Imagerie de Diffusion IVIM

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Comment je fais ?

Antennes

Séquences

IVIM DWI-MRI

- Pré-requis technologiques et instrumentaux

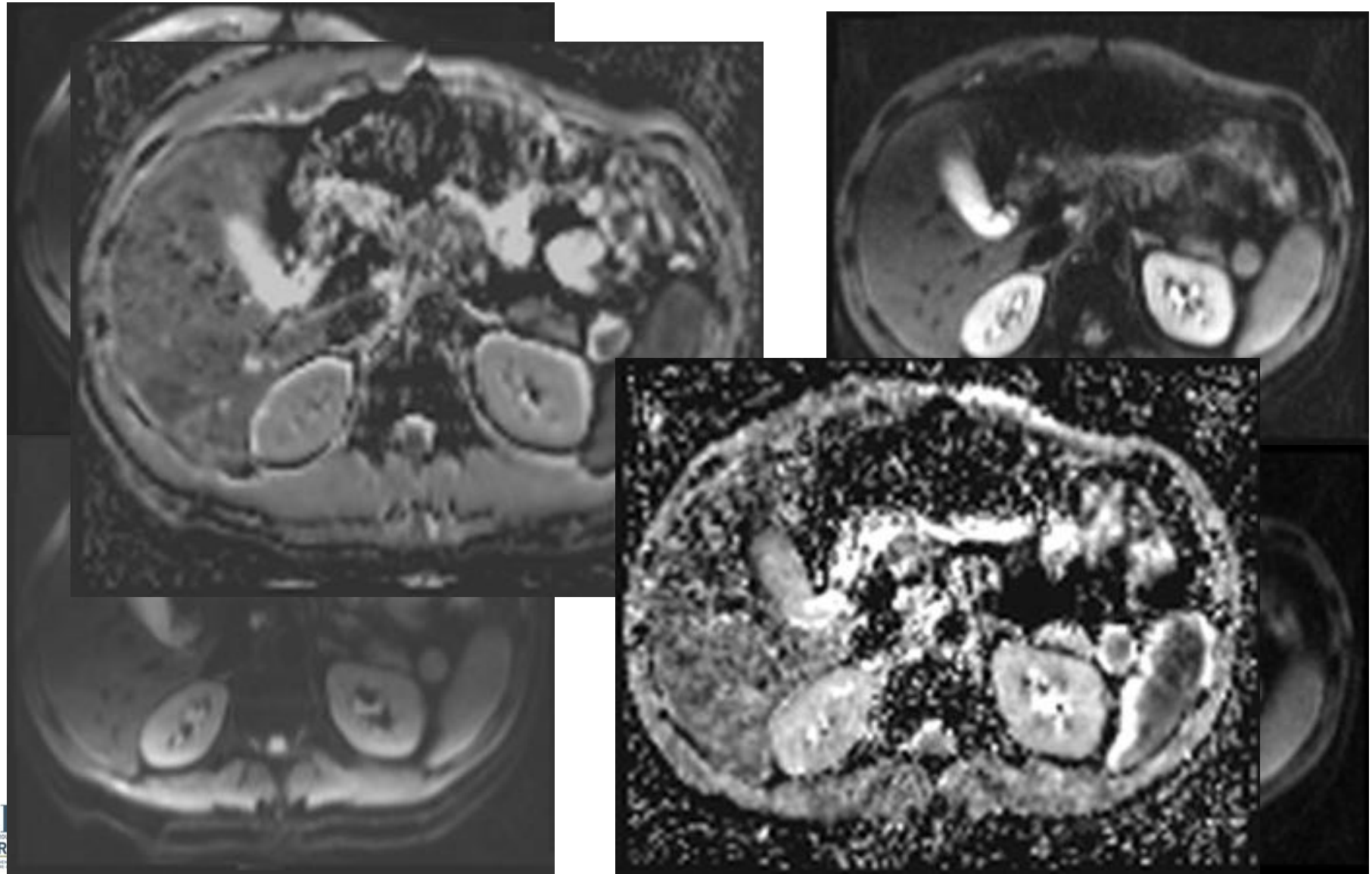
Applications Cliniques

Comment je fais ?

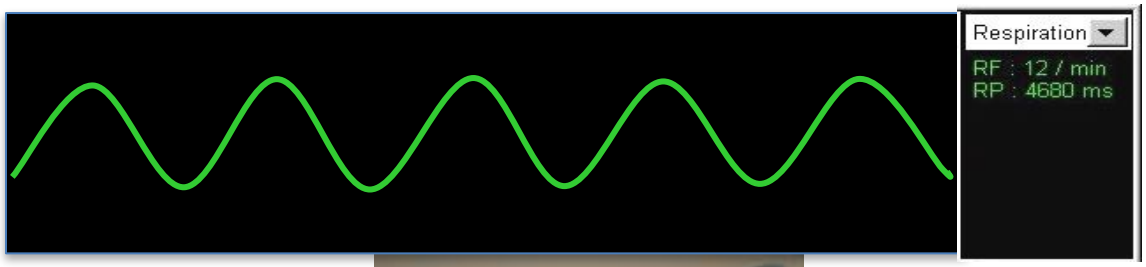
Antennes

Surface

Antenne Corps



- Comment gérer les mouvements ?
  - TE minimum
  - Imagerie parallèle
  - Asservissement respiratoire ?



12 volontaires sains

Trois méthodes de gating

- Respiration libre
- Gating Respiratoire
- Gating Cardiaque

Etude DWI IVIM : 9 valeurs de b : 0, 30, 60, 100, 150, 200, 400, 600, et 900 sec/mm^2

T

Parameter	FB DWI	ET DWI	RT DWI
Echo time (msec)	60	60	60
Repetition time (msec)	2100	3243–7142*	2100
Echo-planar imaging factor	115	115	115
Receiver bandwidth (Hz)	1594	1594	1594
Field of view (mm)	340 × 256	340 × 256	340 × 256
Matrix size	196 × 115	196 × 115	196 × 115
No. of signals acquired	4	4	4
Section thickness (mm)/gap (mm)	7/1.4	7/1.4	7/1.4
No. of sections acquired	20	20	20
Acquisition time (min)	3.7	8.3 (6.5–13.0)†	6.8 (6.4–10.8)†

Lee et al. Radiology 2014; Ahead of print http://dx.doi.org/10.1148/radiol.14140759

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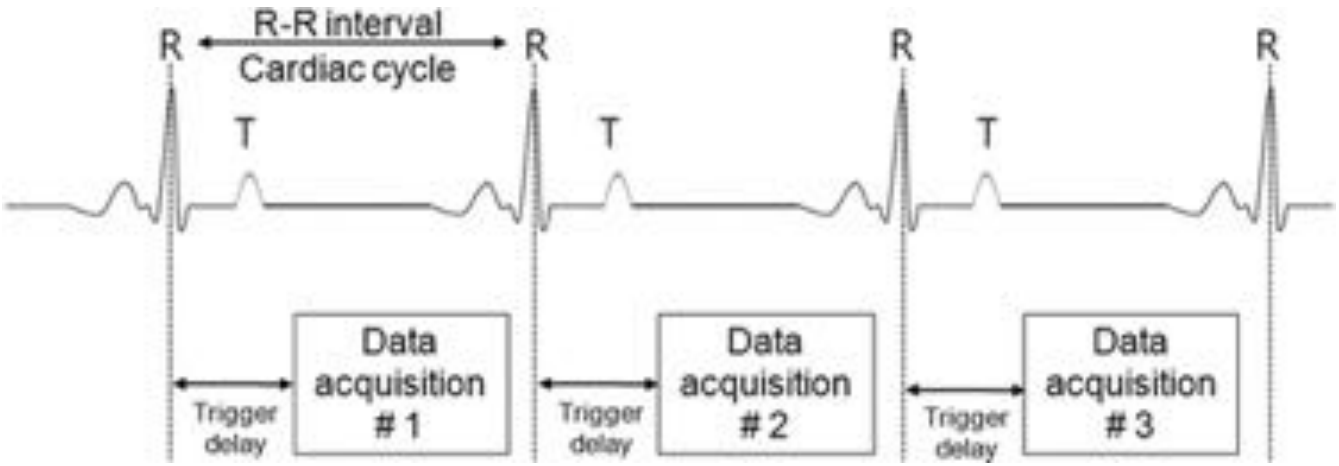
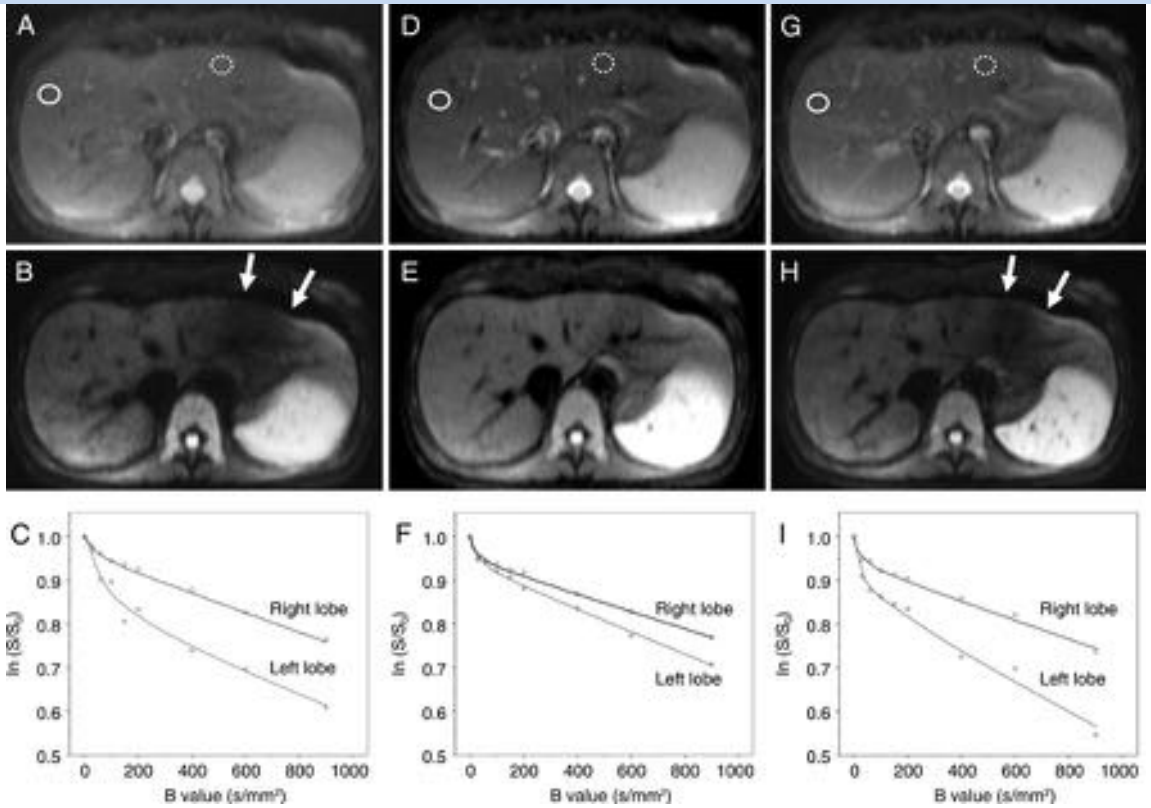
T



Lee et al. Radiology 2014; Ahead of print http://dx.doi.org/10.1148/radiol.14140759

Comment commencer en pratique clinique ?

Principes généraux



FB

ET

RT

Lee et al. Radiology 2014; Ahead of print http://dx.doi.org/10.1148/radiol.14140759

Comment commencer en pratique clinique ?

Principes généraux

Parameters	Within-Subject CV (%)			
	FB DWI	ET DWI	FIT DWI	P Values*
ADC				
Right lobe	4.33 (2.95, 5.70)	3.17 (1.79, 4.55)	2.33 (1.50, 3.16)	.279, .022,† .334
Left lobe	4.74 (3.12, 6.37)	4.12 (2.37, 5.88)	6.96 (2.16, 11.75)	.658, .365, .245
Mean	4.15 (2.66, 5.64)	3.40 (1.75, 5.05)	4.59 (1.24, 7.93)	.566, .806, .546
D value				
Right lobe	4.11 (2.51, 5.71)	4.05 (2.81, 5.30)	3.19 (1.83, 4.54)	.960, .378, .292
Left lobe	12.51 (4.61, 20.40)	5.34 (3.46, 7.21)	16.17 (7.35, 25.00)	.087, .072, .023†
Mean	7.57 (3.45, 11.69)	4.52 (2.96, 6.08)	9.73 (4.53, 14.93)	.184, .097, .074
f value				
Right lobe	15.77 (10.63, 20.90)	9.86 (7.13, 12.59)	11.85 (5.91, 17.78)	.024,† .396, .525
Left lobe	16.81 (9.60, 24.02)	8.47 (6.19, 10.74)	12.10 (5.22, 18.98)	.032,† .023,† .347
Mean	13.83 (9.49, 18.18)	7.60 (5.79, 9.42)	10.05 (4.91, 15.19)	.020,† .151, .348
D* value				
Right lobe	74.18 (43.69, 104.6[illegible])	71.87 (47.53, 96.21)	75.03 (55.04, 95.03)	.919, .964, .813
Left lobe	156.61 (96.72, 216.4[illegible])	88.34 (31.57, 145.11)	103.75 (49.18, 158.33)	.119, .224, .181
Mean	95.60 (56.31, 134.9[illegible])	57.05 (40.00, 74.10)	63.74 (27.90, 99.58)	.103, .209, .756

Lee et al. Radiology 2014; Ahead of print http://dx.doi.org/10.1148/radiol.14140759

Comment je fais ?

Séquences

Diffusion Weighted Whole Body MRI

- Respiration : Impact sur WB – imaging ?
  - 10 volontaires
  - DWI SE EPI sequence
  - TE 76, b0 , 400s/mm2
  - Respiration libre

Short- and Midterm Reproducibility of Apparent Diffusion Coefficient Measurements at 3.0-T Diffusion-weighted Imaging of the Abdomen[1]

ORIGINAL RESEARCH ■ GASTROINTESTINAL IMAGING

Adam C. Braithwaite, MD
Brian M. Dale, PhD
Daniel T. Boll, MD
Elmar M. Merkle, MD

Purpose: To test the hypothesis that there is no significant variability in apparent diffusion coefficients (ADCs) at assessment of the short- and midterm reproducibility of ADC measurements in a healthy population.

Materials and Twenty healthy male volunteers were enrolled in this pro-

Figure 1

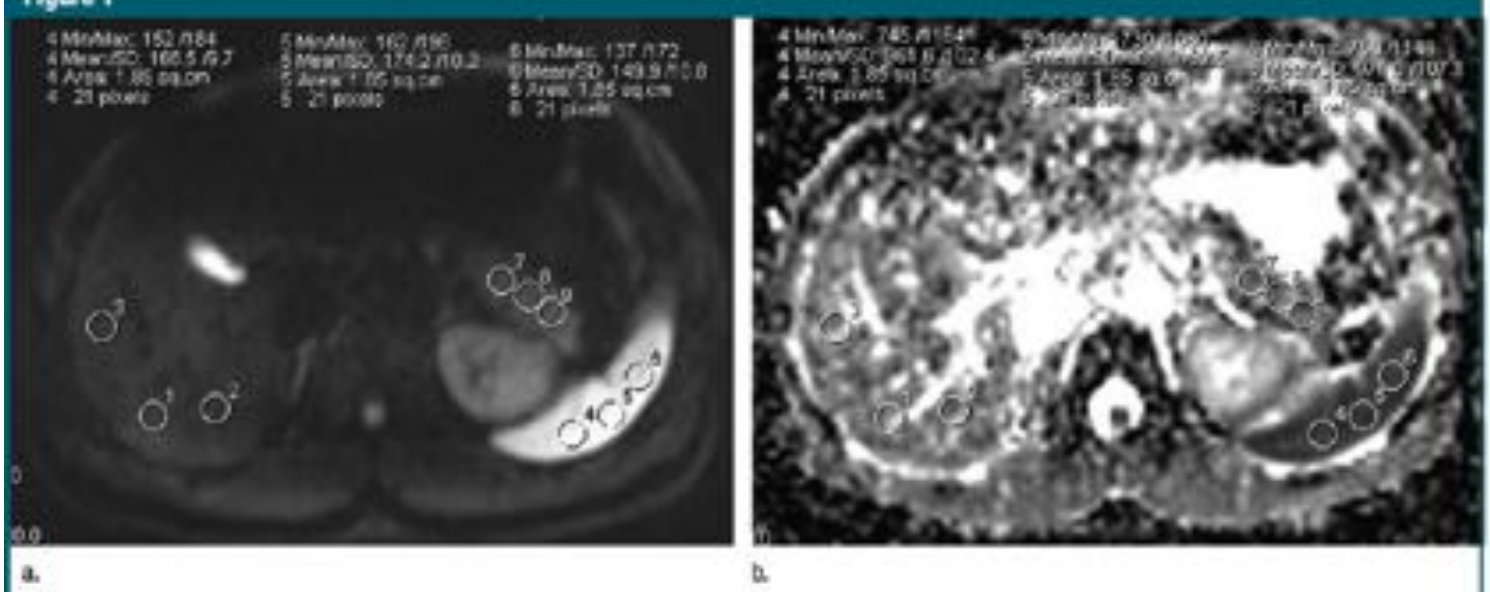


Figure 1: (a) Axial two-dimensional DW image of liver, spleen, and pancreatic tail, acquired with *b* value of 0 sec/mm². Three ROIs (1–9) each are placed in these anatomic areas. (b) The same ROIs have been copied from the DW image onto the corresponding ADC map.

Comment je fais ?

Séquences

Diffusion Weighted Whole Body MRI

- Variation intra-individuelle ADC ± 14%
- Seuil de signification > 27%

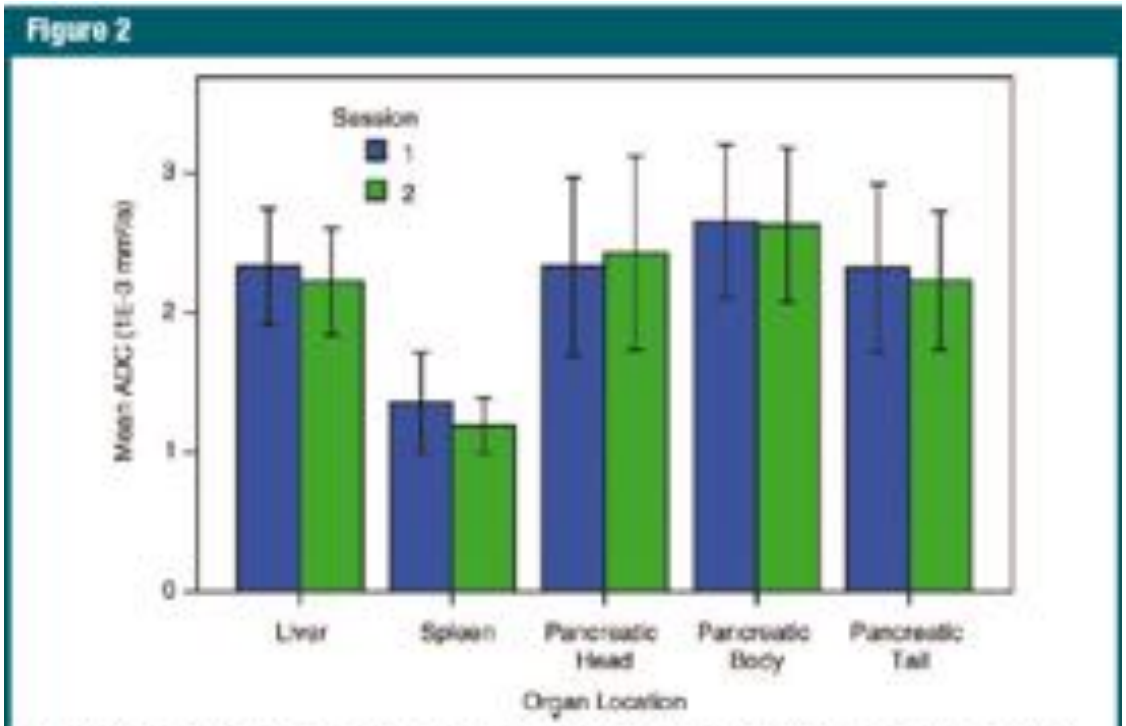


Figure 2: Graph illustrates mean ADCs in various anatomic locations measured during two DW imaging sessions. The mean ADCs in the various anatomic locations were significantly different ($P < .001$) from each other, with the spleen having the lowest mean ADC and the pancreatic body having the highest. However, the ADCs were not significantly different ($P = .497$) between the two imaging sessions.

Comment je fais ?

Séquences

Diffusion Weighted Whole Body MRI

- Respiration : Impact sur WB-DWI ?

JOURNAL OF MAGNETIC RESONANCE IMAGING 30:561–568 (2009)

Original Research

Diffusion-Weighted Imaging of the Liver: Comparison of Navigator Triggered and Breathhold Acquisitions

Bachir Taouli, MD,[1*] Alison Sandberg, MD,[1] Alto Stemmer, PhD,[2] Tejas Parikh, MD,[1] Samson Wong, MD,[1] Jian Xu, PhD,[3] and Vivian S. Lee, MD, PhD[1]

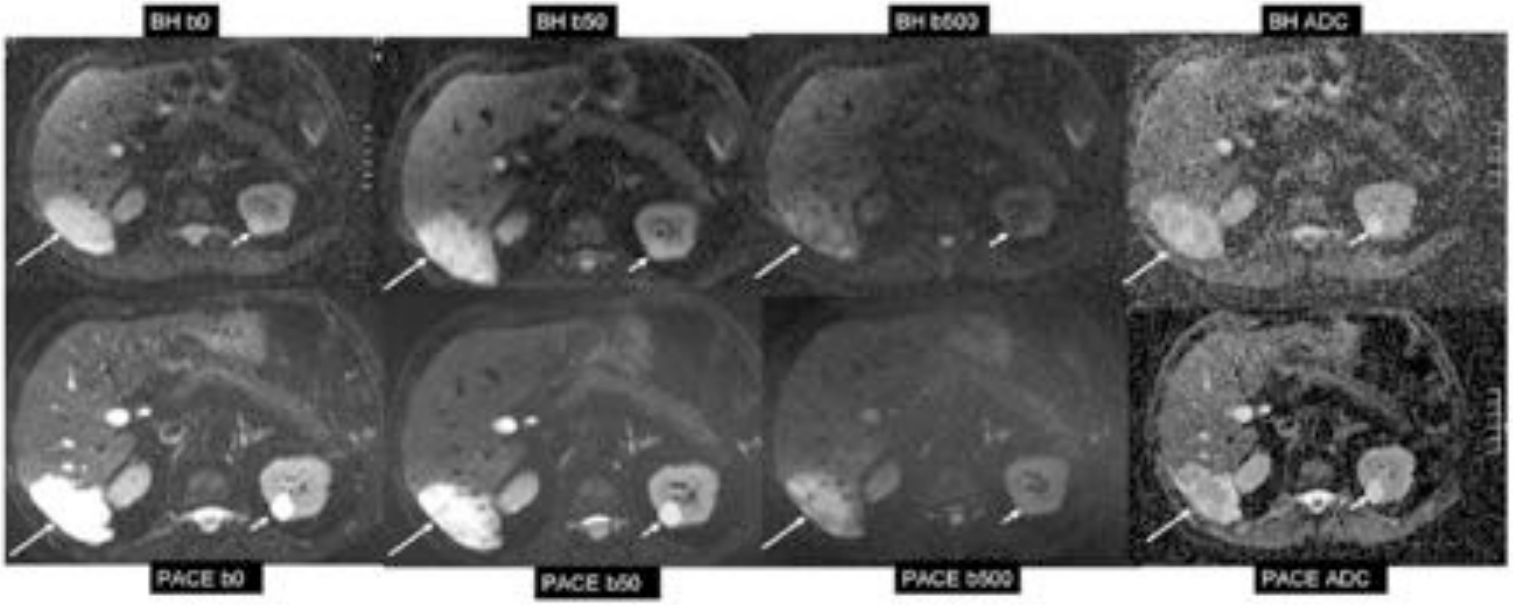
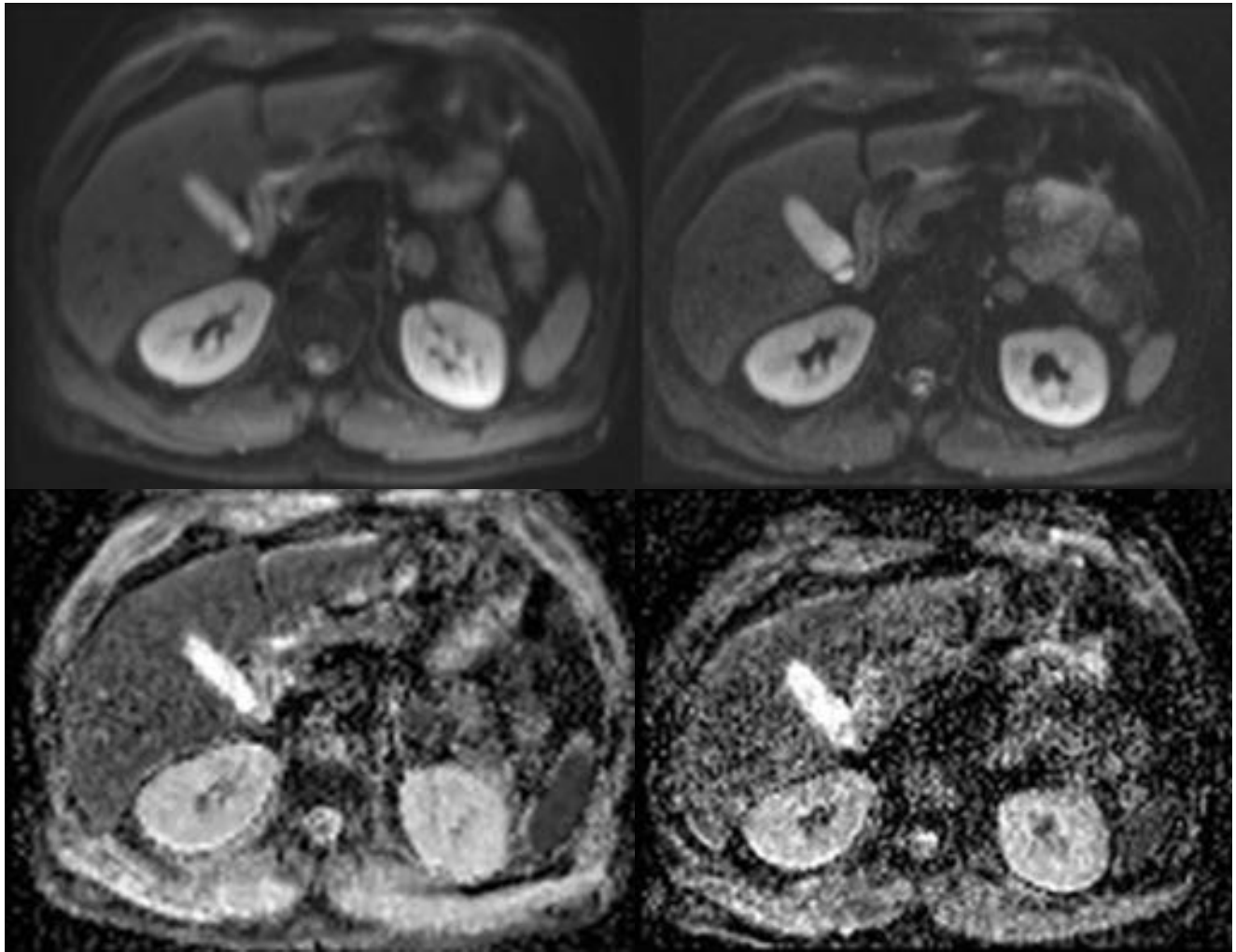
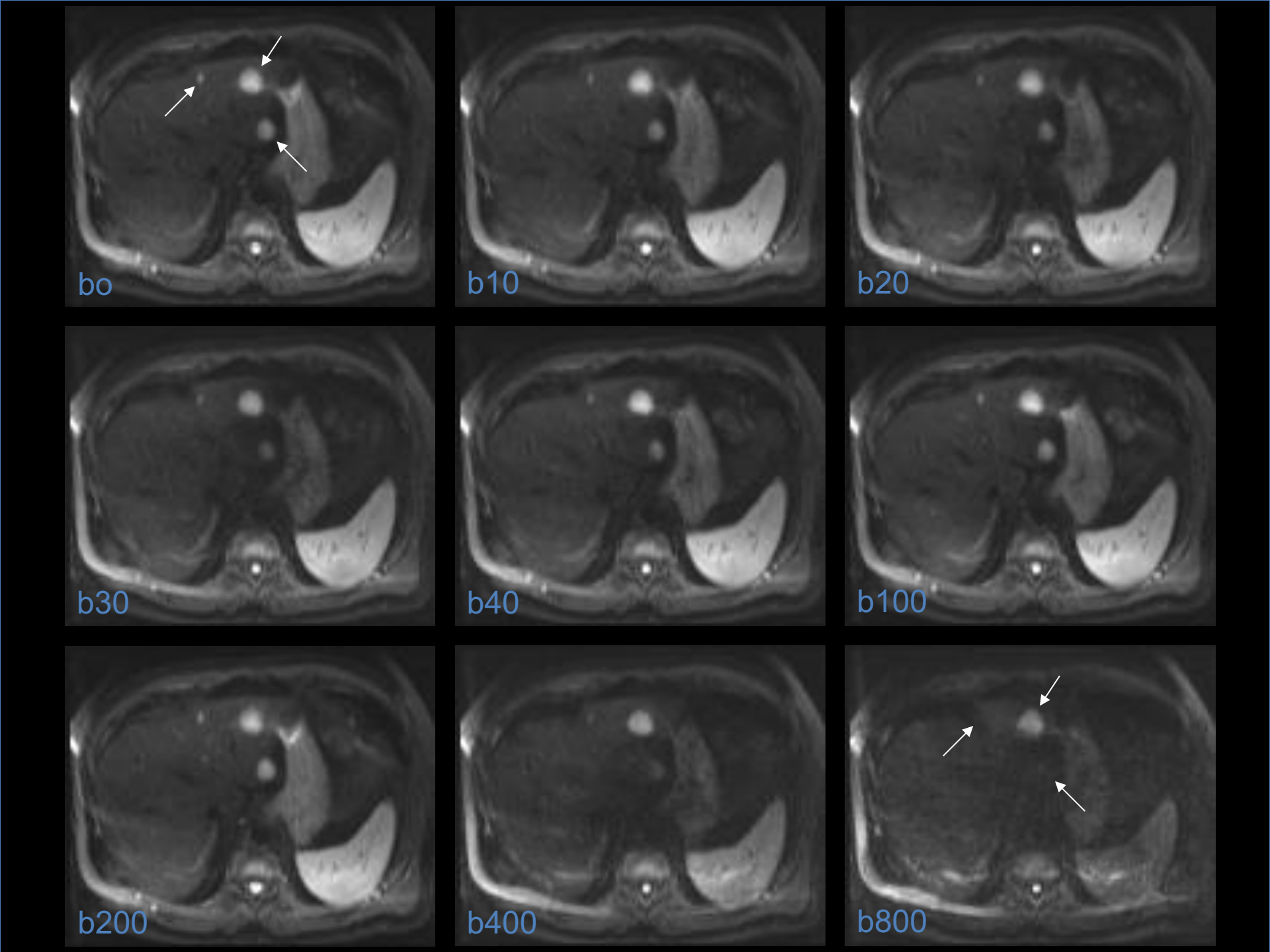


Figure 2. A 75-year-old man with hemangioma of the right posterior hepatic lobe (long arrows) demonstrated with breathhold DWI and respiratory triggered (PACE) DWI for b = 0, 50, and 500 s/mm^2 and corresponding ADC maps. An associated left renal cyst is present (short arrow). PACE DWI shows better image quality, and better lesion conspicuity than BH DWI. ADC map for PACE DWI shows better lesion delineation and less noise contamination.

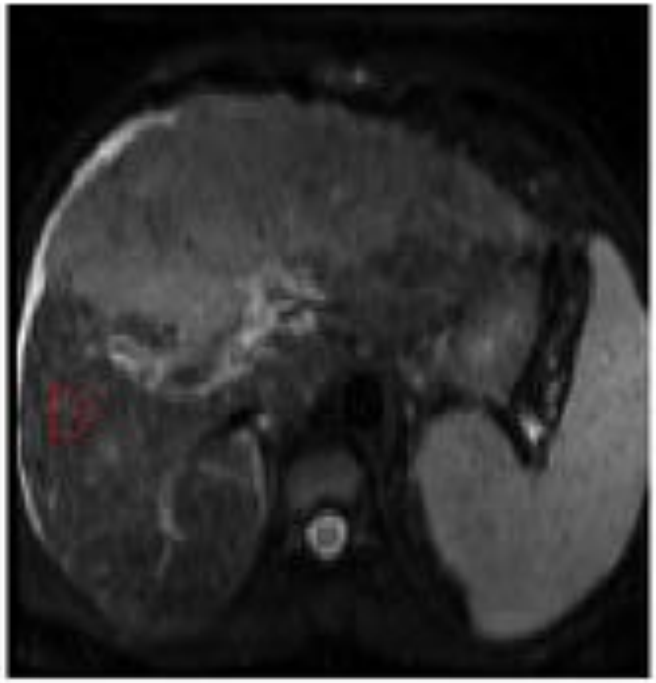
- Nombre de gradients de diffusion ?

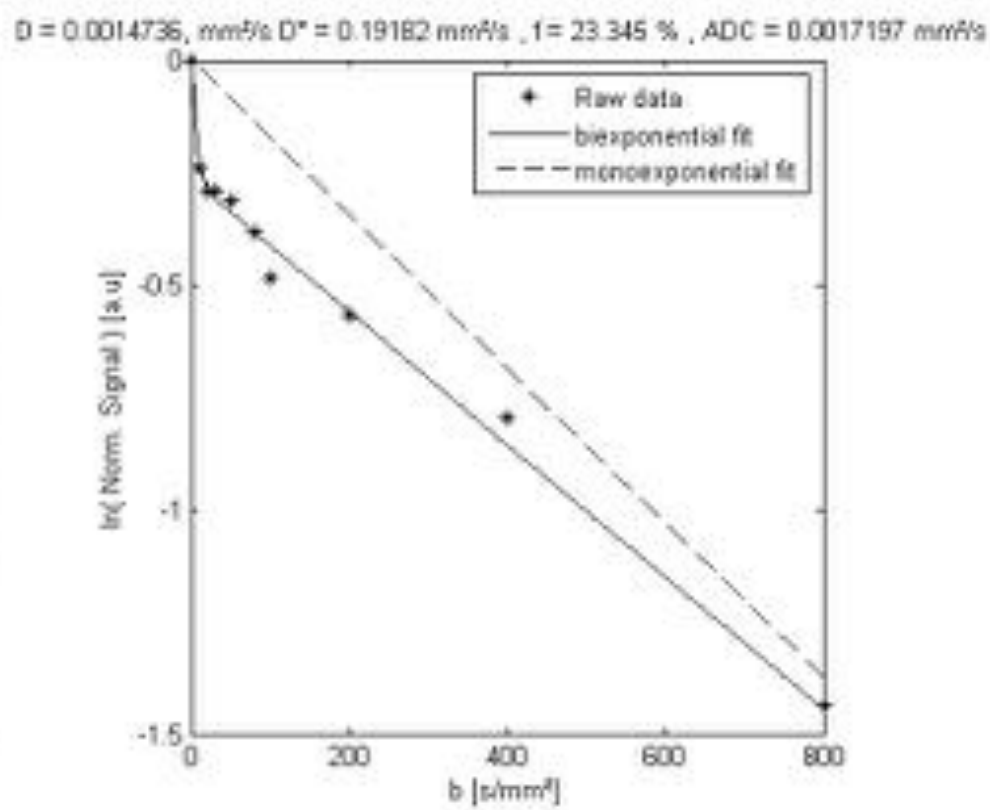
Mêmes paramètres ; Nex=2




bo
b10
b20
b30
b40
b100
b200
b400
b800

- Choix des valeurs de b ?





- Choix des facteurs de diffusion b – **Détection**

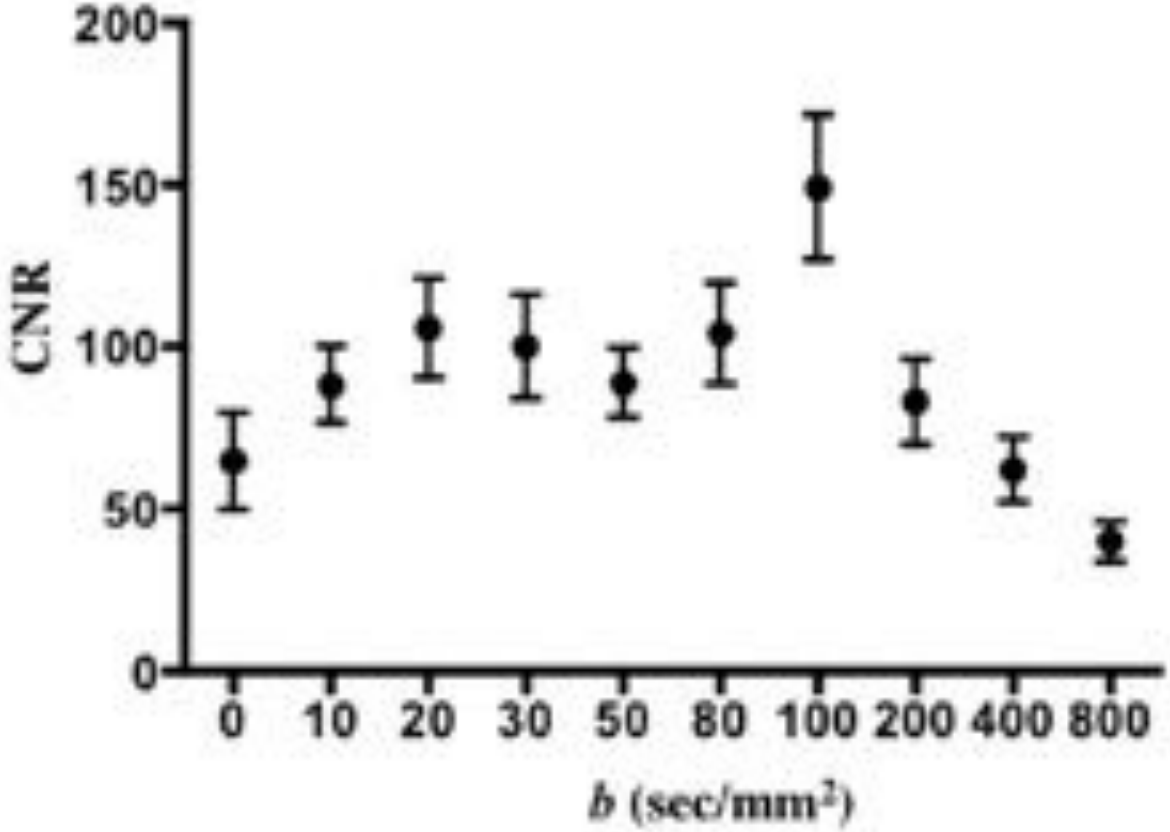
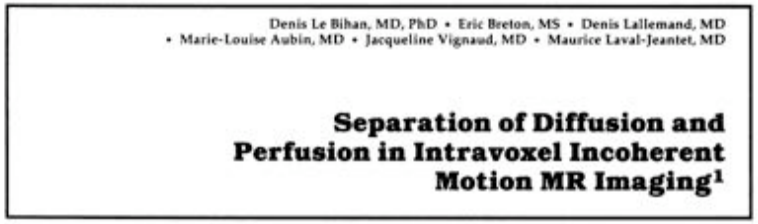


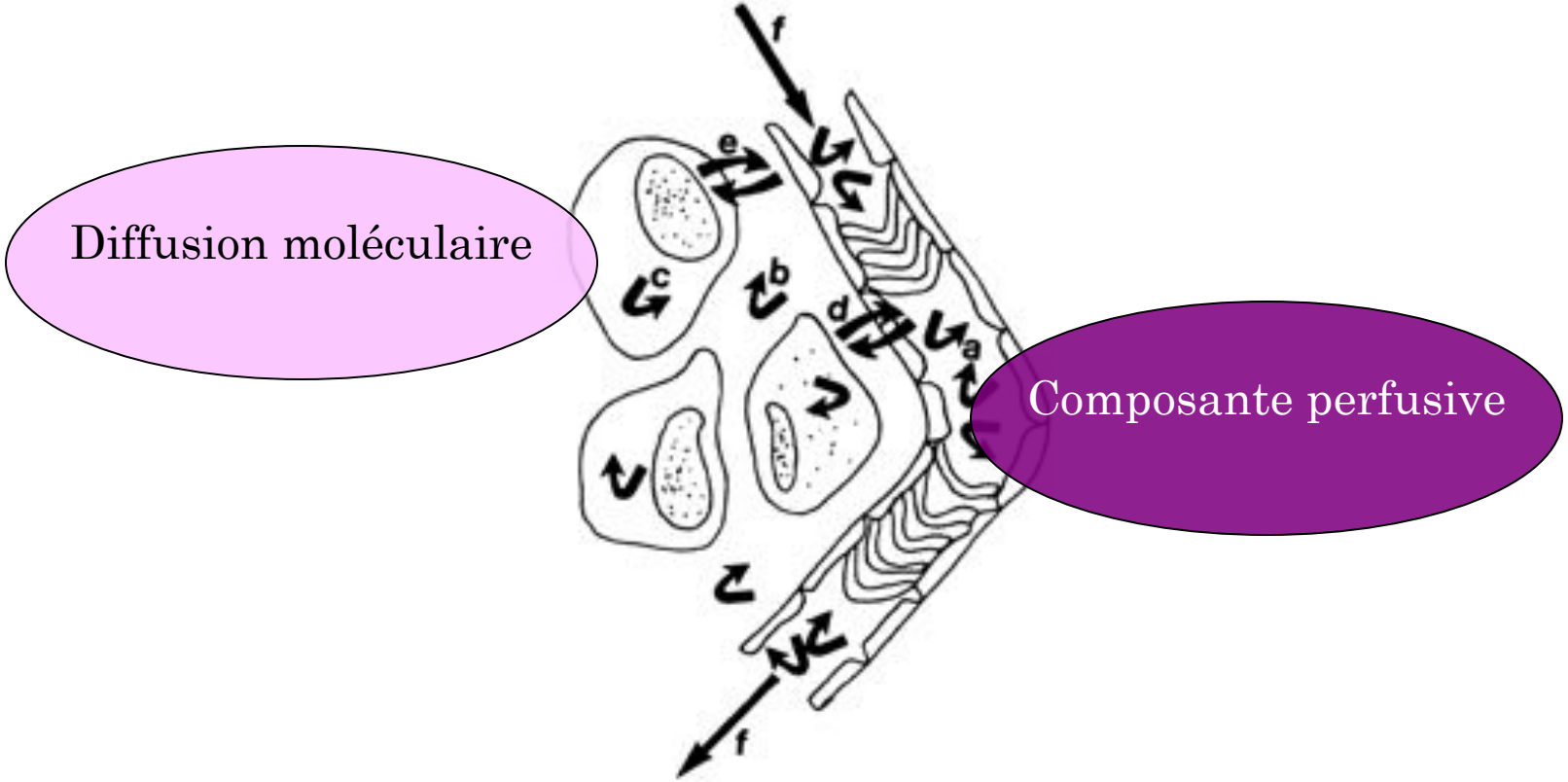
Figure 4. Mean (±SD) metastasis to liver CNR of 35 metastases larger than 10 mm detected with IVIM-DWI. The maximum CNR was obtained with $b = 100$ s/mm^2.

Chiaradia et al. JMRI 2013

- Principes de la diffusion


Denis Le Bihan, MD, PhD • Eric Breton, MS • Denis Lallemand, MD • Marie-Louise Aubin, MD • Jacqueline Vignaud, MD • Maurice Laval-Jeantet, MD

Separation of Diffusion and Perfusion in Intravoxel Incoherent Motion MR Imaging[1]



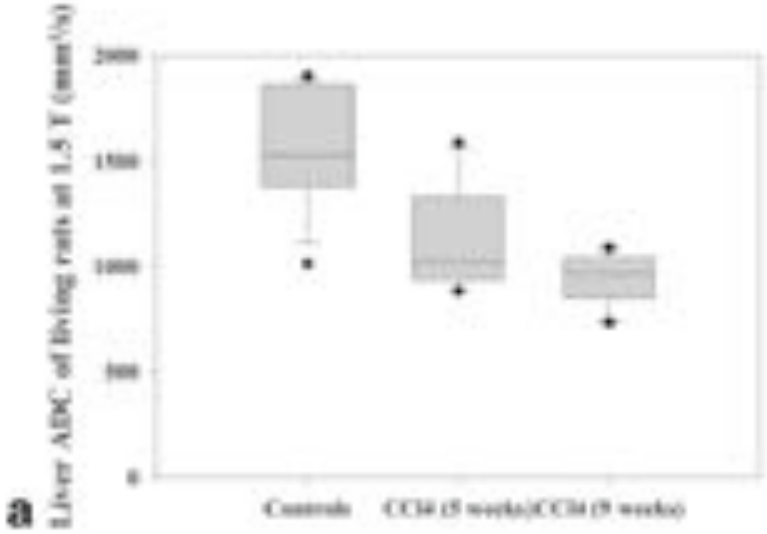
- Choix des valeurs de b ?
  - b 0, 500, 1000 s/mm^2
  - Modèle animal CCl4

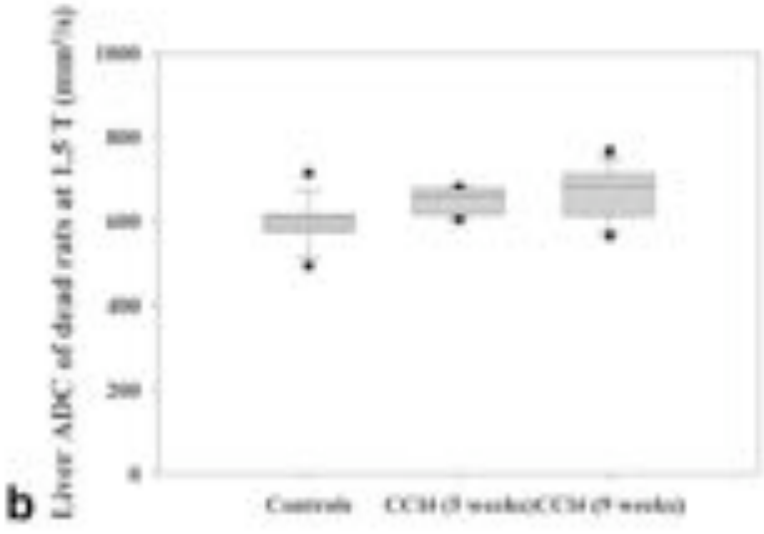
JOURNAL OF MAGNETIC RESONANCE IMAGING 25:122–128 (2007)

Original Research

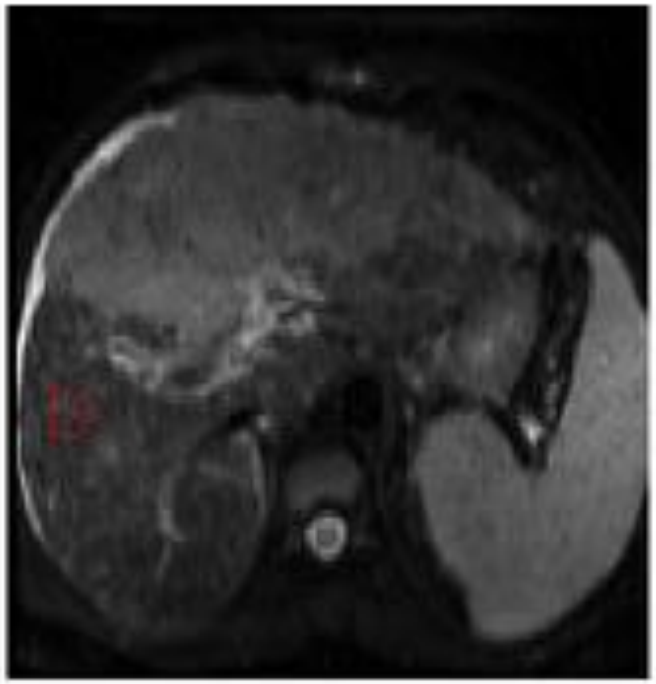
Assessment of Diffusion-Weighted MR Imaging in Liver Fibrosis

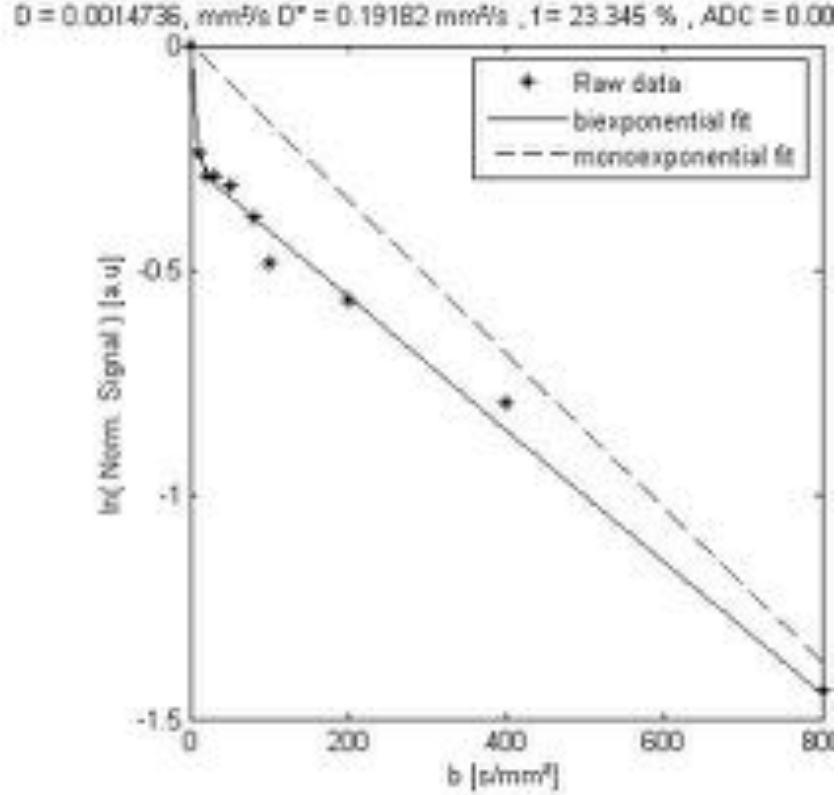
Laurence Annet, MD, PhD,[1*] Frank Peeters, PhD,[1] Jorge Abarca-Quinones, BS,[1] Isabelle Leclercq, MD, PhD,[2] Pierre Moulin, MD,[3] and Bernard E. Van Beers, MD, PhD[1]



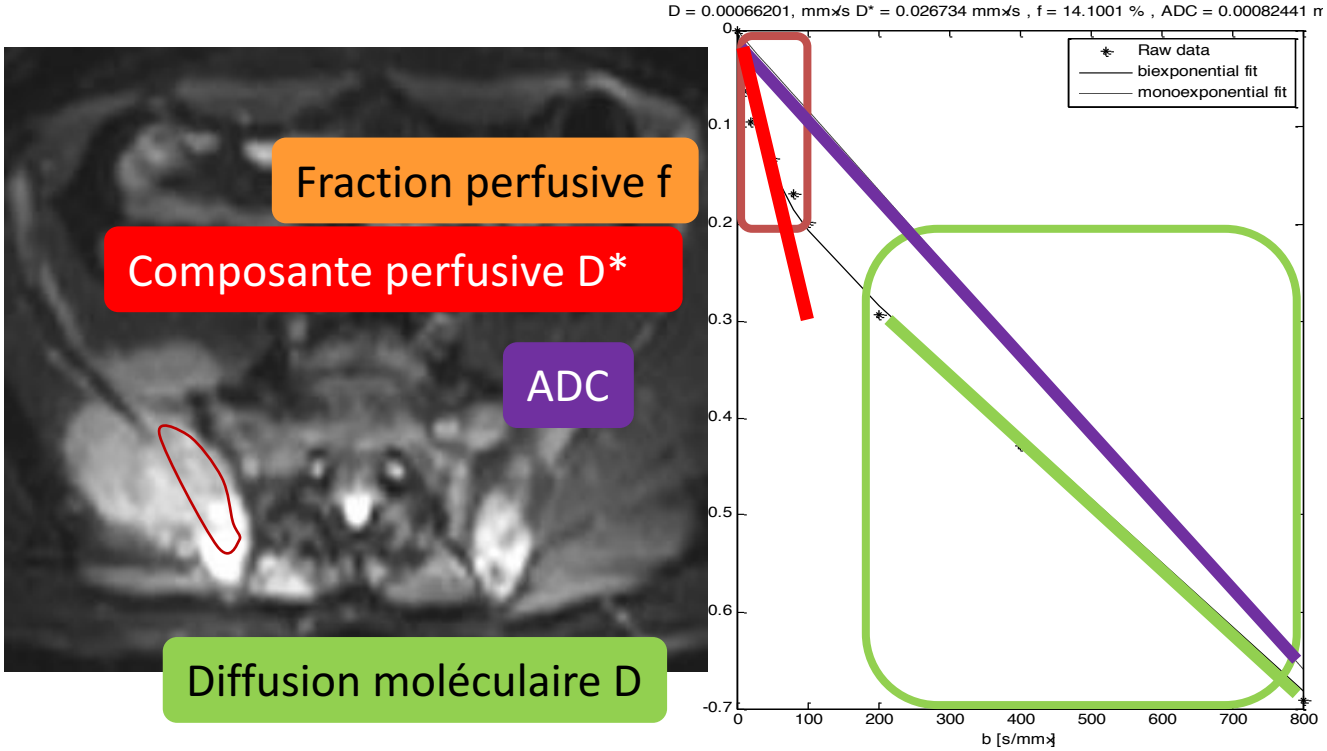


- Choix du facteur b - **Quantification**



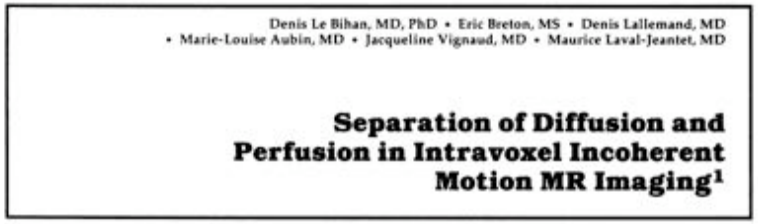


- Choix du facteur b - **Quantification**



$$S=S_0[(1-f).\exp^{(-b.D)}+f.\exp^{-b(D+D^*)}]$$

- Principes de la diffusion


Denis Le Bihan, MD, PhD • Eric Breton, MS • Denis Lallemand, MD • Marie-Louise Aubin, MD • Jacqueline Vignaud, MD • Maurice Laval-Jeantet, MD

Separation of Diffusion and Perfusion in Intravoxel Incoherent Motion MR Imaging[1]

$$B = \frac{S(b)}{S(0)} = \exp(-bD).F = \underbrace{f.\exp(-b(D+D^*))}_{\text{Microcirculation Composante perfusive}} + \underbrace{(1-f).\exp(-bD)}_{\text{Diffusion moléculaire}}$$

b<100s/mm^2 : composante perfusive non négligeable

b>100s/mm^2: composante perfusive négligeable

- Application clinique

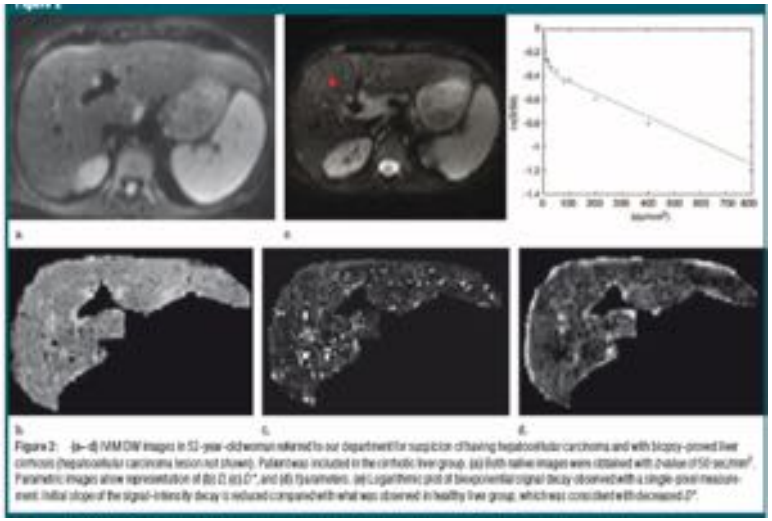
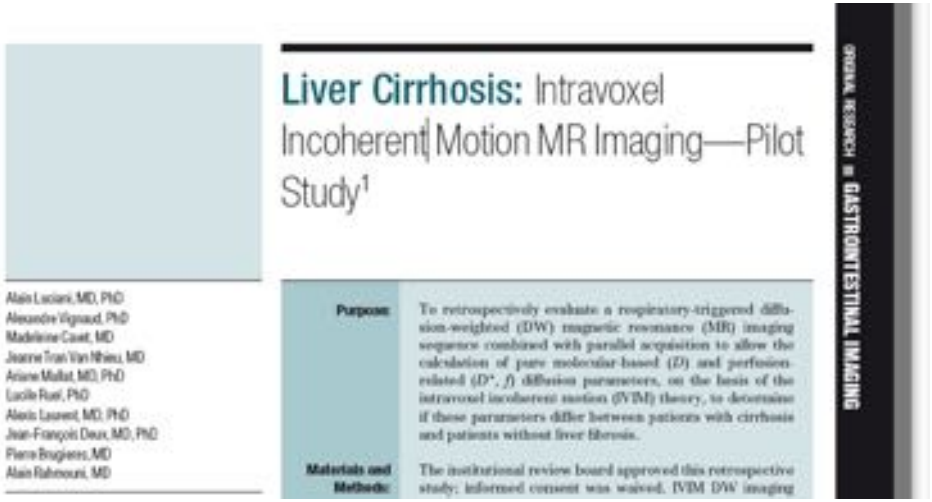


Figure 2: (a–d) IVIM DW images in 51-year-old woman referred to our department for suspicion of having hepatocellular carcinoma and with biopsy-proved liver cirrhosis (hepatocellular carcinoma lesion not shown). Patient was included in the cirrhotic liver group. (a) Both native images were obtained with b value of 50 sec/mm². Parametric images show representation of (b) D, (c) D*, and (d) f parameters. (e) Logarithmic plot of biexponential signal decay observed with a single pixel measurement. Initial slope of the signal-intensity decay is reduced compared with what was observed in healthy liver group, which was consistent with decreased D*.



ORIGINAL RESEARCH ■ GASTROINTESTINAL IMAGING

Liver Cirrhosis: Intravoxel Incoherent Motion MR Imaging—Pilot Study[1]

Alain Luciani, MD, PhD
Alexandre Vignaud, PhD
Madeleine Cavet, MD
Jeanne Tran Van Nhieu, MD
Ariane Mallat, MD, PhD
Lucile Ruel, PhD
Alexis Laurent, MD, PhD
Jean-François Deux, MD, PhD
Pierre Brugieres, MD
Alain Rahmouni, MD

Purpose: To retrospectively evaluate a respiratory-triggered diffusion-weighted (DW) magnetic resonance (MR) imaging sequence combined with parallel acquisition to allow the calculation of pure molecular-based (*D*) and perfusion-related (*D**, *f*) diffusion parameters, on the basis of the intravoxel incoherent motion (IVIM) theory, to determine if these parameters differ between patients with cirrhosis and patients without liver fibrosis.

Materials and Methods: The institutional review board approved this retrospective study; informed consent was waived. IVIM DW imaging

Table 4

Mean global ADC and *D*, *D, and *f* Parameters Assessed in 37 Patients in Pilot Study**

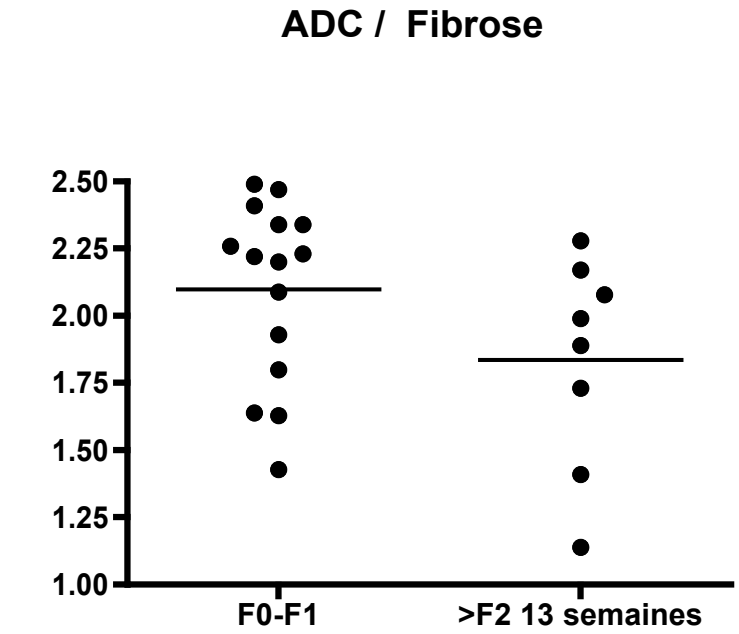
Parameter	Healthy Liver Group	Cirrhotic Liver Group	*P* Value
ADC ($\times 10^{-3}$ mm²/sec)	1.39 ± 0.2	1.23 ± 0.4	.03
D ($\times 10^{-3}$ mm²/sec)	1.10 ± 0.7	1.19 ± 0.5	.4 (NS)
*D** ($\times 10^{-3}$ mm²/sec)	79.1 ± 18.1	59.4 ± 20.0	.009
f (%)	27.0 ± 5.3	30.0 ± 5.7	.07 (NS)

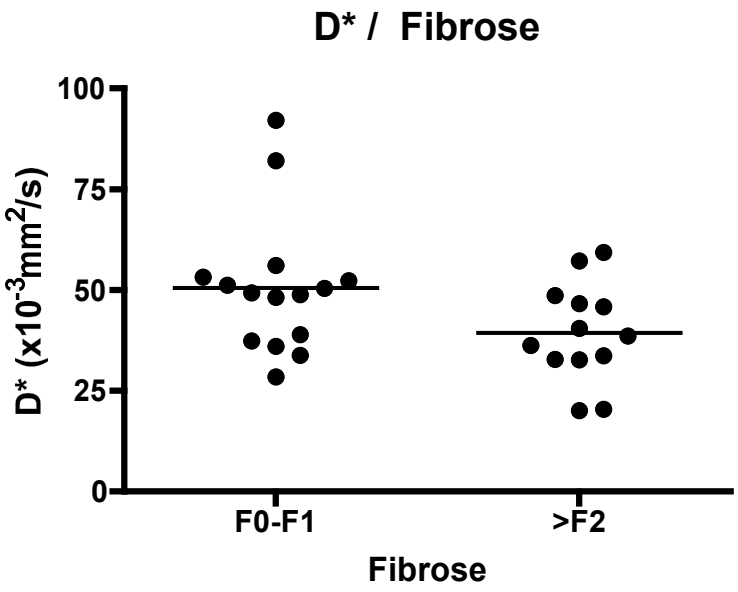
Note.—Unless otherwise indicated, data are means ± standard deviations. NS = not significant.

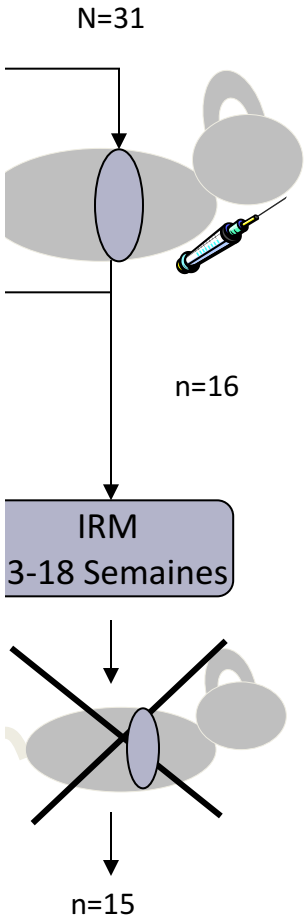
IVIM e

/BK/6J

- Modèle animal murin
- TAA 0.03%
- Eau de boisson
- Adaptation poids 6 semaines



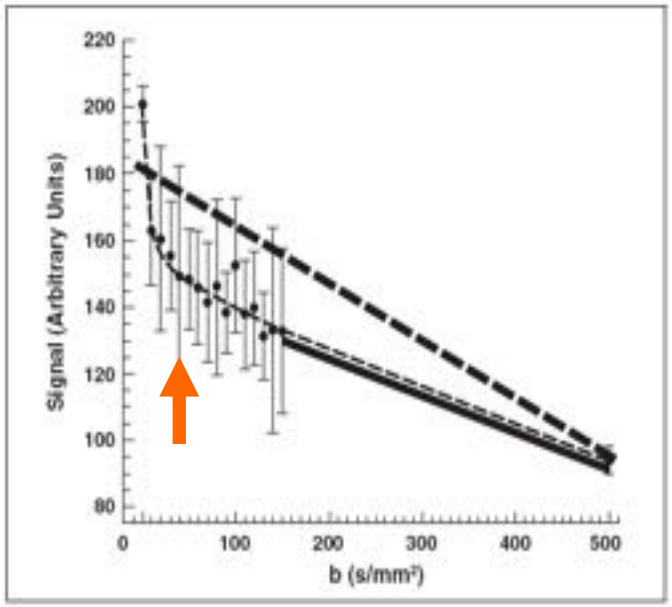




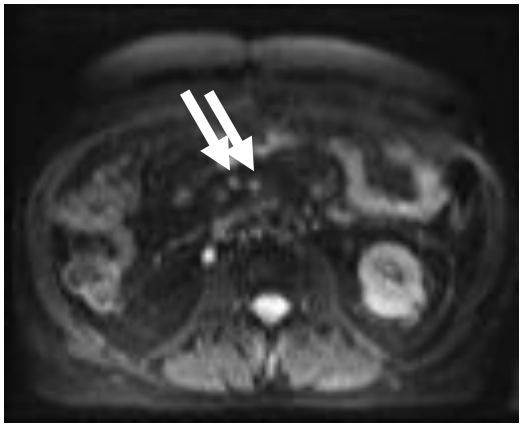
Sacr
anat

rifice - Exploration
tomopathologique

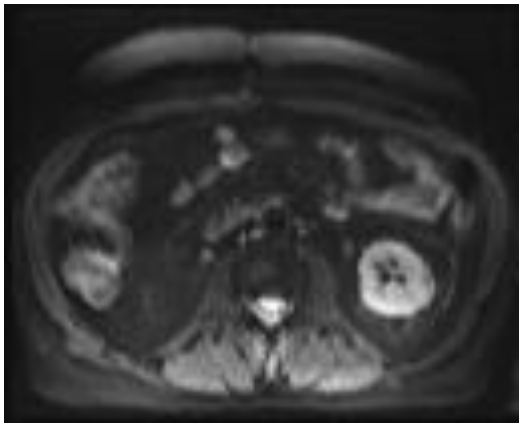
- Choix du facteur b



- T2 WI
- Limite effet « perfusion »
- Filtre vitesse



b = 0 s/mm2



b = 50 s/mm2

Koh DM et al. *AJR* 2007;188:1622-1635

Pourquoi améliorer analyse DWI ?

RÉPARTITION DES TUMEURS HÉPATIQUES

Tumeur N = 140	Nombre		Taille (mm)	
	Total	Naïf	Moyenne	Déviation standard
CHC	50	27	52,78	44,9
Métastase *	29	7	33,69	17,22
HNF	14		49,93	25,38
Adénome	3		34,7	28,9
Angiome	34		30,65	16,98
Kyste	10		32,3	15,43

Pourquoi améliorer analyse DWI ?

Exemple des Tumeurs Hépatiques

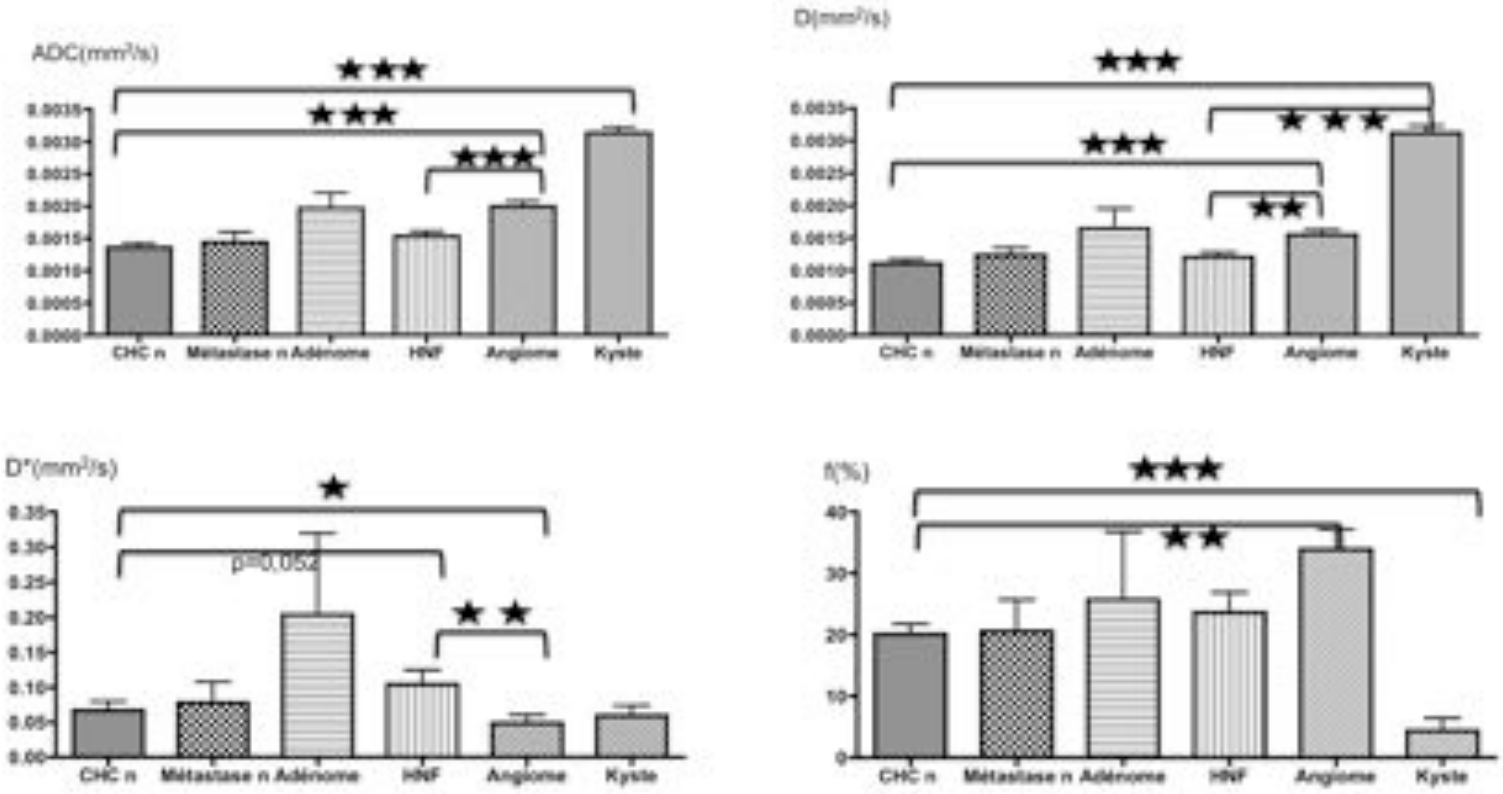
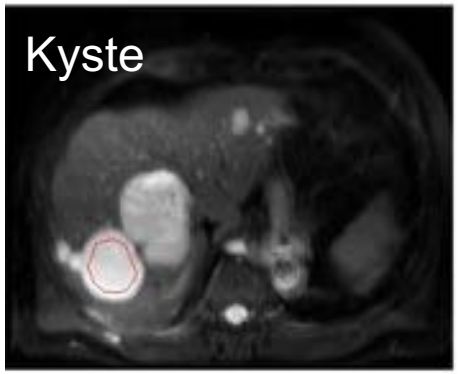
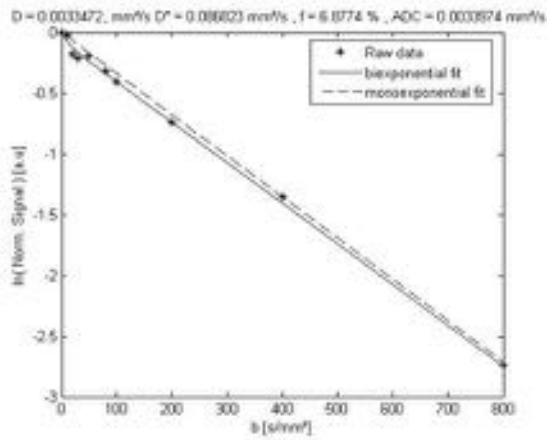


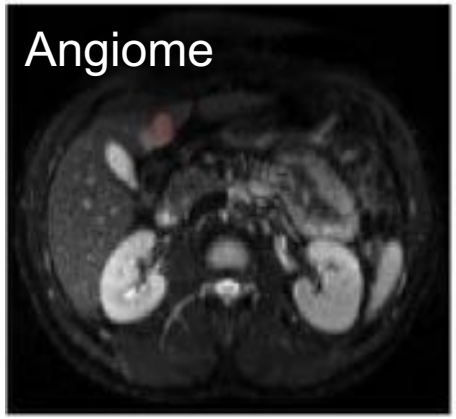
Figure 1 : Paramètres IVIM des lésions hépatiques. ★★★ p<0,0005 - ★★ 0,0005<p<0,005 - ★ 0,005<p<0,05

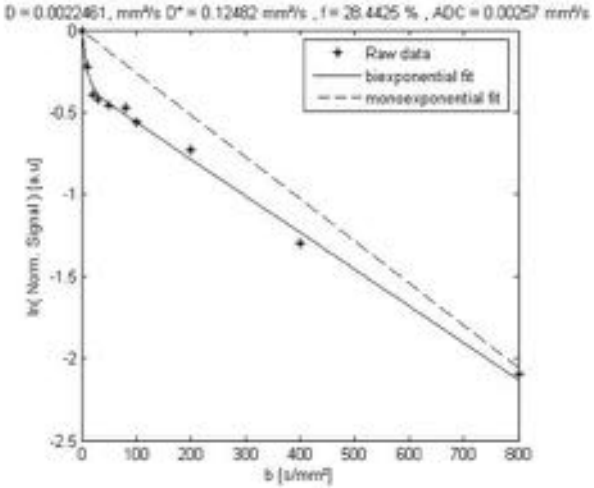
Pourquoi améliorer analyse DWI ?

Exemple des Tumeurs Hépatiques



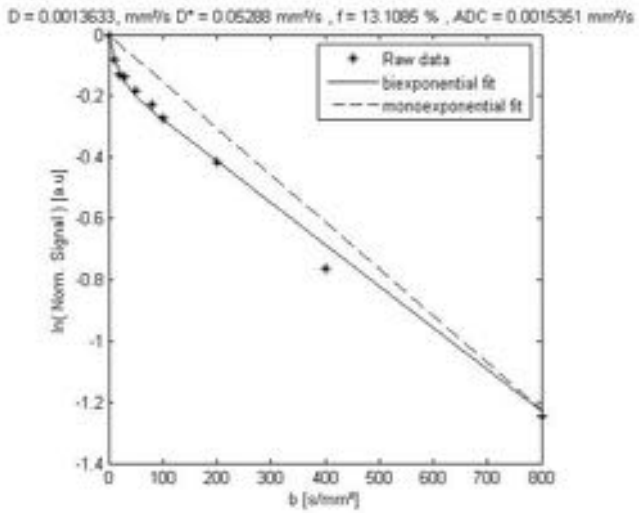


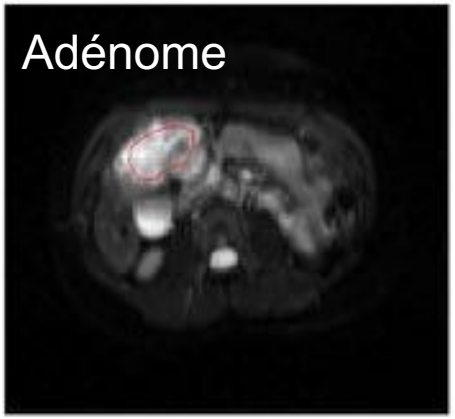


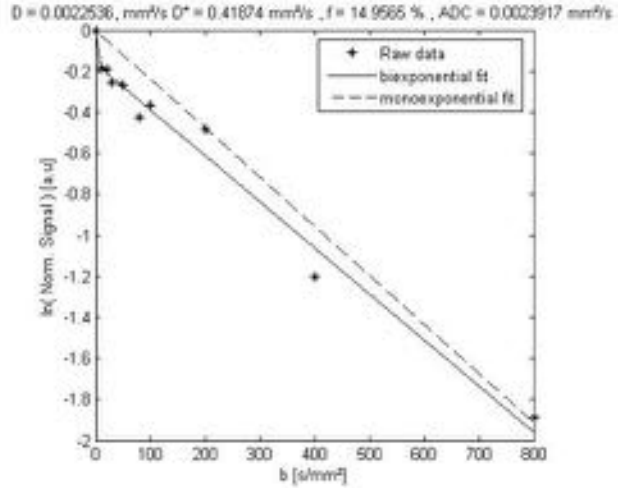


Pourquoi améliorer analyse DWI ?

Exemple des Tumeurs Hépatiques

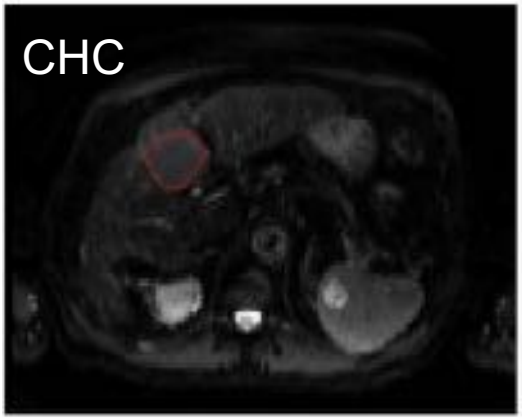


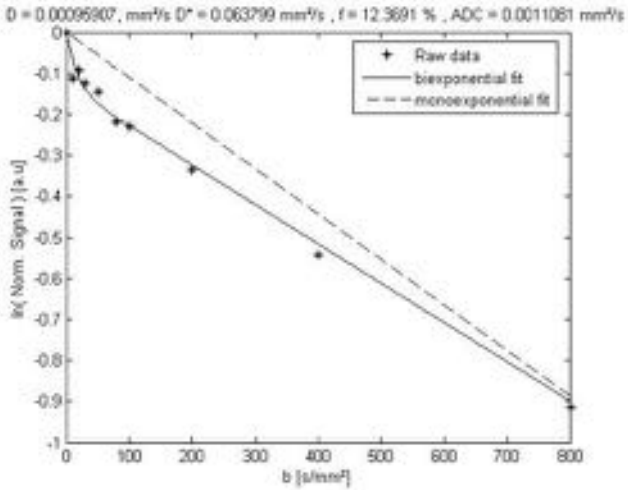


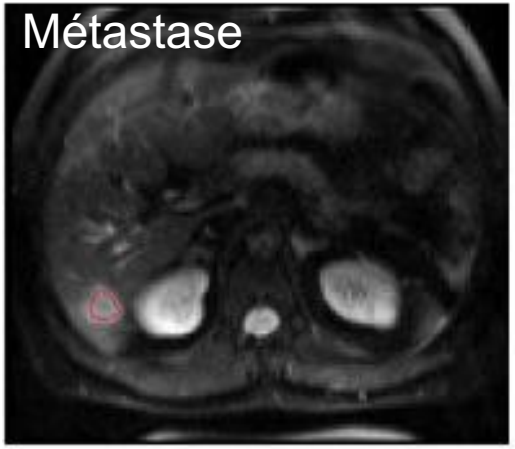


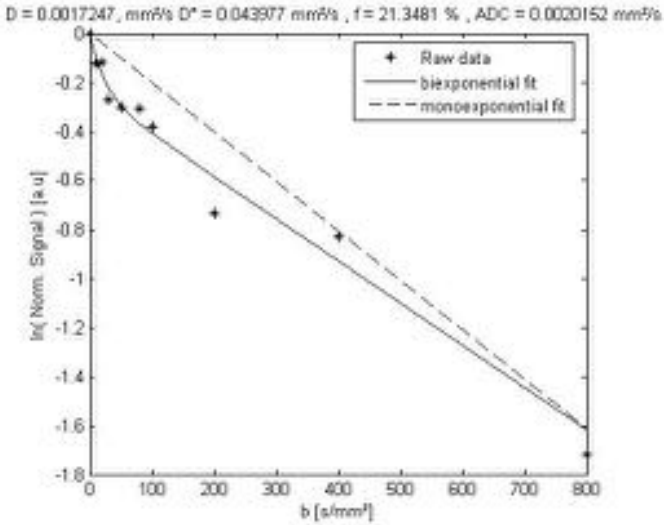
Pourquoi améliorer analyse DWI ?

Exemple des Tumeurs Hépatiques









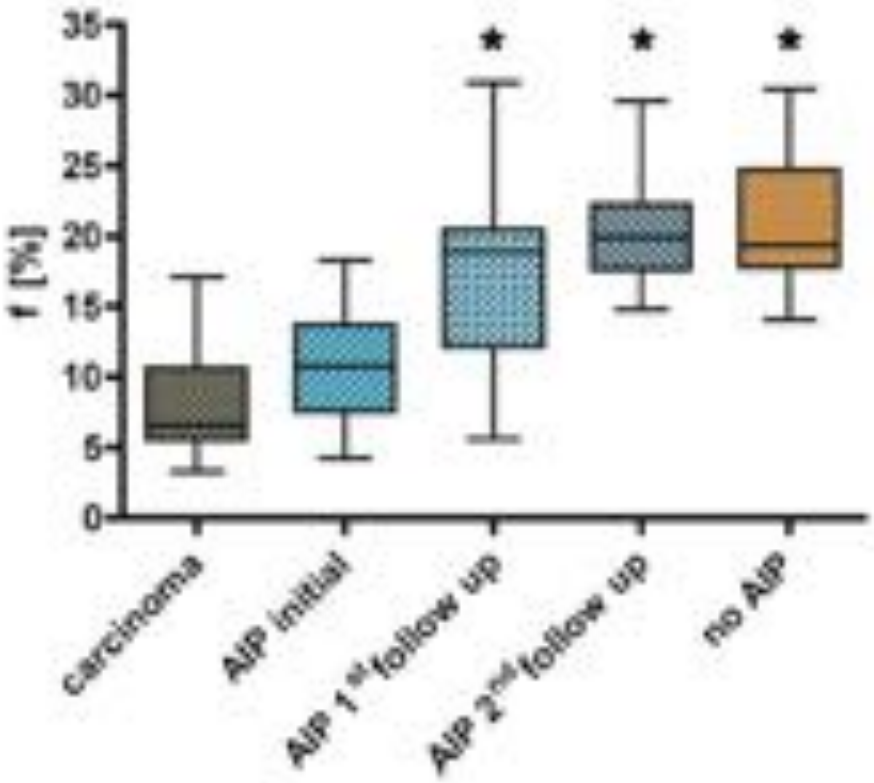
Pourquoi améliorer analyse DWI ?

Exemple des Tumeurs pancréatiques

Diffusion weighted images were acquired using a single-shot echo-planar imaging (SE-EPI) pulse sequence in expiratory breath-hold with the following imaging parameters: TR=1300 ms, TE=60 ms, FOV=350×273 mm^2, matrix size=100×78, 14 slices, slice thickness/gap=5/0.25 mm, spectral fat saturation, 4 averages, bandwidth=3000 Hz/pixel, k-space based parallel imaging technique (GRAPPA) acceleration factor of two, *b*-values=0, 50, 100, 150, 200, 300, 400, 600, and 800 s/mm^2 and a total measurement time of 12 minutes. The

Table 1 Comparison of mean IVIM-parameters and ADC in AIP-examinations

	AIP initial	AIP 1st follow up	AIP 2nd follow up	p-value
mean f (%)	10.5±4.3	17.1±6.7	20.4±4.3	p<0.0001
mean D (*10^{-3} mm^2/s)	1.19±0.28	1.13±0.22	1.13±0.2	p=0.668
mean D* (*10^{-3} mm^2/s)	52.9±59.3	34.1±51.1	14.0±4.4	p=0.412
mean ADC (*10^{-3} mm^2/s)	1.28±0.18	1.34±0.25	1.38±0.24	p=0.549



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HEPATOBILIARY-PANCREAS

IVIM DW-MRI of autoimmune pancreatitis: therapy monitoring and differentiation from pancreatic cancer

Miriam Klauß[1] · Klaus Maier-Hein[2] · Christine Tjaden[3] · Thilo Hackert[3] · Lars Grenacher[1] · Bram Stieltjes[4]

- Nouvelles approches
  - Etudes non gaussiennes : Kurtosis
  - Membranes / Barrières

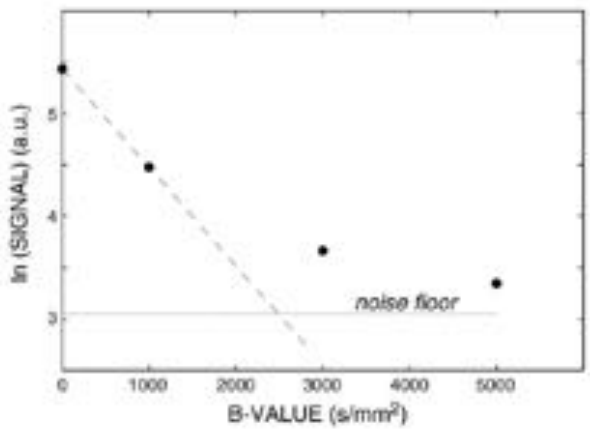


Fig. 1. Plot of the logarithm of signal decay vs. b value in a selected WM ROI belonging to the corpus callosum, averaged over all pixels. The dashed line represents the predicted mono-exponential decay at b=1000 s mm^{-2}, while the dotted line represents the noise floor, calculated as the average of the pixel intensities in a ROI outside the brain.

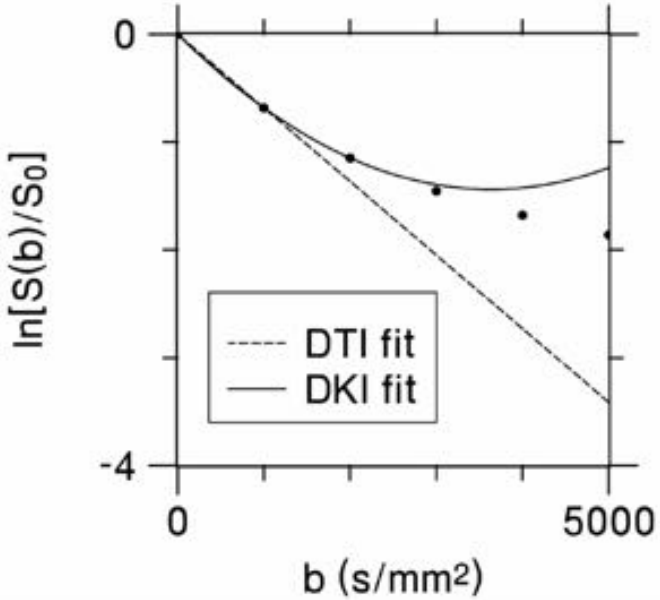
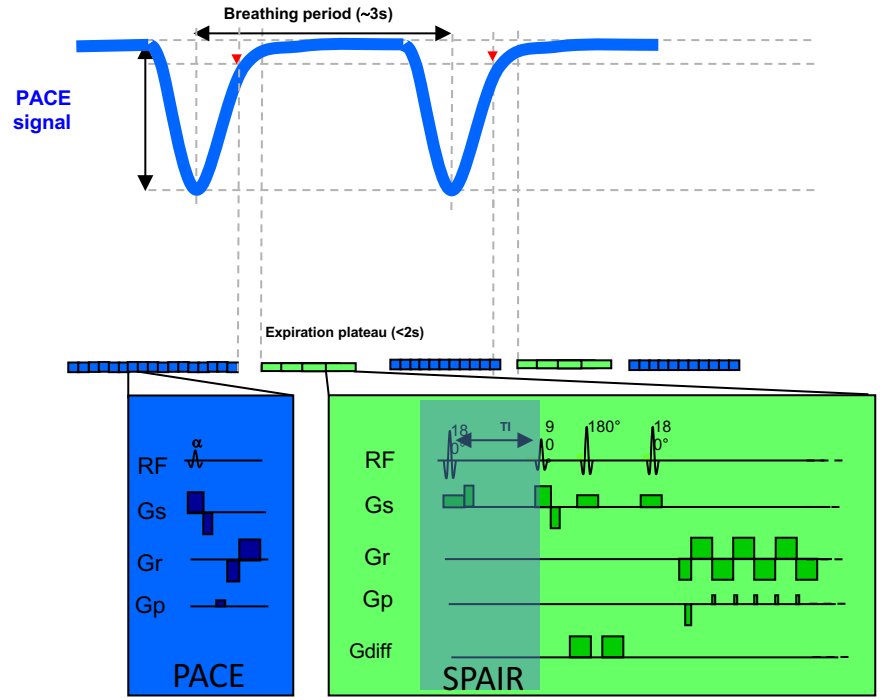


Figure 2.
Comparison of DTI and DKI fitting models. For DTI, the logarithm of diffusion-weighted signal intensity (circles) as a function of the b-value is fit, for small b-values, to a straight line. In brain, this fit is often based on the signal for $b = 0$ and $b = 1000$ s/mm^2. For DKI, the logarithm of the signal intensity is fit, for small b-values, to a parabola. In brain, this fit may be based on the signal for $b = 0$, $b = 1000$, and $b = 2000$ s/mm^2.

Key Points

Recommandations



1. Chronogramme séquence DWI

1. **Vérifier suppression de graisse**
2. **Vérifier monitoring respiratoire**
   1. **TR et fréquence respiratoire**
   2. **PACE trigger**

Courtesy: Dr Alexandre Vignaud, PhD
UNIRS, I2BM, CEA, Neurospin

Simplified diagram of hepatic Single-Shot Echo-Planar-Imaging sequence (SS EPI).

- *Respiratory trigger using PACE (Prospective Acquisition CorrEction) for the respiration.*
- *During the expiration plateau as many as possible slices are acquired for a given b-value (if it is not enough concatenations are used).*
- *Fat Saturation is done using a SPAIR (SPectral Adiabatic Inversion Recovery) preparation and Inversion Time (TI) 230ms (at 3T).*

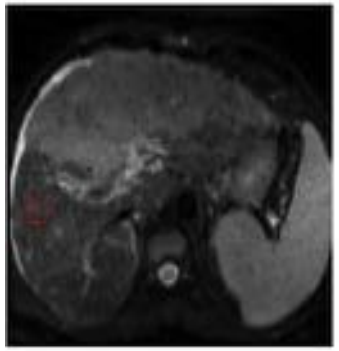
Key Points

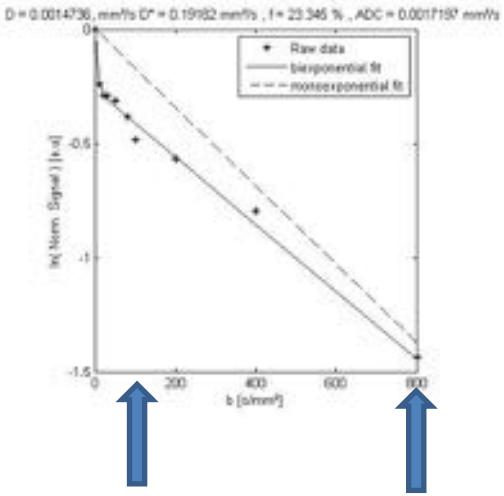
Recommandations

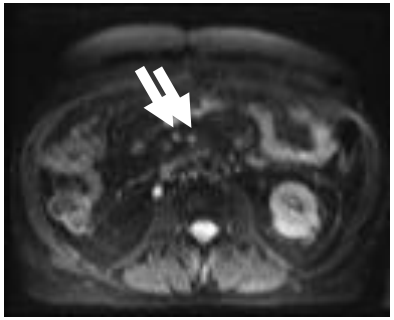
2. **Comment otimiser les séquences**

   1. **Choix des valeurs de b**
   2. Optimiser RSB
   3. Compromis…

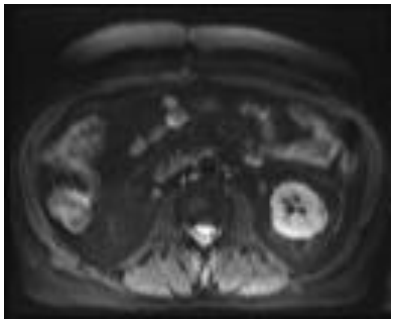
- Au moins 2 valeurs de b
  - b faible ➔ Détection ➔ 50 s/mm^2
  - b élevé➔ Characterization ➔ 800 s/mm^2
- Ou IVIM
  - Multiples valeurs de b values < et > 100 s/mm^2







b = 0 s/mm2



b = 50 s/mm2

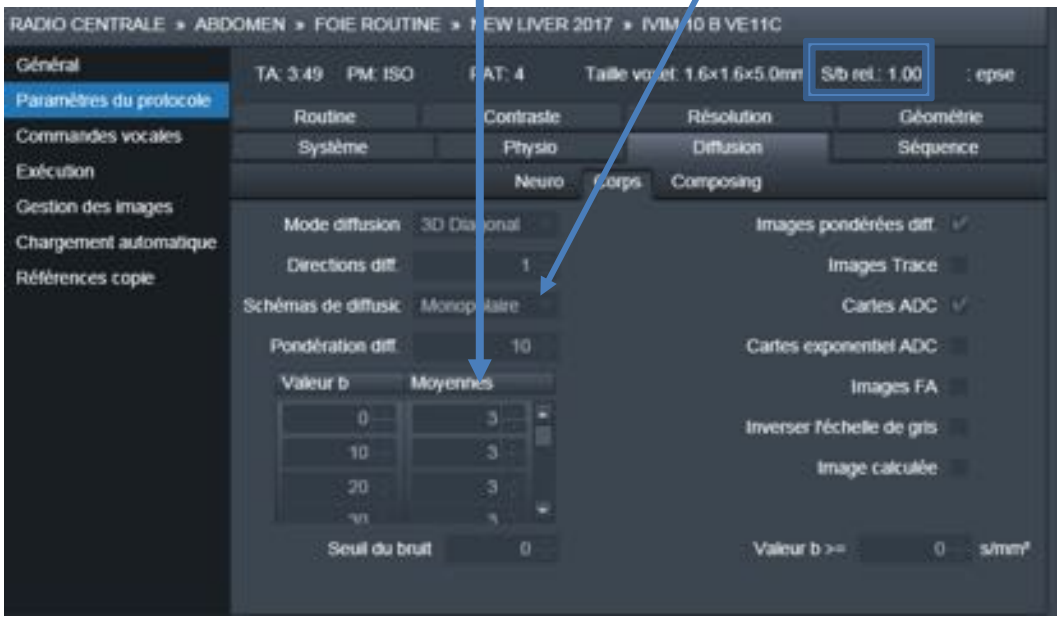
Recommandations

2. **Comment otimiser les séquences**

   1. Choix des valeurs de b
   2. **Optimiser RSB**
   3. Compromis…

Courtesy: Dr Alexandre Vignaud, PhD
UNIRS, I2BM, CEA, Neurospin

- Champ magnétique
  - 3 T > 1.5T
- Antennes
  - Surface
  - Canaux multiples
- Nb excitations variable pour chaque valeur d b
- Acquisitions monopolaires ➔ Reduit TE ➔ augmente SNR



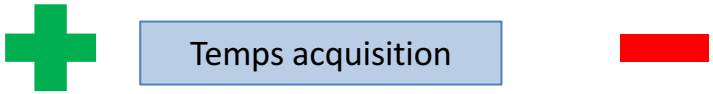
Recommandations

- ❑ Conserver résolution spatiale
- ❑ reduction de durée du train EPI ➔ Reduit distorsion ➔ augmente bande passante

- ❑ Augmenter résolution spatiale ➔ Durée train EPI plus longs ➔ Distorsion
- ❑ Augmentation de bande passante ➔ Réduit RSB

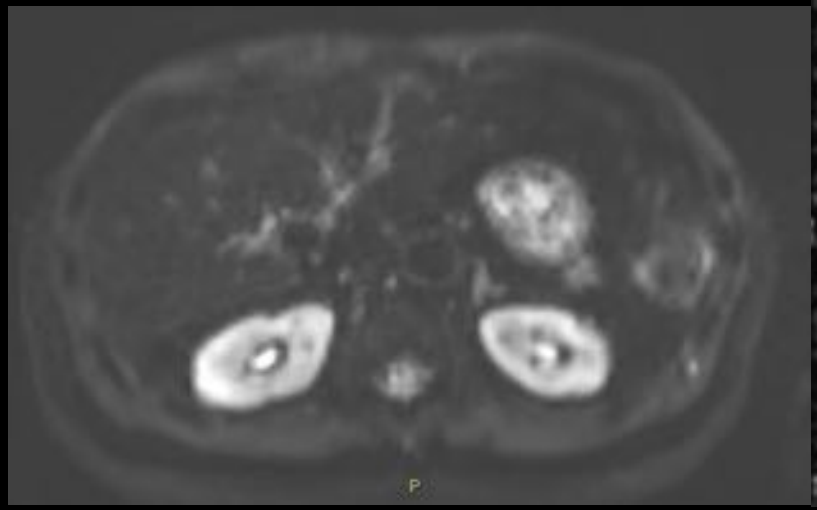
2. Comment otimiser les séquences

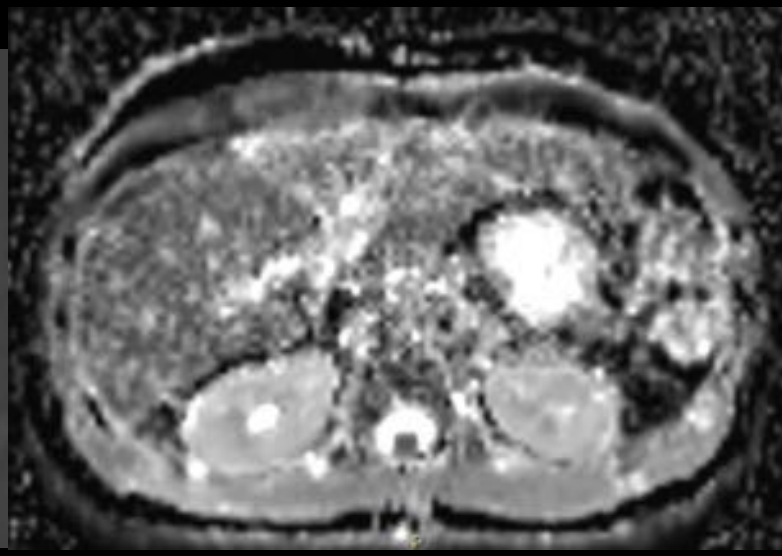
1. Choix des valeurs de b
2. Optimiser RSB
3. **Compromis**…



Siemens MRI
Verio 3T

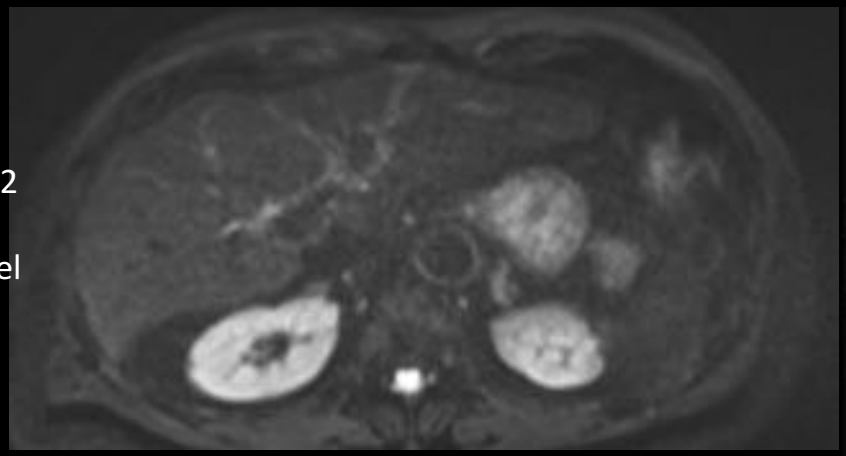
- b 800s/mm2
- 32 channel
- iPAT 2
- ADC maps

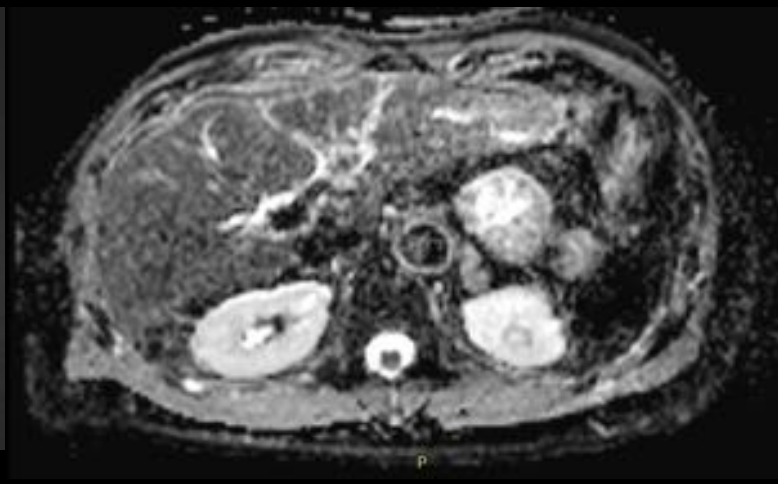




Siemens MRI
Skyra 3T

- b 800s/mm2
- 60 Channel
- Caipi parallel
- SMS
- ADC Maps



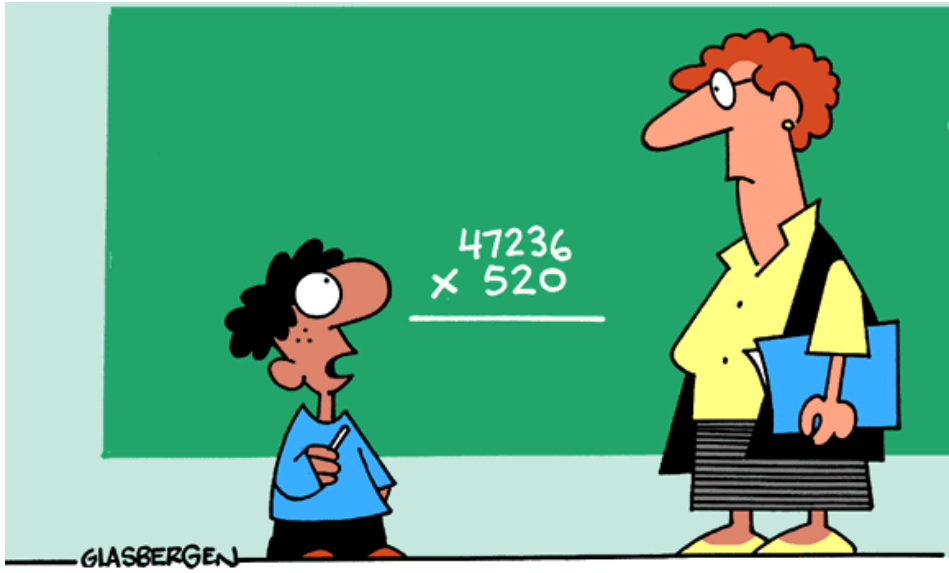


Messages

- Instrumentation
- Instrumentation
- Instrumentation

Applications cliniques

- Pas encore définies ….
- Standardisation ?
- Sélectionner études cliniques adaptées….



"AREN'T THERE ENOUGH PROBLEMS IN THE WORLD ALREADY?"