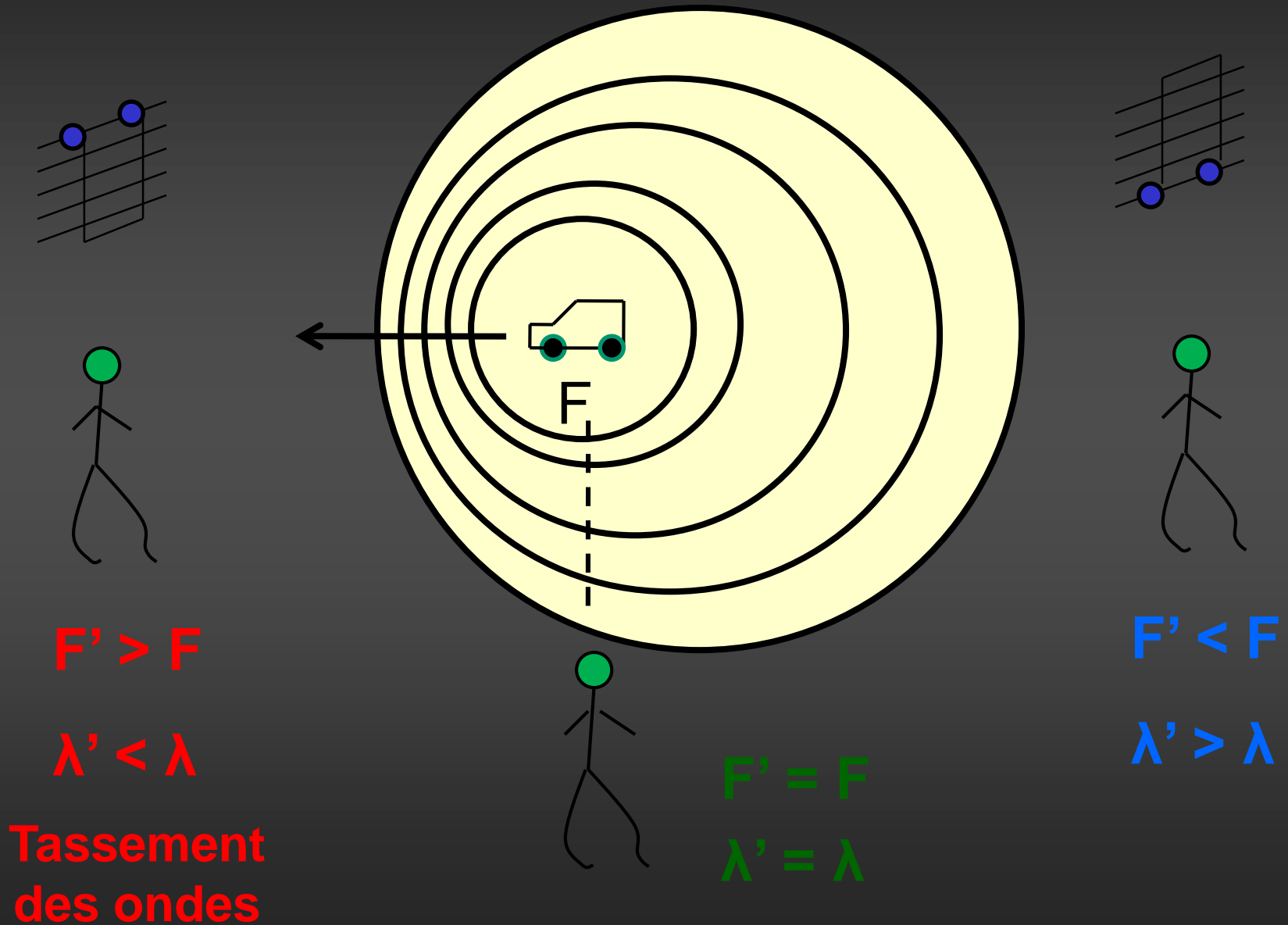


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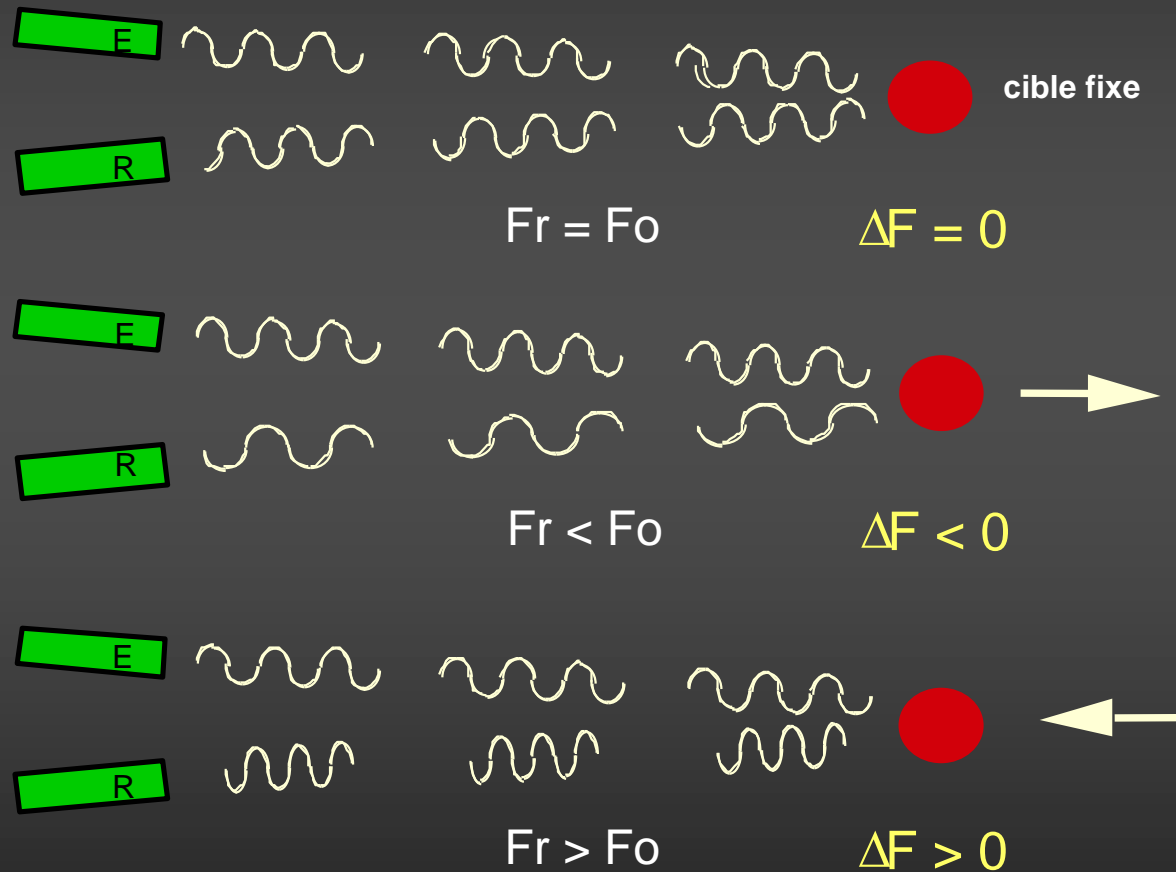
# BASES TECHNIQUES ET PRATIQUES DU DOPPLER

---

# L'effet DOPPLER



# PRINCIPE DE L'EFFET DOPPLER



# RELATION FREQUENCE-VITESSE

---

\* Tir dans l'axe du vaisseau

$$\Delta F = 2V/c \cdot F_0$$

$\Delta F$  : fréquence Doppler mesurée

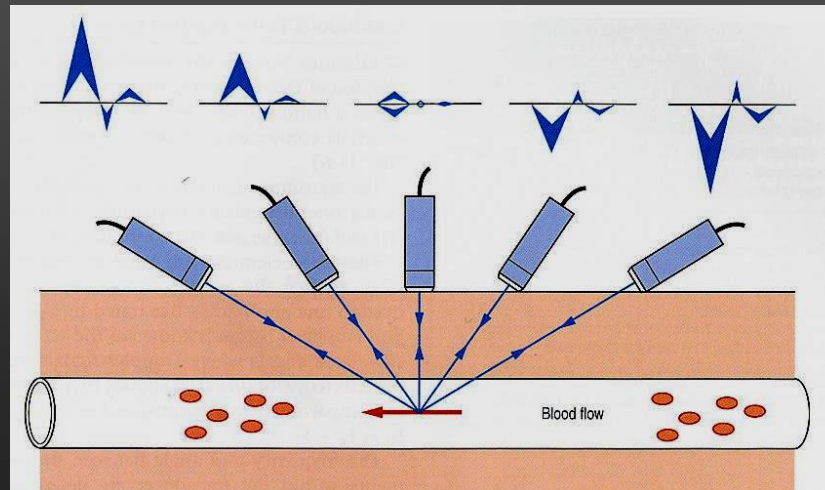
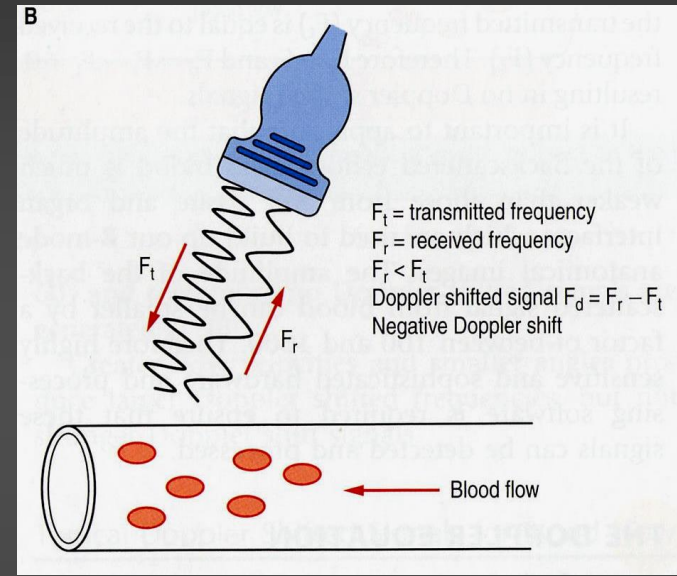
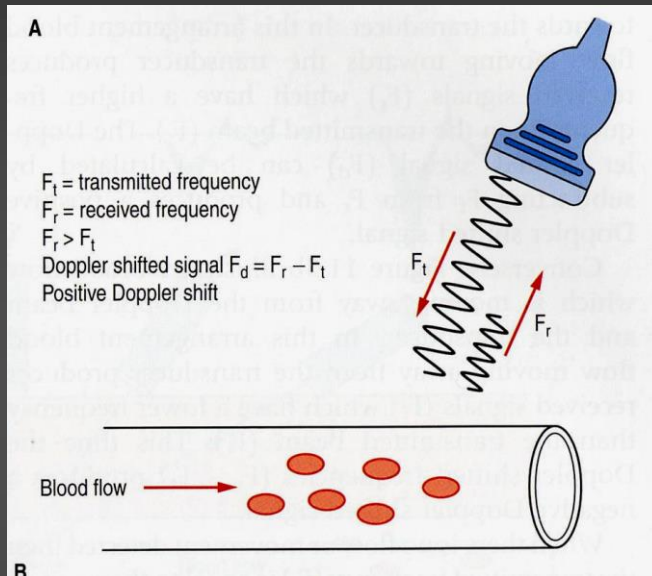
$V$  : vitesse circulatoire

$c$  : vitesse de propagation des US dans les tissus (1540 m/s)

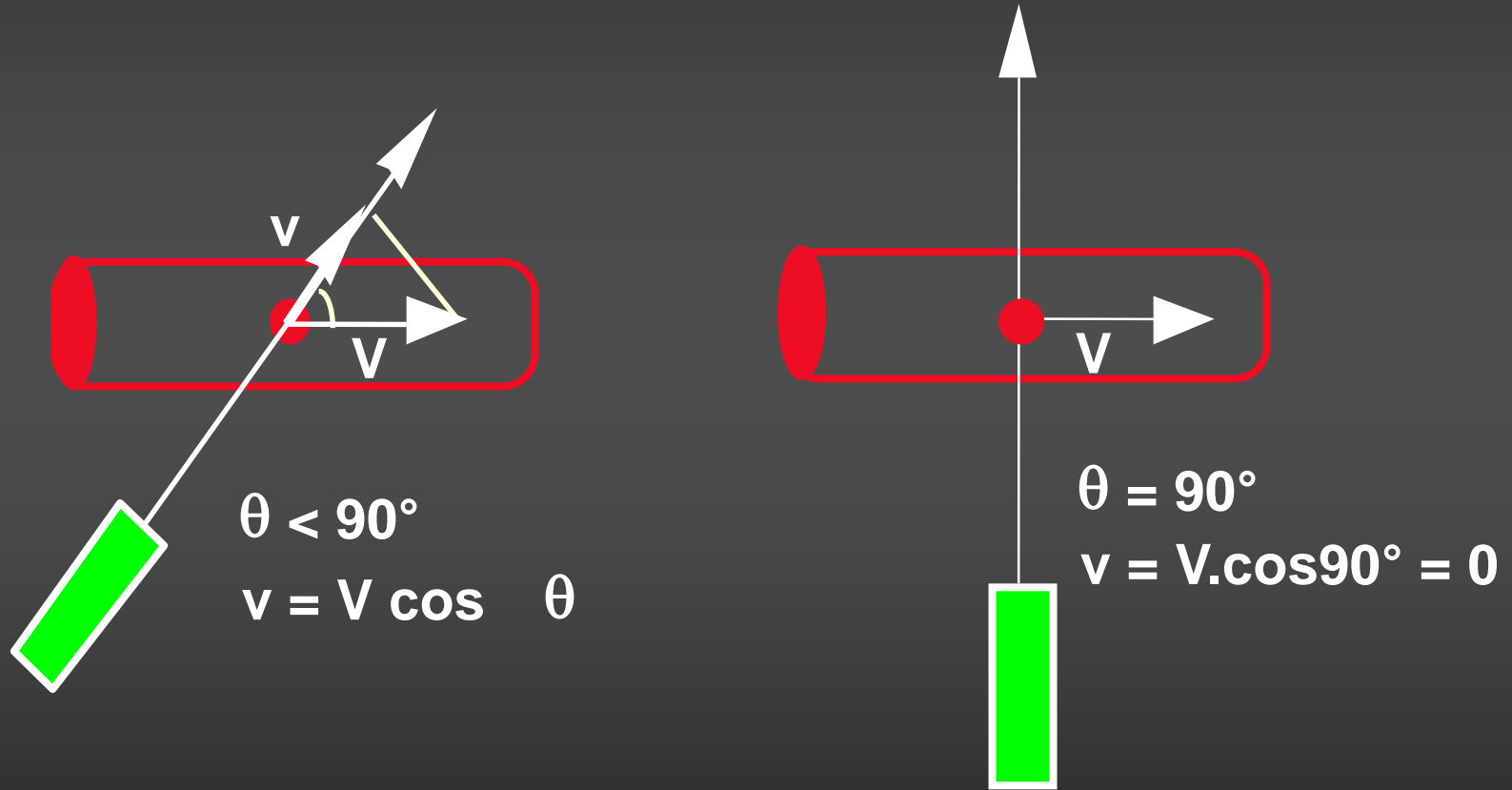
$F_0$  : fréquence d'émission de la sonde

*$\Delta F$  se situe dans la gamme des fréquences audibles*

# PRINCIPE DE L'EFFET DOPPLER



# PRINCIPE DE L'EFFET DOPPLER



# RELATION FREQUENCE-VITESSE

\* Tir désaxé par rapport au vaisseau

$$\Delta F = 2V/c \cdot F_0 \cdot \cos \theta$$

$\Delta F$  : fréquence Doppler mesurée

$V$  : vitesse circulatoire

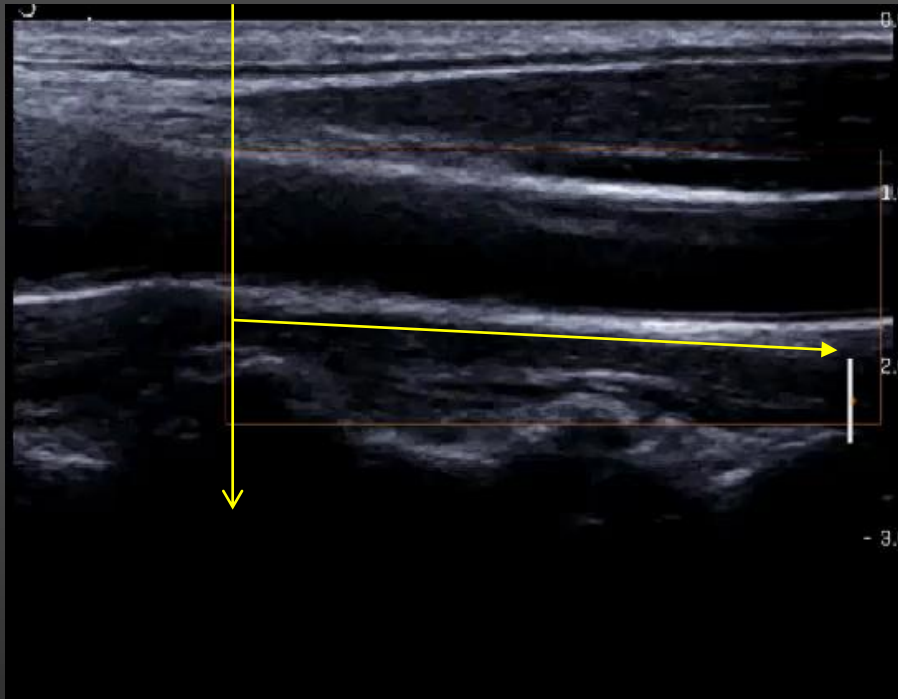
$c$  : vitesse de propagation des US dans les tissus (1540 m/s)

$F_0$  : fréquence d'émission de la sonde

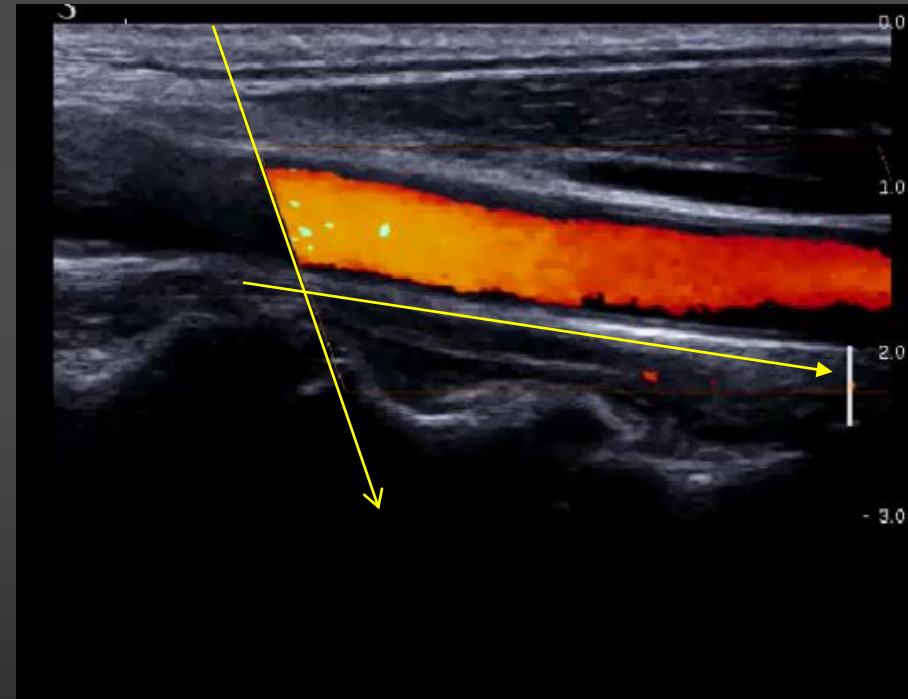
$\theta$  : angle Doppler

*Seule la direction du vaisseau n'est pas connue par le système*

# OPTIMISATION DE L'ANGLE DOPPLER



ACI avec angle doppler proche de  $90^\circ$



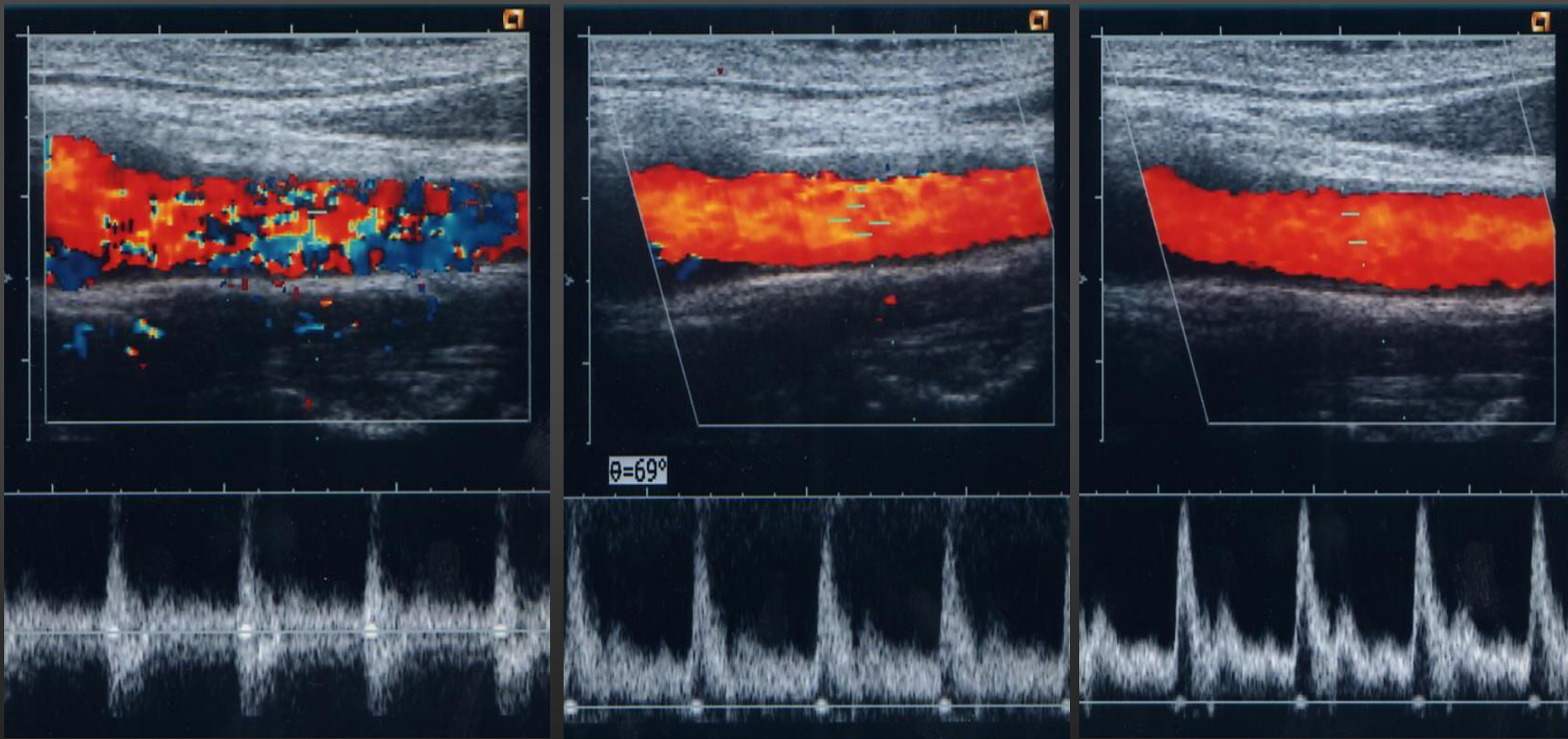
ACI avec angle doppler proche de  $60^\circ$



# OPTIMISATION DE L'ANGLE DOPPLER

Obtenir un bon signal impose une optimisation de l'angle doppler (si possible  $<60^\circ$ ):

- par inclinaison manuelle de la sonde
- par inclinaison électronique
- par les deux



# Conversion fréquence - vitesse

Cette conversion n'est indispensable que lorsqu'une mesure de vitesse ou de débit est nécessaire

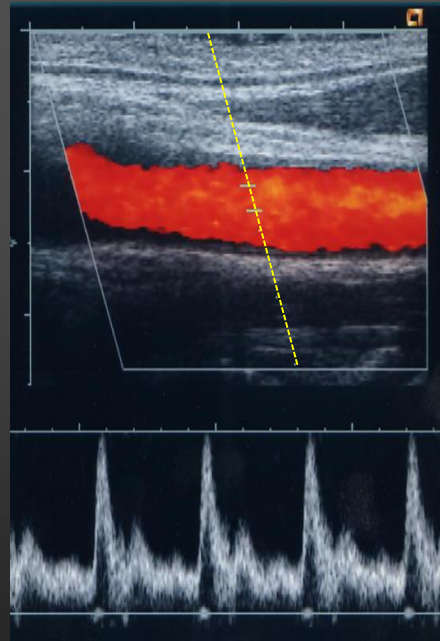
Angle $\theta$	$0^\circ$	$10^\circ$	$20^\circ$	$30^\circ$	$40^\circ$	$50^\circ$	$60^\circ$	$70^\circ$	$80^\circ$	$90^\circ$
Cos $\theta$	1	0,98	0,94	0,87	0,77	0,64	0,50	0,34	0,17	0
Erreur relative (%)		4	6,3	11,5	17	22	32	47	100	

# Conversion fréquence - vitesse

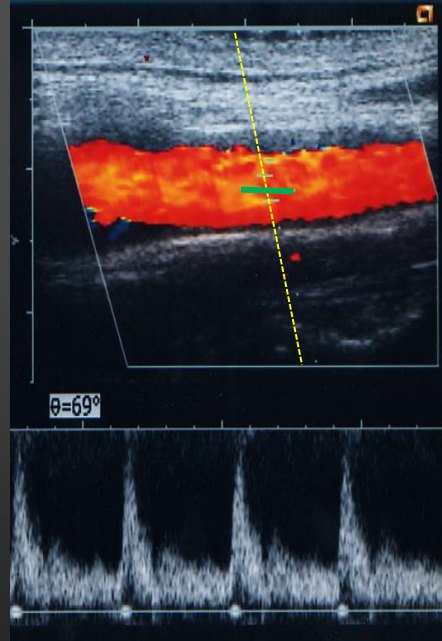
Toute mesure de vitesse ou de débit impose :

- une optimisation de l'angle doppler (si possible  $< 40^\circ$ )
- et une correction de l'angle doppler : en plaçant le caliper électronique dans l'axe du vaisseau

Pas de correction d'angle



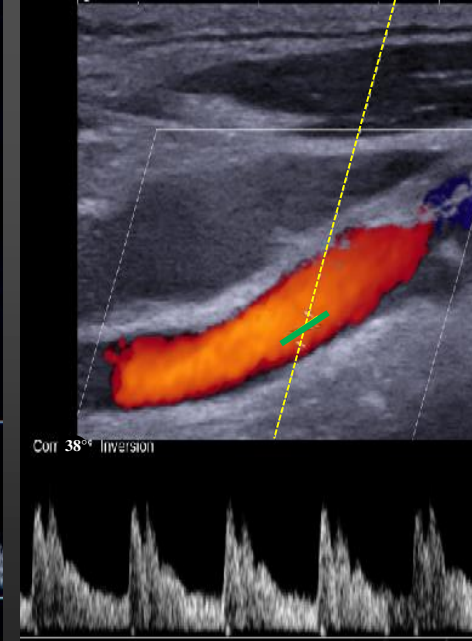
Correction d'angle mais angle sous-optimal



Correction d'angle mais angle presque optimal



Correction d'angle et angle optimal

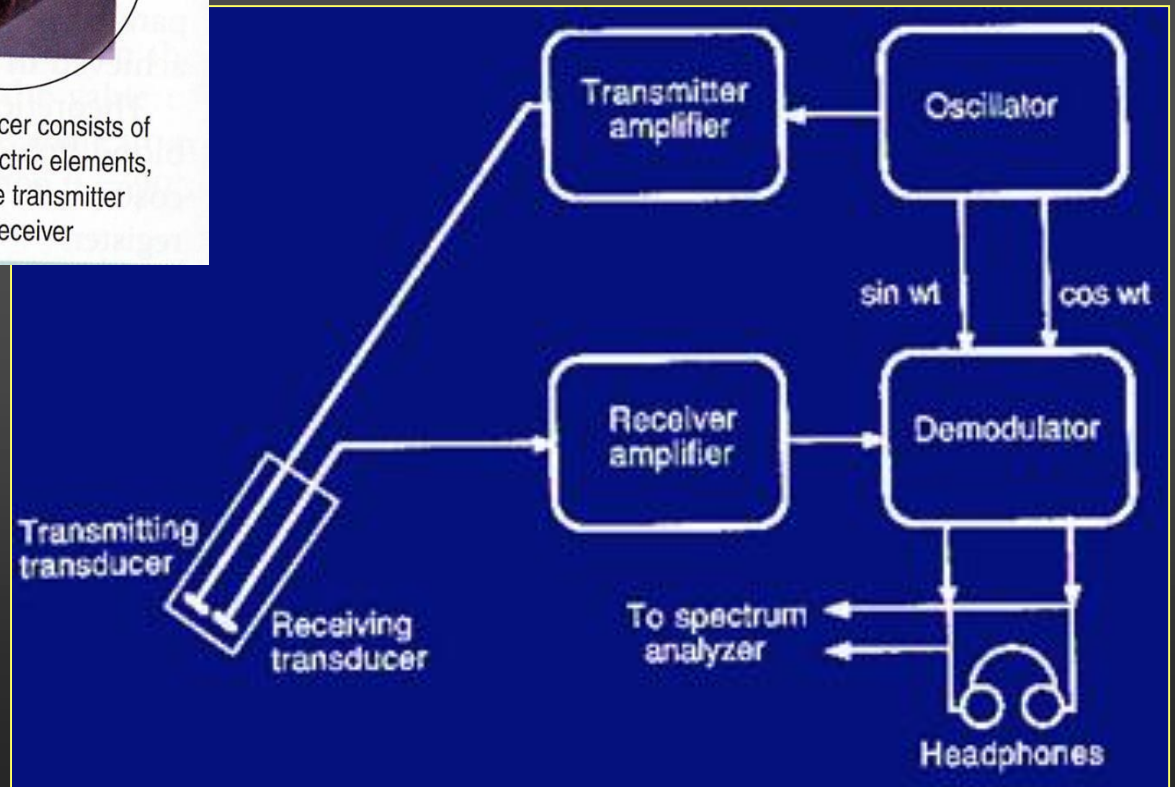
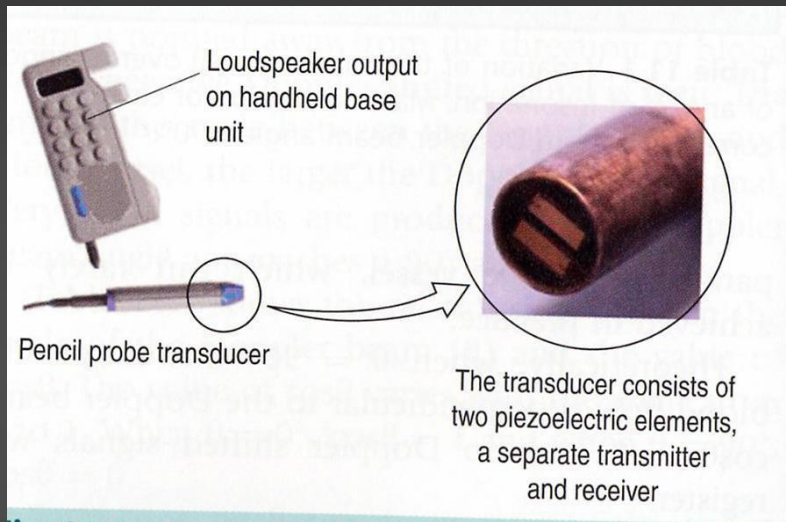


# MODES D'ACQUISITION DOPPLER

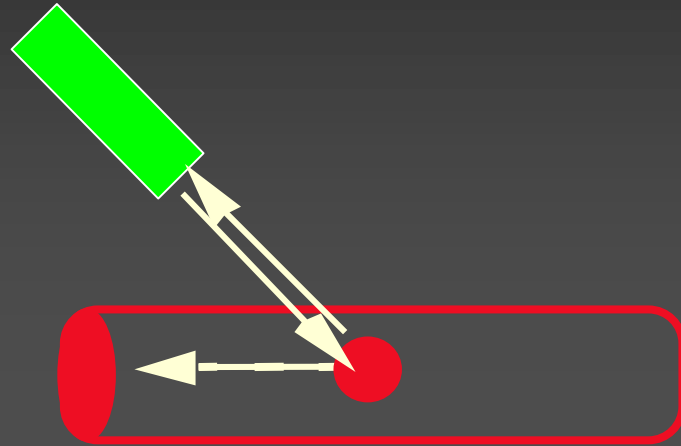
---

- Le Doppler continu
- Le Doppler pulsé
- Le Doppler couleur :
  - mode fréquentiel
  - mode énergie ou puissance

# DOPPLER CONTINU



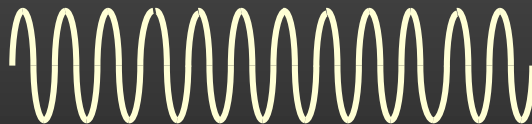
# DOPPLER CONTINUU



$F_0$



$F_r$

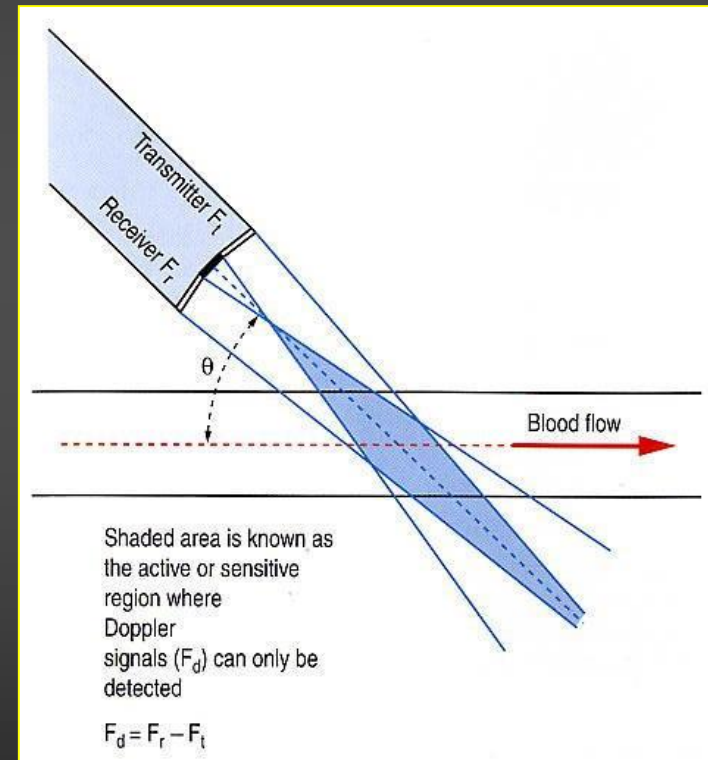


$\Delta F$

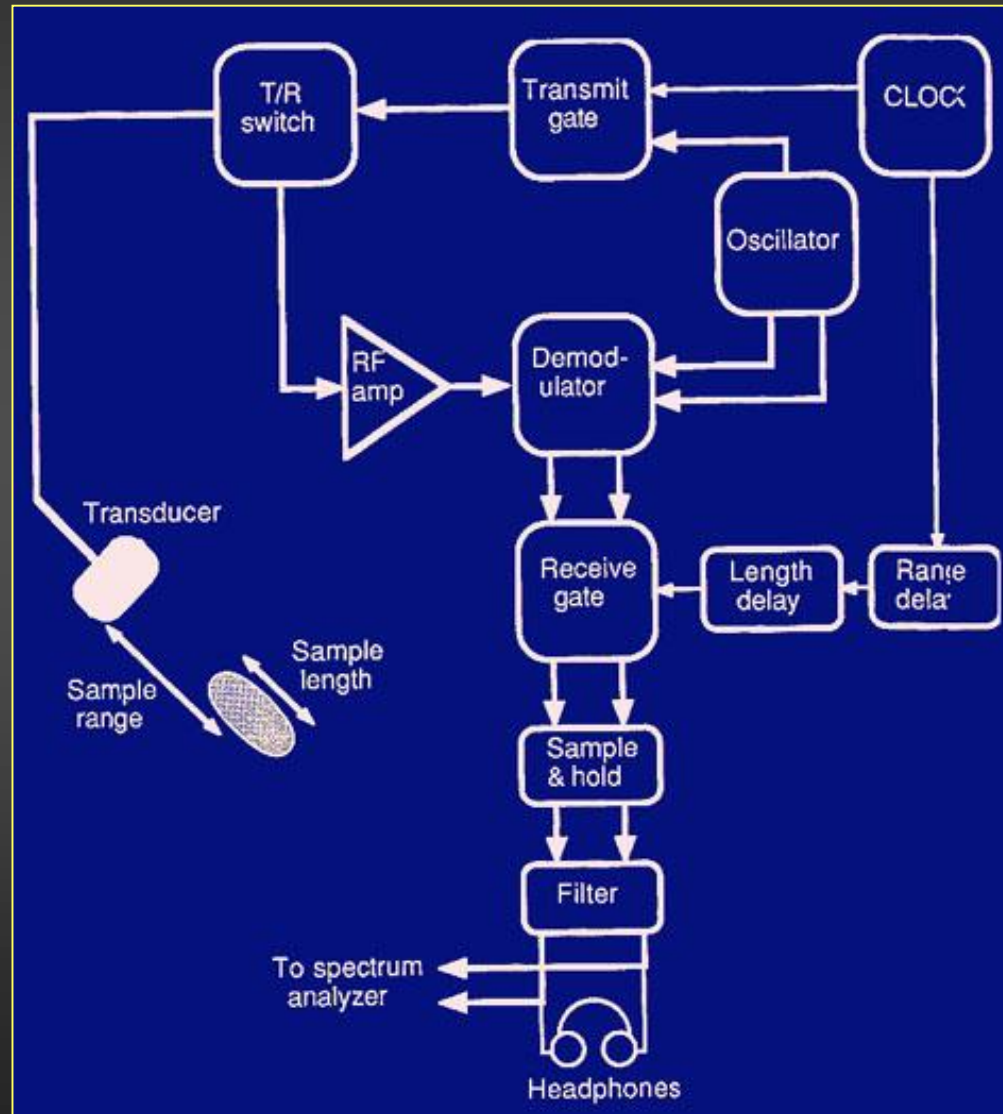


# DOPPLER CONTINU

- Avantages :
  - simple
  - pas cher
  - très sensible
  - aucune limitation de quantification de fréquences
- Inconvénients :
  - pas de focalisation en profondeur

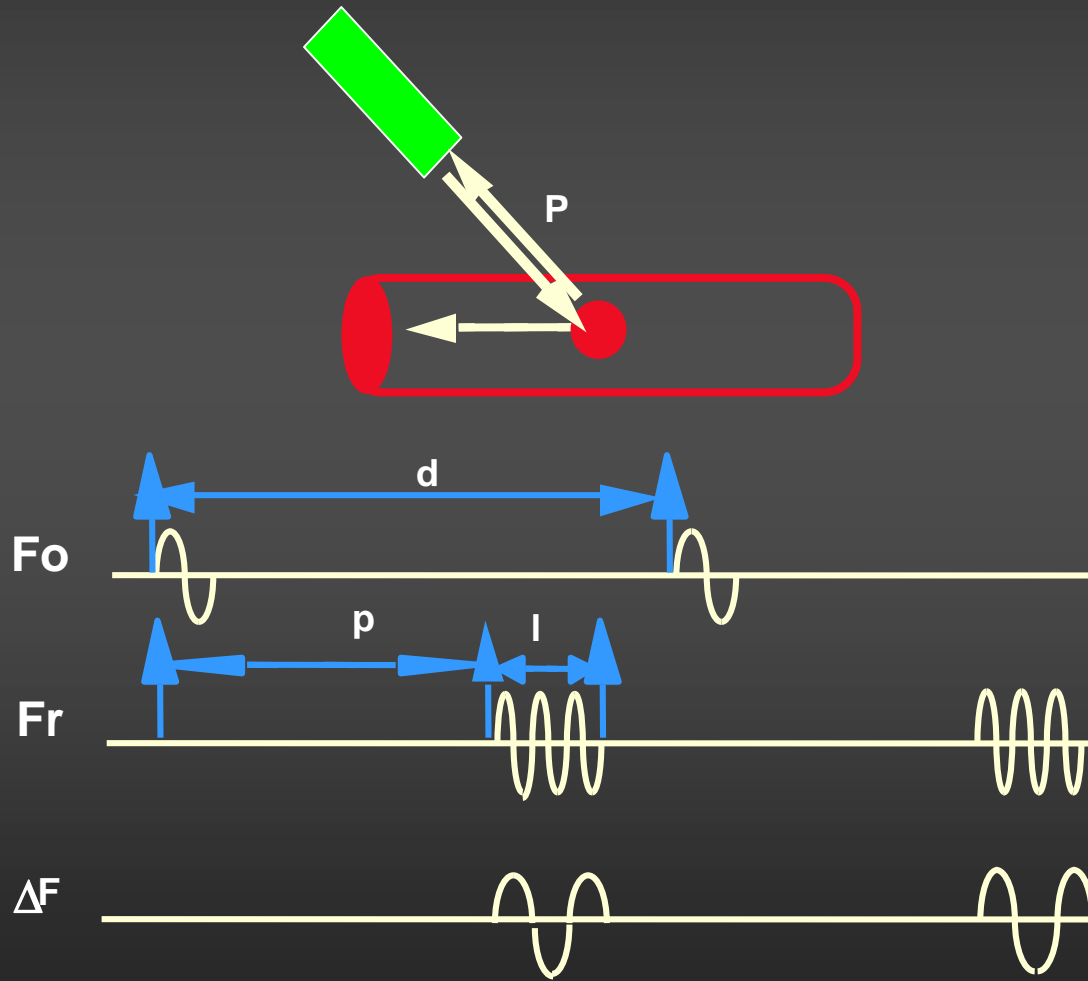


# DOPPLER PULSE



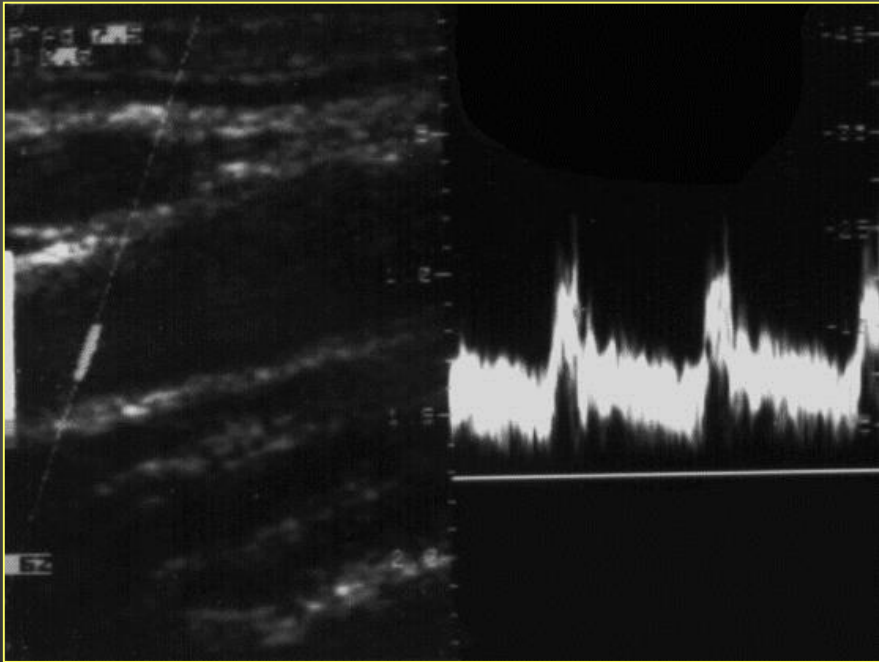


# DOPPLER PULSE

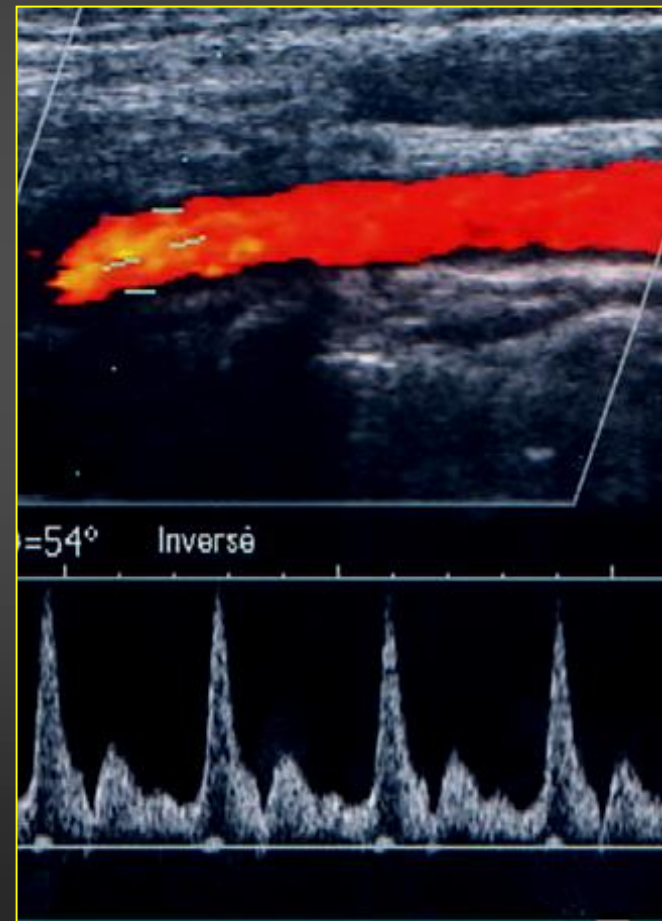


# DOPPLER PULSE

Mode duplex



Mode triplex

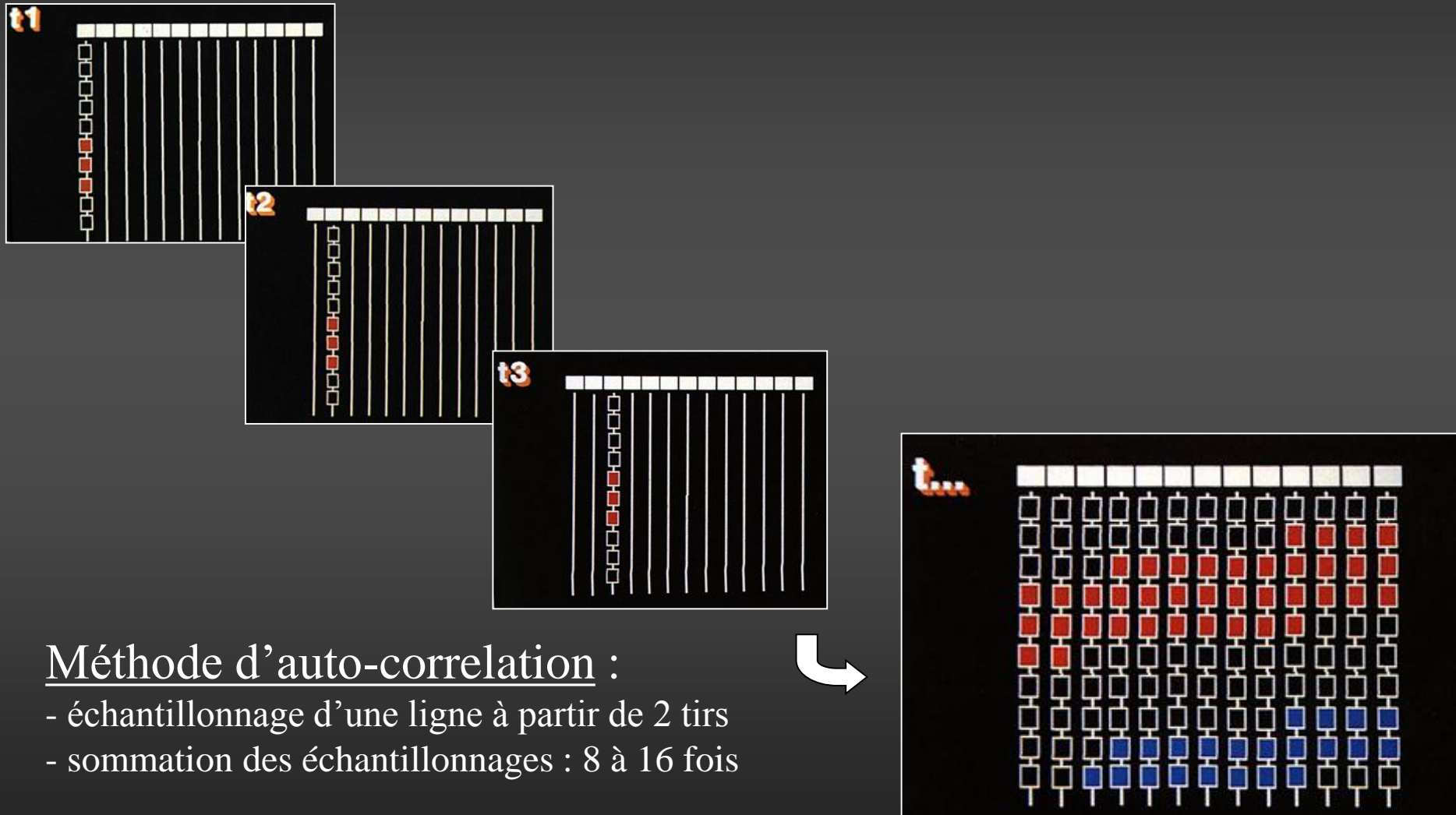


# DOPPLER PULSE

---

- Avantages :
  - permet de choisir la profondeur d'exploration
- Inconvénients :
  - ambiguïté fréquentielle: limitation de quantification de fréquences élevées
  - ambiguïté spatiale
  - dépôt d'énergie

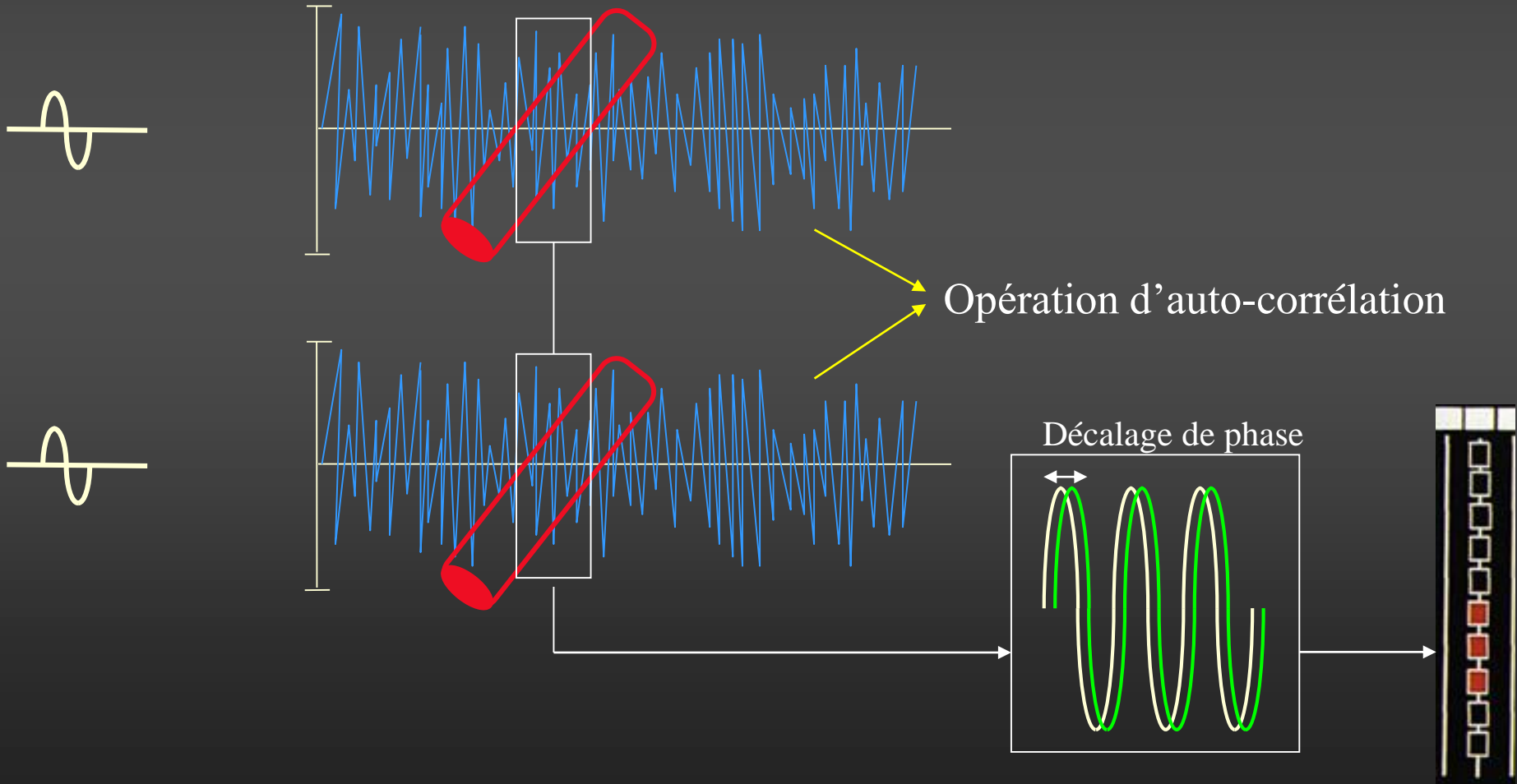
# DOPPLER COULEUR



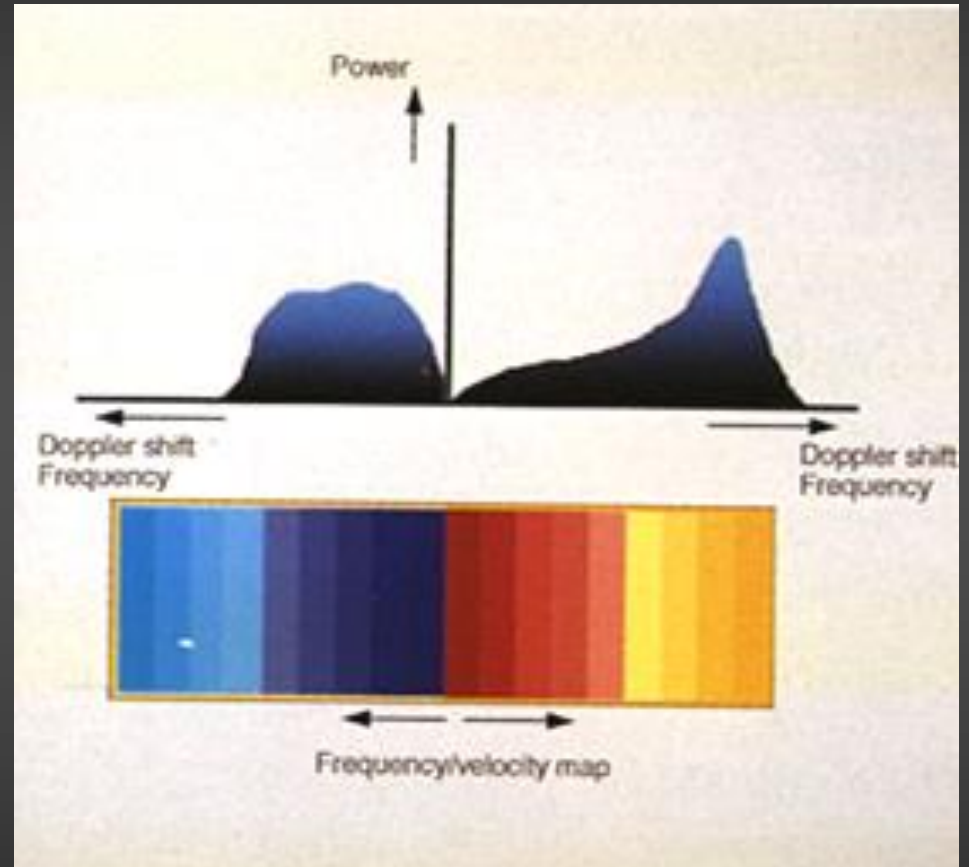
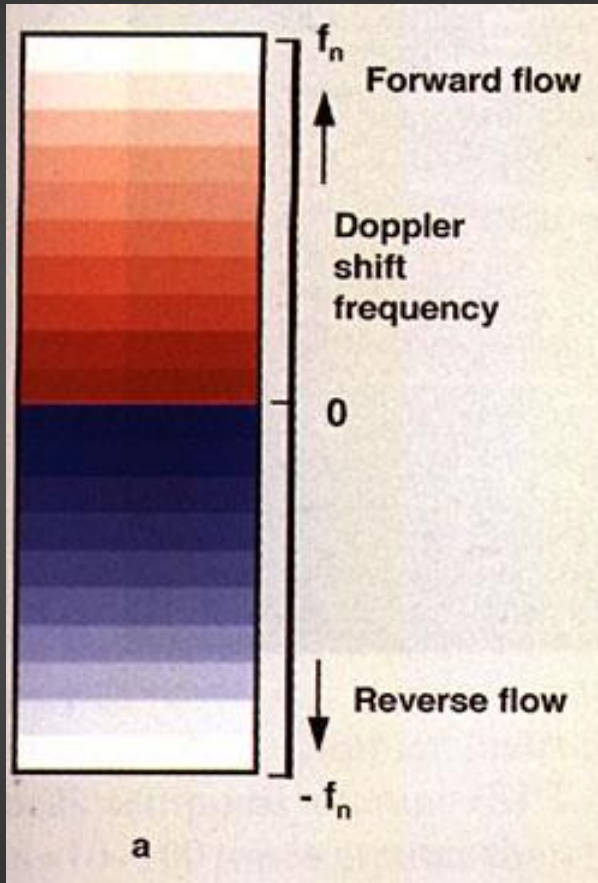
# DOPPLER COULEUR

émission

réception

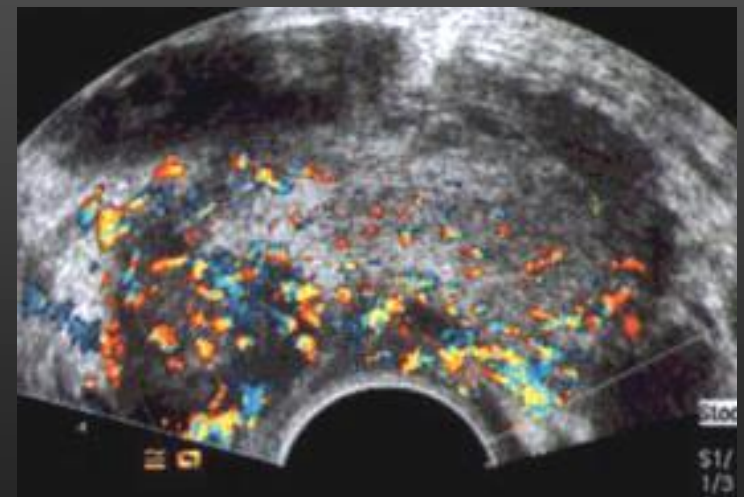
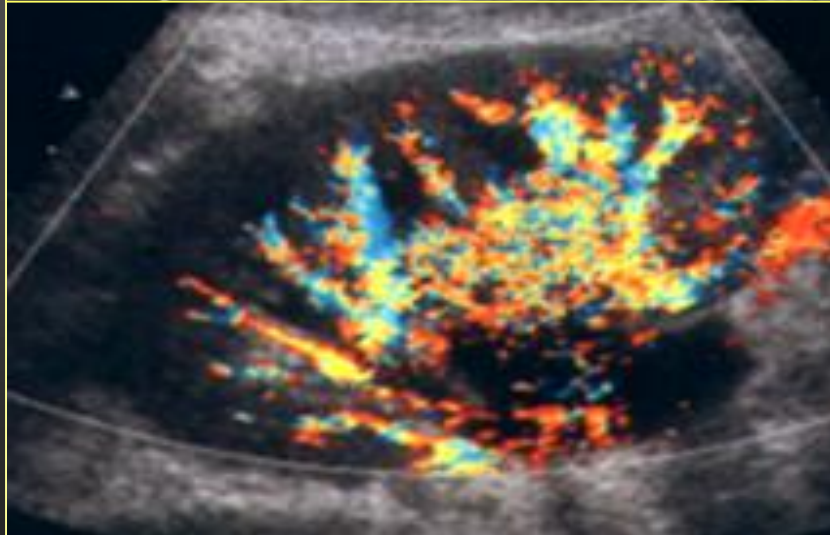
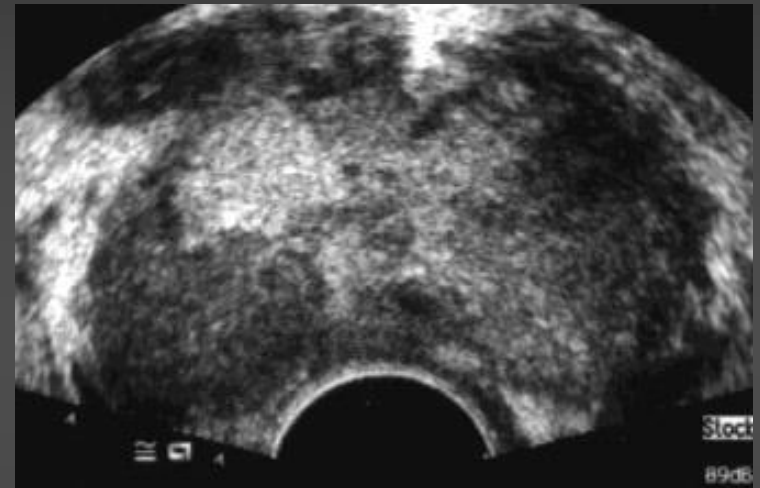
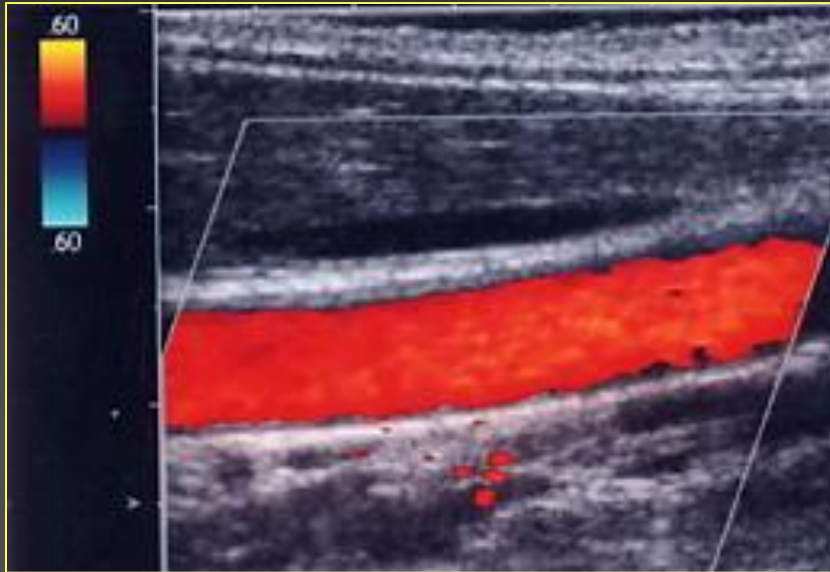


# DOPPLER COULEUR



Au sein de chaque voxel couleur : on extrait une valeur de fréquence moyenne et de sa variance

# DOPPLER COULEUR



# DOPPLER PULSE : rôle de la PRF

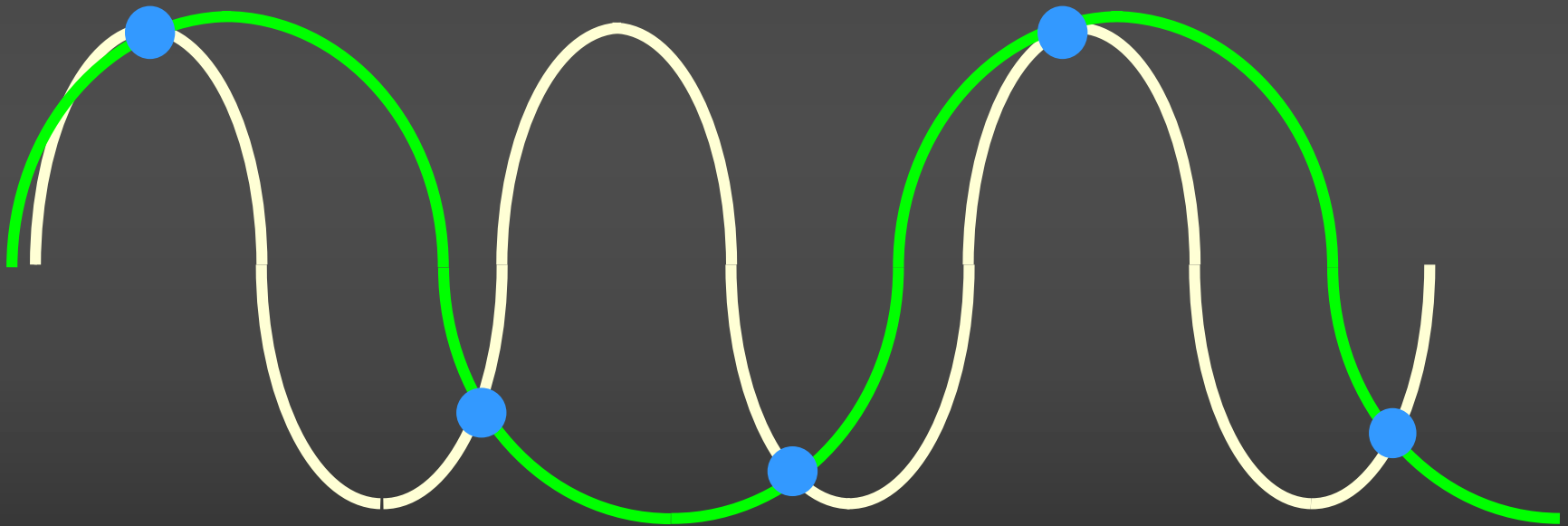
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- PRF et sensibilité au flux :  
une PRF élevée ne permet pas de détecter les flux lents; pour détecter les flux lents, la PRF doit être basse
- PRF et quantification des fréquences élevées :  
pour quantifier les fréquences élevées, la PRF doit être élevée (au moins le double de la fréquence Doppler)
- PRF et profondeur d'exploration :  
la PRF maximale accessible est d'autant plus basse que le volume d'échantillonnage est profond



# AMBIGUITE FREQUENTIELLE

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# AMBIGUITE FREQUENTIELLE

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- Théorème de Shannon :

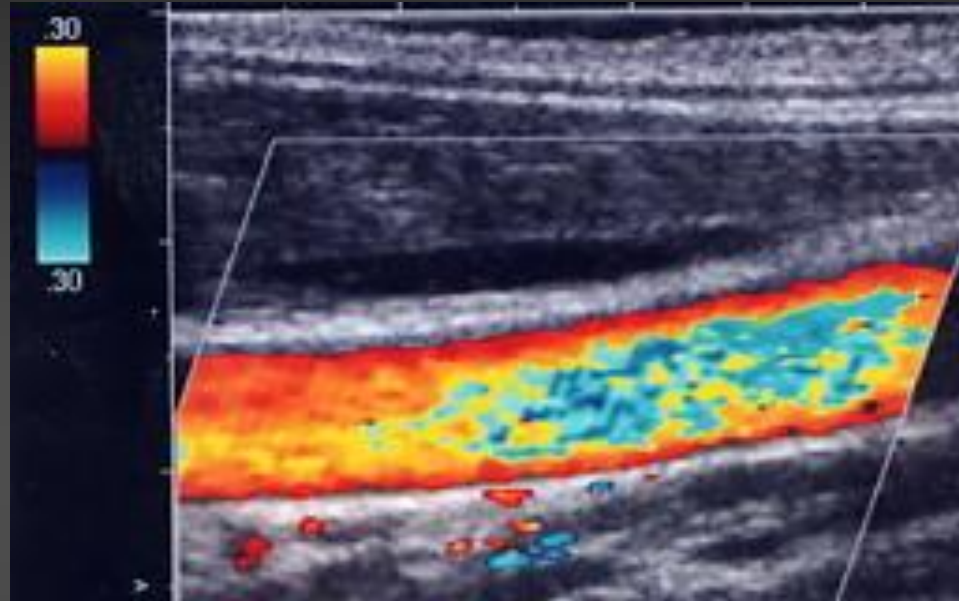
*« pour échantillonner sans ambiguïté un signal fréquentiel, la fréquence d'échantillonnage (PRF) doit être au moins égale au double de celle du signal »*

$$PRF = 2 \cdot \Delta F$$

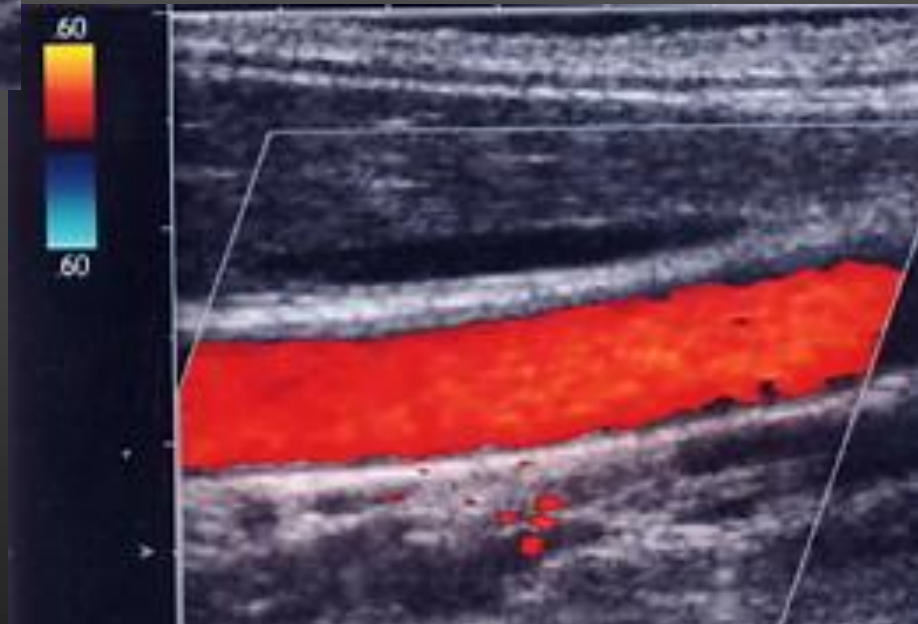
- Fréquence de Nyquist :

*« fréquence maximale échantillonnable, ie la moitié de la PRF »*

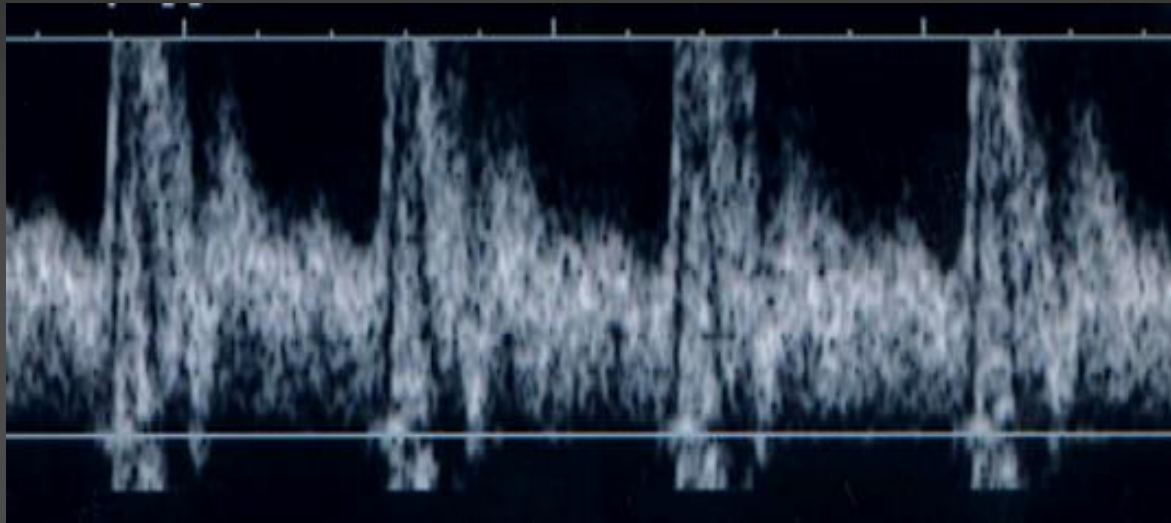
# PHENOMENE D'ALIASING



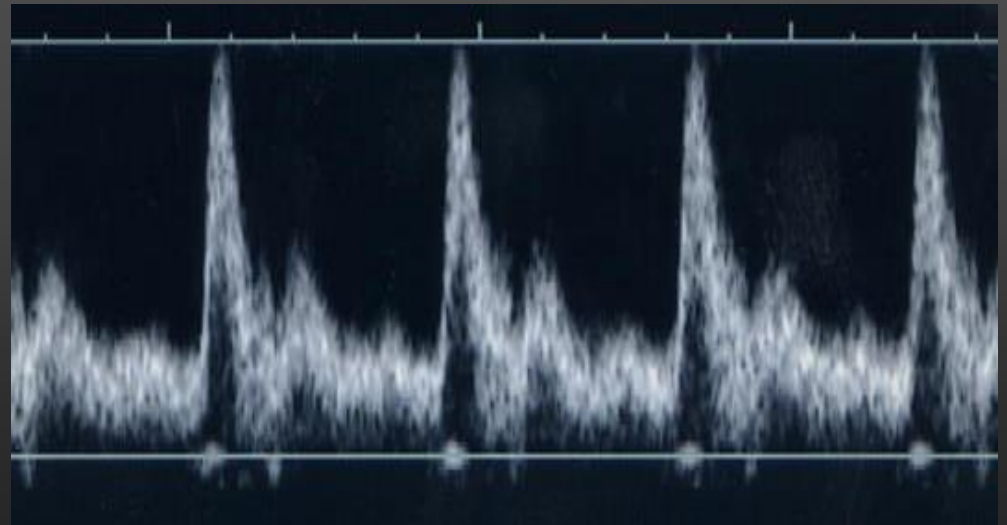
- Effet de la PRF



# PHENOMENE D'ALIASING



- Effet de la PRF



# PHENOMENE D'ALIASING

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- Solutions :
  - augmenter la PRF (ou l'échelle de vitesse)
  - diminuer la profondeur de la fenêtre couleur
  - diminuer  $F_0$
  - passer en Doppler continu

# PHENOMENE D'ALIASING

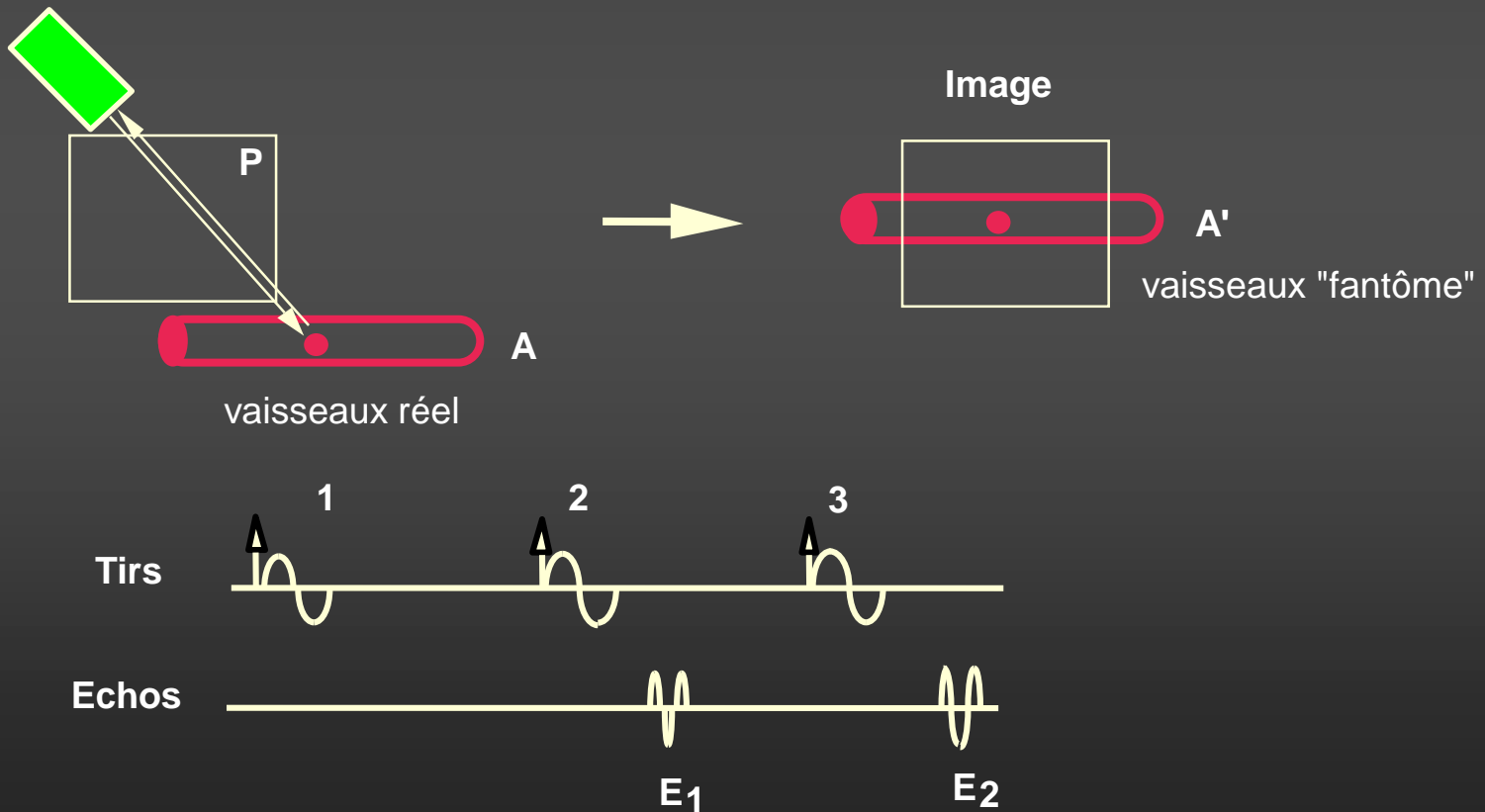
- Effet de la profondeur sur la PRF



Plus on augmente la profondeur de la fenêtre couleur, plus la PRF maximale diminue

# AMBIGUITE SPATIALE

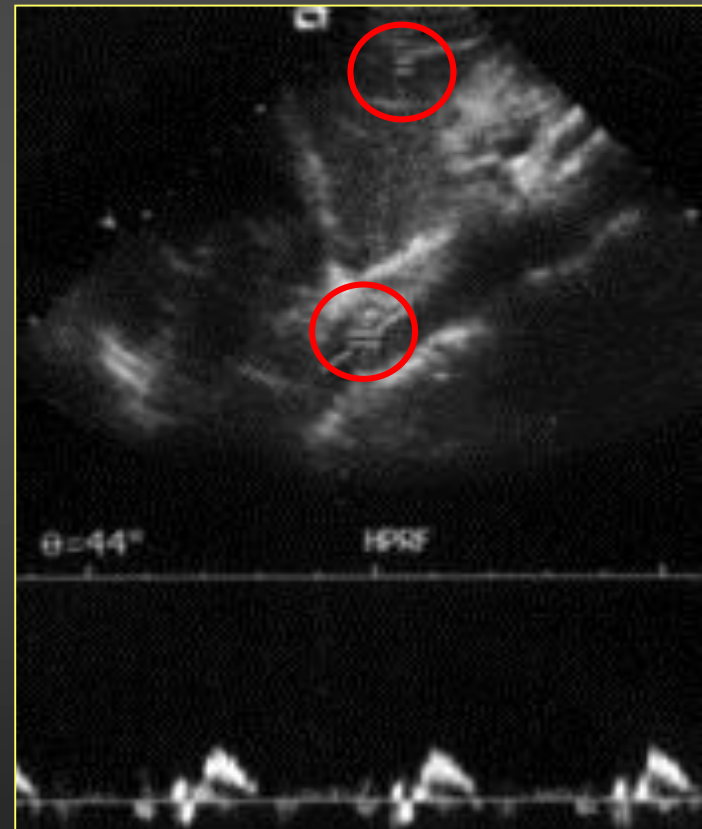
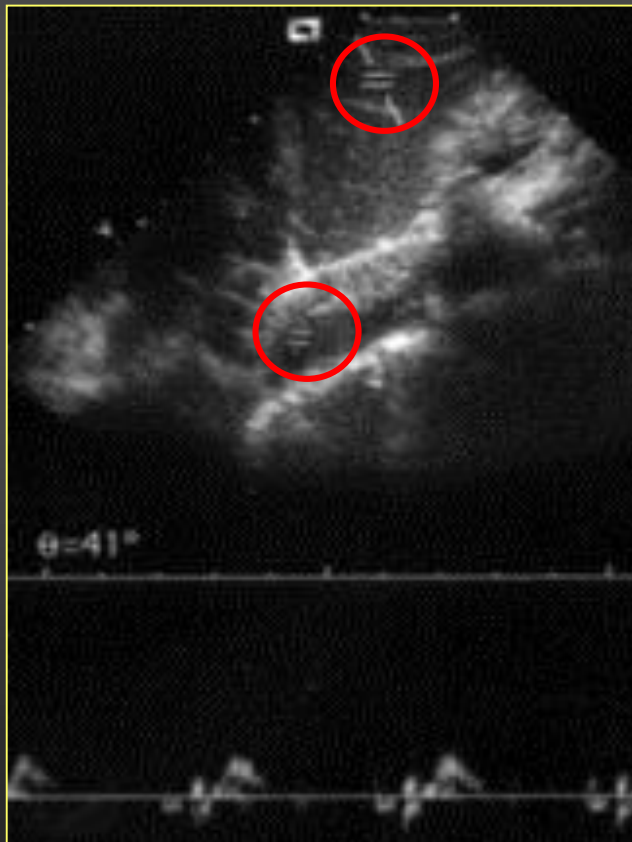
Apparaît lorsqu'on utilise un champ proximal avec une PRF très élevée :  
L'écho du vaisseau, situé « hors champ » arrive à la sonde après le 2<sup>ème</sup> tir



# AMBIGUITE SPATIALE

Lorsqu'on utilise une PRF très élevée en doppler pulsé, apparaissent parfois 2 volumes d'échantillonnage au lieu d'1 :

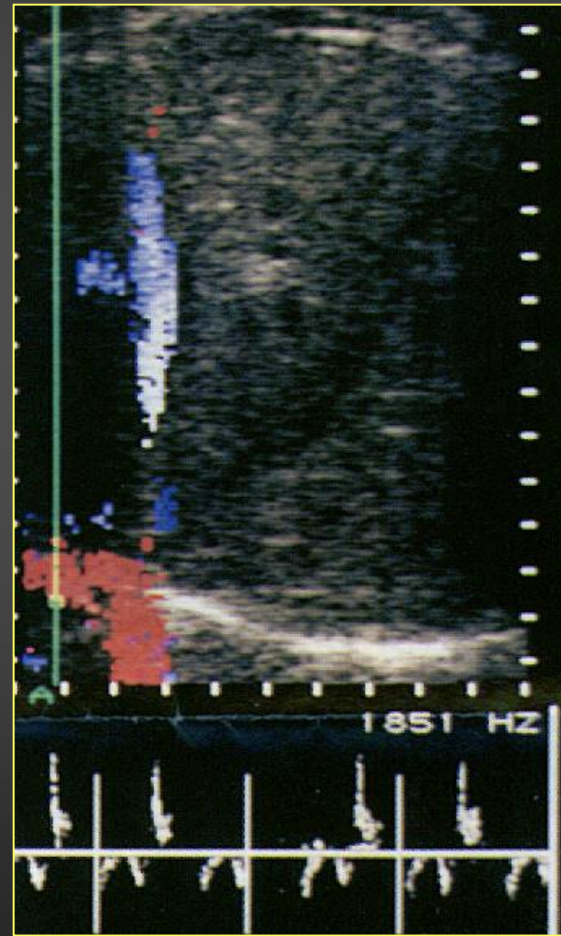
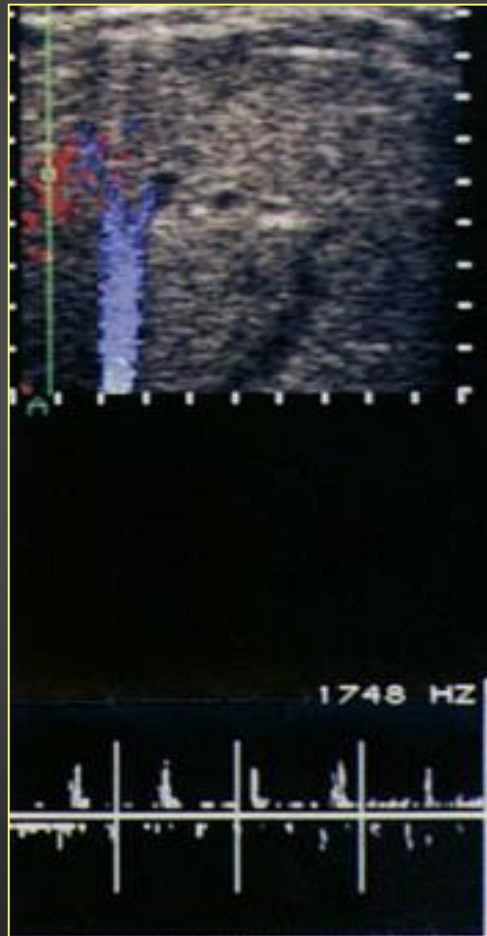
Le signal obtenu dans le volume proximal correspond au signal du volume distal





# AMBIGUITE SPATIALE

Signal rouge  
artefactuel car champ  
proximal avec PRF  
élevée



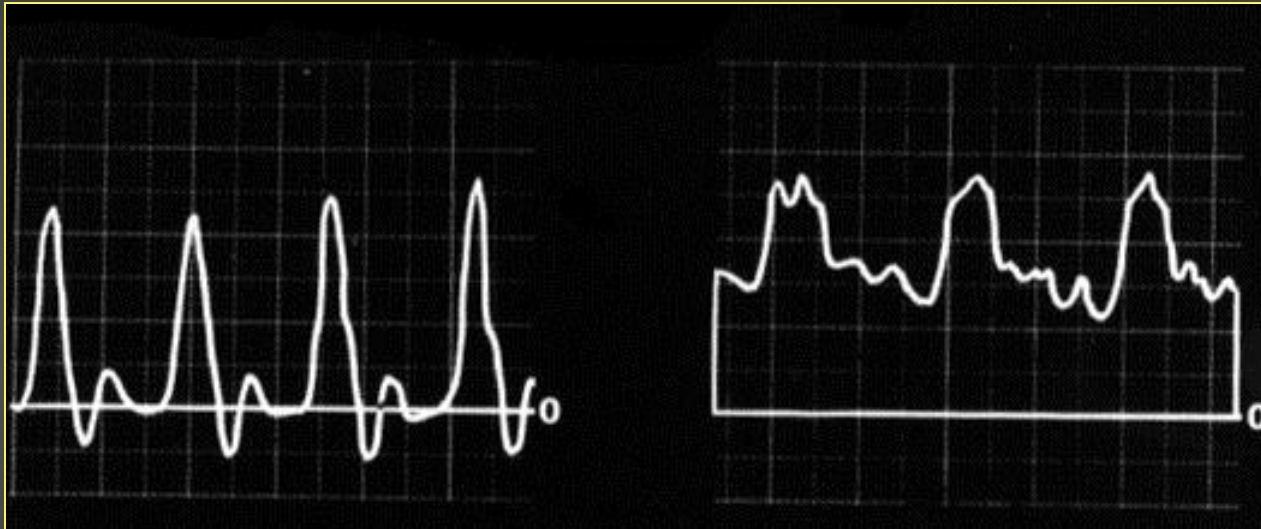
Correspond en fait au  
signal de la VCI qui  
disparaît en élevant la  
PRF

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# ANALYSE DU SIGNAL DOPPLER

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# TRACE ANALOGIQUE

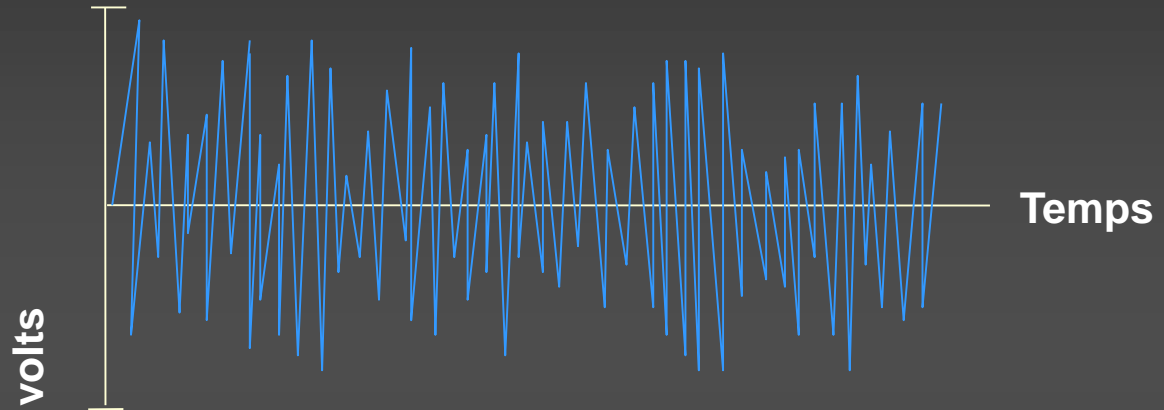


- *Informe sur le type de modulation systolo-diastolique du flux, mais pas sur le profil de l'écoulement*
- *Ne permet pas de caractériser les anomalies*

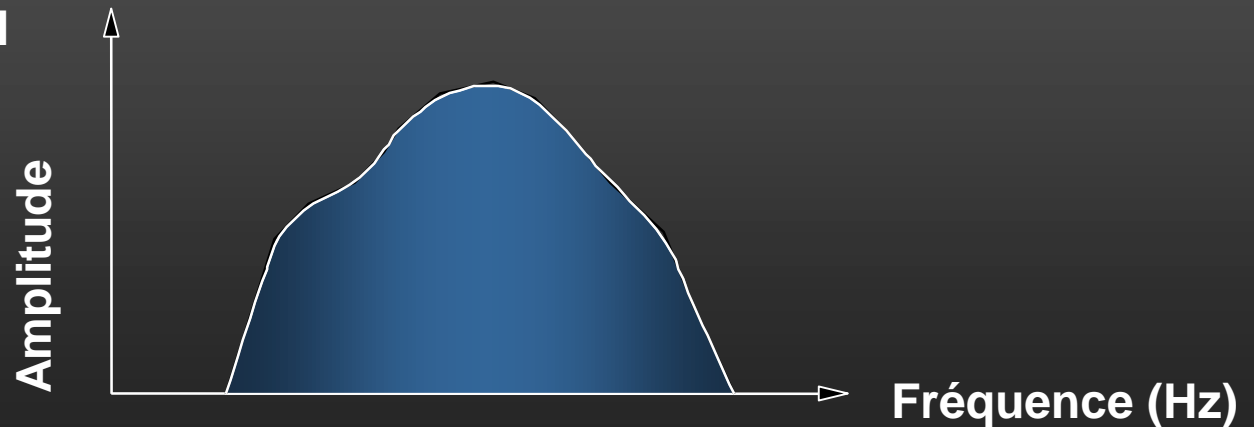
# LE SPECTRE DE FREQUENCES

**Domaine temporel**

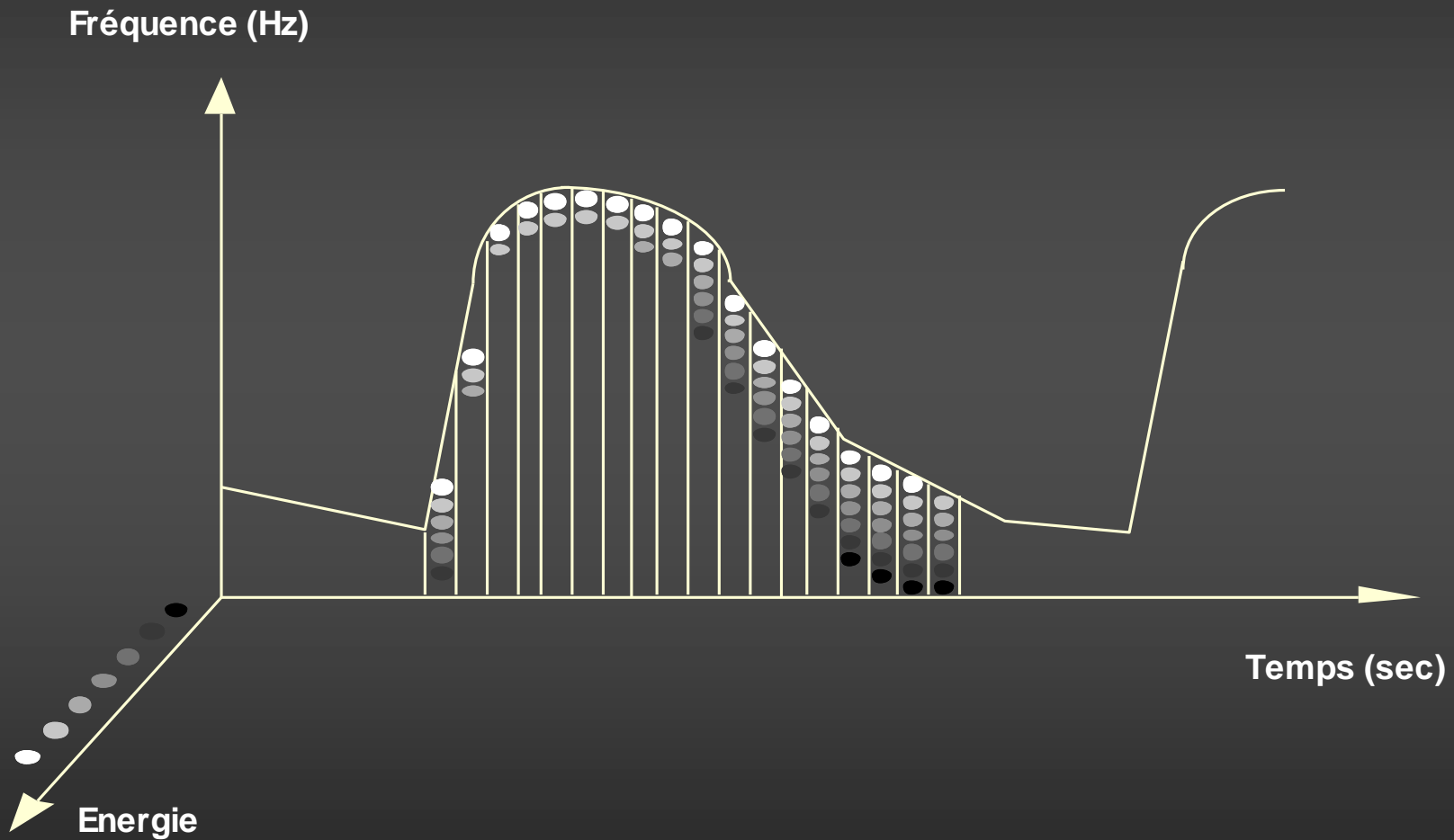
*transformation  
de Fourier*



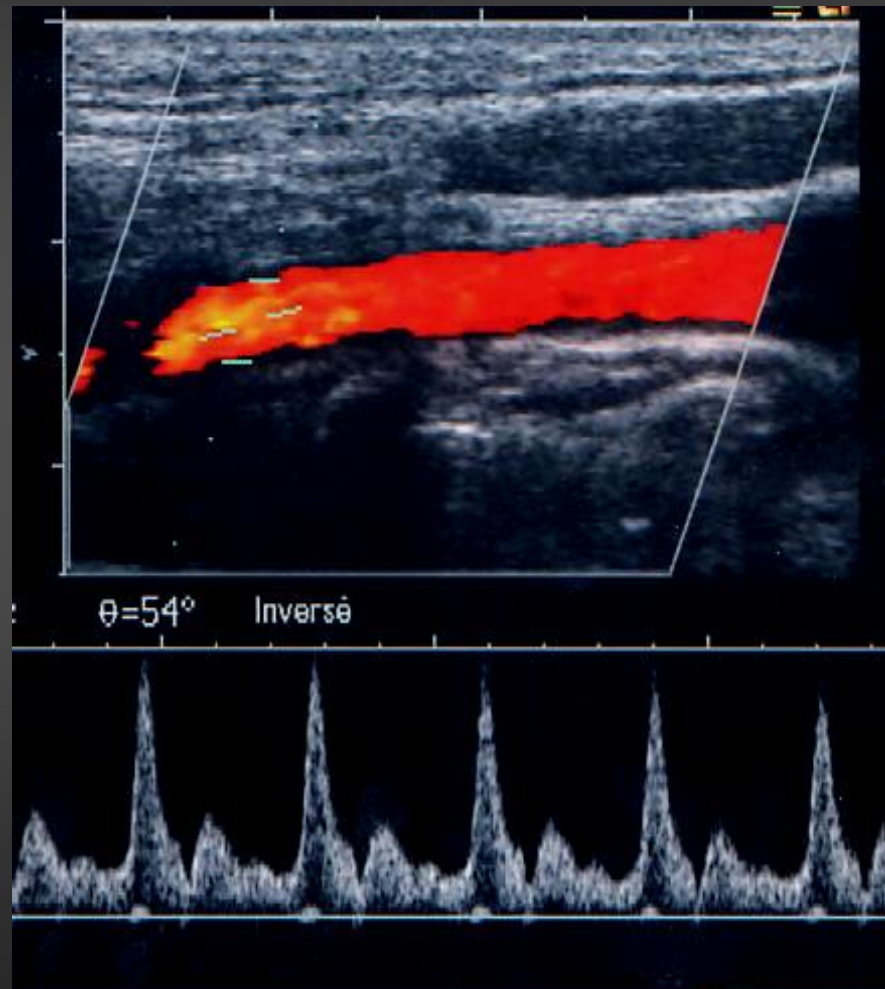
**Domaine fréquentiel**



# LE SPECTRE DE FREQUENCES



# LE SPECTRE DE FREQUENCES

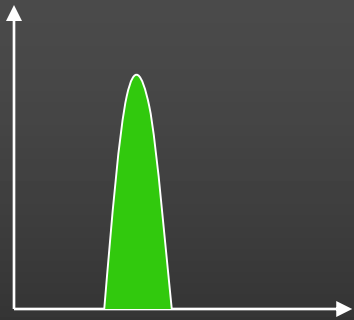
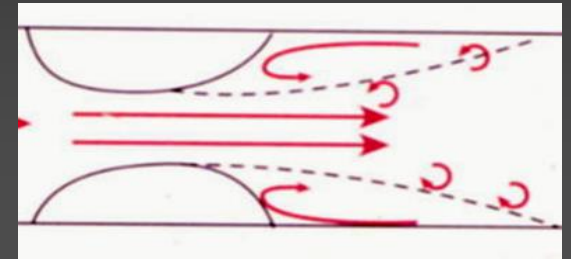
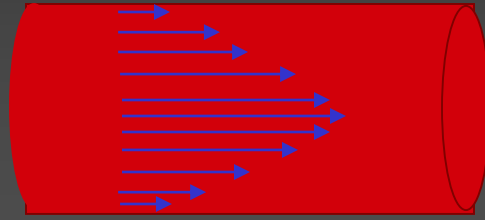


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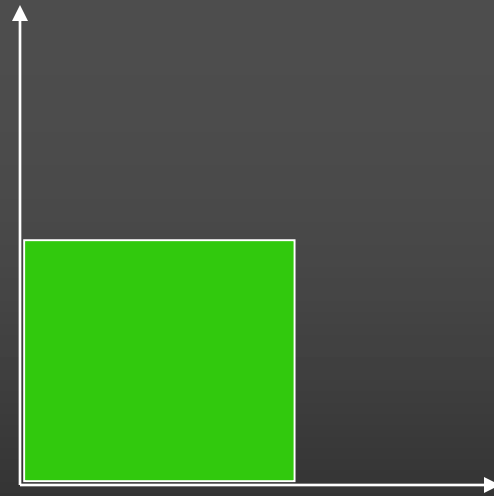
MODULATION FREQUENTIELLE  
DU FLUX : NOTIONS DE PROFIL  
D'ÉCOULEMENT

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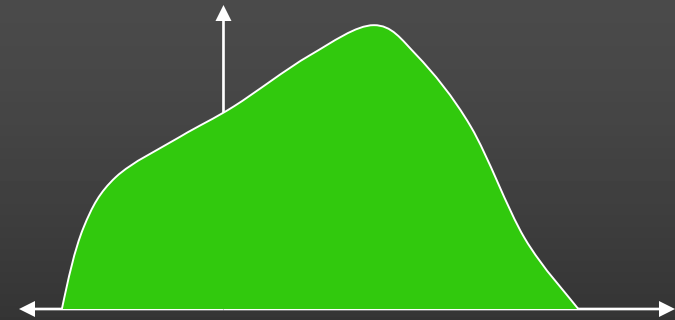
# SPECTRE ET PROFIL DE L'ÉCOULEMENT



Flux plateau



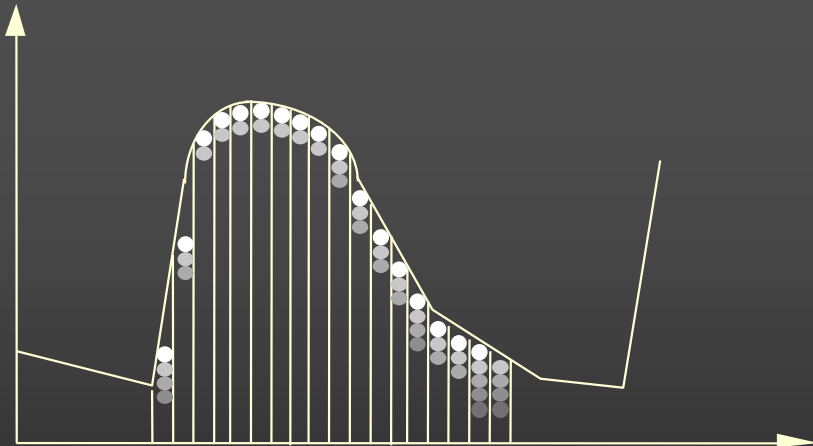
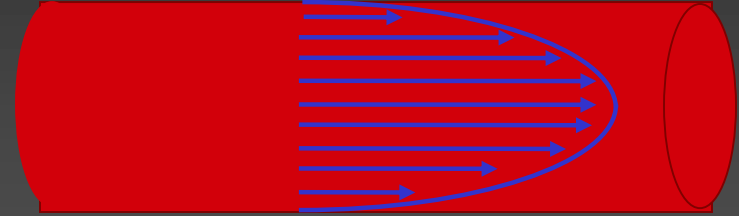
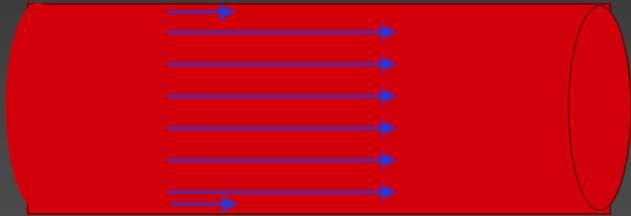
Flux laminaire



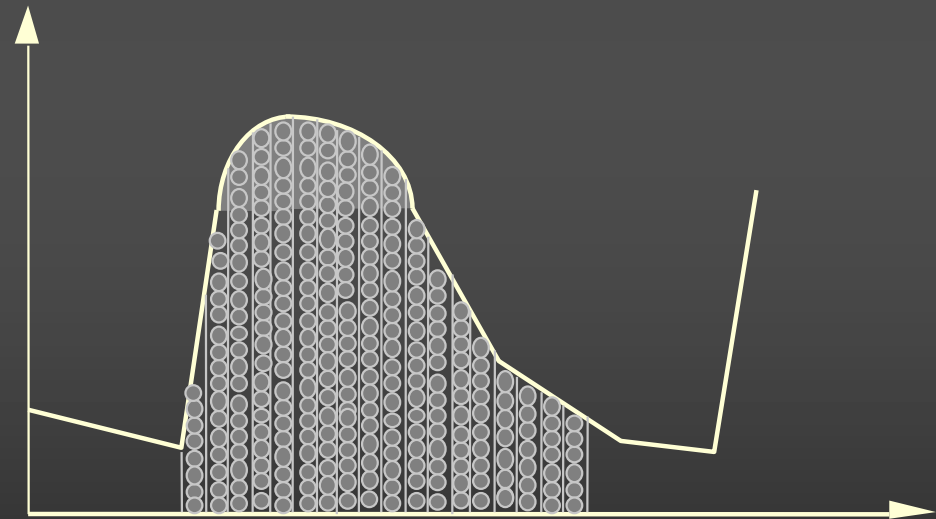
Sténose



# SPECTRE ET PROFIL DE L'ÉCOULEMENT

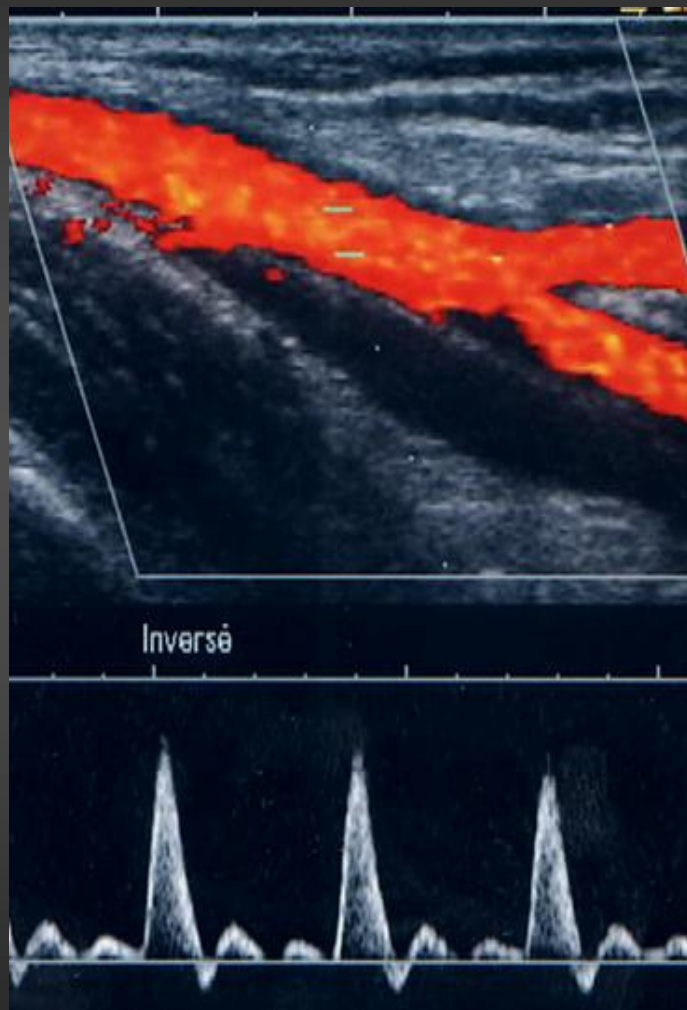


Flux plateau

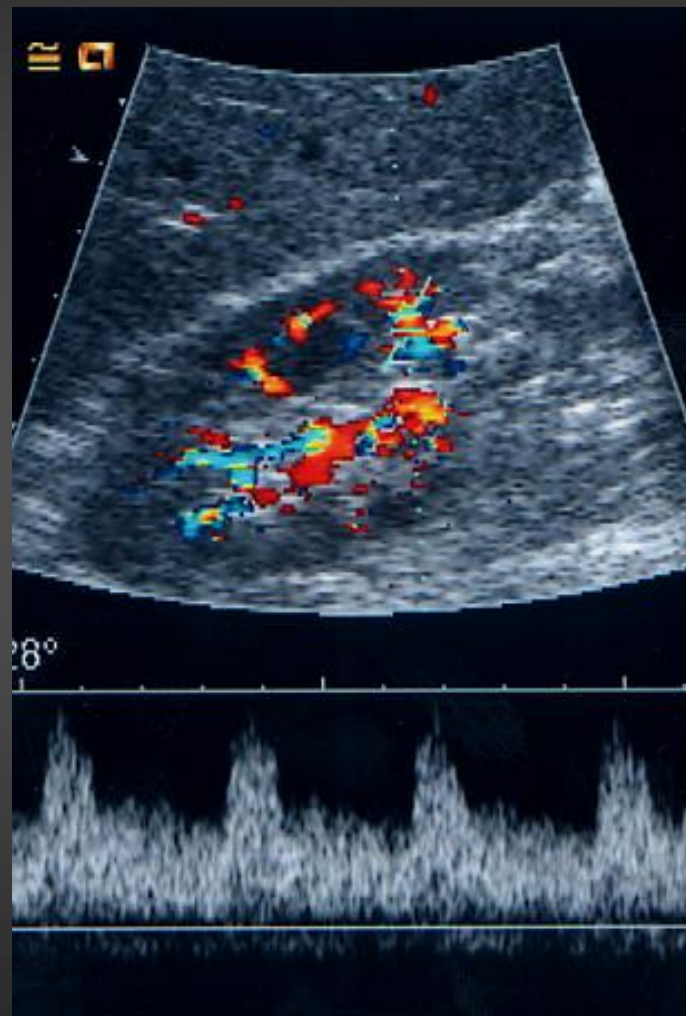


Flux laminaire

# SPECTRE ET PROFIL DE L'ÉCOULEMENT



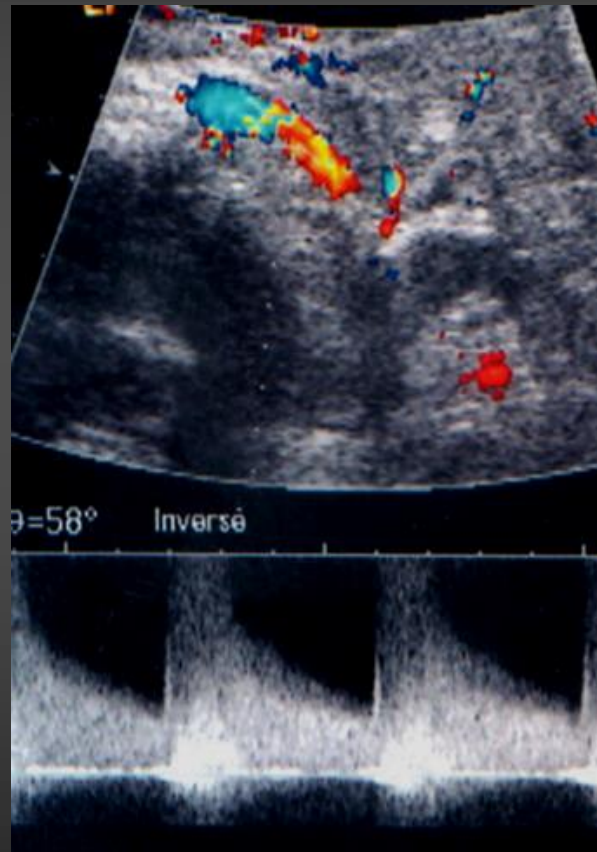
Flux plateau



Flux laminaire

# ALTERATIONS DU PROFIL DE L'ÉCOULEMENT

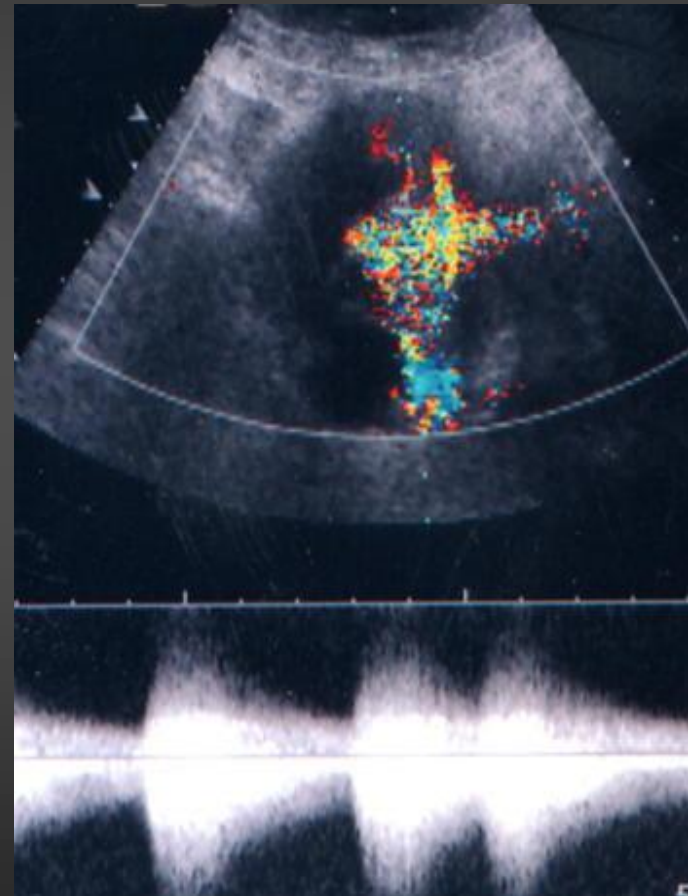
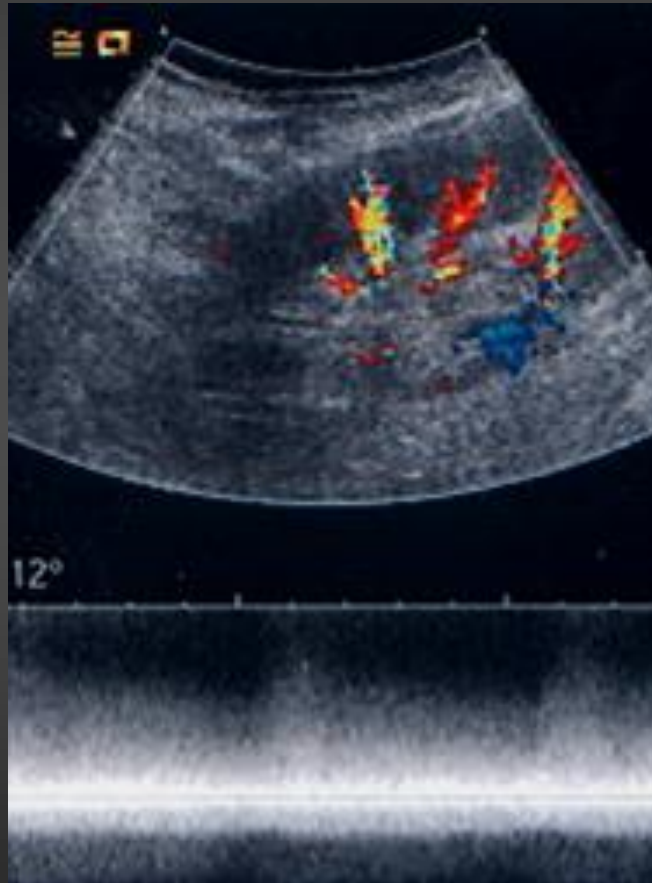
## Sténoses artérielles



*Accélération et dispersion du profil en regard du rétrécissement*

# ALTERATIONS DU PROFIL DE L'ÉCOULEMENT

## Shunts artério-veineux



*Accélération et dispersion du profil sur l'axe afférent*

# ALTERATIONS DU PROFIL DE L'ÉCOULEMENT

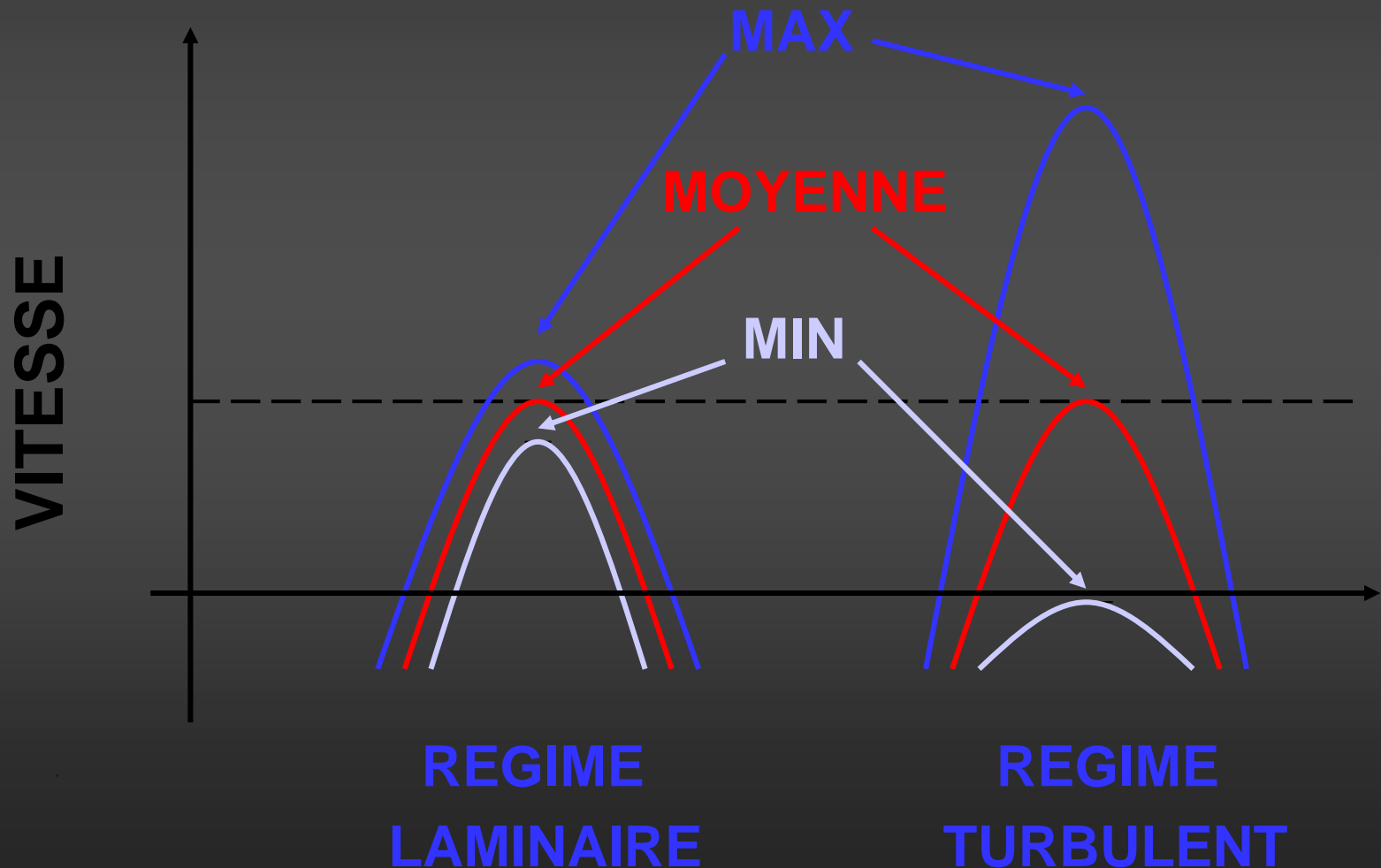
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- On observe un passage d'un profil laminaire à un profil turbulent dans trois circonstances :
  - *Réduction du diamètre*
    - sténose
  - *Augmentation des vitesses circulatoires*
    - shunts artério-veineux
  - *Diminution de la viscosité sanguine*
    - hémocrite bas (exceptionnel)

*(Nombre de Reynolds)*

# ALTERATIONS DU PROFIL DE L'ÉCOULEMENT

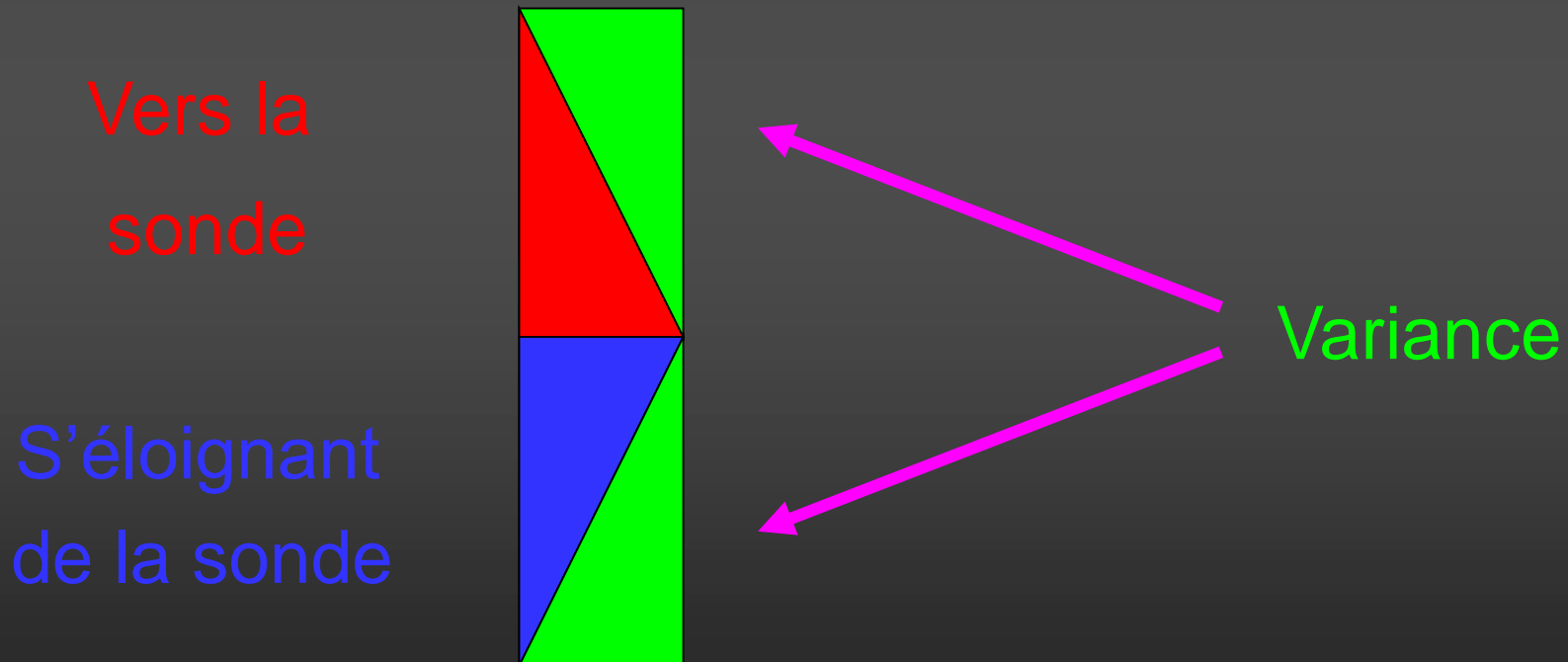
La Variance : dispersion des vitesses autour de la moyenne



# ALTERATIONS DU PROFIL DE L'ÉCOULEMENT

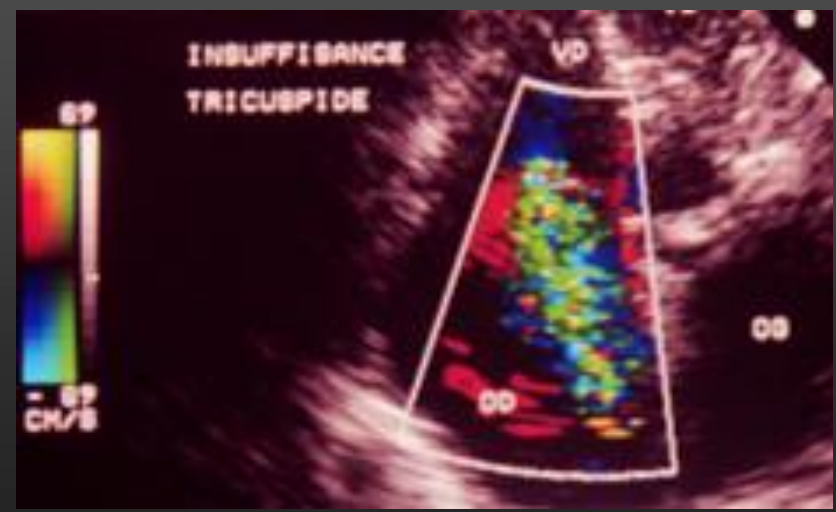
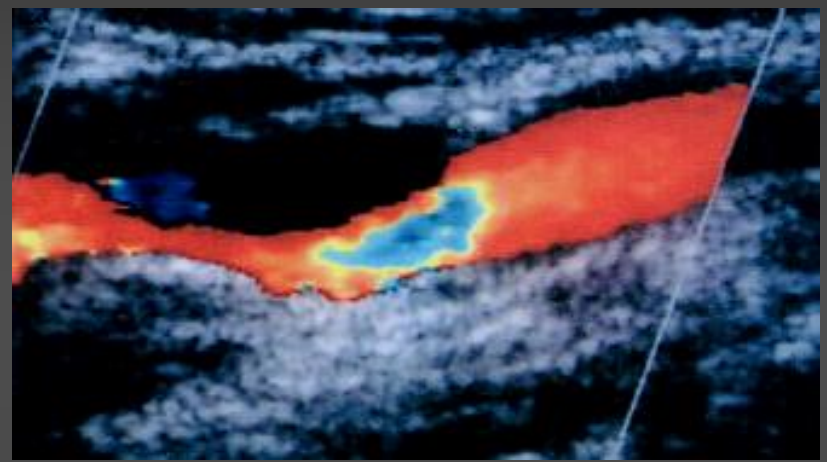
La Variance : dispersion des vitesses autour de la moyenne

Addition d'une troisième couleur



# ALTERATIONS DU PROFIL DE L'ÉCOULEMENT

En DC: non visible, en dehors des flux rétrogrades



Encodage de la variance

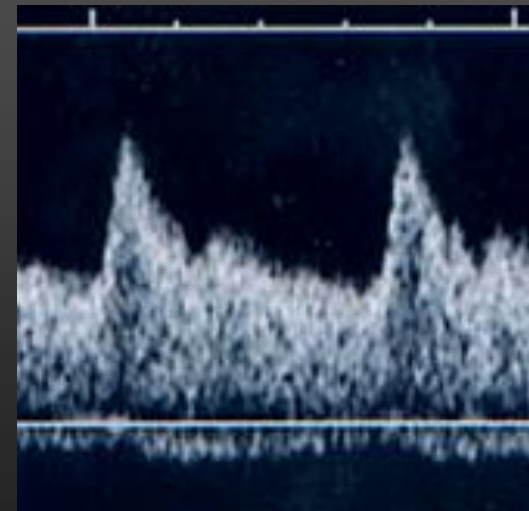
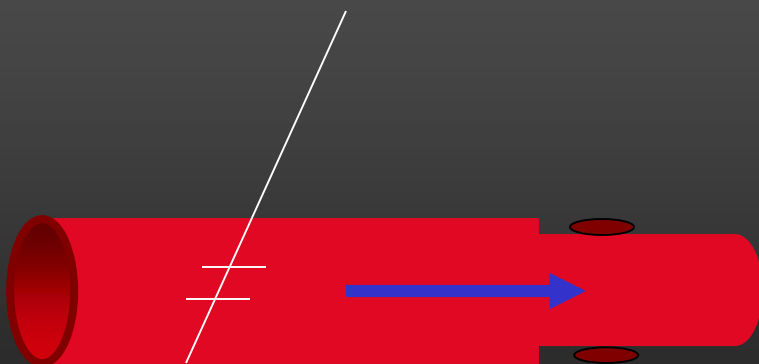
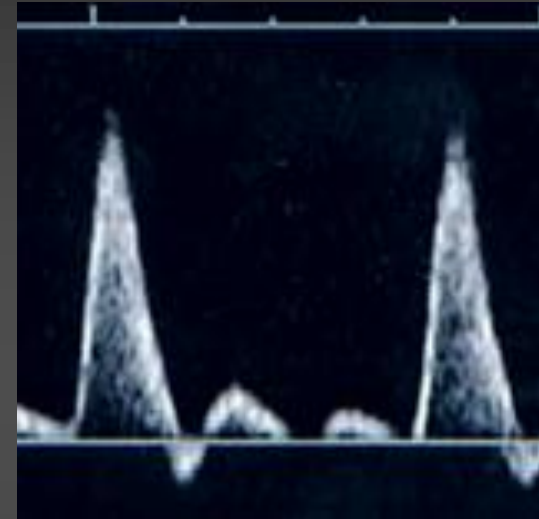
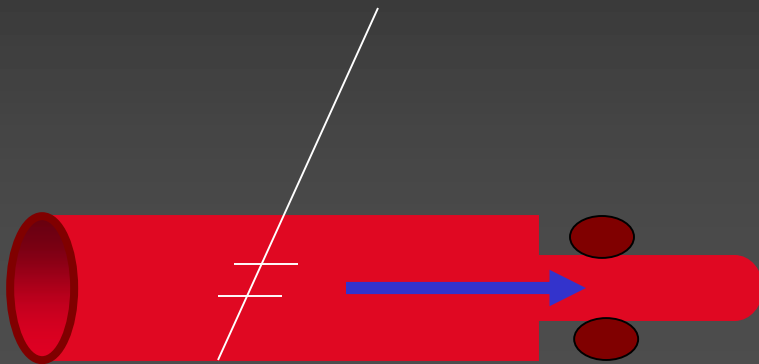


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MODULATION TEMPORELLE DU  
FLUX : NOTIONS DE RESISTANCES  
VASCULAIRES

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# RESISTANCES VASCULAIRES

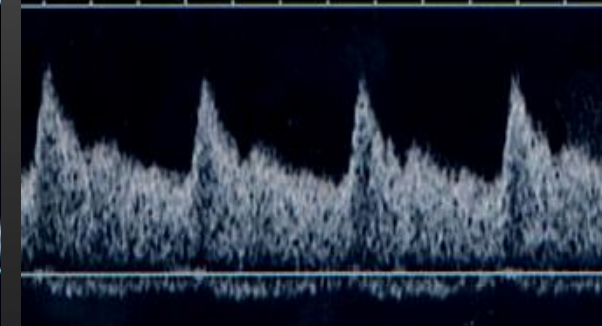
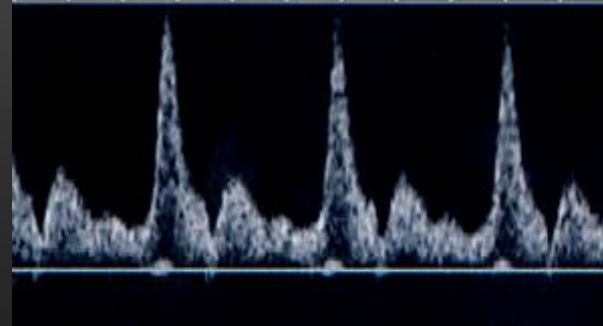
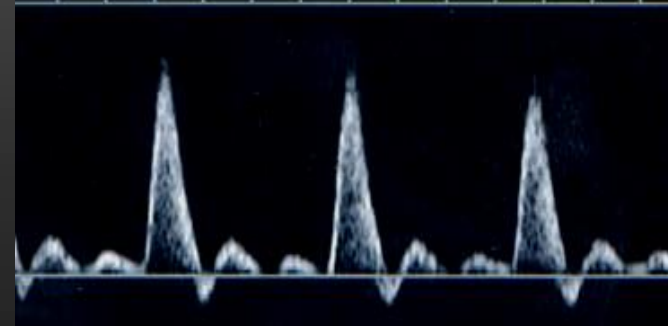
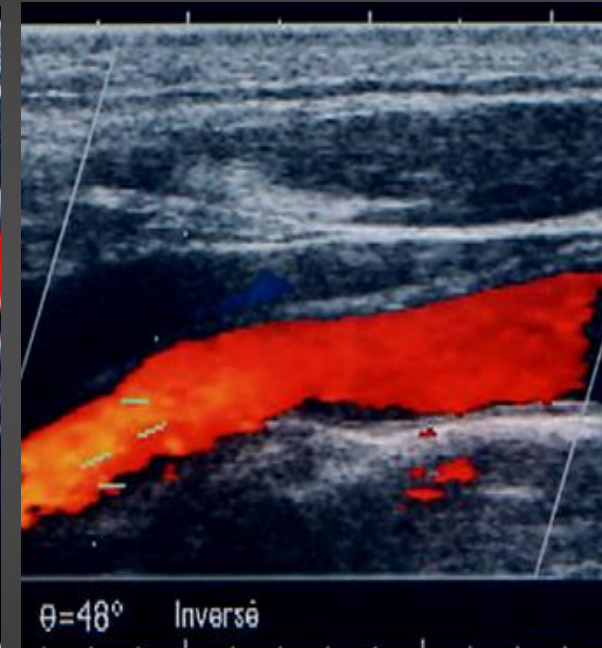
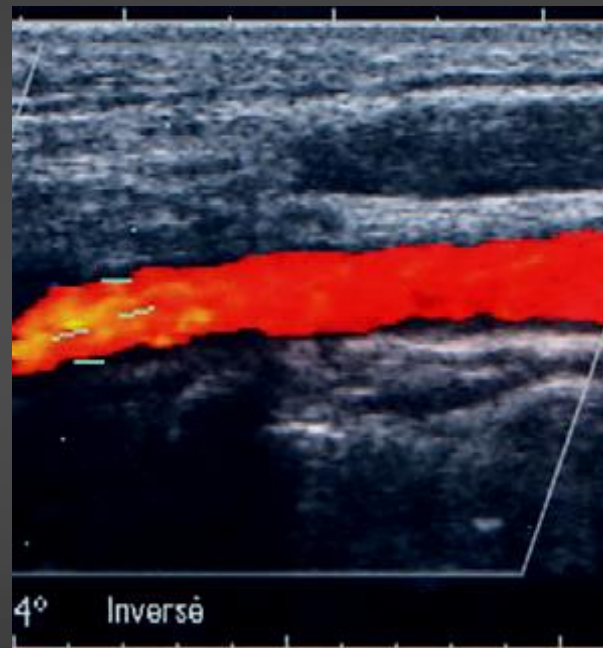
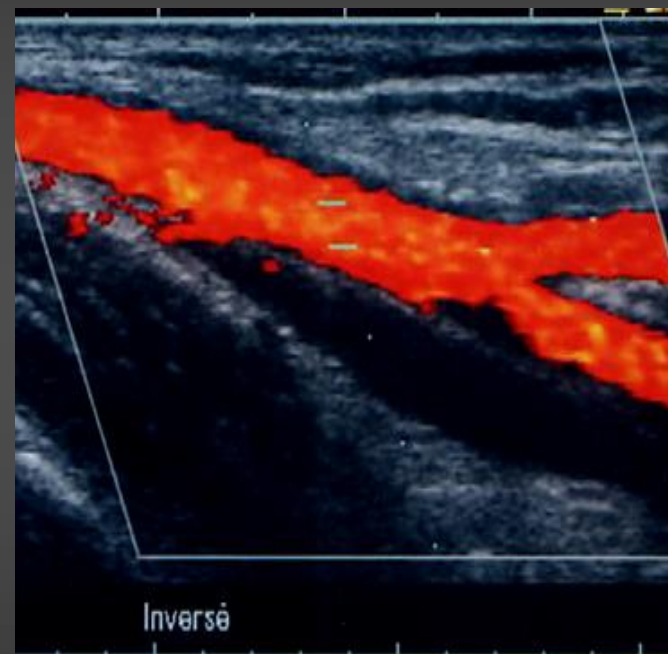


# RESISTANCES VASCULAIRES

Artère brachiale

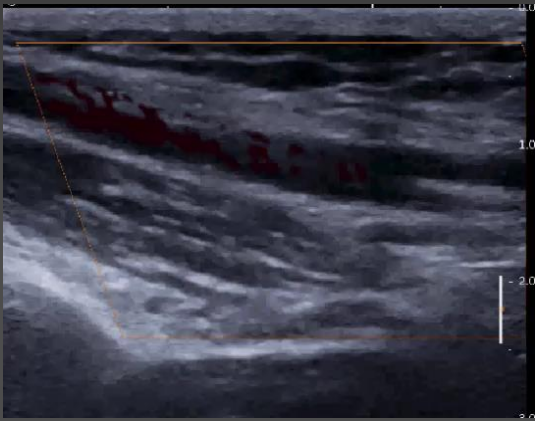
Artère carotide externe

Artère carotide interne

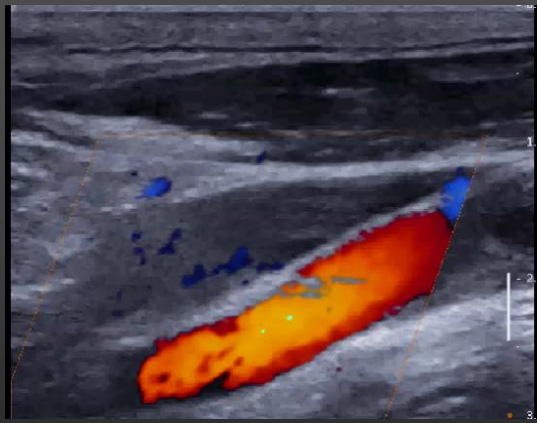
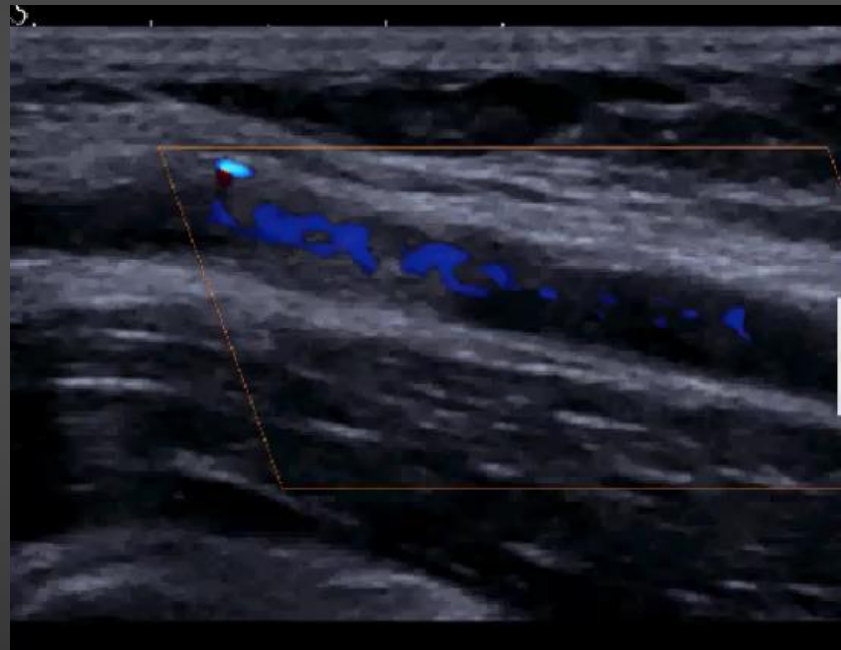


# RESISTANCES VASCULAIRES

Artère brachiale



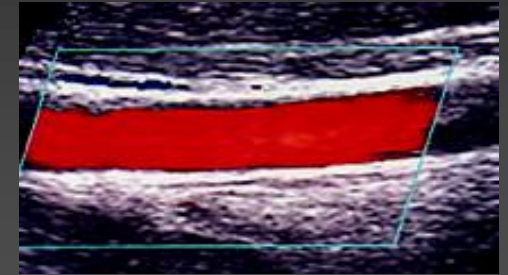
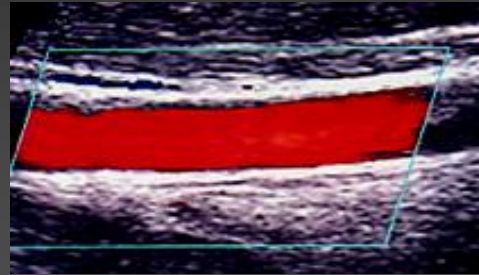
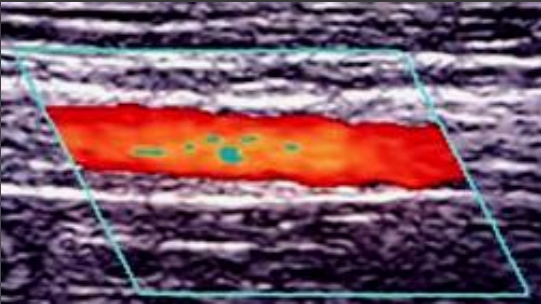
Artère brachiale : contraction-relaxation



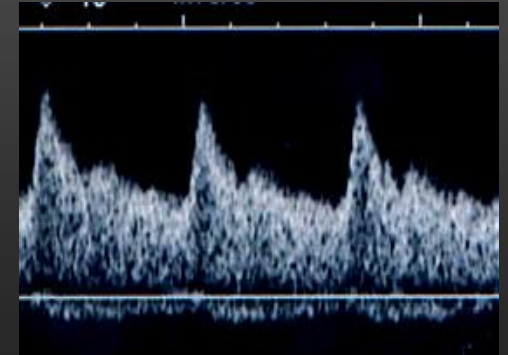
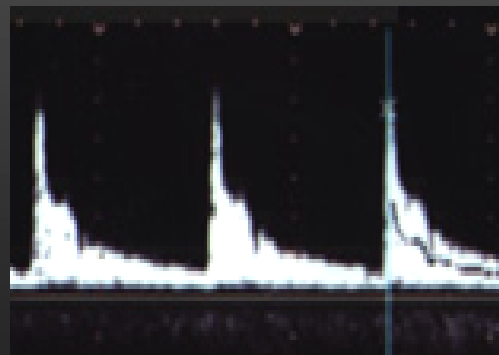
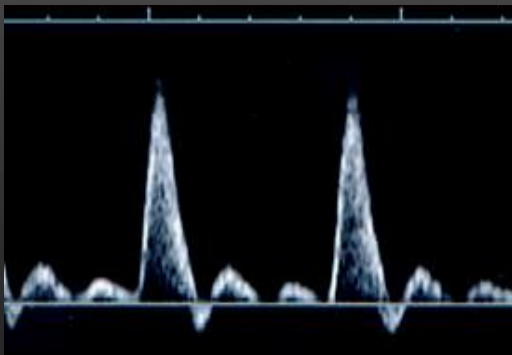
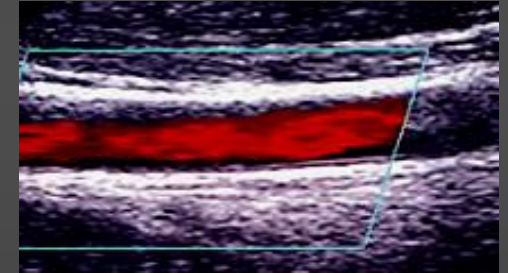
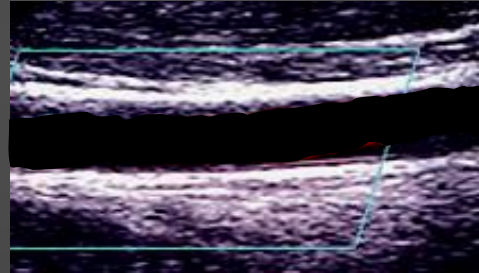
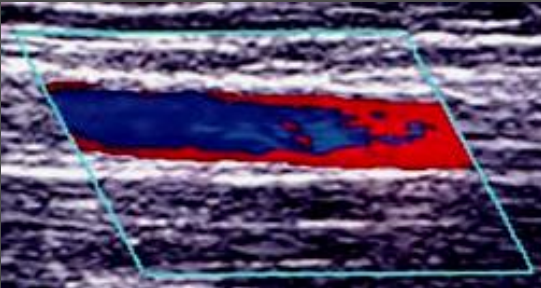
Artère carotide interne

# RESISTANCES VASCULAIRES

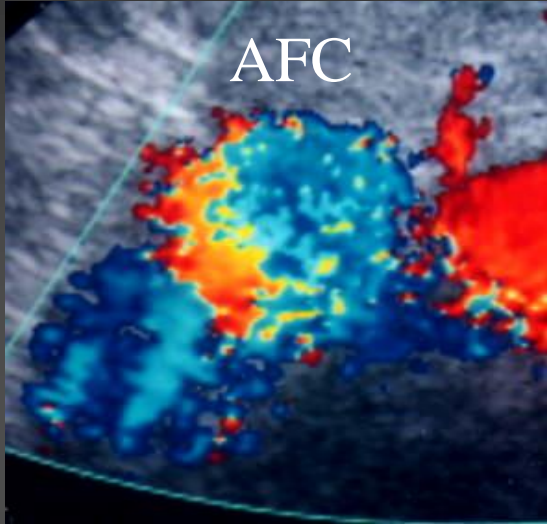
systole



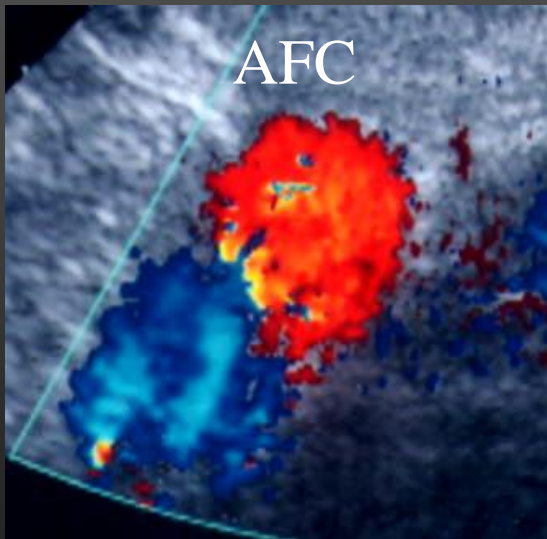
diastole



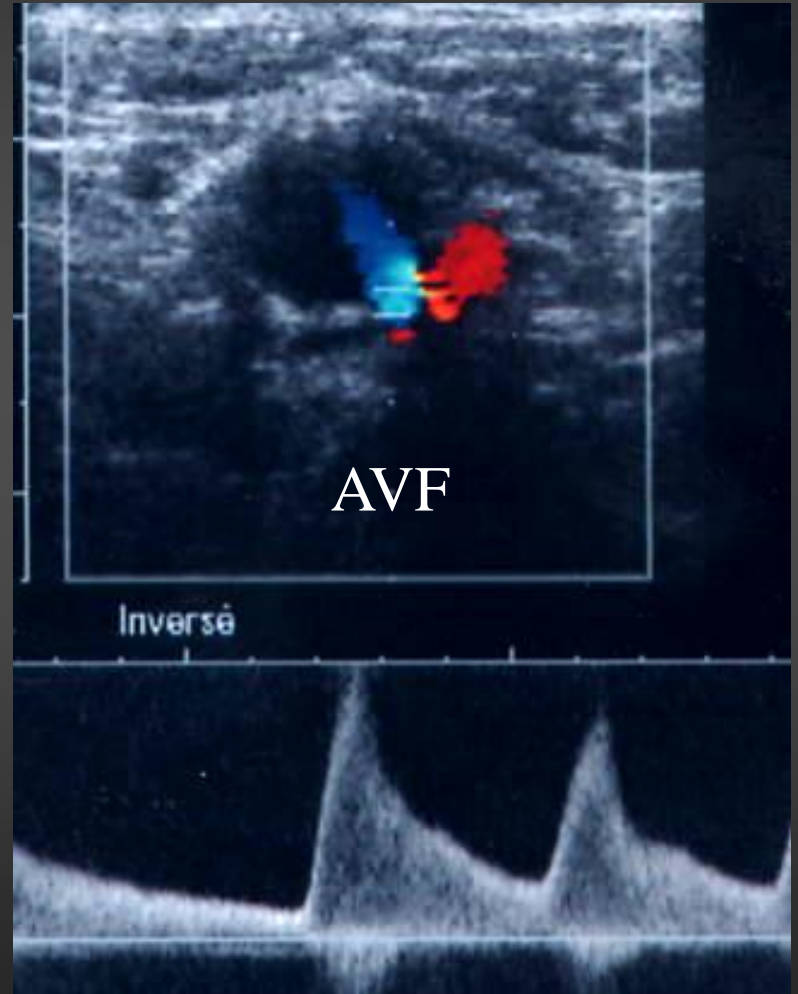
# RESISTANCES VASCULAIRES



systole

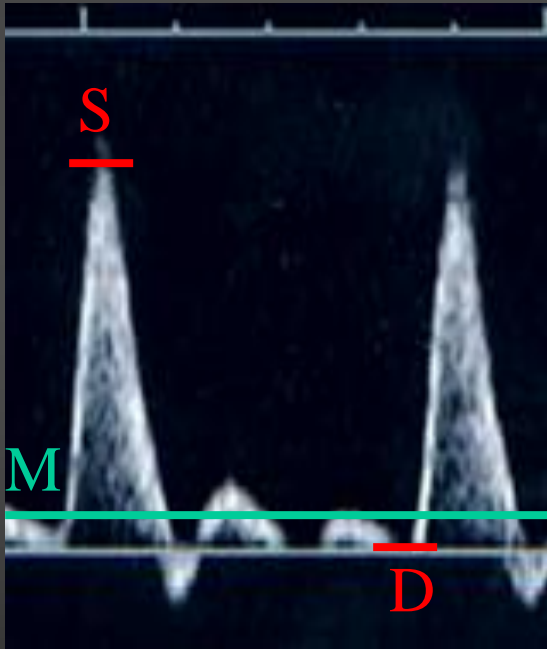


diastole

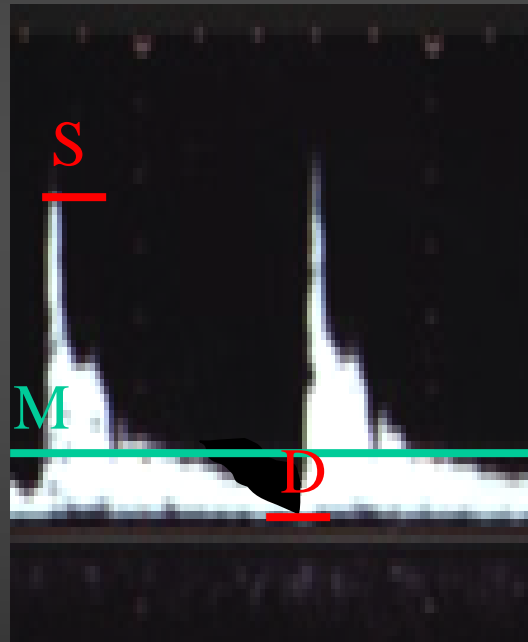


# RESISTANCES VASCULAIRES

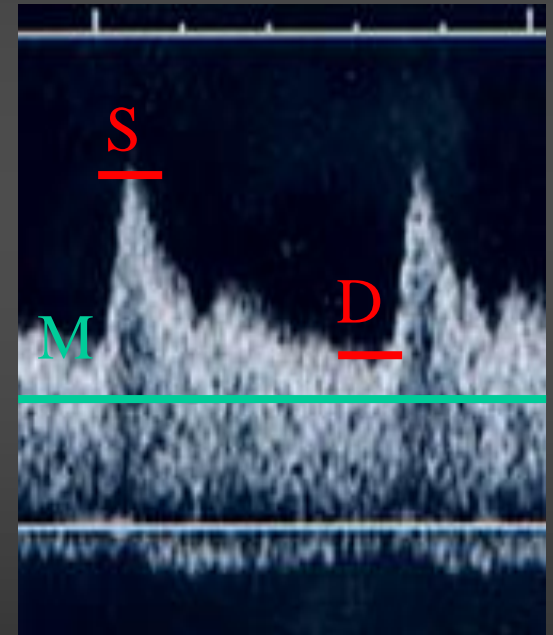
- Quantification d'index



$$RI = S - D / S$$



$$PI = S - D / M$$



# RESISTANCES VASCULAIRES

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- *RI et PI dépendent* :
  - des résistances vasculaires périphériques
  - de la compliance des parois vasculaires
  - de la surface de section du lit vasculaire

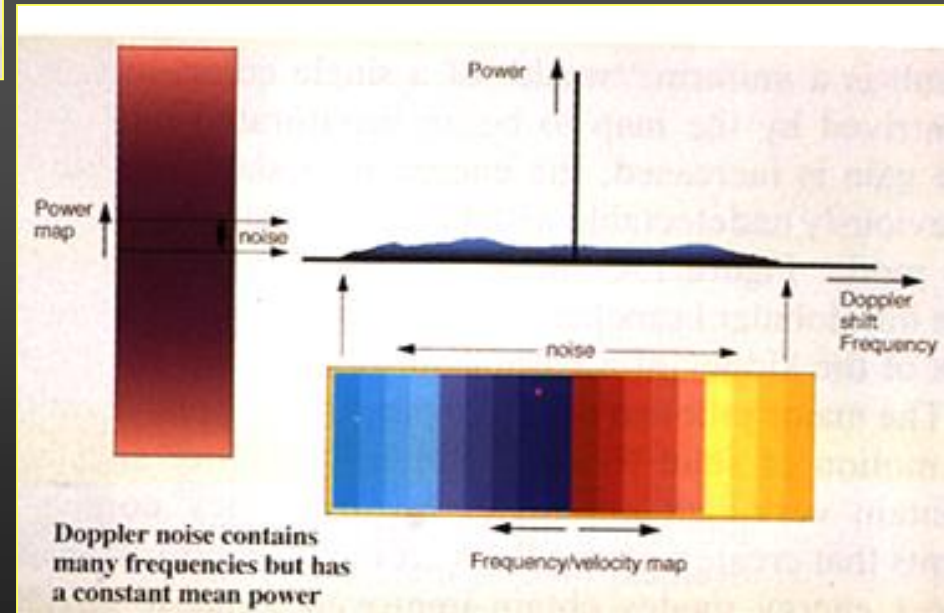
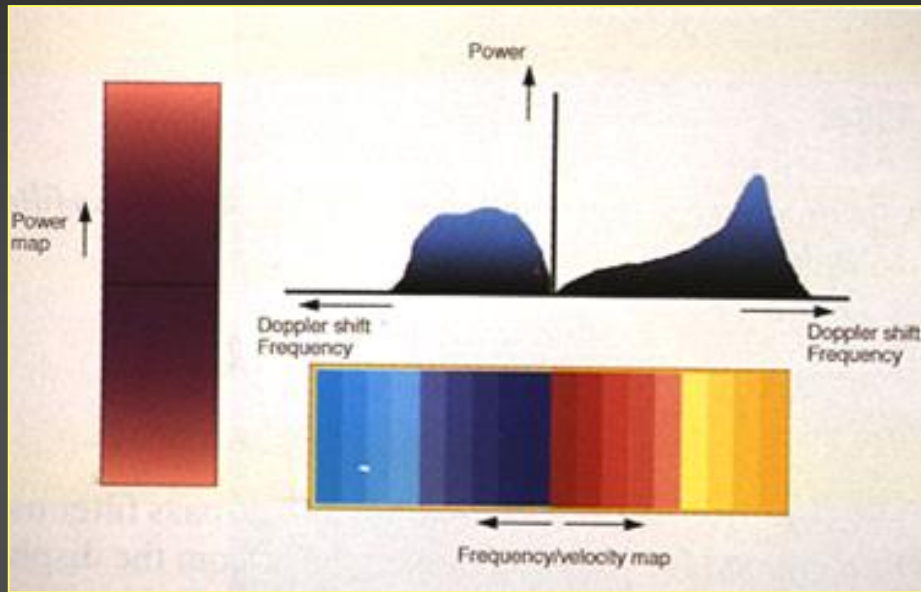


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# DOPPLER ENERGIE

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# DOPPLER ENERGIE



# DOPPLER ENERGIE

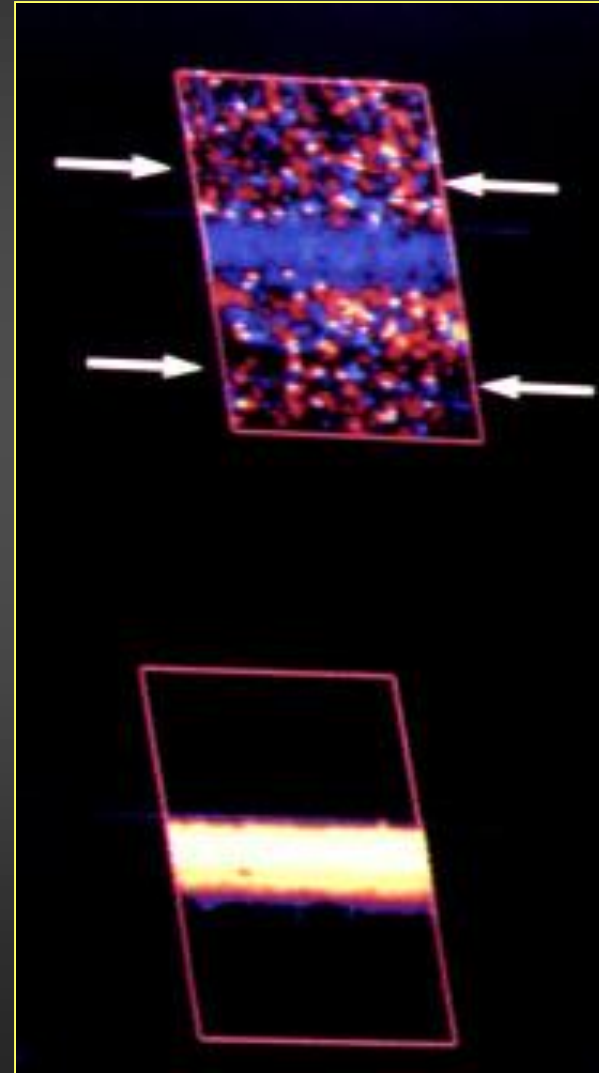
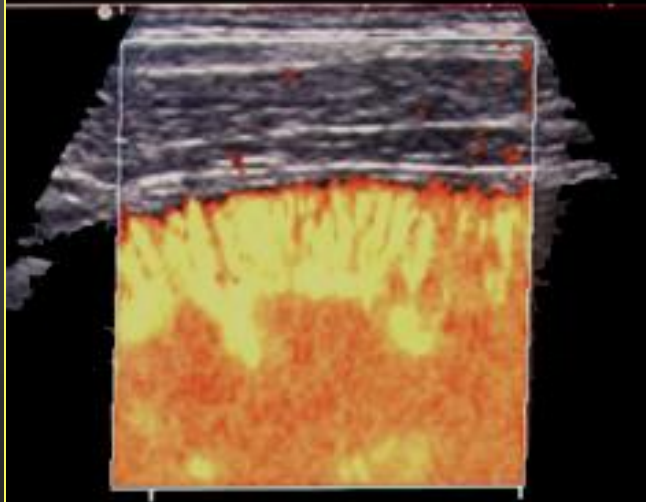
- Bonne sensibilité à angle Doppler élevé



# DOPPLER ENERGIE



# DOPPLER ENERGIE

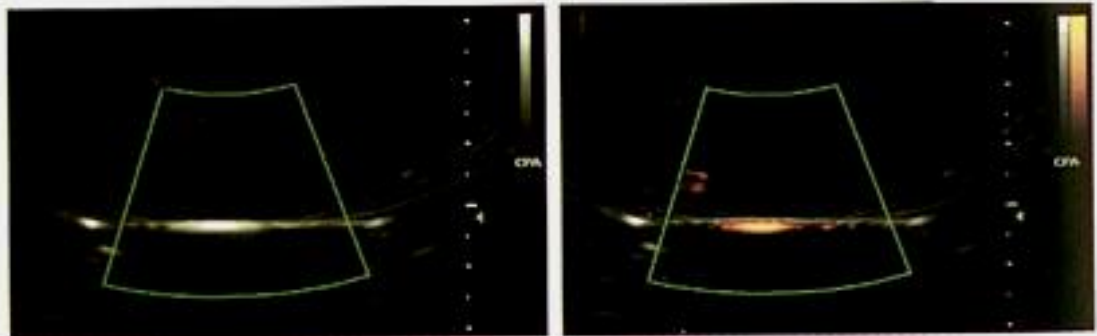
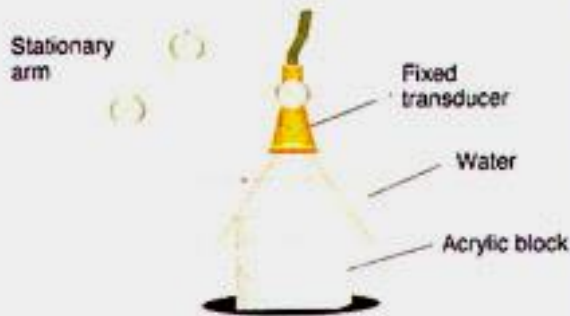
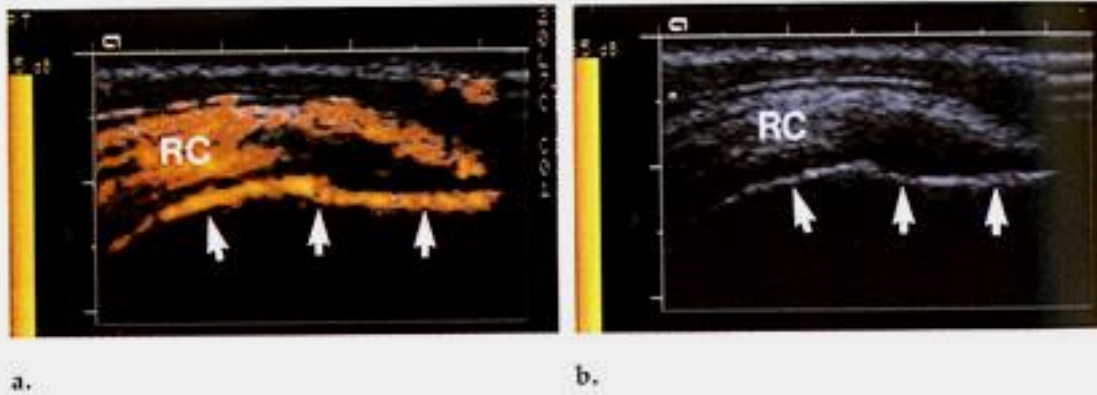


# DOPPLER ENERGIE

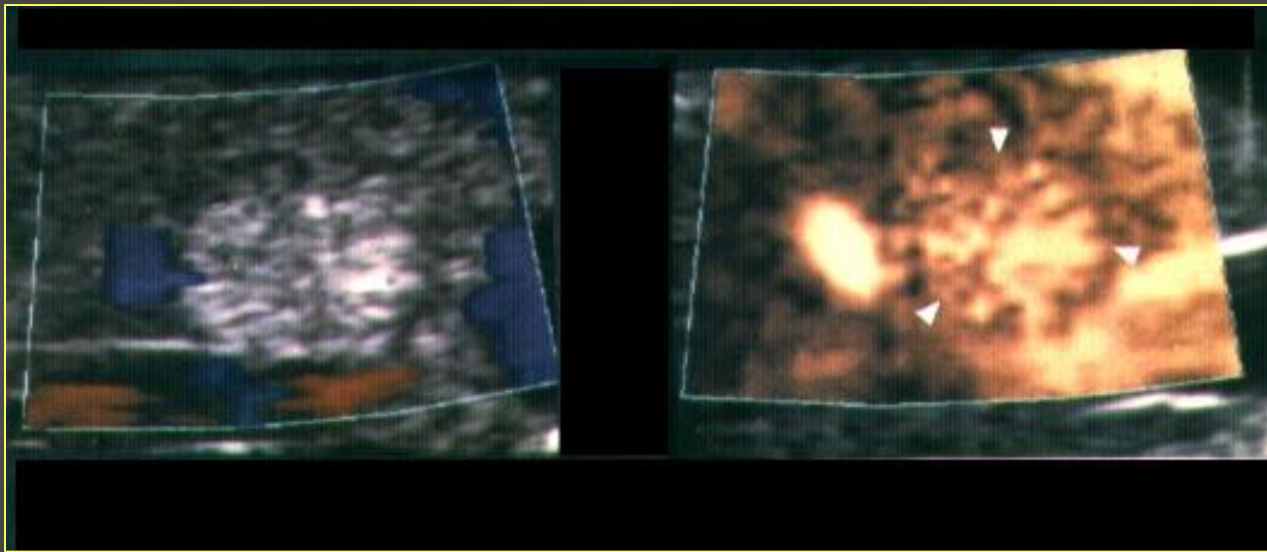
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- Avantages :
  - bon remplissage endo-luminal par le signal
  - moins angle-dépendant
  - meilleure anatomie des petits vaisseaux parenchymateux
- Inconvénients :
  - imagerie morphologique :
    - pas d'information sur le sens d'écoulement
    - pas d'information sur les vitesses
  - artefacts :
    - sensible aux artefacts de mouvement
    - présence d'artefacts sur les structures hyperéchogènes

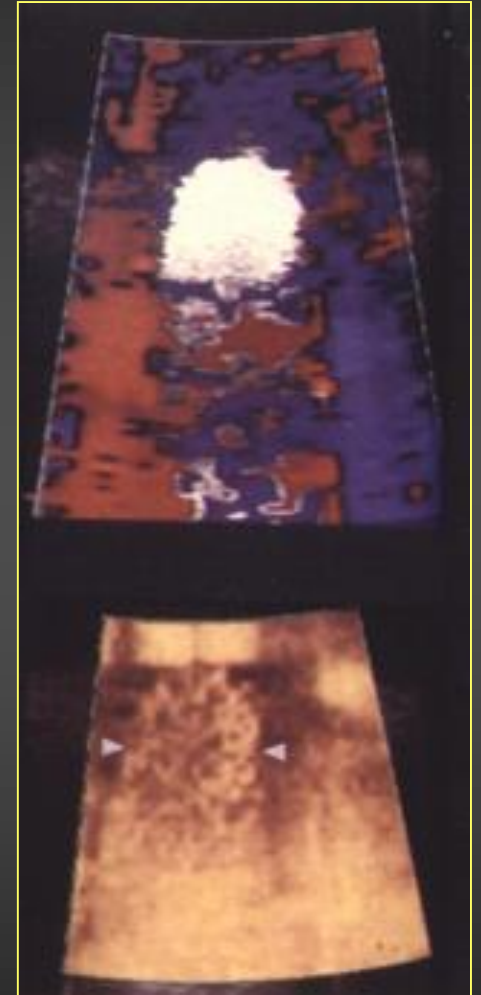
# DOPPLER ENERGIE: Artefacts



# DOPPLER ENERGIE: Artefacts



Hémangiome du foie



Eponge



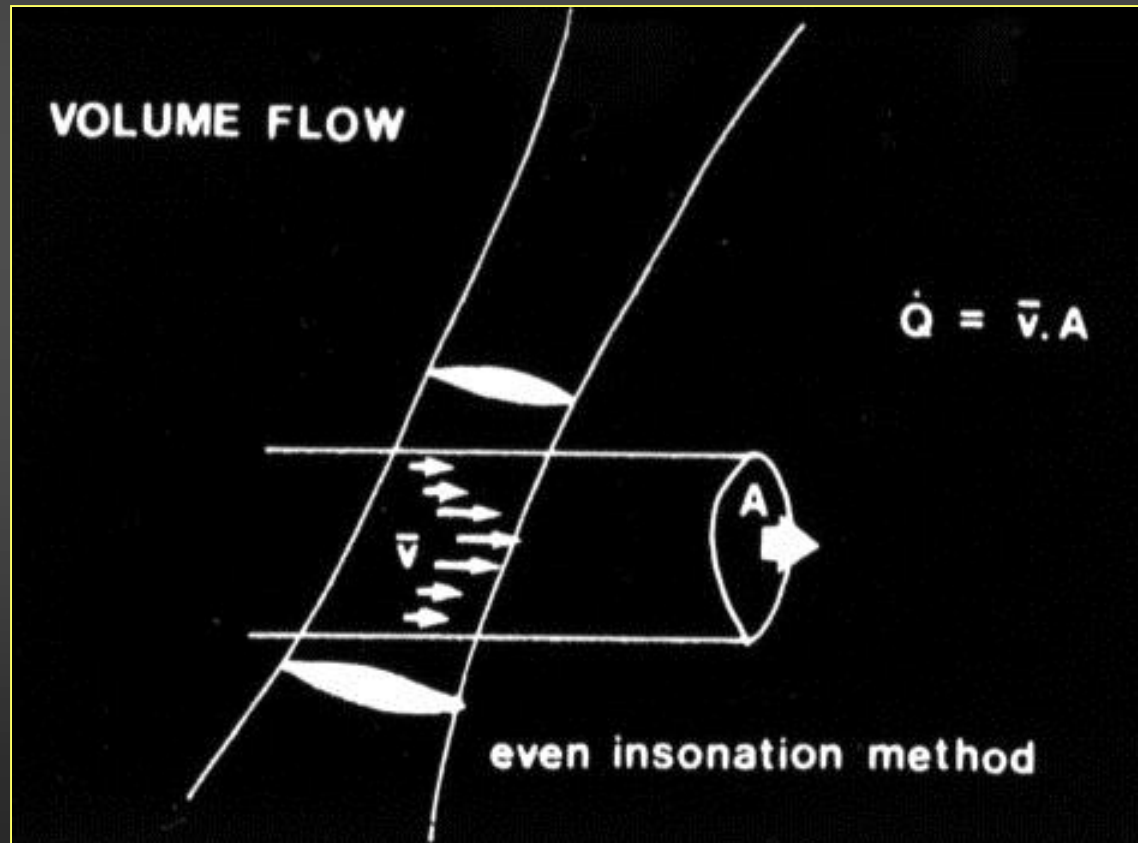
# DEBIMETRIE

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- Méthodes :
  - insonation uniforme
  - intégration des profils d'écoulement

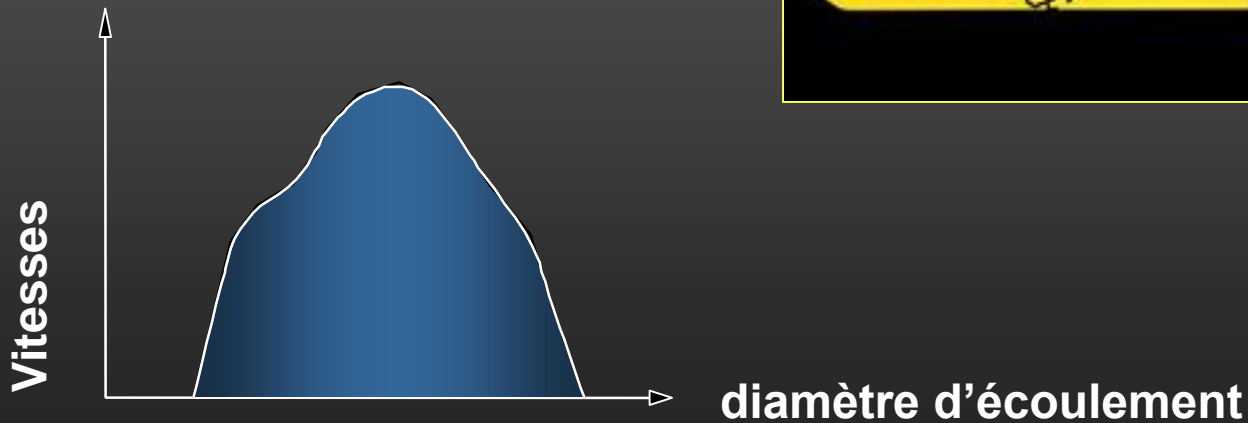
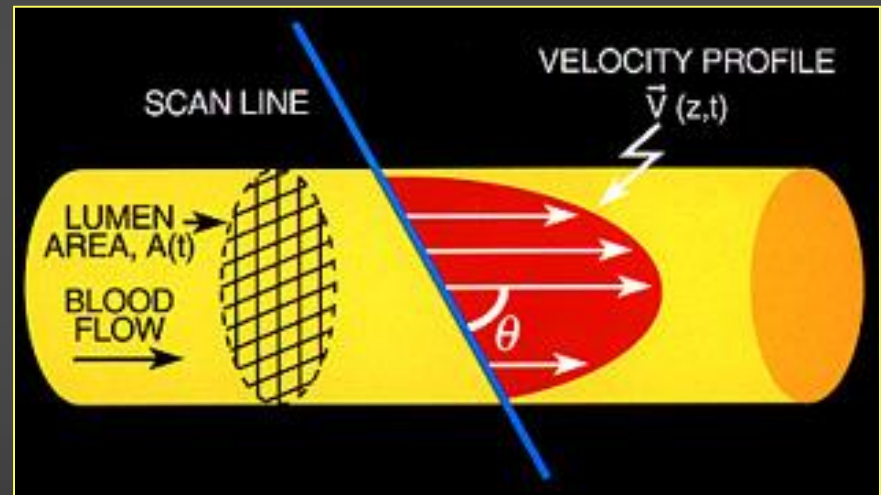
# DEBIMETRIE

- Insonation uniforme



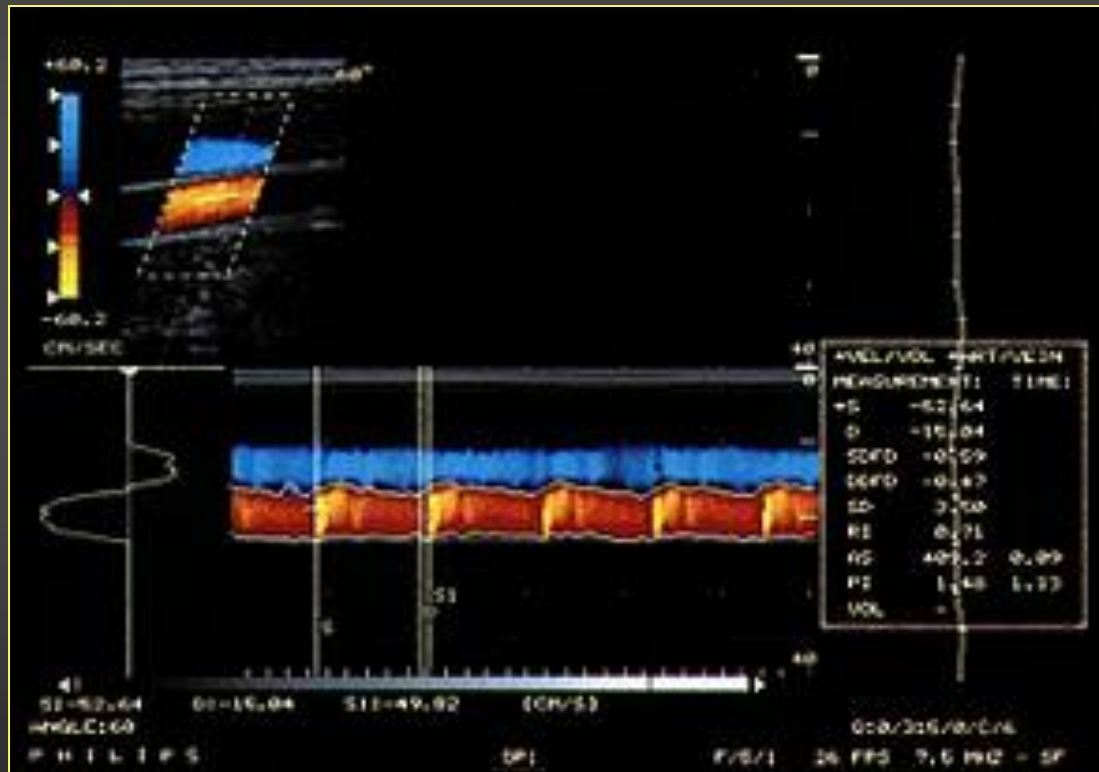
# DEBIMETRIE

- Intégration des profils d'écoulement



# DEBIMETRIE

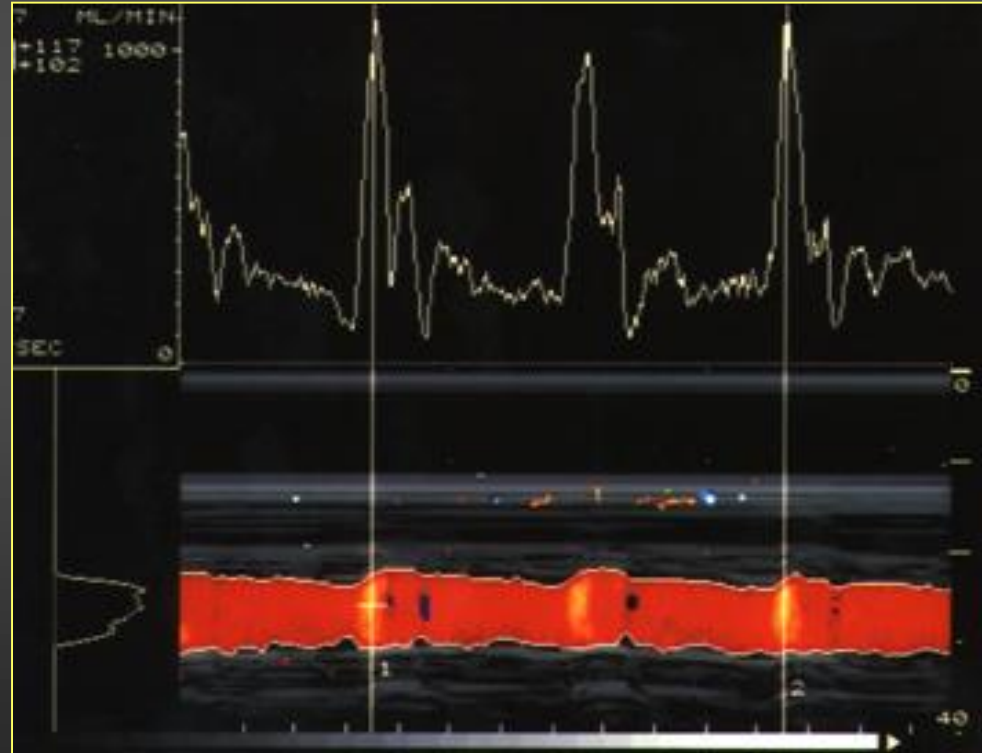
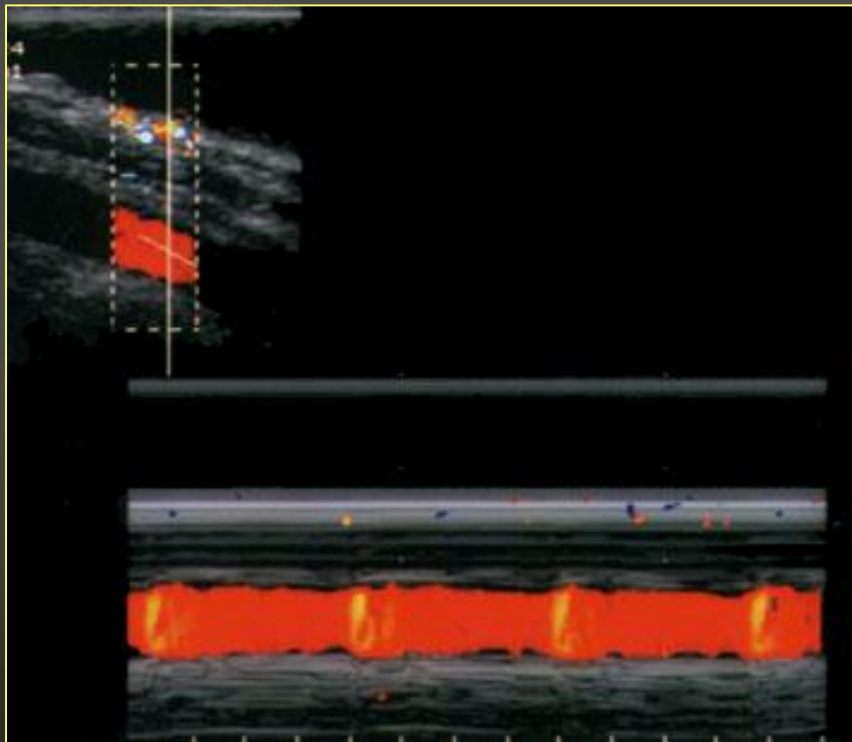
- Intégration des profils d'écoulement



*Méthode CVI, Philips*

# DEBIMETRIE

- Intégration des profils d'écoulement :



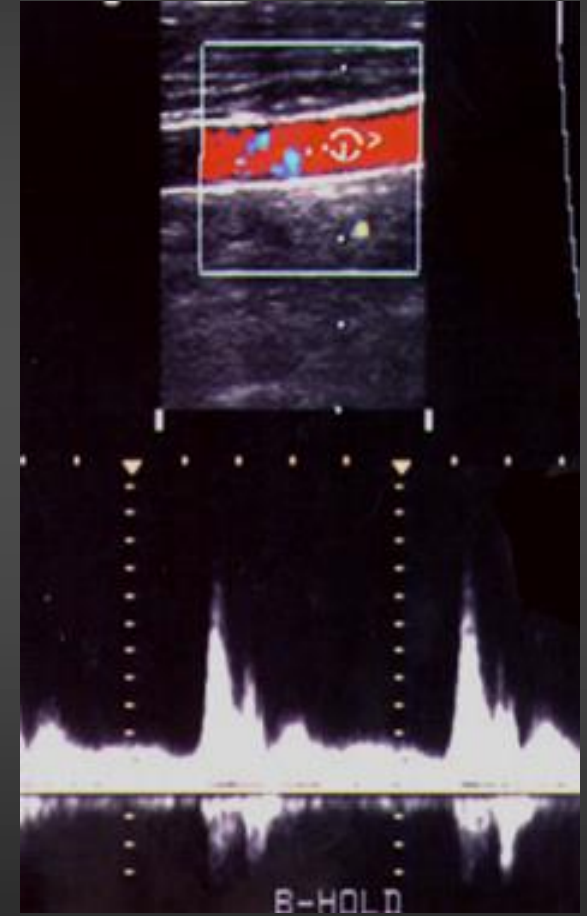
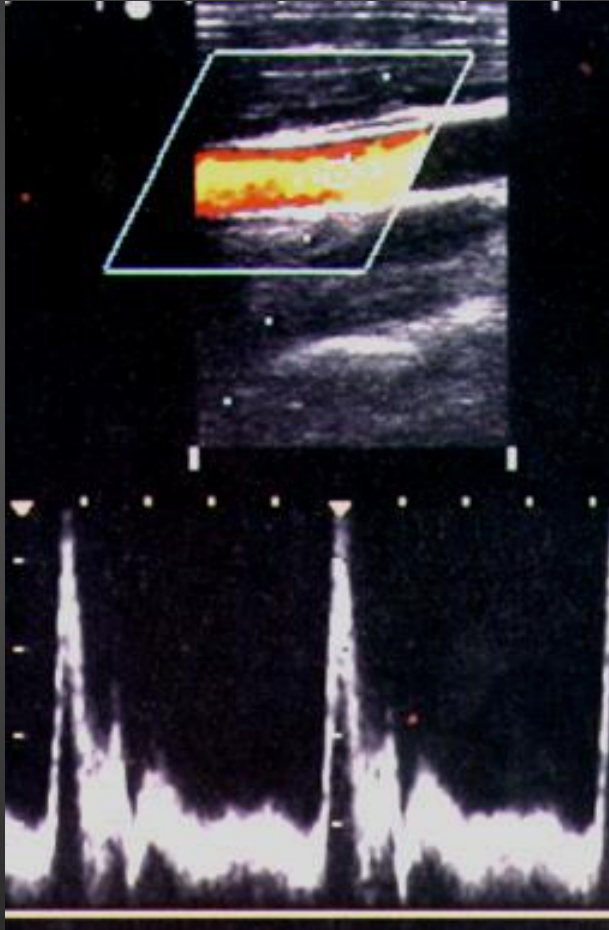
*Méthode CVI, Philips*

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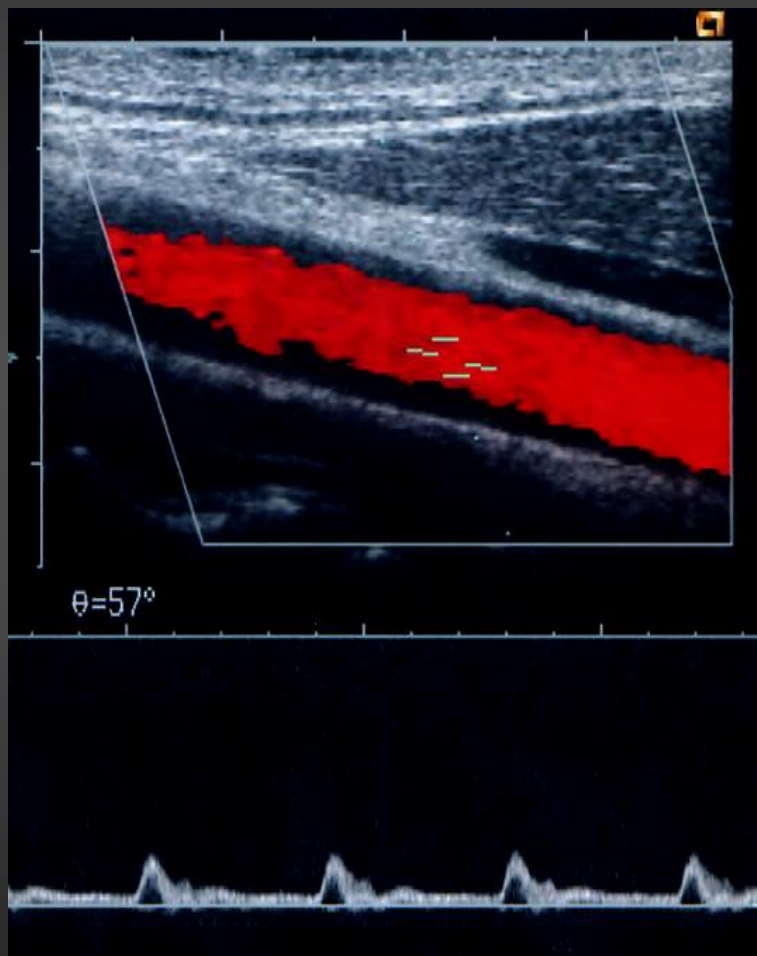
# REGLAGE DES PARAMETRES TECHNIQUES

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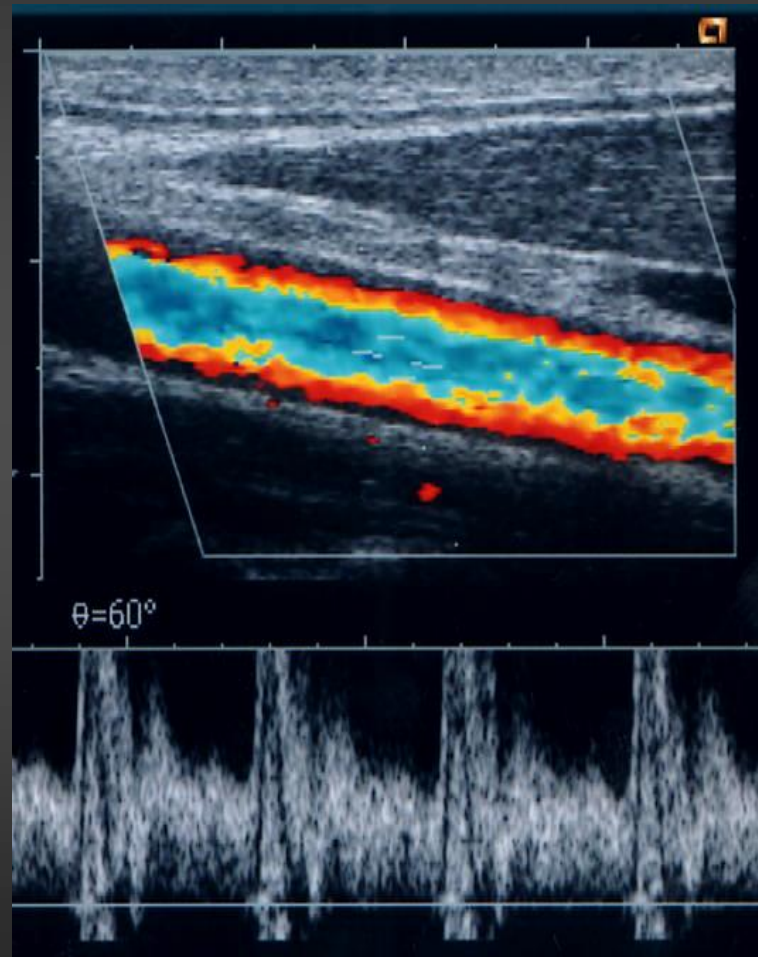
# OPTIMISATION DE L'ANGLE DOPPLER



# OPTIMISATION DE LA PRF



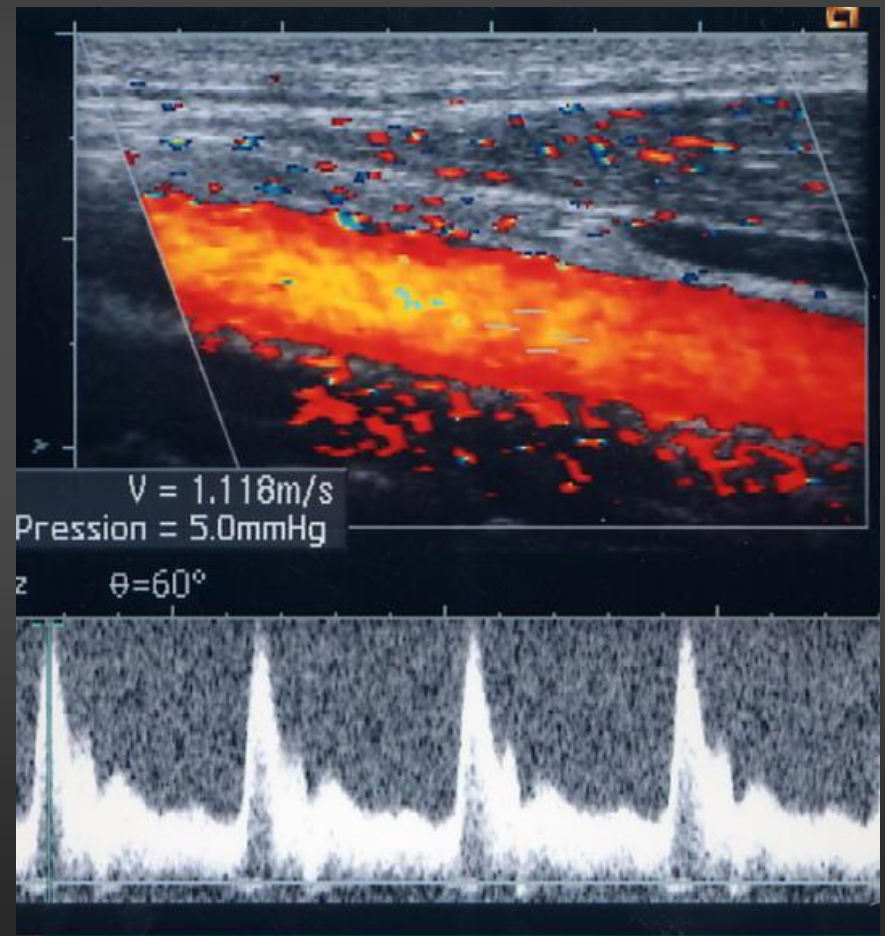
PRF trop élevée



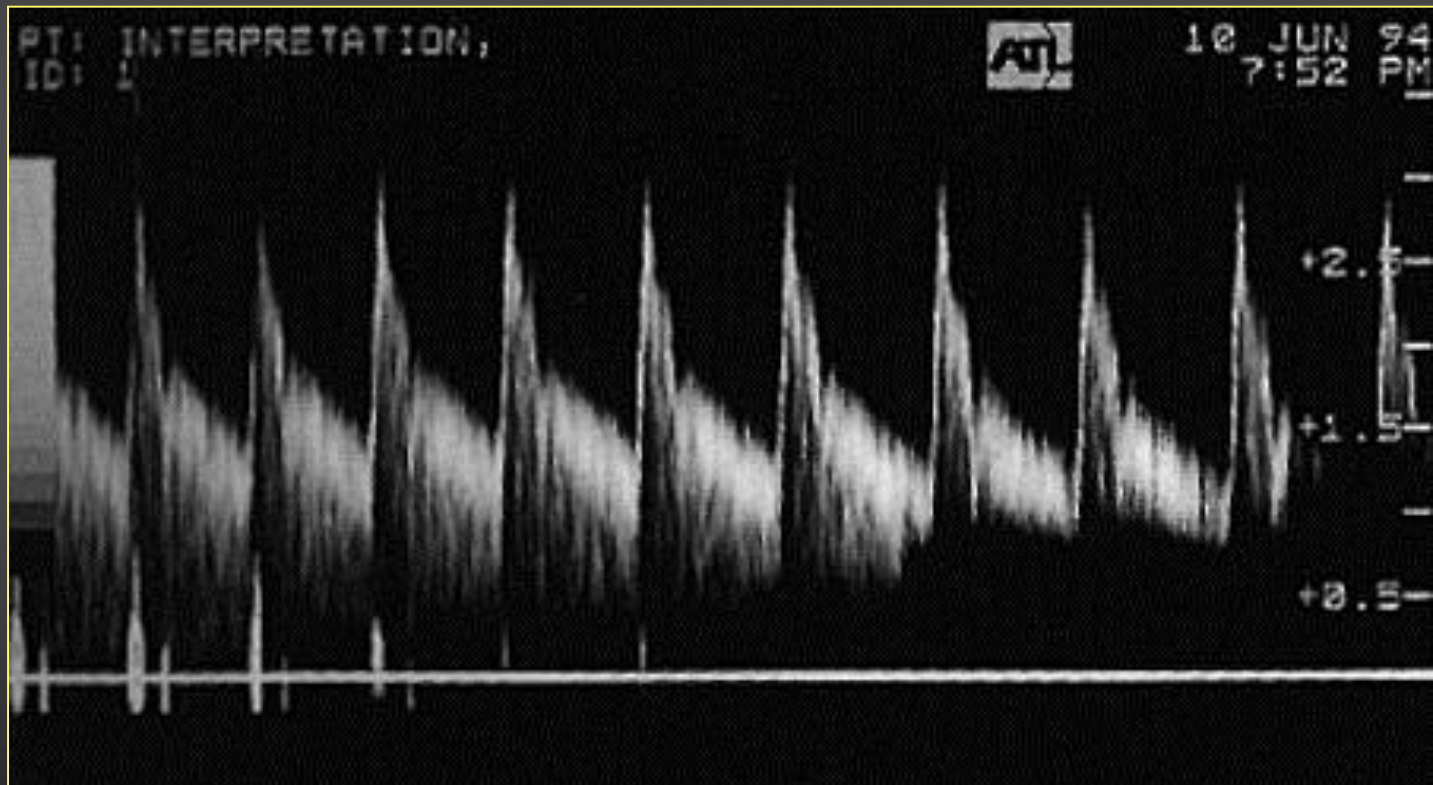
PRF trop basse



# EFFET DU GAIN DOPPLER



# EFFET DU FILTRE PASSE-HAUT

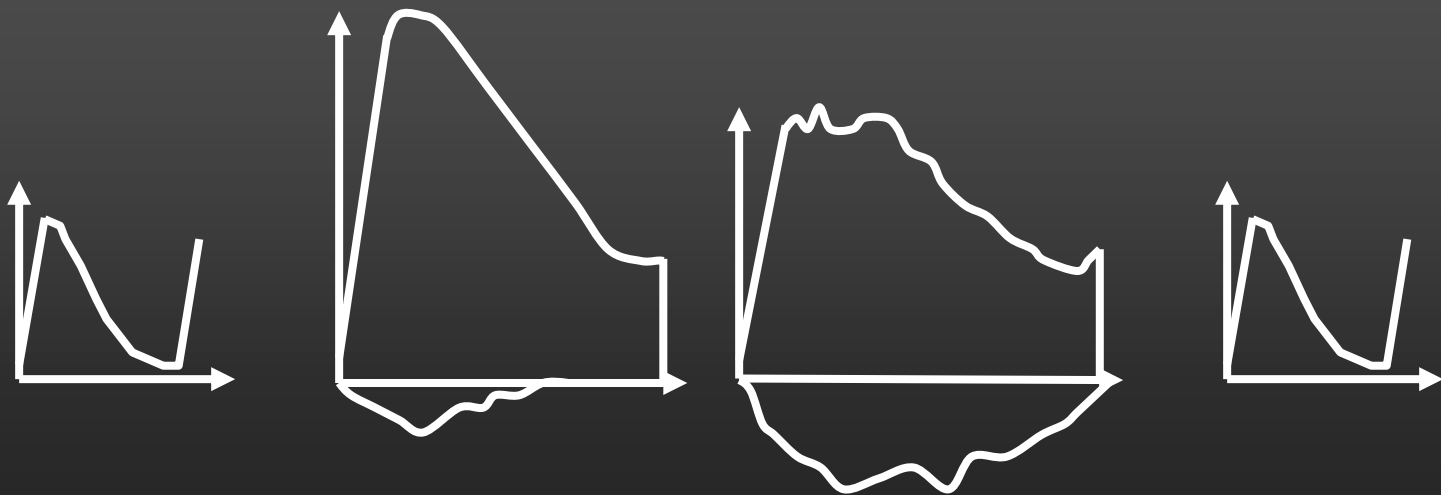
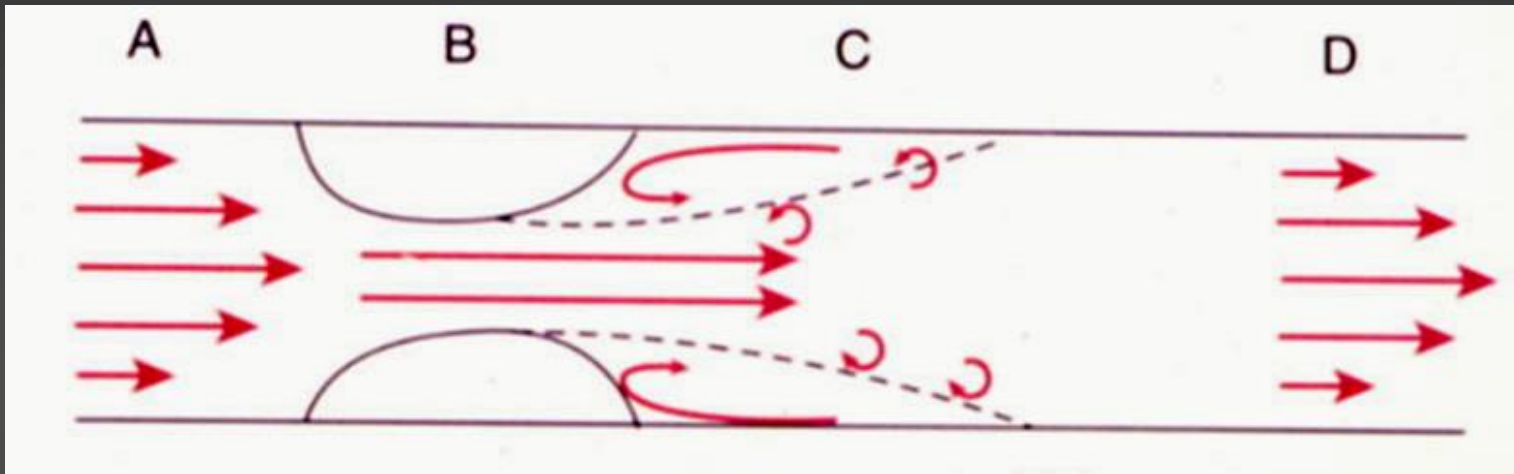


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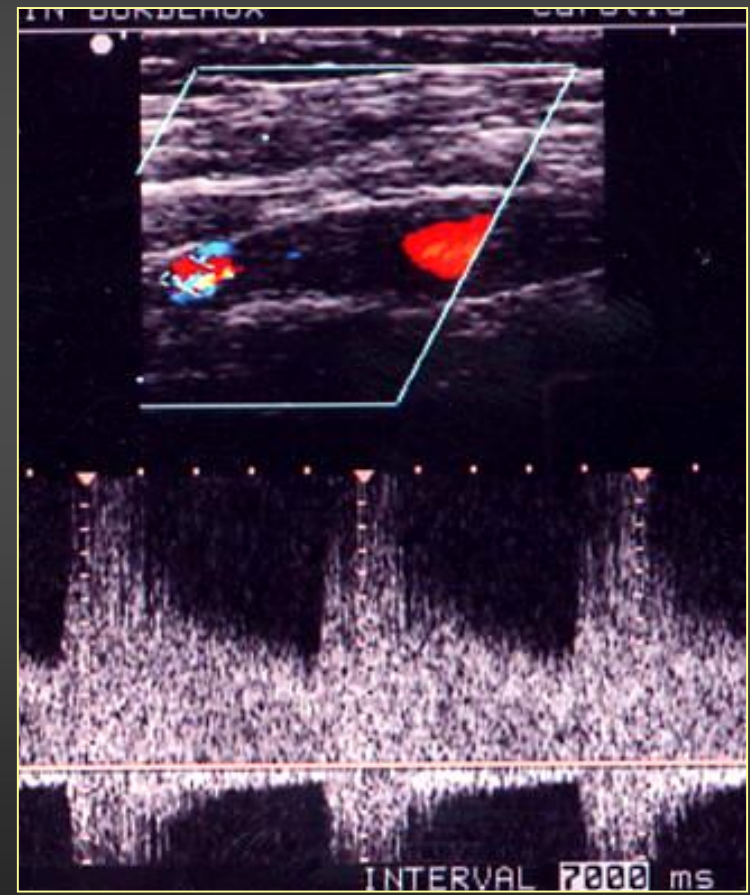
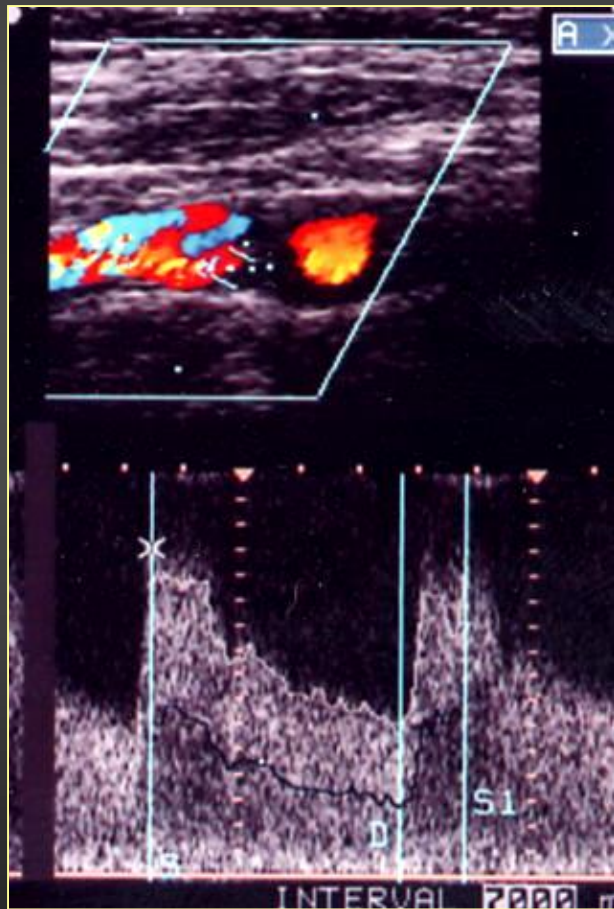
# BASES DU DOPPLER : SEMEIOLOGIE

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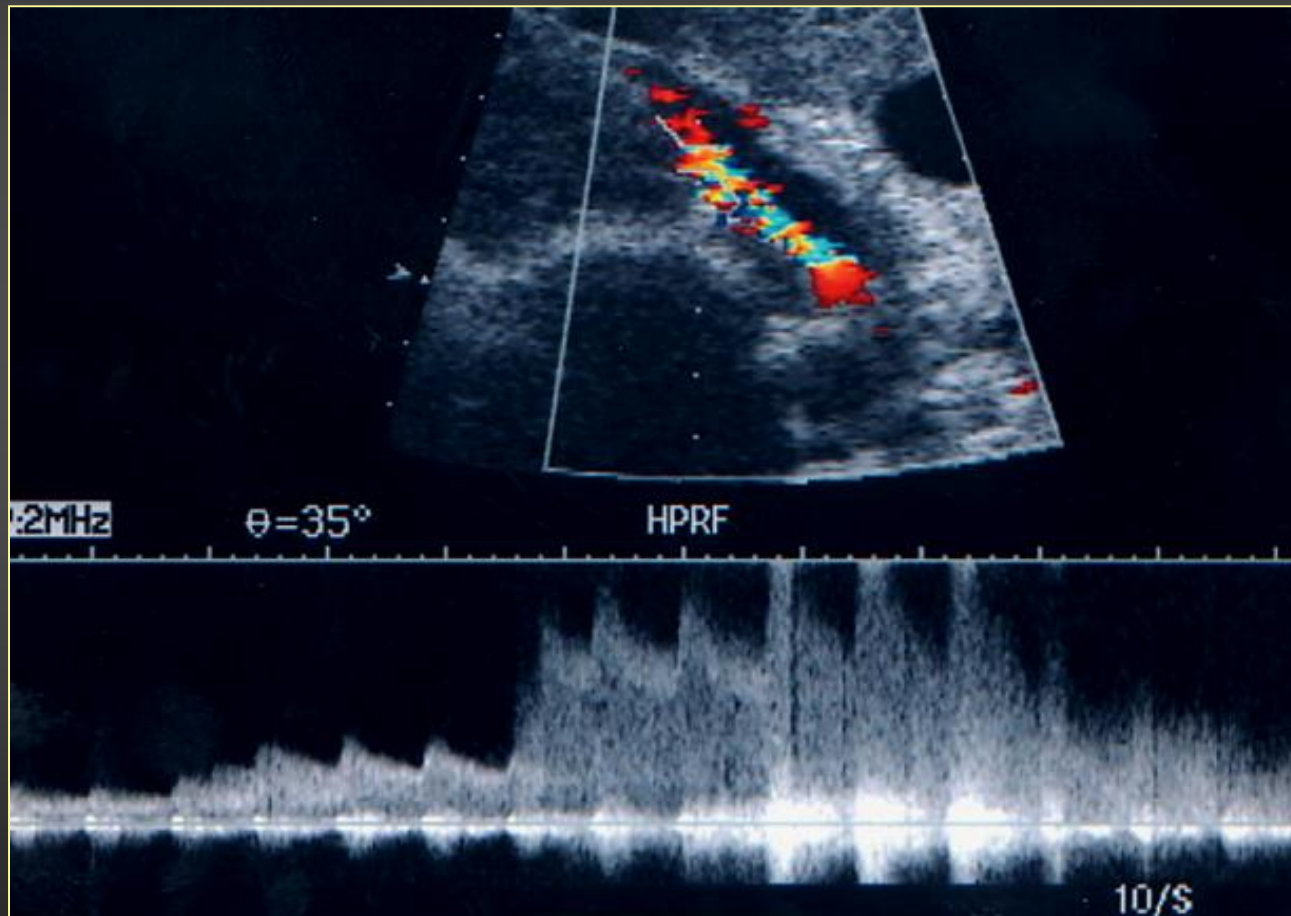
# STENOSE ARTERIELLE



# STENOSE ARTERIELLE



# STENOSE ARTERIELLE

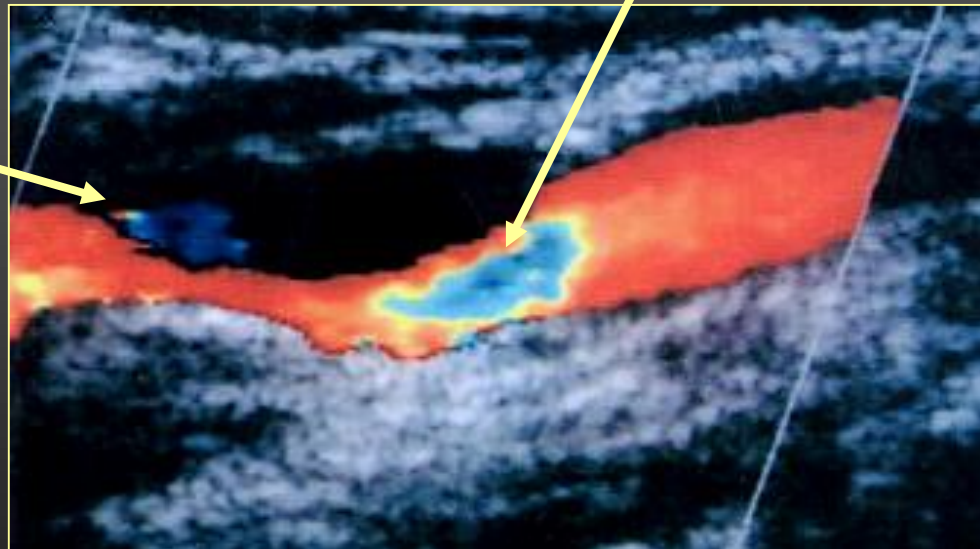


# STENOSE ARTERIELLE

- Signes directs en DC :
  - aliasing localisé
  - flux rétrogrades
  - artéfact péri-vasculaire

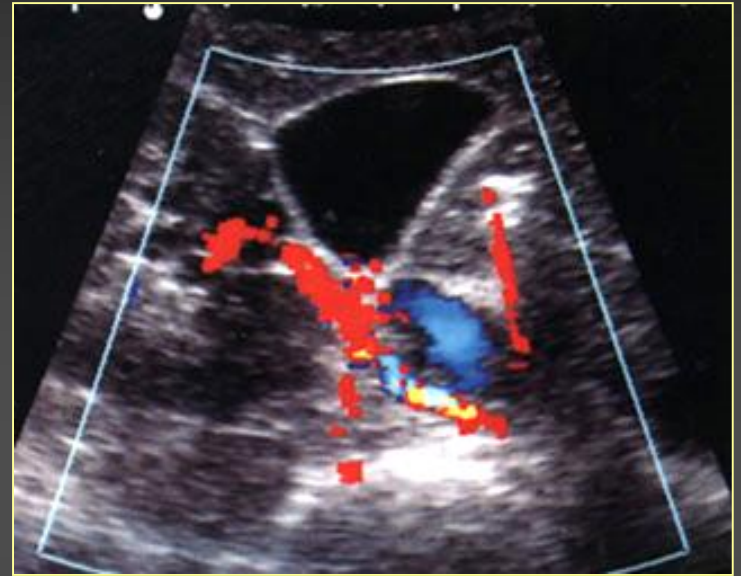
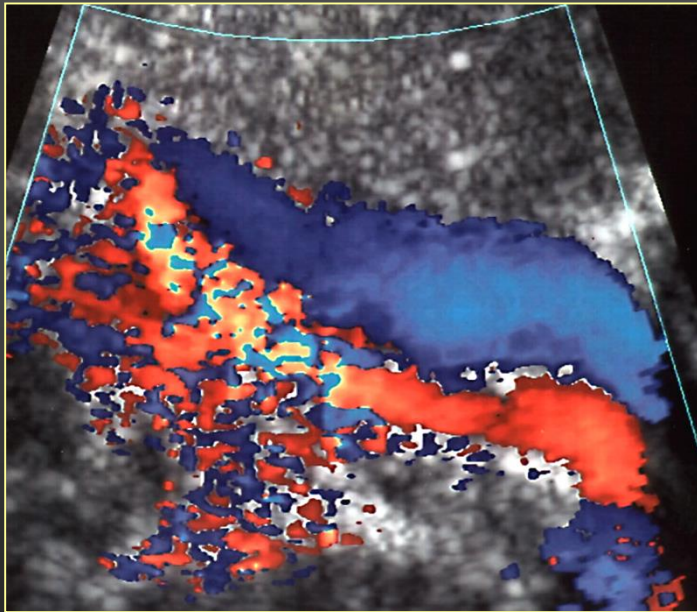
flux rétrograde  
(turbulences)

accélération



# STENOSE ARTERIELLE

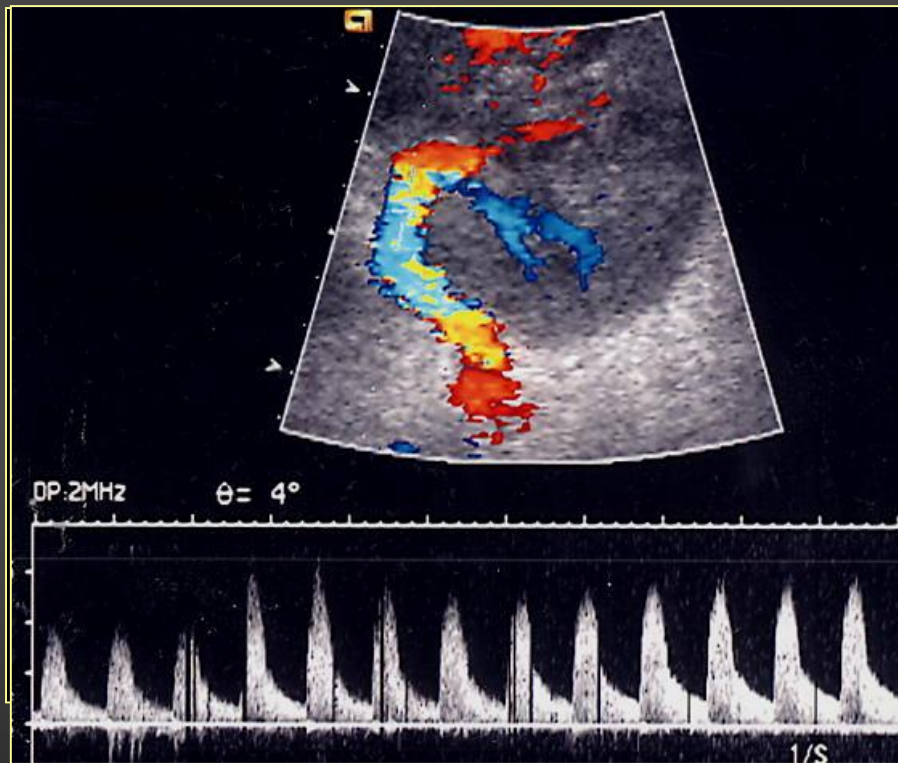
Artefact péri-vasculaire



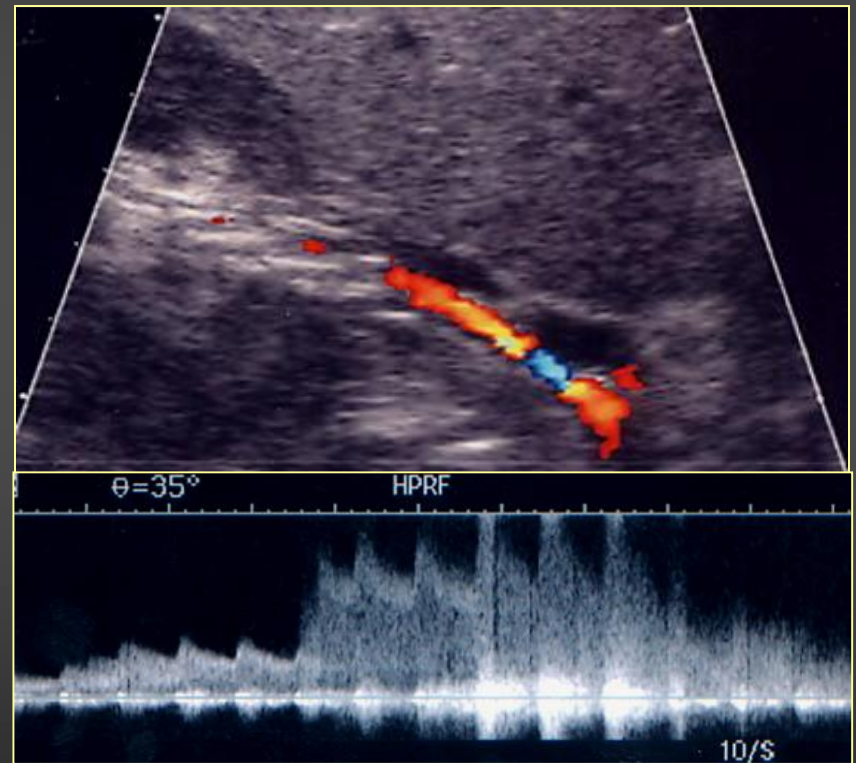


# STENOSE ARTERIELLE

## Aliasing localisé



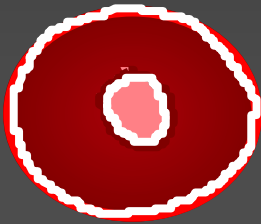
diminution de l'angle Doppler



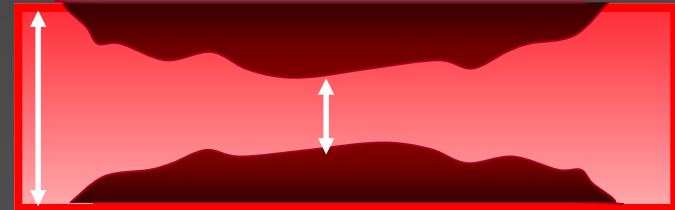
angle Doppler inchangé

# QUANTIFICATION DES STENOSES

- Estimation morphologique

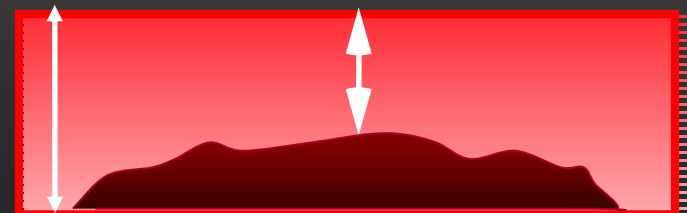


surface



diamètre

$$\% \text{ Sténose} = (1 - [St/N]) \times 100\%$$



# QUANTIFICATION DES STENOSES

- Estimation morphologique



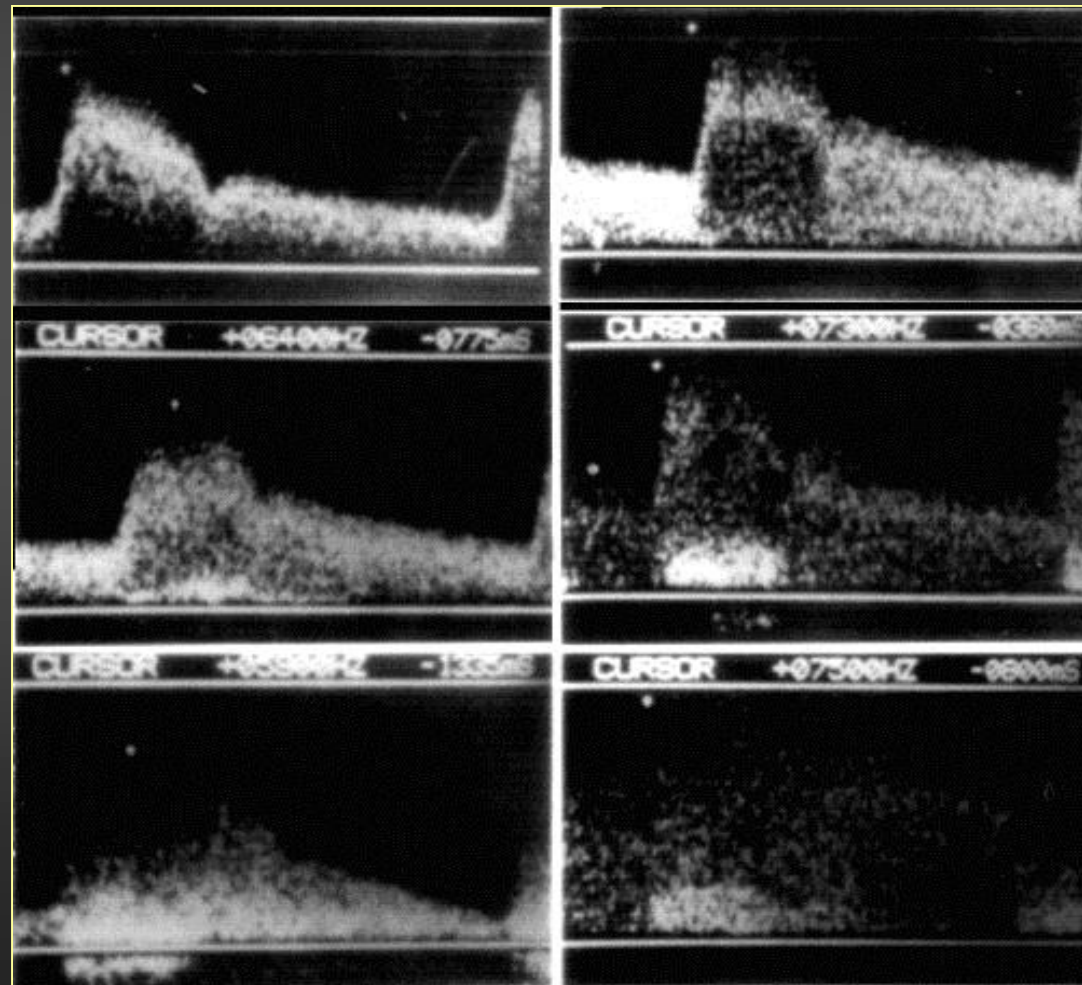
% de réduction de diamètre



% de réduction de surface

# QUANTIFICATION DES STENOSES

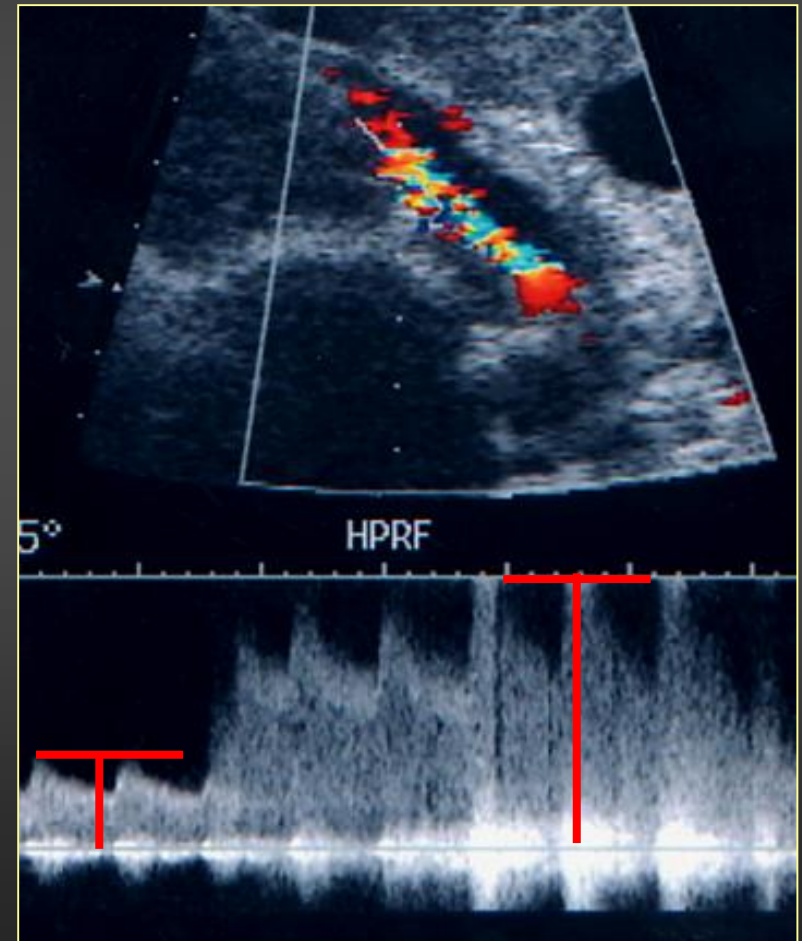
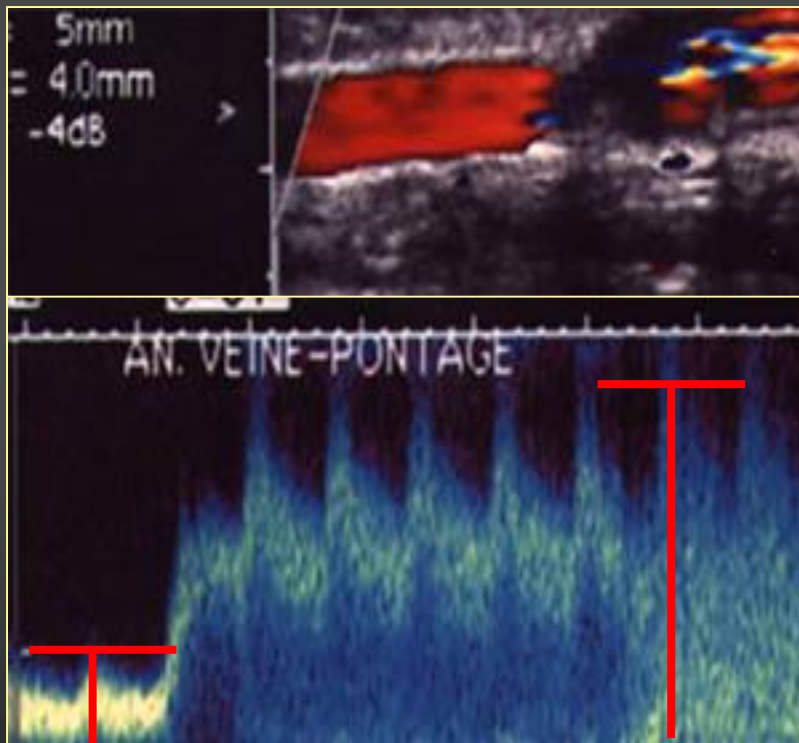
- Degré d'altération spectrale



*Arbeille*

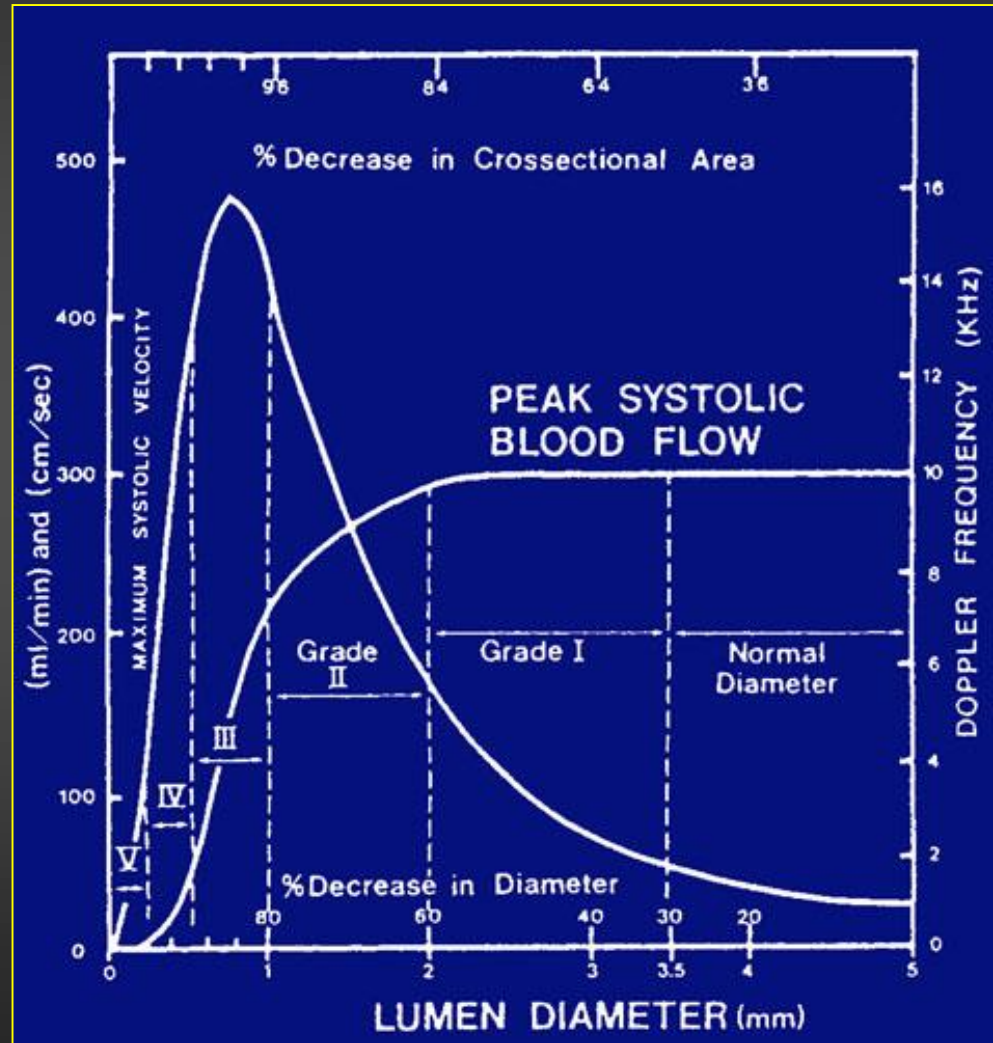
# QUANTIFICATION DES STENOSES

- Rapports de vitesses systoliques maximales ou de rapport/segment normal

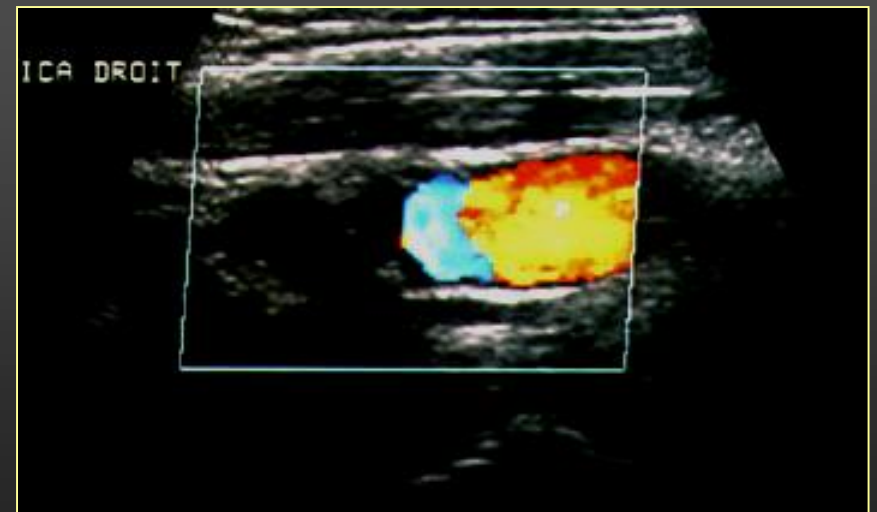


# QUANTIFICATION DES STENOSES

Relation % sténose vs  
vitesse et débit



# L'OCCLUSION ARTERIELLE



# L'OCCLUSION ARTERIELLE

- Pièges

*angle Doppler  
trop grand*

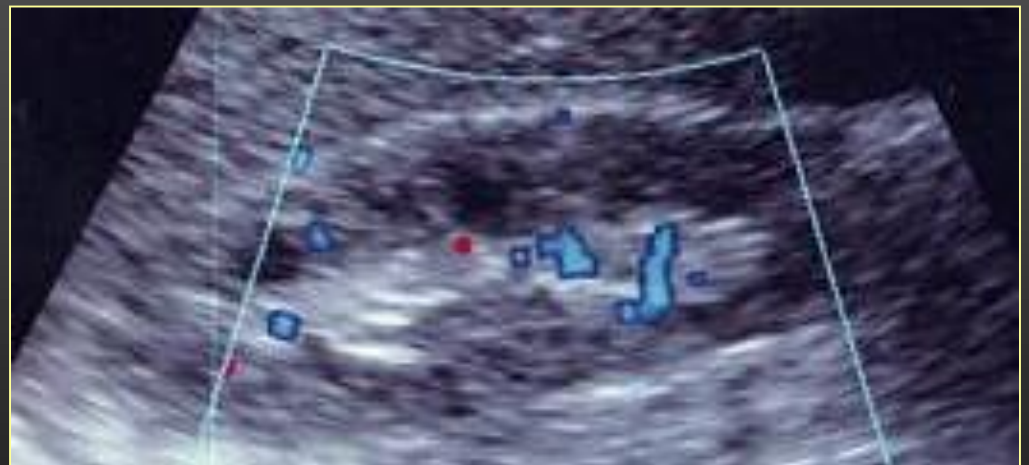
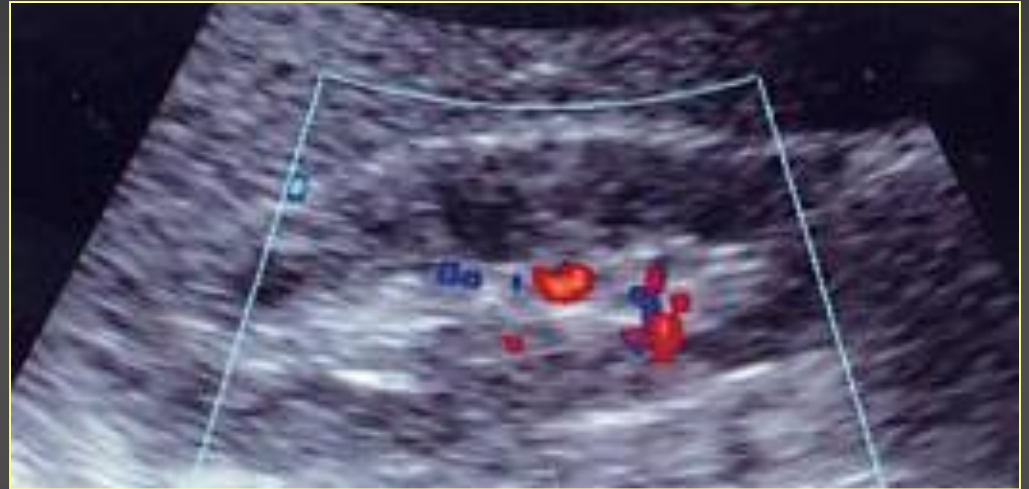
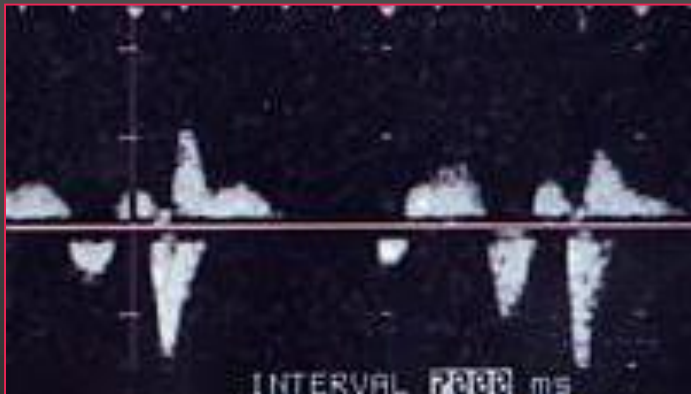




# L'OCCLUSION ARTERIELLE

- Pièges

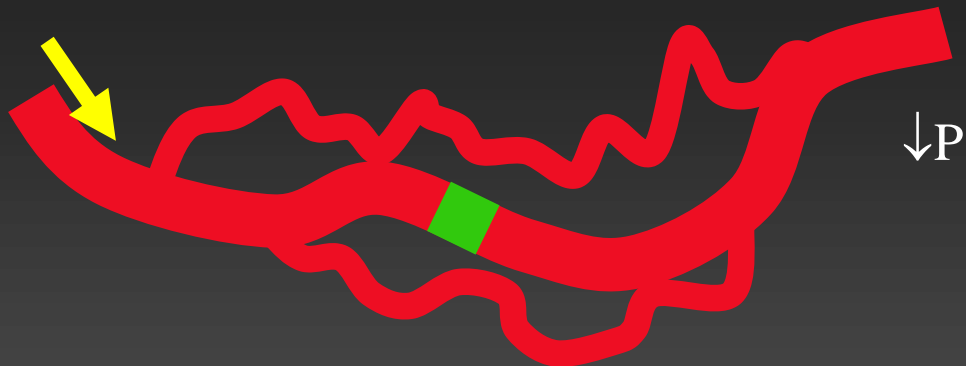
*veines perméables*



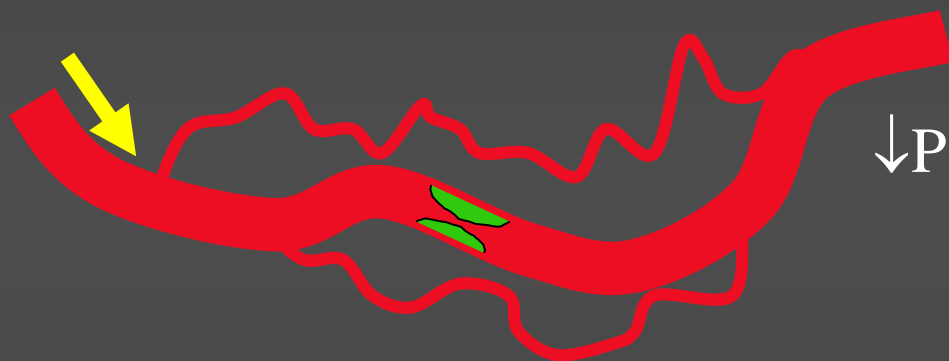
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# SIGNES INDIRECTS D'OBSTACLE VASCULAIRE

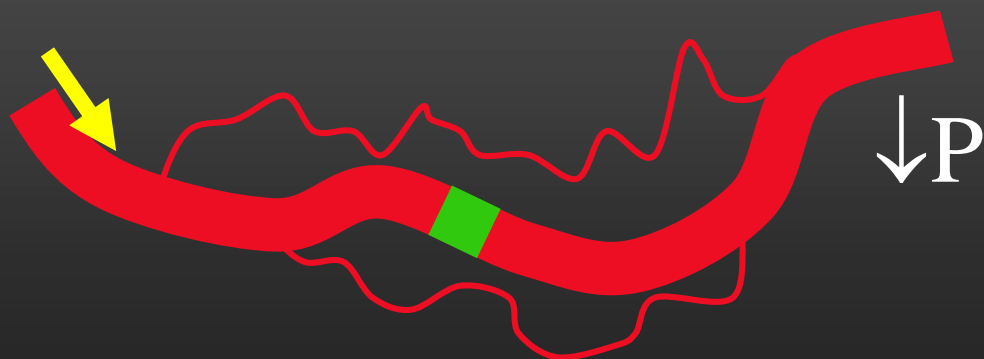
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**Obstacle avec collatéralité développée :**  
bonne suppléance



**Obstacle avec collatéralité modérée :**  
insuffisance à l'effort

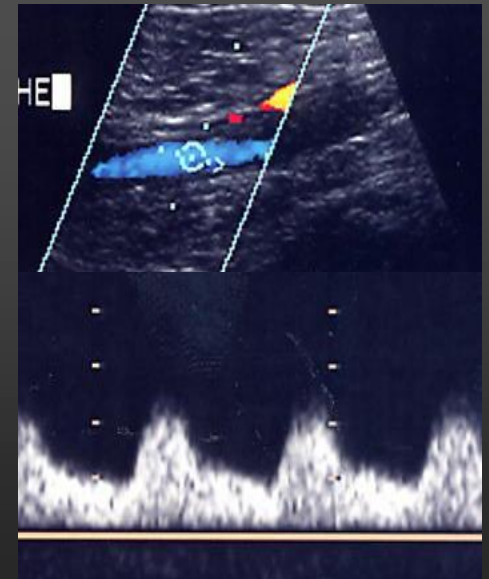
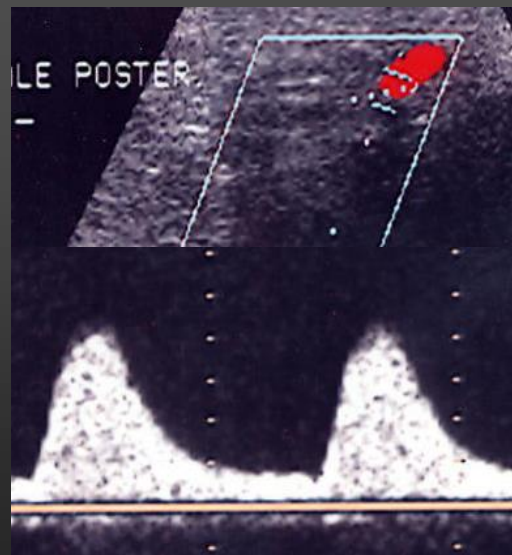
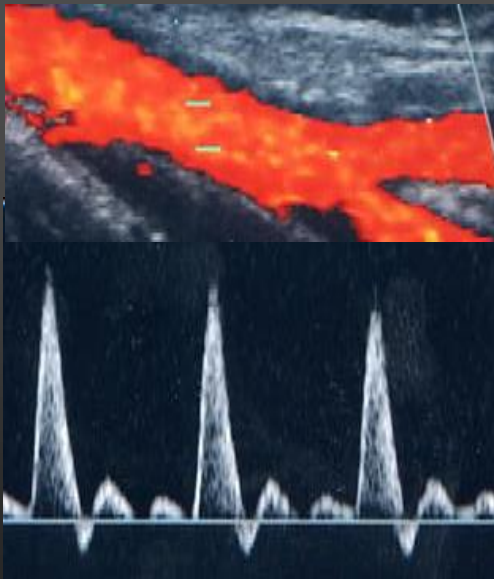
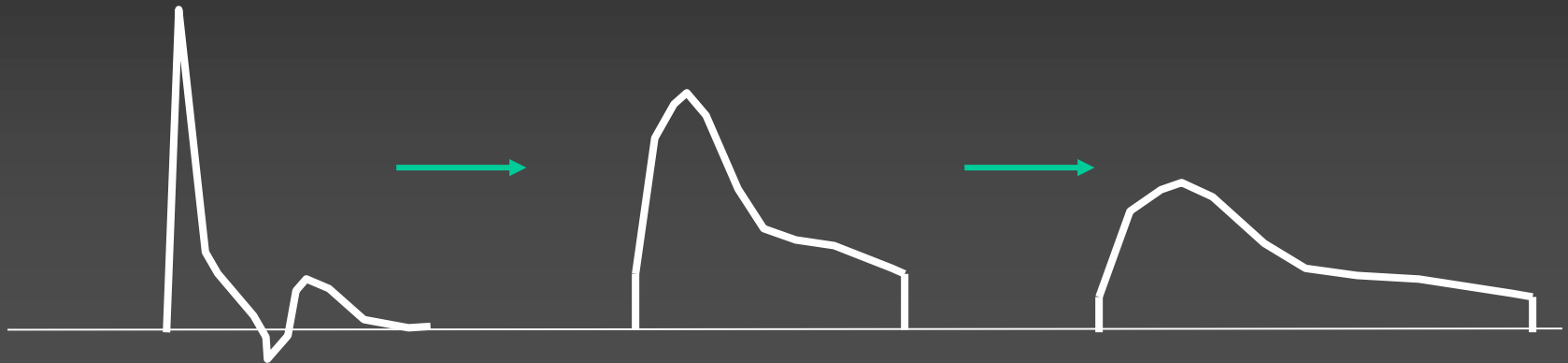


**Obstacle avec collatéralité faible :**  
insuffisance artérielle sévère

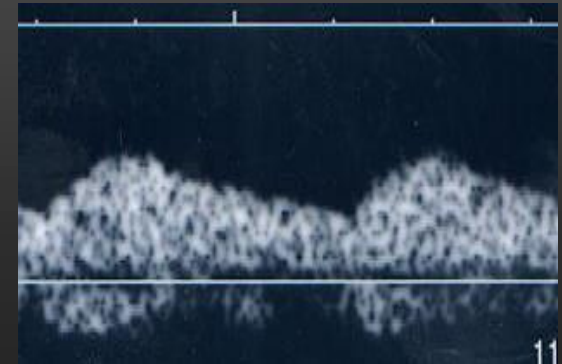
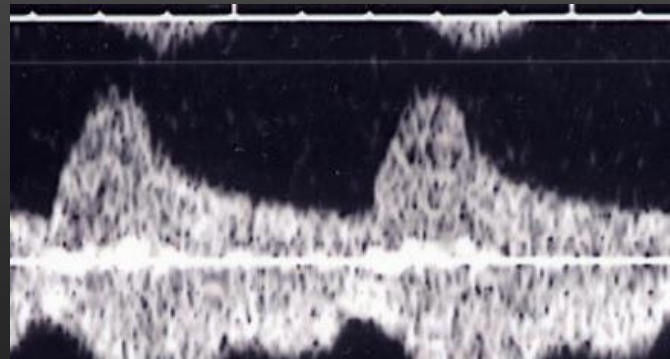
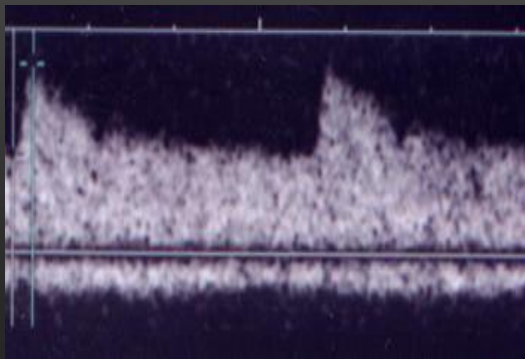
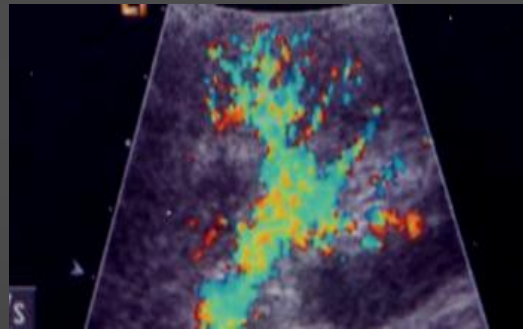
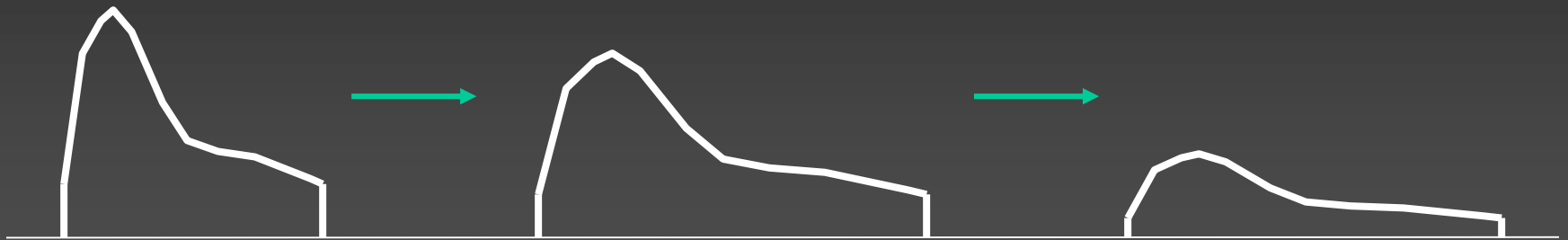
# Signes hémodynamiques d'hypoperfusion

- On observe en distalité, en aval de l'obstacle :
  - une *diminution des résistances vasculaires* liée à la vasodilatation
  - un *ralentissement de l'accélération systolique* lié à l'obstacle qui freine la propagation de l'onde de pouls (ou onde de pression systolique)

# Obstruction vasculaire: signes d'aval

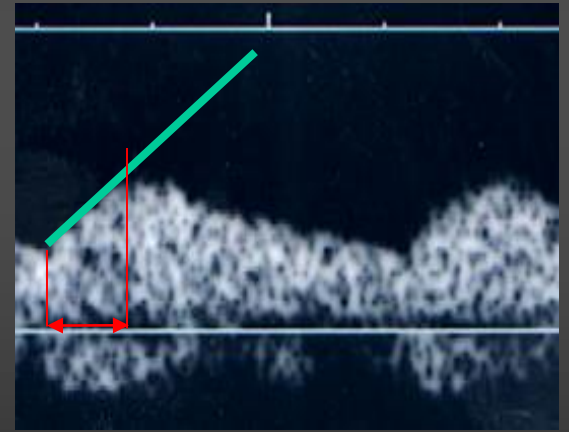
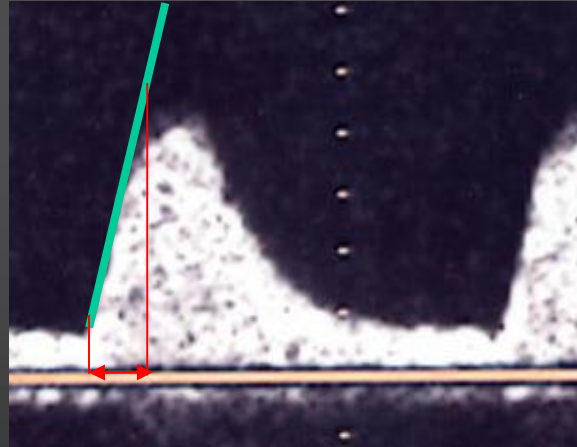
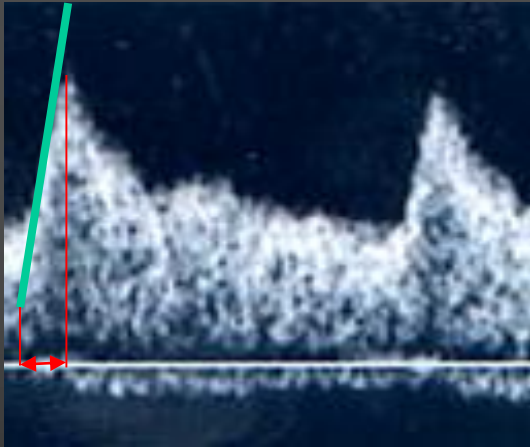


# Obstruction vasculaire: signes d'aval



# Obstruction vasculaire: signes d'aval

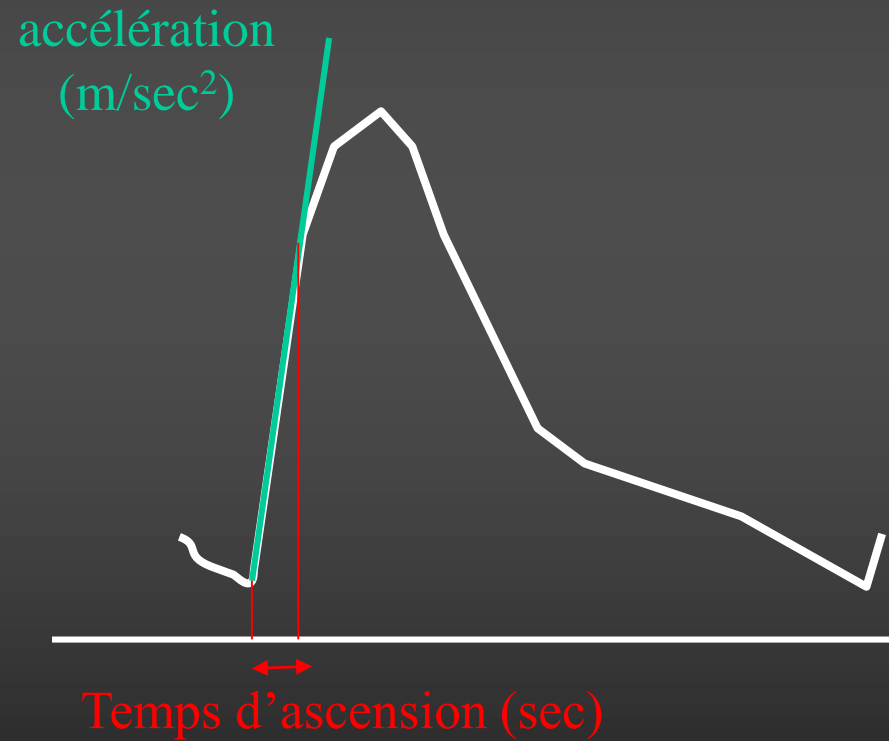
- Diminution de l'accélération systolique



# Obstruction vasculaire: signes d'aval

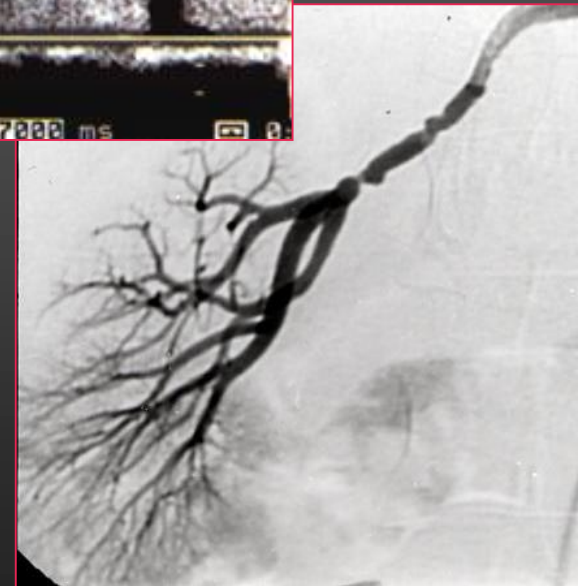
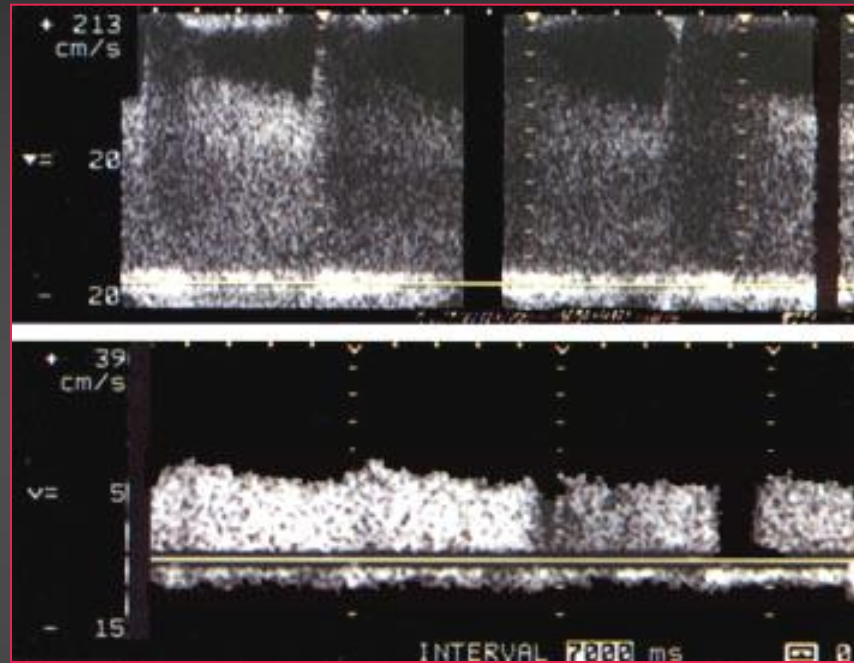
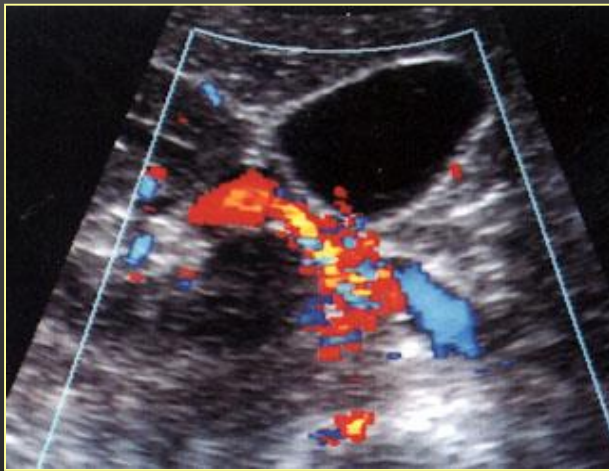
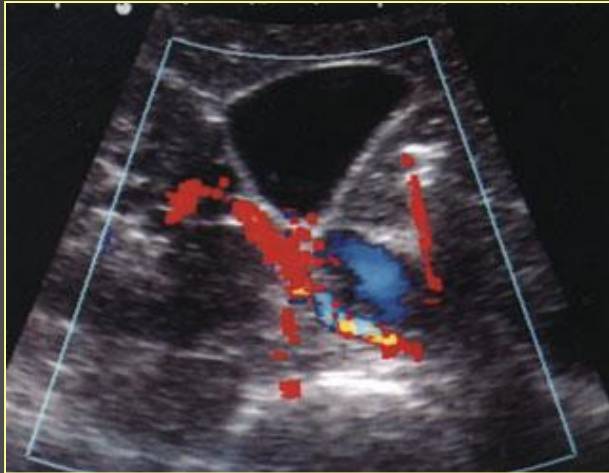
- Quantification de l'accélération systolique :

- Soit la **pente d'accélération**
  - Mesure angle-dépendante donc sujette à erreurs +++
- Soit le **temps d'ascension**
  - Plus robuste car angle-indépendant



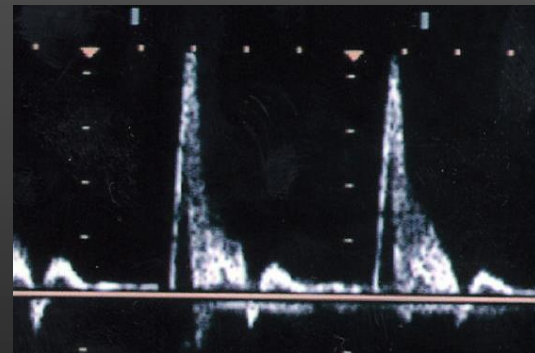
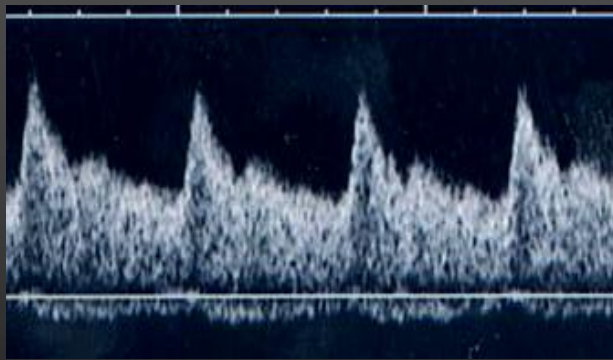
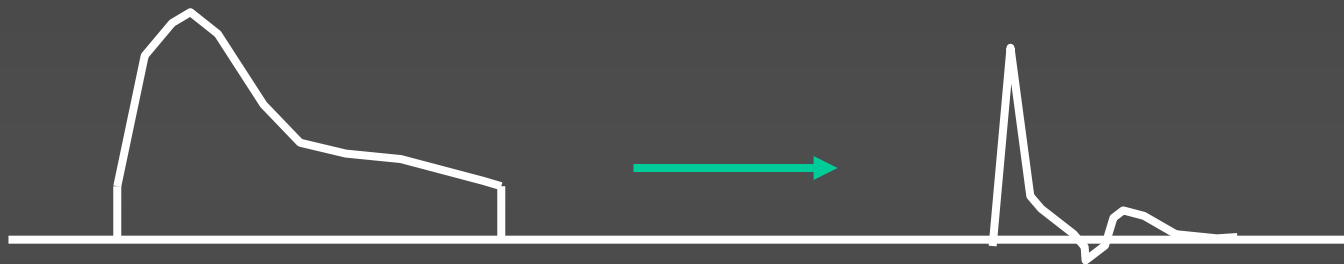


# Sténose > 75%



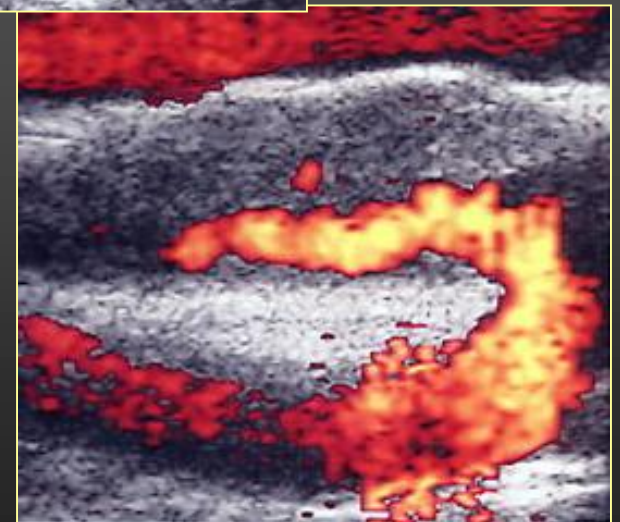
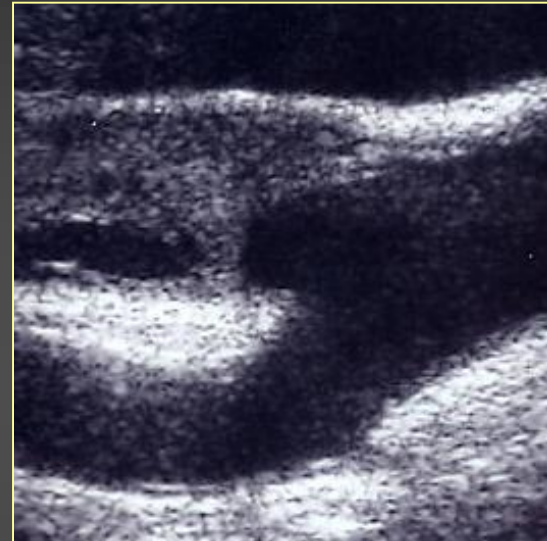
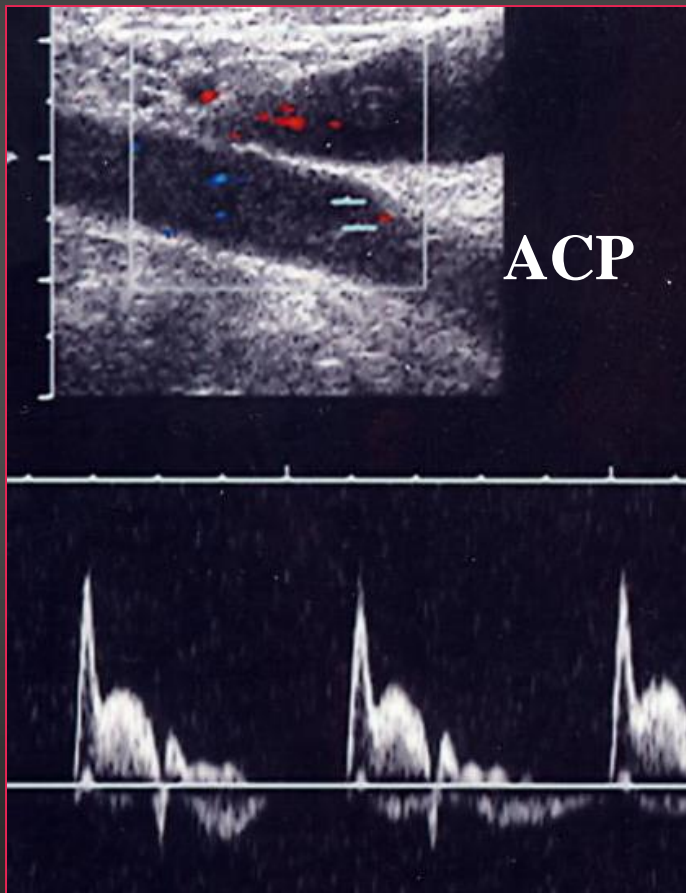
# Obstruction vasculaire: signes d'amont

On observe, en amont d'un obstacle serré mal compensé, une résistance additionnelle :



*Mais cela n'est perceptible que sur les écoulements initialement à basse résistance*

# Obstruction vasculaire: signes d'amont



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# LES SHUNTS ARTERIO-VEINEUX

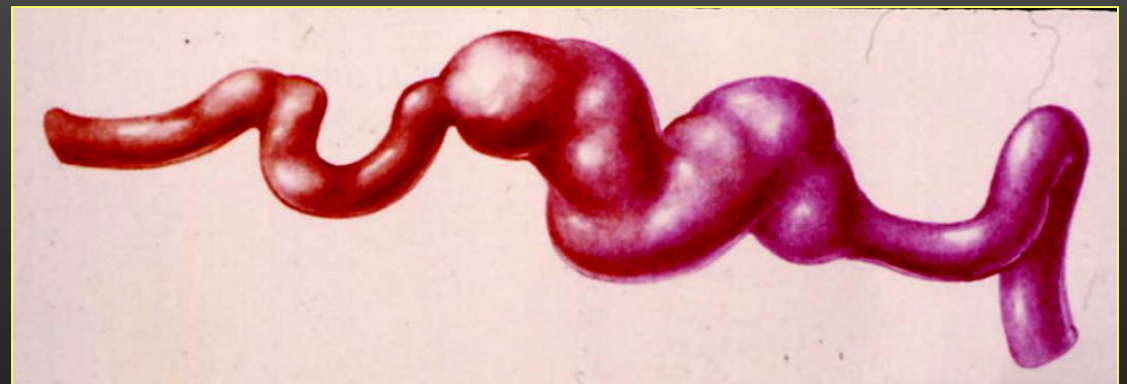
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# SHUNTS ARTERIO-VEINEUX



Shunts microscopiques :

- Malformations vasculaires à nidus
- Tumeurs malignes



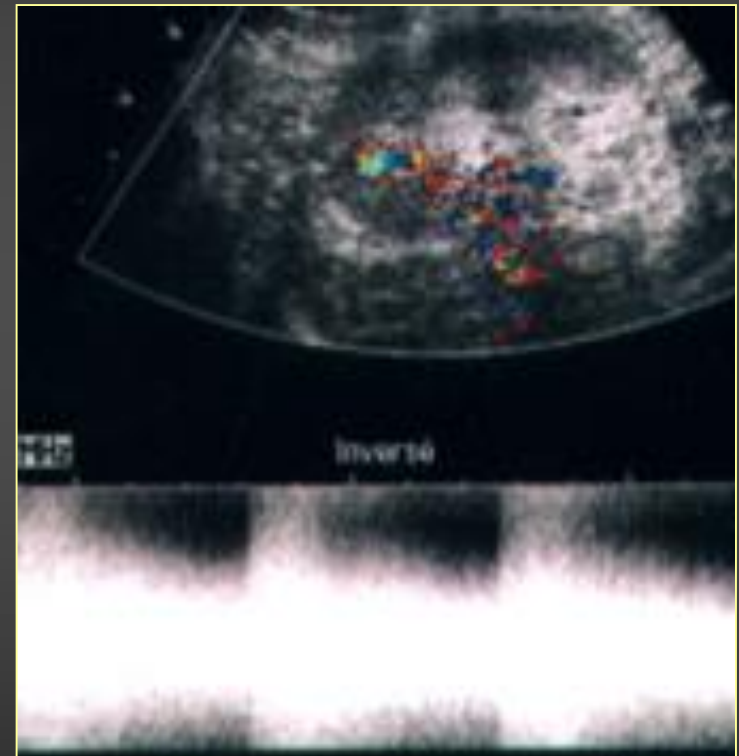
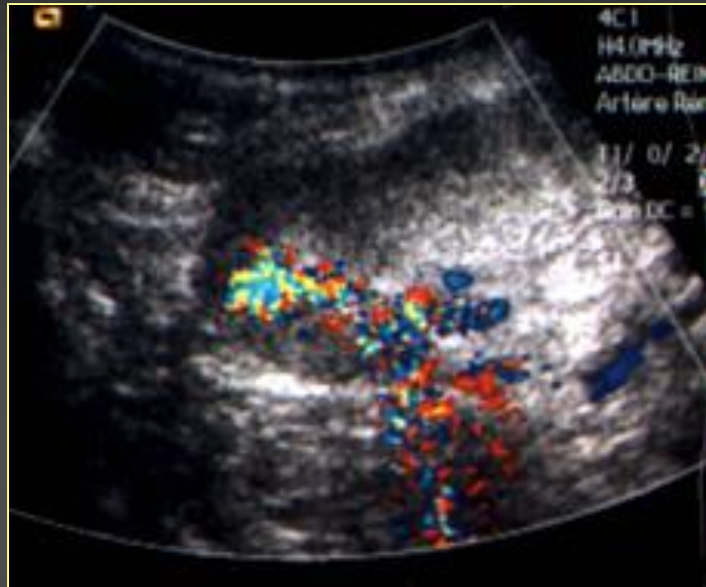
Shunts microscopiques :  
fistules AV  
(*congénitales ou acquises*)

# SHUNTS ARTERIO-VEINEUX

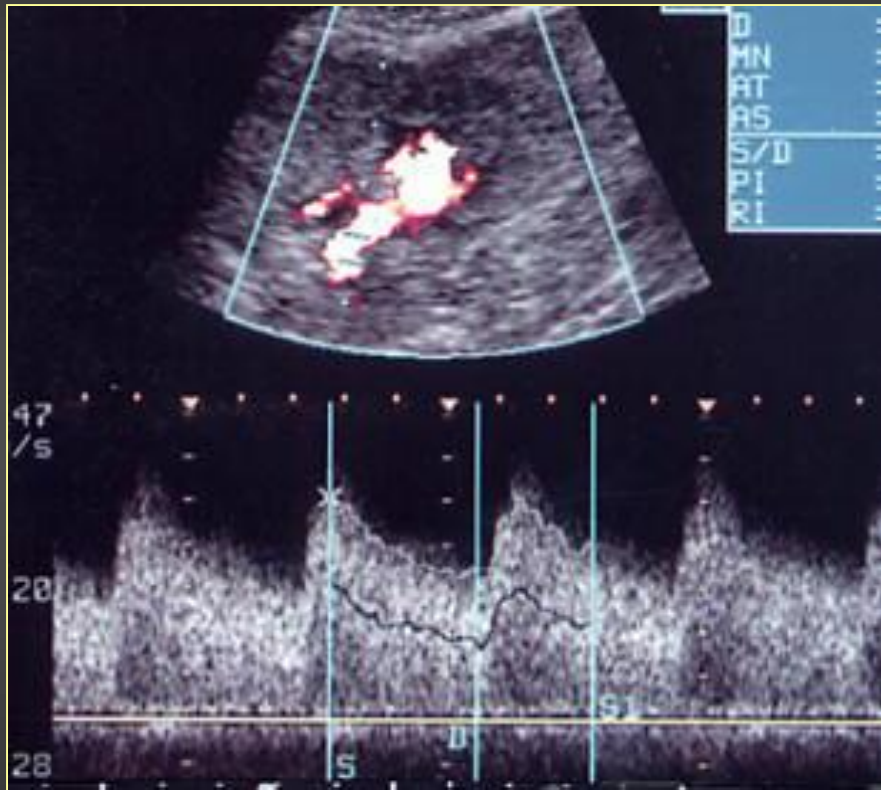
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- Signes artériels :
  - Accélération des vitesses circulatoires sur tout l'axe afférent
  - Altération du profil de l'écoulement
  - Diminution des résistances
  - Plus marquées au fur et à mesure que l'on se rapproche du shunt
- Signes veineux :
  - Accélération des vitesses circulatoires
  - Perte de la modulation respiratoire
  - Modulation artérielle

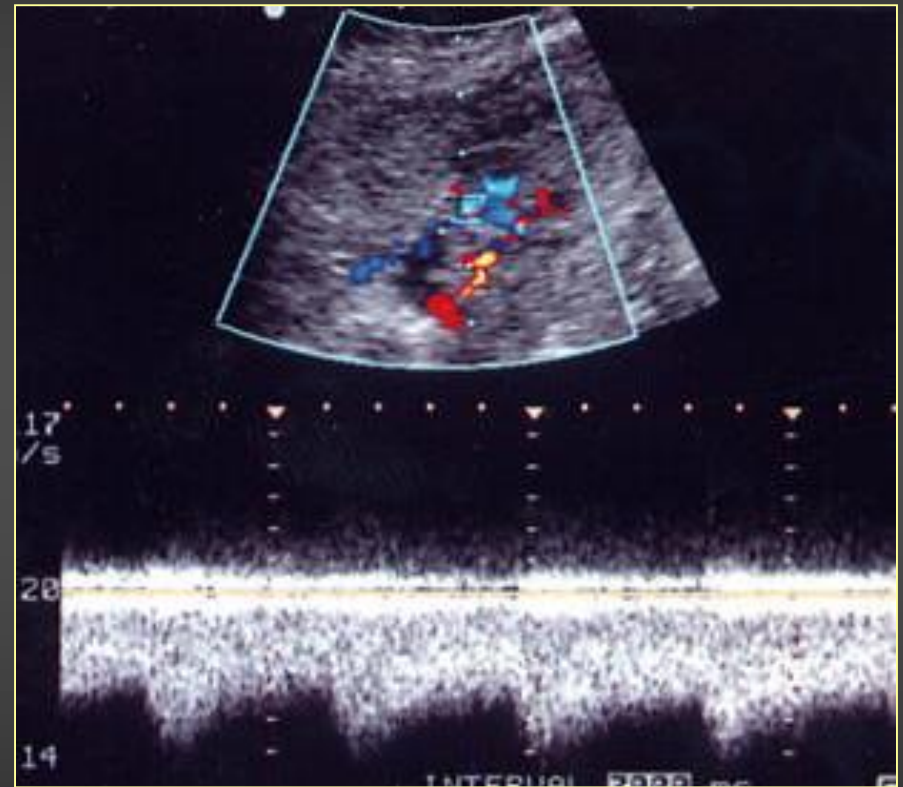
# SHUNTS ARTERIO-VEINEUX



# SHUNTS ARTERIO-VEINEUX



Artère afférente



Veine efférente



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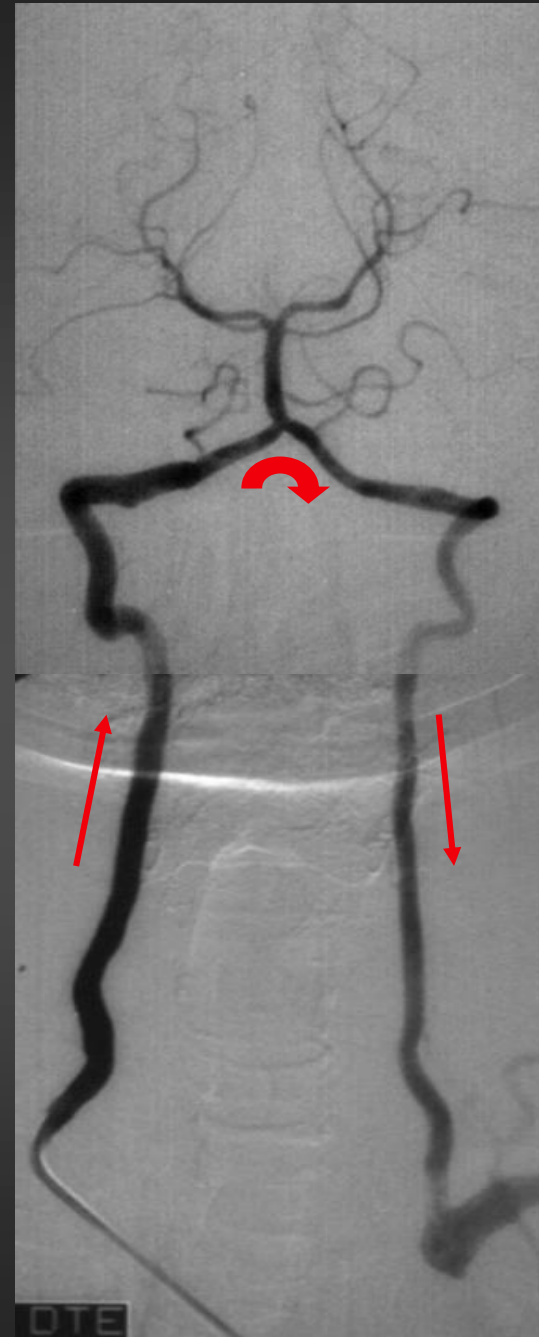
# LE VOL VASCULAIRE

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# Vol Sous-Clavier

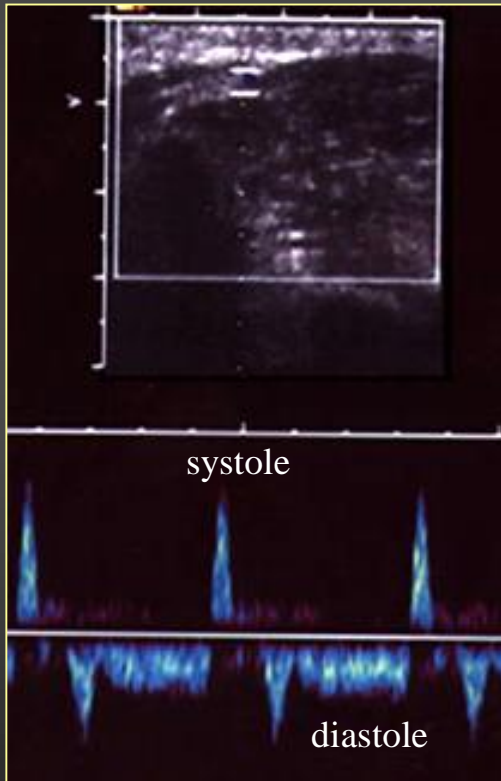


Sténose de l'artère  
sous-clavière G

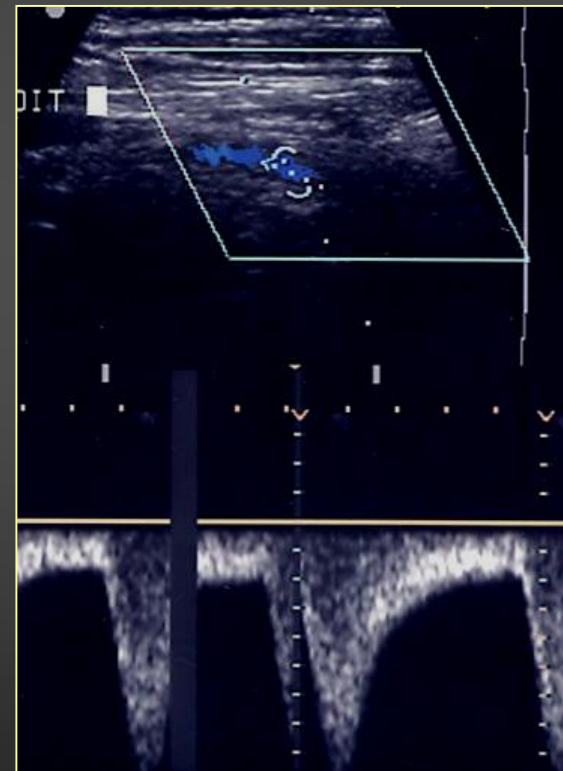


# Vol Sous-Clavier

- Doppler de l'artère vertébrale G :

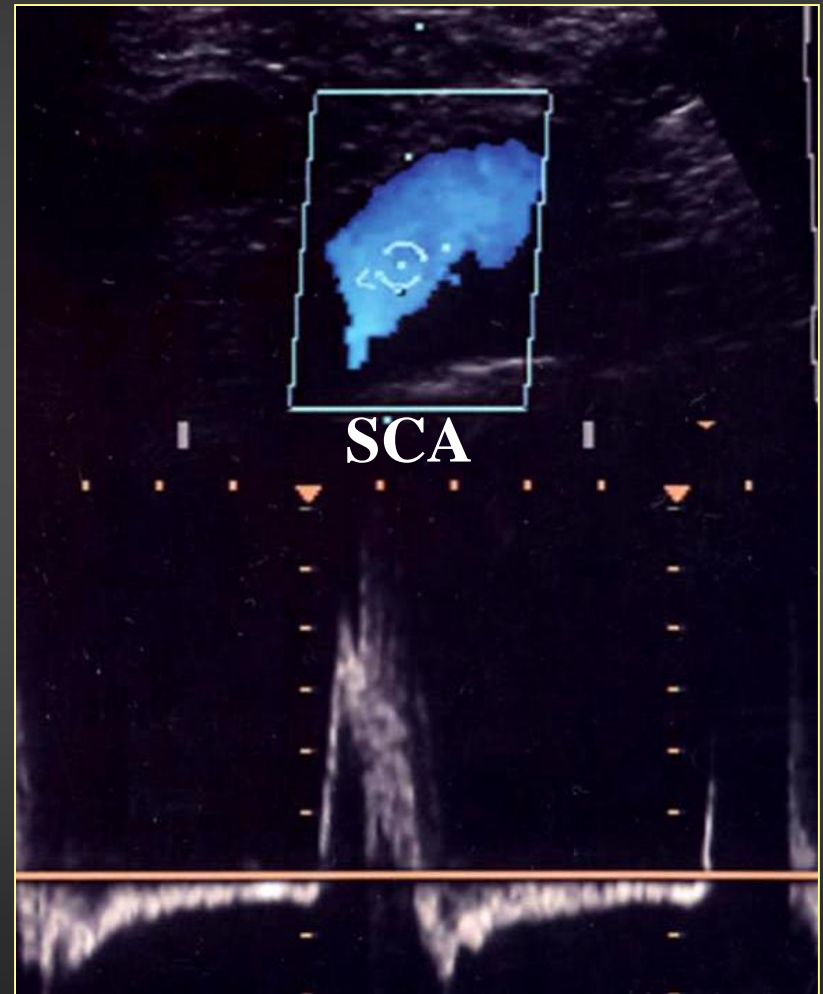
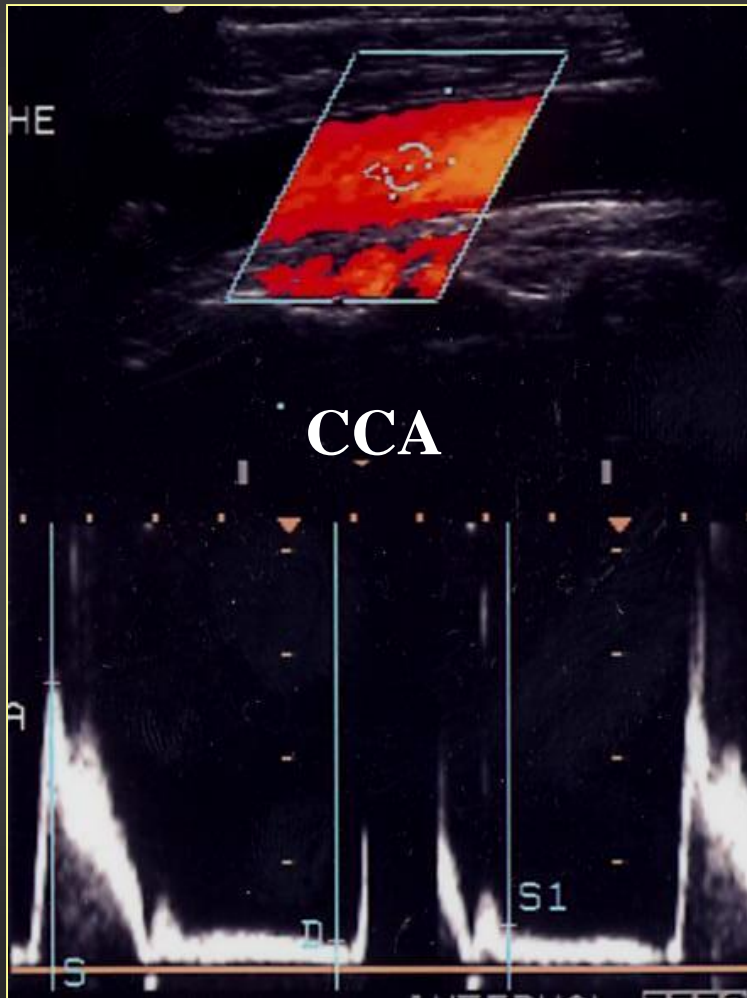


Vol intermittent

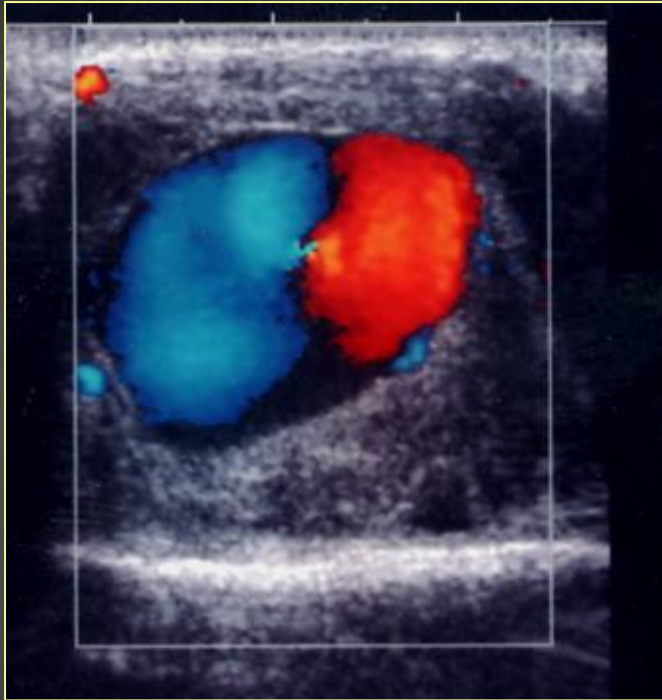


Vol permanent

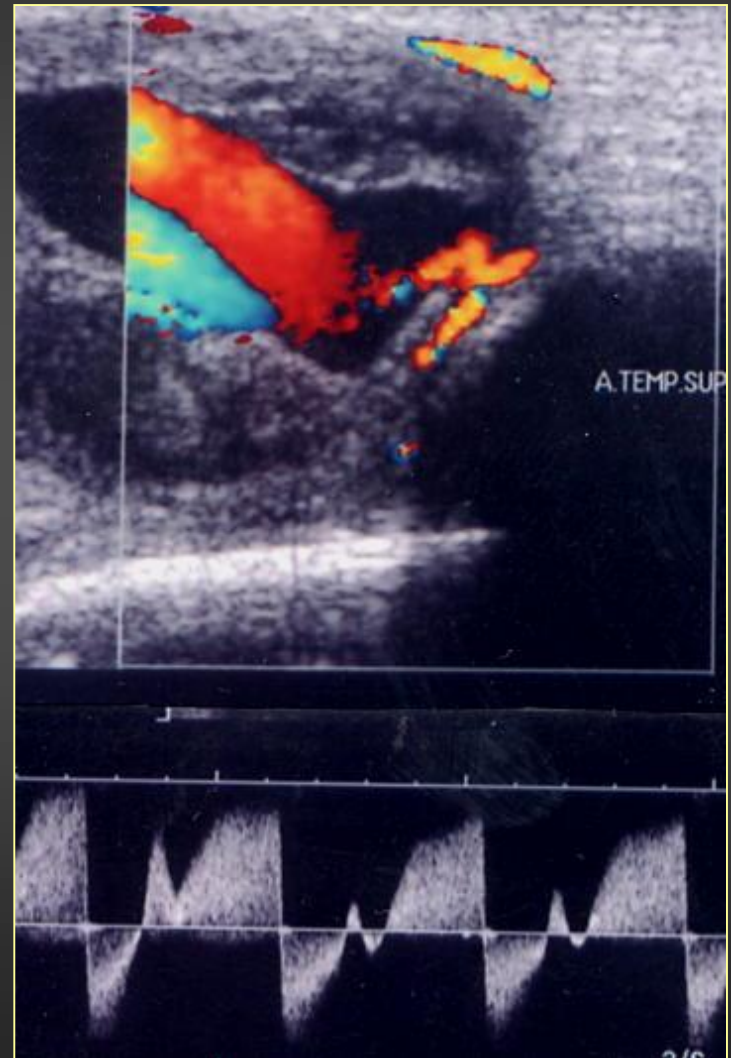
# VOL VASCULAIRE : insuffisance aortique



# Anévrismes et pseudo-anévrismes



Flux en « aller-retour » au niveau du collet étroit



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# BASES DU DOPPLER : PIEGES ET ARTEFACTS

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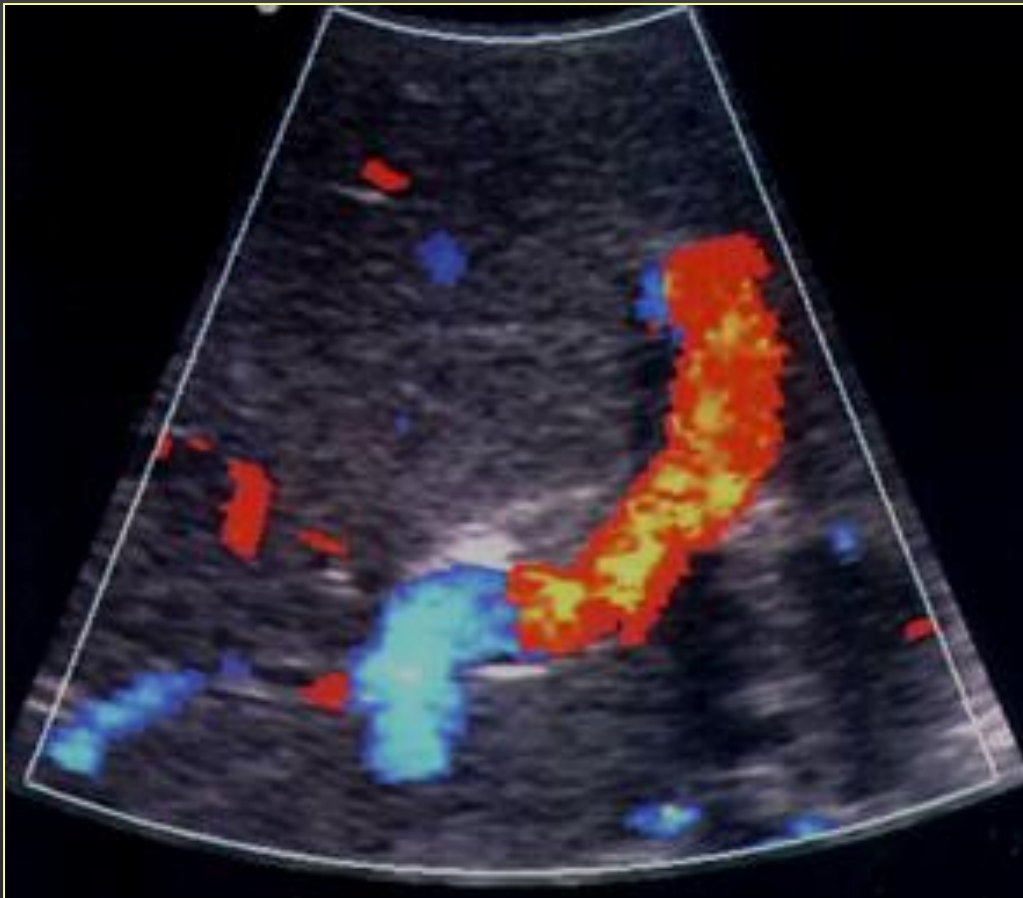
# Pièges et artefacts

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- Changements de couleur dans un vaisseau
- Flux extra-vasculaires
- « Bruits »

# Changement de couleur dans un vaisseau

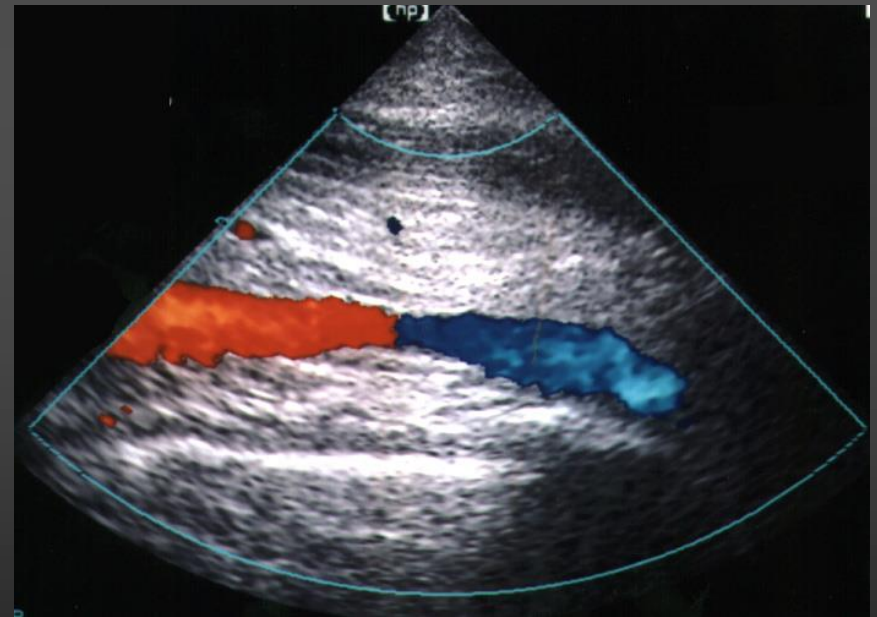
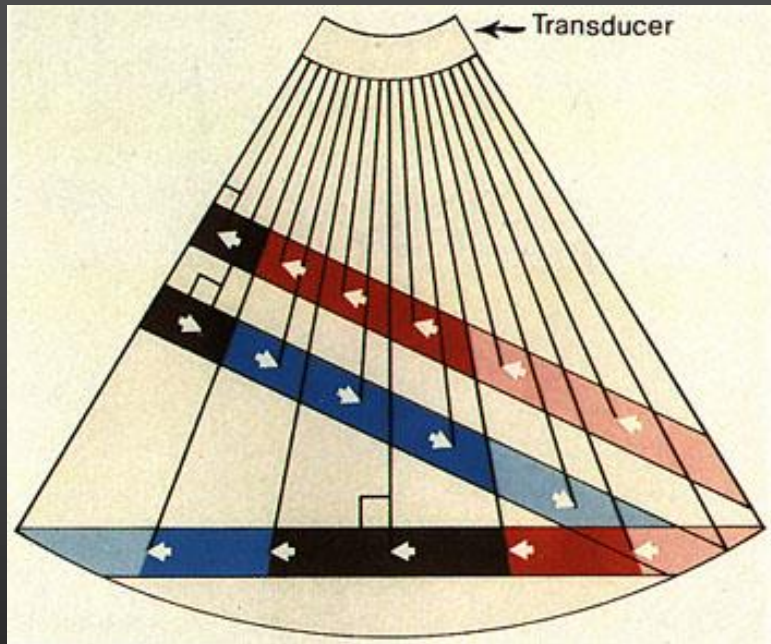
- Sinuosités et bifurcations





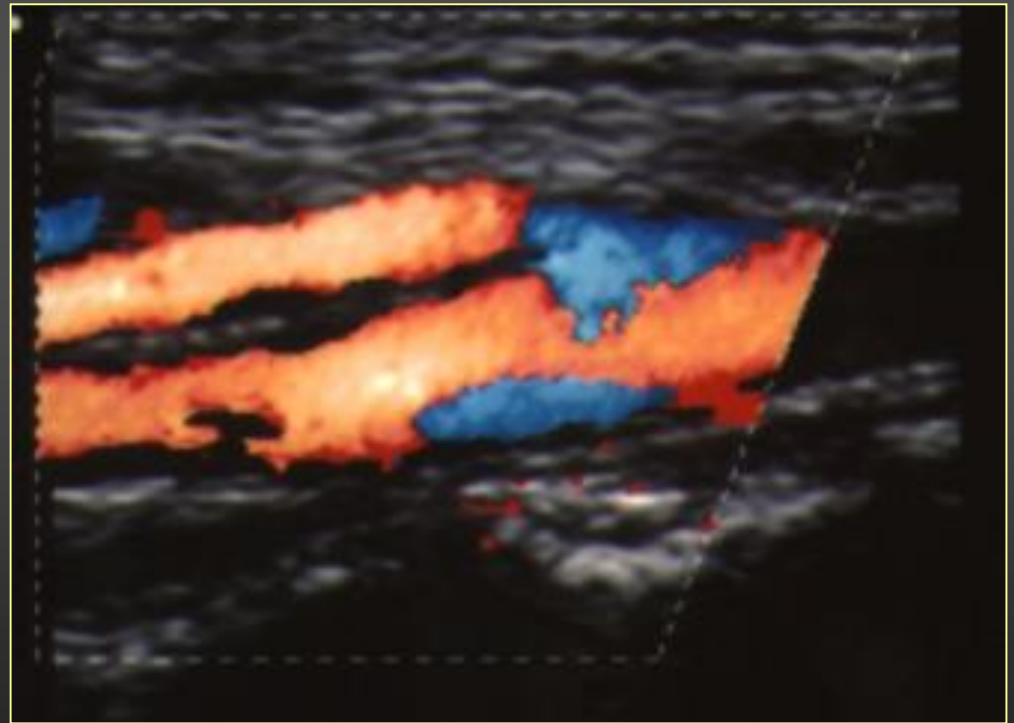
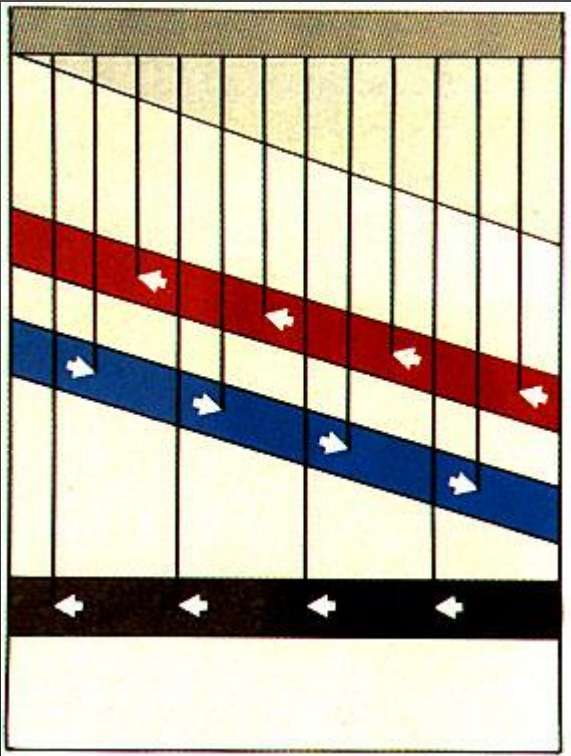
# Changement de couleur dans un vaisseau

- Aspect normal d'un **vaisseau rectiligne** vu avec une sonde **sectorielle** : les changements de couleur traduisent des changements d'angle doppler dans le champ de l'image

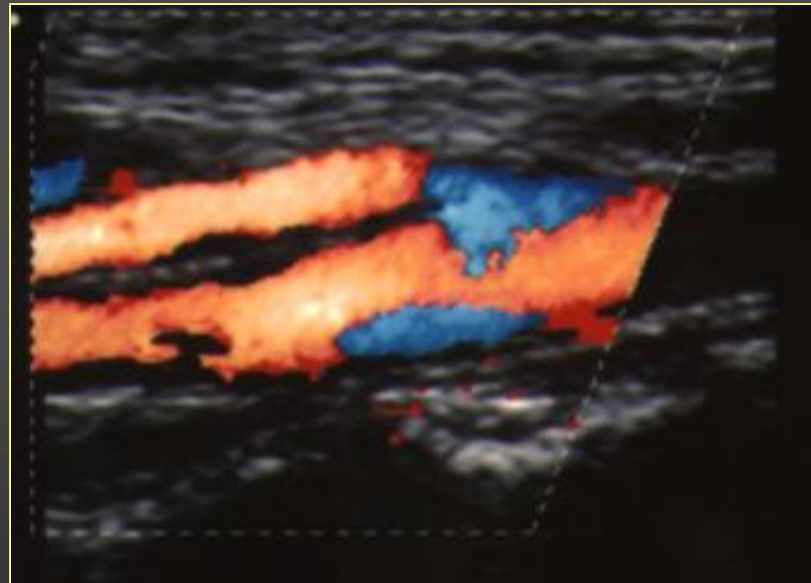
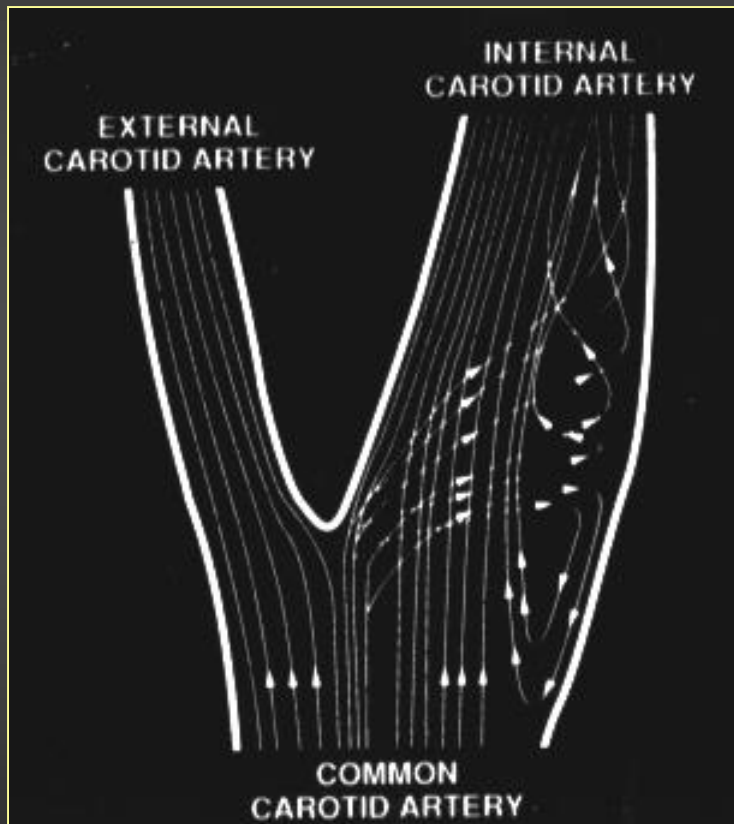


# Changement de couleur dans un vaisseau

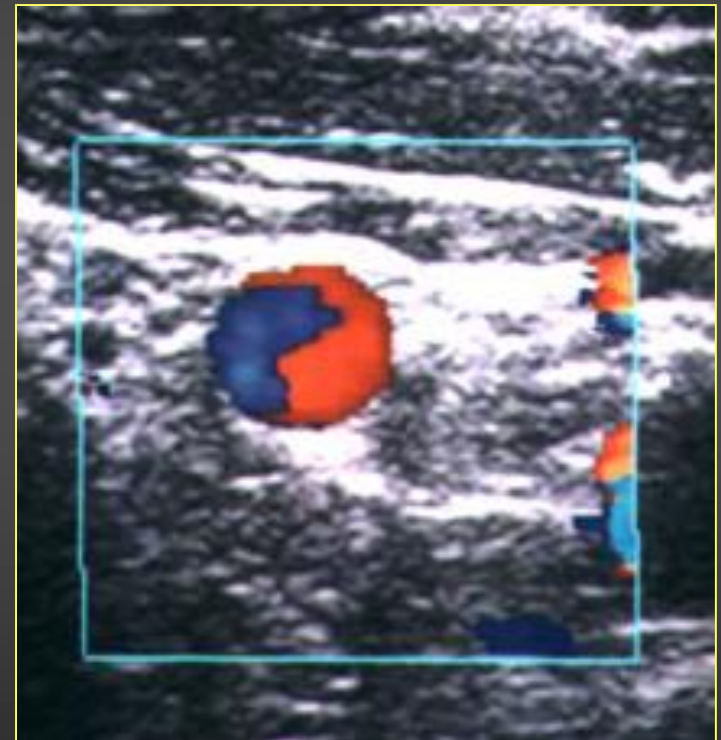
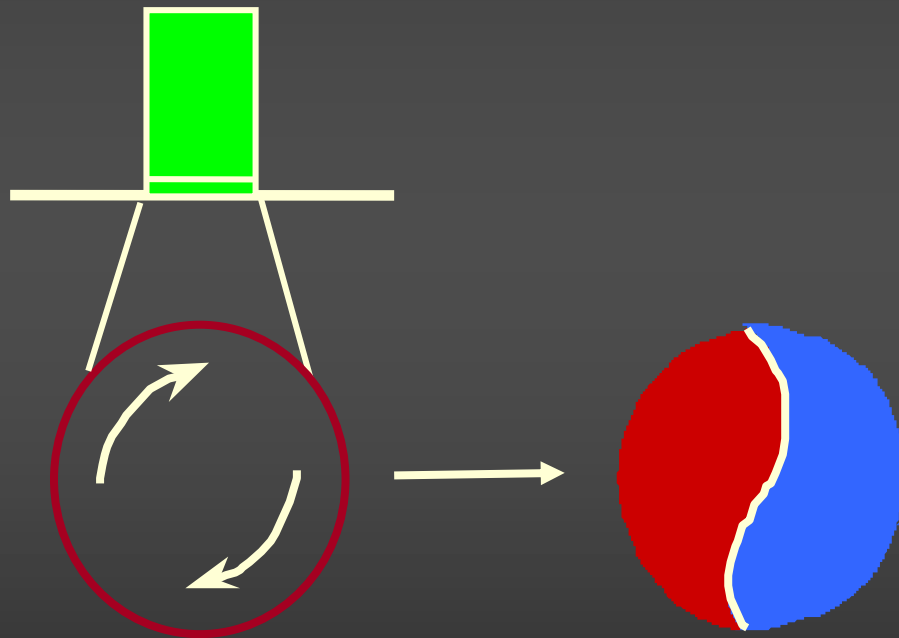
- Aspect normal d'un **vaisseau rectiligne** vu avec une sonde **linéaire** : les changements de couleur traduisent des changements de direction des lignes de flux



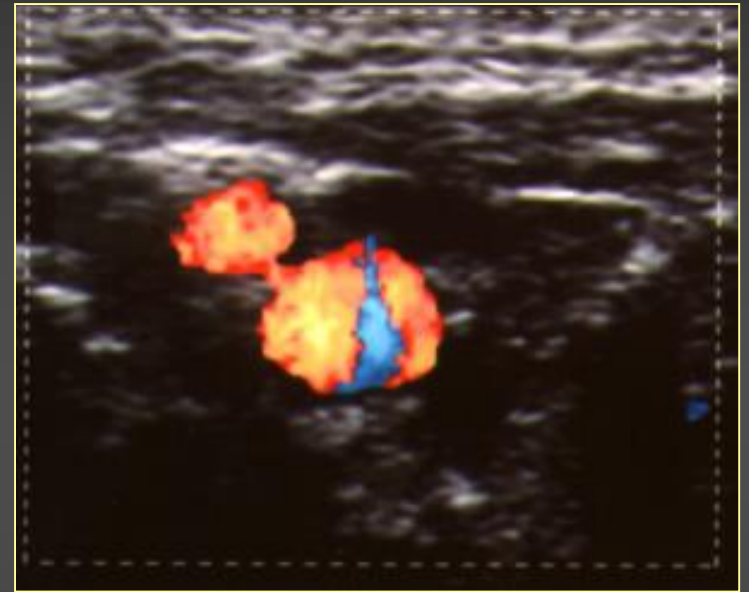
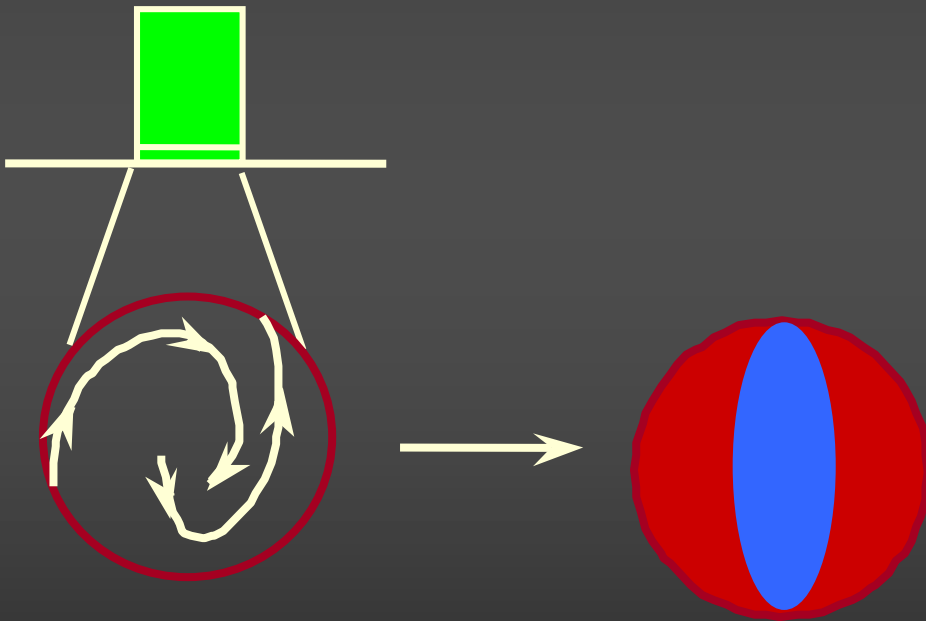
# Séparation des lignes de flux



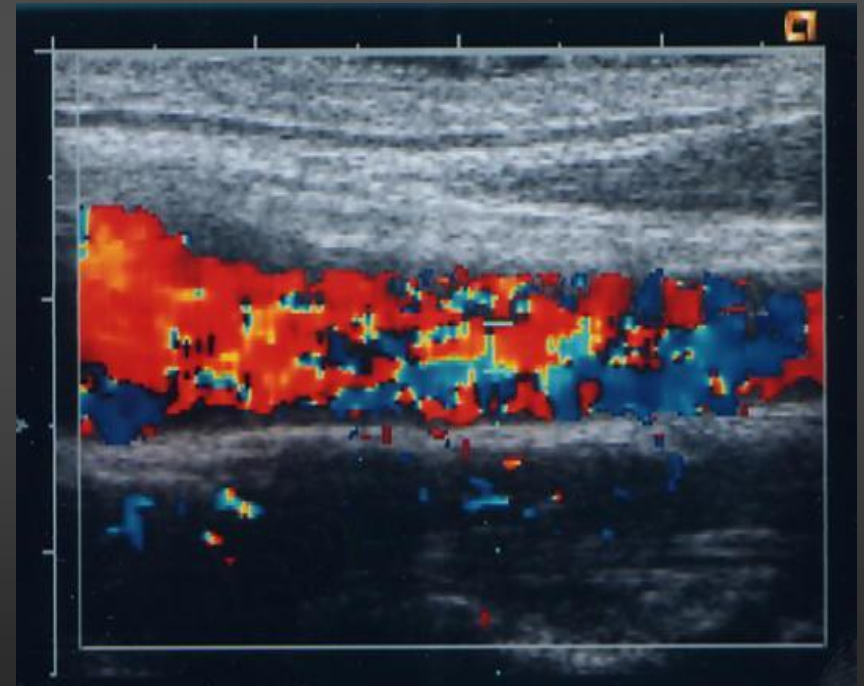
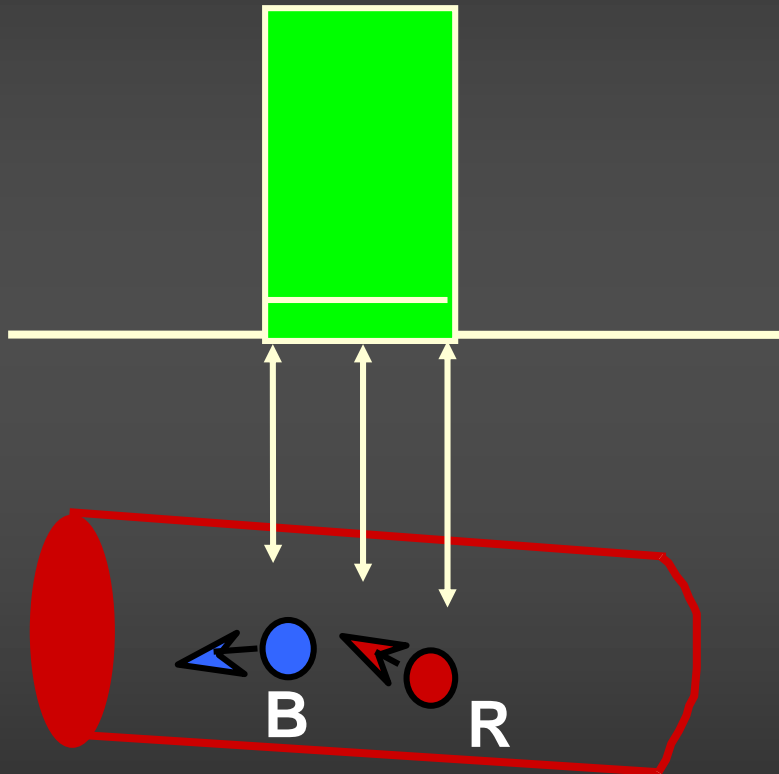
# Flux hélicoïdal



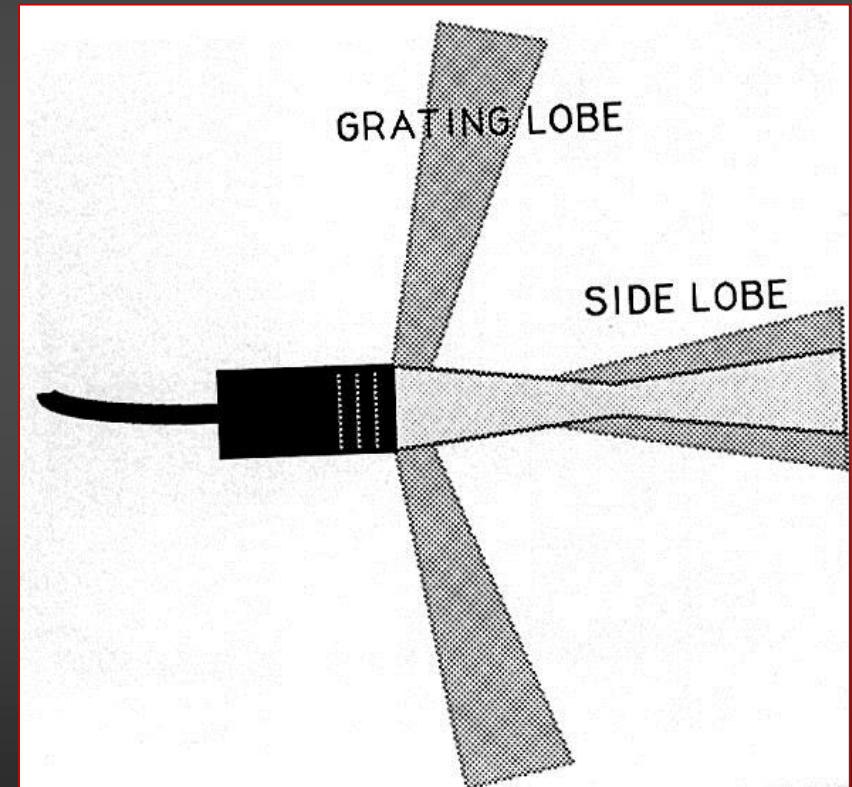
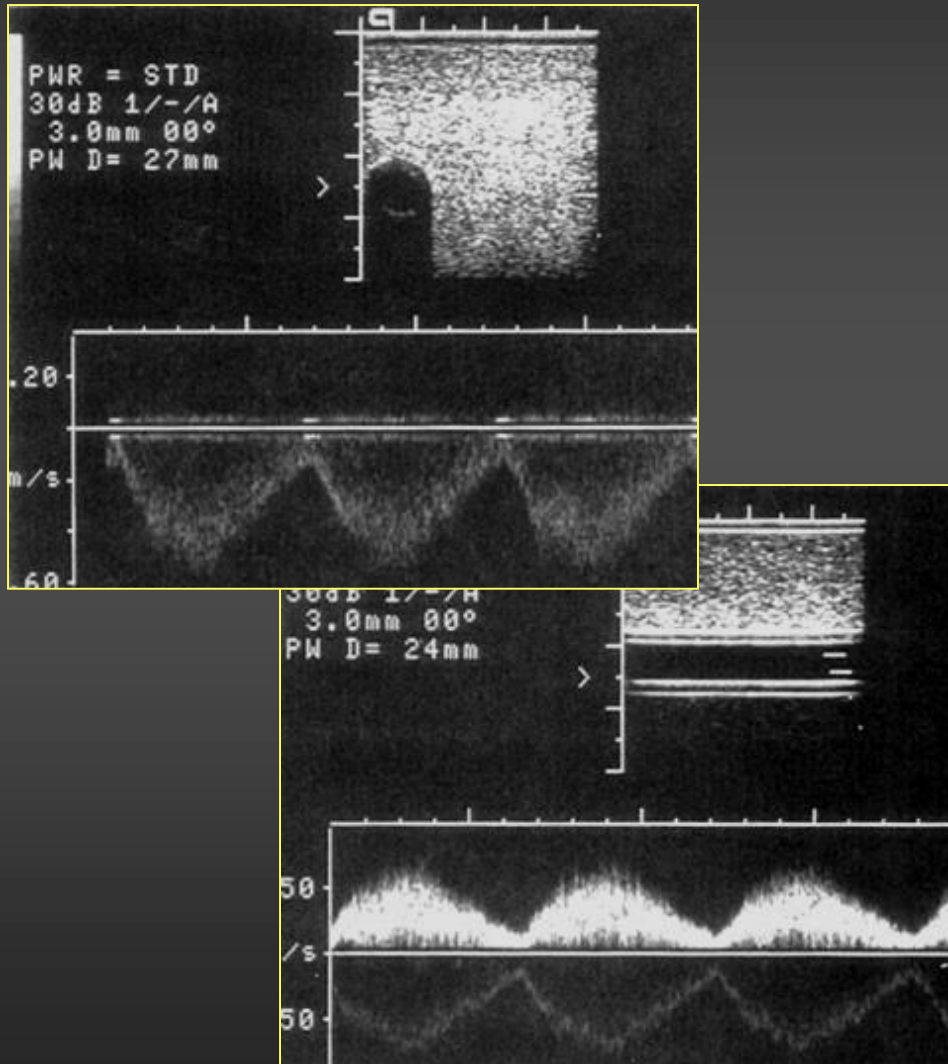
# Flux helicoidal



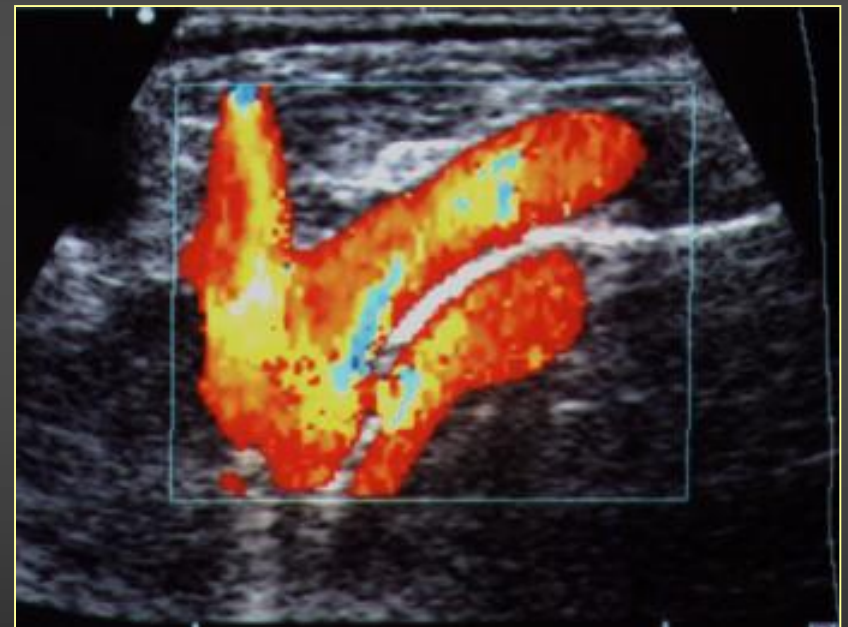
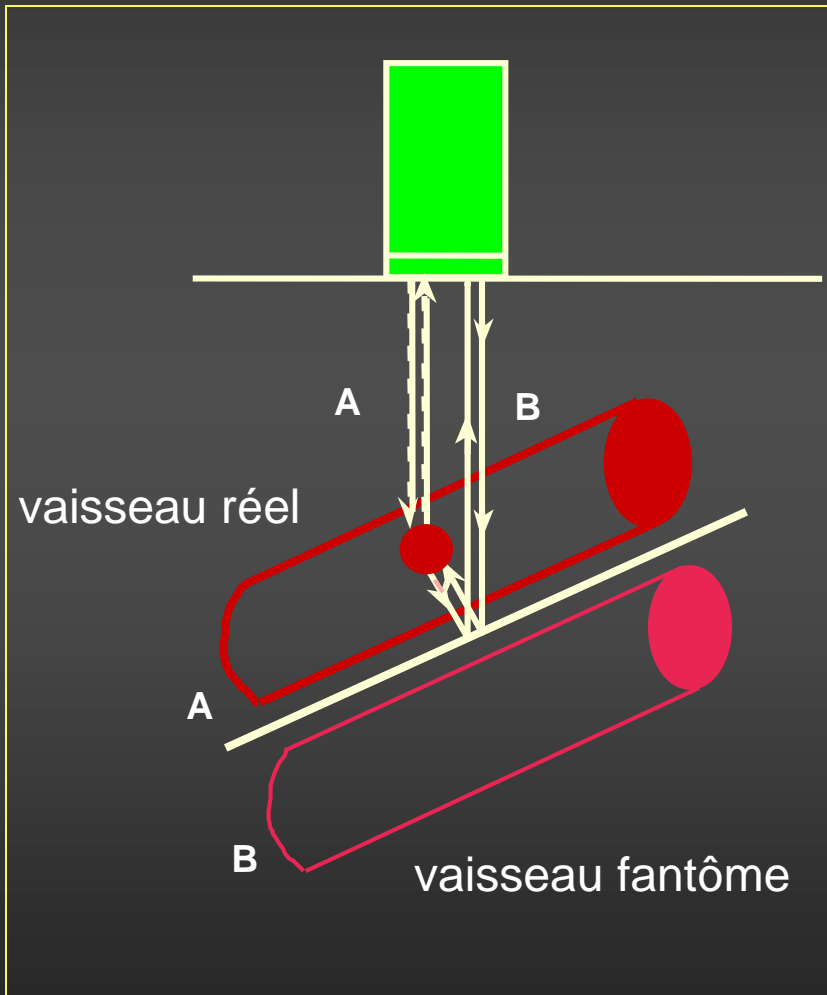
# Angle Doppler trop grand



# Flux extra-vasculaire : *Lobes latéraux*



# Flux extra-vasculaires : *Artefact en miroir*



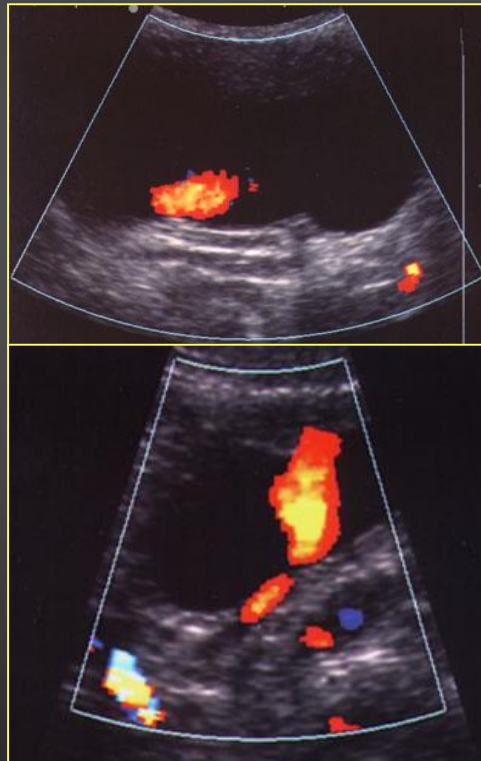


# Flux extra-vasculaires

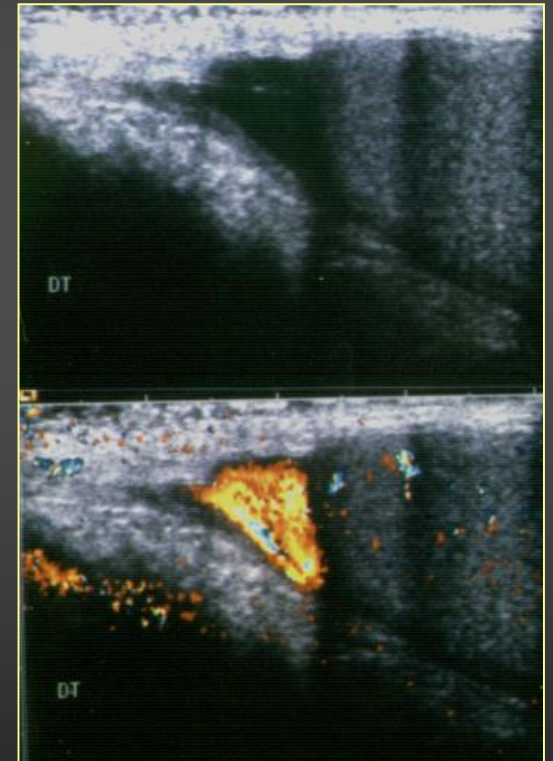
- Liquides en mouvement



ascite

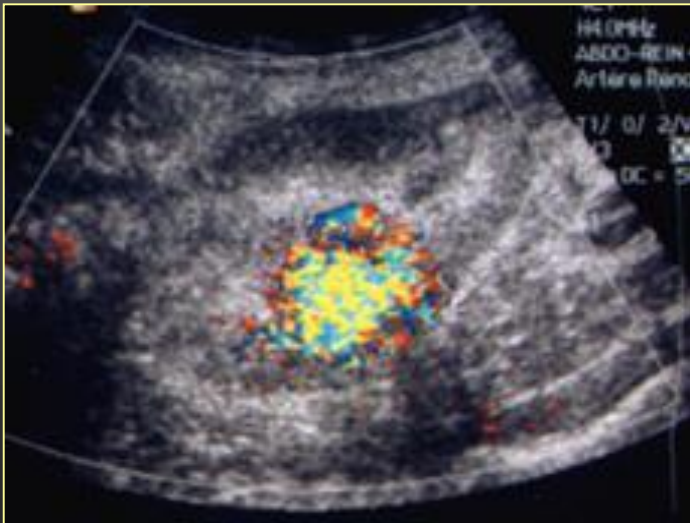


jets urétéraux

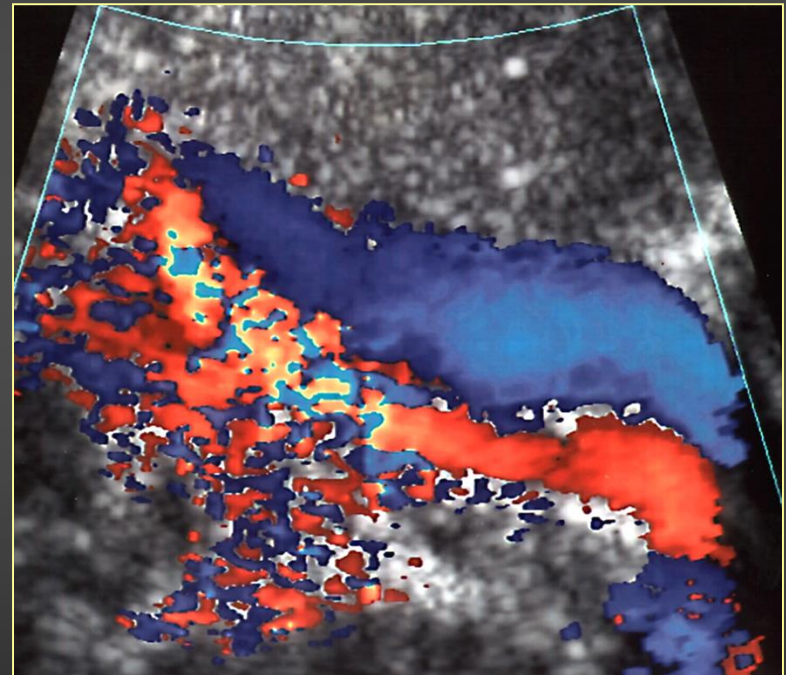


hydrocèle

# Pièges et artefacts : « bruits »

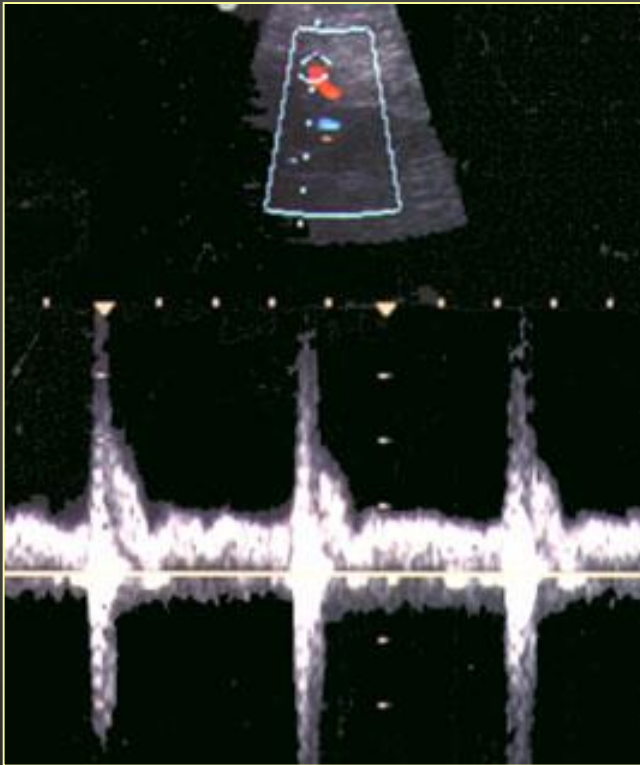


- Artefact péri-vasculaire

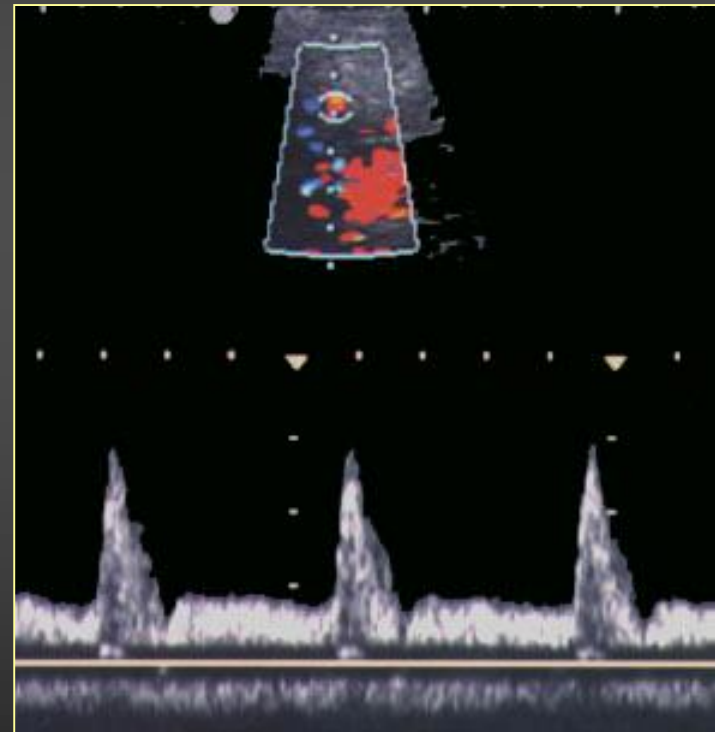


# Bruits de paroi : filtrage

*A proximité de l'aorte : Ostium de l'AMS*



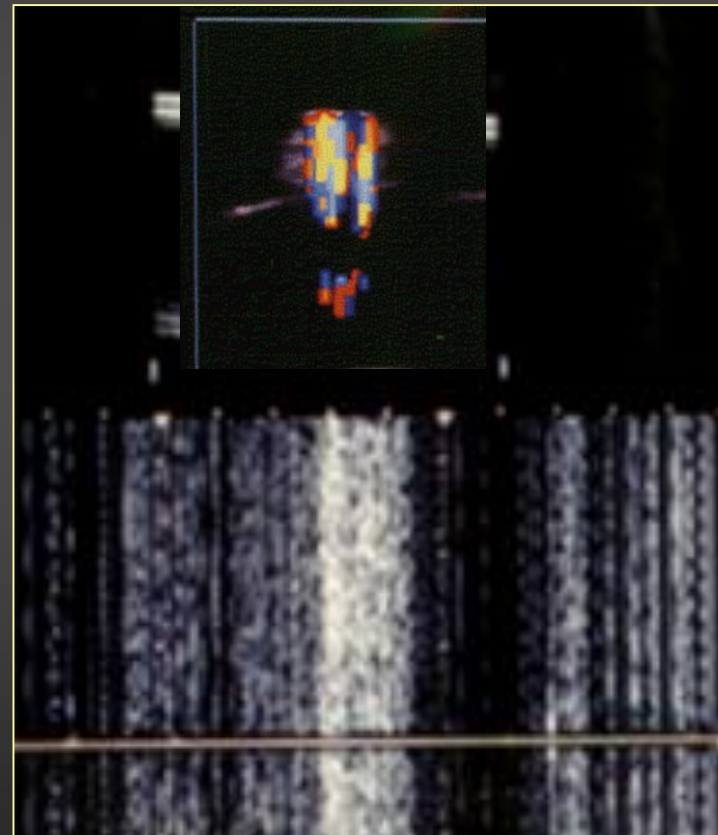
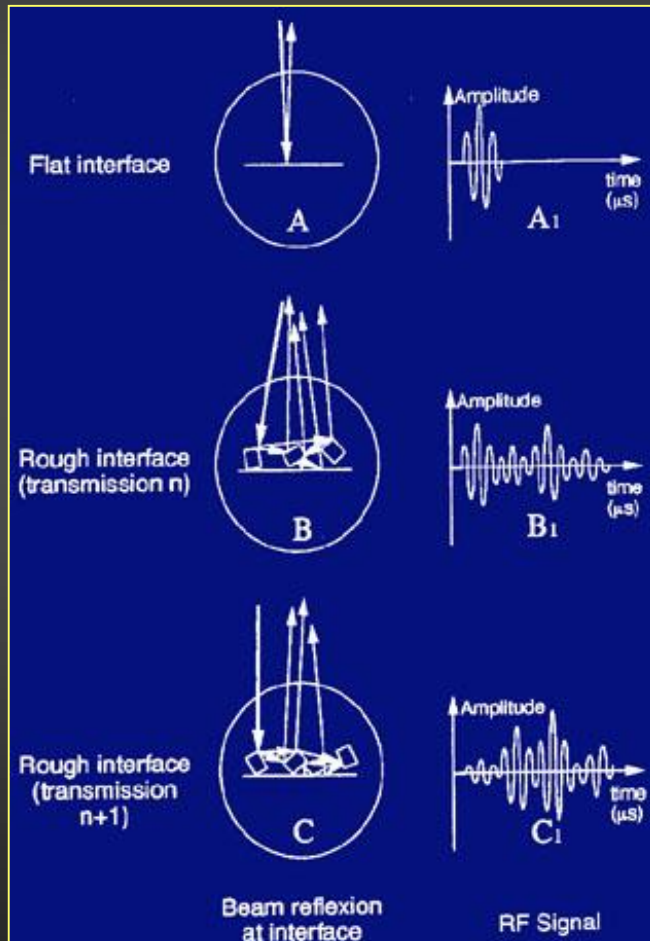
Filtre 50 Hz



Filtre 200 Hz

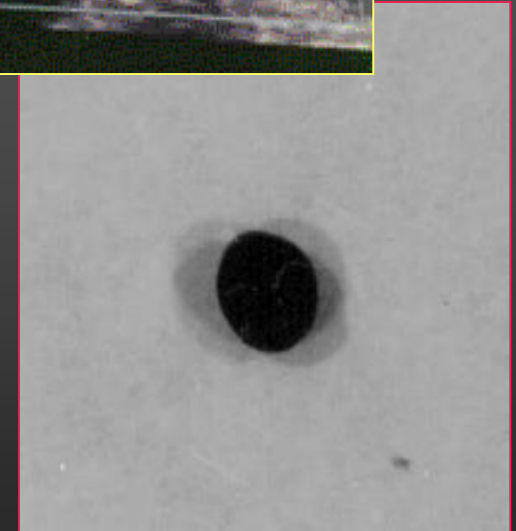
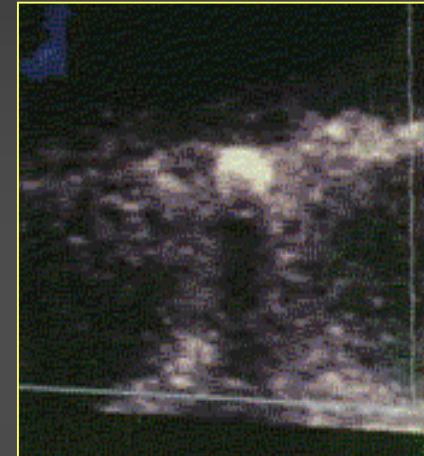
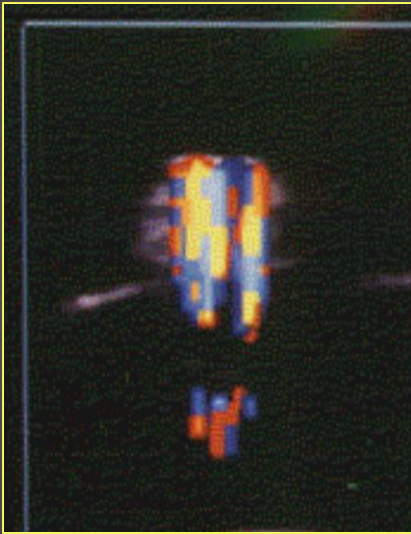
# Artefact de scintillement

En arrière des calcifications



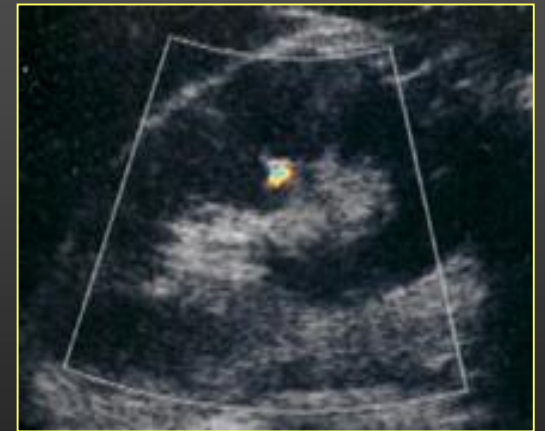
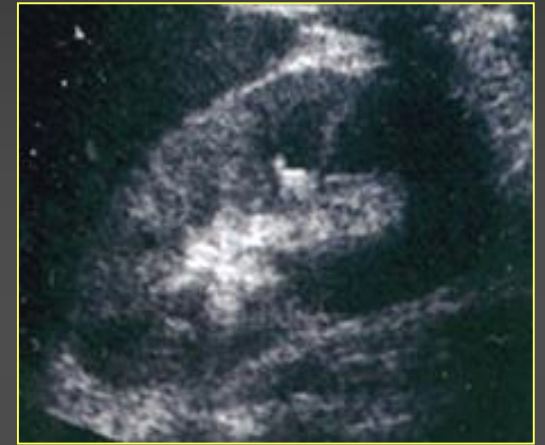
# Artefact de scintillement

Sa présence dépend du degré d'irrégularité de leur surface



# « Bruits » : Artefact de scintillement

## Lithiases urinaires



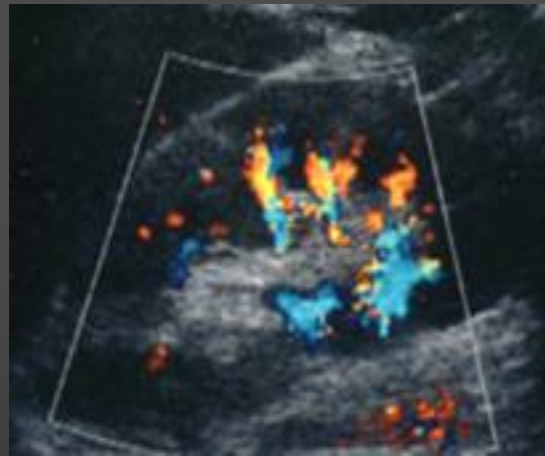
# Artefact de scintillement

Cet artefact est indépendant de la PRF

=> Augmenter la PRF facilite sa détection en effaçant les vaisseaux



Mode B



Mode Doppler  
PRF basse



Mode Doppler  
PRF haute

# Pièges et artefacts : « bruits »



cathéter



stent

