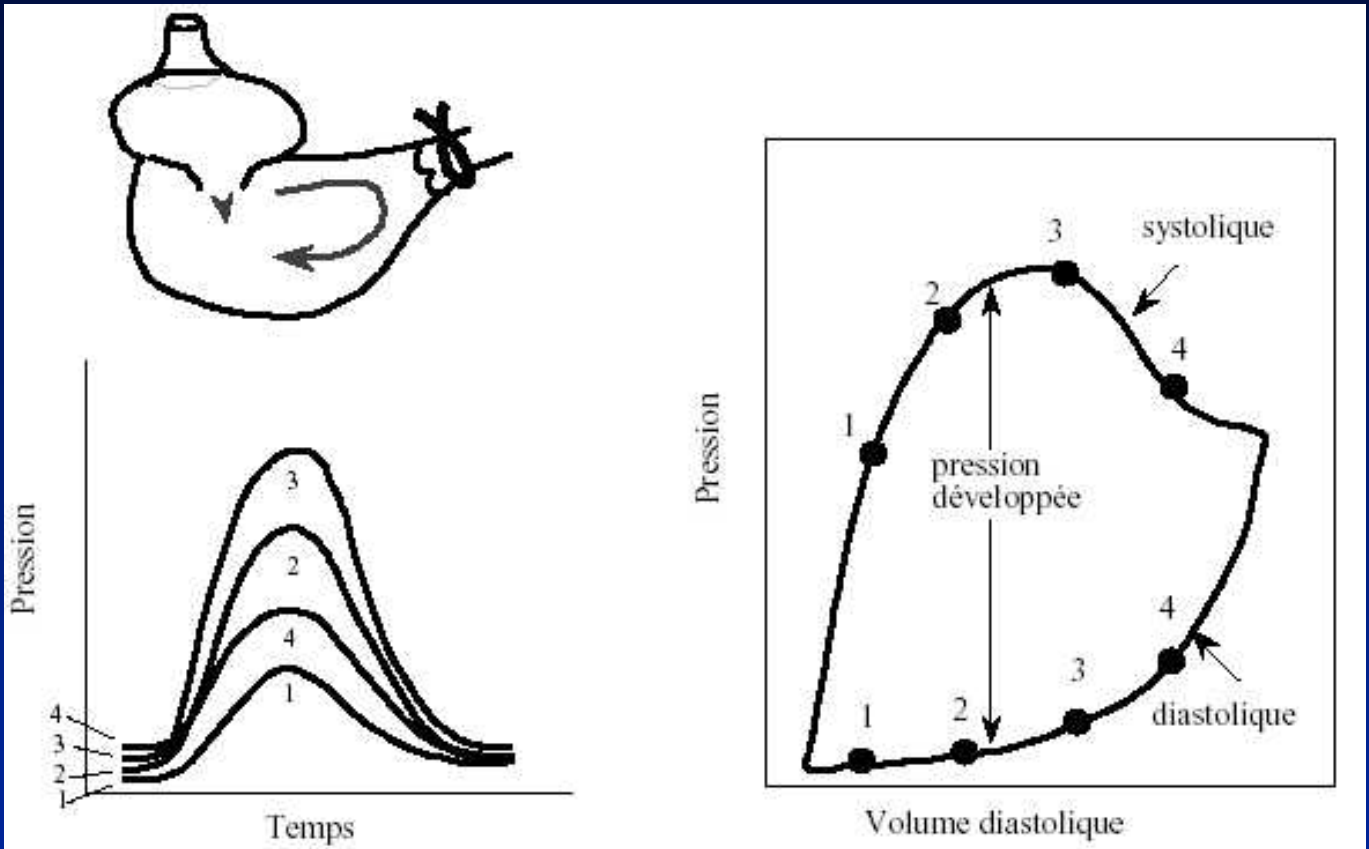



Figure IV. 8 :

*Expérience de Frank (1895) sur coeur de grenouille clampé à l'aorte alors que le remplissage ventriculaire est libre. Les cycles cardiaques 1,2,3,4 se déroulent avec des volumes télédiastoliques croissants. Jusqu'au 3e cycle, la pression produite par le ventricule augmente. Cependant au 4e cycle, la pression systolique décroît.*

**Frank 1895**

# Transposition de la relation force – longueur au niveau du cœur éjectant

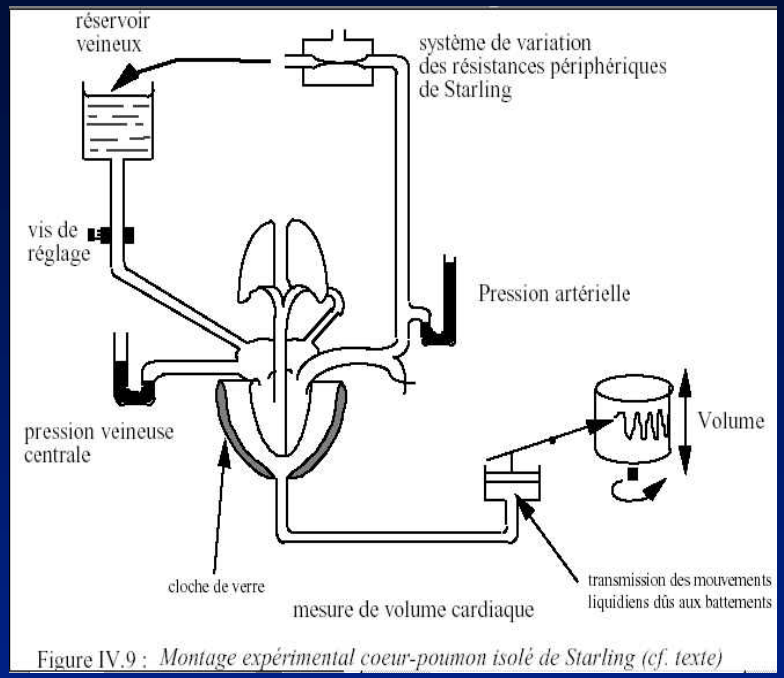
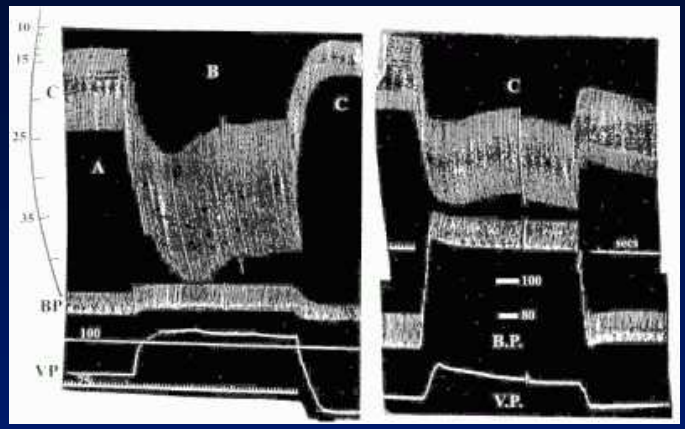
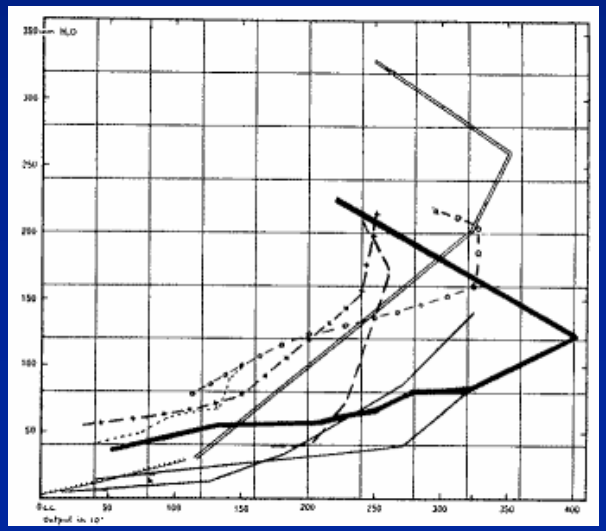


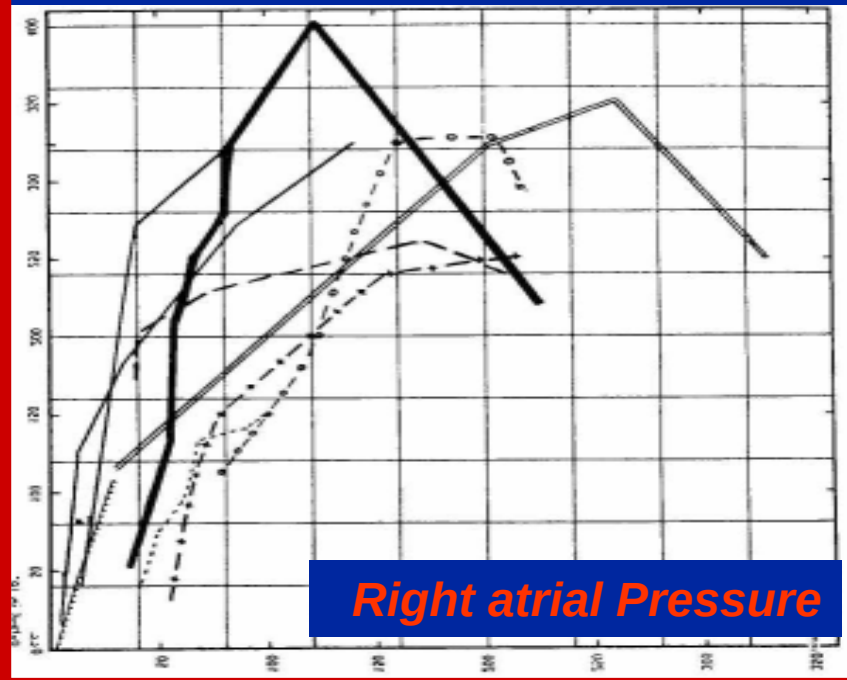

Figure IV.9 : *Montage expérimental coeur-poumon isolé de Starling (cf. texte)*



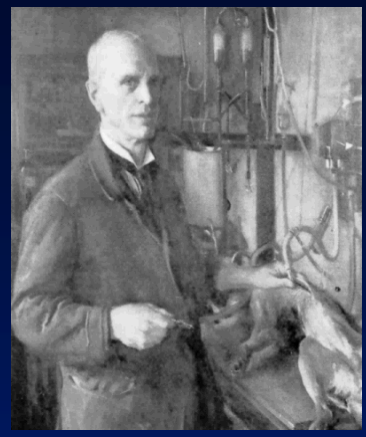



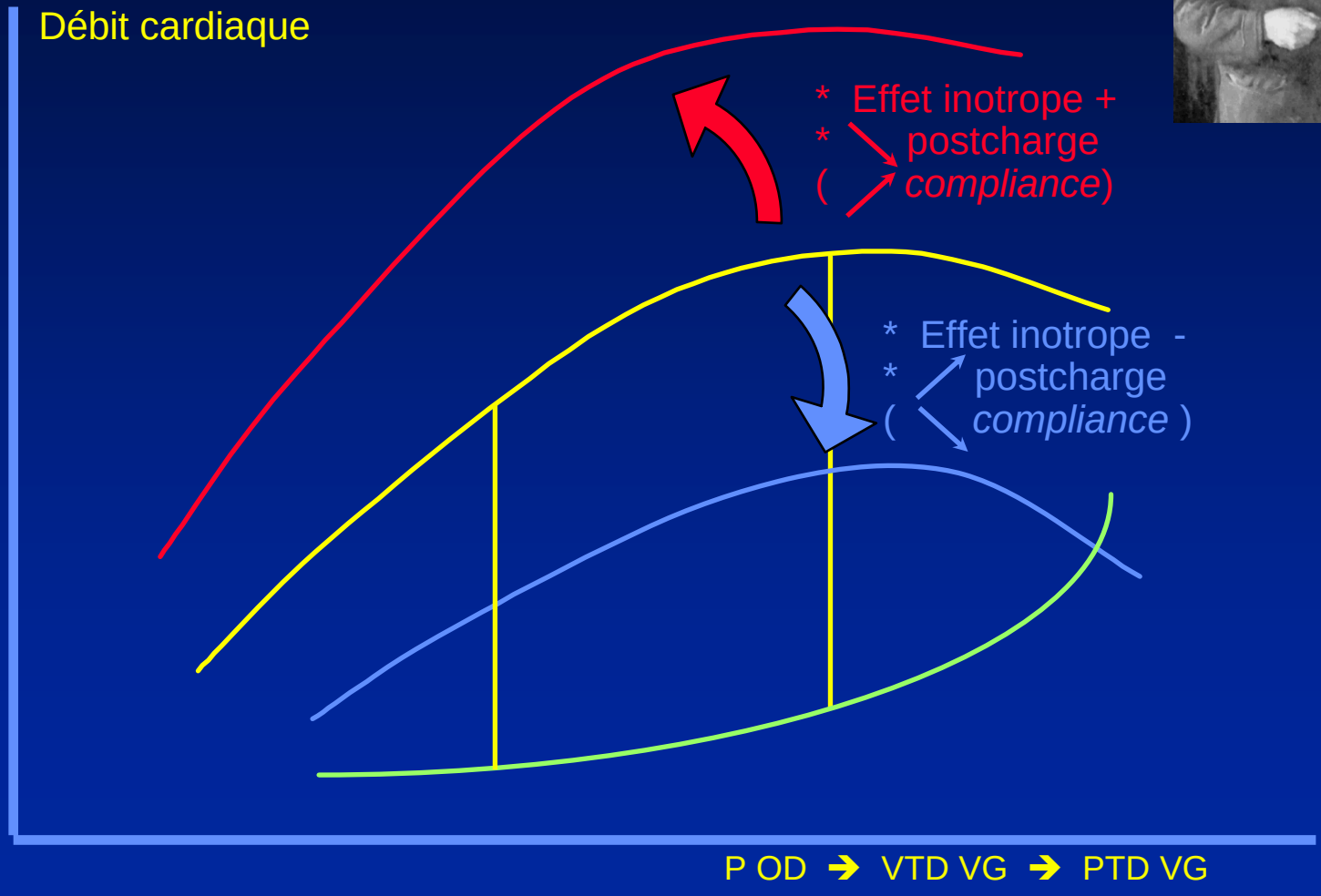
**Starling 1912**

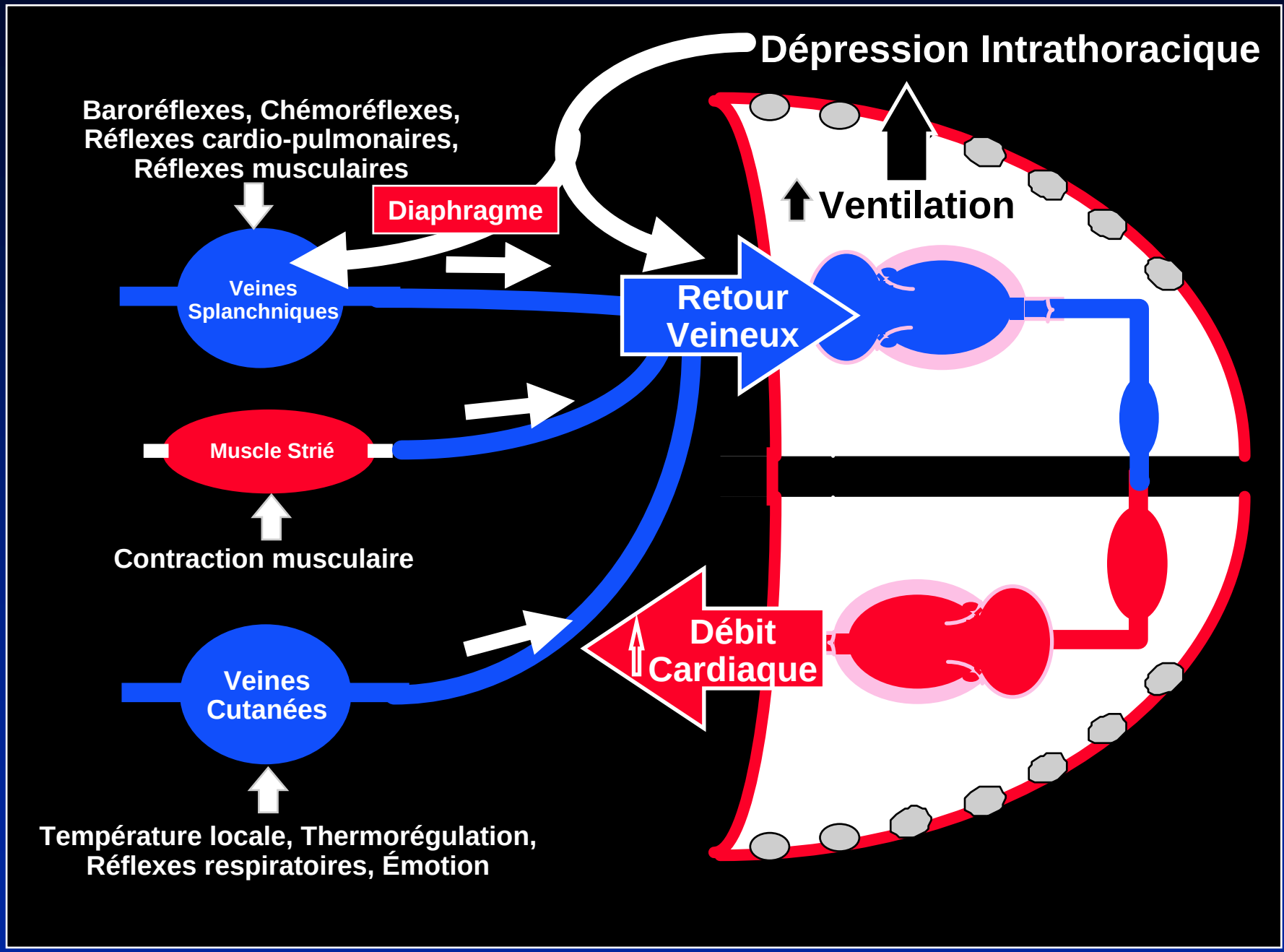
## Cardiac Output



# Courbes de fonction ventriculaire



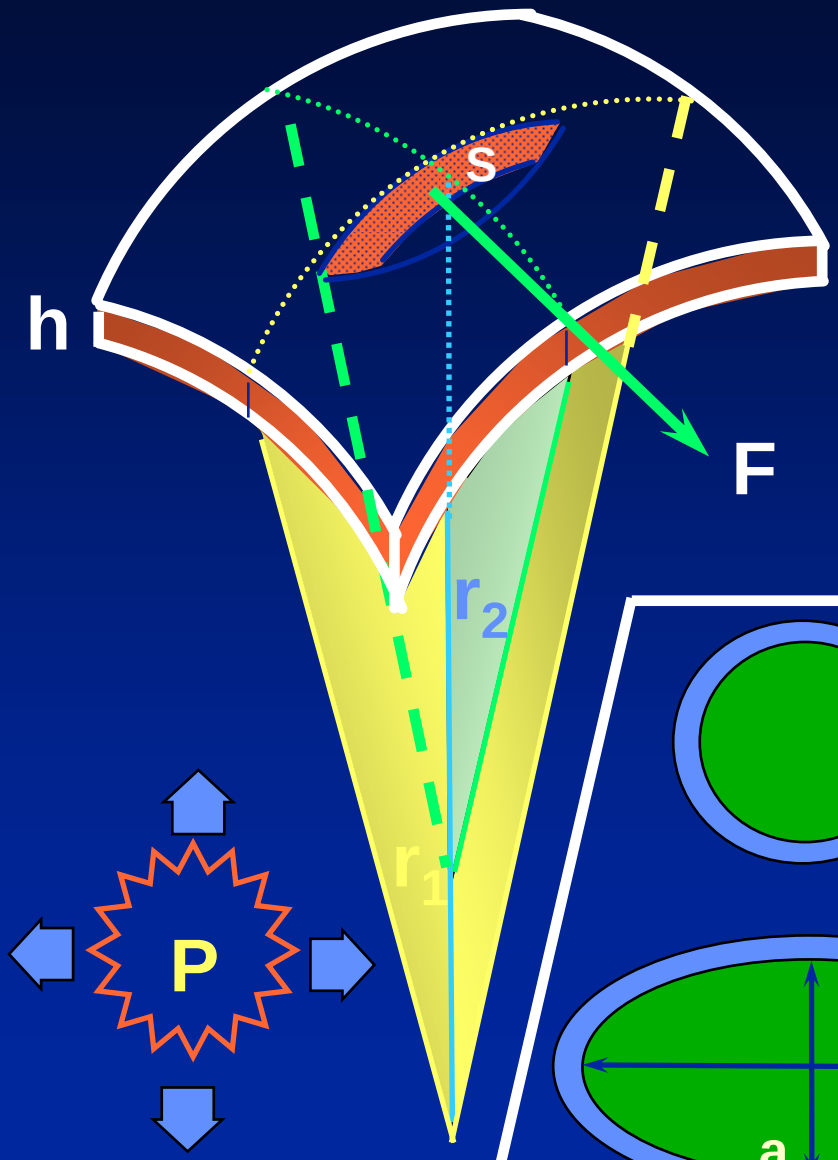



Dépression Intrathoracique
Baroréflexes, Chémoréflexes,
Réflexes cardio-pulmonaires,
Réflexes musculaires
Diaphragme
Ventilation
Veines
Splanchniques
Retour
Veineux
Muscle Strié
Contraction musculaire
Débit
Cardiaque
Veines
Cutanées
Température locale, Thermorégulation,
Réflexes respiratoires, Émotion

# Postcharge
## du ventricule

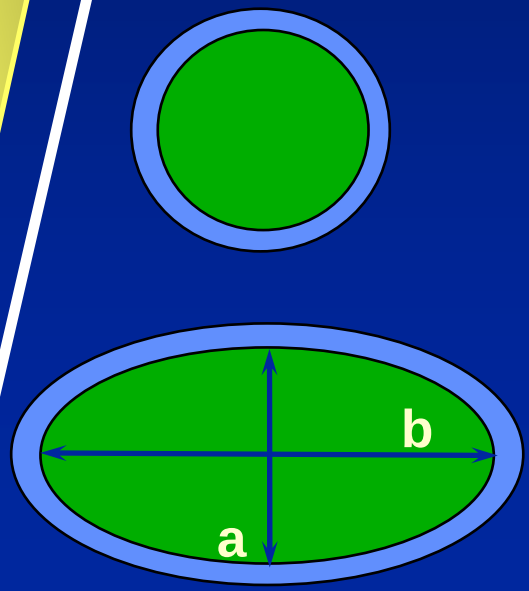
# Postcharge

## Contrainte pariétale
Loi de Laplace



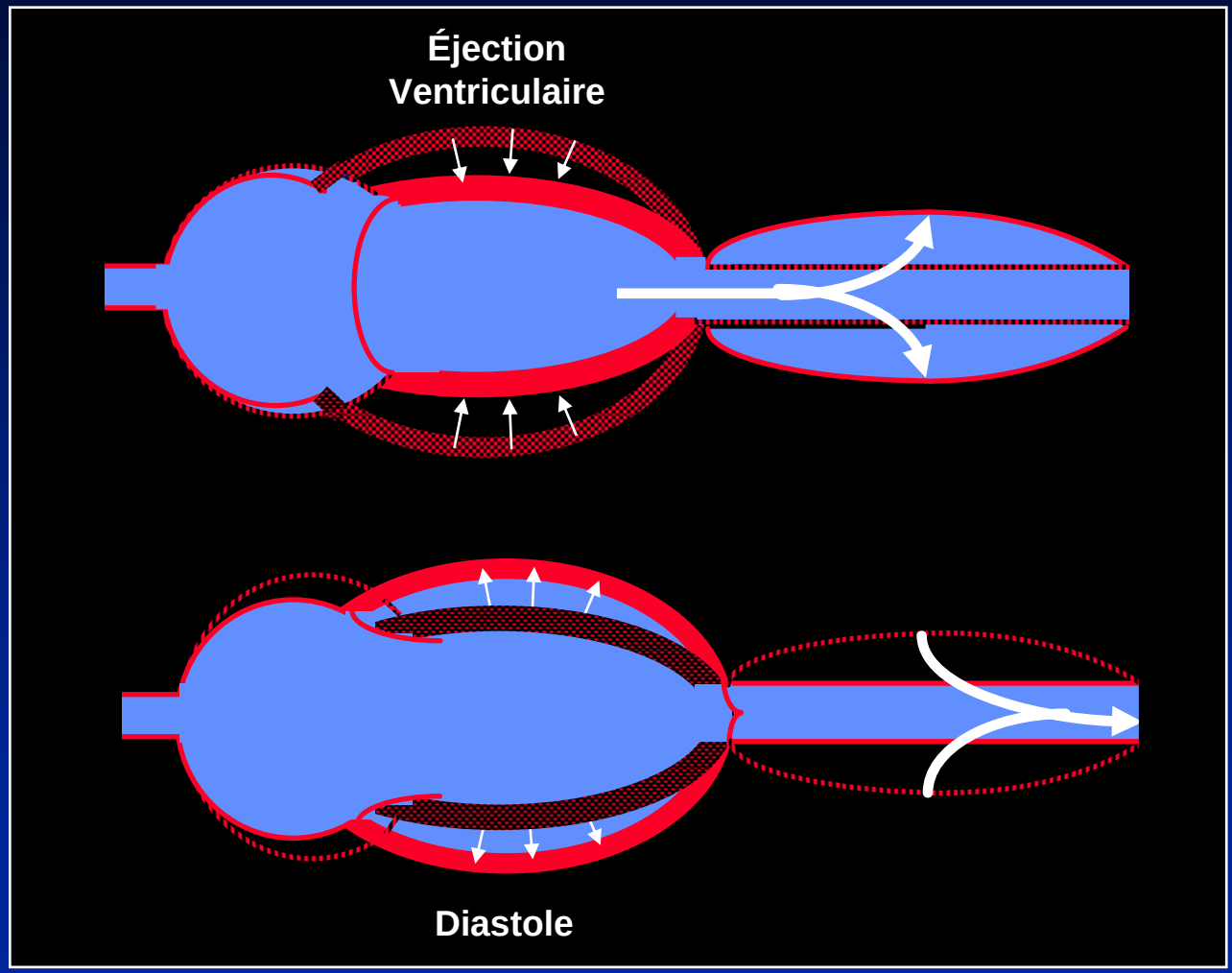

$$\sigma = F / S$$

$$P = \sigma \times h \times ( 1/r_1 + 1/r_2 )$$




$$\sigma = P\ r / 2h$$

$$\sigma = P\ r / h \times f( a / b )$$


Éjection
Ventriculaire
Diastole

Postcharge

# Contrainte pariétale ( F / S )

***Paramètre « régulé »***

**Rôle de la *géométrie ventriculaire***

***contrainte***

**Laplace : $\sigma$ = P x r / h x f ( a ,b )**

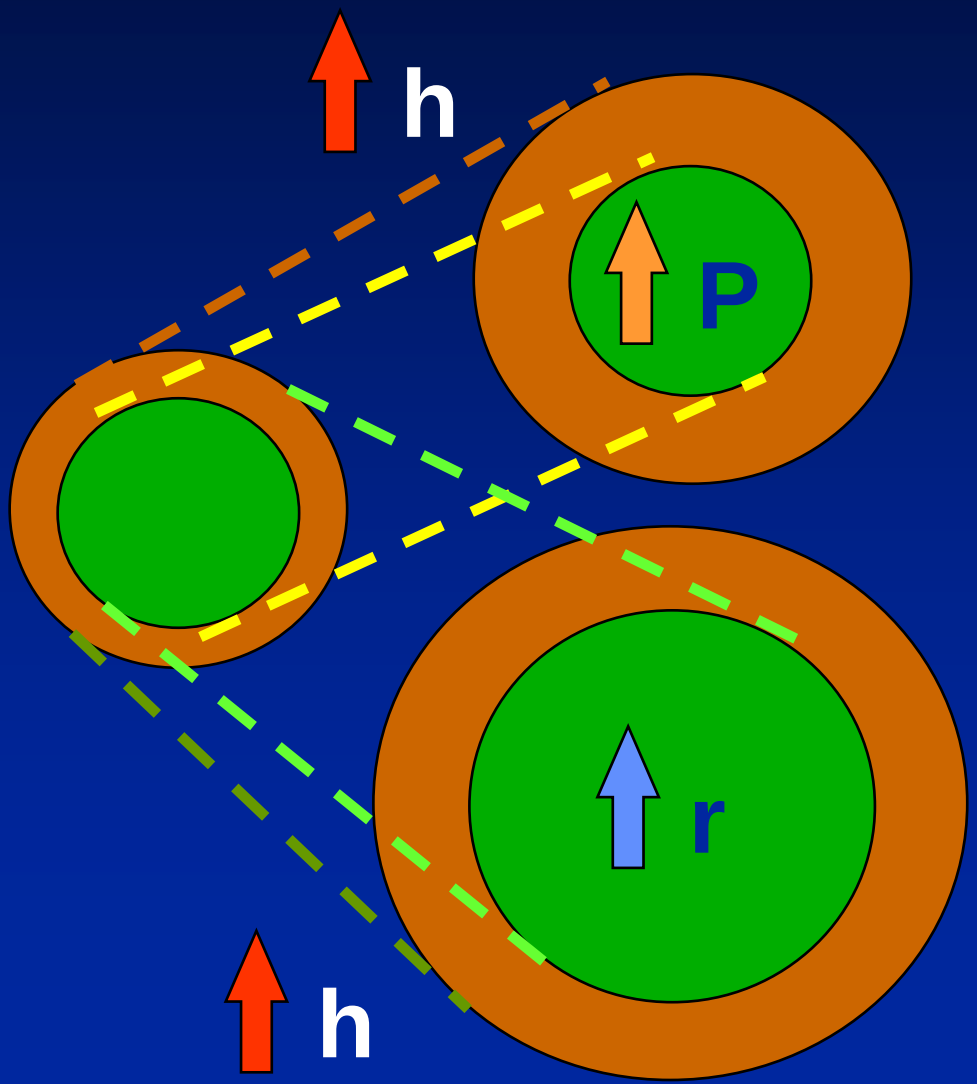
**Rôle des propriétés $\Phi$ du système artériel**

**Notion d' *impédance artérielle***

**Z = f ( R, L, C, fréquence)**

# GÉOMÉTRIE VENTRICULAIRE ET CONTRAINTE PARIÉTALE

$$\sigma = P \times \frac{r}{h} \times f(a, b)$$



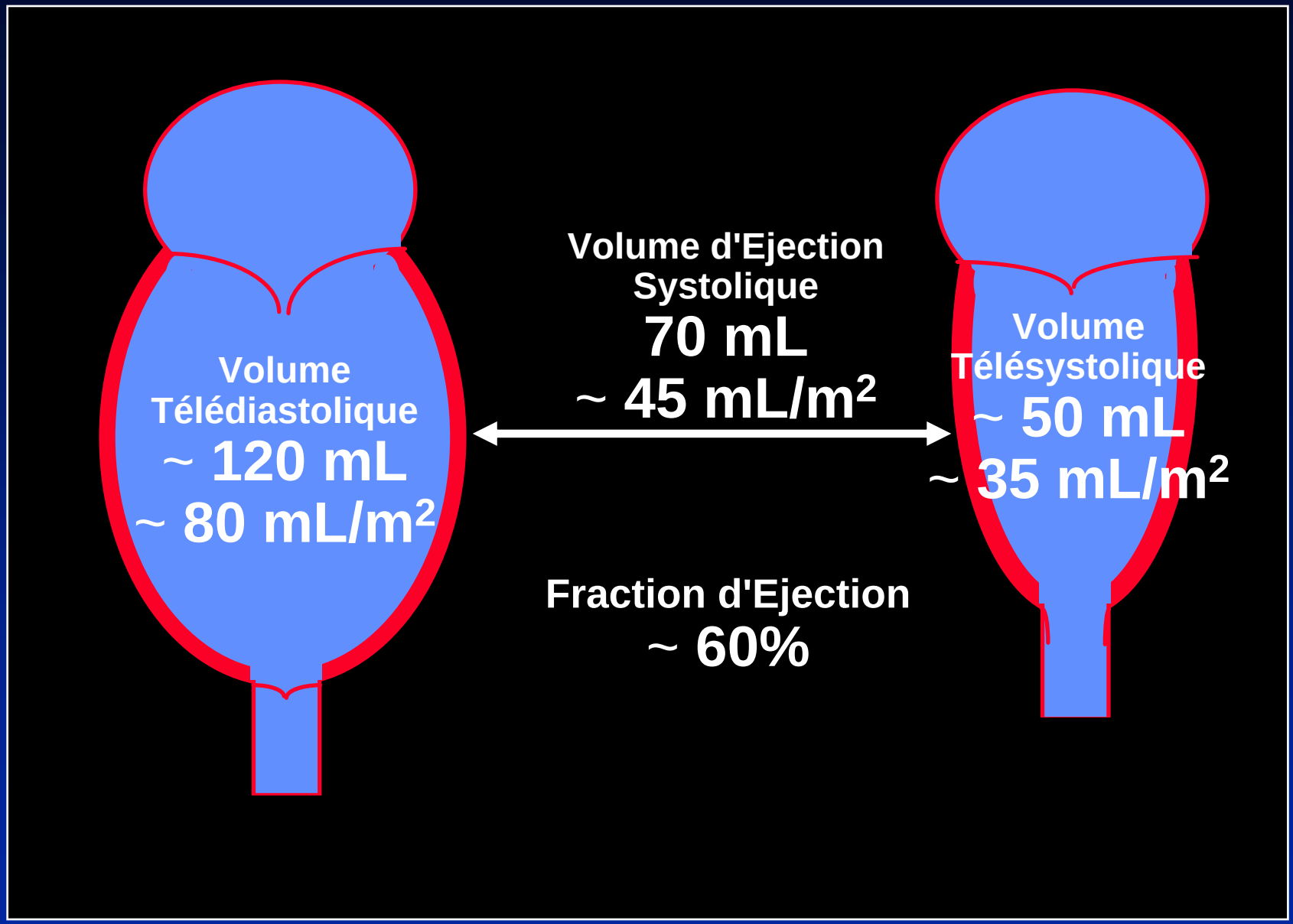

**Surcharge barométrique**

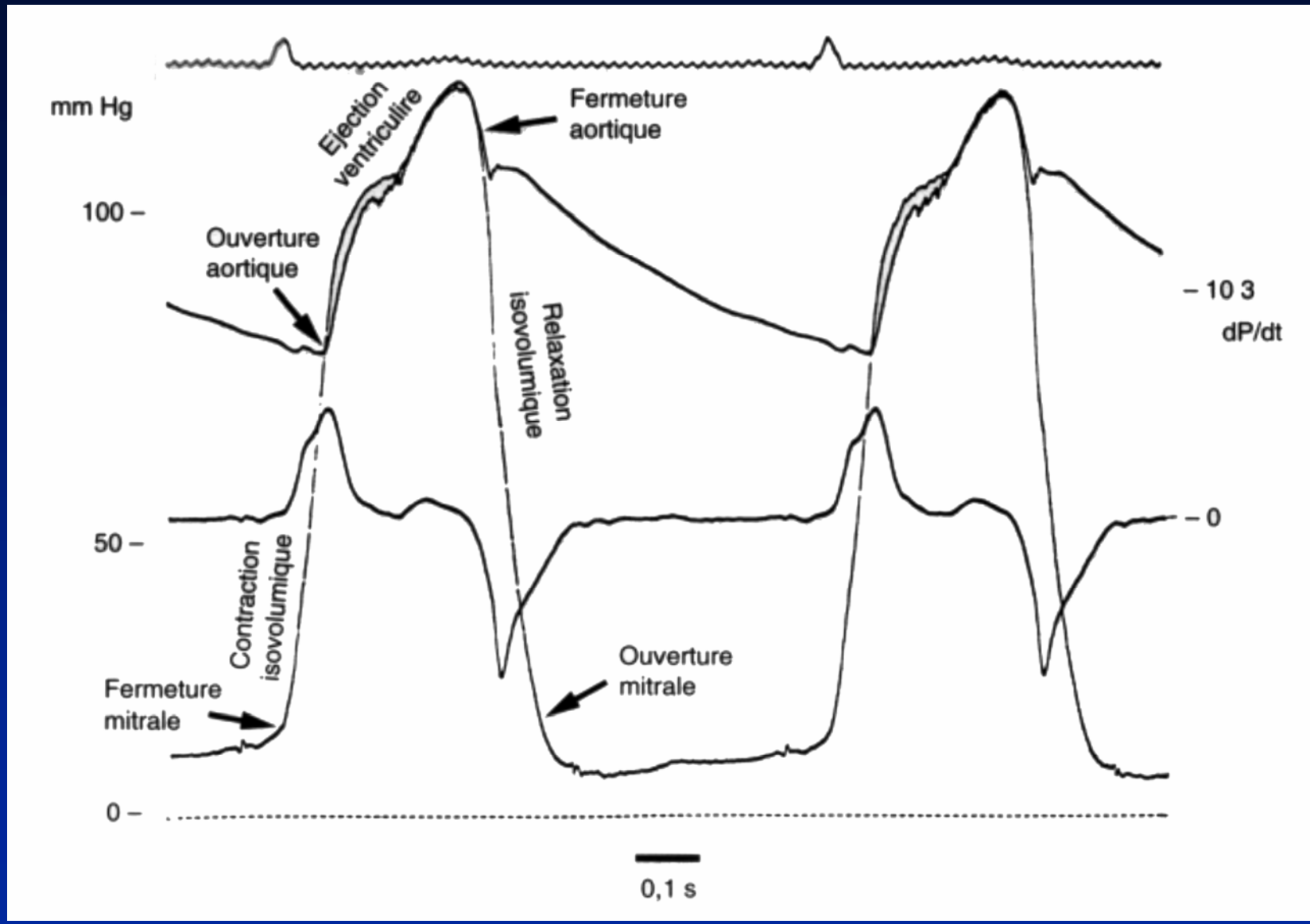
**h / r**

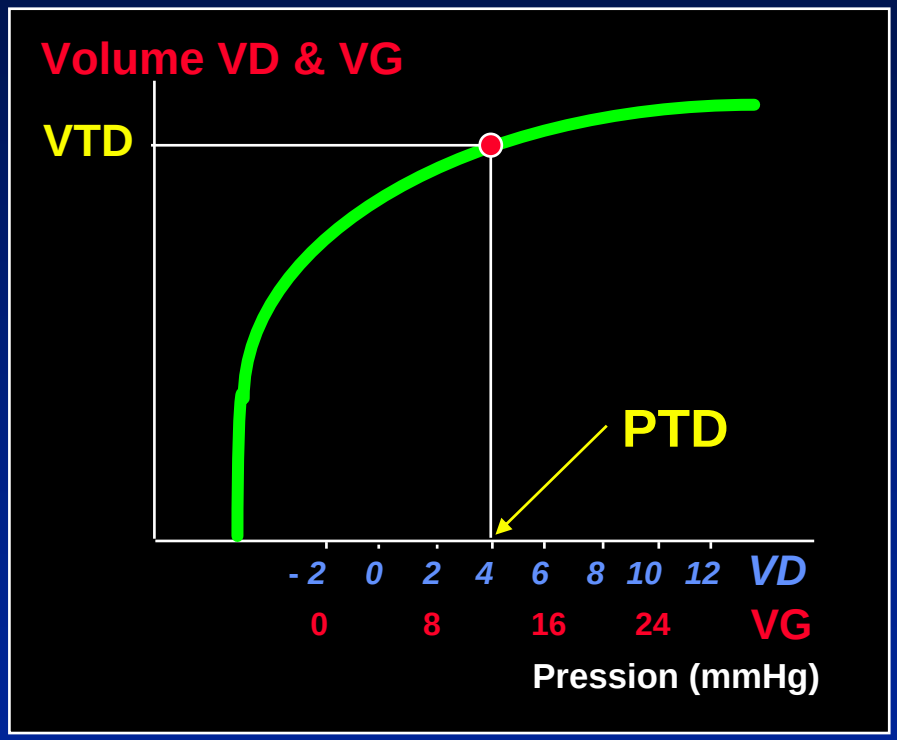
**Surcharge volumétrique**

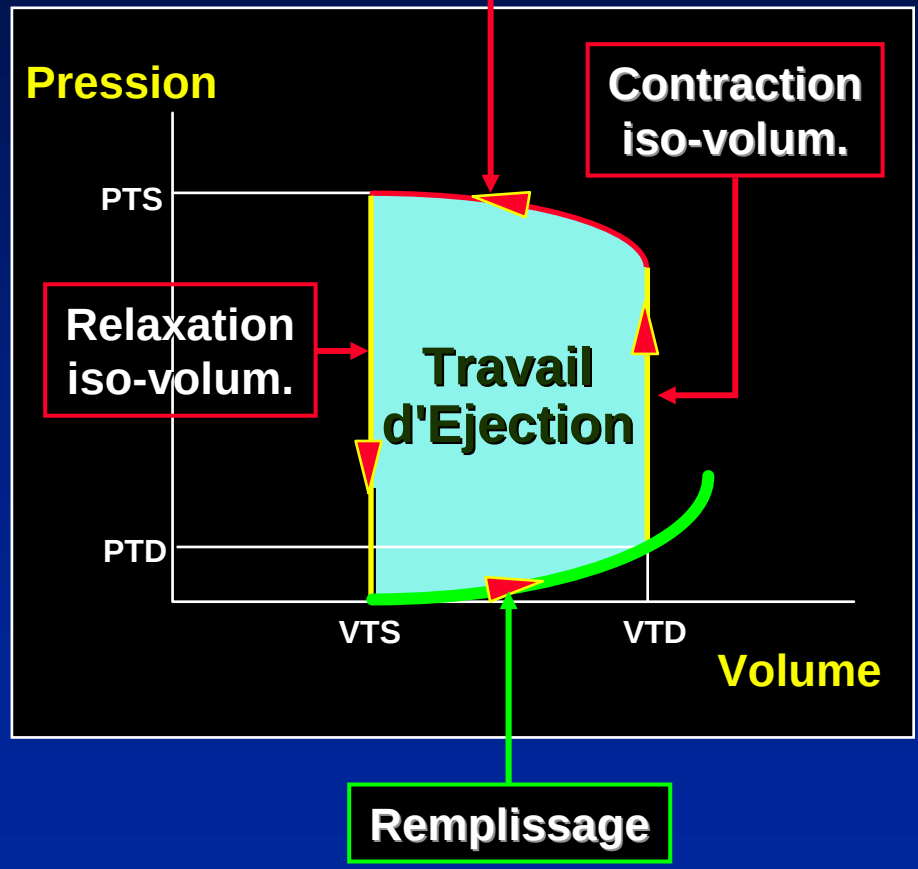
**h / r**

# Contractilité
## du ventricule

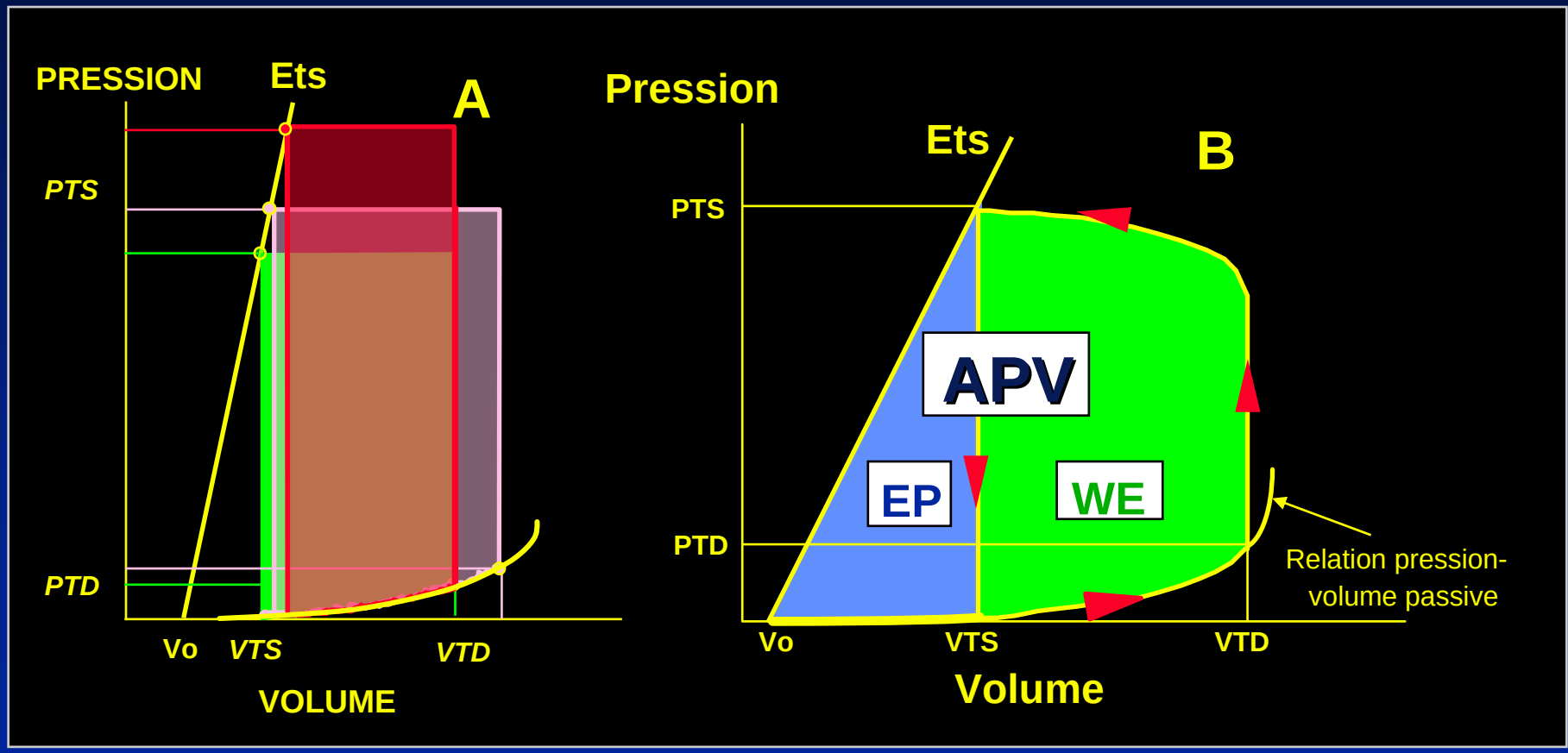

Volume
Télédiastolique
~ 120 mL
~ 80 mL/m²
Volume d'Ejection
Systolique
70 mL
~ 45 mL/m²
Volume
Télésystolique
~ 50 mL
~ 35 mL/m²
Fraction d'Ejection
~ 60%


mm Hg
100 –
50 –
0 –
Ejection ventriculire
Fermeture aortique
Ouverture aortique
Relaxation isovolumique
Contraction isovolumique
Fermeture mitrale
Ouverture mitrale
– 10 3
dP/dt
– 0
0,1 s

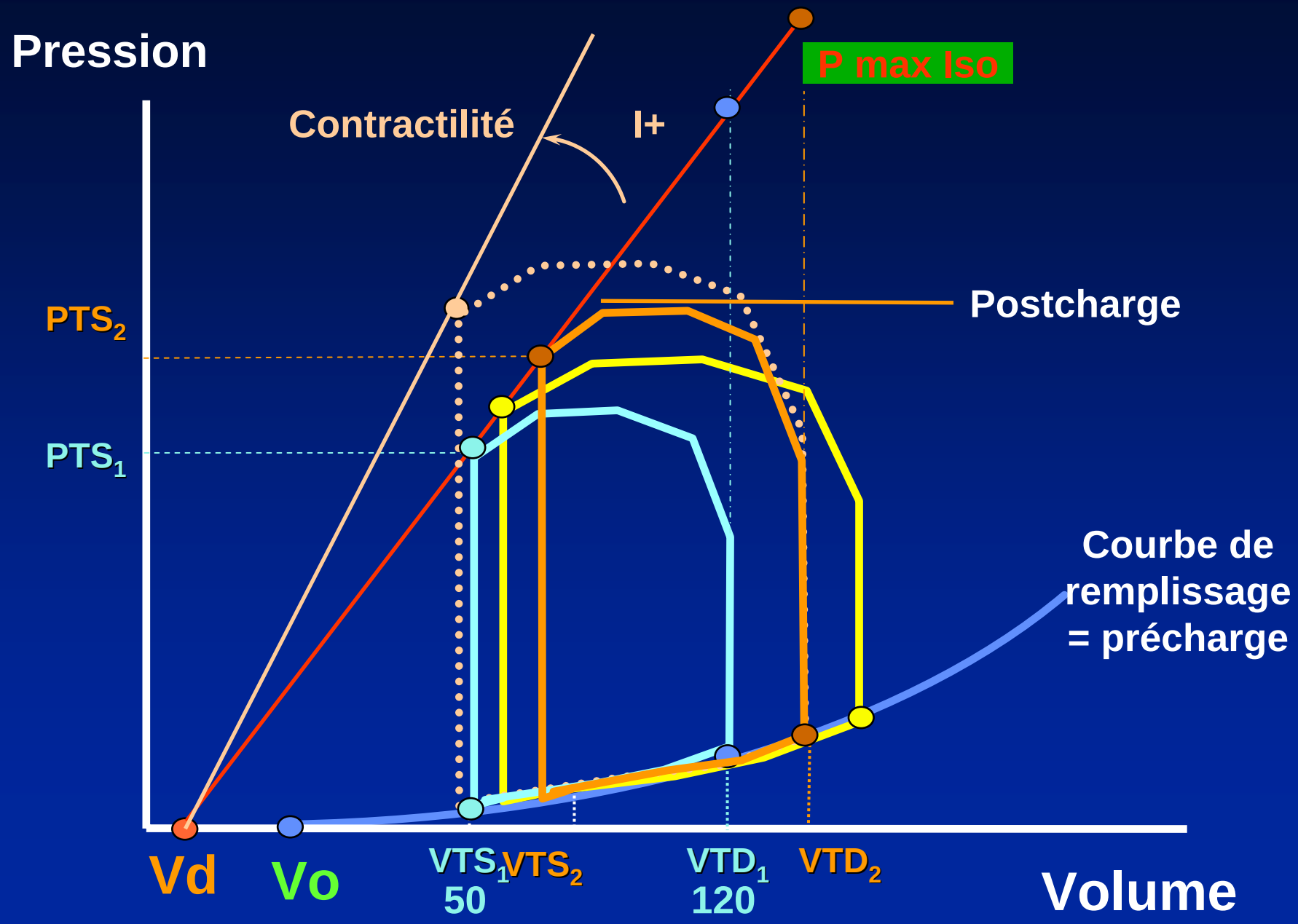

Volume VD & VG
VTD
PTD
- 2
0
2
4
6
8
10
12
VD
0
8
16
24
VG
Pression (mmHg)


Ejection
Pression
Contraction iso-volum.
PTS
Relaxation iso-volum.
Travail d'Ejection
PTD
VTS
VTD
Volume
Remplissage

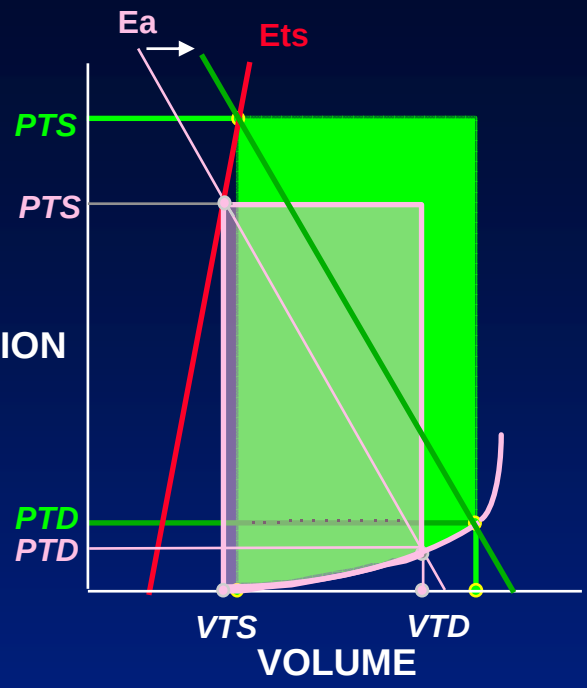
# Performance Contractile



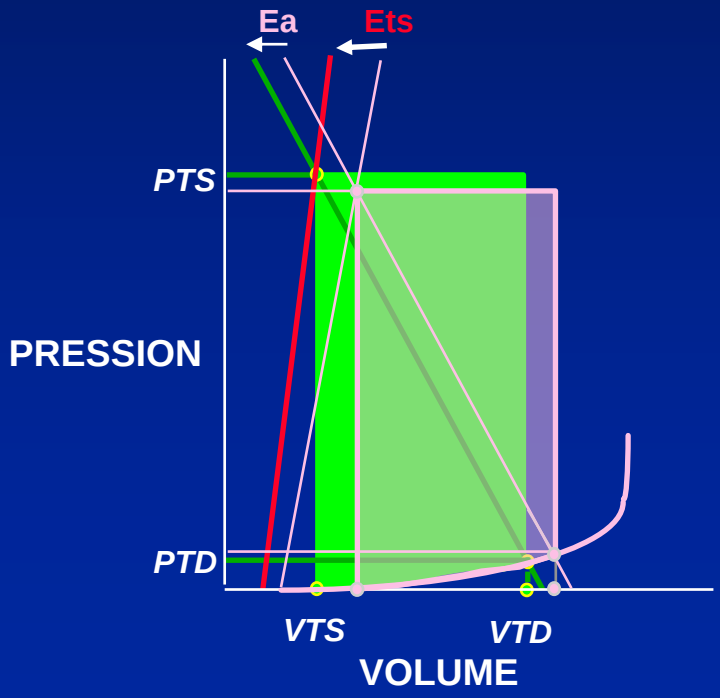
# Relation PTS - VTS



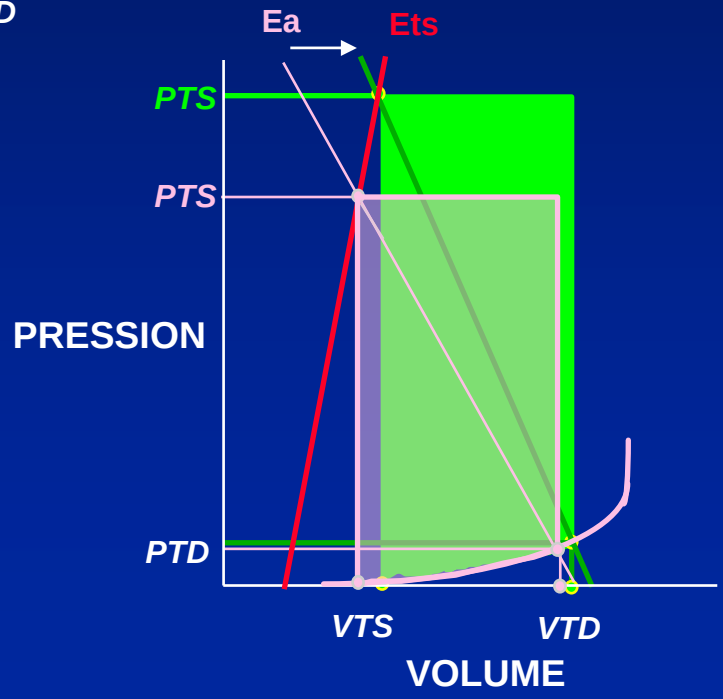
## Augmentation de Pré-charge



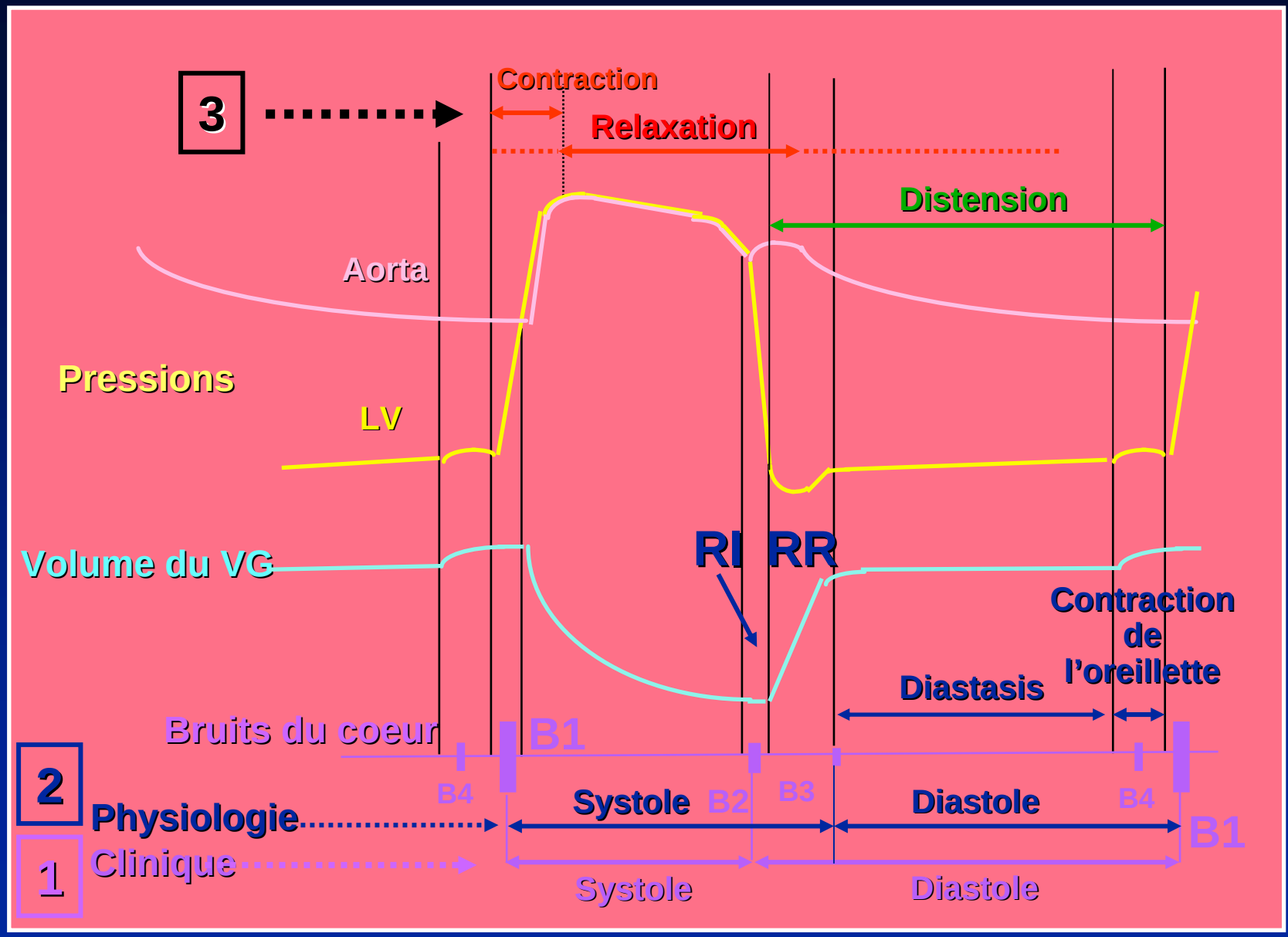

## Augmentation de Contractilité

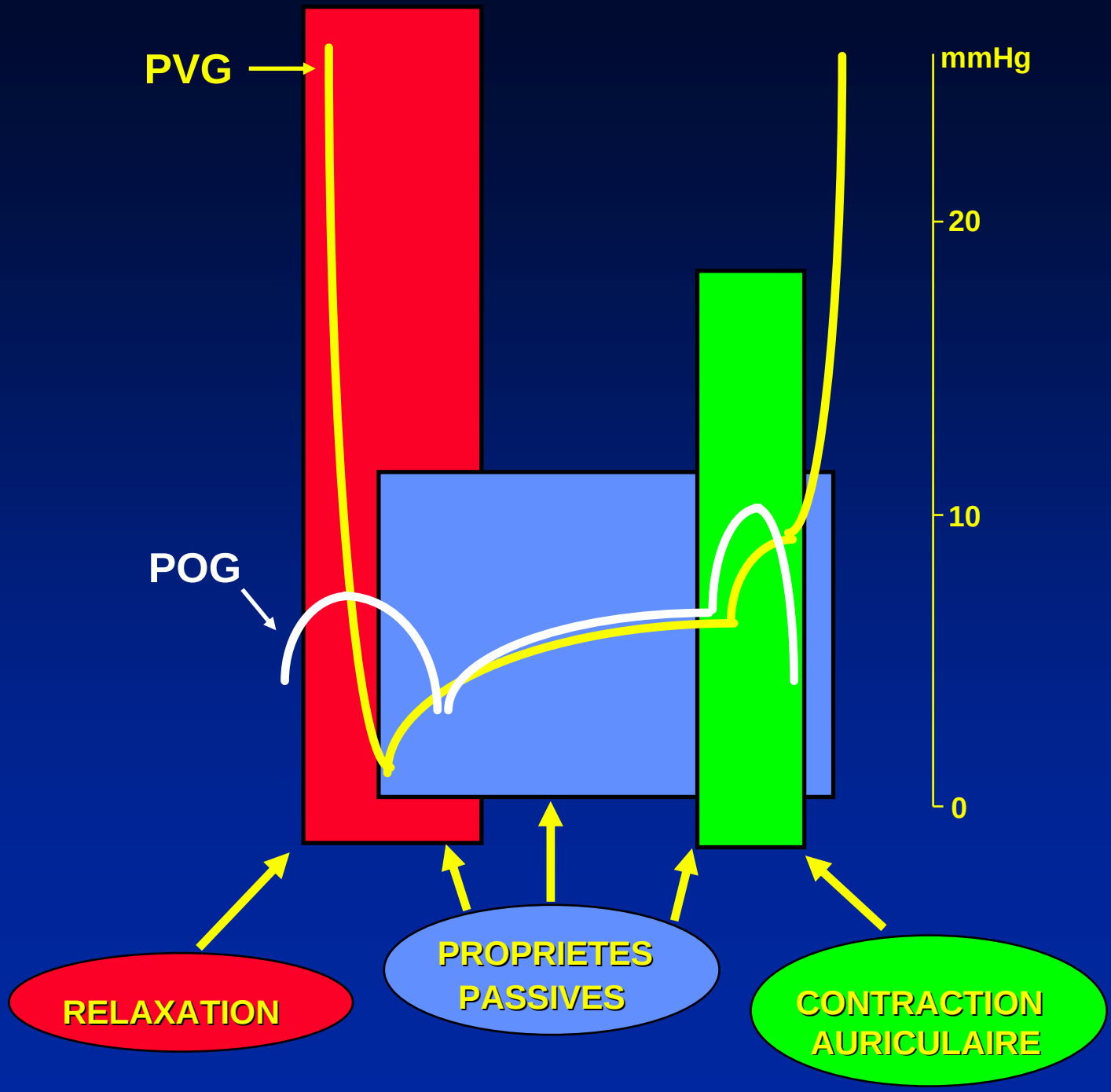



## Augmentation de Post-charge

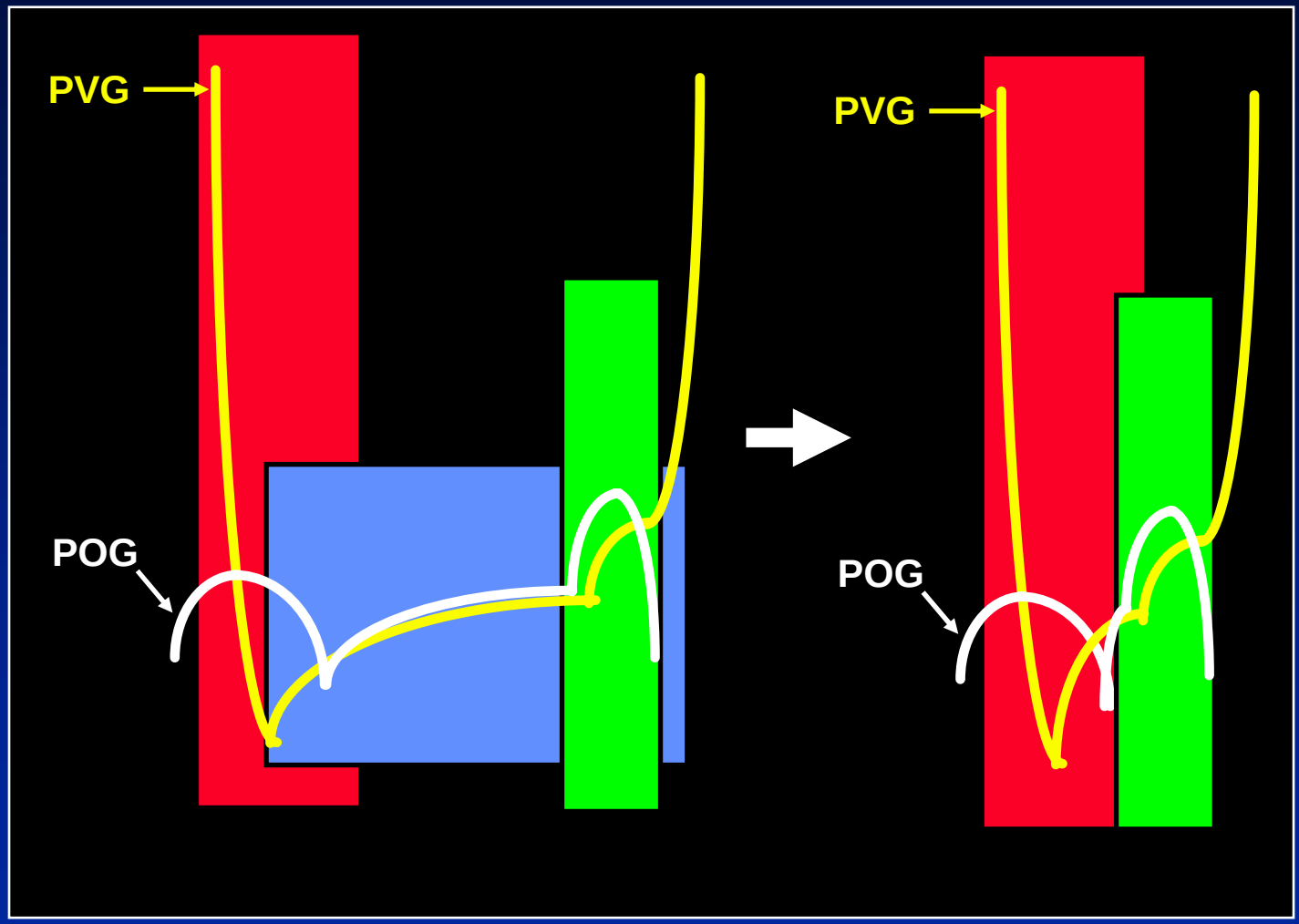


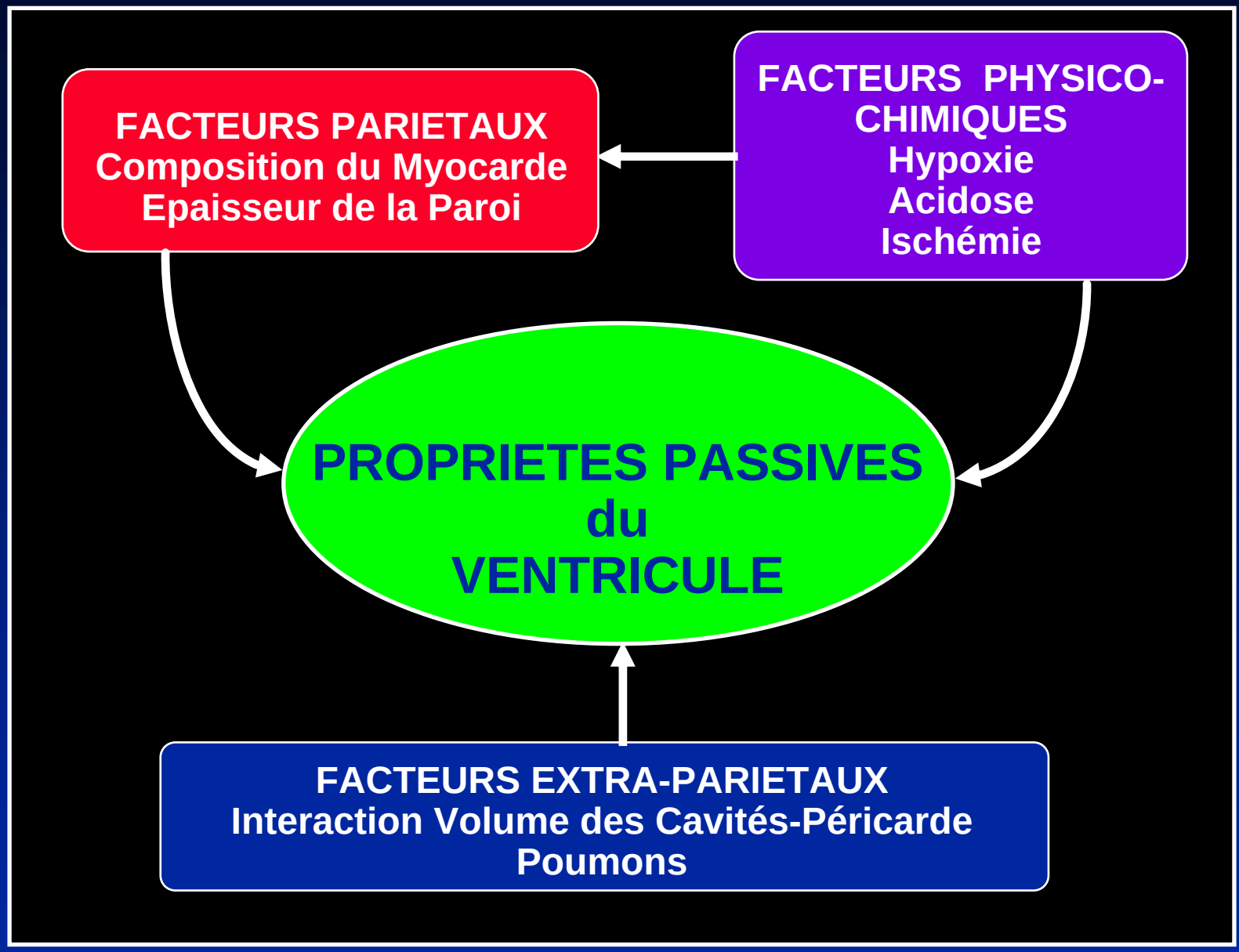
# Relaxation et propriétés passives du ventricule


3
Contraction
Relaxation
Distension
Aorta
Pressions
LV
Volume du VG
RI
RR
Contraction
de
l'oreillette
Diastasis
Bruits du coeur
B1
B4
Systole
B2
B3
Diastole
B4
B1
2
Physiologie
1
Clinique
Systole
Diastole

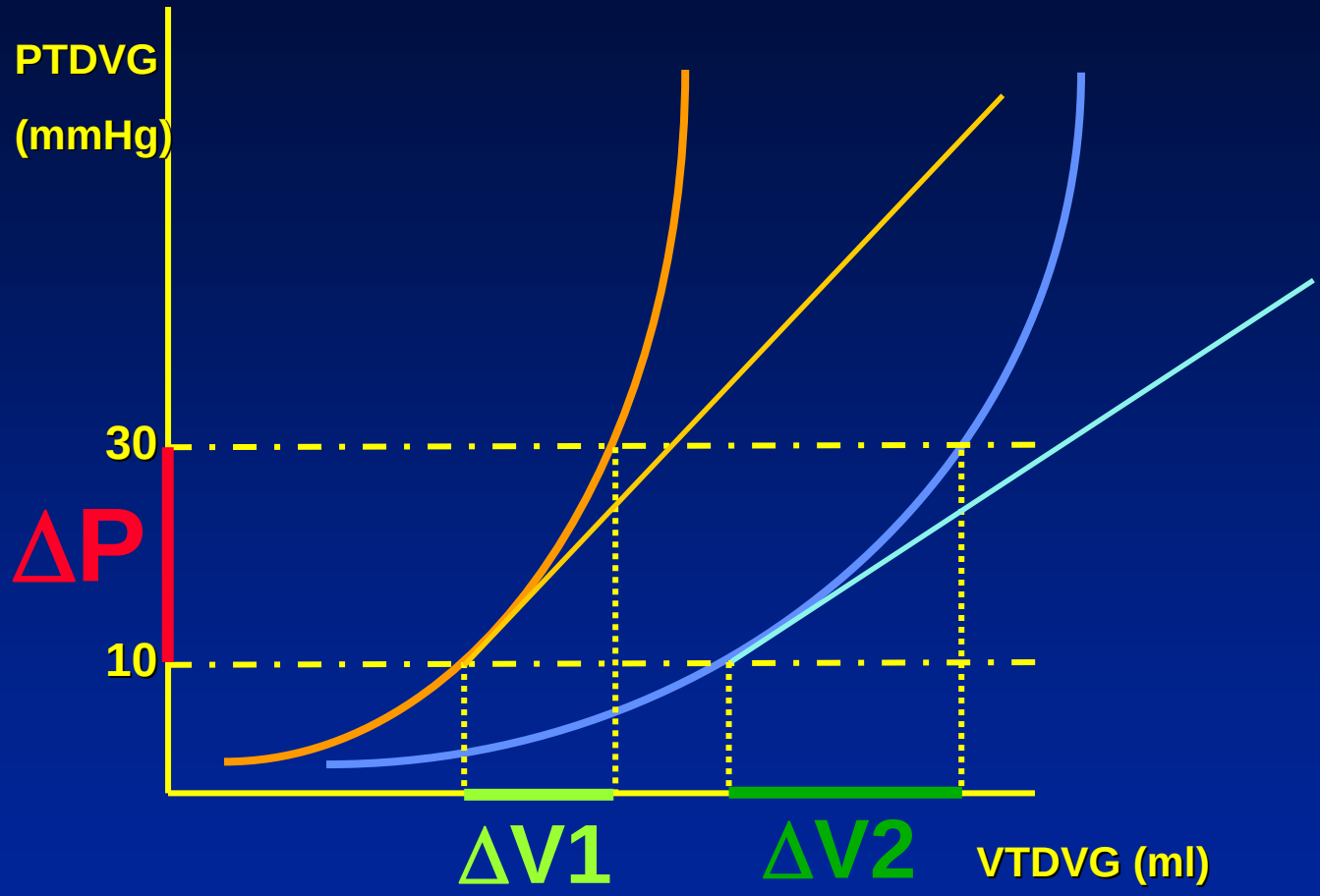

PVG
POG
mmHg
20
10
0
RELAXATION
PROPRIETES PASSIVES
CONTRACTION AURICULAIRE

# Augmentation de la Fréquence Cardiaque




FACTEURS PARIETAUX
Composition du Myocarde
Epaisseur de la Paroi
FACTEURS PHYSICO-CHIMIQUES
Hypoxie
Acidose
Ischémie
PROPRIETES PASSIVES
du
VENTRICULE
FACTEURS EXTRA-PARIETAUX
Interaction Volume des Cavités-Péricarde
Poumons

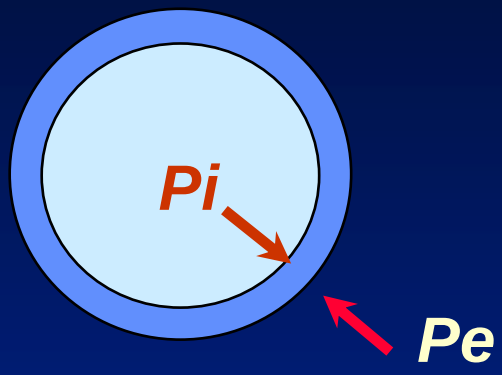
# Compliance/Rigidité ventriculaire

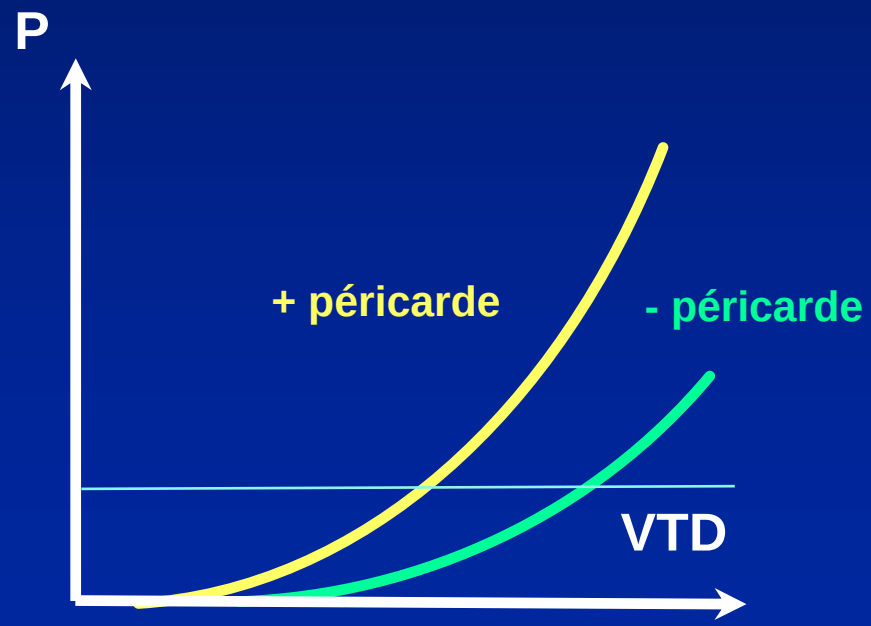



$$R = \Delta P / \Delta V = 1 / C$$

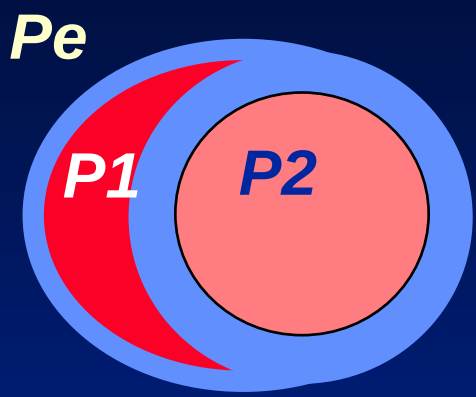
# Précharge

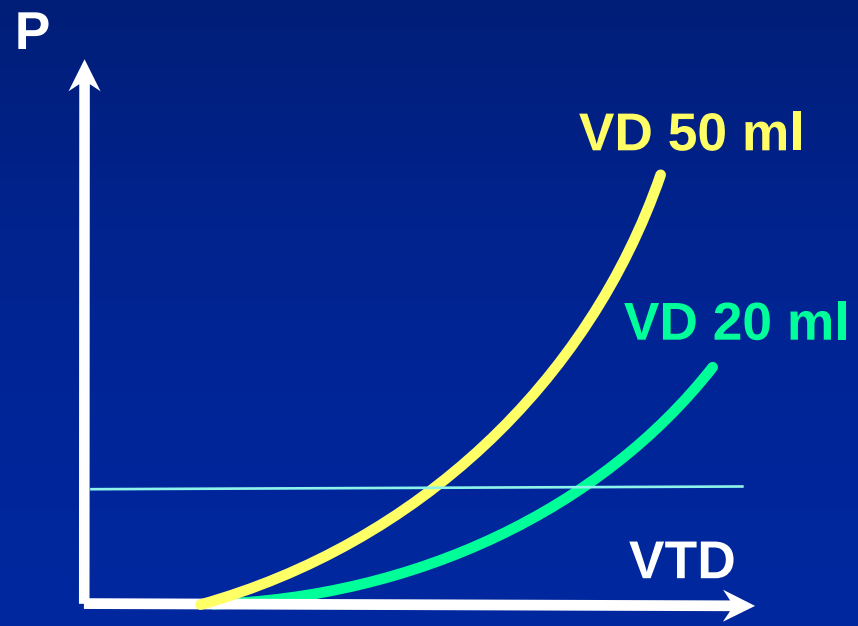
## Rôle du péricarde

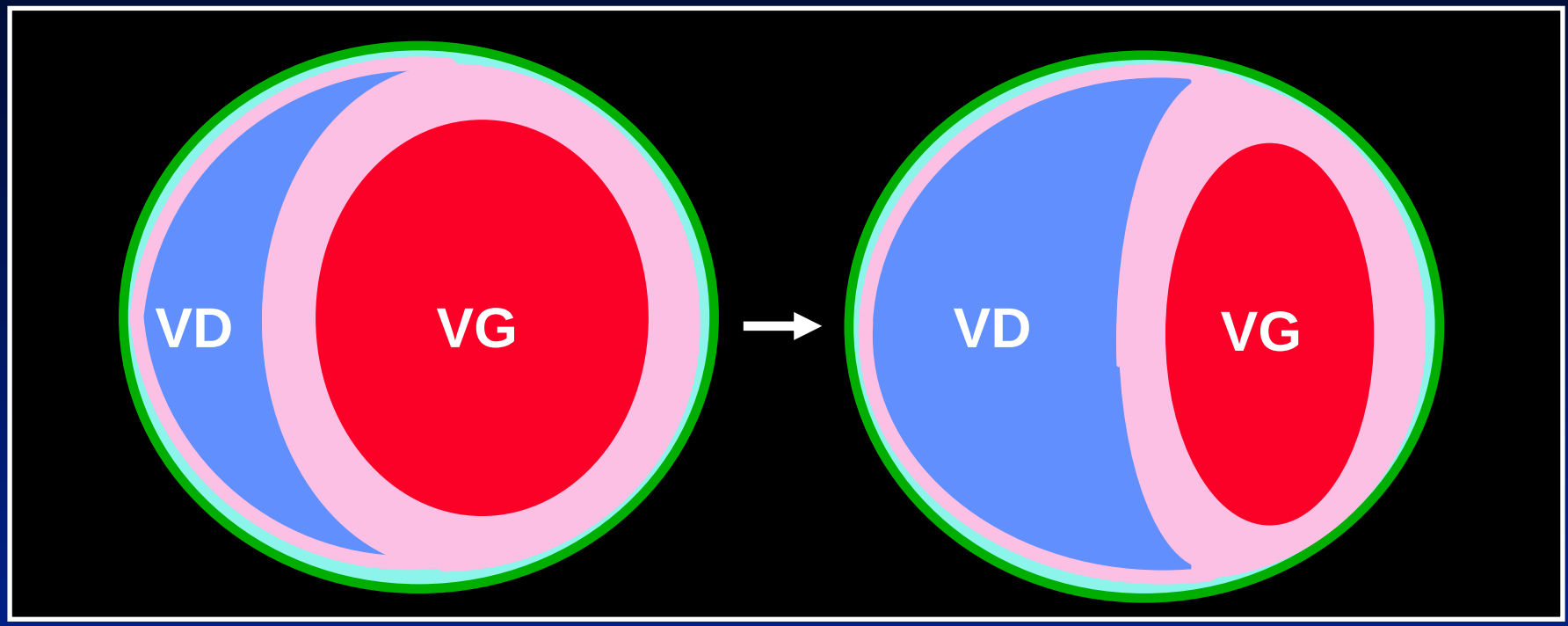


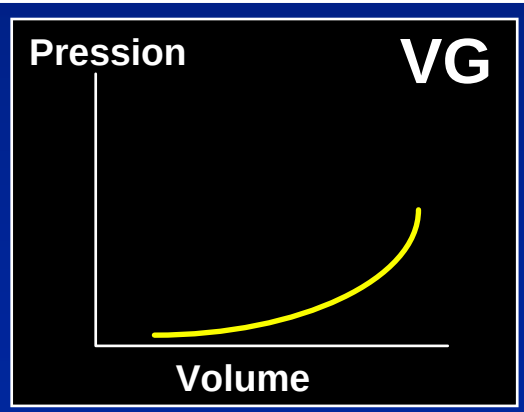



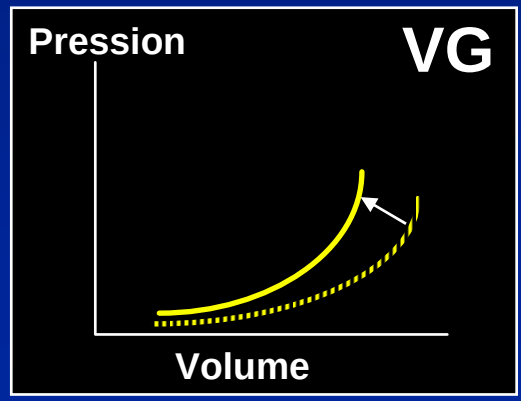

## Interaction VD / VG



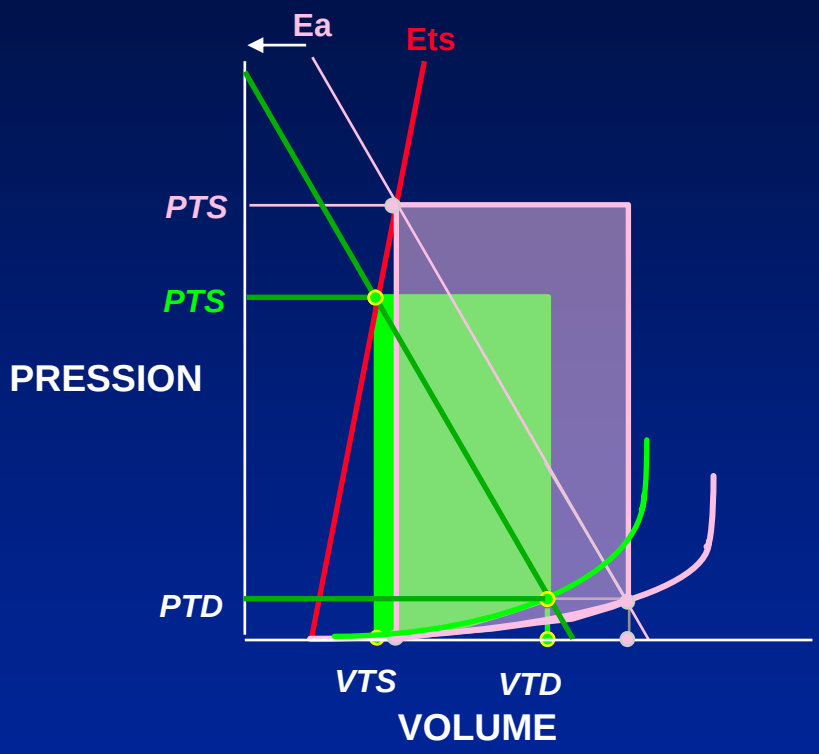




VD
VG
VD
VG

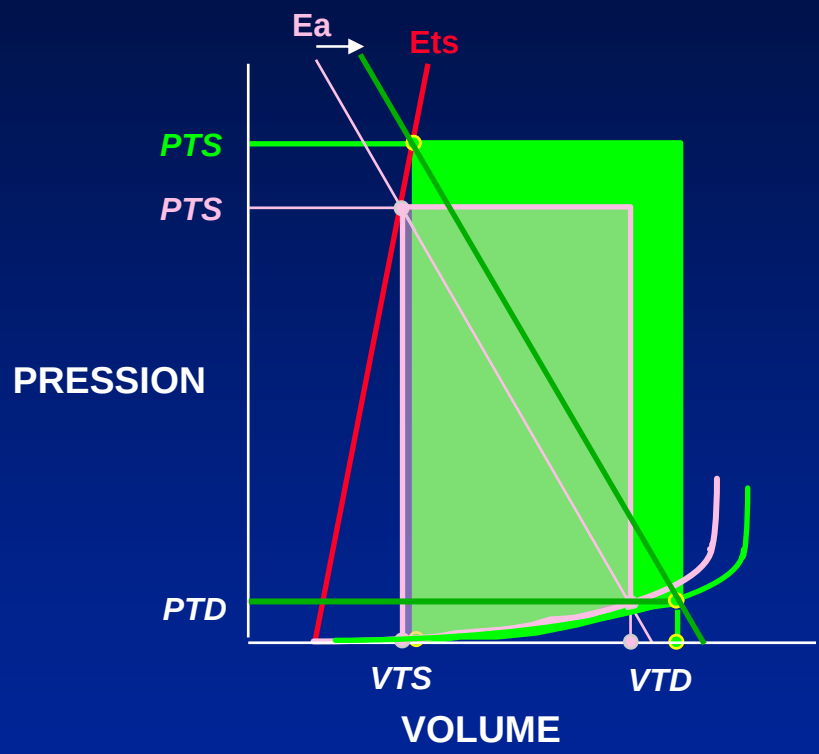

Pression
VG
Volume

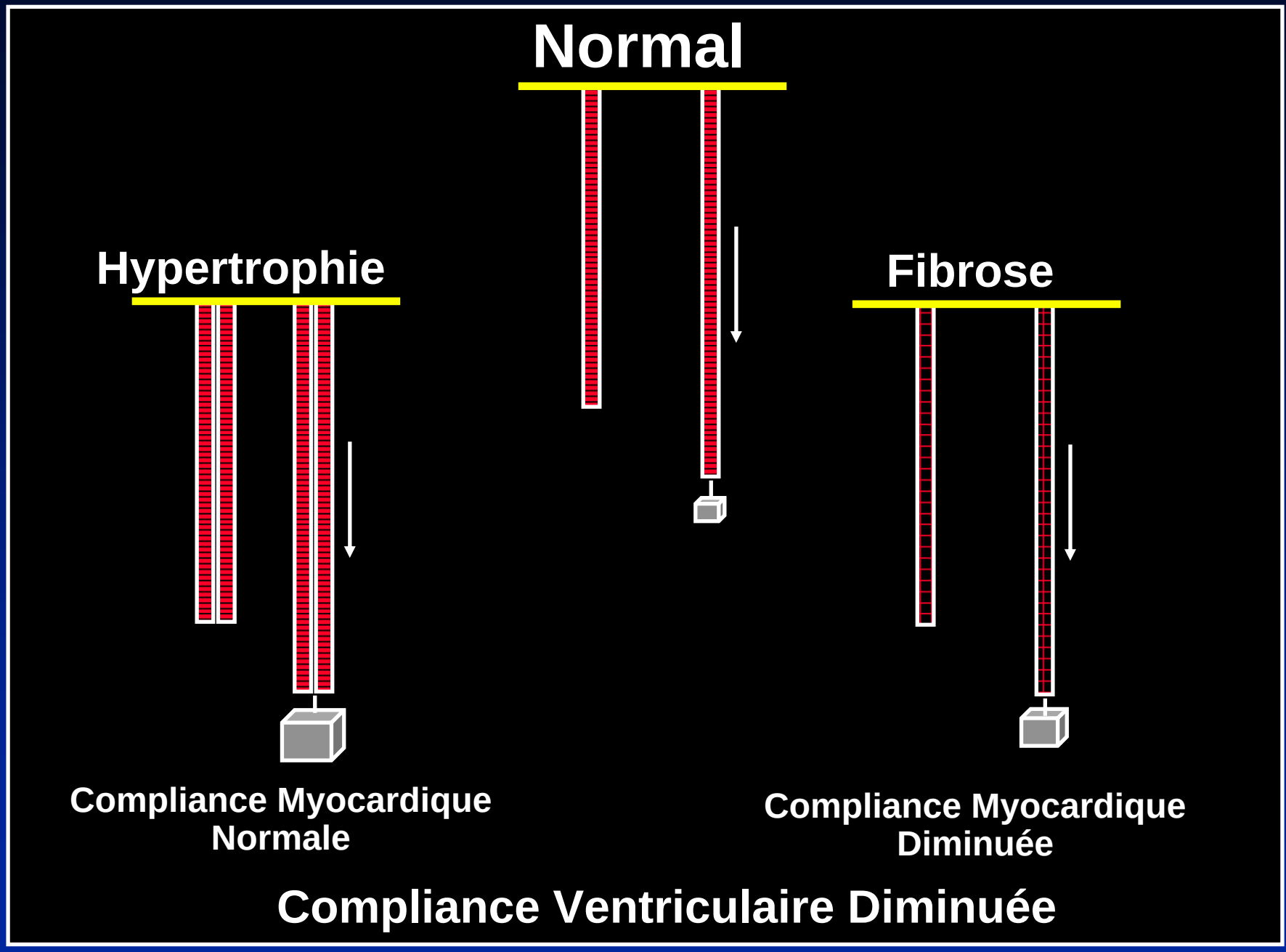

Pression
VG
Volume

## Diminution de Compliance




## Augmentation de Compliance




Normal
Hypertrophie
Fibrose
Compliance Myocardique Normale
Compliance Myocardique Diminuée
Compliance Ventriculaire Diminuée

# Déterminants de la performance ventriculaire

- **Précharge** → longueur initiale des fibres
  - Retour veineux
  - Compliance ventriculaire
- **Postcharge** → résistance à l'éjection
  - Contrainte pariétale
  - Propriétés physiques du système artériel
- **Contractilité** → force pour une L init. donnée
  - Intrinseque
  - extrinseque
- **Effet de le fréquence cardiaque**
  - Relation force/fréquence (« escalier positif »)