

Enseignement d'IRM DES Paris 2016 Flux + Angiographie

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Creatis

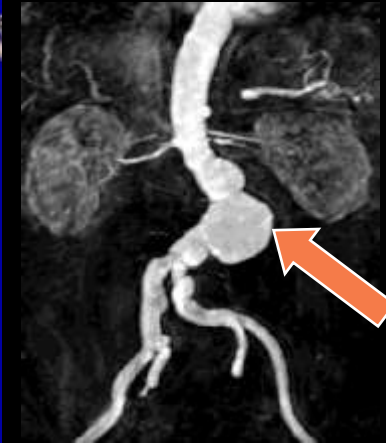


Objectifs Pédagogiques

1. Décrire les différents phénomènes de flux en IRM
2. Expliquer le principe des gradients de compensation de flux
3. Détailler les méthodes d'ARM sans injection de produit de contraste (technique, résultats, avantages et inconvénients) :
 1. ARM par temps de vol (TOF)
 2. ARM par contraste de phase (PCA)
 3. ARM 3D balanced steady-state free precession SSFP and flow-sensitive dephasing (FSD)magnetization preparation
 4. Fresh blood imaging (FBI)
 5. Quiescent interval single-shot (QISS),Ghost
4. Décrire la technique d'angio IRM avec injection de produit de contraste, ses contraintes liées à l'injection, ses avantages

Problématique Médicale

- Pathologie évolutive de la paroi vasculaire:
 - Anomalies morphologiques de la lumière et de l'arbre vasculaire
 - Sténose
 - Anévrisme
 - Fistule ou MAV
 - Anomalies fonctionnelles du flux sanguin et de la paroi vasculaire: (*vulnérabilité*)
 - Évaluation des vitesses et gradients
 - Forces de cisaillement
 - Rupture de la plaque: infarctus
 - Embolies et thrombose: AVC



Principes

- **Contraste : propriétés physico-chimique du flux sanguin**
 - Vitesse
 - Direction
 - Presence de turbulence
- **Suppression du signal des tissus stationnaires**
- **Progrès liés à l'imagerie parrallèle**
 - Resolution spatiale
 - Resolution temporelle

IRM Vasculaire

- **Exploration:**
 - . De la lumière vasculaire
 - . De la paroi vasculaire
- **Quantification**
 - . des flux

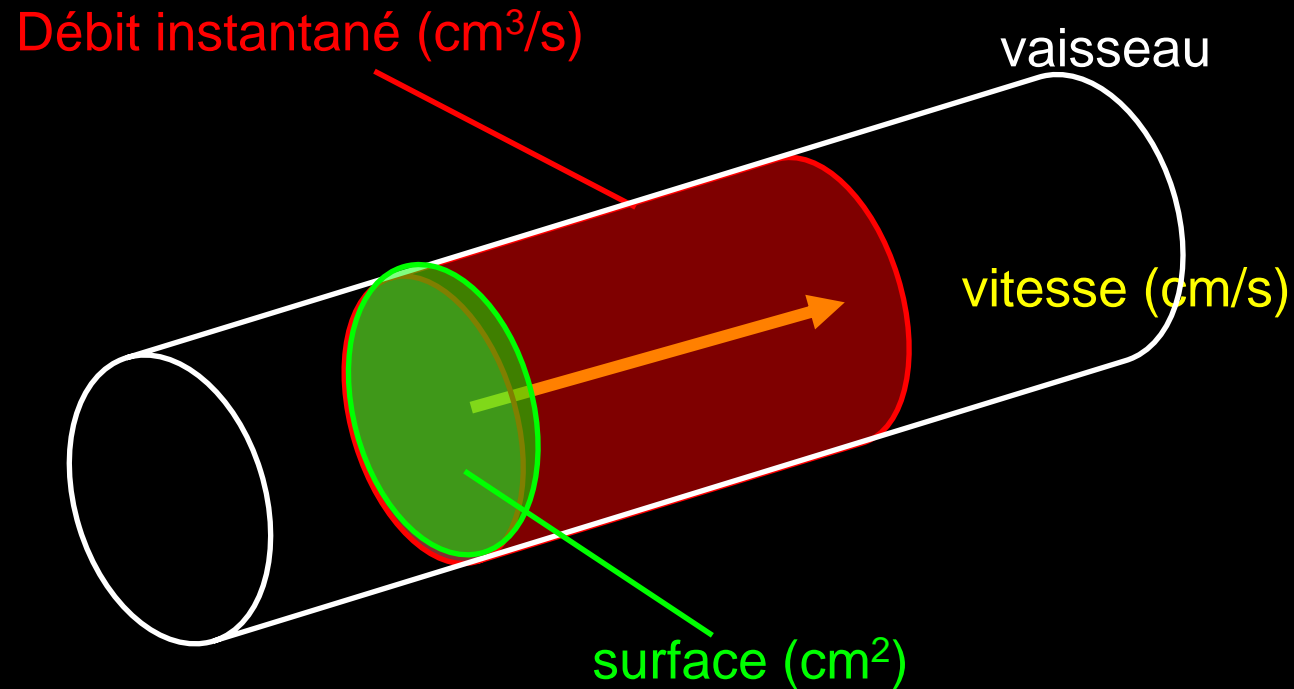
IRM Vasculaire

- **Exploration de la lumière vasculaire**
 - . Temps de vol
 - . Contraste de Phase
 - . Effet T1 des produits de contraste
 - . FBI: imagerie sang frais
 - . bSSFP (imagerie à l'état d'équilibre) and Flow-Sensitive Dephazing (FSD)

IRM Vasculaire

- **Exploration de la paroi vasculaire**
 - Imagerie haute résolution « sang noir »
 - Multi-paramétrique
 - produits de contraste

Flux Sanguin



à l'origine de perturbations du codage spatial et d'artéfacts

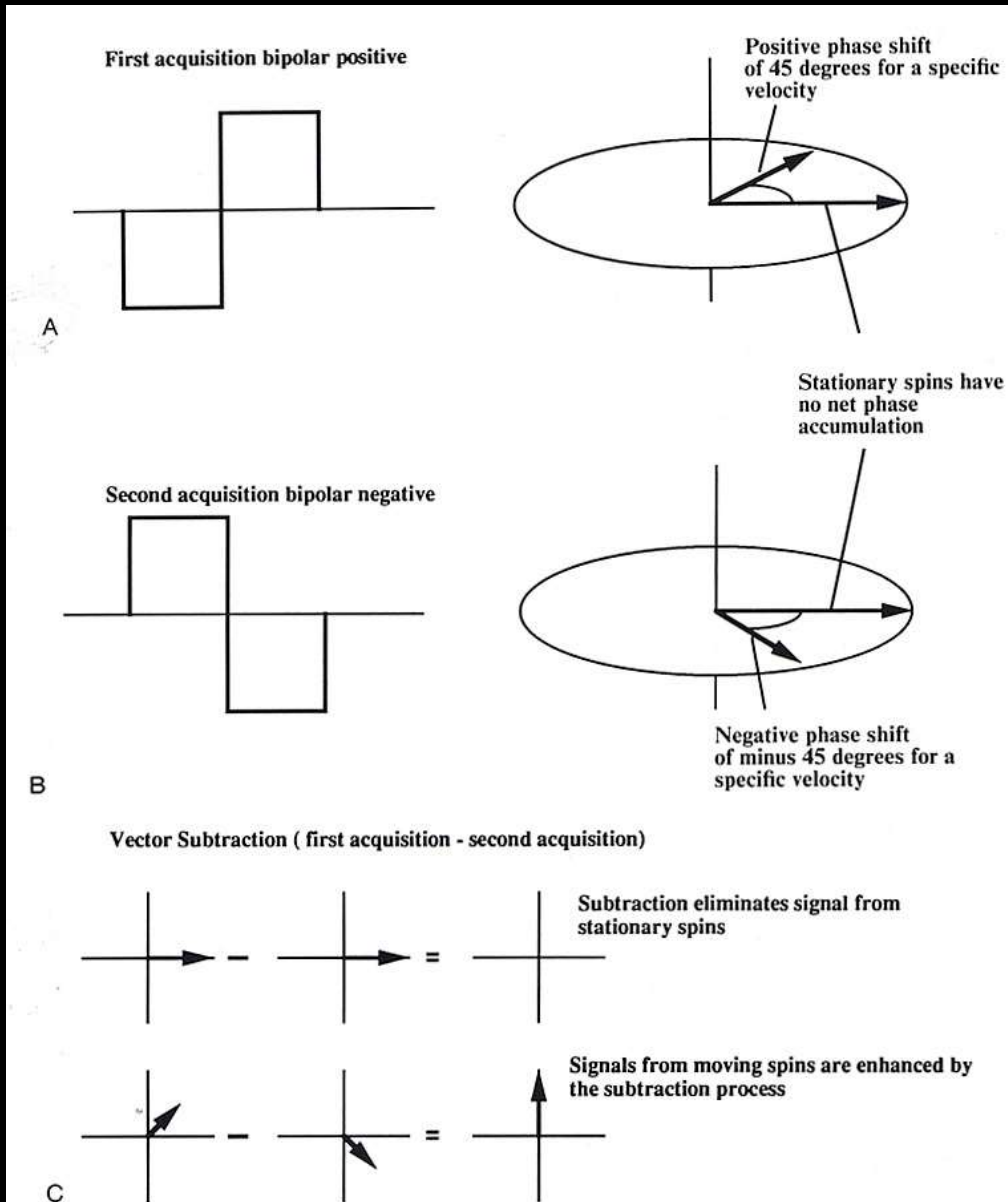
1 Contraste de Phase

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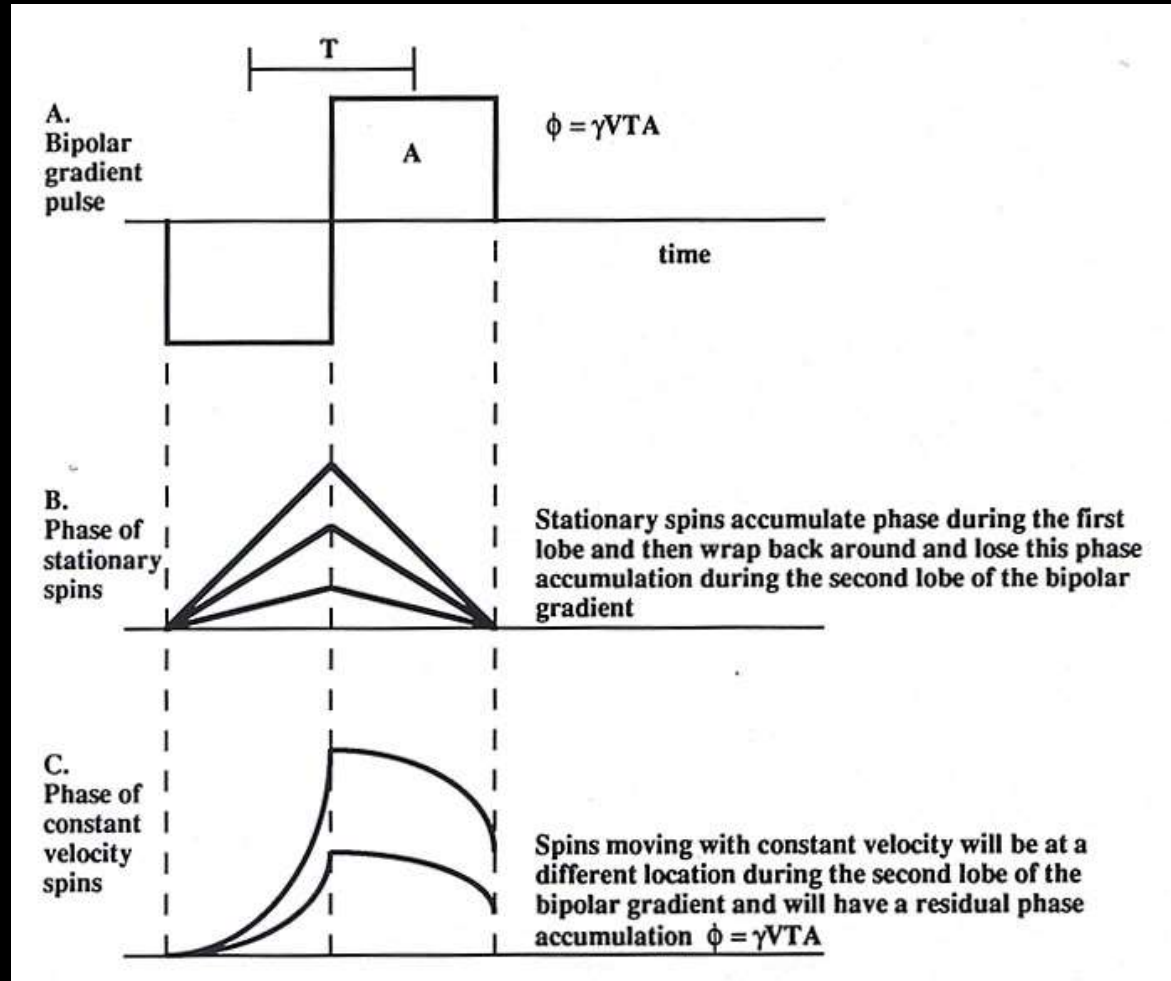


Contraste de Phase

- Methode de phase
- relaxation transversal
 - Carte des vitesses sanguines
 - Déphasage # vitesse sang
 - Sang est "blanc" car en mouvement

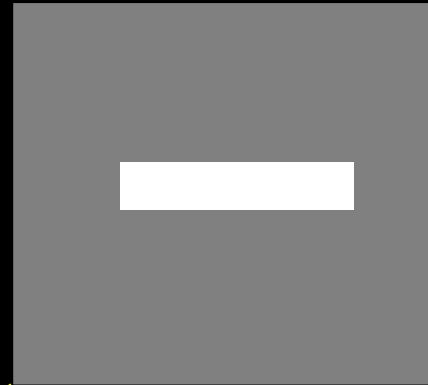
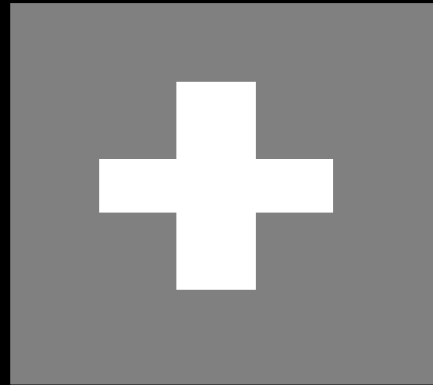


Sequence : Contraste de Phase



Imagerie fonctionnelle – quantification des flux

Images



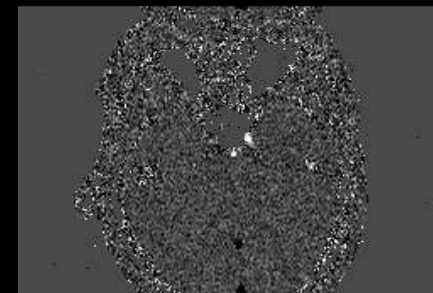
2 acquisitions avec
différentes
sensibilités de flux



FFE/M
anatomique



PCA/M
flux anatomique



PCA/P
flux quantitatif

Imagerie fonctionnelle – quantification des flux

Principe

Le contraste entre un vaisseau et les tissus est déterminé par:

- *Différence* de phase ϕ (du signal RM) entre les spins en mouvement et les spins statiques.

Dans les séquences en Angiographie par Contraste de Phase (PCA) :

- la phase ϕ est proportionnelle à la vitesse du sang : $\phi \sim v$
- spins statiques : $\phi = 0$
- spins en mouvement : $\phi = 180^\circ v / V_{enc}$
- V_{enc} est la vitesse encodée ajustable dans la séquence

Images dependent de l'encodage des gradients:

- gradients forts encodent flux lents
- gradients faibles encodent flux rapides



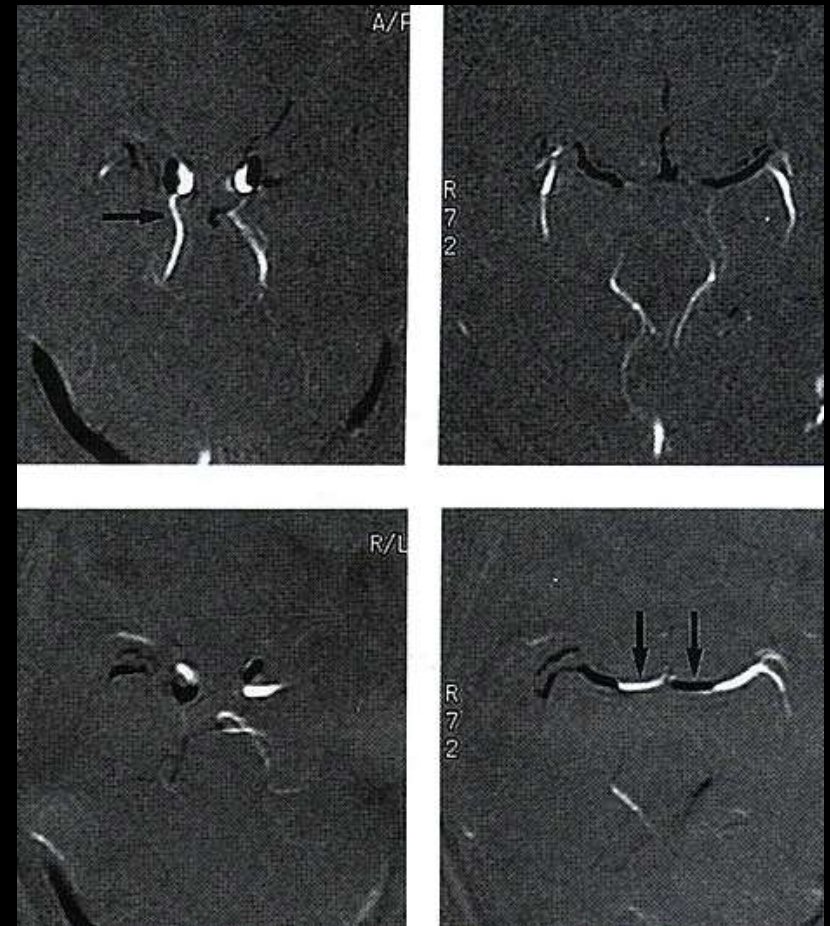
Low VENC factors



High VENC factors



Gradients peuvent coder
le sens du flux



Contraste de Phase : Indications cliniques

MR Angiography

Venous Occlusive Disease

- **3D PC**

VENC 15-20 cm/sec

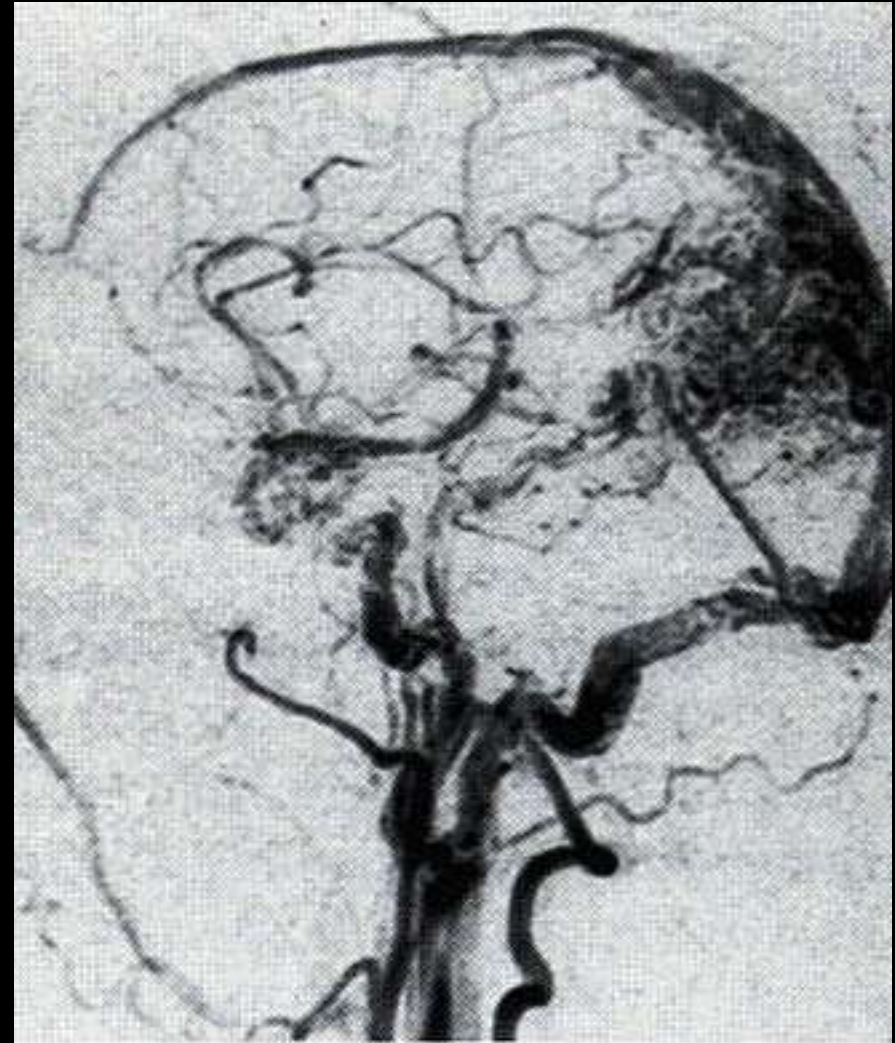
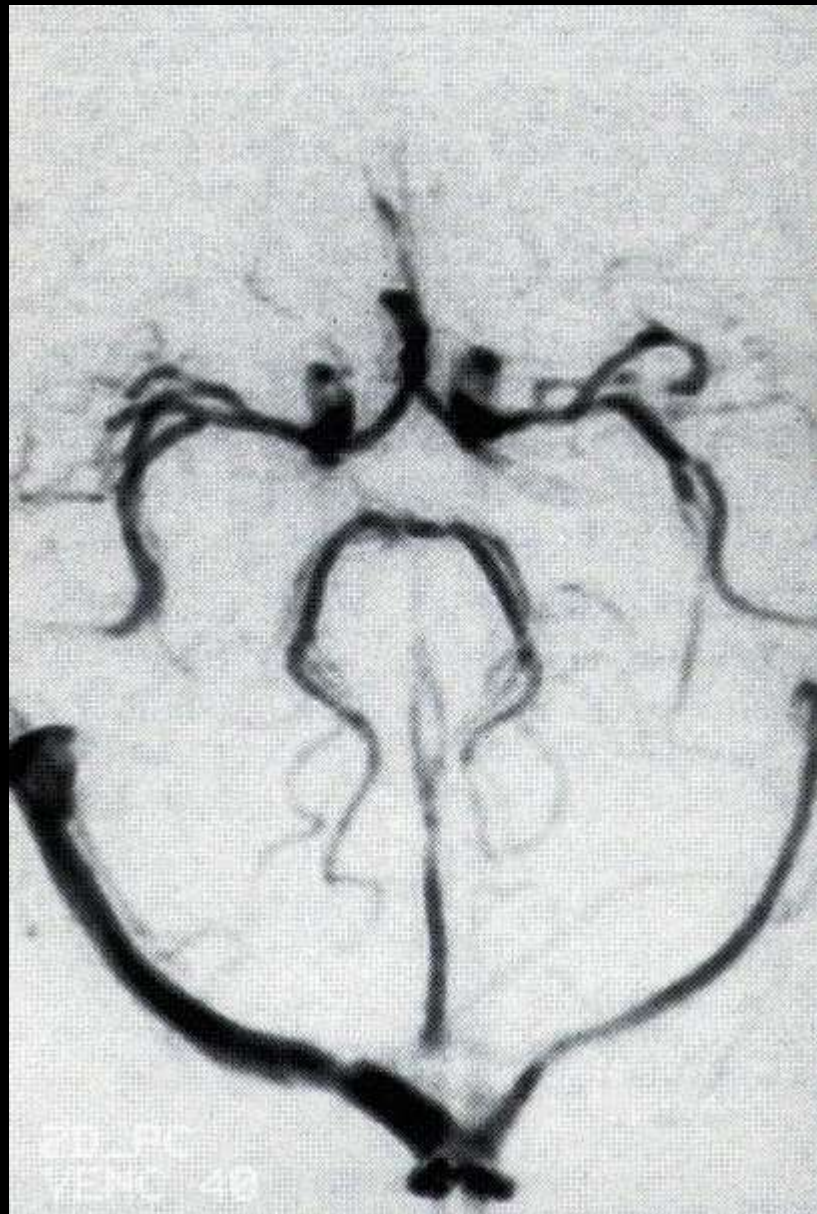
- **2D PC Slab**

Sagittal - Superior sagittal sinus

Axial - Transverse sinuses

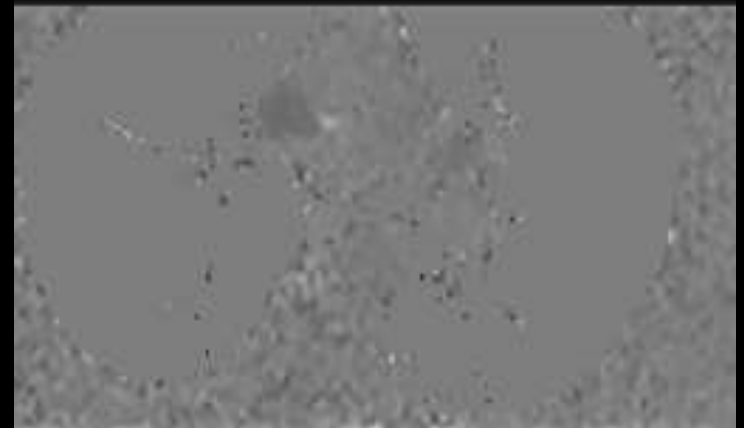
Coronal - Internal jugular veins

Applications Cliniques



Contraste de Phase: Imagerie des Flux: Applications Cardiaques

**Codage des vitesses
en niveau de gris à
différents moments
du cycle cardiaque**

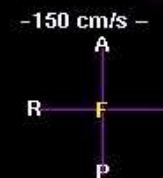


Analyse: Selection d'une ROI et propagation temporelle au cours d'un cycle cardiaque

Flux:	-289.40 ml/s	Peak vel:	-81.76 cm/s
Mean vel:	-59.36 cm/s	Max vel:	0.59 cm/s
Area:	4.88 cm ²	Min vel:	-81.76 cm/s
Pixels:	355	Stddev vel:	17.06 cm/s



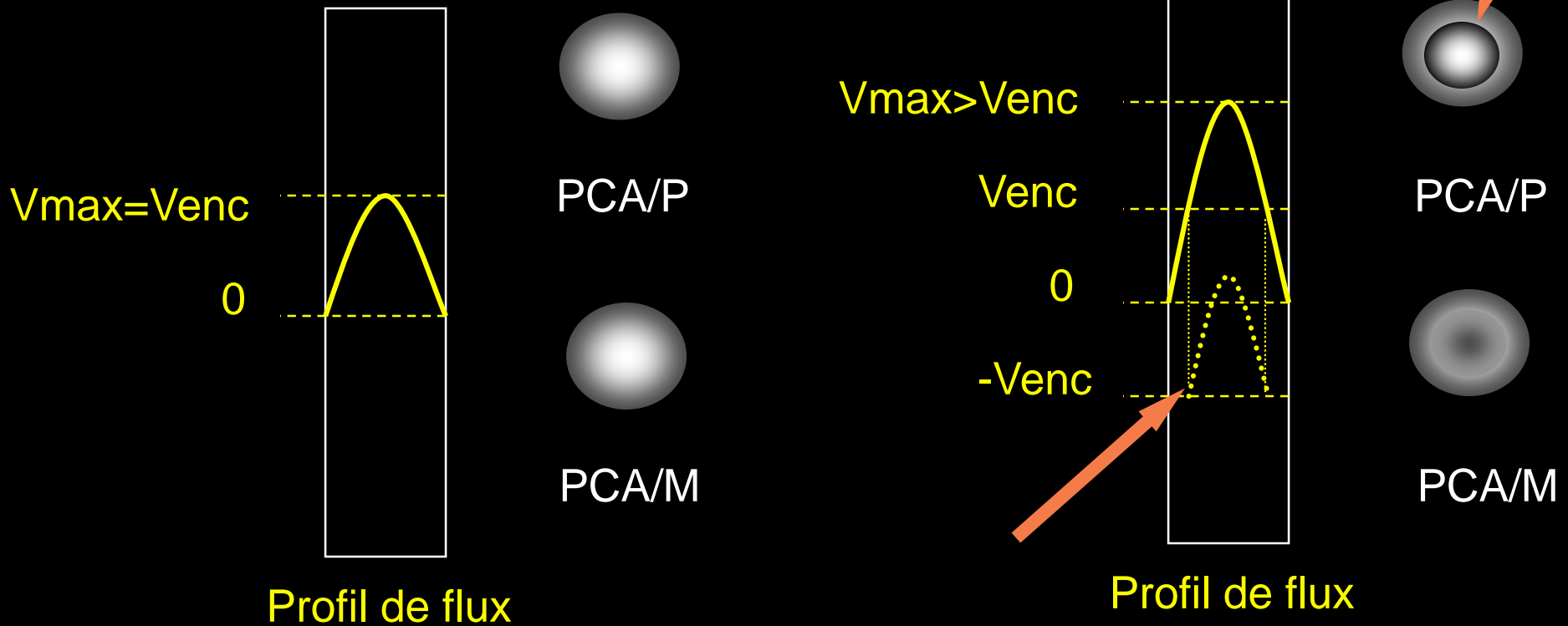
PCA / P
SI 1
Ph 4 / 120 ms
VS AP 0, RL 0, FH 150 cm/s



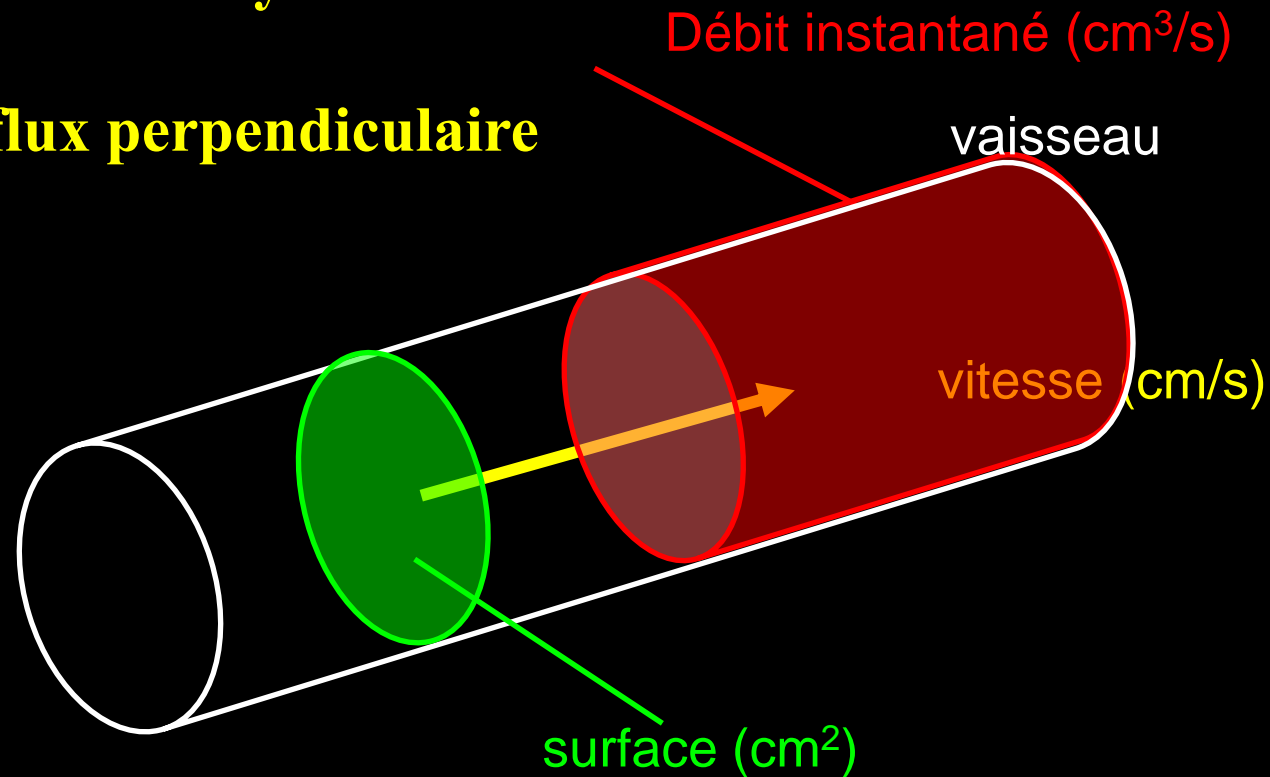
Quantification des Flux

Attention au choix de la vitesse !

4m/sec si RA



1. **Vitesse: maximale, minimale, moyenne,**
2. **Débit/cycle (vitesse moyenne x surface)**
3. **seulement si flux perpendiculaire à la coupe!!)**



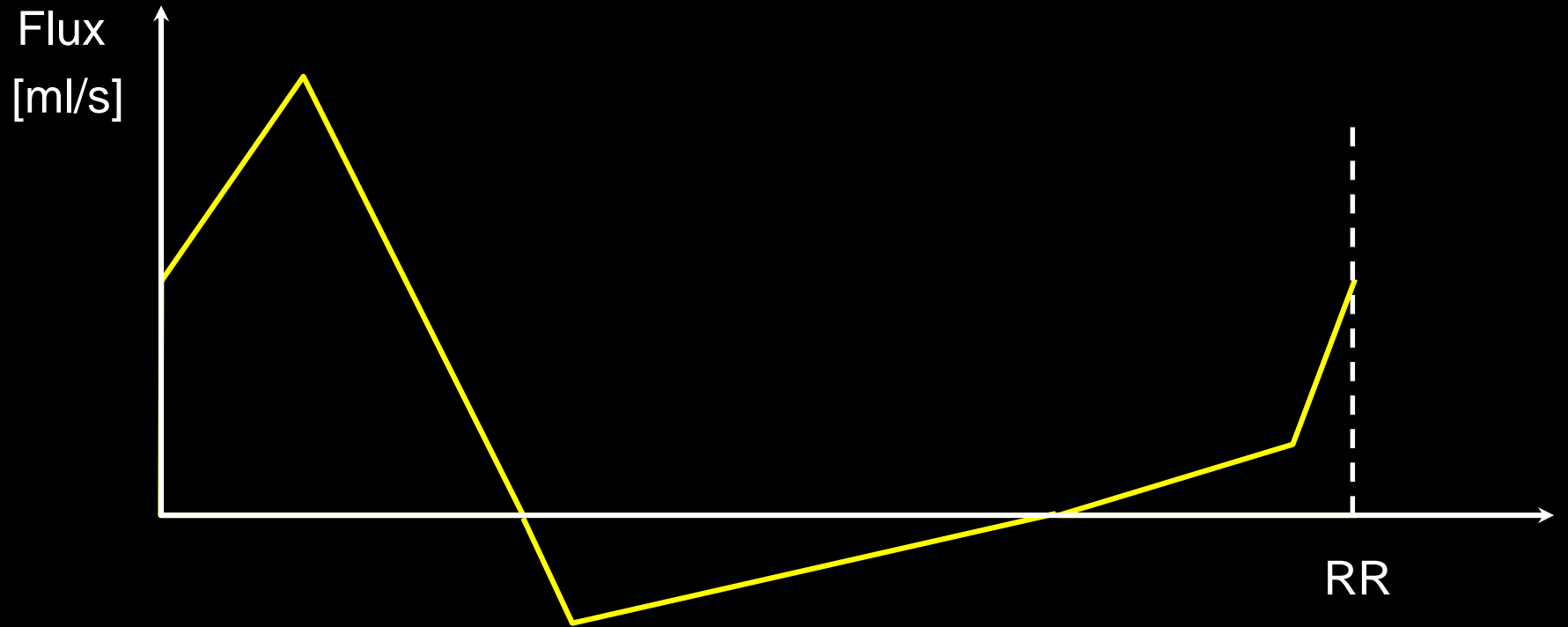
Flux

Analyse:

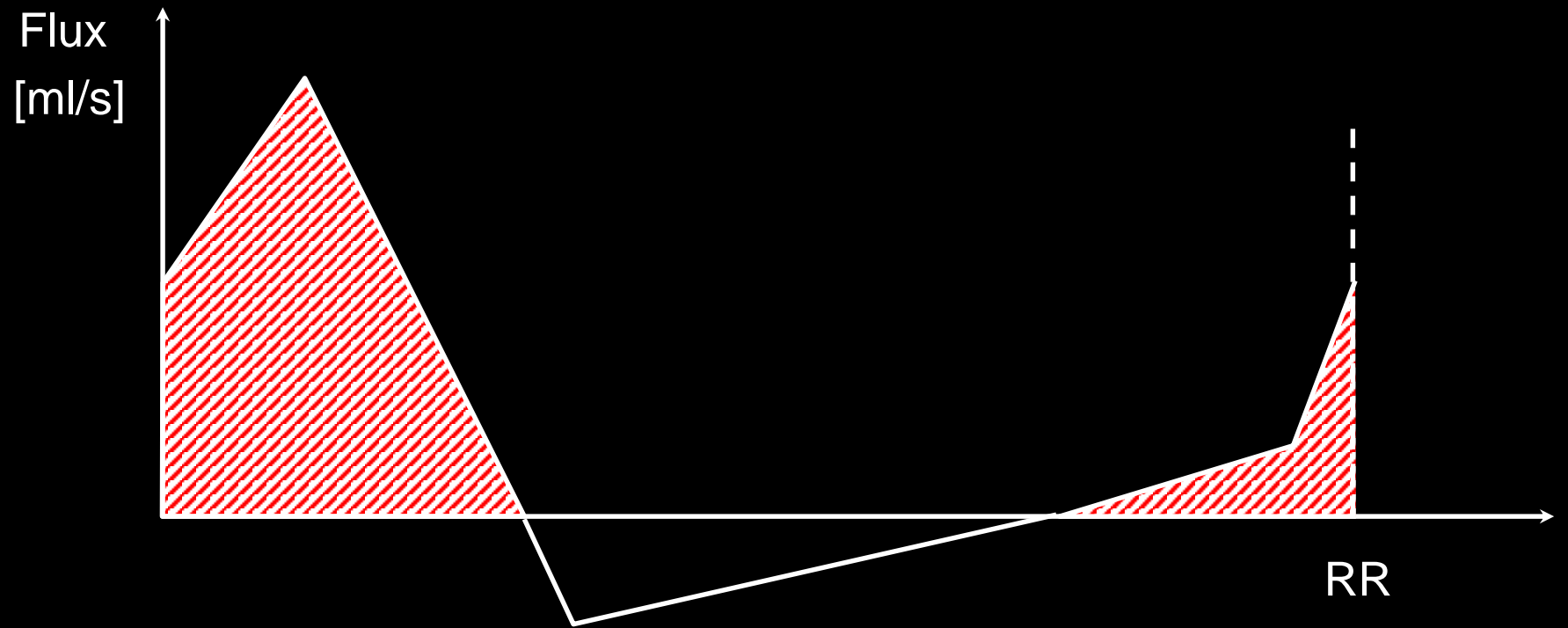
Résultats par intervalle RR

- **Volume du flux éjecté**
- **Volume du flux régurgité**
- **Fraction de régurgitation, (flux éjecté/ flux régurgité)**
- **Volume d'éjection (flux éjecté - flux régurgité.)**

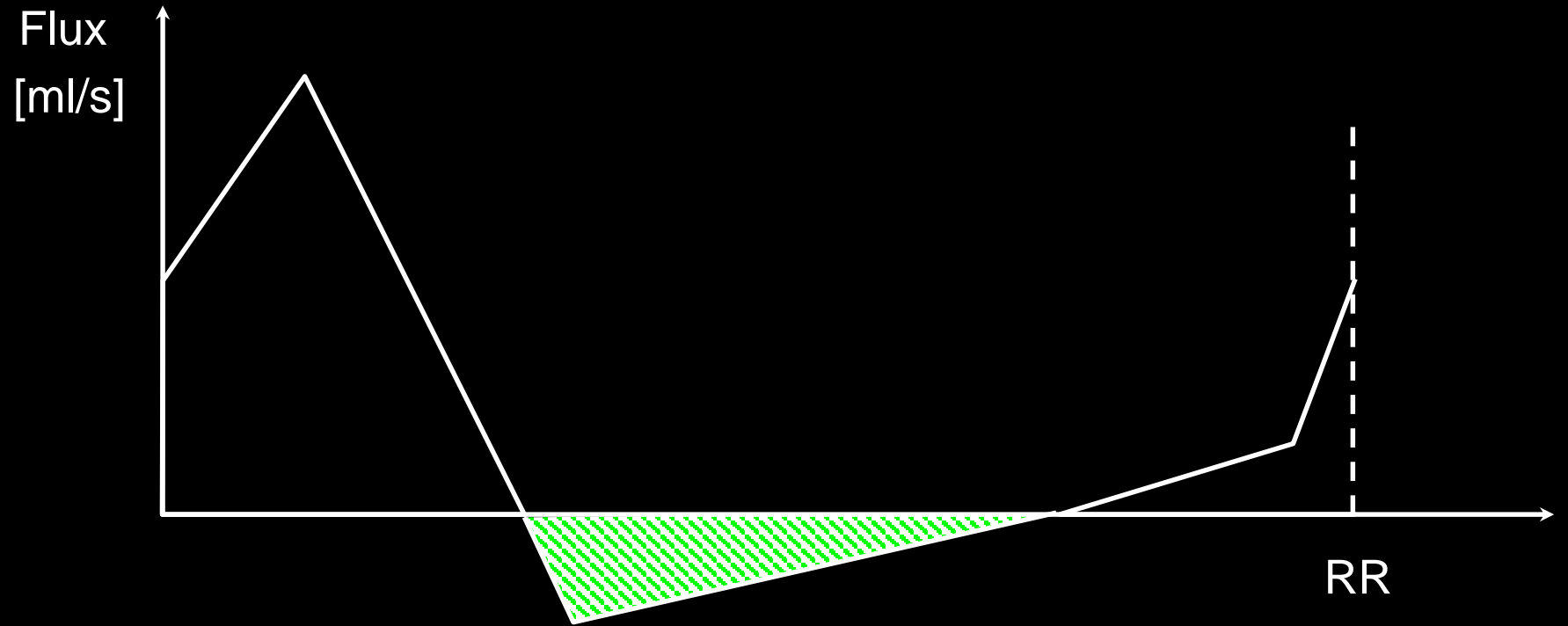
Description Graphique Flux dans un intervalle RR



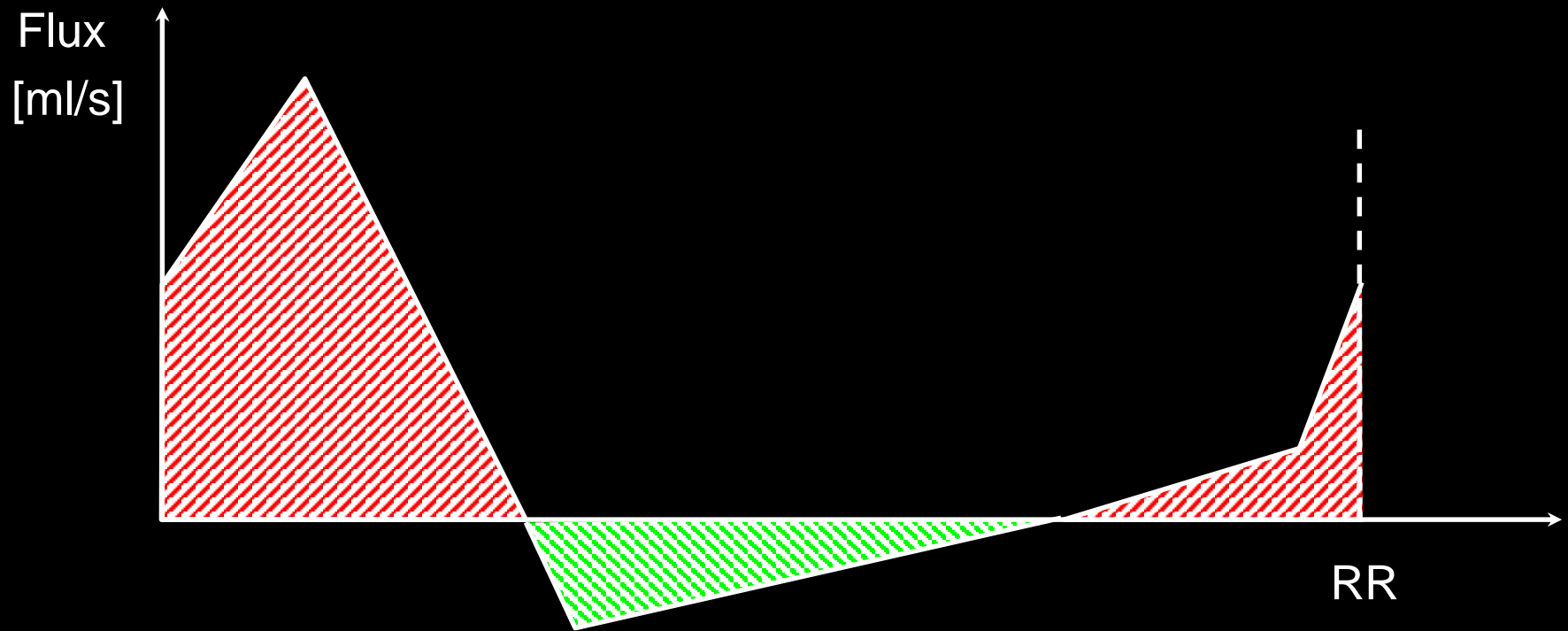
Volume éjecté



volume régurgitant

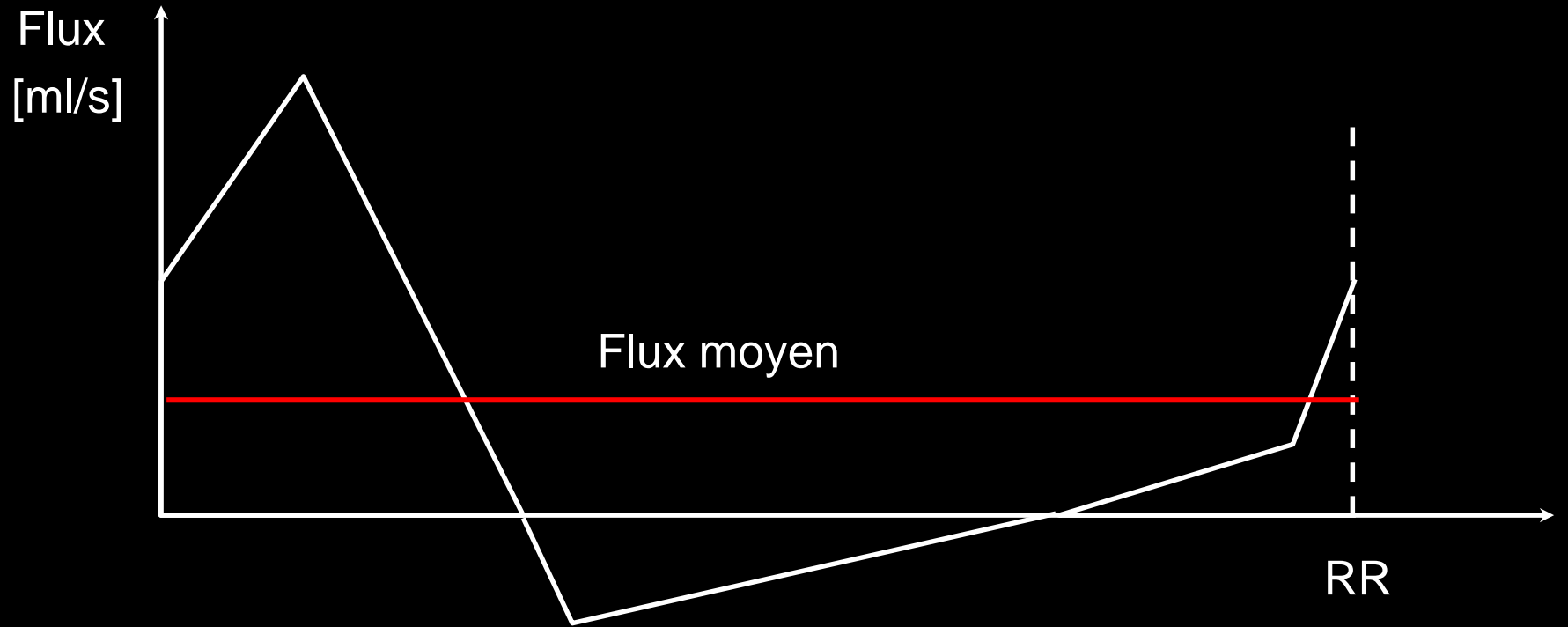


Stroke volume

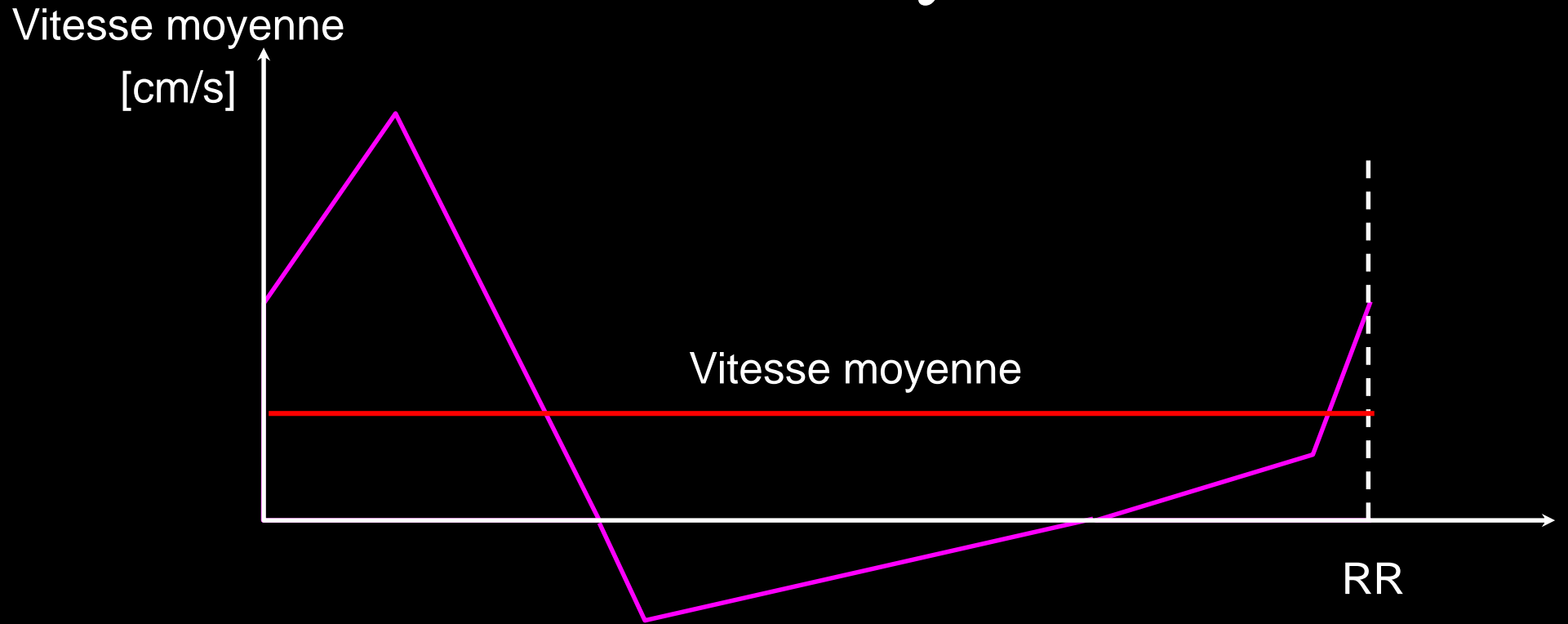


Stroke volume = volume éjecté – volume régurgité

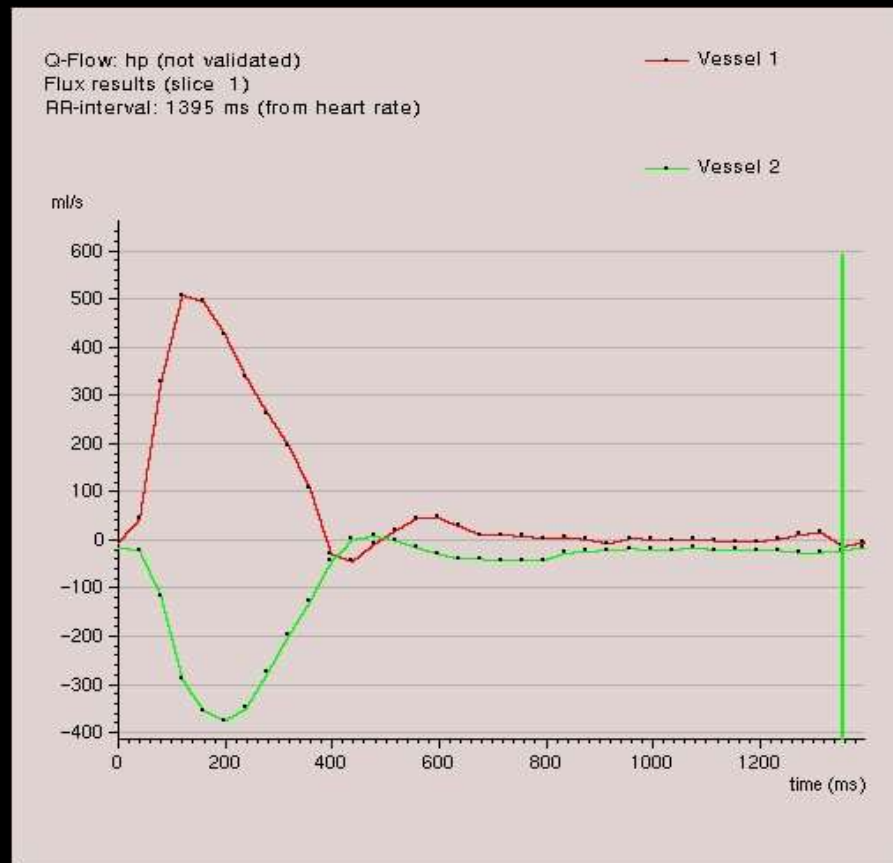
Flux moyen



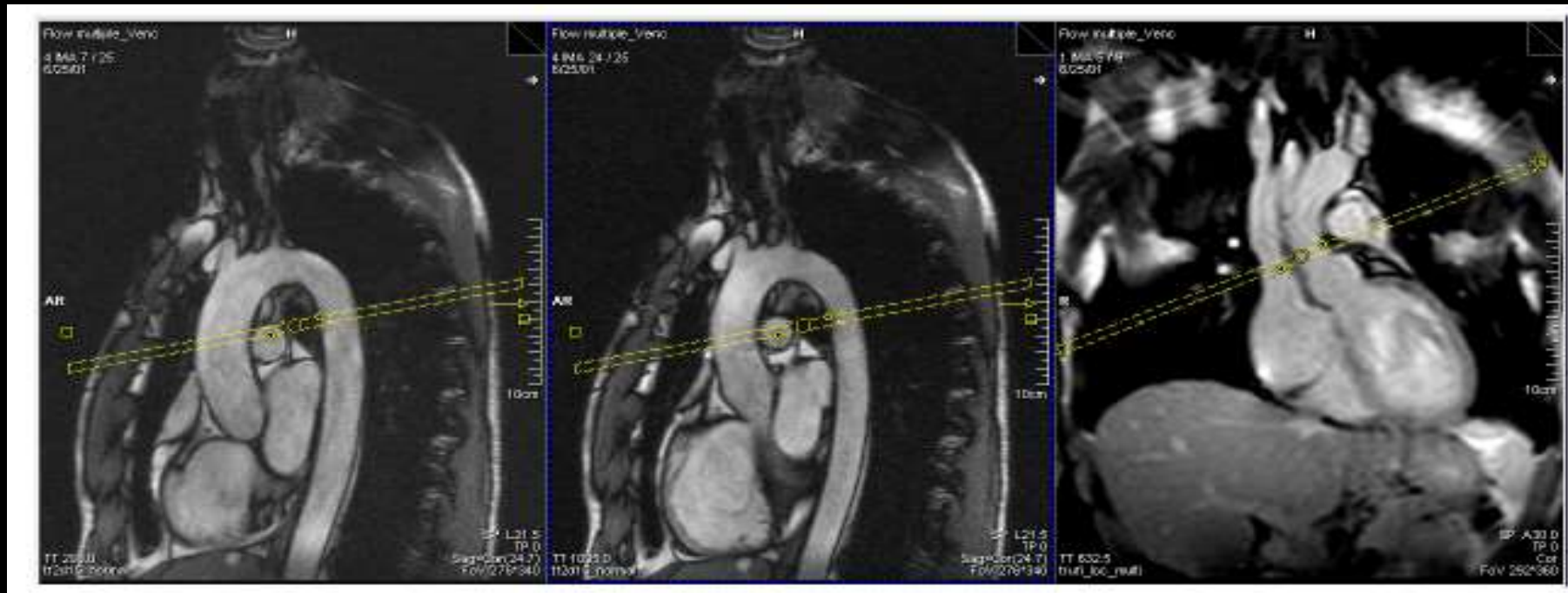
Vitesse moyenne



Graphique Flux



Ex. valve aortique Evalauation de l'IA

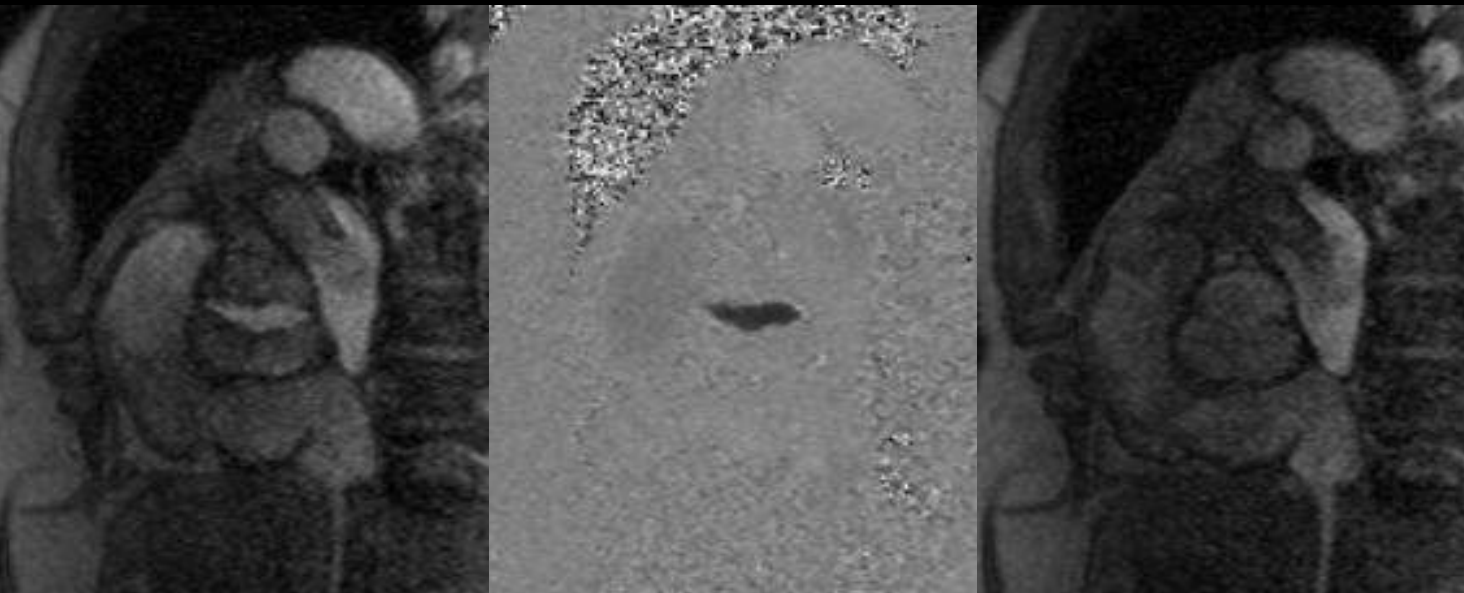


Positionnement de coupe dans aorte ascendante et descendante pour quantification de Flux à travers le plan



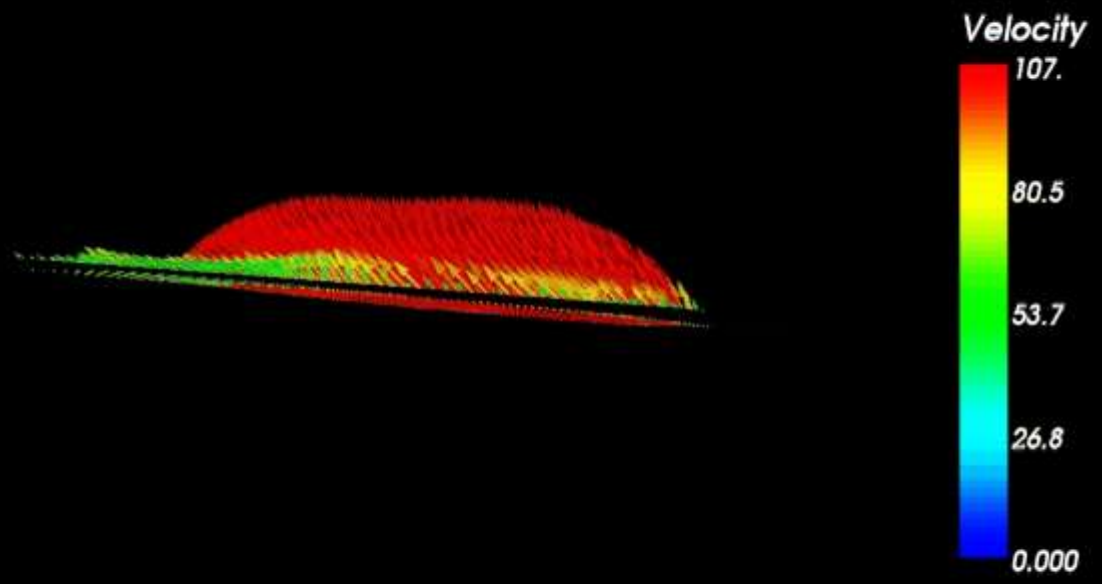
Imagerie des Flux

Valve Aortique: Evaluation du RA et de l'IA



Flash Cine

Ouverture/fermeture vAo



Nouveaux Développements

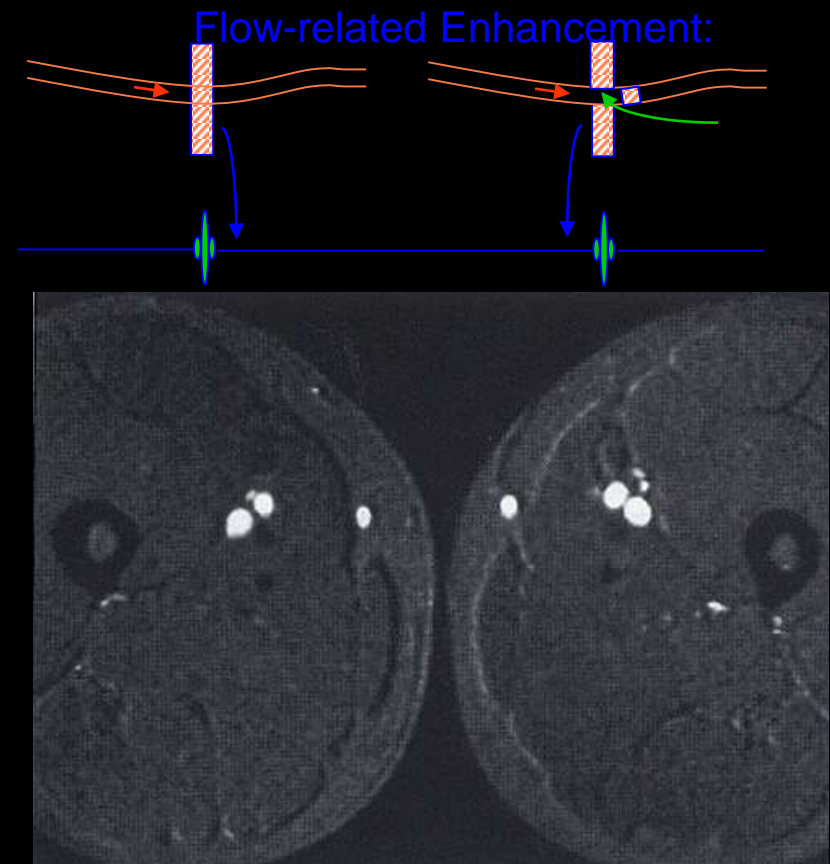
- Echantillonnage non cartésien de l'espace des K :
 - Spirale, radiale
 - Projection reconstruction
 - VIPR
 - 3D

Aorte + Valves 4D



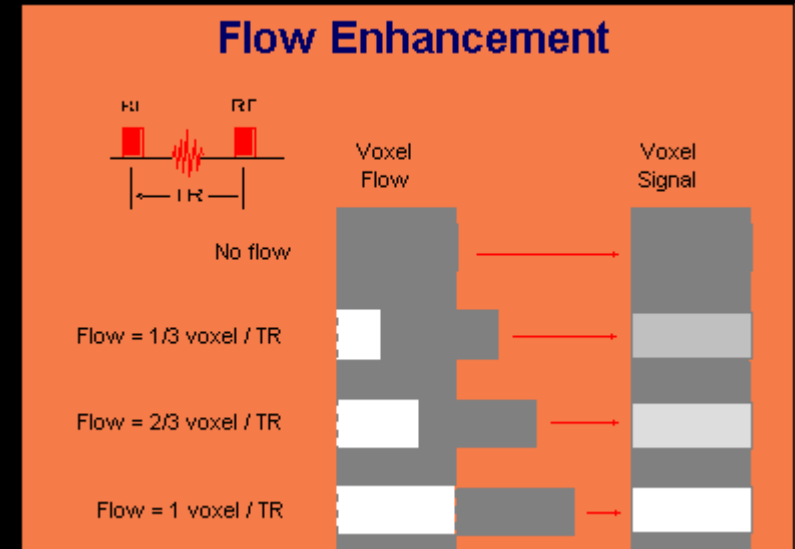
Temps de Vol

- Repose sur les propriétés du sang :
 - TOF: méthode de magnitude relaxation longitudinale
 - Suppression des tissus stationnaires
 - Maximisation des protons du sang qui entre dans le volume
 - ◆ Protons entrant sont complètement relaxés et blanc
 - ◆ Tissus stationnaires saturés et noirs
 - ◆ Bande de saturation



TOF: Principes

- Association de :
 - Maximisation de l'entrée de coupe et minimisation de la sortie de coupe
 - Saturation des spins stationnaires
- Variations de la vitesse du flux impose d'adapter les paramètres:
 - Épaisseur de coupe
 - Orientation de coupe
 - TR
 - TE

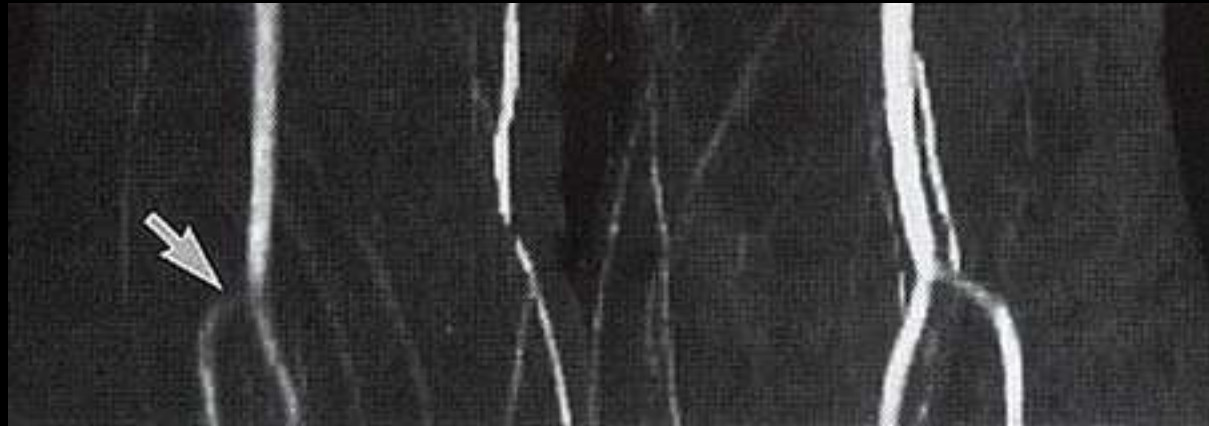


Flow related enhancement and saturation: Vessel orientation / slice

In plane saturation artifacts :



2D TOF : artéfacts de saturation dans le plan

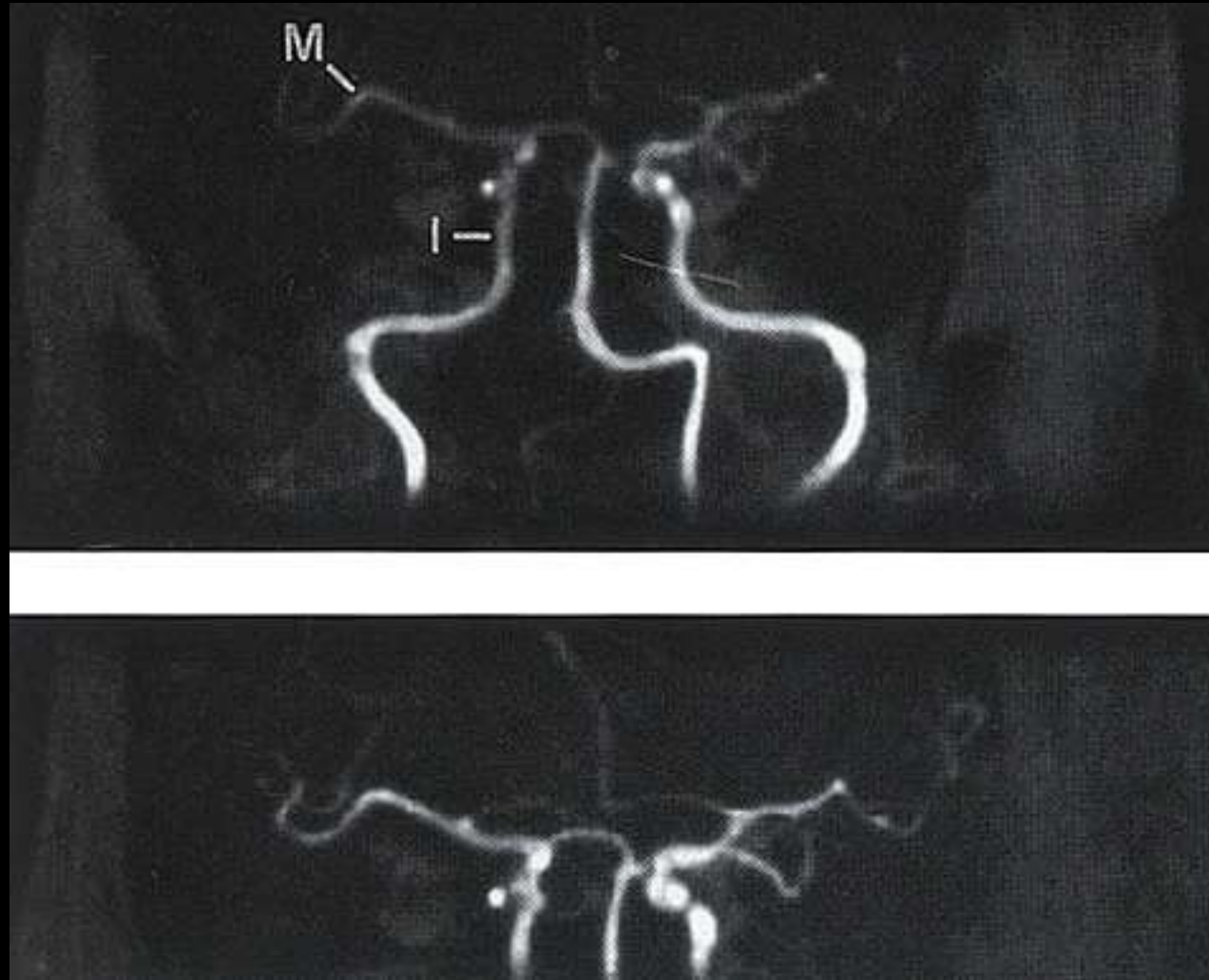


3D vs. 2D Time of Flight

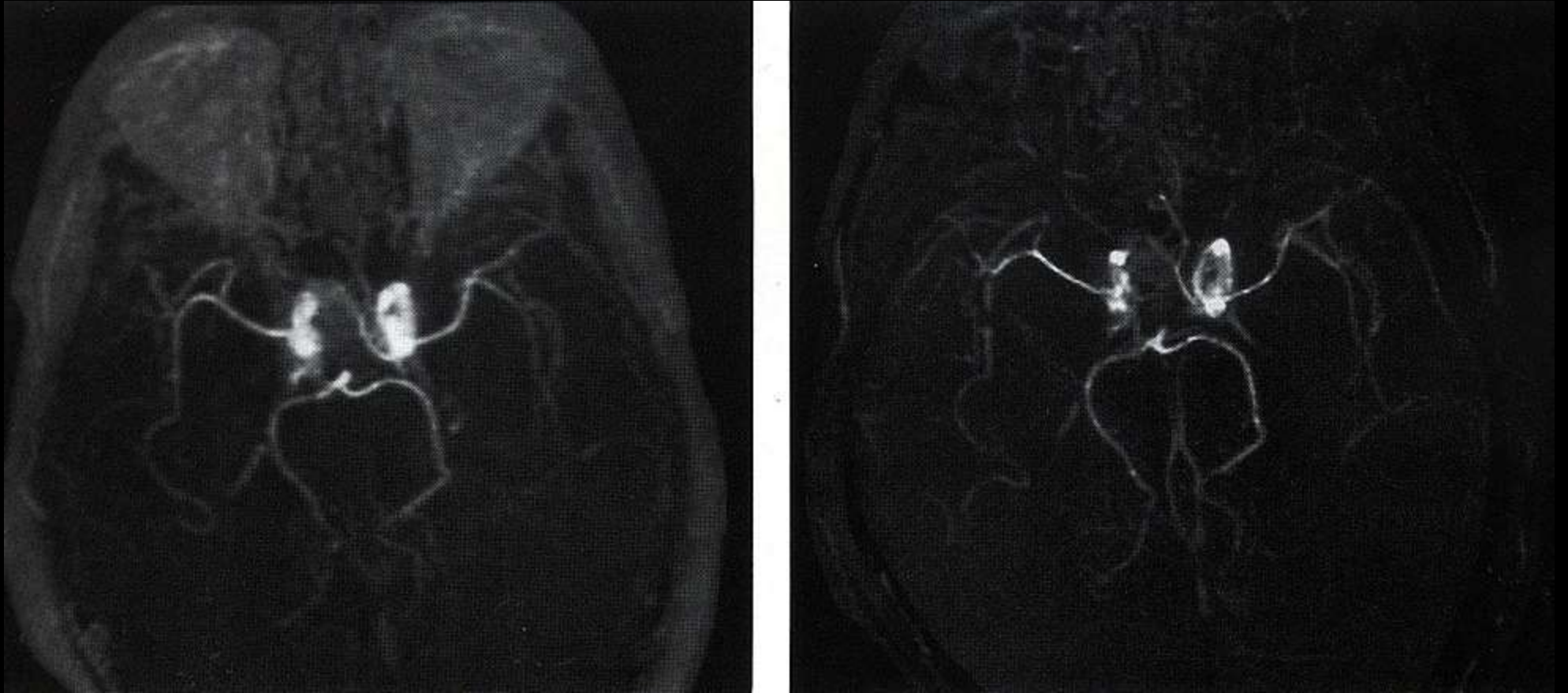


- Higher signal-to-noise
- Shorter imaging times
- Less intravoxel dephasing
- More saturation effects
- Smoother vessel contours

3D MOTSA: Moins d'artéfacts de saturation

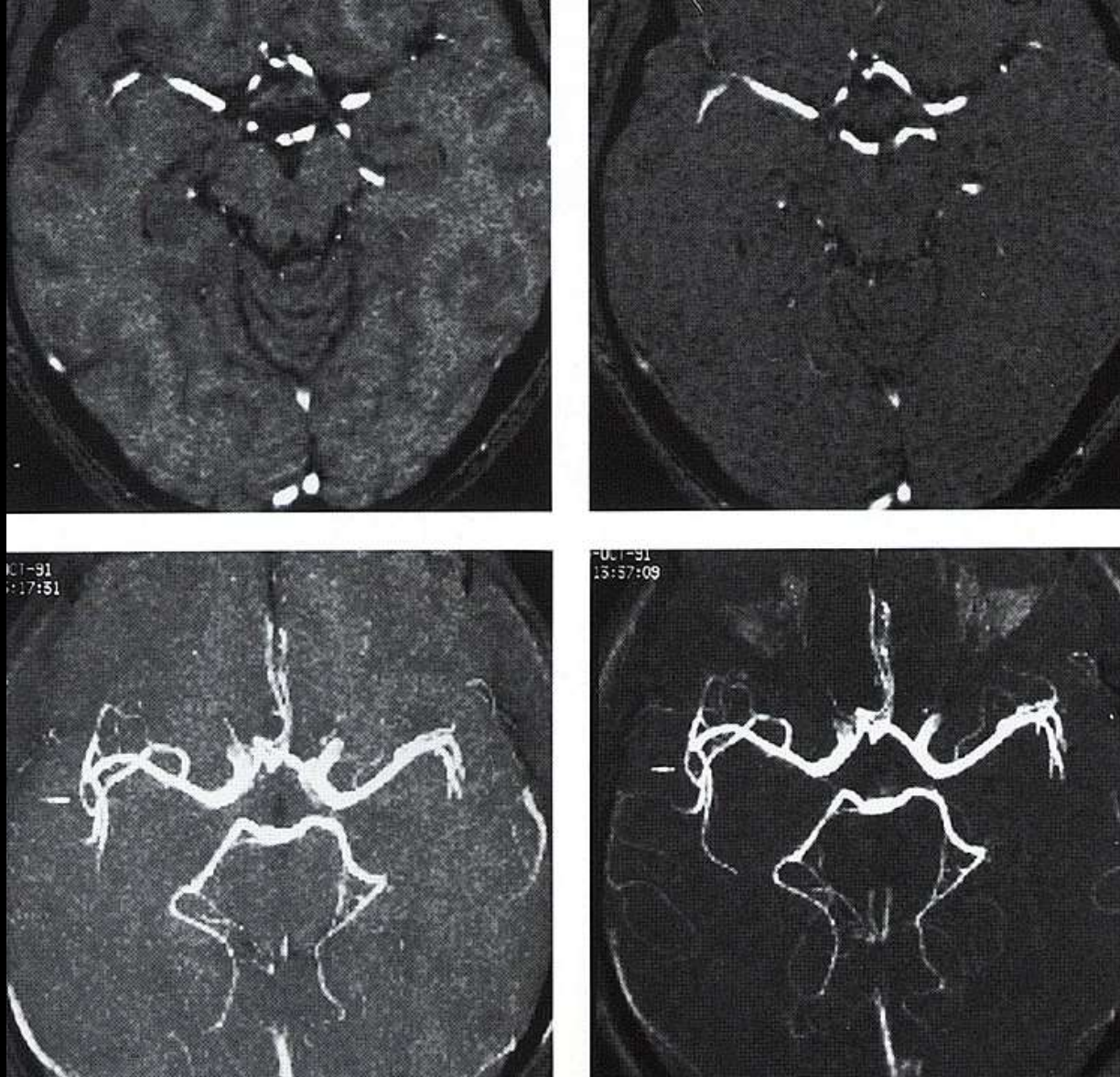


Effet de saturation de la graisse

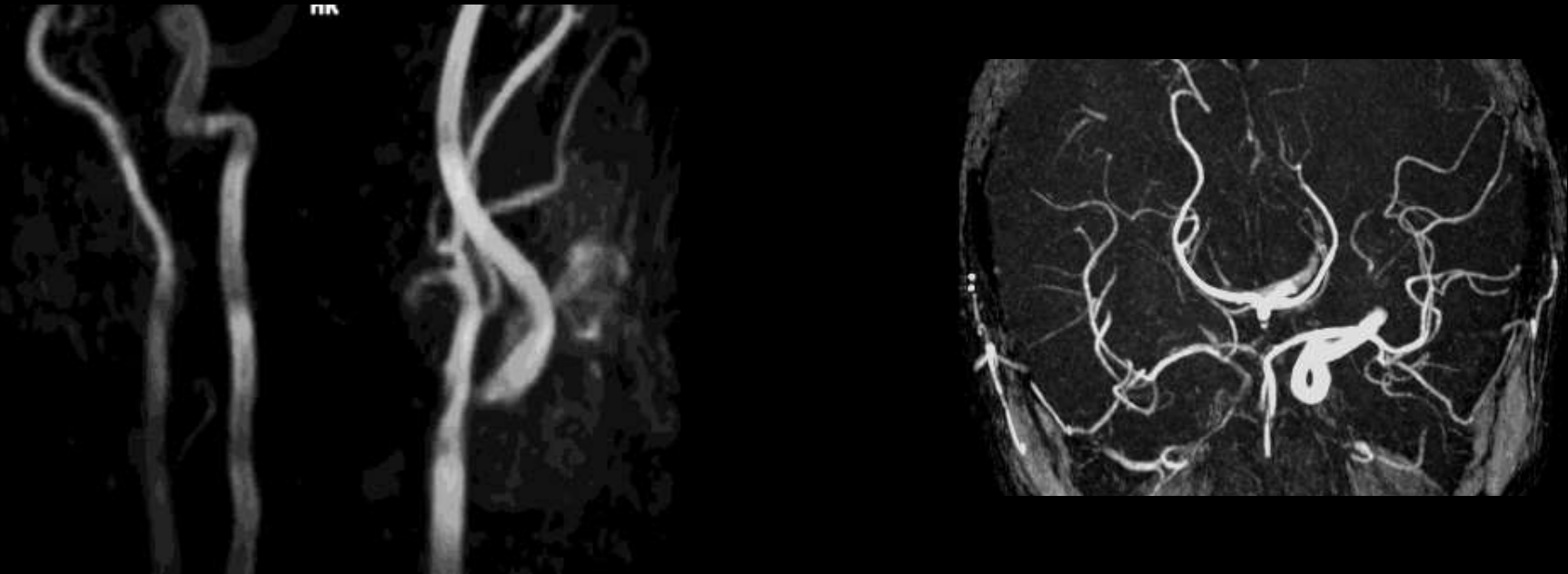


3D TOF 35/5/15°

Transfert de Magnetisation augmente le contraste en 3D TOF

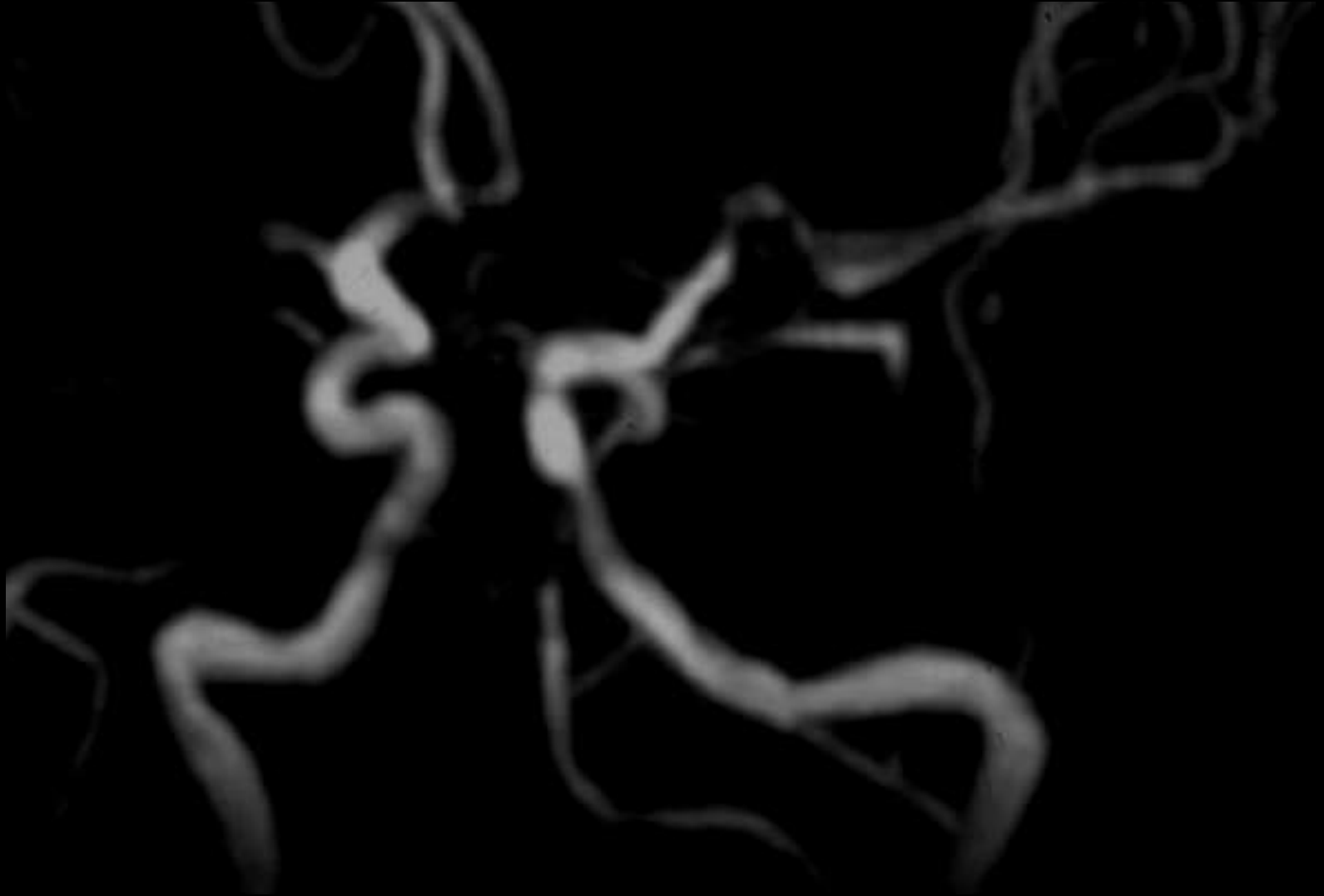


Indications TOF: Artères carotides



ICA occlusion
et vol vertebraal

Intracranial MRA at 3T: haute resolution



LIMITES DU TEMPS DE VOL ET DU CONTRASTE DE PHASE

- Signal dépendant des flux : problèmes avec flux lent et turbulent
 - Saturation ↘
 - Déphasage ↗
- Artéfacts
- Durée d'acquisition: 1H 30
- Géométrie d'acquisition restreinte

TOF Artéfacts de Mouvements



TOF: Artéfacts de Saturation

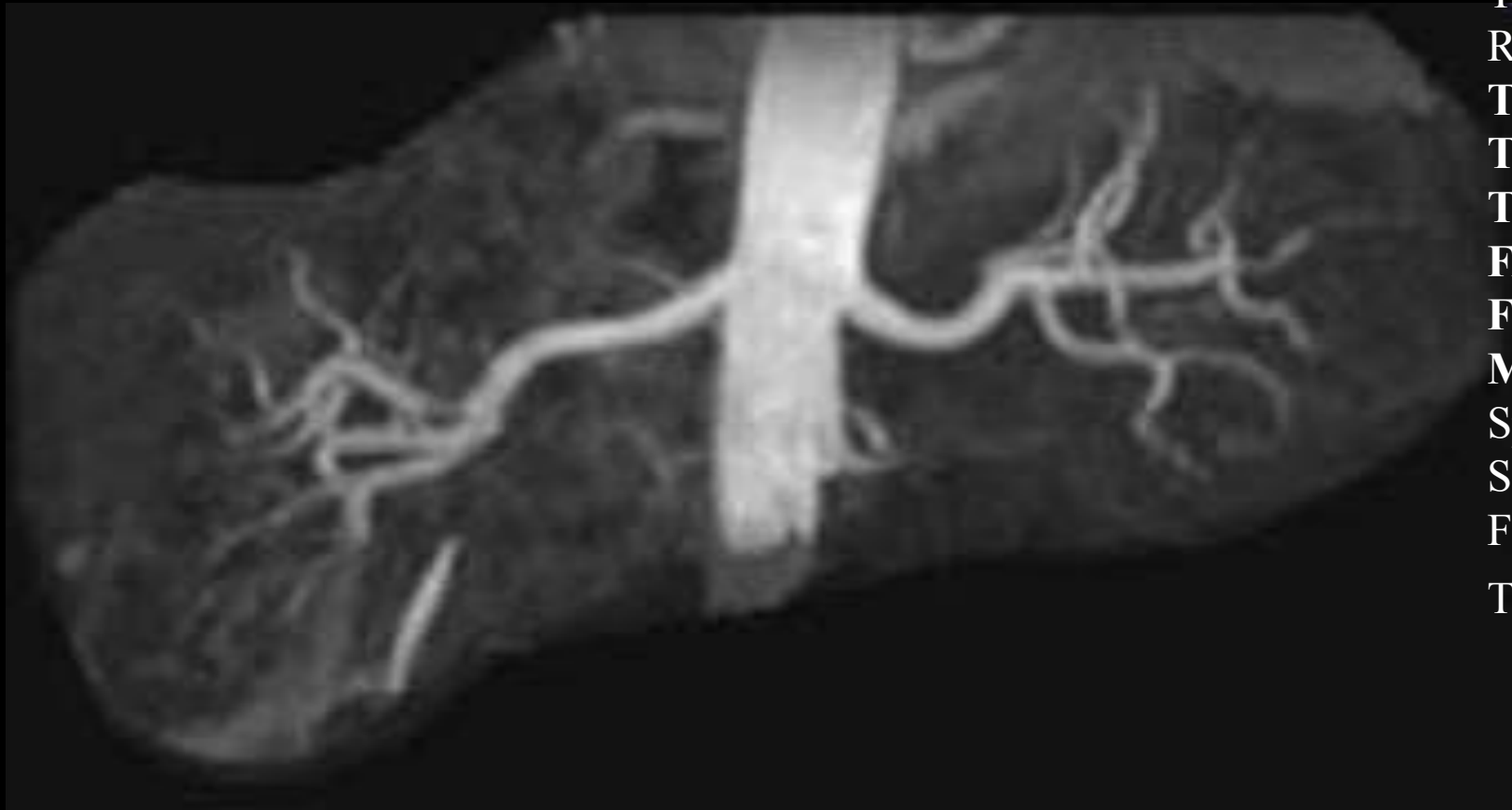


ANGIOGRAPHIE

ARTERES RENALES NORMALES

TECHNIQUE T-SLIP :

(Time Spatial labeling inversion Pulse)
avec SSFP et synchro respiratoire



Time-Slip SSFP
Respiratory-gating
TR = 5.2 ms
TI = [1200 1800] ms
TE = 2.6 ms
FA = 120
FOV = 35x35 cm
Matrix = 256X256
Speeder = 2
Slice # = 35
Fat Sat = ON
Time = 4.30 min.

Angiographie 3D écho de spin ultra-rapide avec synchronisation ECG sans produit de contraste (FBI)

- 1. une acquisition 3D en écho de spin ultra-rapide en demi-plan de Fourier**
- 2. une synchronisation ECG prospective**
- 3. l'absence d'injection de produit de contraste intra-vasculaire**
- 4. une préparation de l'aimantation par impulsion d'inversion pour supprimer le signal de la graisse (STIR)**

ARM FBI

Principes

1. **Echo de spin ultra-rapide 3D demi-Fourier**
2. **Synchronisation ECG prospective**
3. **Préparation STIR**

Optimisation

1. **TE court, plan coronal, codage de phase dans la direction des vaisseaux**
2. **Calibration du délai entre onde R et acquisition ++**
3. **Double acquisition pour soustraire le signal veineux**

Résultats

1. **Coronal**
2. **Possible en thorax/abdomen**
3. **Rapide**
4. **Perte de signal pour les flux rapides (alternative : acquisition en diastole)**

ANGIOGRAPHIE MEMBRES INFÉRIEURS

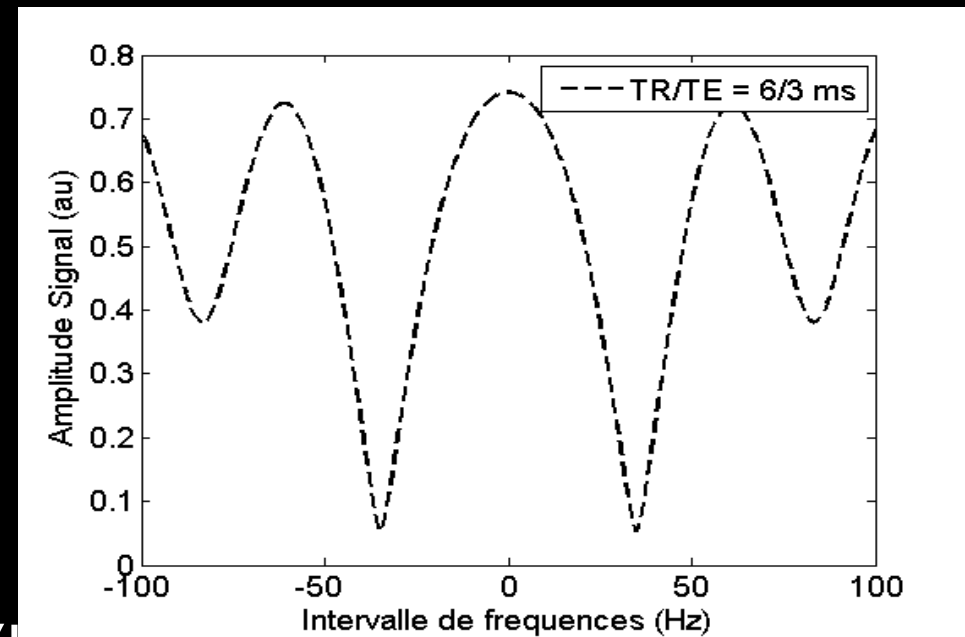
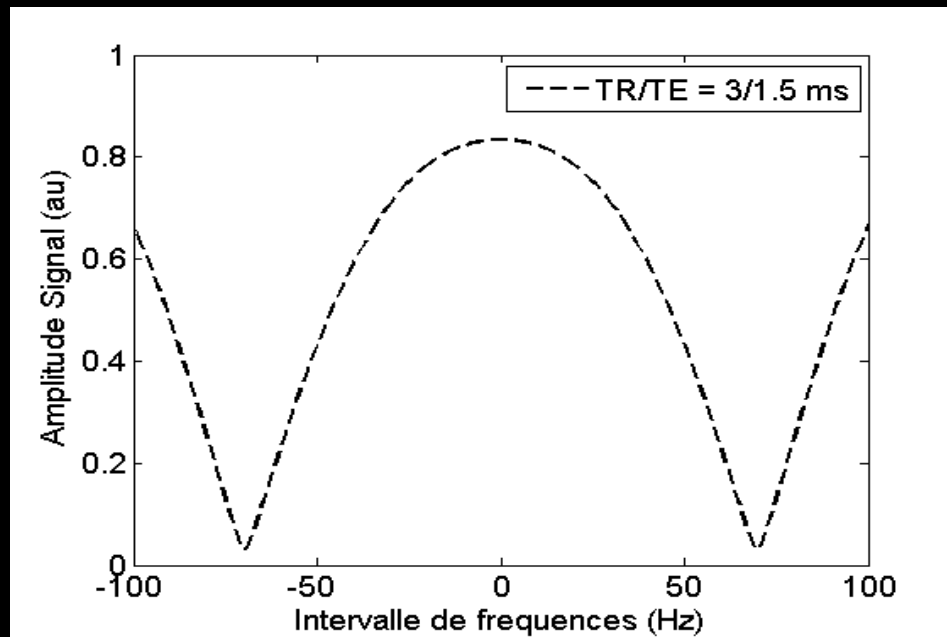
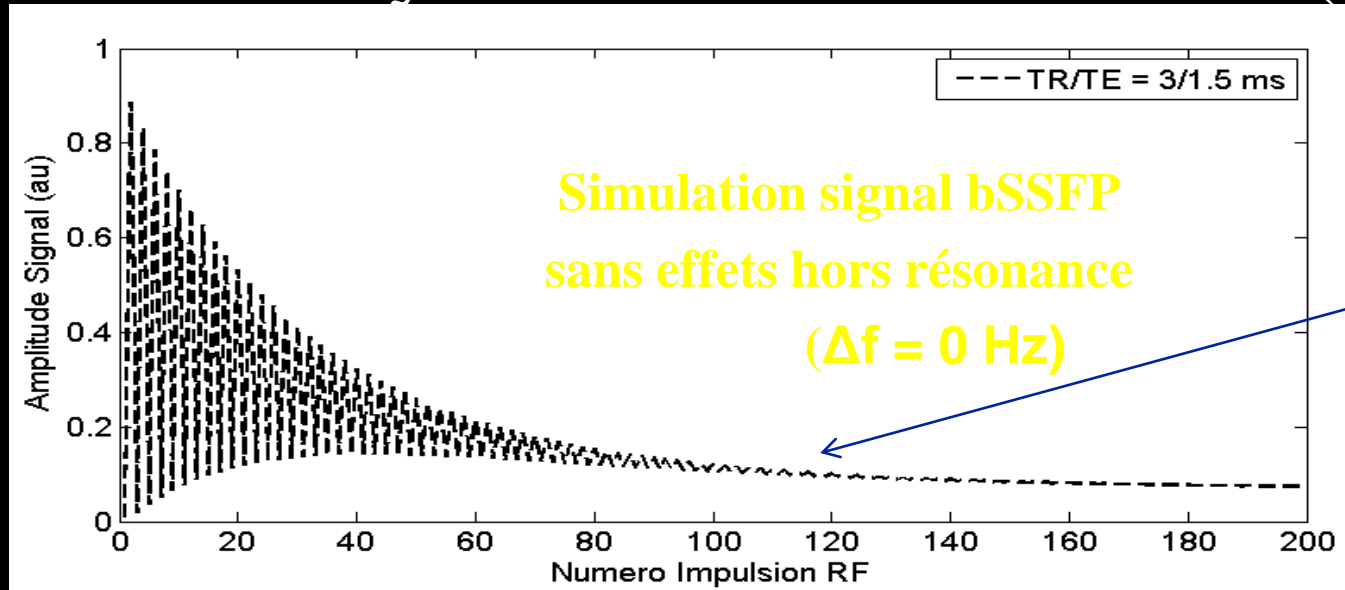
TECHNIQUE FBI



Angiographie IRM sans injection d'agent de contraste

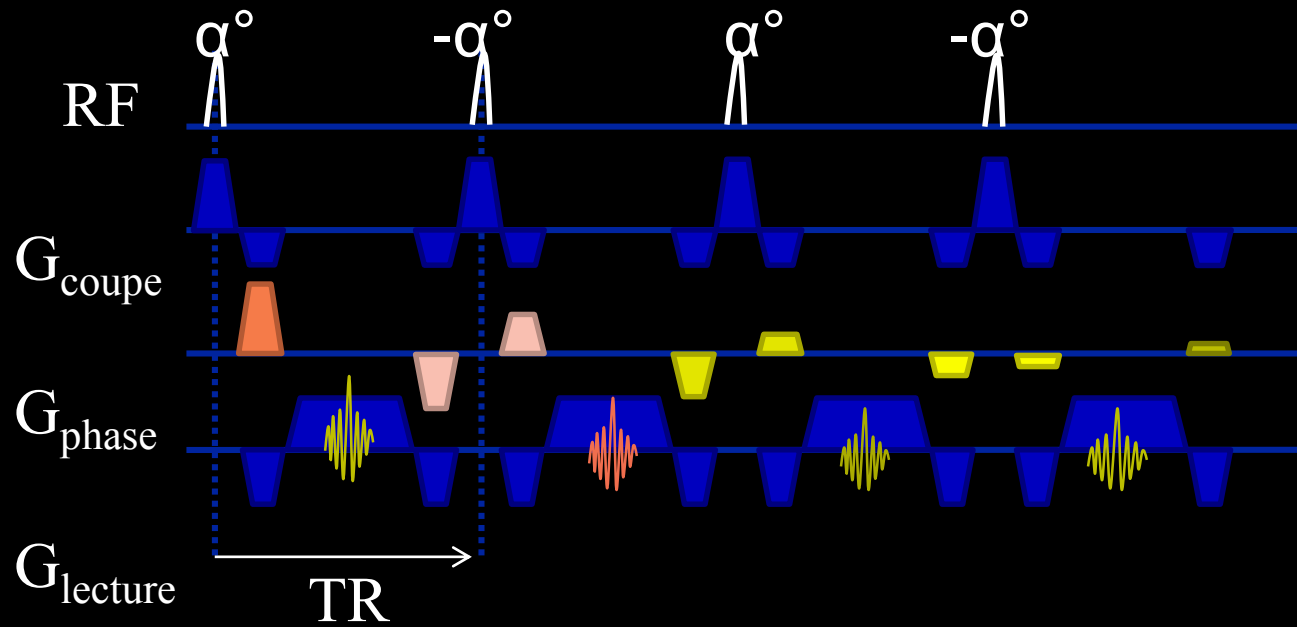
- Séquence bSSFP -

Balanced Steady State Free Precession (bSSFP)

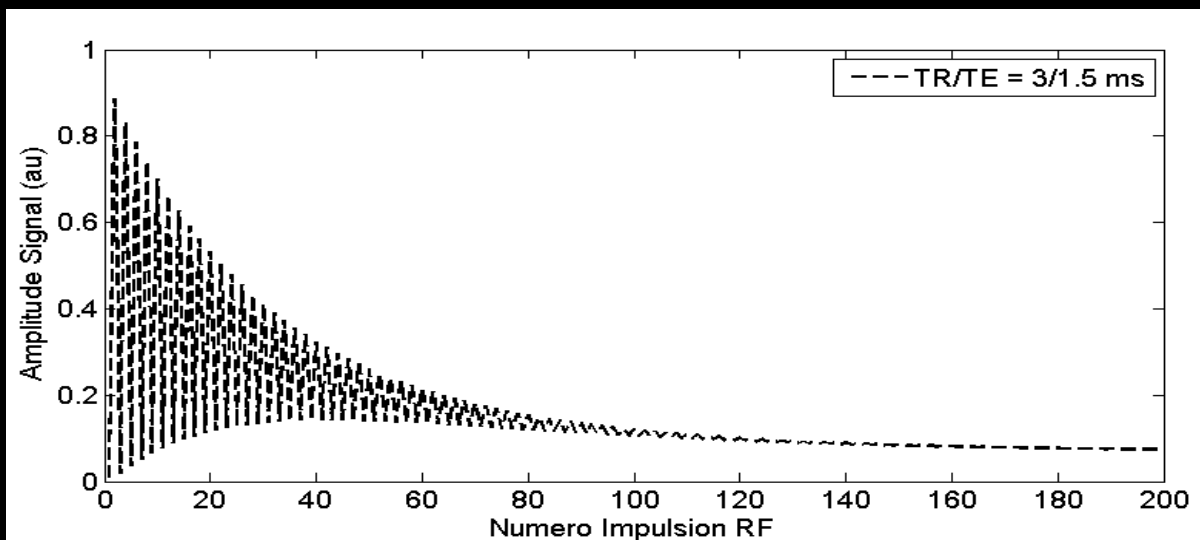


Δf (Hz)

Balanced Steady State Free Precession (bSSFP)



Espace de k



Simulation signal bSSFP
TR/TE = 3/1.5 ms; flip 70°
sans effets hors résonance

Signal1 **Cardiaque** **PACE**

1er signal/mode **ECG/Prospectif**

Cycle moyen ms

Cycle capturé

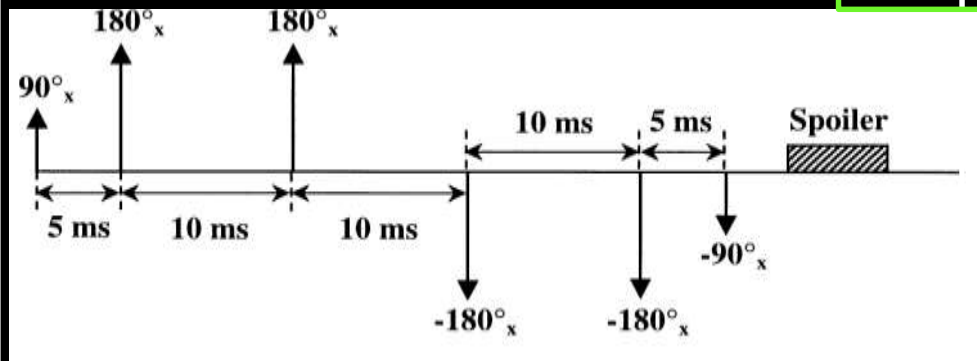
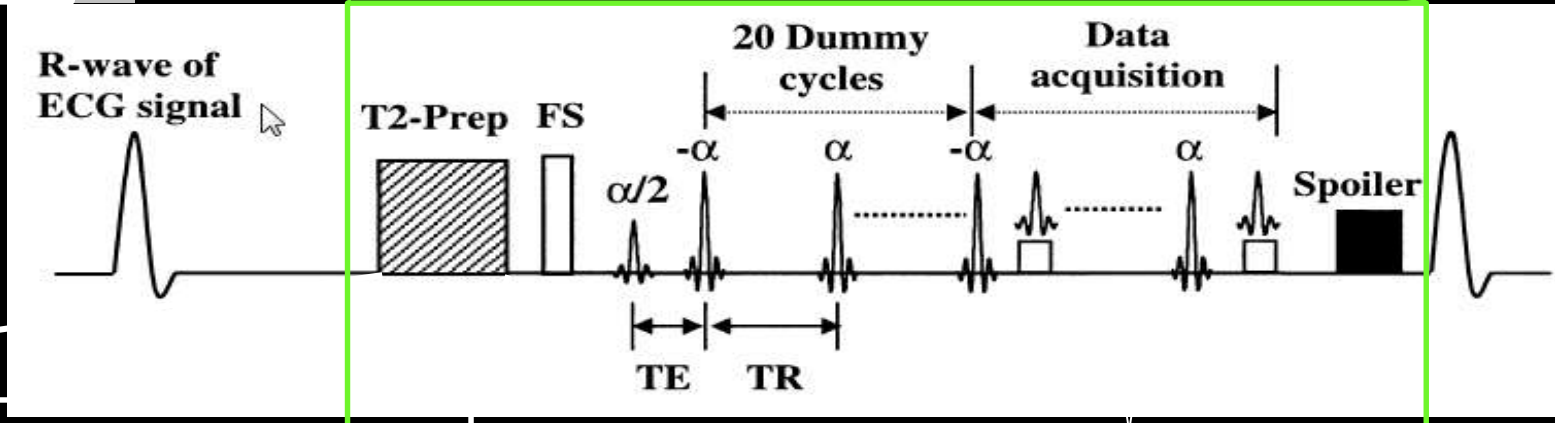
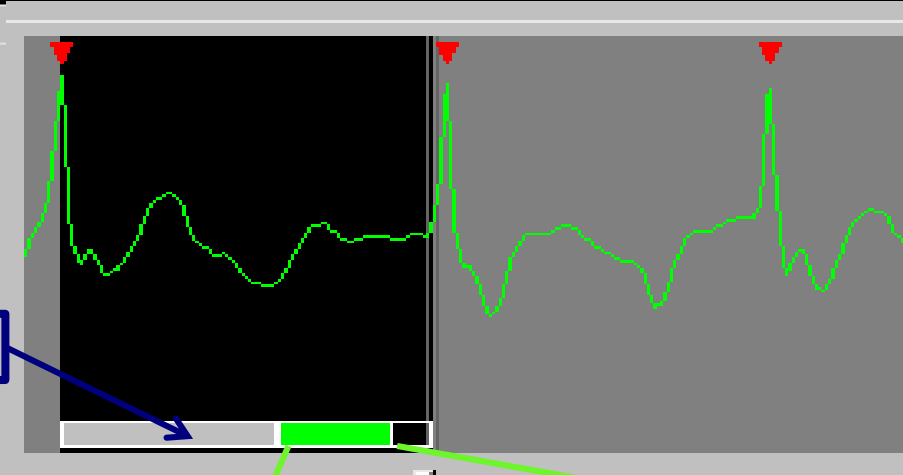
Fenêtre acqui. ms

Imp. déclenc.

Temp. décl. ms

TR ms

Concaténations



Acquisition
bSSFP
segmentée

Contraste Sang - Myocarde avec la sequence 3D bSSFP (TrueFISP)

Simulation numérique:

Séquence: bSSFP @ 1.5T

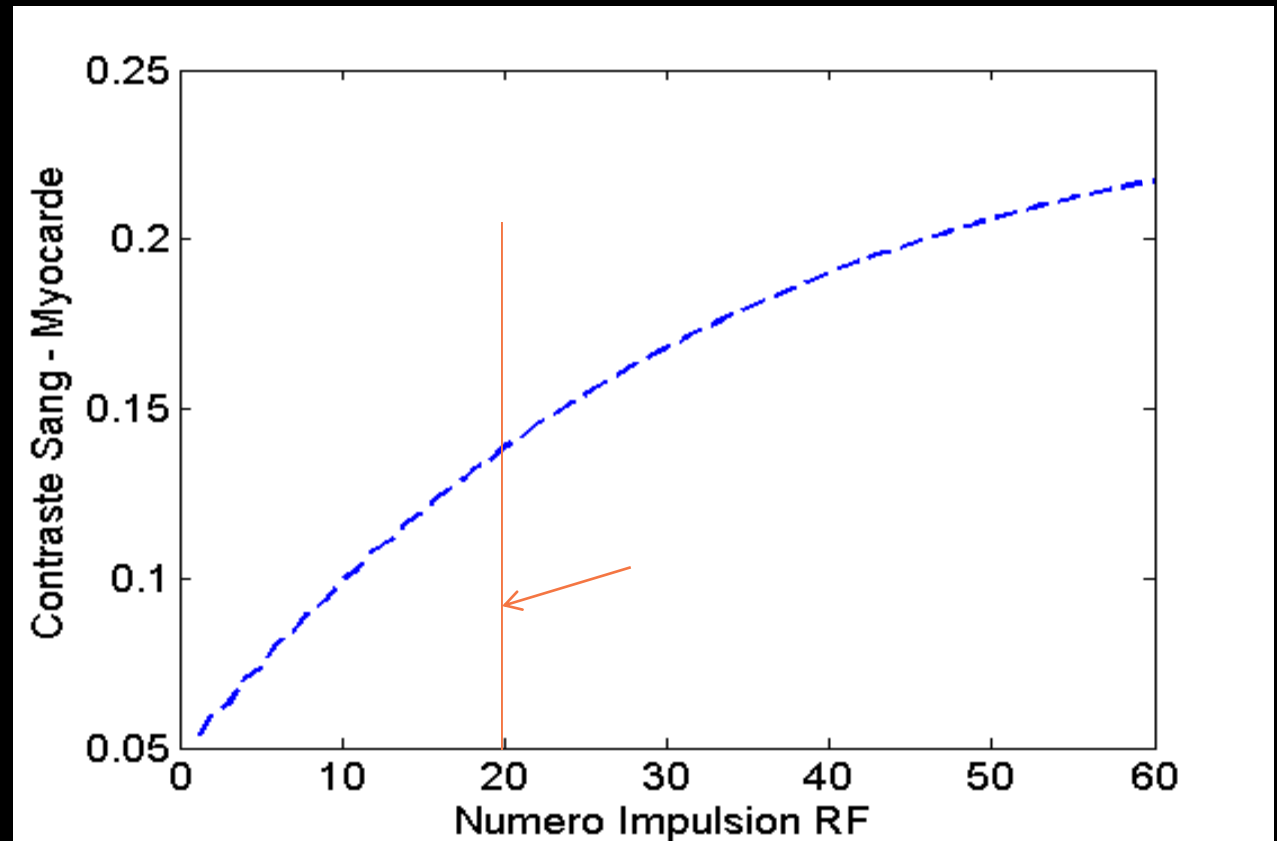
Sang: T1/T2 = 1200/250
ms

Myocarde: T1/T2 =
900/50 ms

TR/TE = 3/1.5 ms

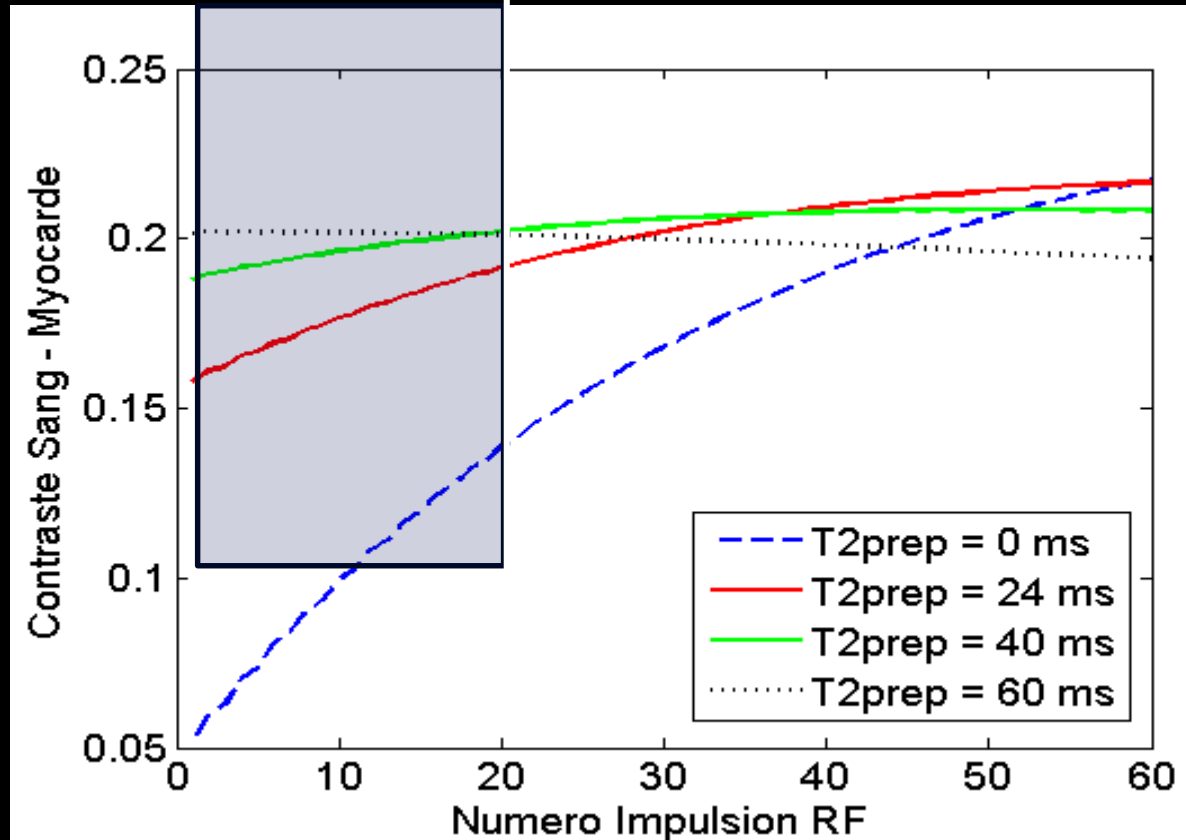
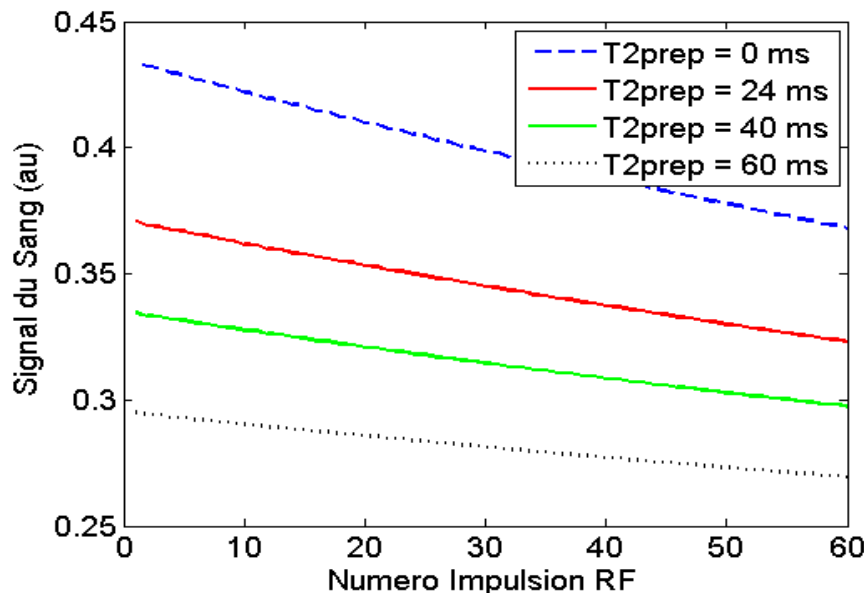
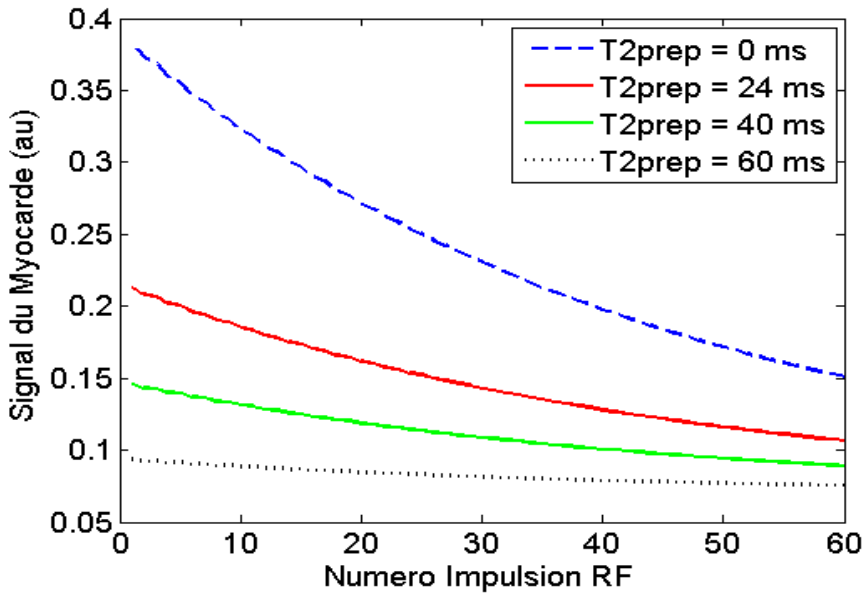
Angle = 70°

Sans effets hors-
résonance



Role de la Preparation T2 -> augmenter le contraste

Centre de l'espace de k



Contraste Sang - Myocarde avec la sequence 3D bSSFP (TrueFISP)

Simulation numérique:

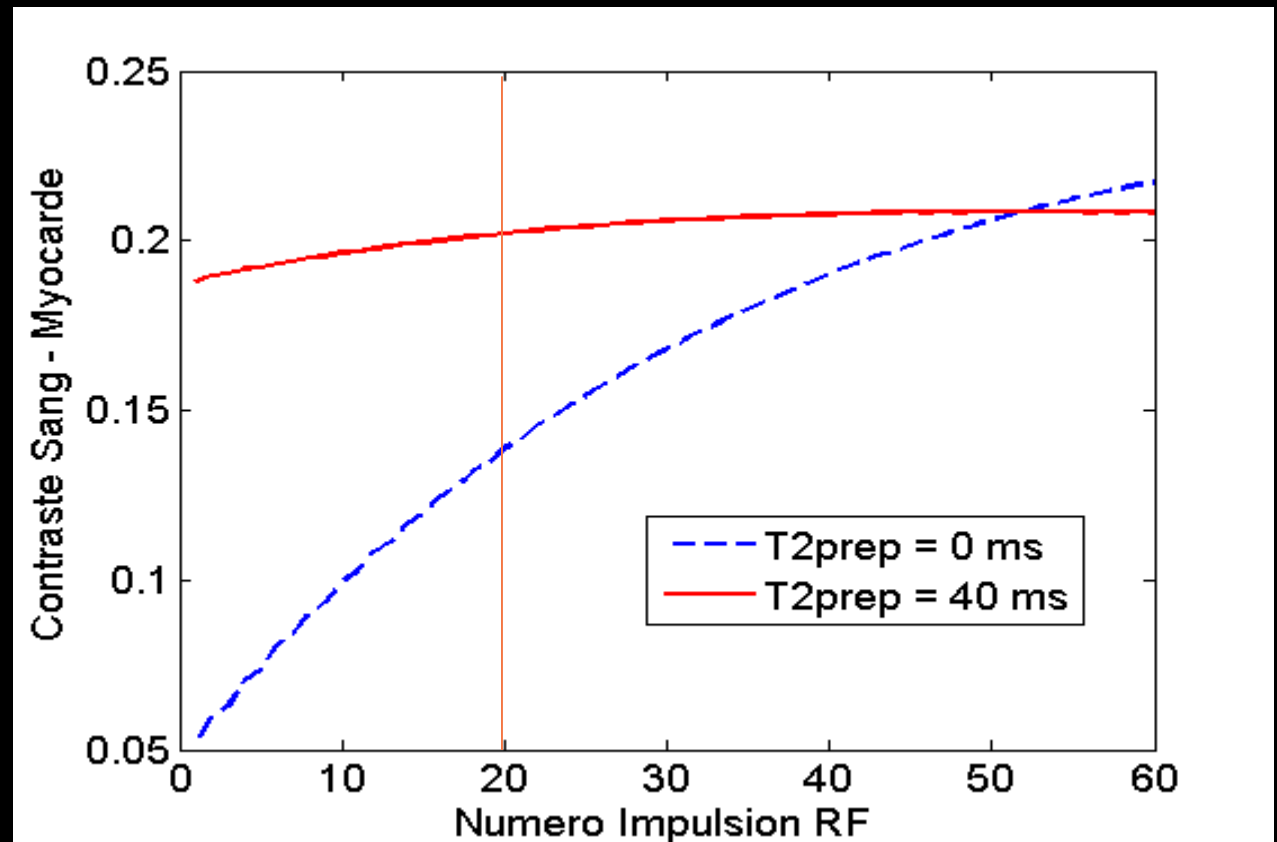
Séquence: bSSFP @ 1.5T
+ $T_{2\text{prep}} = 40$ ms

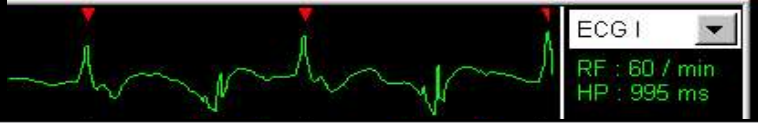
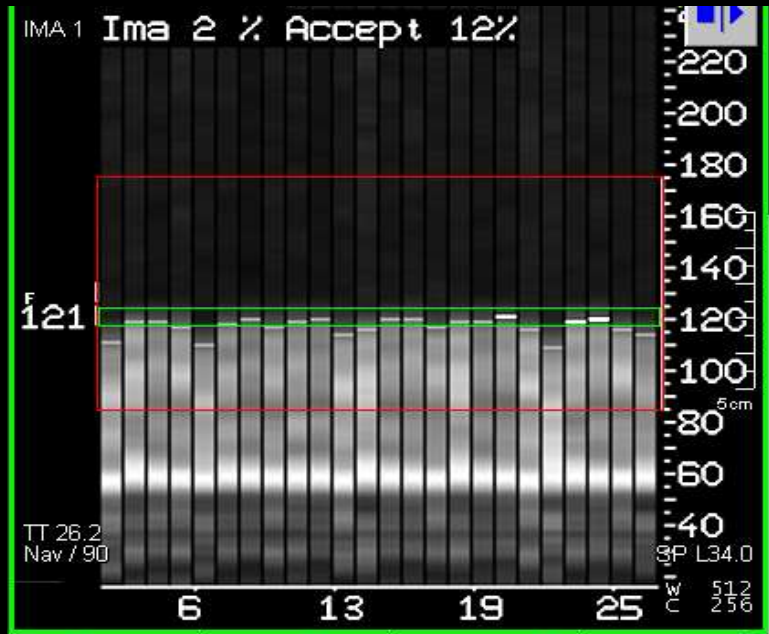
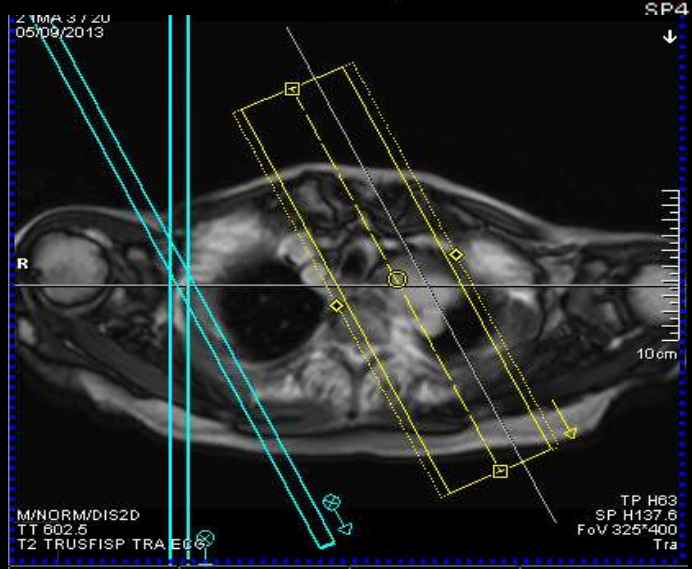
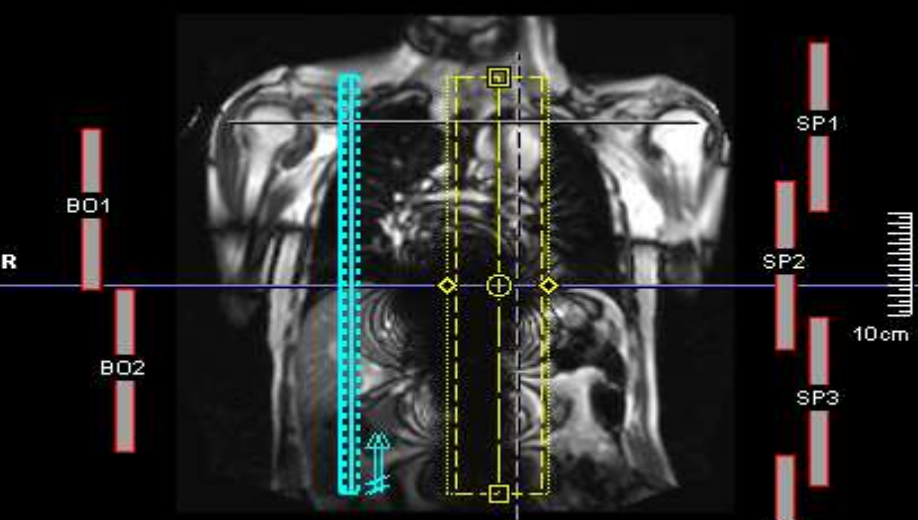
Sang: $T_1/T_2 = 1200/250$
ms

Myocarde: $T_1/T_2 = 900/50$
ms

$TR/TE = 3.1/1.3$ ms

Angle = 70°



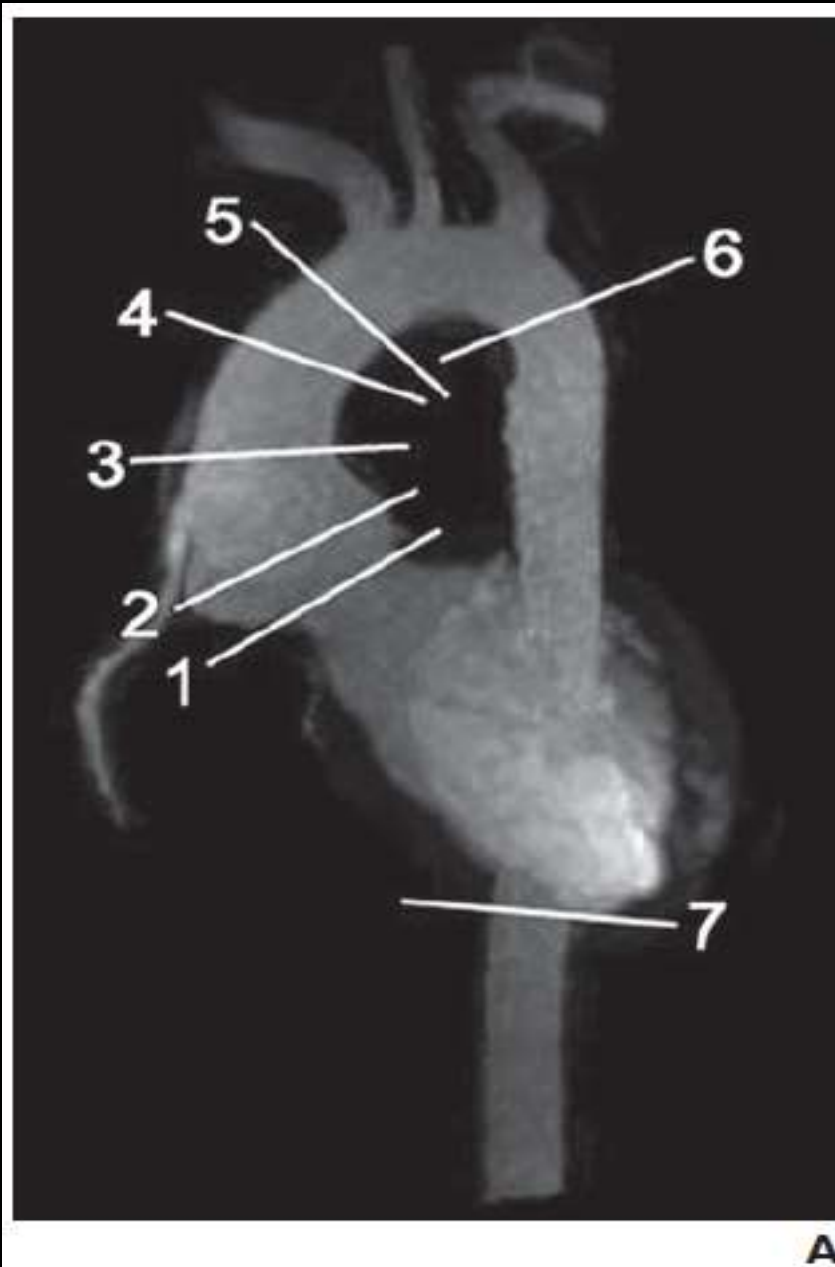


Signal1 Cardiaque PACE

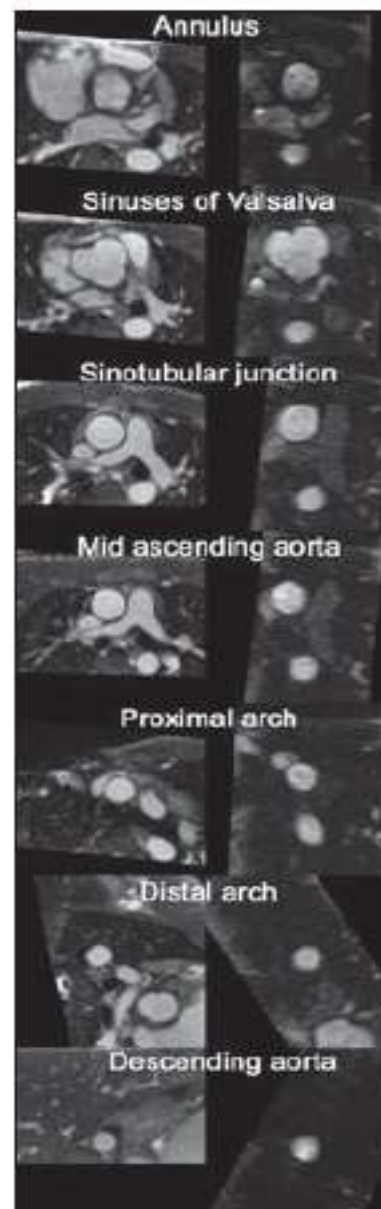
1er signal/mode ECG/Prospectif

Cycle moyen	945 ± 6	ms
Cycle capturé	-pas réglé-	
Fenêtre acqui.	946	ms
Imp. déclenc.	1	
Temp. décl.	550	ms
TR	295.51	ms
Concaténations	1	
Segments	40	

Phases 1



A



B

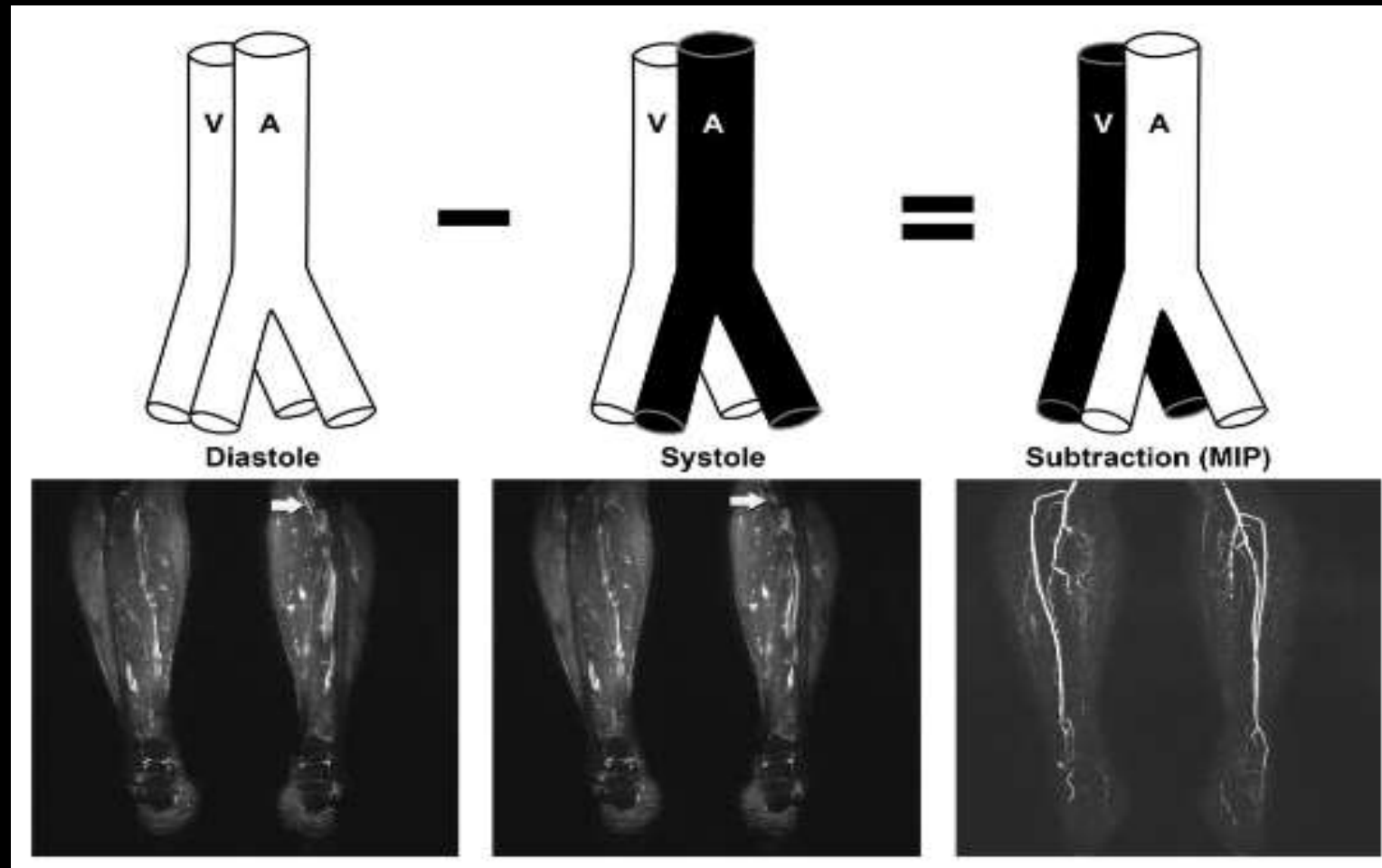
Fig. 2—23-year-old man with history of Ross procedure and dilated aortic root.

A, Volume-rendered image from 3D steady-state free precession (SSFP) data set indicates seven locations at which measurements were made: 1, annulus; 2, sinuses of Valsalva; 3, sinotubular junction; 4, mid ascending aorta; 5, proximal arch; 6, distal arch; and 7, descending aorta.

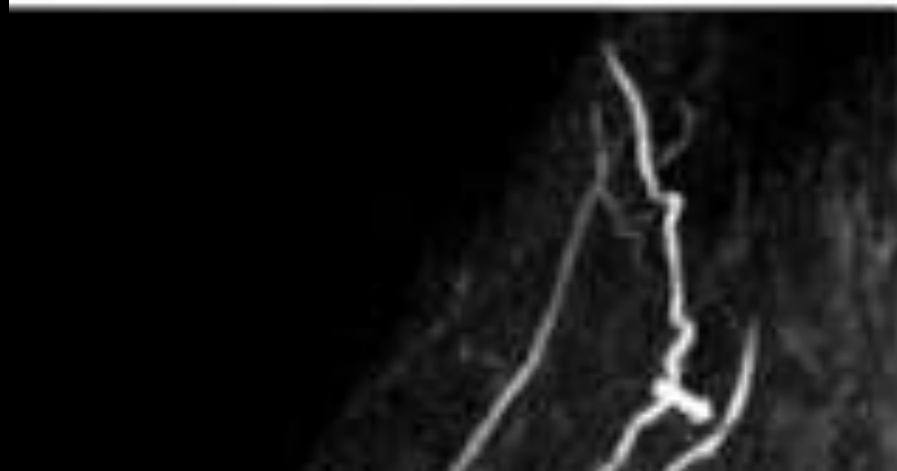
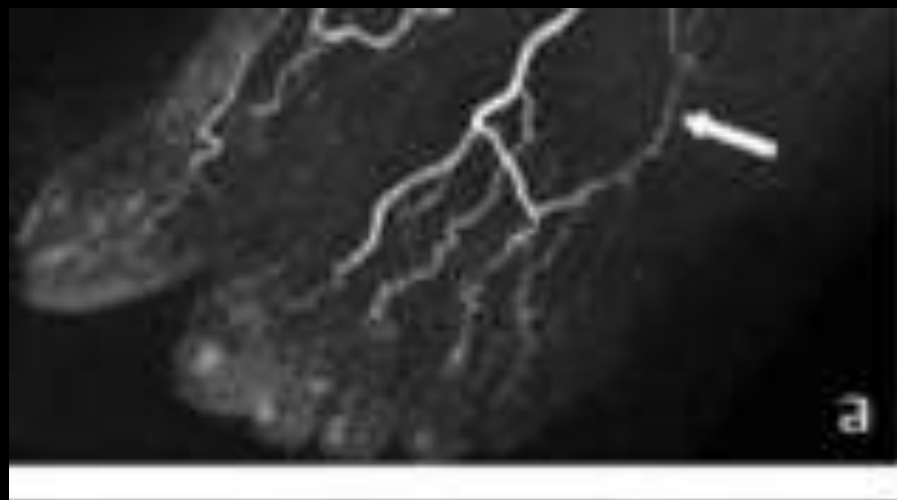
B, Multiplanar reformatted images from 3D SSFP (*left*) and contrast-enhanced MR angiography (*right*) data sets at annulus, sinuses of Valsalva, sinotubular junction, mid ascending aorta, proximal arch, distal arch, and descending aorta.

NATIVE

Angiographie sans-injection - séquence FSE



ARM bSSFP and FSD ECG triggered

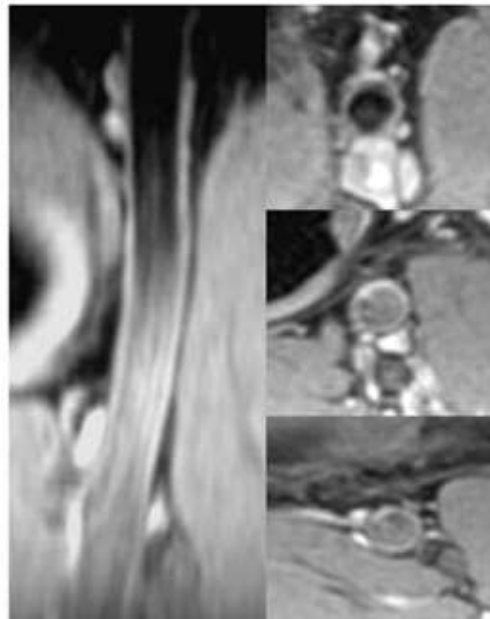
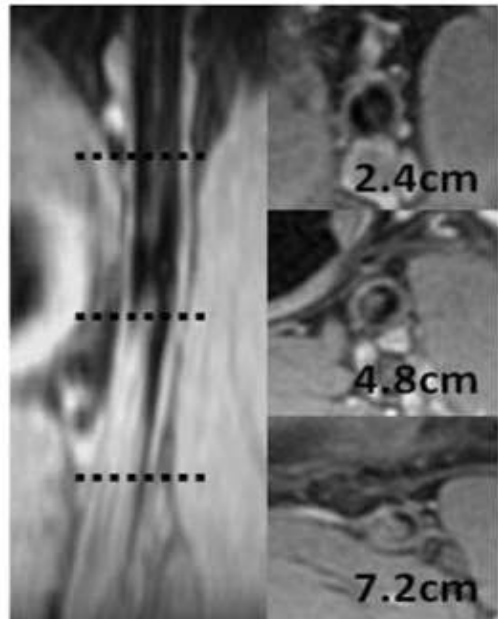


Angiographie Black-Blood

Adaptées aux acquisitions 2D

DIR

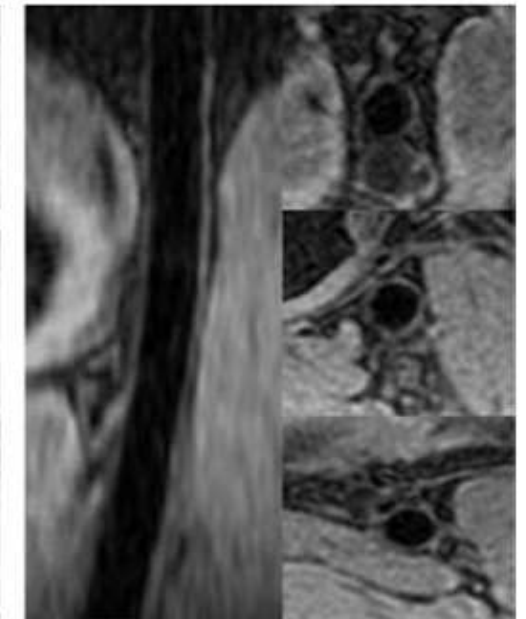
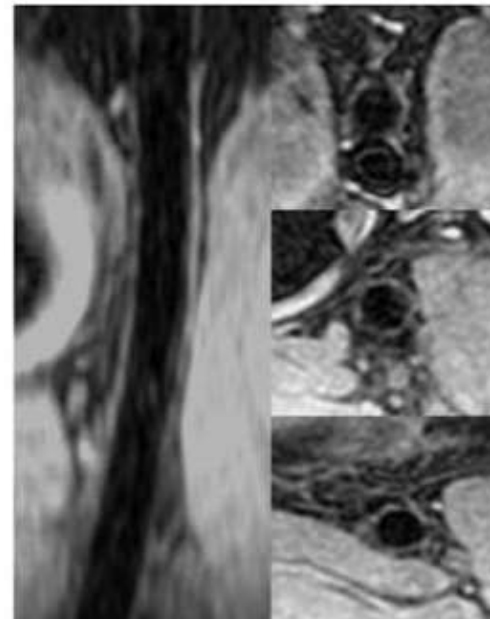
SPSAT



Adaptées aux

MSPREP

T2IR



DIR- double inversion-récupération

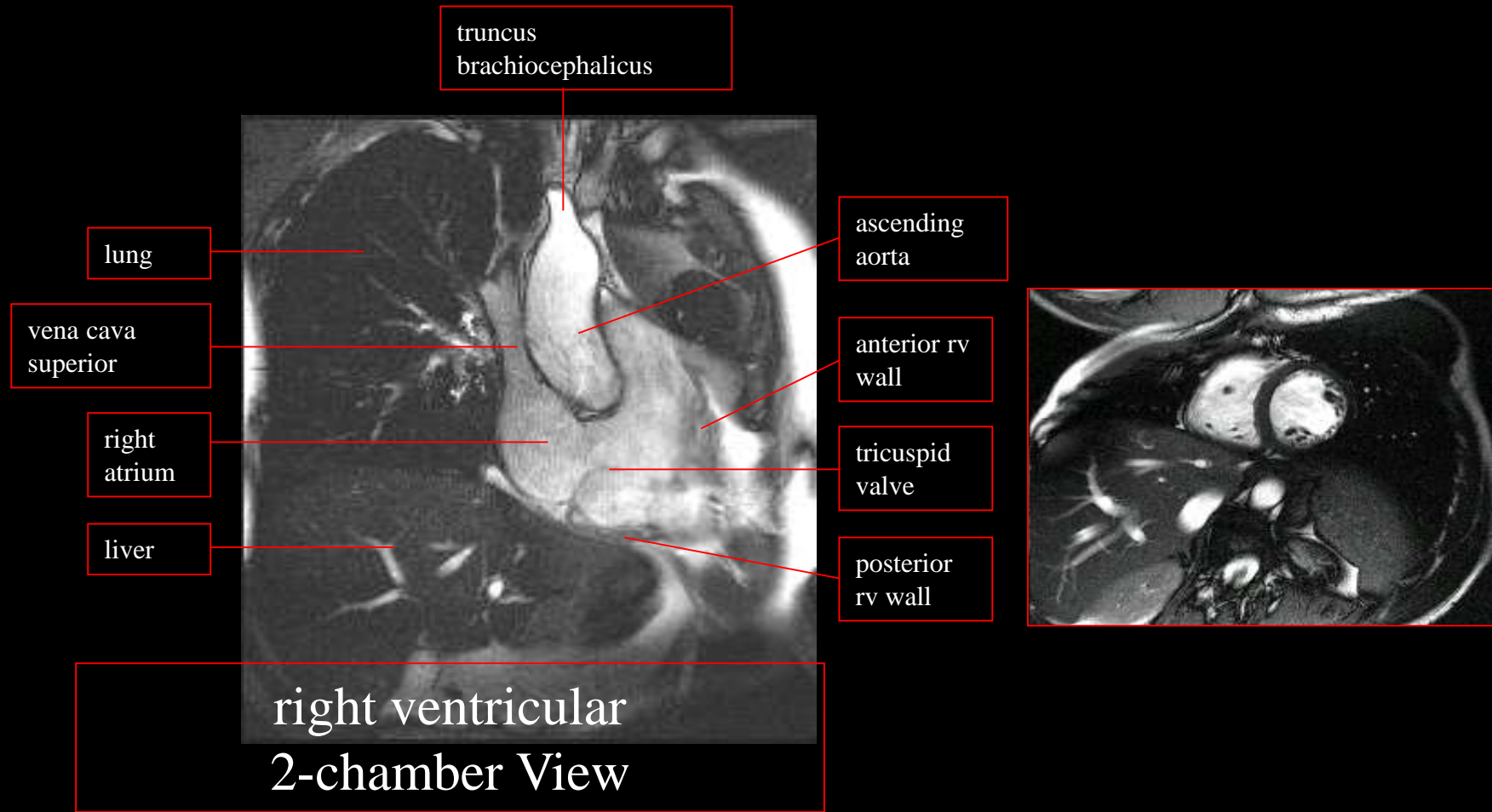
SPSAT – presaturation spatiale

- **MSPREP** – gradients sensibles au mouvement (encodage de vitesse)
- **T2IR** – préparation T2 inversion-récupération

Steady State Free Precession: SSFP

True FISP, Balanced FFE , Fiesta

- echos stimulés induisent un état d'équilibre et reduisent les effets de saturation



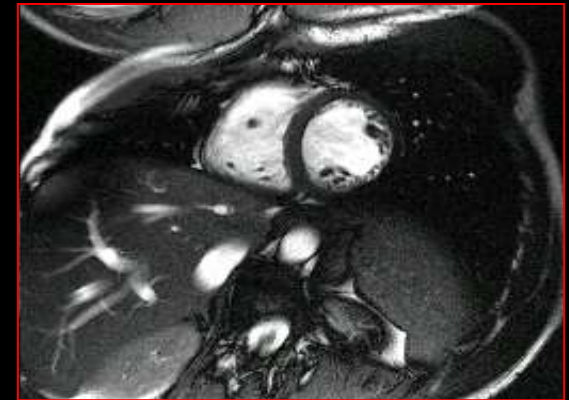
Steady State Free Precession: SSFP

True FISP, Balanced FFE , Fiesta

- echos stimulés induisent un état d'équilibre et reduisent les effets de saturation

Indications:

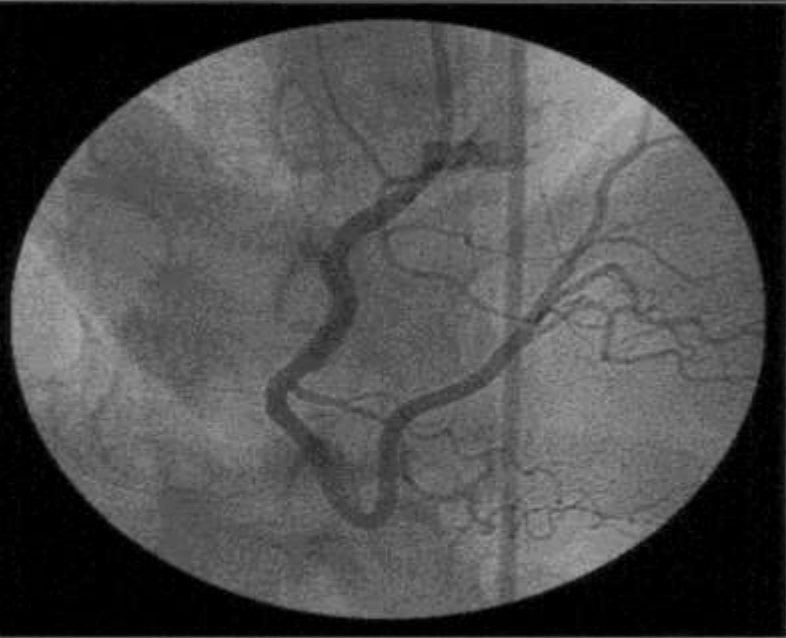
- Imagerie de l'aorte
- Imagerie Cardiaque



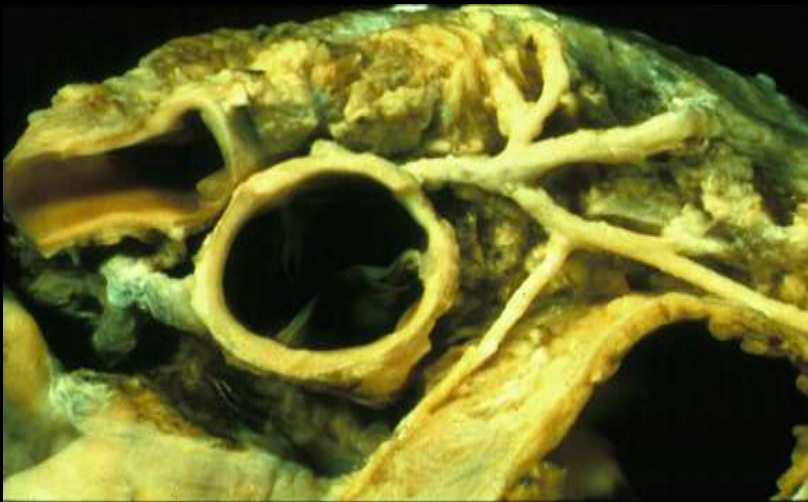
RCA

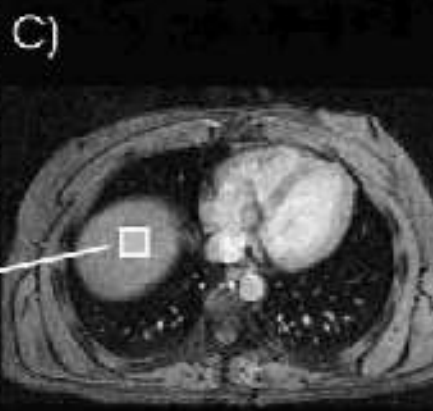
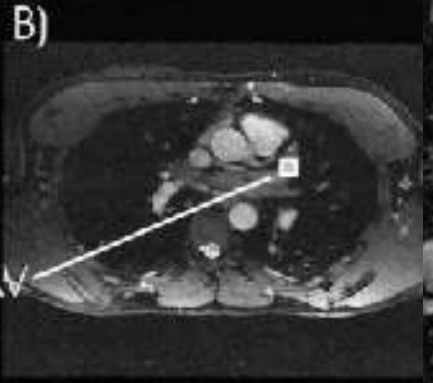
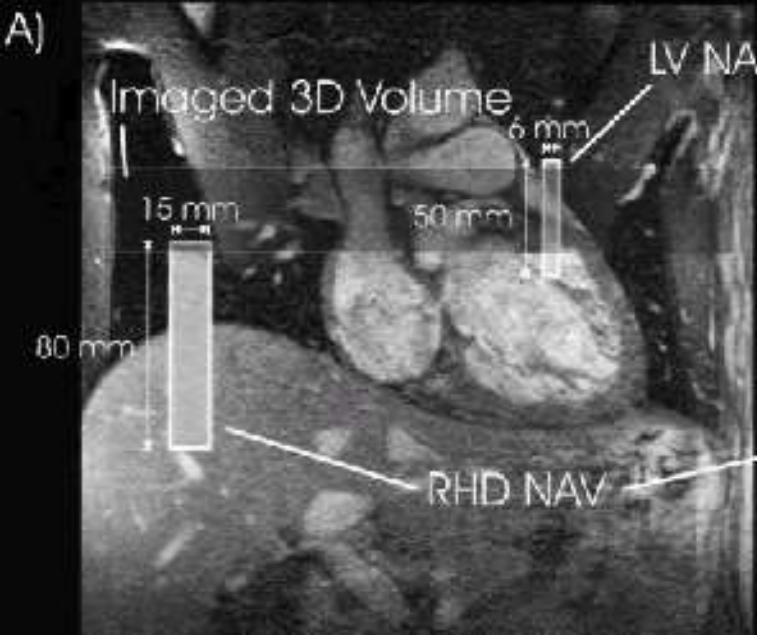
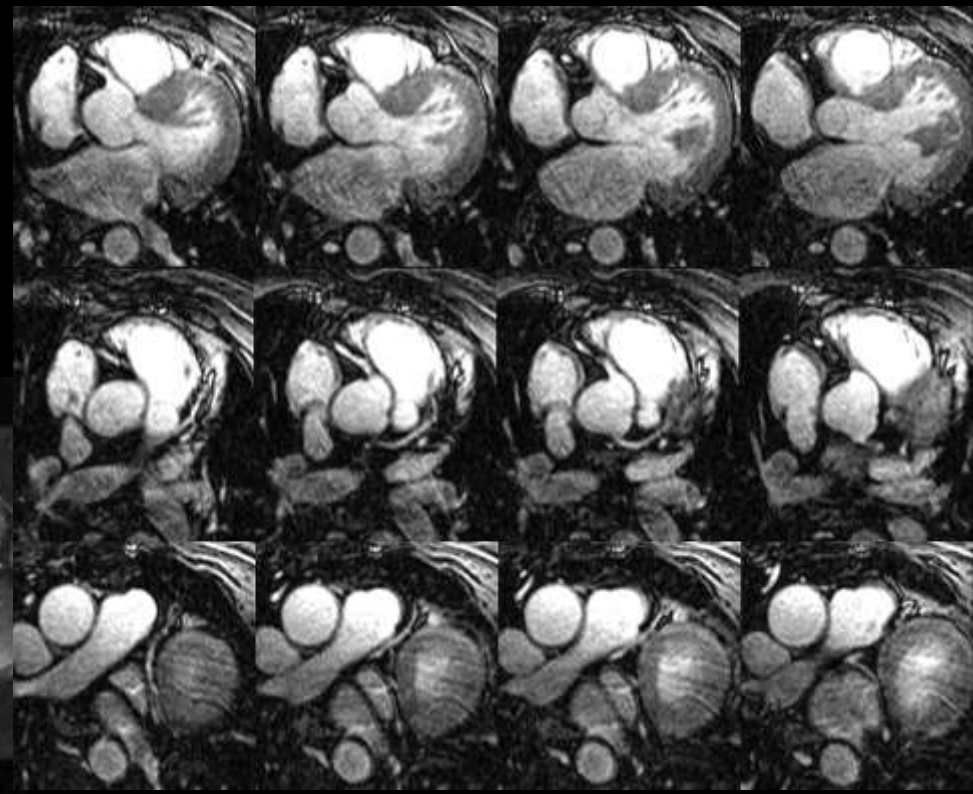
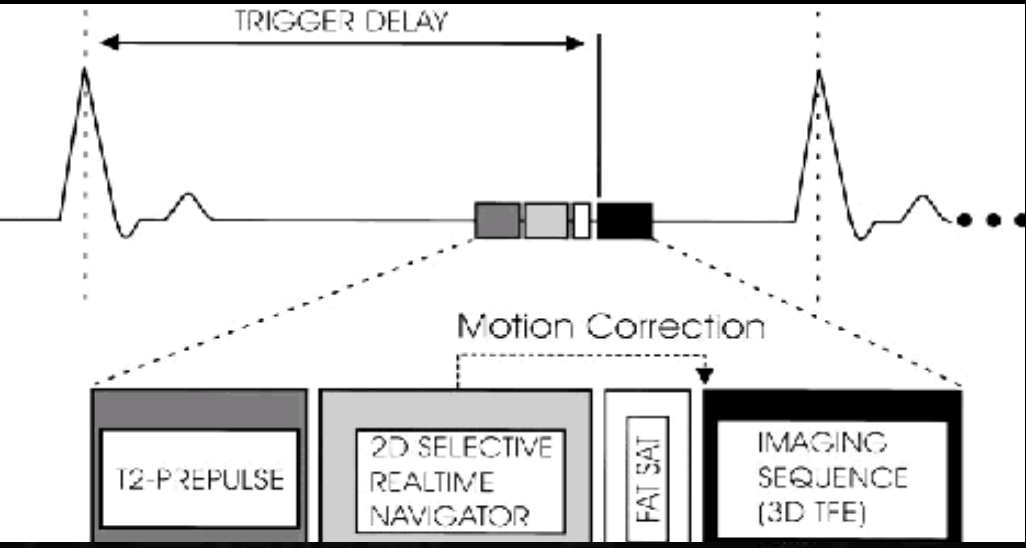


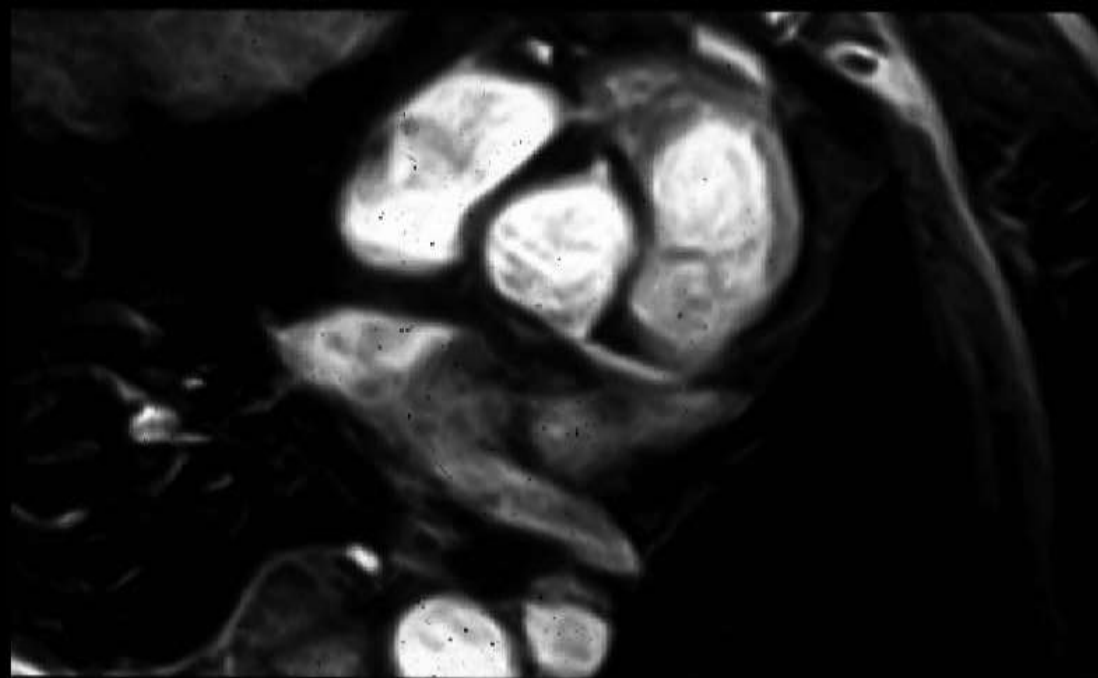
Diastole



Systole

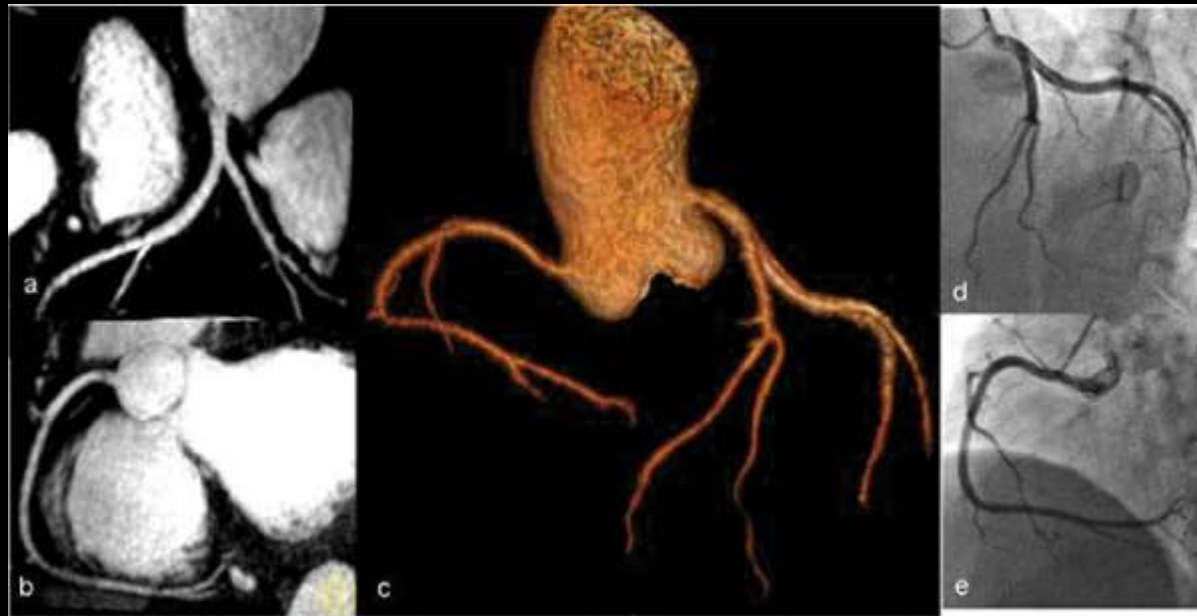






Coronary MRA at 3T

ECG-triggered, navigator-gated, inversion-recovery, segmented gradient-echo sequence
32-channel cardiac coils



ARM avec Injection de GD

- **Association de l'injection de GD à Imagerie rapide 3D**
- **Amélioration des équipements**
 - gradients puissants
 - antennes en réseau phasé

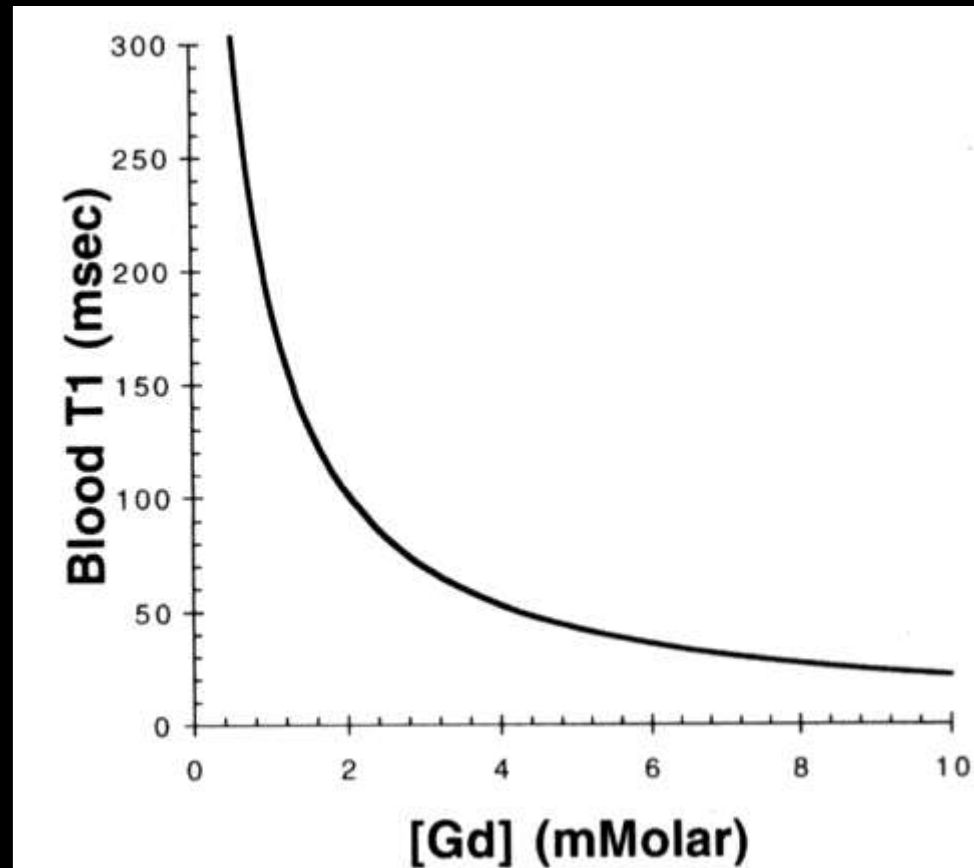
PRINCIPES DE L'ARM AVEC GADOLINIUM

- Signal indépendant des flux
- Signal dépendant du raccourcissement du T1, du sang lié à l'injection intraveineuse du Gd

$$\frac{1}{T1} = \frac{1}{T1,0} + r1c$$

T1 sang = 1200 ms → T1 (sang + Gd) = 100 ms

Evolution du T1 sang / cc GD

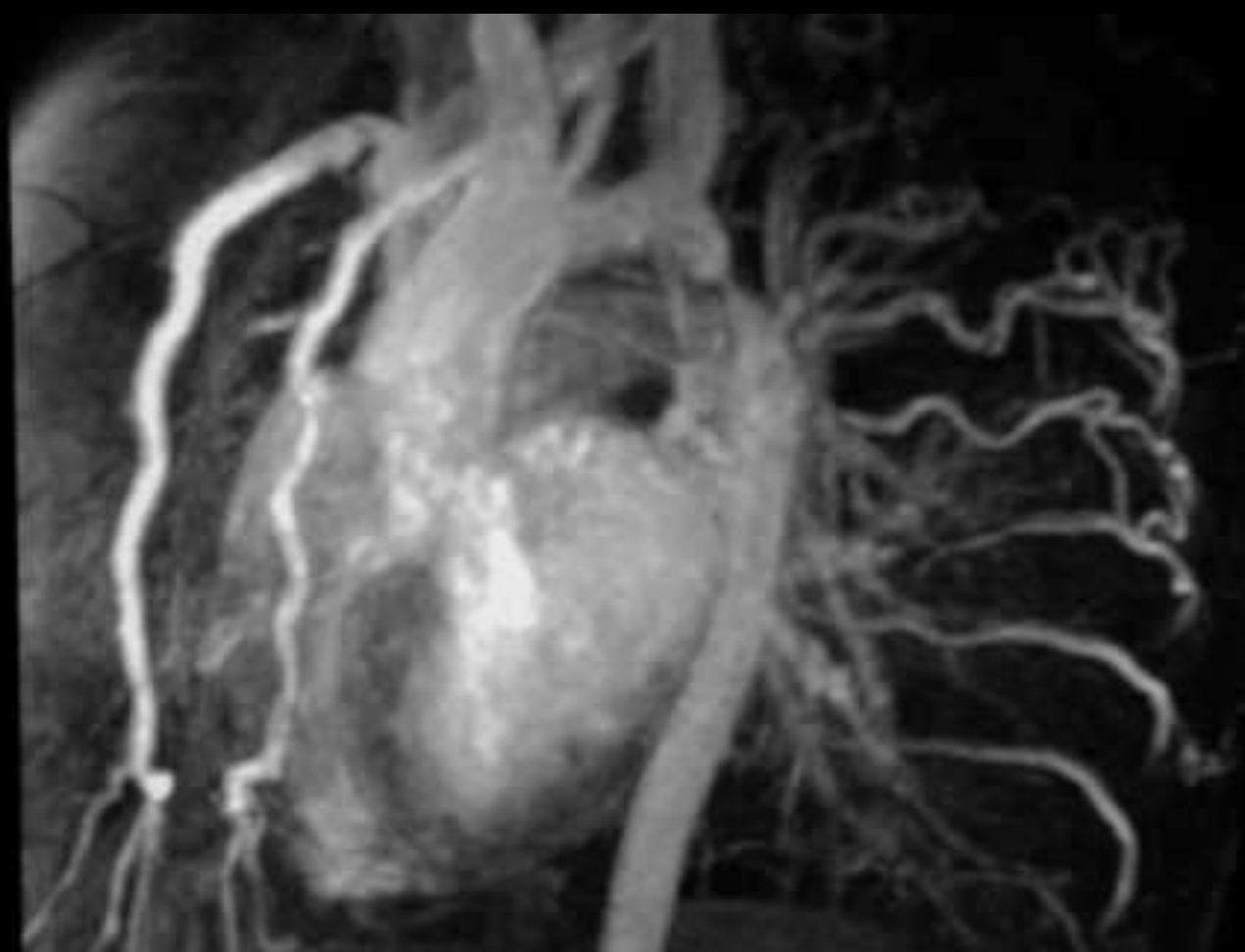


Apport du Gd

Absence d'artefact de saturation

- Meilleure appréciation du luminogramme des sténoses et anévrismes
- Meilleure exploration des artères quelque- soit leurs positions dans le volume
 - Artères rénales (ostium , tronc et 1 segmentaires)



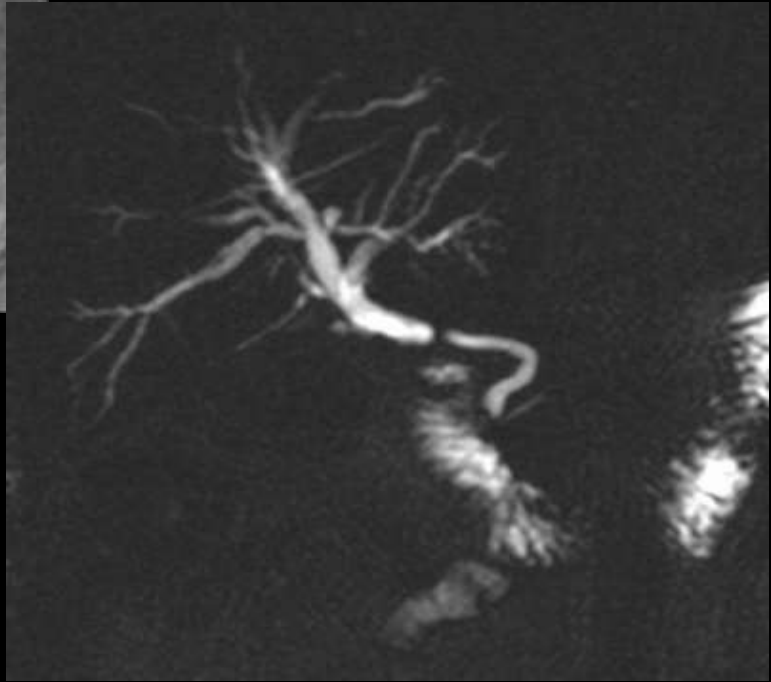
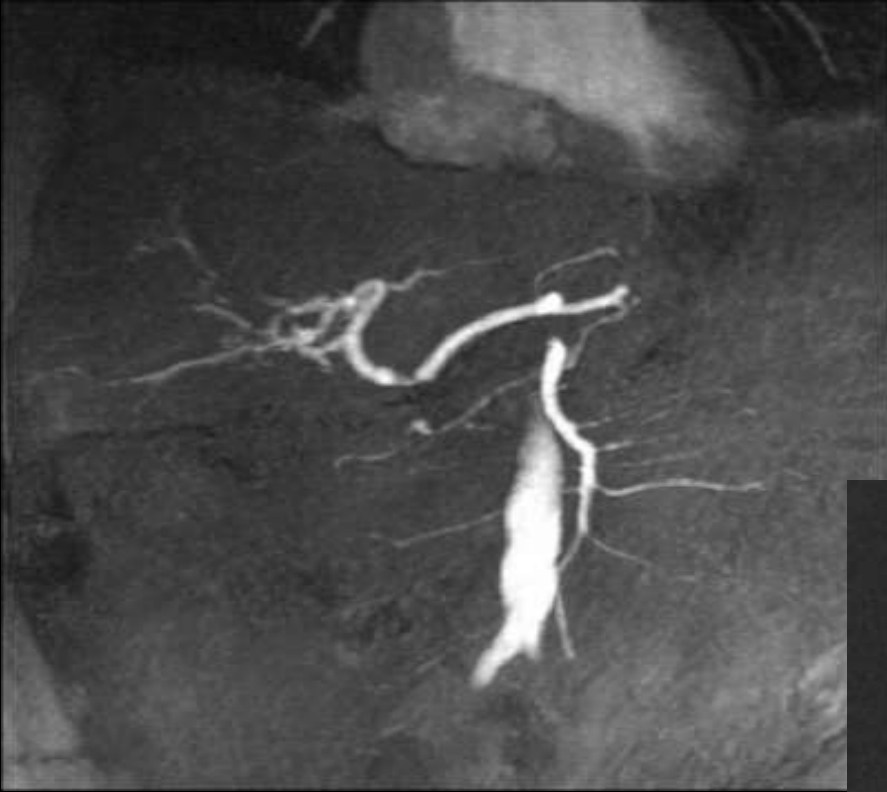


Apport de l'imagerie du premier passage de Gd

Exploration de grandes régions anatomiques en une apnée :

- Aorte
- Membres inférieurs
- Arche aortique et TSA





DERIVES DU GADOLINIUM

- Agent extra-cellulaire
- Néphrotoxicité ?
- Effets secondaires 1/20.000
- Faible volume : 15-20 cc

ARM AVEC GADOLINIUM*

ASSOCIE :

- Injection intra-veineuse
 - Gd 0,1 mmol/kg par acquisition
- Imagerie rapide du 1er passage
- Géométrie d'acquisition optimale
- Soustraction

Ph. Douek et Al. AJR 1995

PARAMETRES DE L'ARM AVEC GADOLINIUM

- Spécifiques aux patients
- “Mécanique” du Gd
- Configuration optimale de la séquence

PARAMETRES SPECIFIQUES DU PATIENT

- Timing du bolus +++
- Structures vasculaires à visualiser
- Immobilité et apnée

PREPARATION DU PATIENT

- Motivation
- Bonne voie veineuse
- positionnement des bras

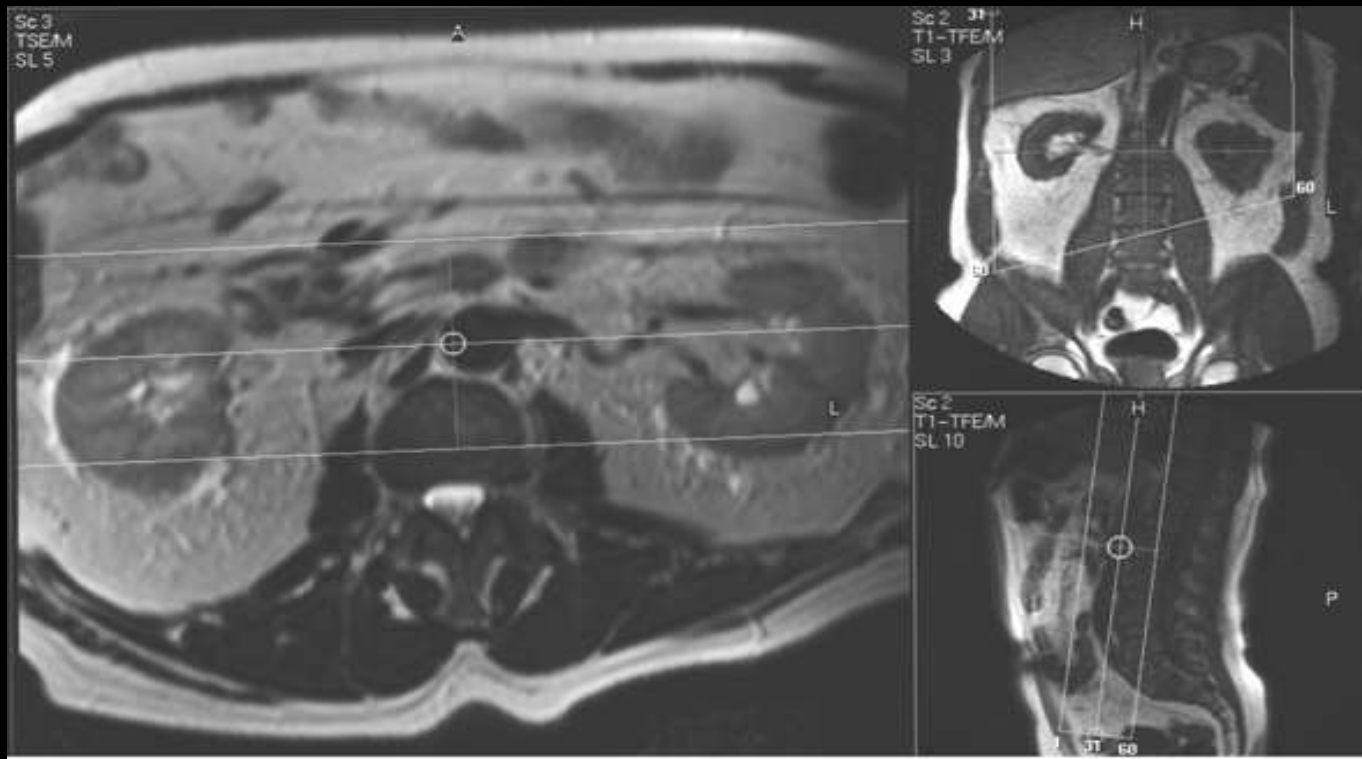
Technique: positionnement

Repérage axial et sagittal

Volume coronal oblique

Inclure TC, MS, reins et bifurcation aortique

FOV de 300 à 450 mm



PROTOCOLE D'ACQUISITION*

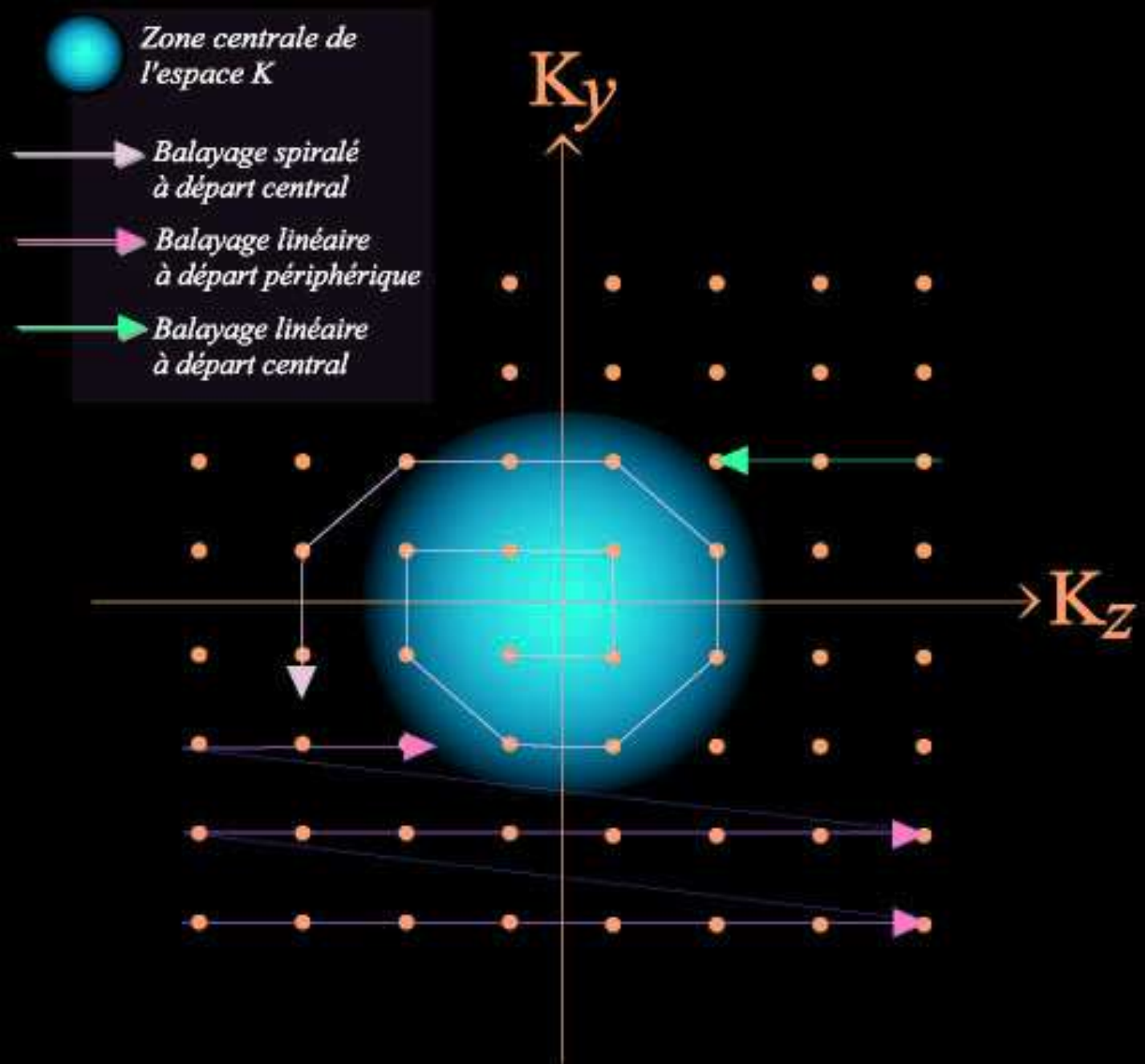
- Mesure du temps de transit (dose test : 2 ml Gd ou automatique)
- Série masque (écho de gradient 3D)
- Acquisition de 2 ou 3 séries après injection I.V.
- bolus (2ml/sec) de 0,1 mmol/kg de Gd
- Antenne adaptée: Corps en réseau phasé, Rachis, Tête, flexible dédiée

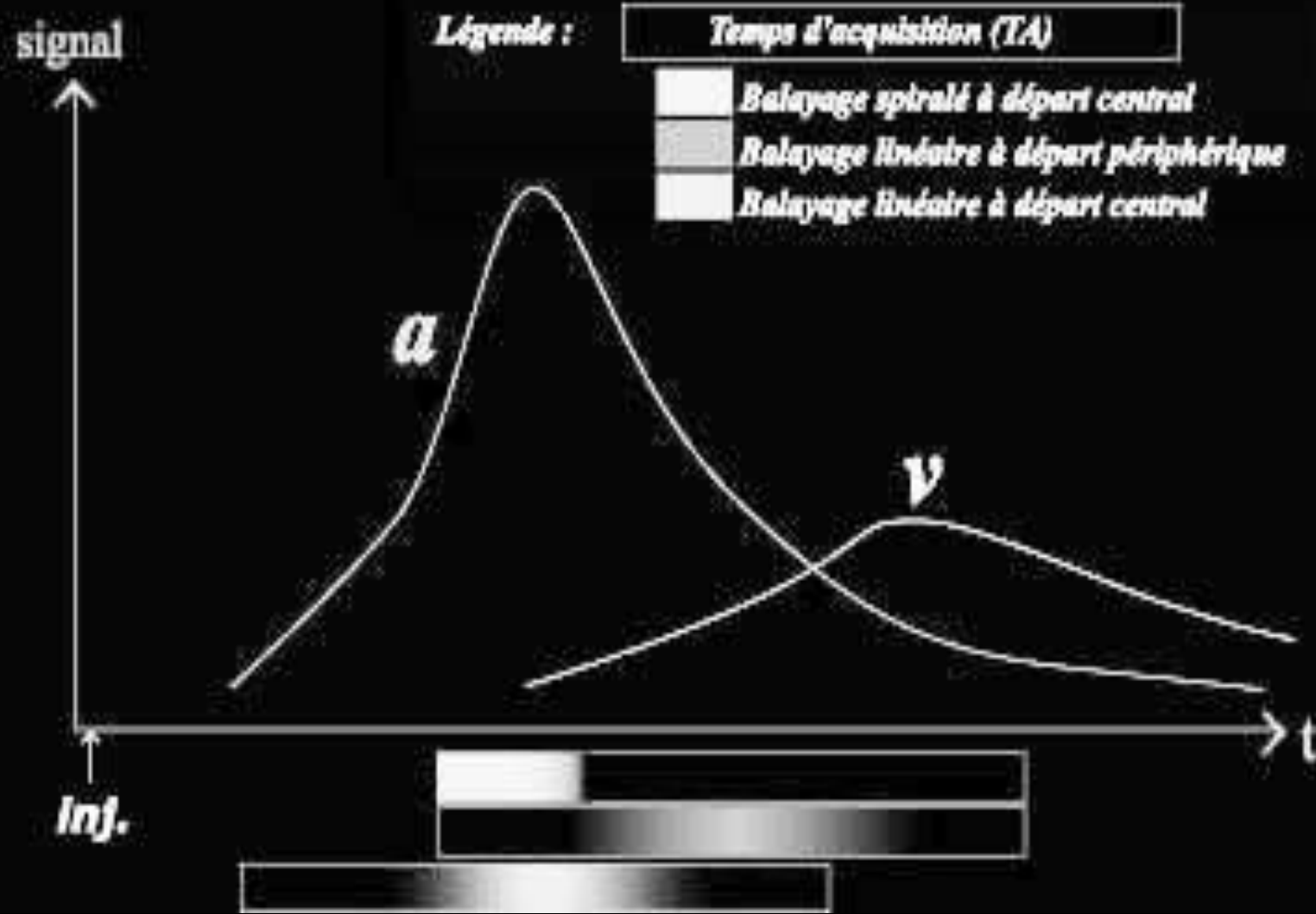
*Ph.Douek et Al. AJR 1995

GADOLINIUM

- Combien ?
- A quelle vitesse ? injecteur amagnétique
- Quel timing/acquisition de l'espace de fourrier?





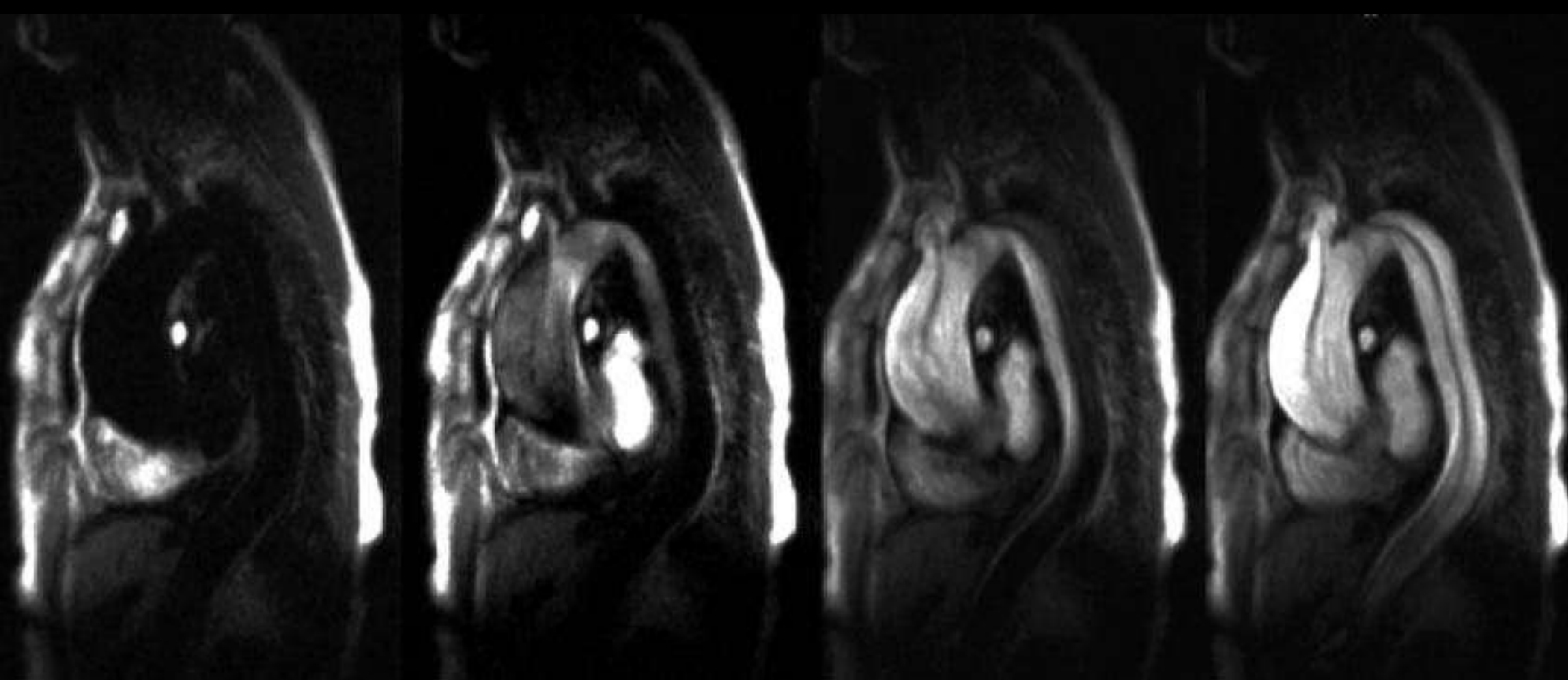


TEMPS DE TRANSIT MOYEN SELON LES TERRITOIRES VASCULAIRES

- Aorte abdominale : 14 → 30 sec
- Artères des membres inférieurs : 18 → 35/70 s
- Carotides: 8-12sec
- Artères pulmonaires: 6-10 sec

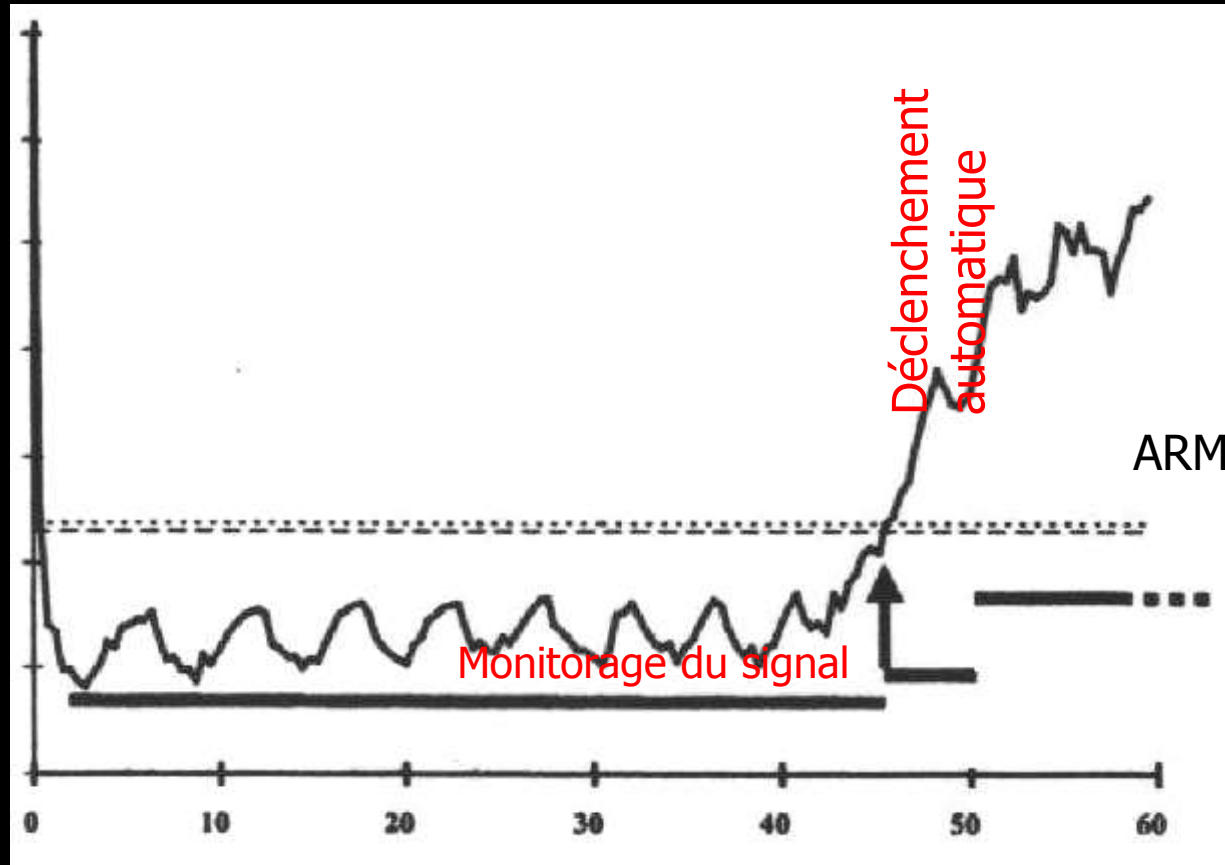
DETERMINATION DU TEMPS DE TRANSIT “Bolus Timing”

- “Smart prep”
- Fluoro IRM
- Time resolved MRA
- Dose test : 2 ml de Gd



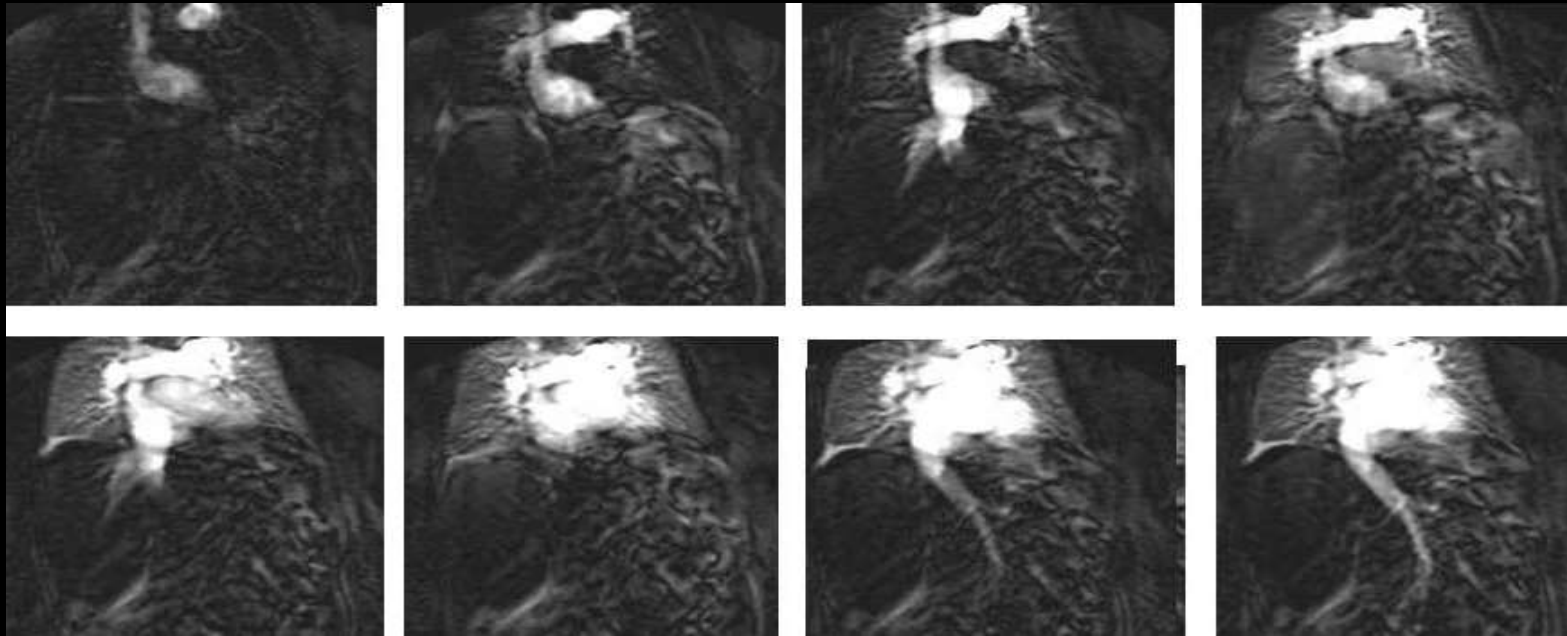
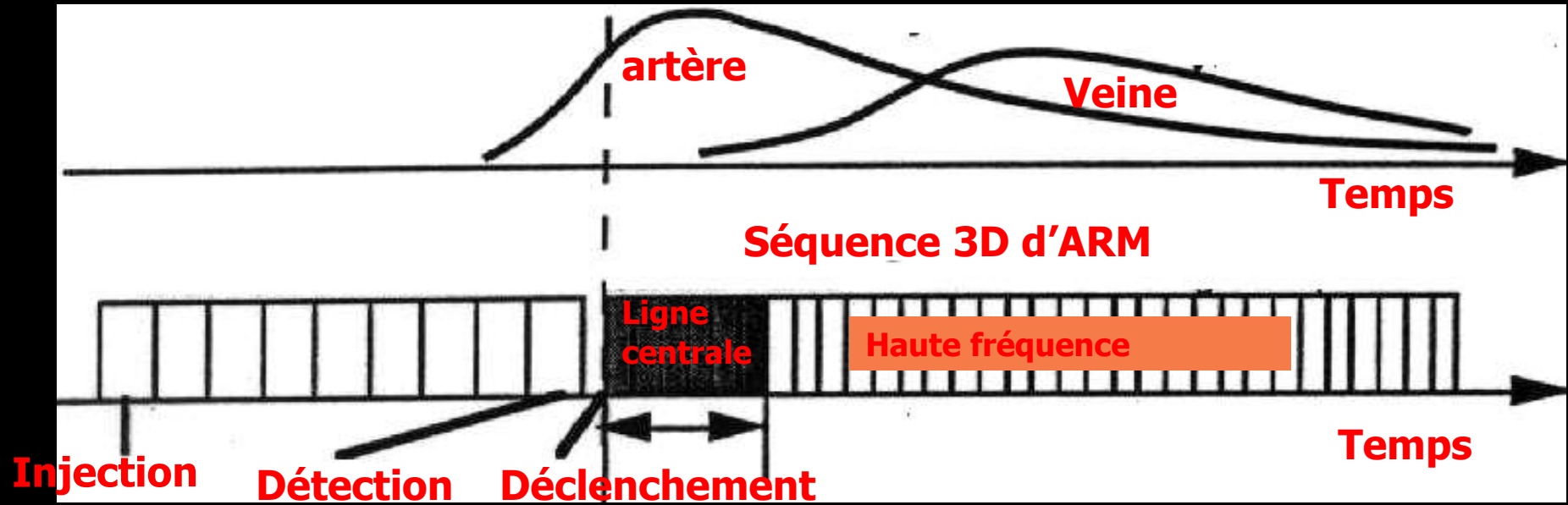
Déclenchement automatique

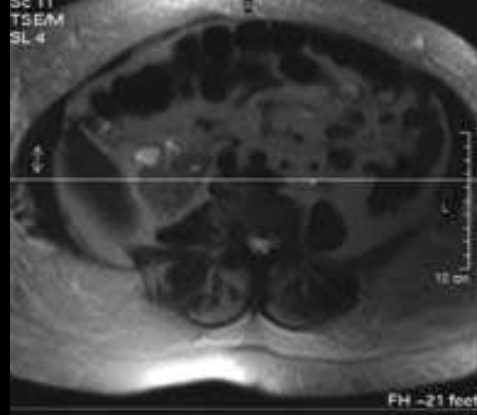
Intensité de signal



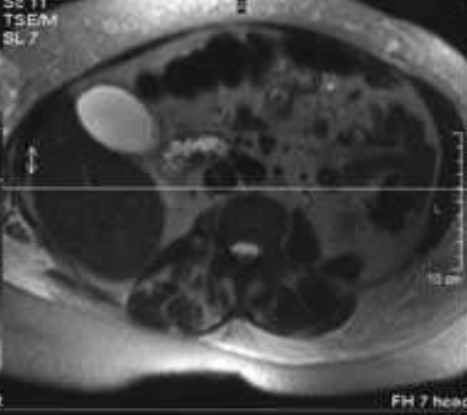
Temps

Déclenchement de l'acquisition par Scopie IRM





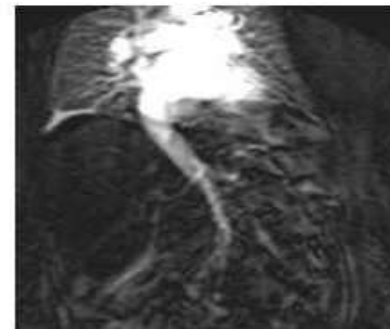
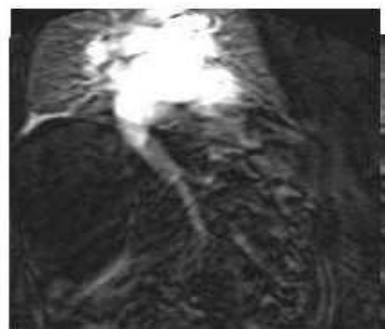
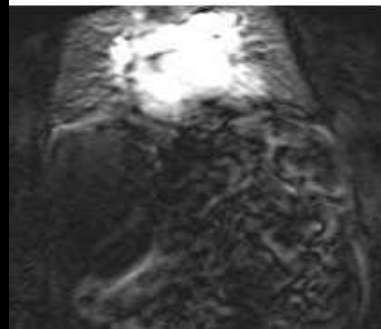
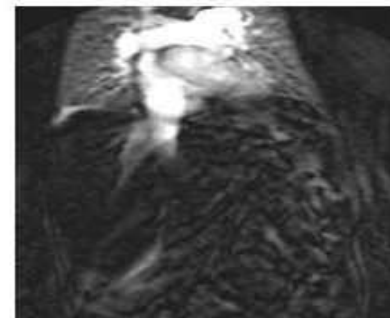
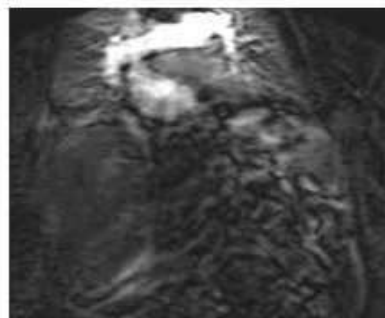
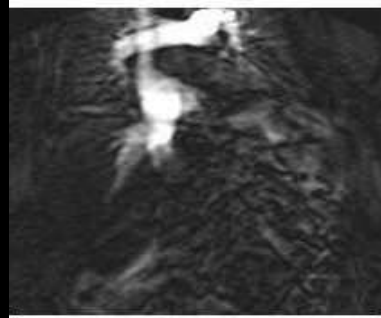
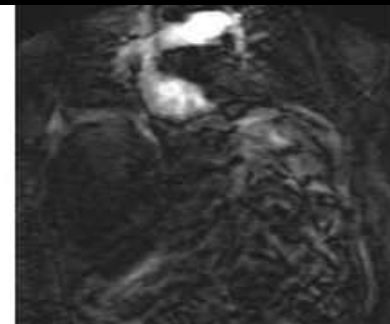
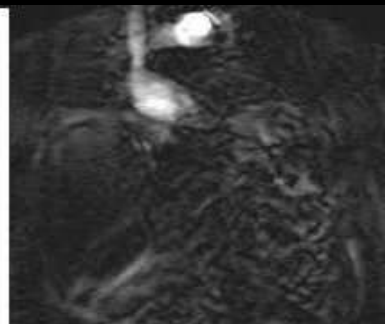
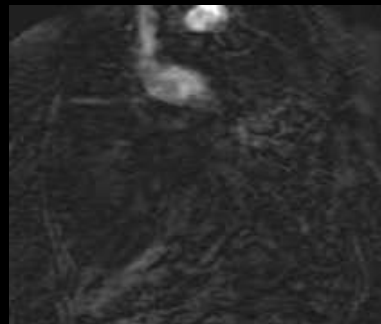
FH -21 feet



FH 7 head



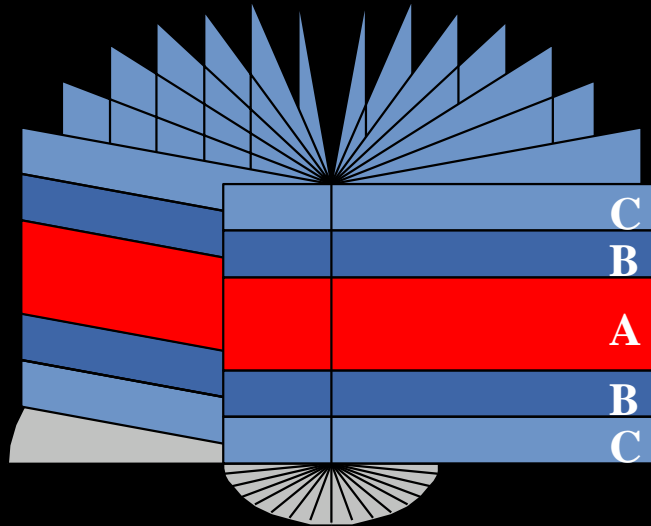
RL -30 eq



PARAMETRES DE LA SEQUENCE D'IMAGERIE

- **Compromis entre résolution spatiale, résolution temporelle et volume d'exploration**
- **2 types de séquences:**
 - **Imagerie dynamique : multiplanaire, 3D**
 - **Imagerie haute résolution**
 - **Aorto-iliaque : 18/24sec; Pixel = 1,5 x 1,5 x 2 mm**
 - **Distalité : 50 sec; Pixel = 1 mm³**

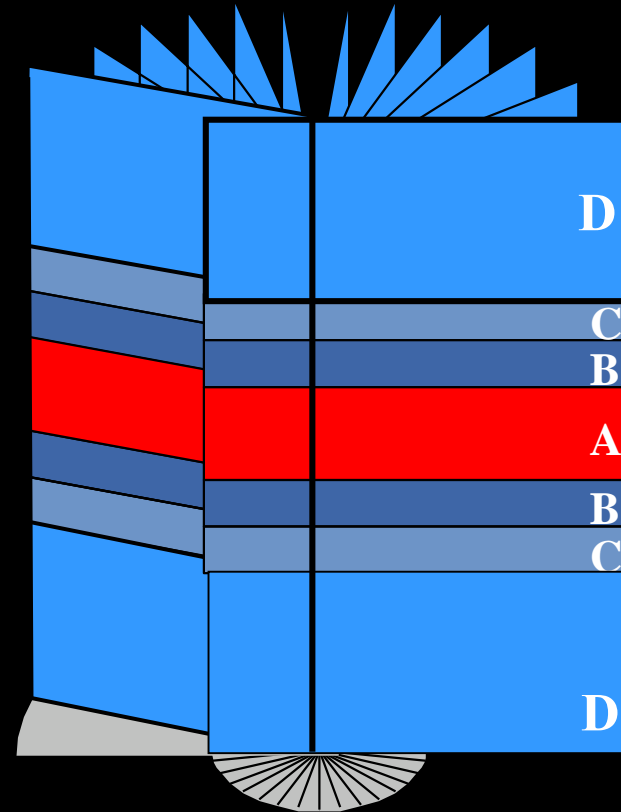
PR HyperTRICKS



PR TRICKS

ABACABAC

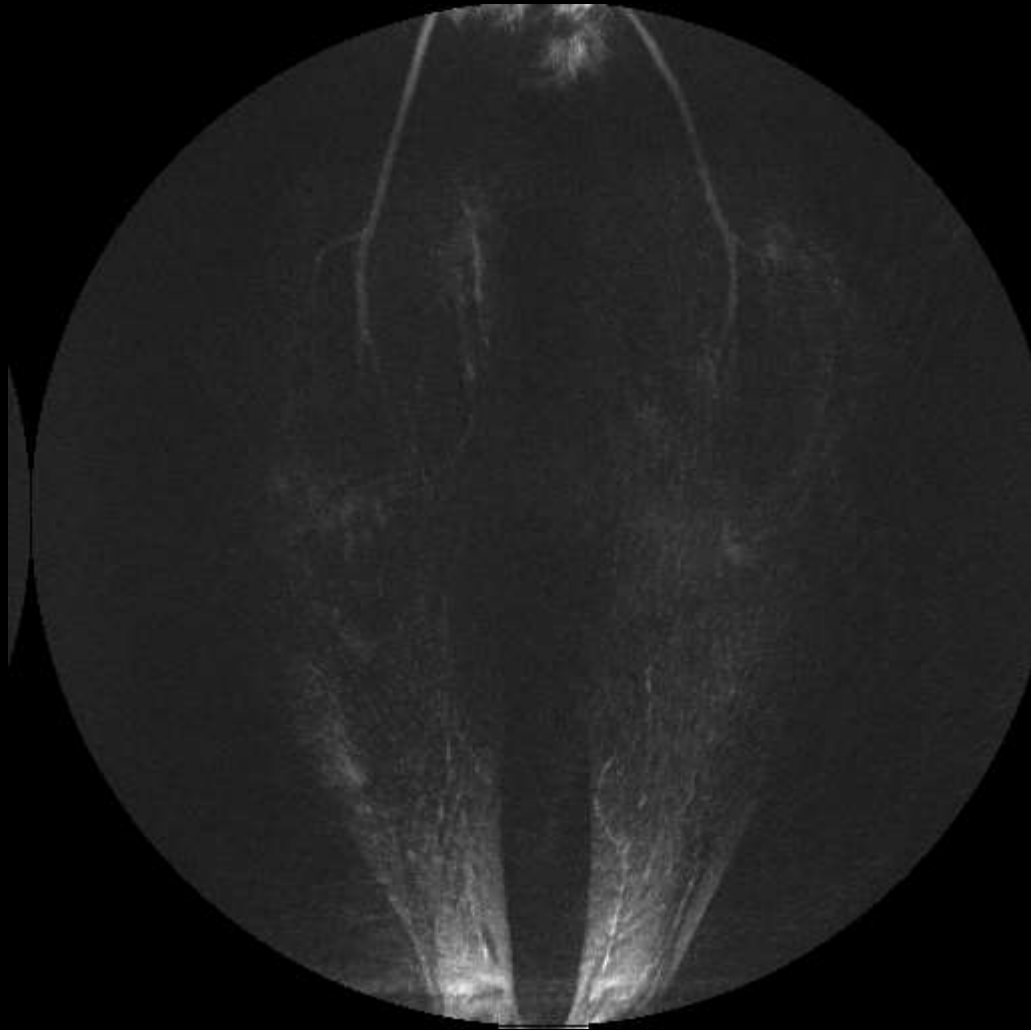
Contrast Arrival



DDDD

Post Venous Phase

PR HyperTRICKS



PROTOCOLE D'ACQUISITION:MI

«technique de suivi de bolus »

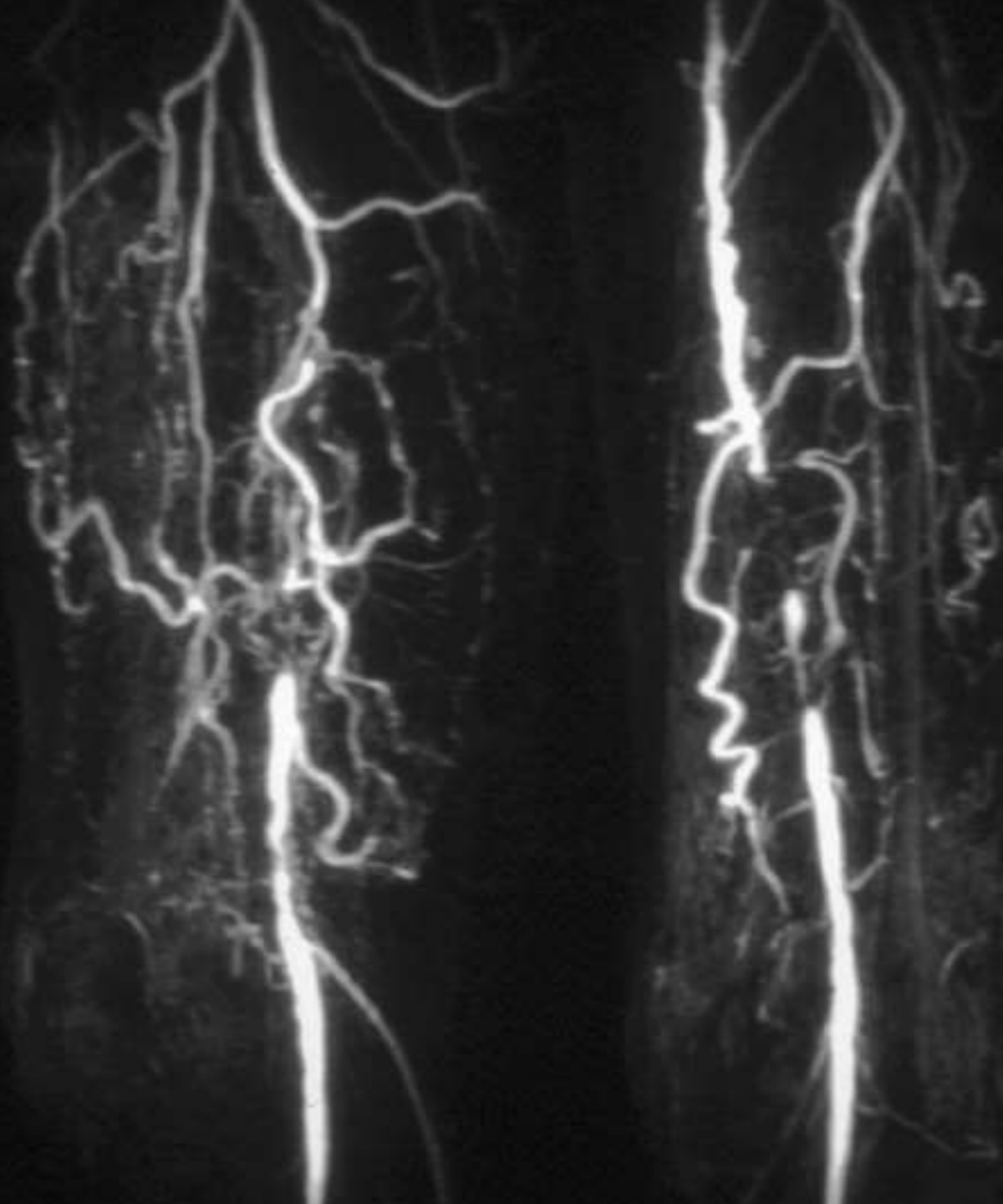
- Une seule série masque avec déplacement de la table
- Acquisition d '1 série après injection de 0.2mmole/kg en infusion lente (0,5mlsec)
- Antenne corps



AngioSURF

Angio -
System for
Unlimited
Rolling
FOVs

www.angioSURF.de

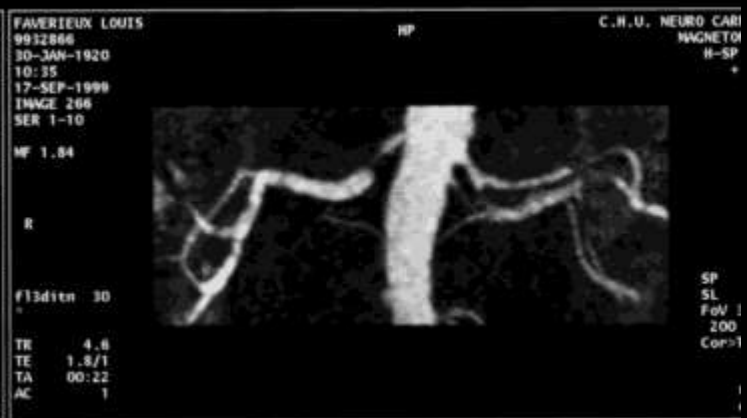
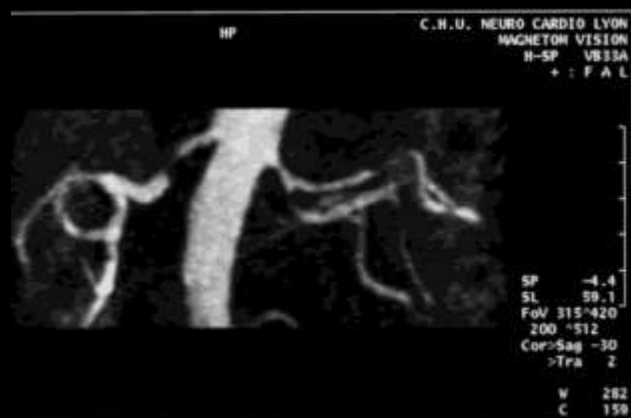


SOUSTRACTION

- Suppression du signal des tissus non vasculaires
- Suppression du signal des veines
- Suppression du signal de la vessie et des uretères.

PROTOCOLE DE TRAITEMENT D'IMAGES

- Analyse des coupes natives
- Soustraction
- MPR, MPVR
- MIP, "MIP ciblé" PARAMETRES

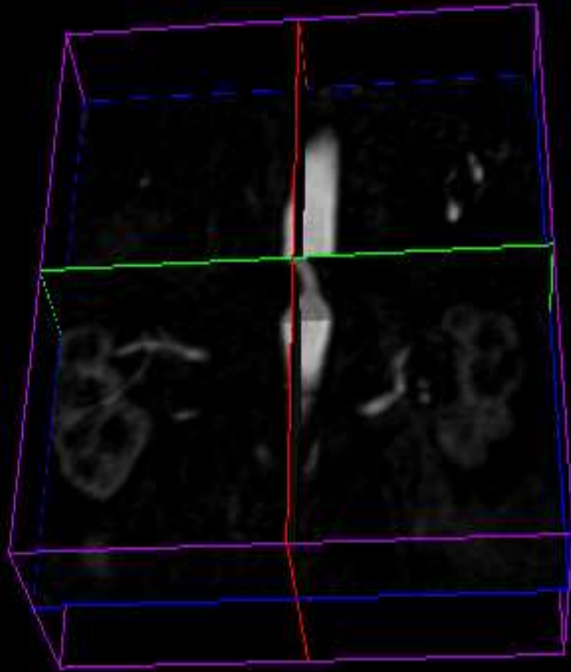


Slice Viewing

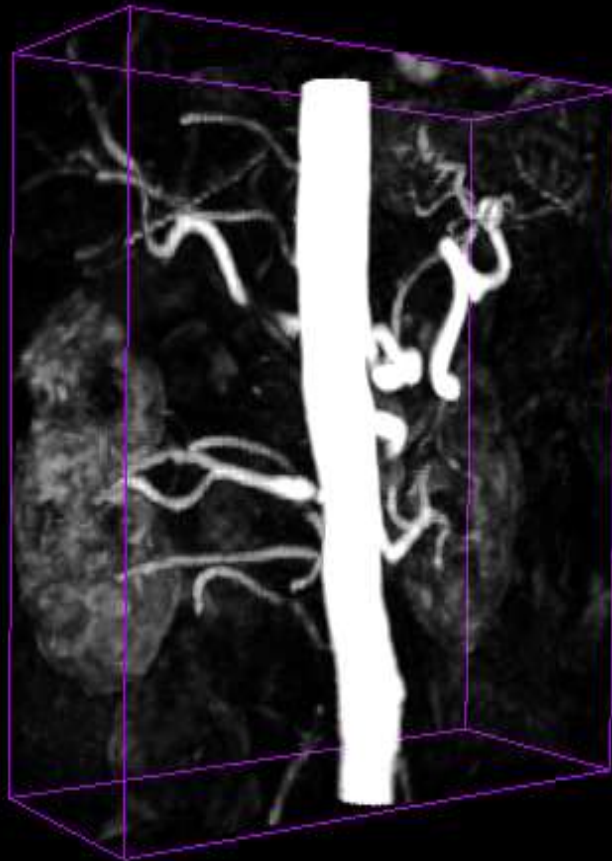
MIP Rendering

Isosurface Rendering

Slice Viewer

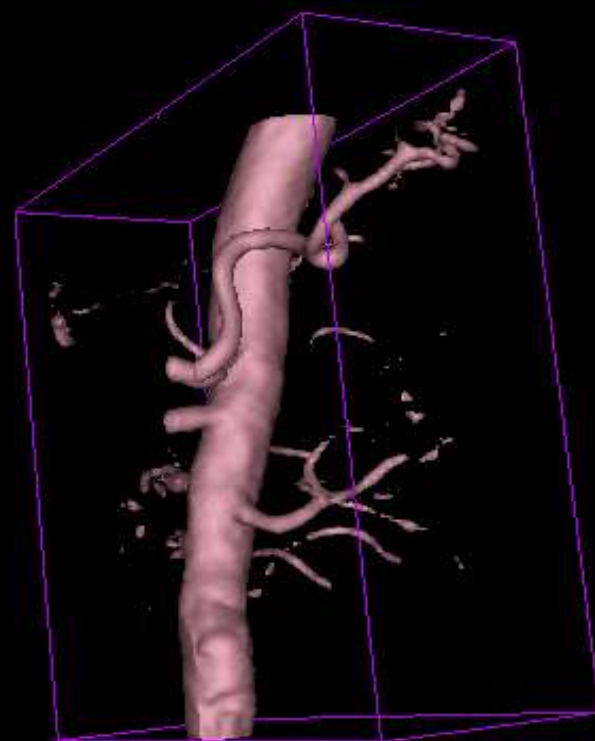
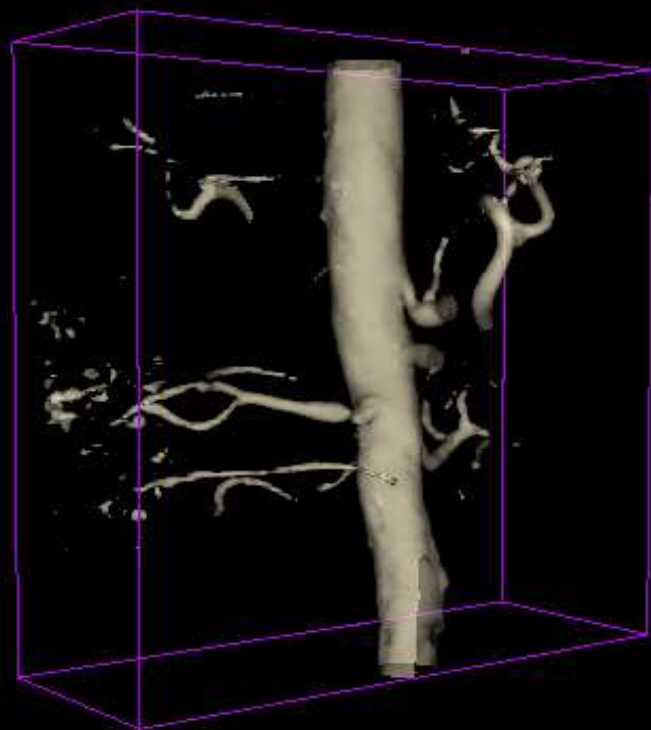
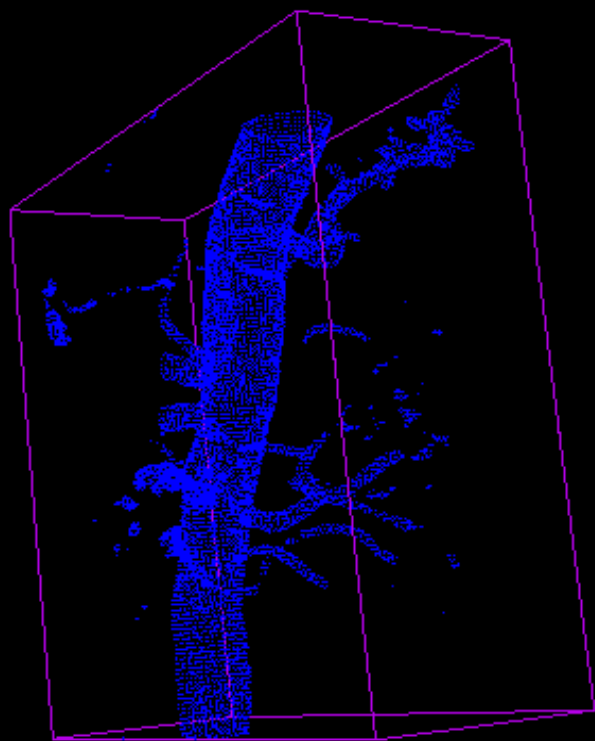


MIP Rendering

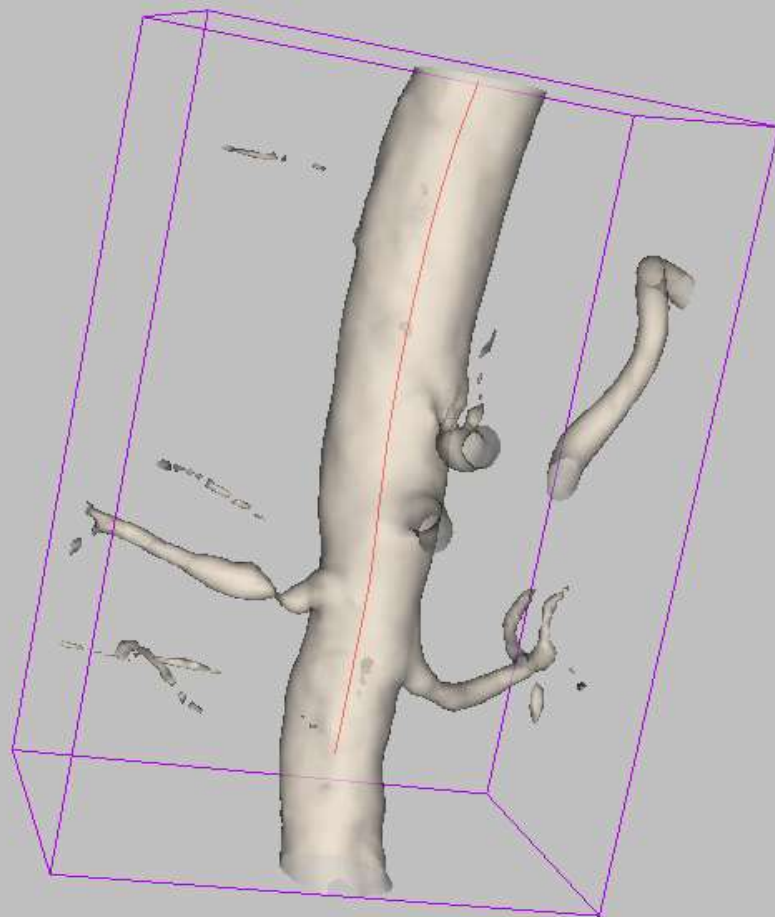


Isosurface Rendering





3D point cloud visualization of a tree trunk and branches, showing the raw data points.



Perpendicular Cross-Sections

Visible

Slice

49



Volume:

VOI slice

Volume slice

Value To Color Mapping:

Greyscale

Color

Vessel Surface

Visible

Isovalue:

174



Shading:

Off

On

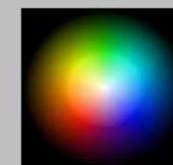
Surface:

Opaque

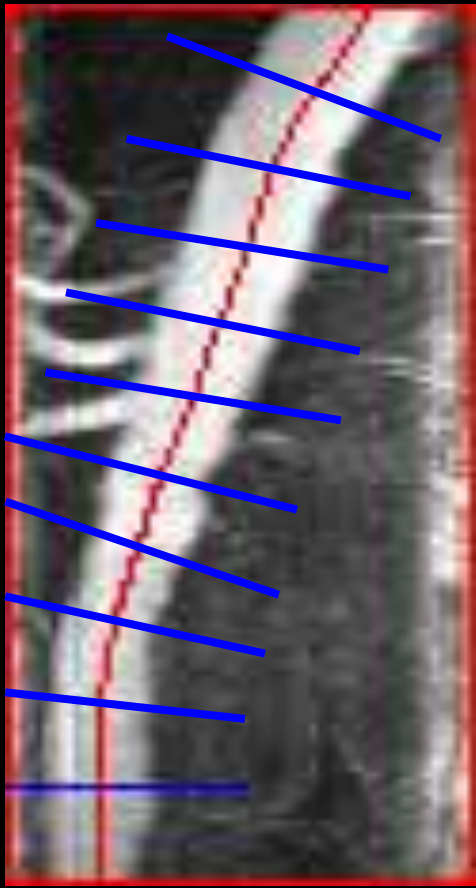
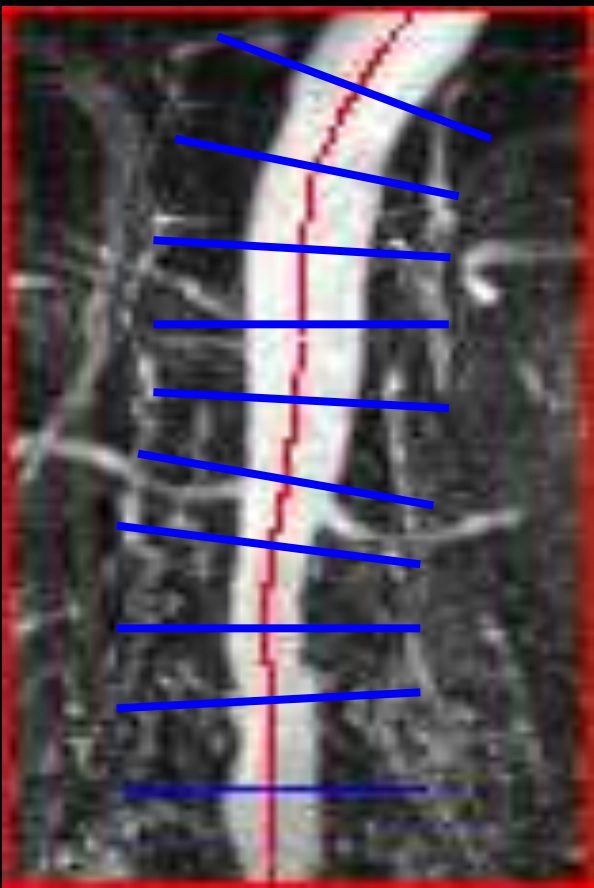
Transparent

Edge Points

Surface Color:

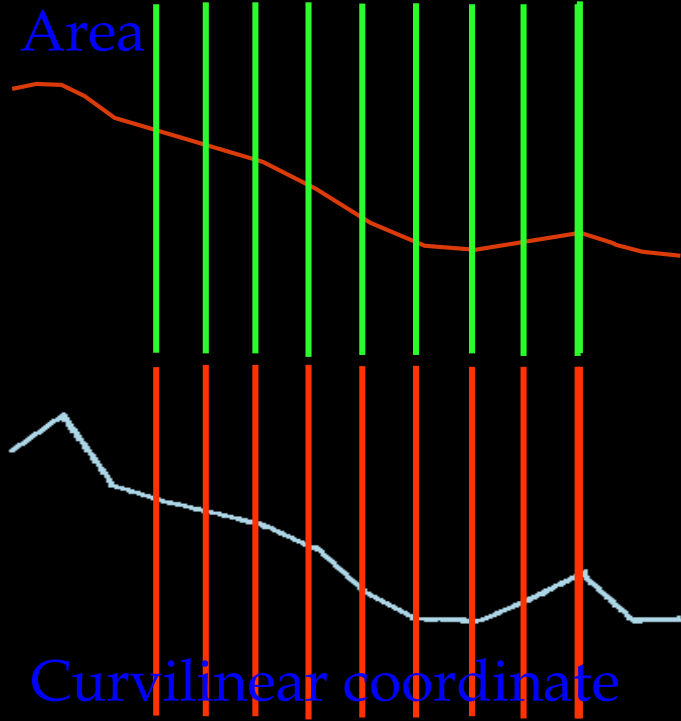


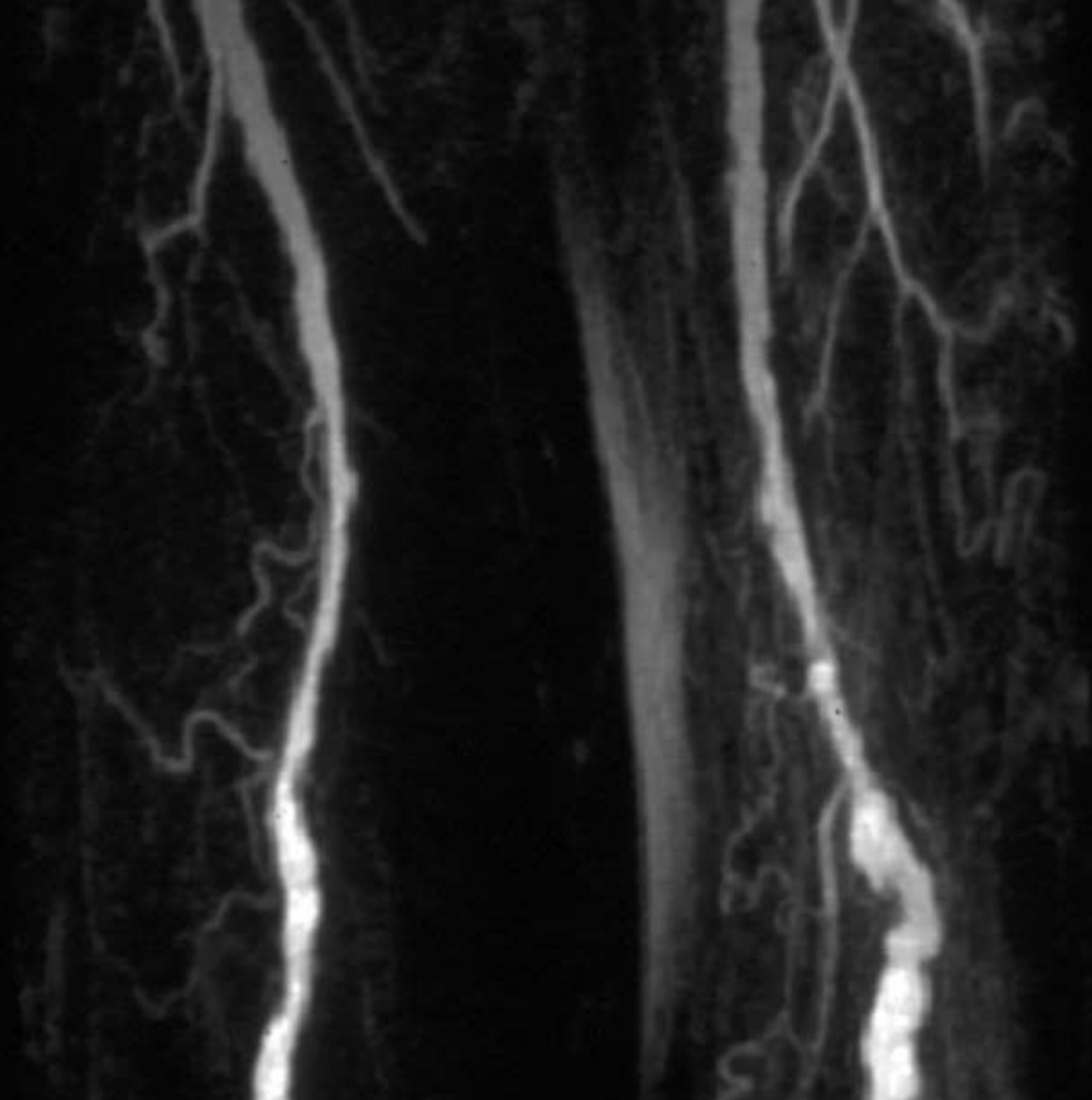
Vessel axis

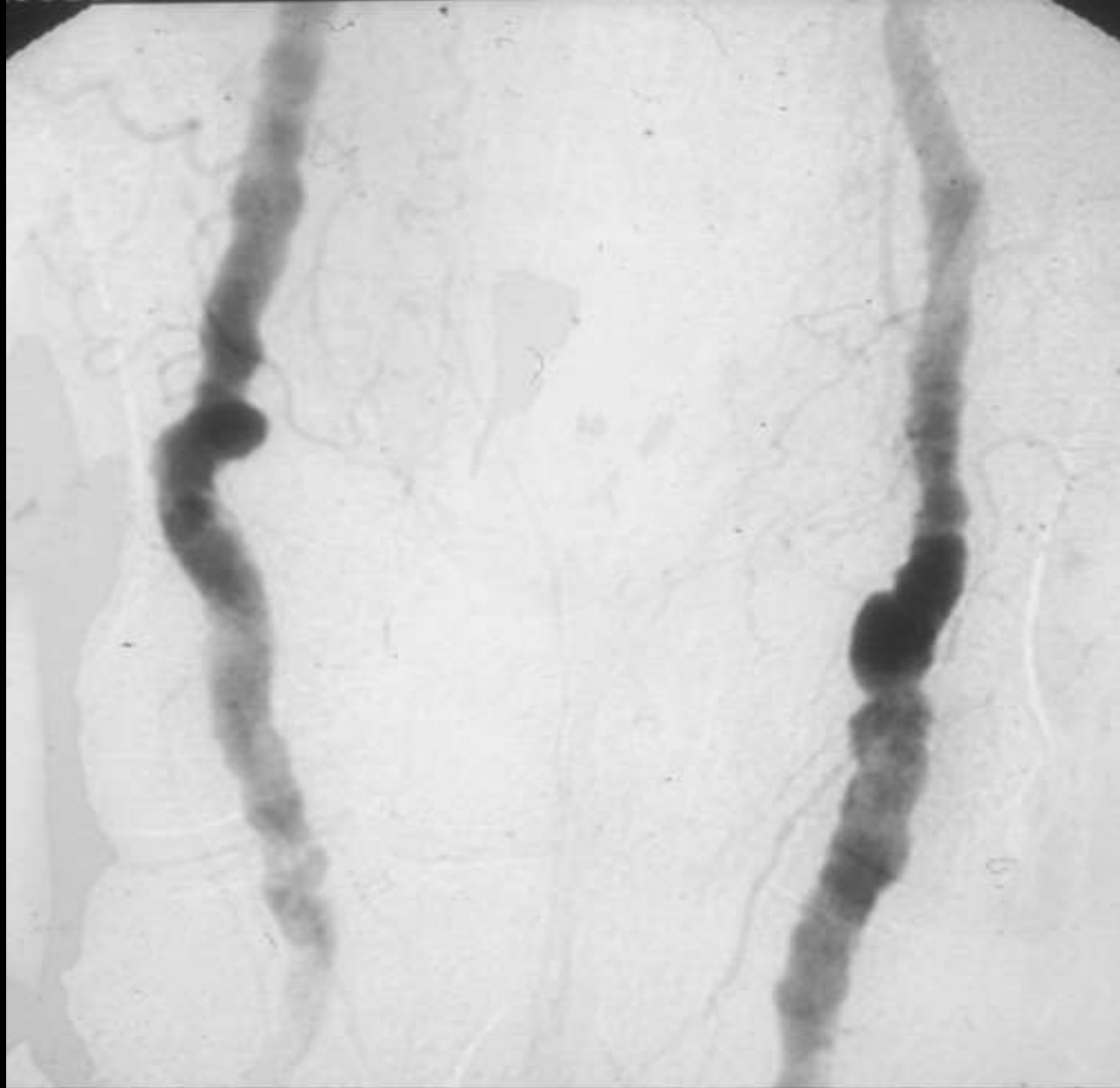


Estimated
from
radius

Measure
d by
active
contour







Limites et Problèmes

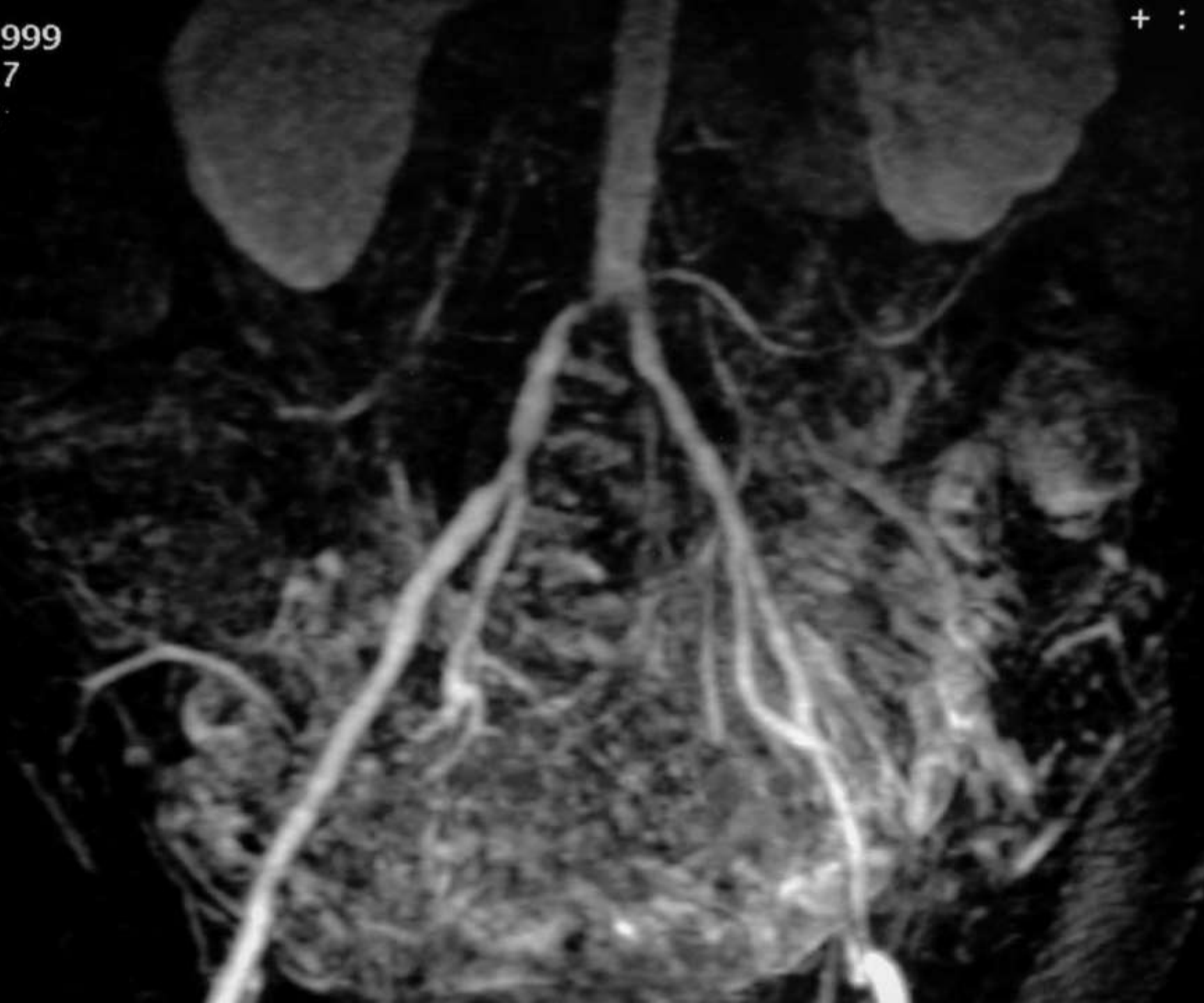
- Quantification de sténose
- Artéfacts liés au clips vasculaires
- Retour veineux
- Artéfacts de mouvements



02
DCT-1999
GE 317
1-12

+ : F A

L.61



0-AUG-1938
0:58
0-AUG-1999
MAGE 579
ER 1-21



20-AUG-1938
10:58
20-AUG-1999
IMAGE 581
SER 1-21

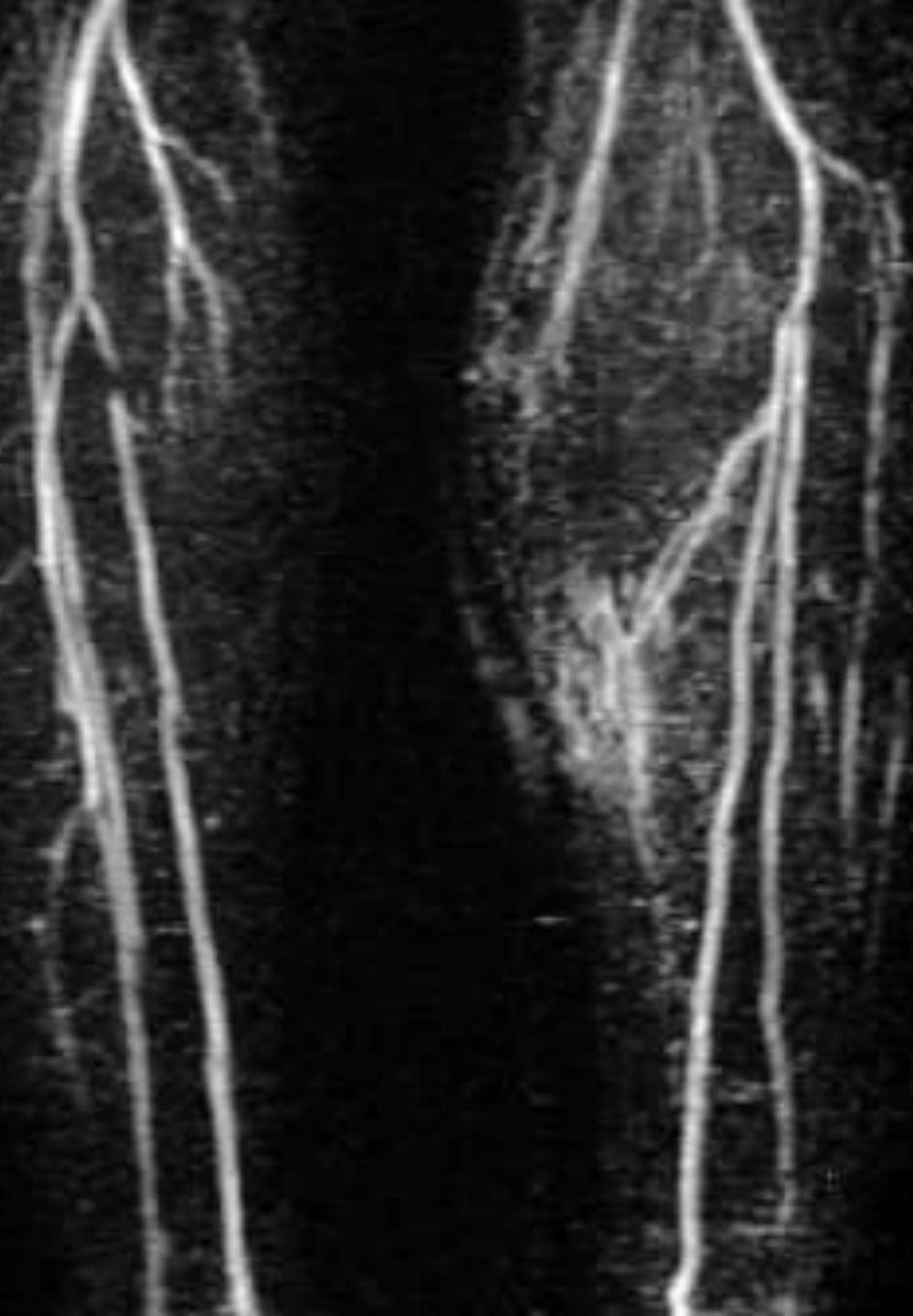


047

99

F-SP VB33

+ : F A



Artéfact: superposition veineuse

Intérêt des coupes natives



MAGE 476
ER 1-21

RPH

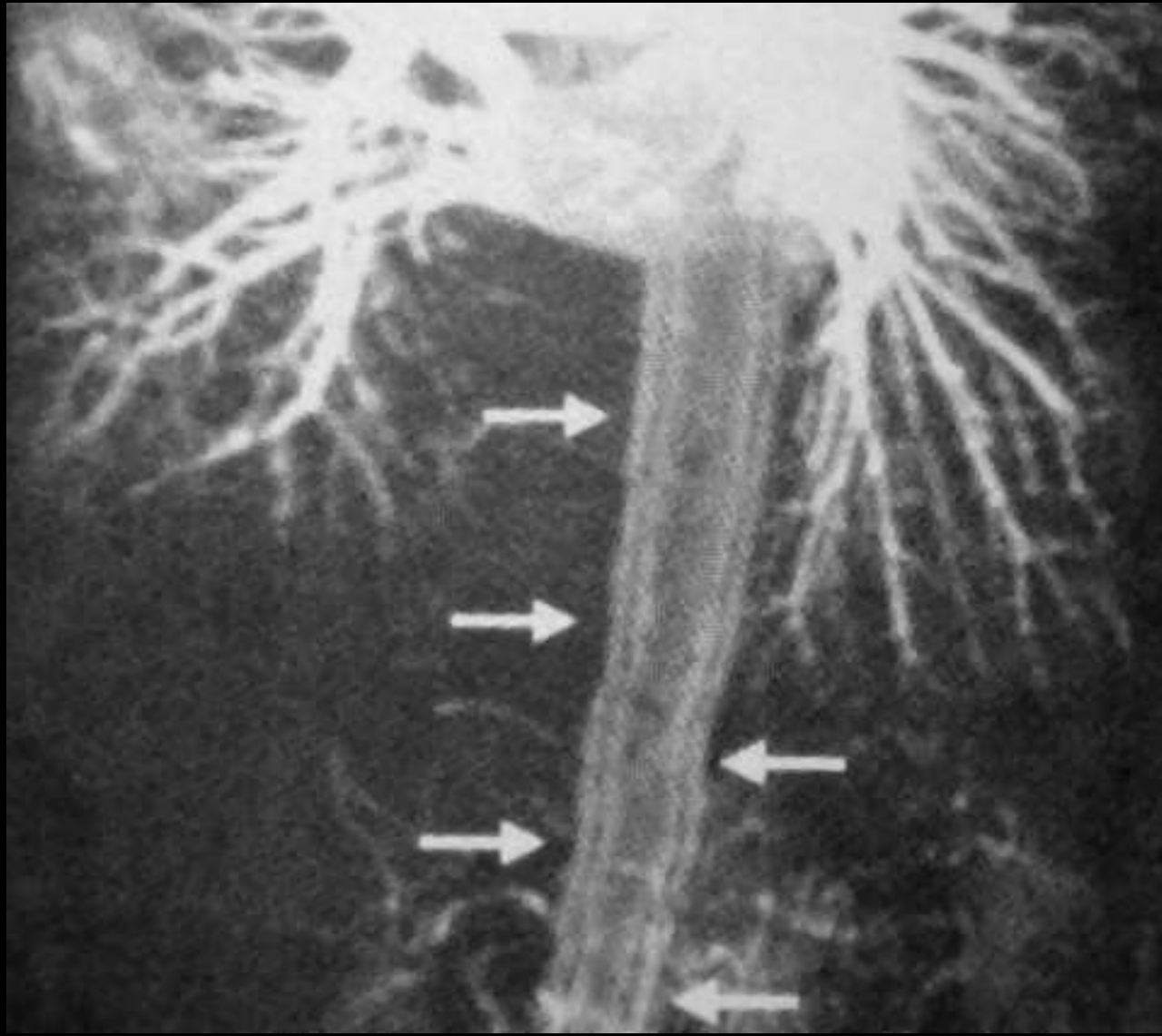
13d 30

F 8

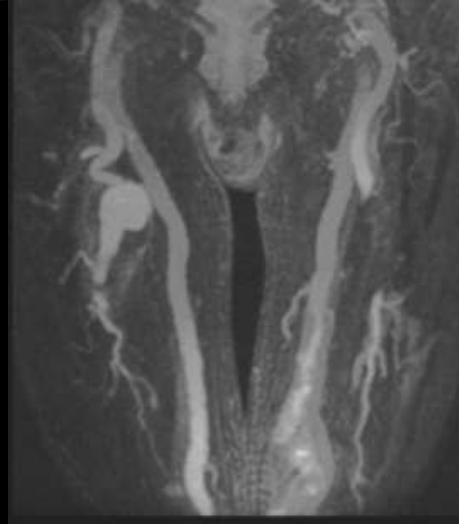
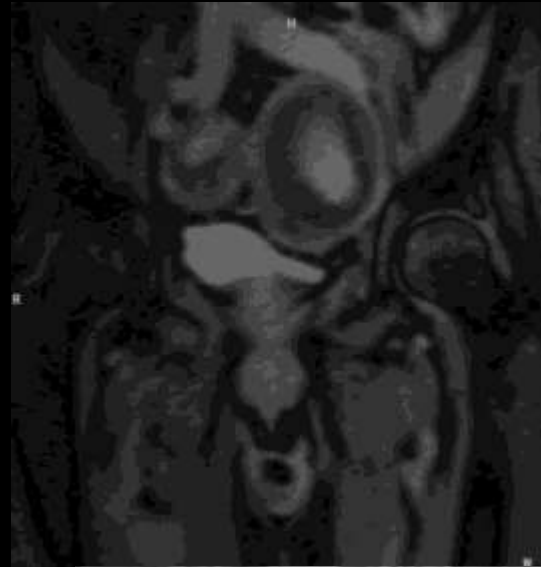


SP -3.0
SL 93.8
FoV 375*500
192 *512o
Cor>Sag 15

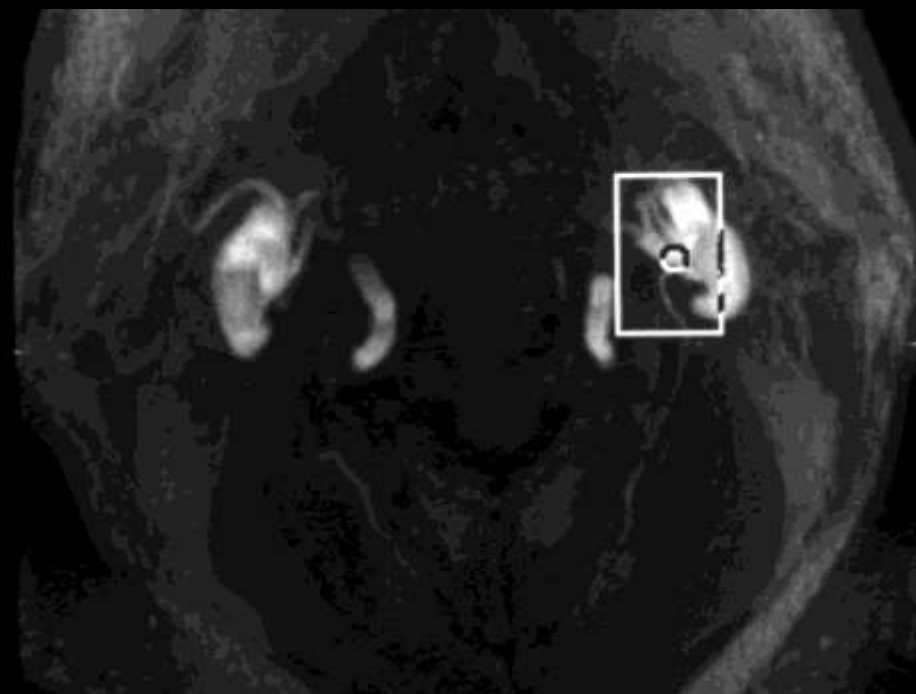




Error Timing and MIP Artifacts



MIP generated artifacts

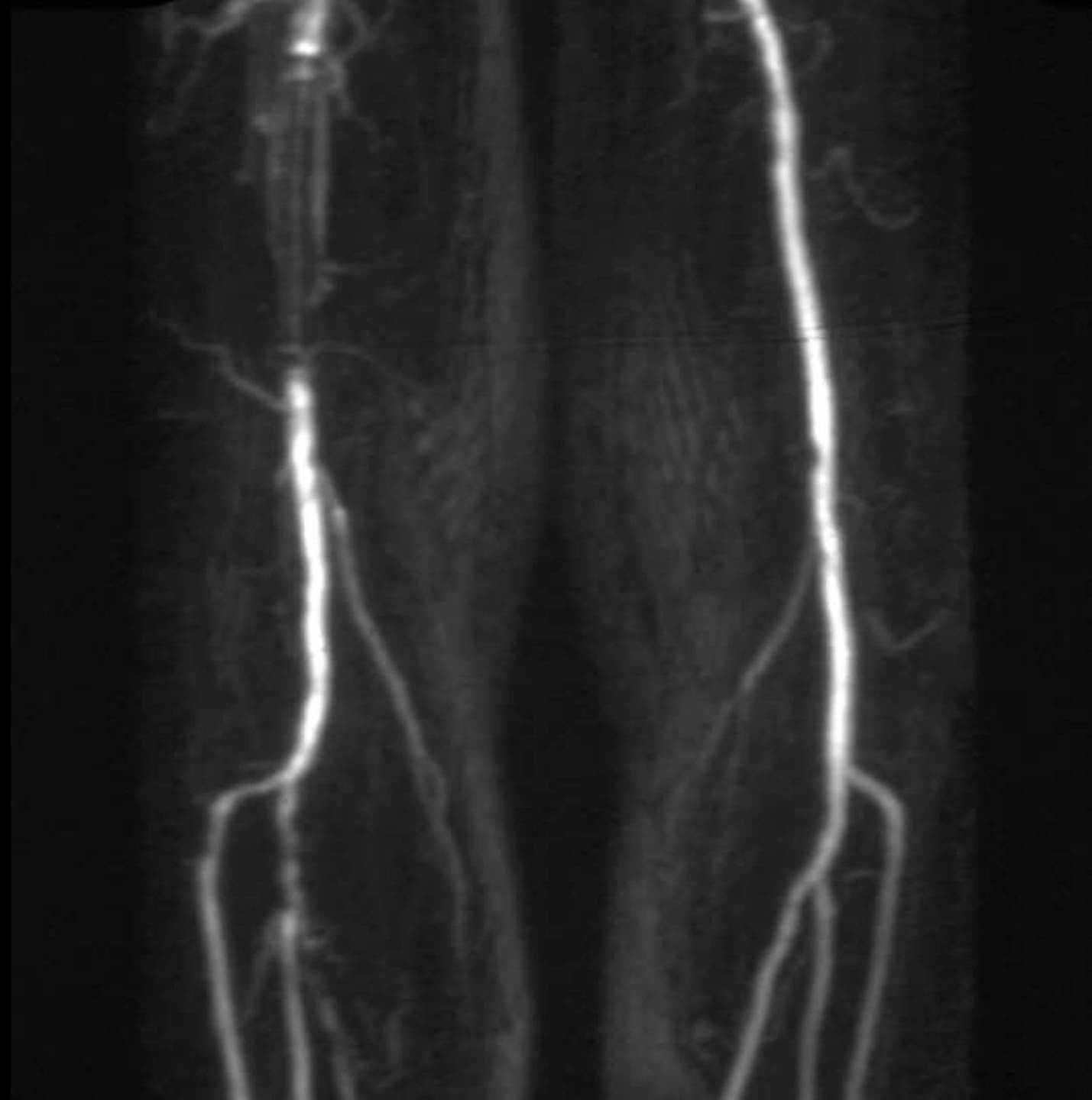


MIP Artifacts

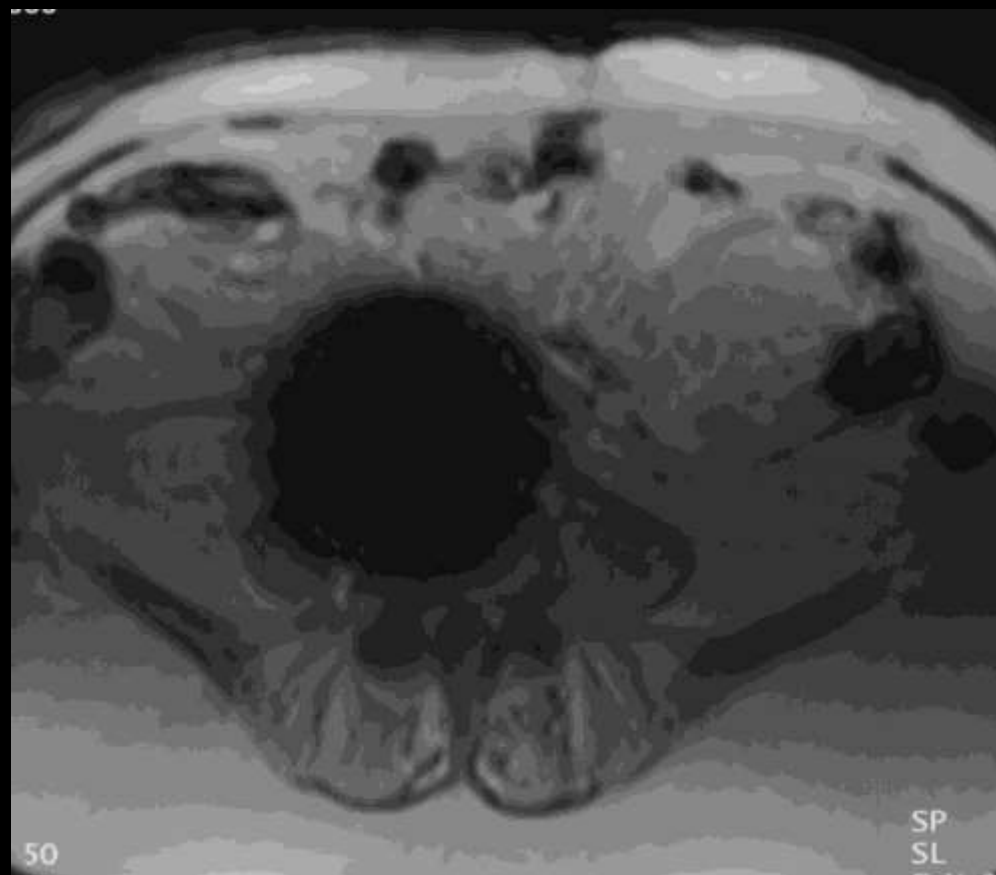


Subtraction Artifacts



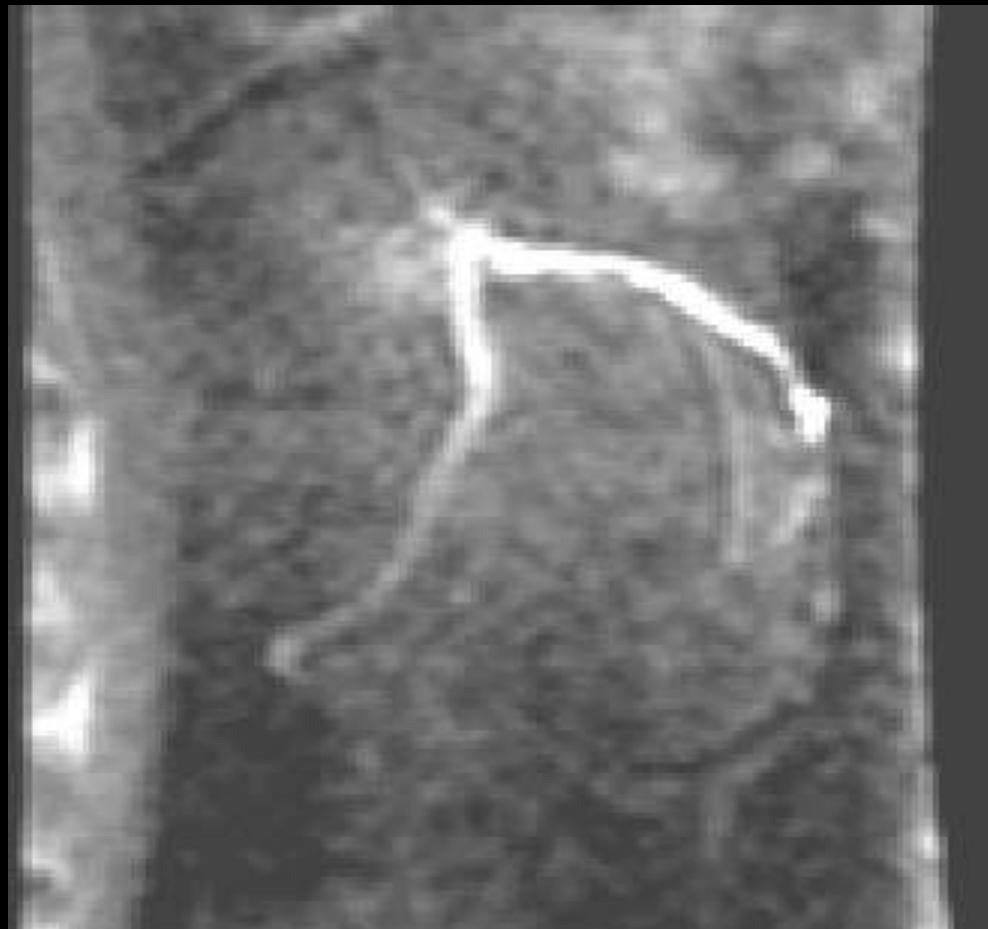


Metallic Susceptibility Artifacts

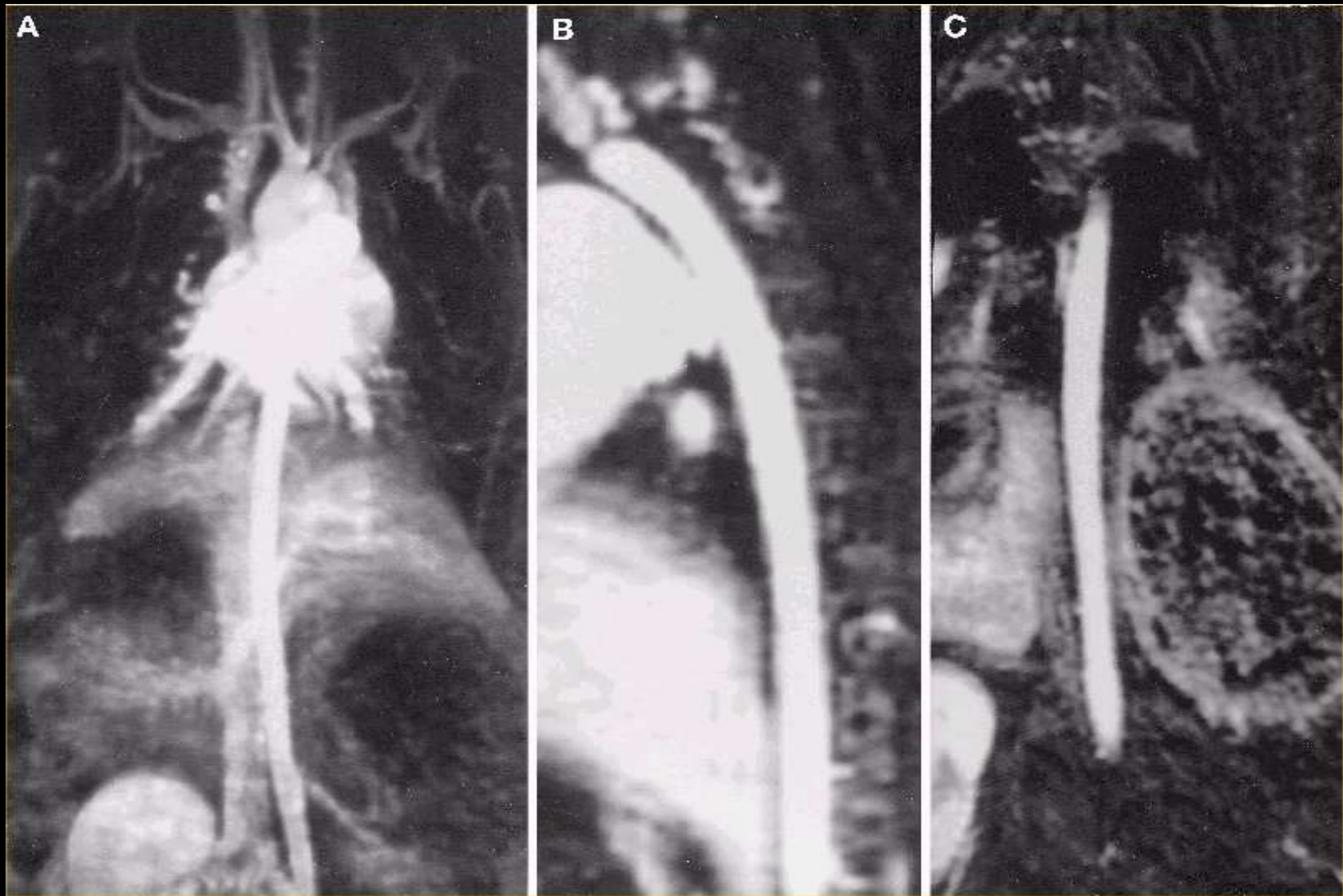


Work in progress



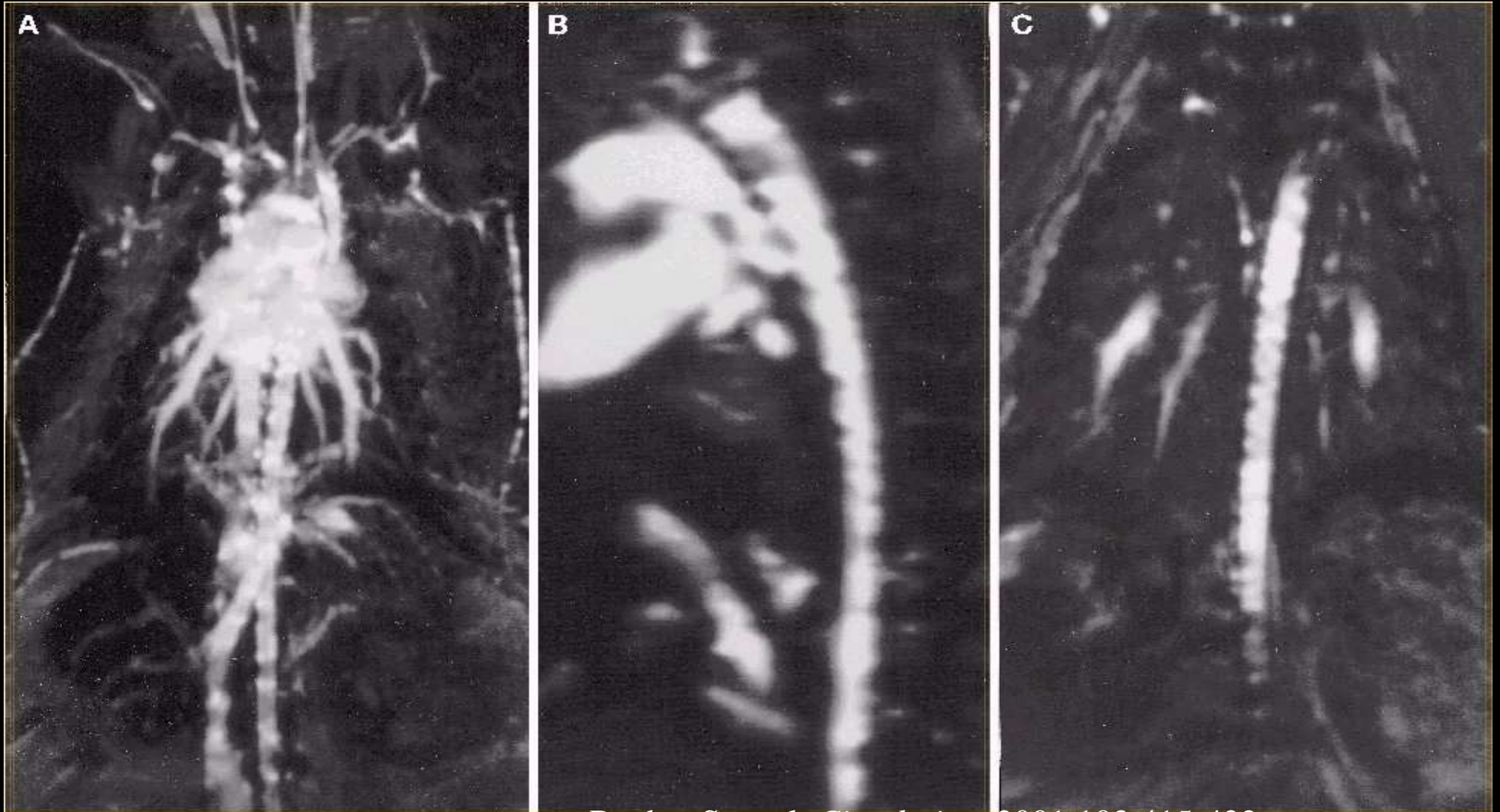


USPIO



Ruehm S, et al. *Circulation*, 2001;103:415-422.

Athérosclérose : ARM USPIO



Ruehm S, et al. *Circulation*, 2001;103:415-422.

Plaque Imaging with Dark Blood Sequence

- 2D Fast spin-echo sequence with a non selective inversion followed by a section-selective inversion pulse that restores the signal in the imaged section.

- Better depiction of mural abnormality:
 - intimal flaps,
 - atherosclerotic plaque,
 - wall thickening,
 - intramural hematoma,

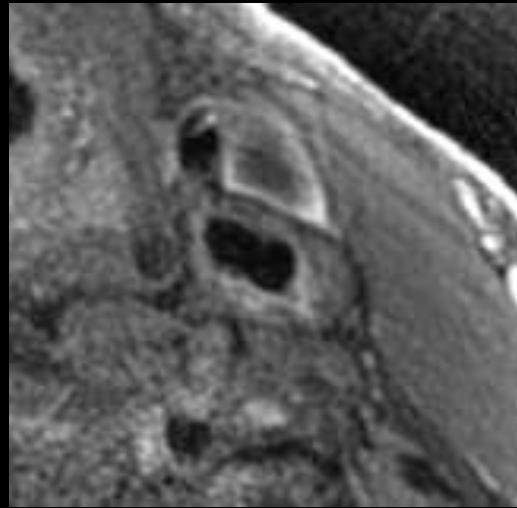


MRI of Atherosclerosis Hemorrhage

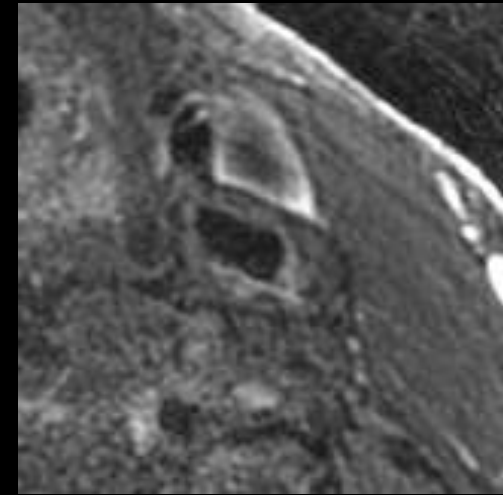


Oblique View

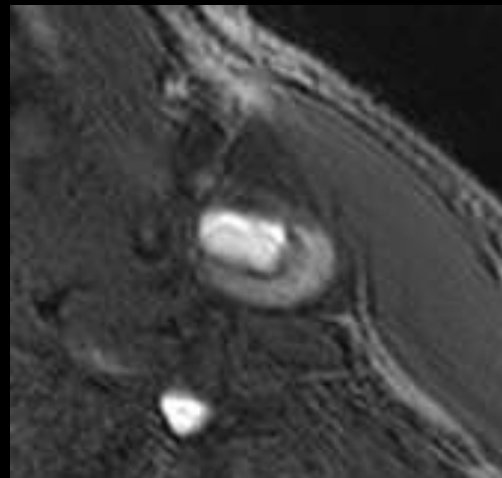
**PD,T2: Shared Echo
T1: Double IR**



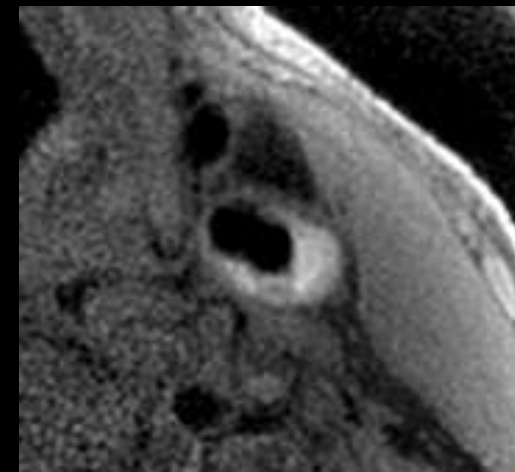
PD



T2



TOF

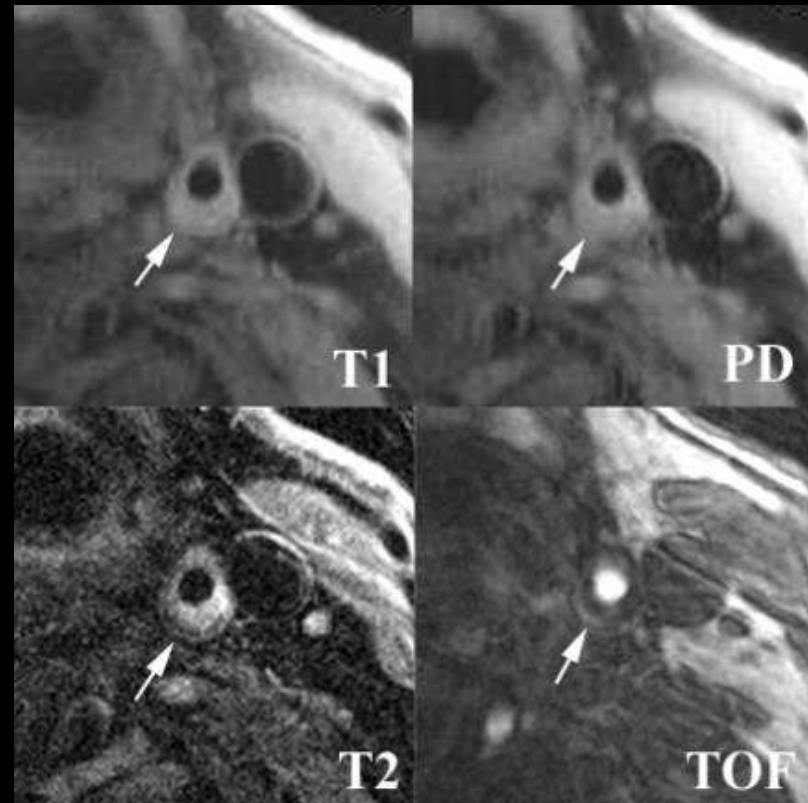


T1

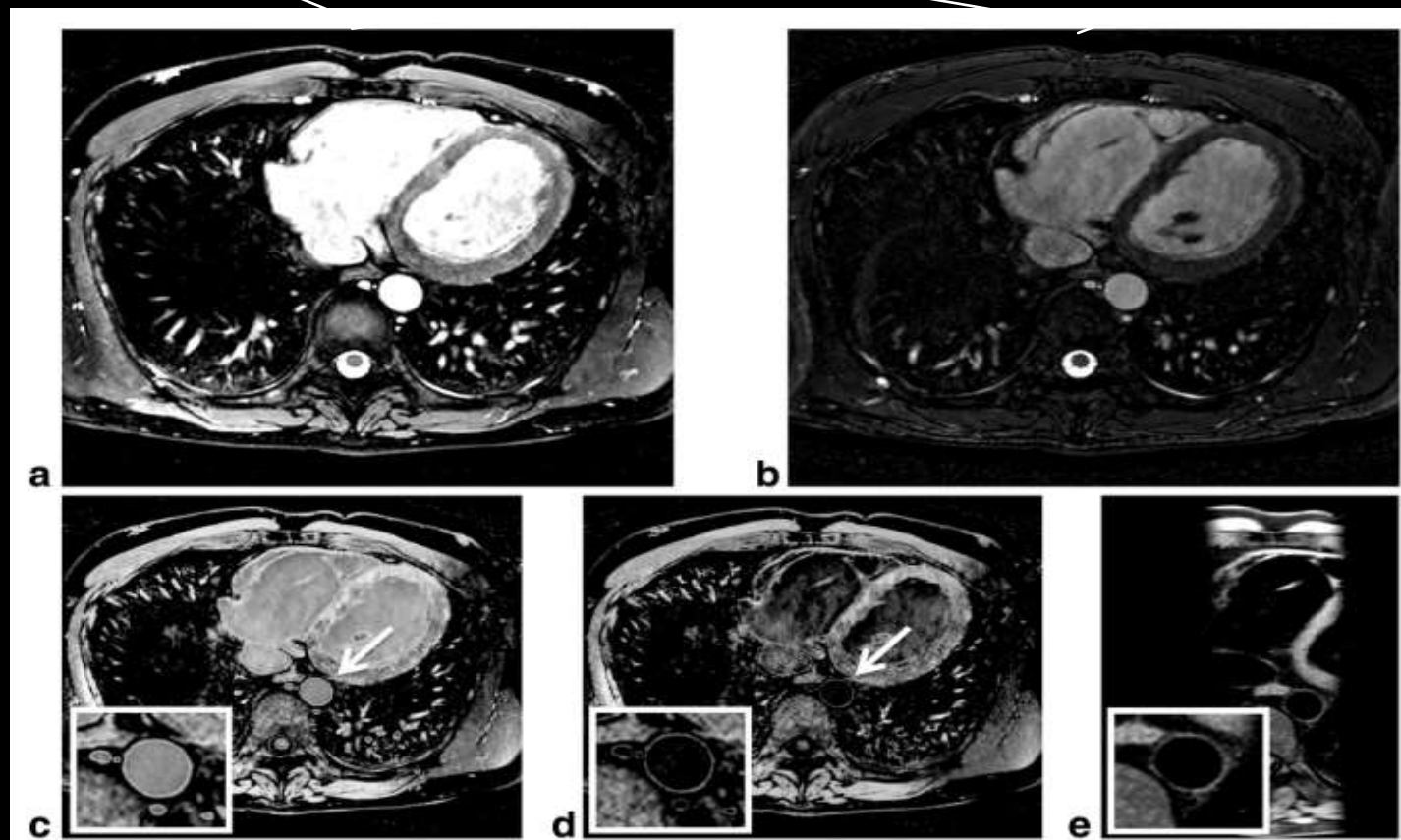
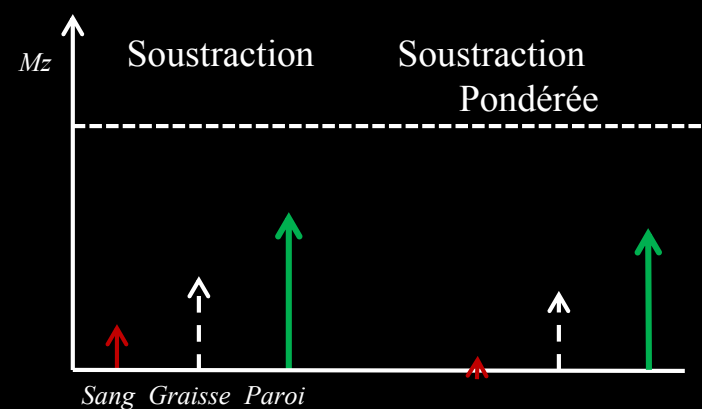
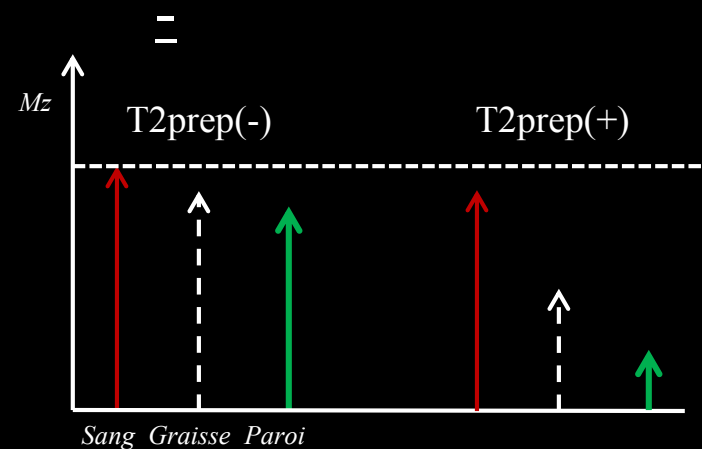
Plaque composition

Multi contrast MRI with

- various sequences:
 - cardiac gated IR FSE
black blood T1,
 - PD
 - T2
 - 3D TOF
- Slice thickness of 2 mm
with 200-400 microns
inplane resolution



Stratégie d'acquisition

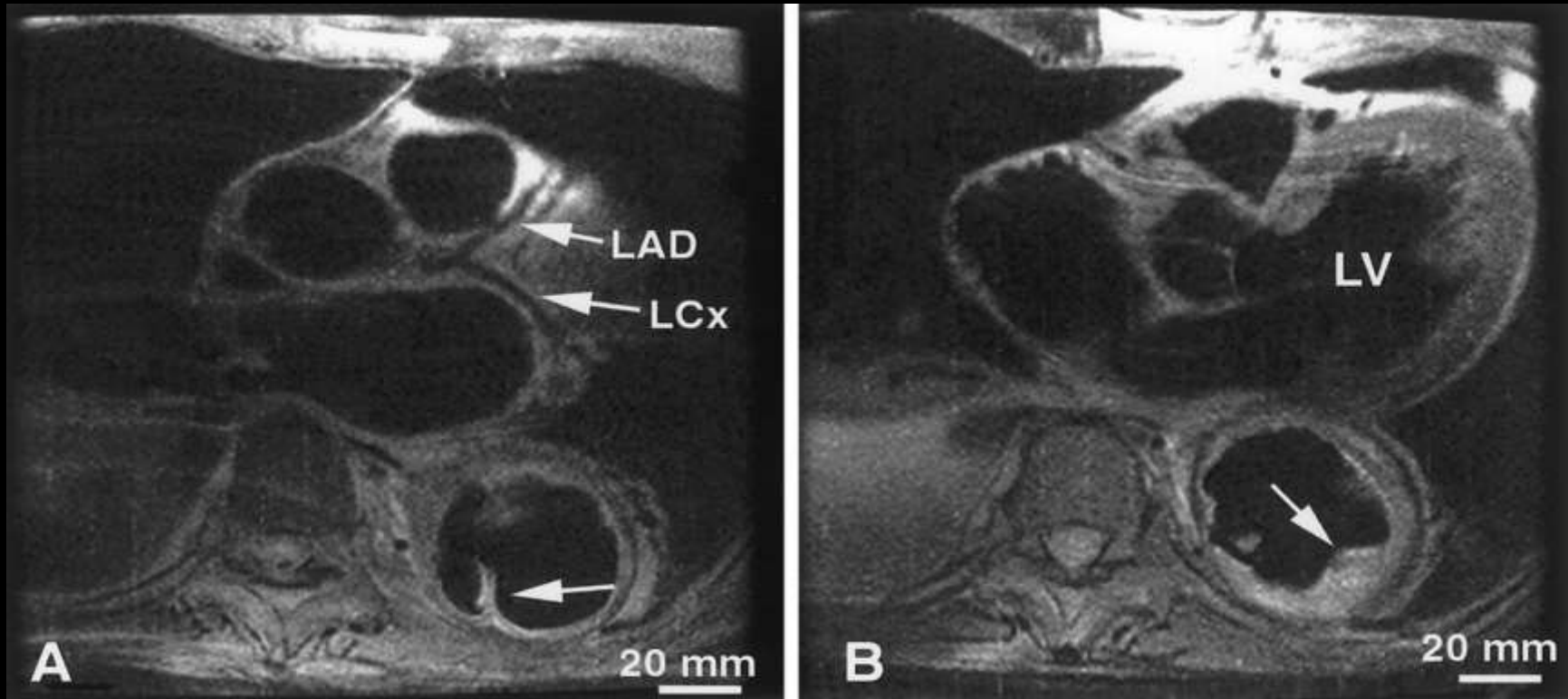


Soustraction Pondérée

Soustraction

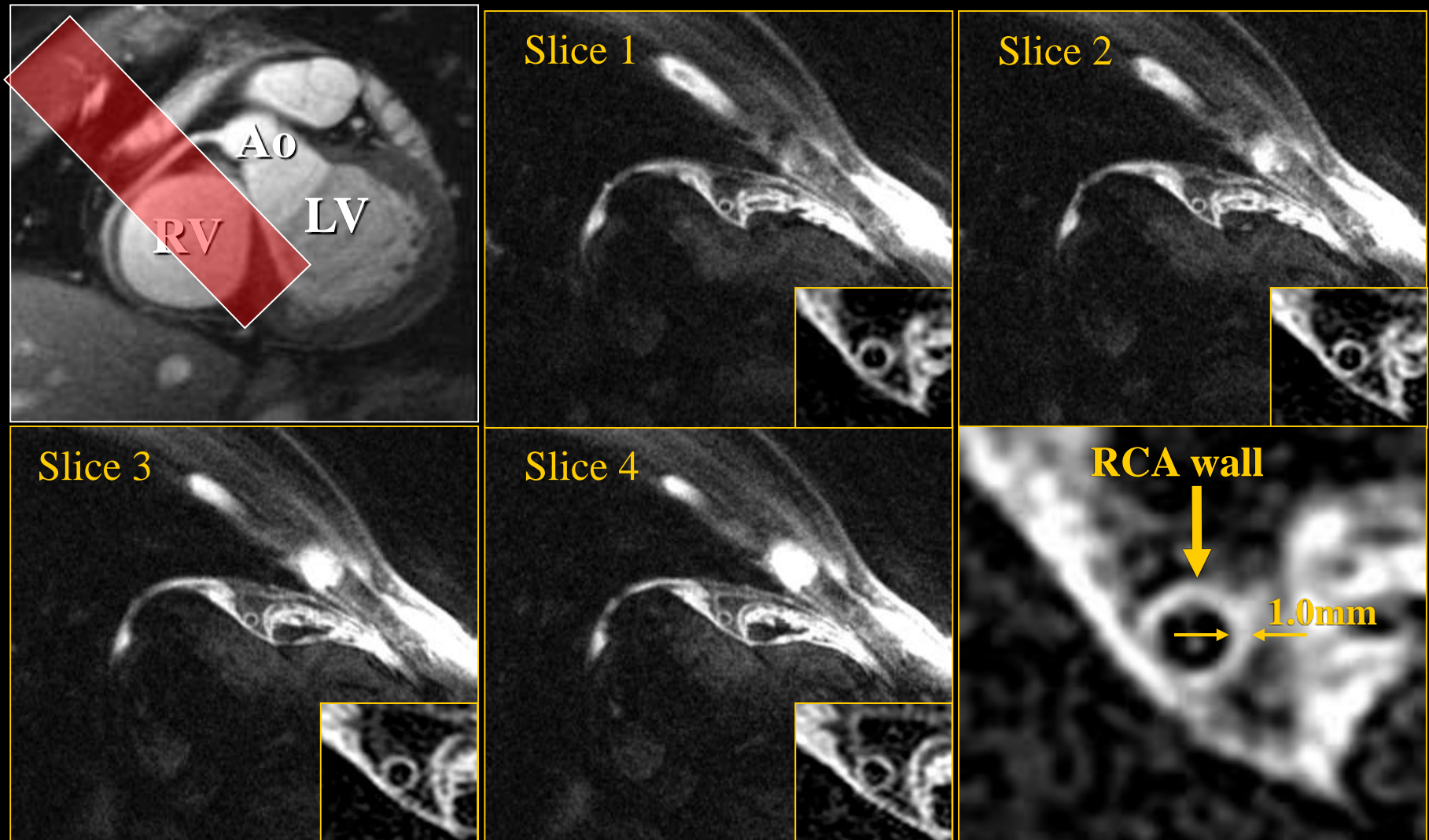
DIR standard

Plaque Imaging with Dark Blood sequence

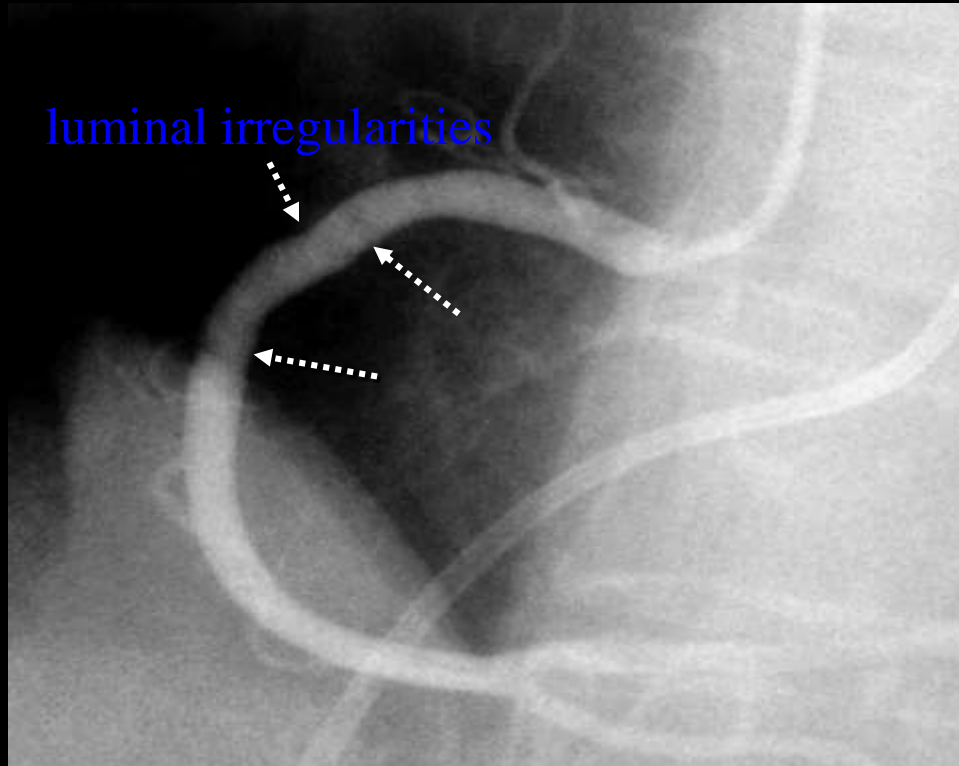


Fayad et al, Circulation 2001

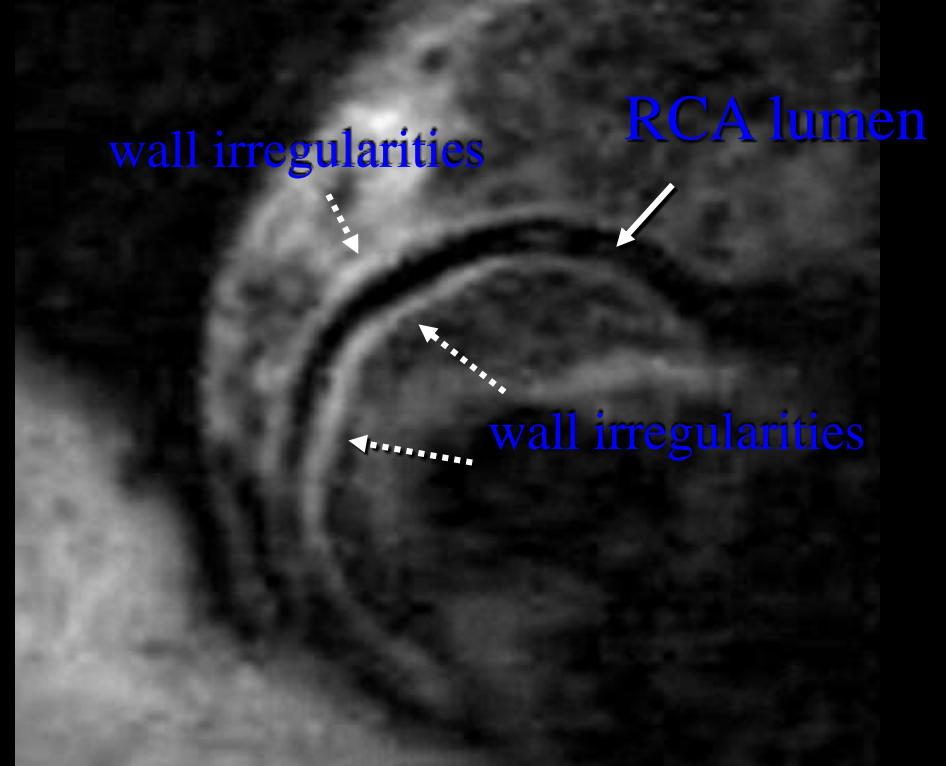
3D Coronary Vessel Wall Imaging



X-ray



MR Wall Scan



CONCLUSIONS

- ARM sans injection :
 - Temps de vol TOF
 - ↳ Indications cliniques limitées
 - ↳ artères carotides intra-cranienne

Contraste de phase:

Flux aortique et cardiaques

CONCLUSIONS

ARM sans injection : Steady State Free Precession: SSFP

- Coeur, artères coronaires, aorte

■ **ARM FBI:**

- Artères rénales
(IR)

CONCLUSIONS

ARM avec produit de contraste

- Simple
- Rapide
- Dynamique
- Robuste et sans risque
- Large champ d'exploitation vasculaire

CONCLUSIONS

- ARM: Techniques Paramétrable et adaptative en fonction:
 - ↳ Patients
 - ↳ Indications cliniques
 - ↳ Structure vasculaire à explorer