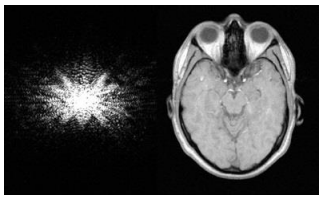
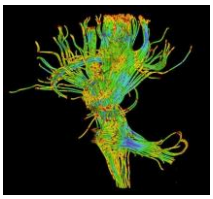
DFGSM2 2018-2019
UE Biopathologie - Imagerie

Compléments de RMN

Formation de l'image
Séquences d'acquisition





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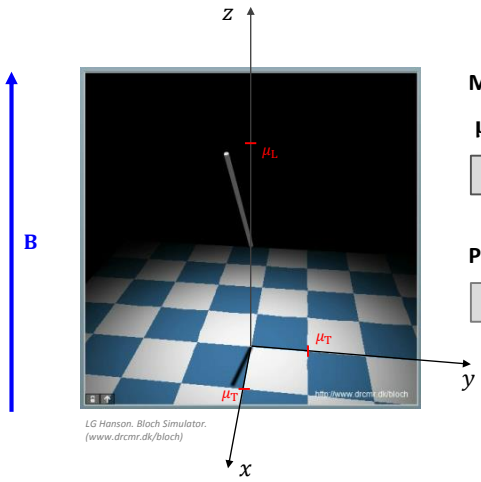
http://scinti.edu.umontpellier.fr/enseignements/cours/

Rappels PACES

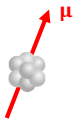


LG Hanson. Bloch Simulator. (www.drcmr.dk/bloch)

Moment magnétique du proton :

$\boldsymbol{\mu} = \gamma \mathbf{J}$

$\bar{\gamma} = 42{,}6 \text{ MHz T}^{-1}$

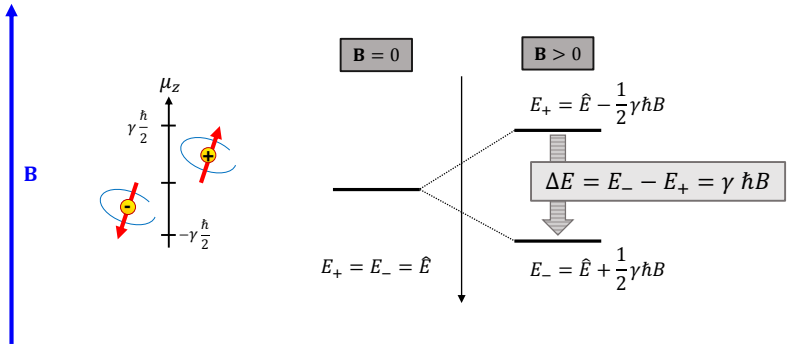


Précession de Larmor :

$\boldsymbol{\omega} = \gamma \mathbf{B}$

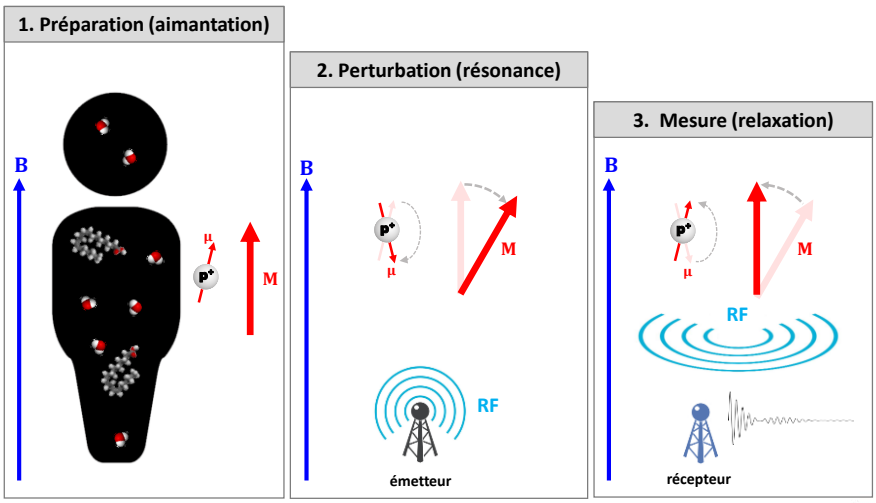
Rappels PACES

Levée de dégénérescence énergétique (effet Zeeman)



Rappels PACES

Séquence de RMN

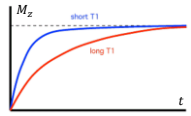


Rappels PACES

1. Préparation (aimantation)

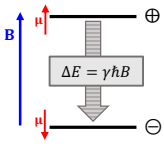
Précession de Larmor : $\omega_0 = \gamma B_0$

Alignement sur le champ
- **Aimantation longitudinale M_z**
- **Cinétique exponentielle T_1**

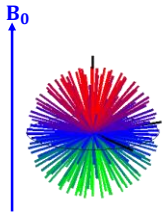


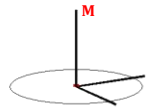
$$M_z(t) = M_L\left(1 - e^{-t/T_1}\right)$$

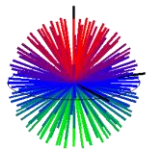
- **Echanges énergétiques :** $E = -\boldsymbol{\mu} \cdot \mathbf{B}$

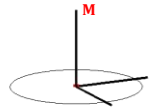


$\langle \wp(\oplus) \rangle > \langle \wp(\ominus) \rangle$









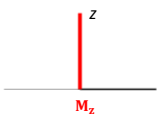
Rappels PACES

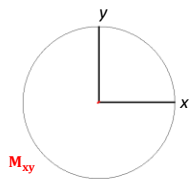
2. Perturbation (résonance)

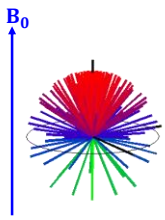
Application d'un champ tournant B_1
- **de** fréquence $\omega_0/2\pi$
- **pendant une durée** τ **(~ms)**

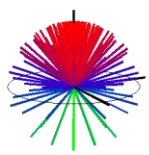
Précession de M autour de B_1
- $\omega_1 = \gamma B_1$
- **Bascule (nutation) d'un angle** $\eta = \tau\ \omega_1$

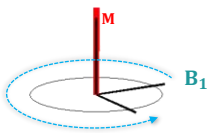
Disparition de M_z
Apparition de M_{xy} (aimantation transverse)

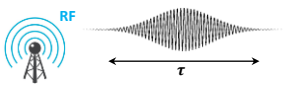


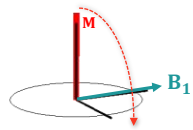










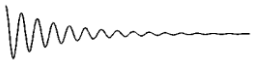


Rappels PACES

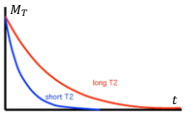
3. Mesure (relaxation)

Arrêt de la stimulation RF B_1

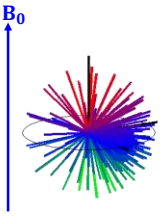
Signal = M_x

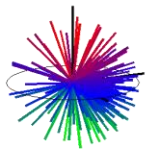


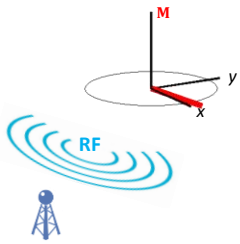
- Déphasage progressif
- Inhomogénéités de champ
- Phénomène entropique
- Cinétique T_2

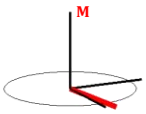


$$M_{xy}(t) = M_T\, e^{-t/T_2}$$









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3. Mesure (relaxation)

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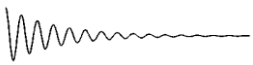
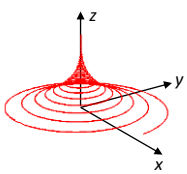
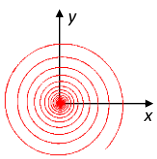
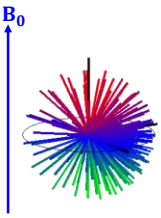


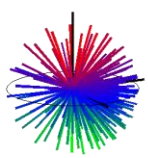
Disparition de M_{xy}
Repousse de M_z

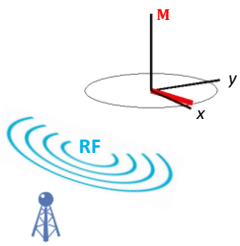
Dans les tissus biologiques : $T_1 \sim 10\ T_2$

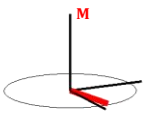








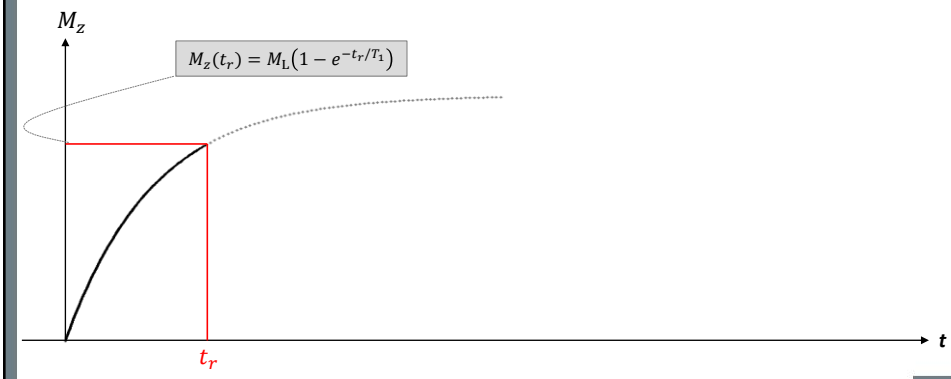




Rappels PACES

Préparation

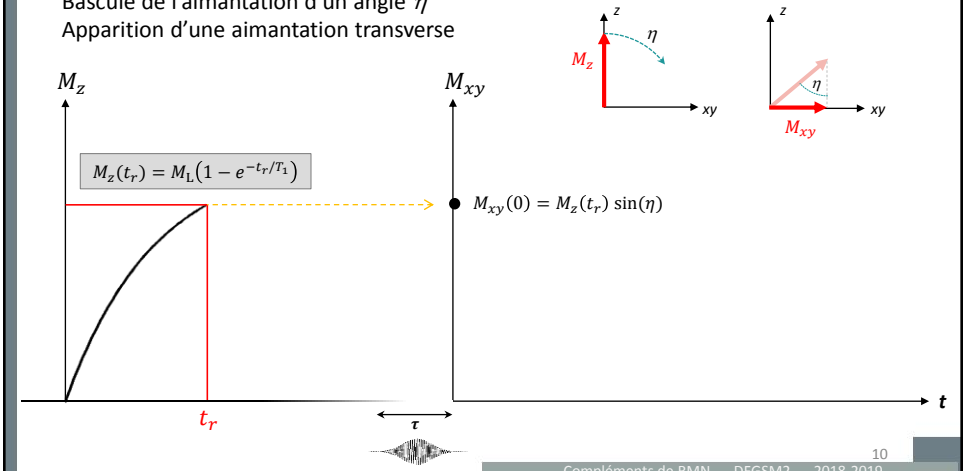
Aimantation longitudinale dans B_0
Relaxation T_1
Durant un temps t_r (temps de répétition)



Rappels PACES

Préparation **RF**

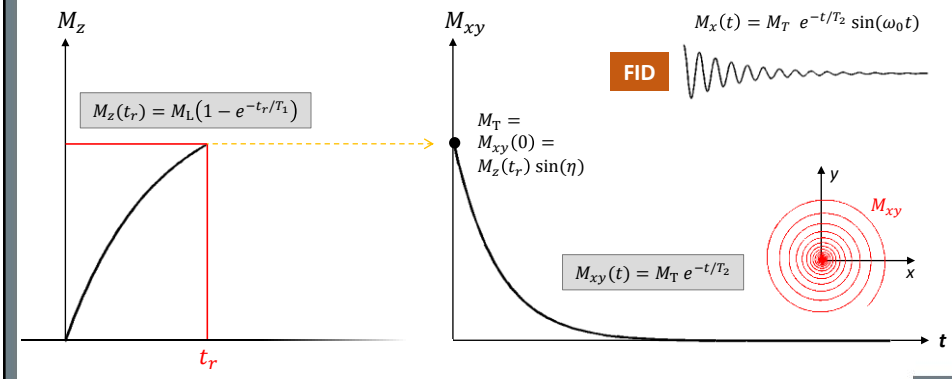
Stimulation RF durant un temps τ
Bascule de l'aimantation d'un angle η
Apparition d'une aimantation transverse



Rappels PACES

Préparation | RF | Mesure

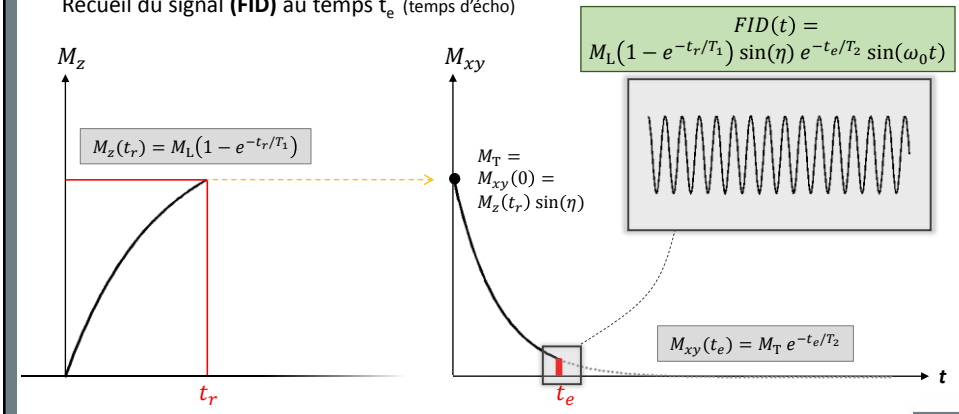
Retour à l'équilibre
Relaxation T_2



Rappels PACES

Préparation | RF | Mesure

Retour à l'équilibre
Relaxation T_2
Recueil du signal **(FID)** au temps t_e (temps d'écho)



Rappels PACES

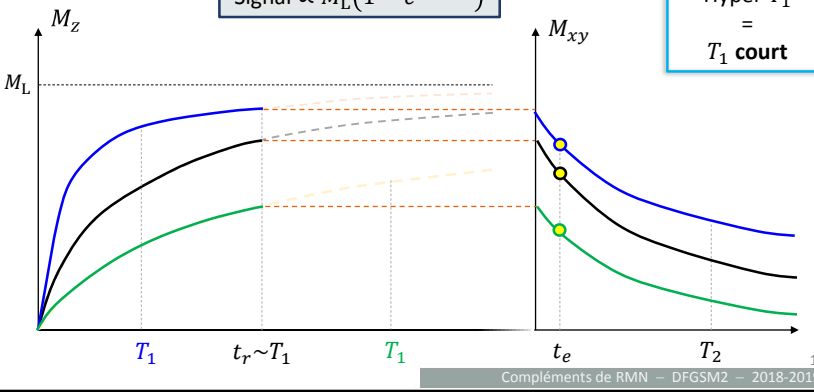
Pondération T_1

$t_r \sim T_1$
$t_e \ll T_2$

$$FID(t) = M_L\left(1 - e^{-t_r/T_1}\right) \sin(\eta)\, e^{-t_e/T_2} \sin(\omega_0 t)$$

Signal $\propto M_L\left(1 - e^{-t_r/T_1}\right)$

Hyper-T_1 = T_1 **court**



Rappels PACES

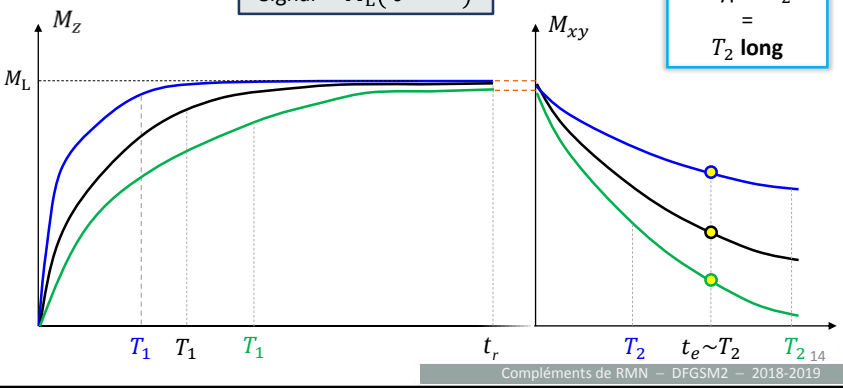
Pondération T_2

$t_r \gg T_1$
$t_e \sim T_2$

$$FID(t) = M_L\left(1 - e^{-t_r/T_1}\right) \sin(\eta)\, e^{-t_e/T_2} \sin(\omega_0 t)$$

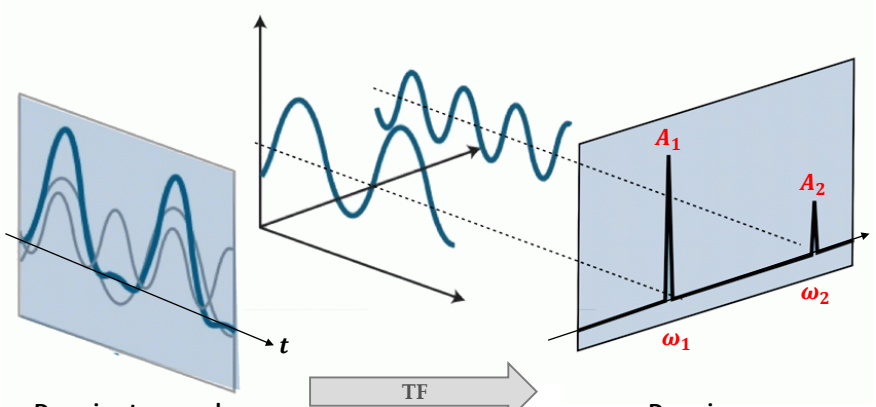
Signal $\propto M_L\left(e^{-t_e/T_2}\right)$

Hyper-T_2 = T_2 **long**



Rappels PACES

Transformée de Fourier (TF)



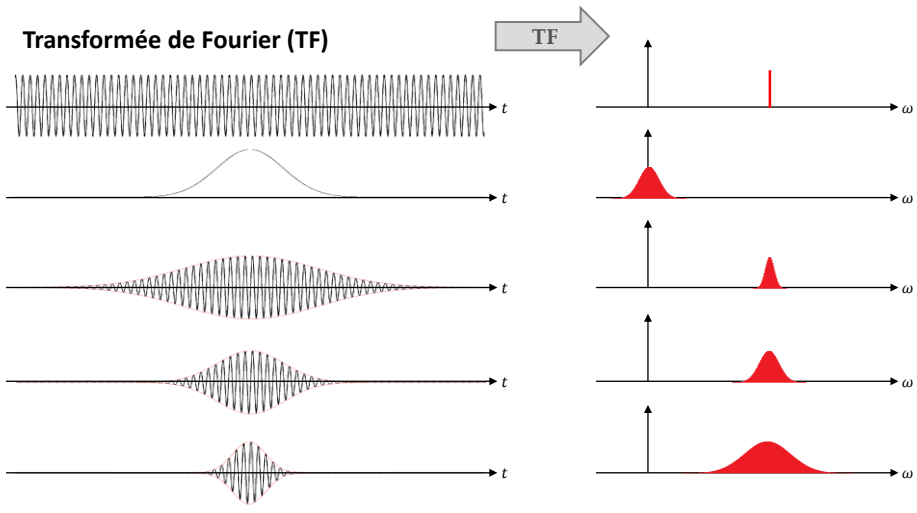
Domaine temporel :

$$f(t) = \sum A_i \, sin(\omega_i t)$$

Domaine fréquentiel : $F(\omega)$

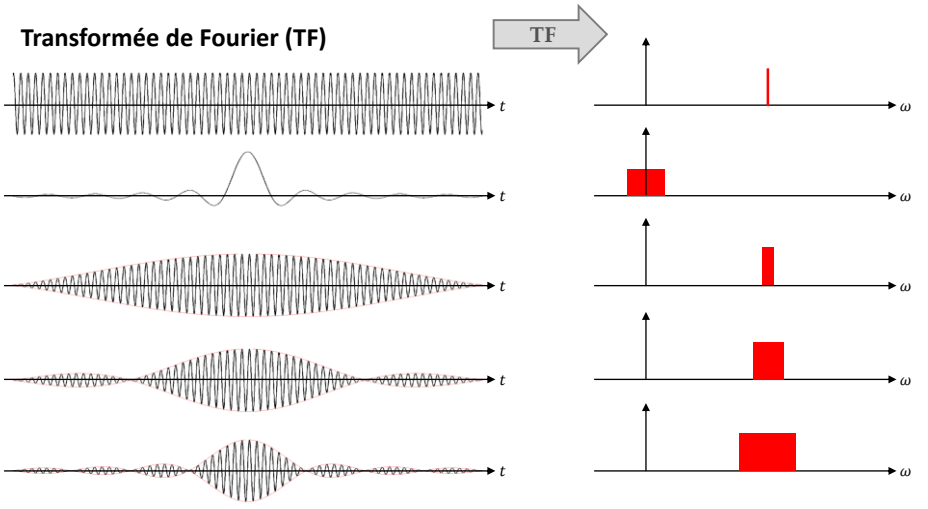
Rappels PACES

Transformée de Fourier (TF)



Rappels PACES

Transformée de Fourier (TF)



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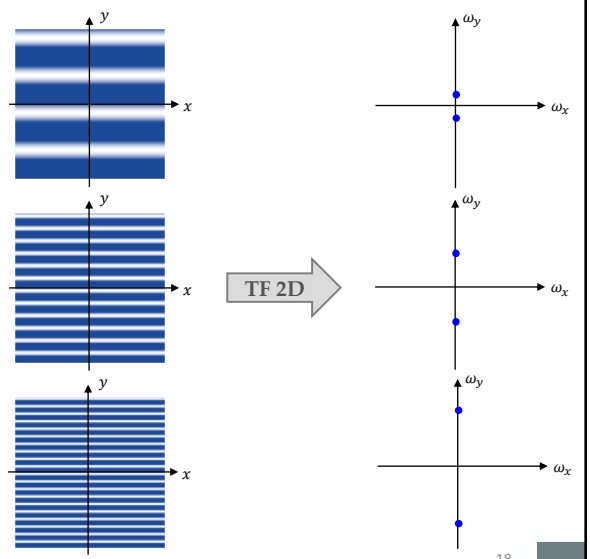
Rappels PACES

Transformée de Fourier (TF)



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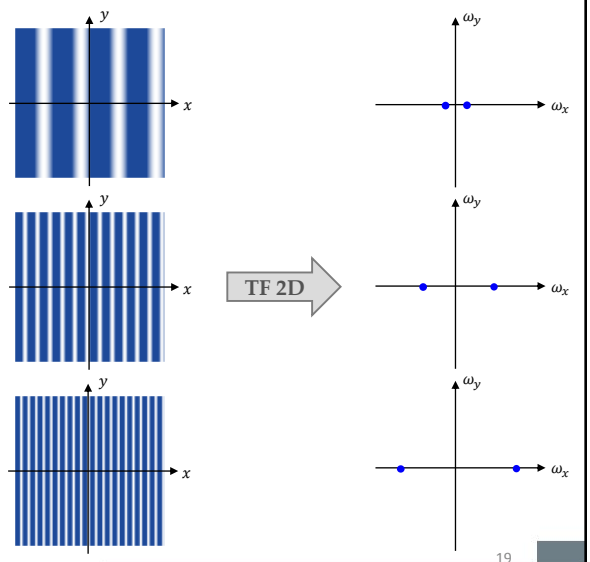
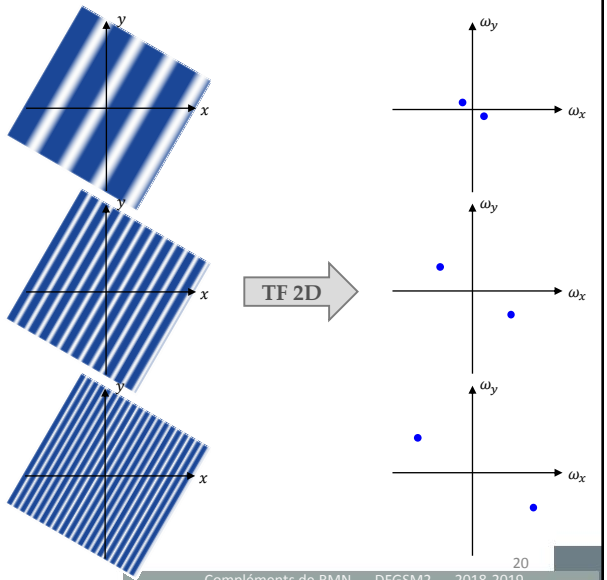
Rappels PACES

Transformée de Fourier (TF)



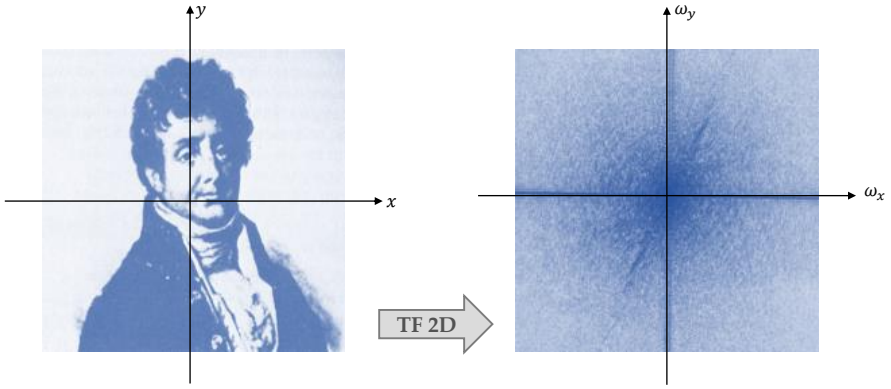
Rappels PACES

Transformée de Fourier (TF)

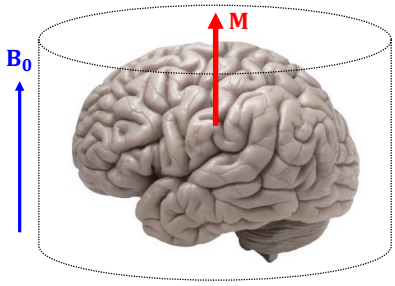


Rappels PACES

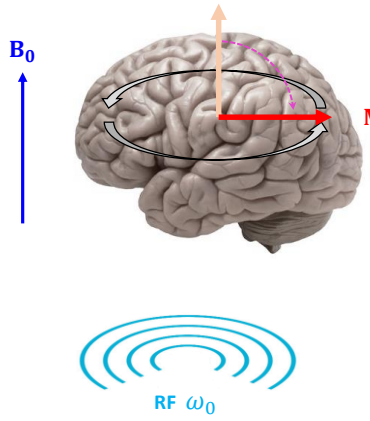
Transformée de Fourier (TF)



Formation de l'image

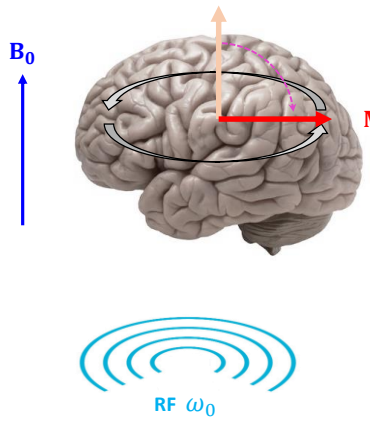


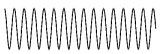
Formation de l'image



FID $\propto M \sin(\omega_0 t)$

Formation de l'image

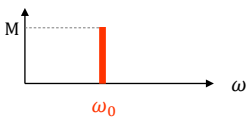




FID $\propto M \sin(\omega_0 t)$

TF

Spectre (**FID**)



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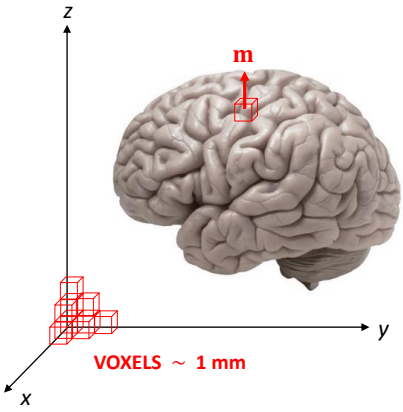
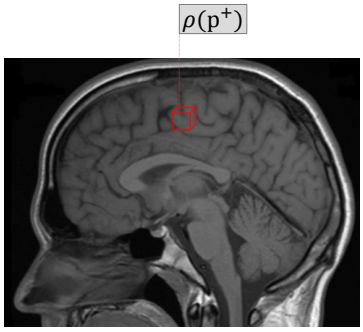
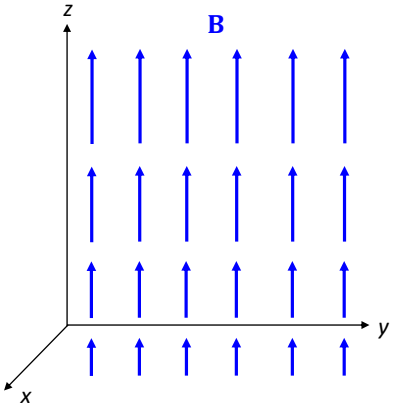




Formation de l'image

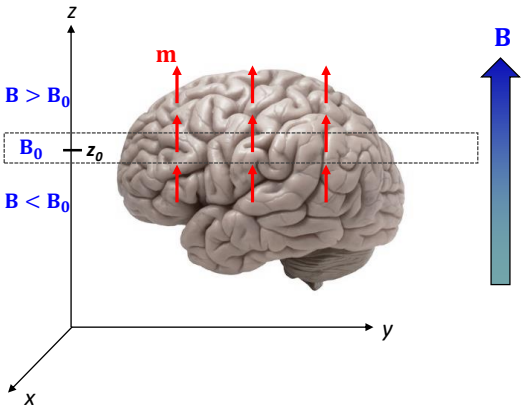


B variable *(gradient d'encodage)*

$$\mathbf{B} = \mathbf{B_0} + \mathbf{G_E}\,(z - z_0)$$

$$\mathbf{G_E} = \frac{\mathbf{dB}}{\mathbf{d}z}$$

Formation de l'image



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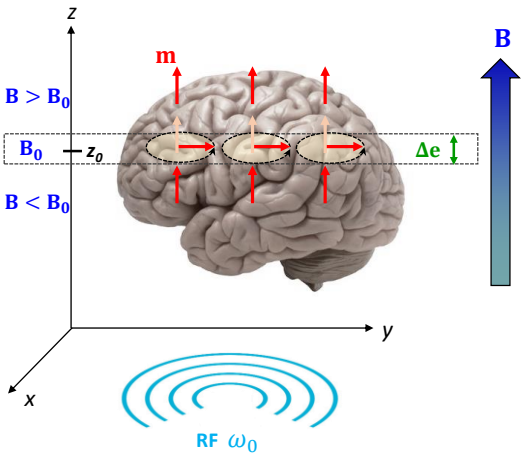
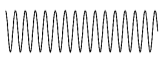
$$\mathbf{G_E} = \frac{\mathbf{dB}}{\mathbf{dz}}$$

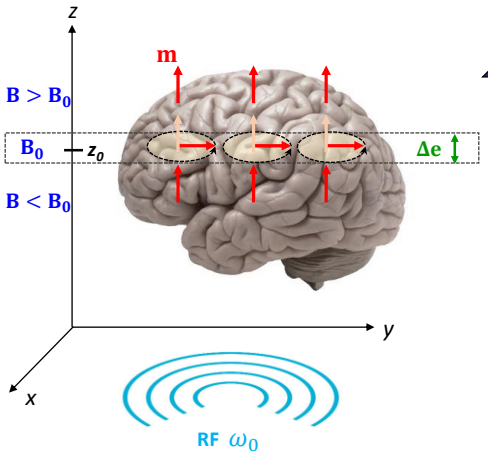
Formation de l'image





FID $\propto m_0 \sin(\omega_0 t)$

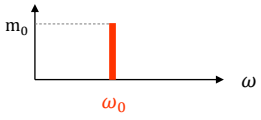
Formation de l'image



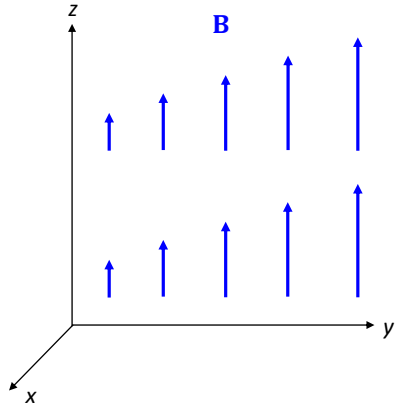
$$\text{FID} \propto m_0 \sin(\omega_0 t)$$

TF

Spectre (**FID**)



Formation de l'image



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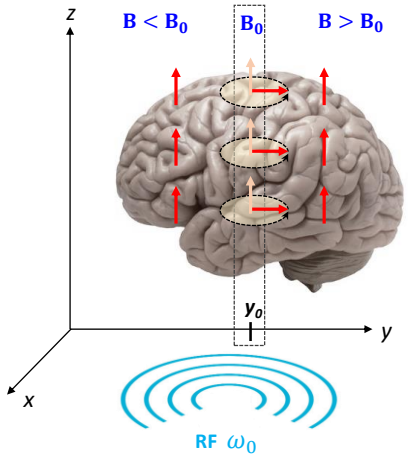
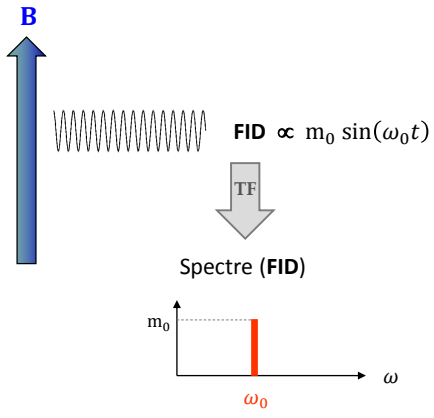
Formation de l'image





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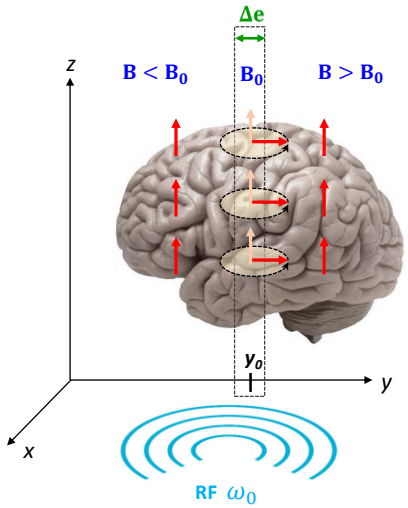
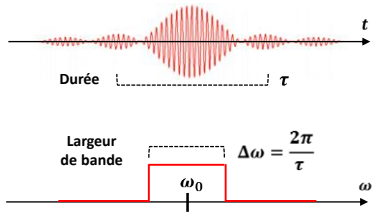


Impulsion radiofréquence



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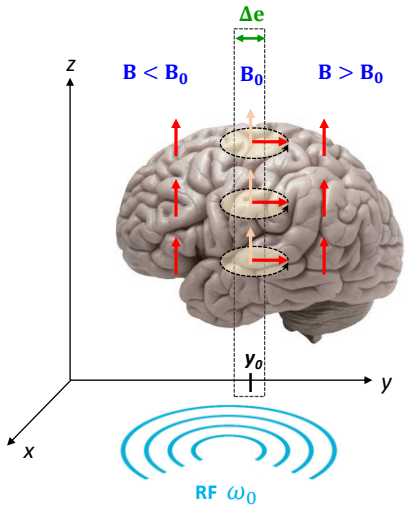
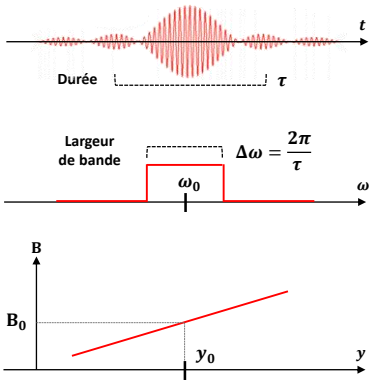
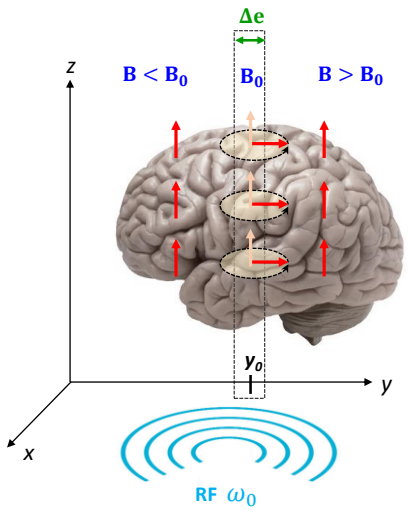


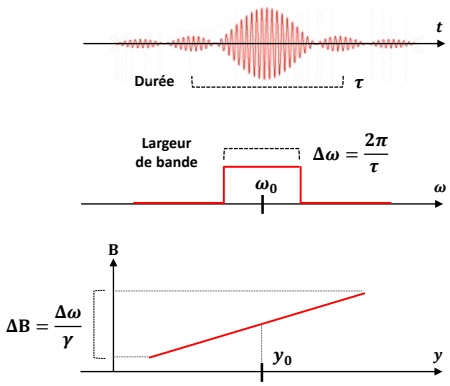
Impulsion radiofréquence



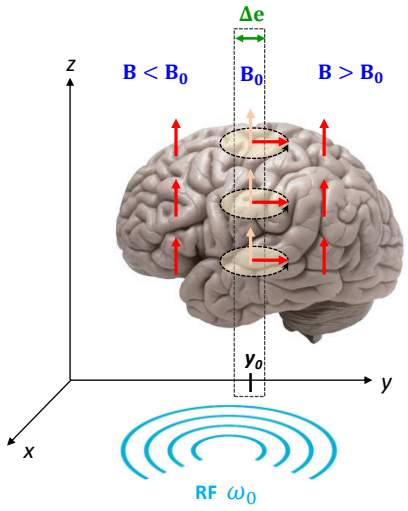
Formation de l'image



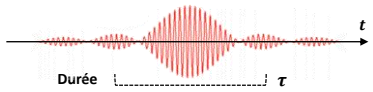
Impulsion radiofréquence

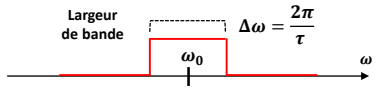


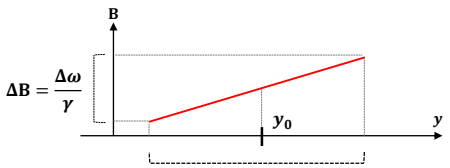
Formation de l'image



Impulsion radiofréquence



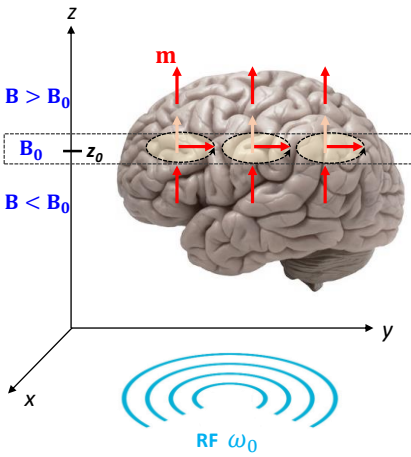


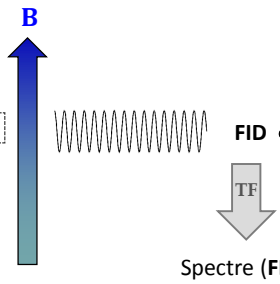


Epaisseur de coupe

$$\Delta e = \frac{\Delta B}{G_E} = \frac{2\pi}{\tau\,\gamma\,G_E}$$

Formation de l'image

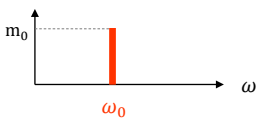




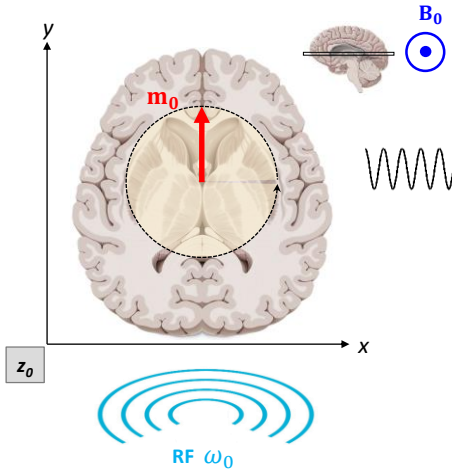
$$\text{FID} \propto m_0 \sin(\omega_0 t)$$

TF

Spectre (**FID**)



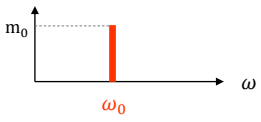
Formation de l'image



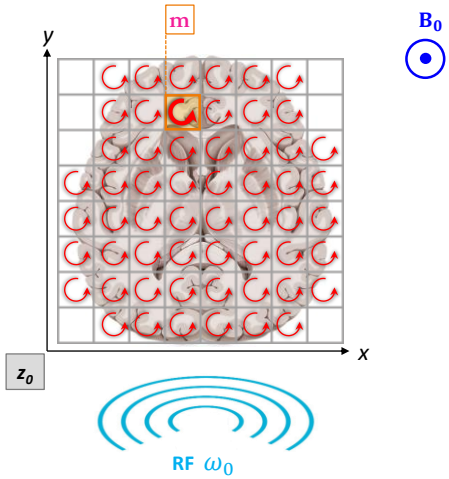
FID ∝ $m_0 \sin(\omega_0 t)$

TF

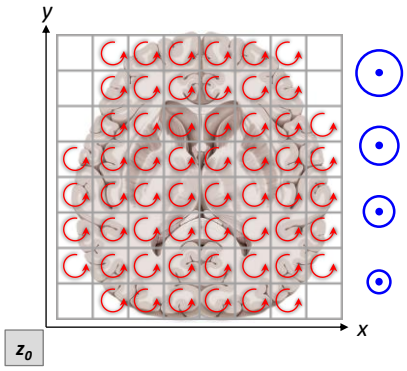
Spectre (**FID**)



Formation de l'image



Formation de l'image

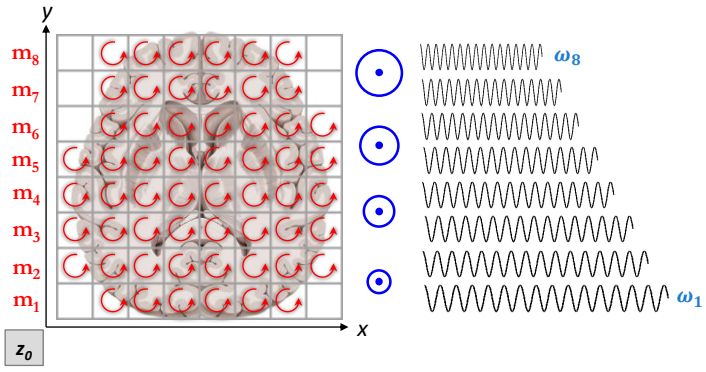


B variable *(gradient de lecture)*

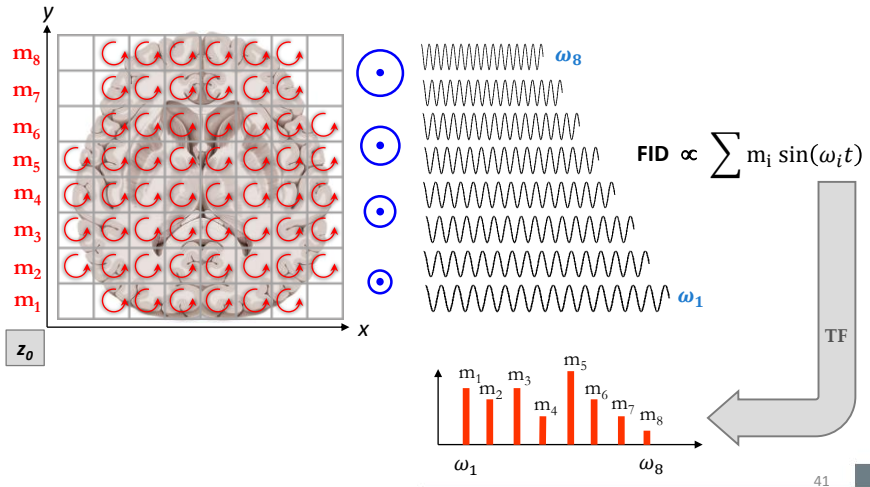
$$\mathbf{B} = \mathbf{B_0} + \mathbf{G_L}\,(y - y_0)$$

$$\mathbf{G_L} = \frac{\mathbf{dB}}{\mathbf{d}y}$$

Formation de l'image



Formation de l'image



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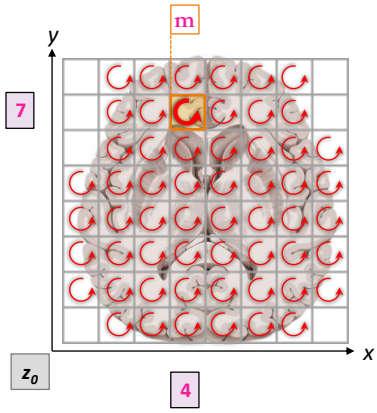

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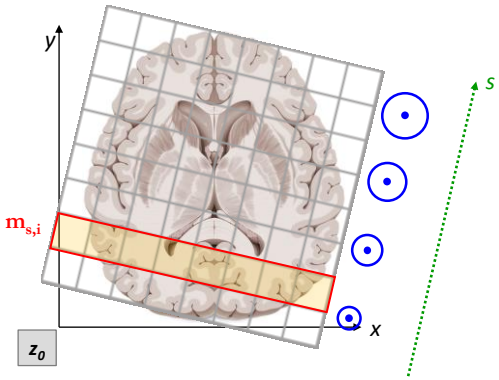

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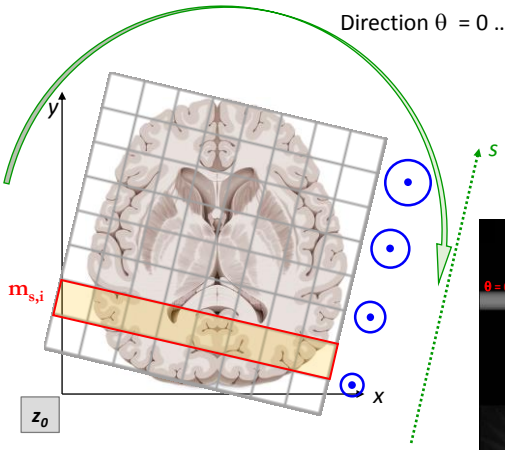
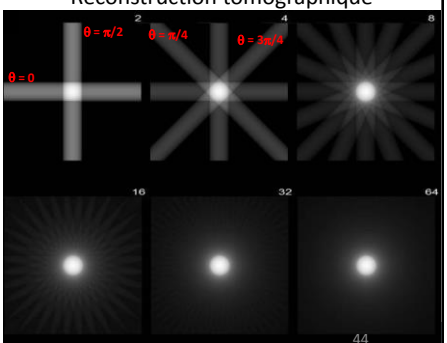
$$\mathbf{G_L} = \frac{\mathbf{dB}}{\mathbf{d}\boldsymbol{s}}$$

Formation de l'image

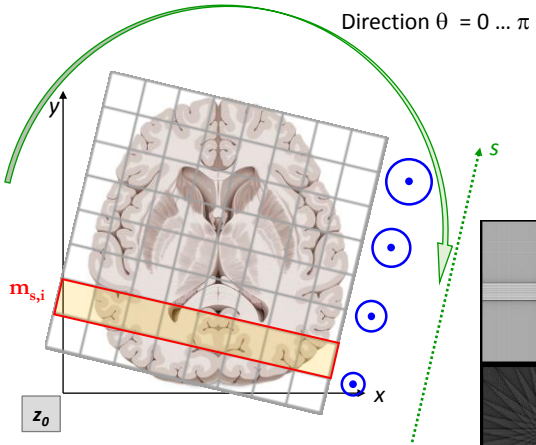
Direction θ = 0 … π



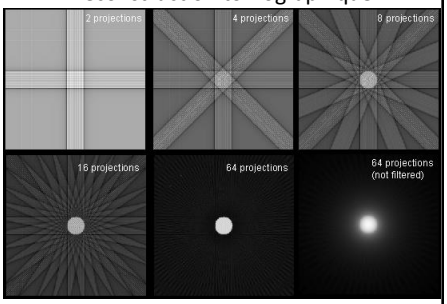
Reconstruction tomographique



Formation de l'image



Reconstruction tomographique



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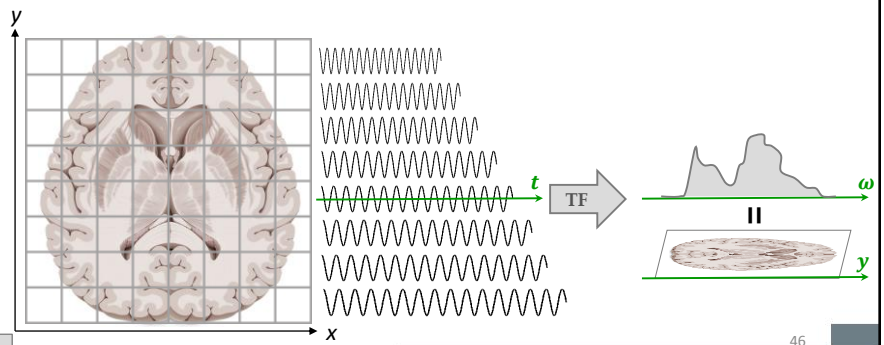
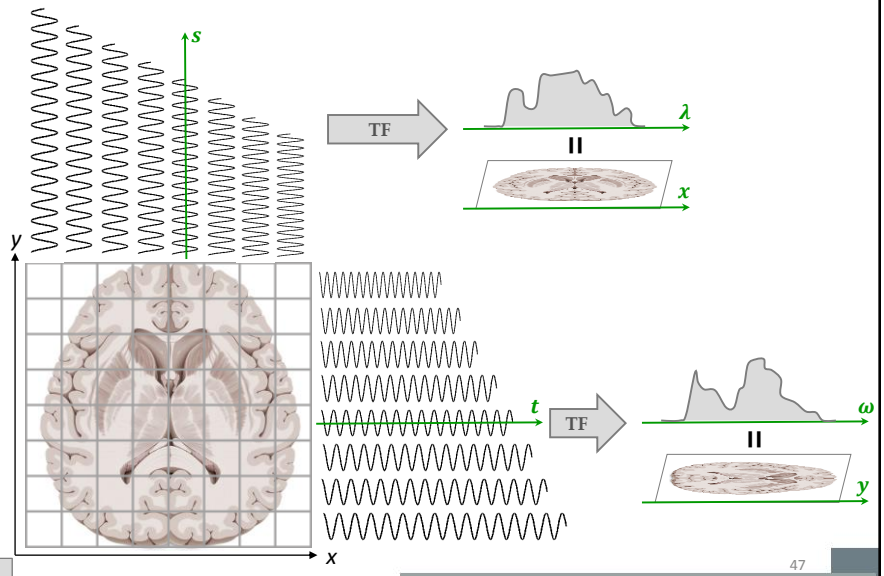


Formation de l'image



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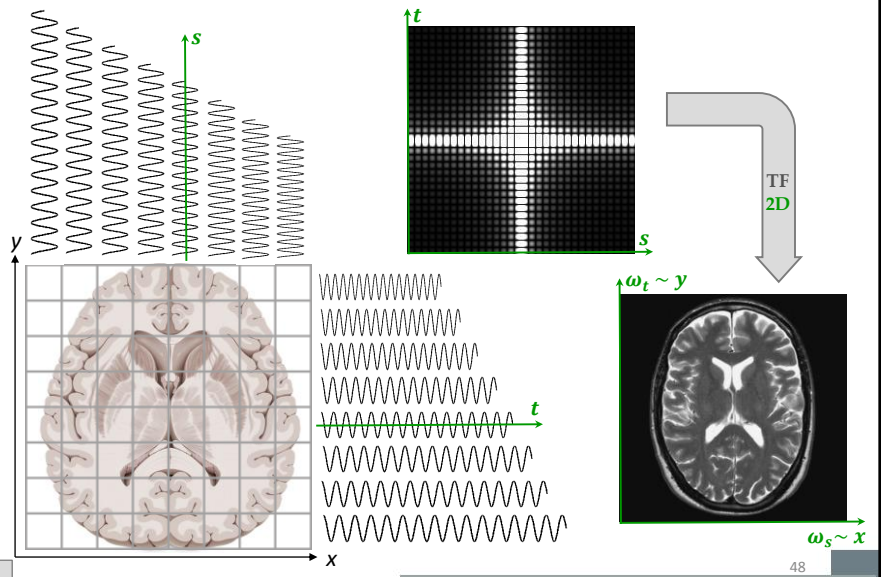

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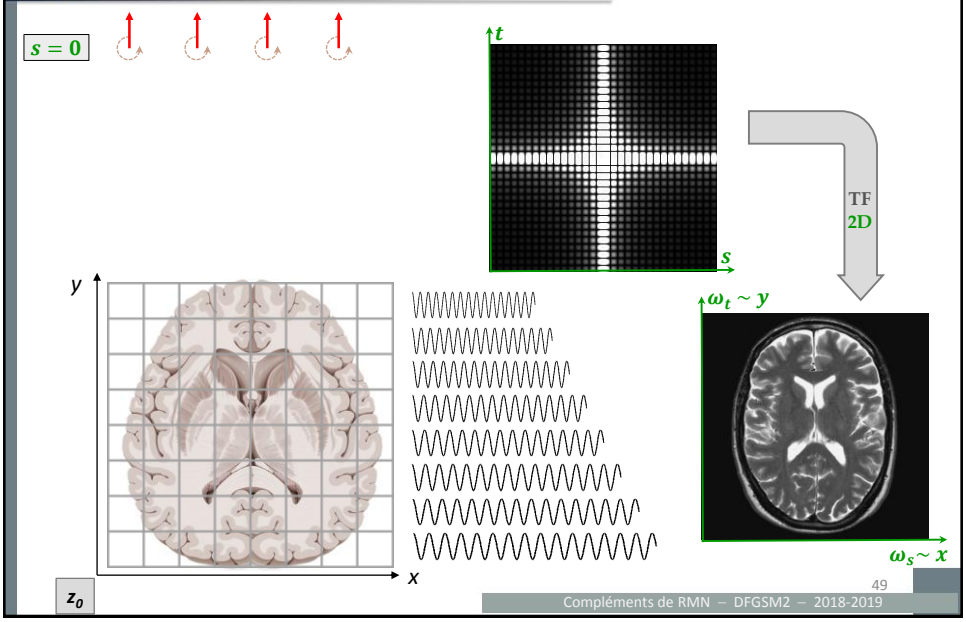

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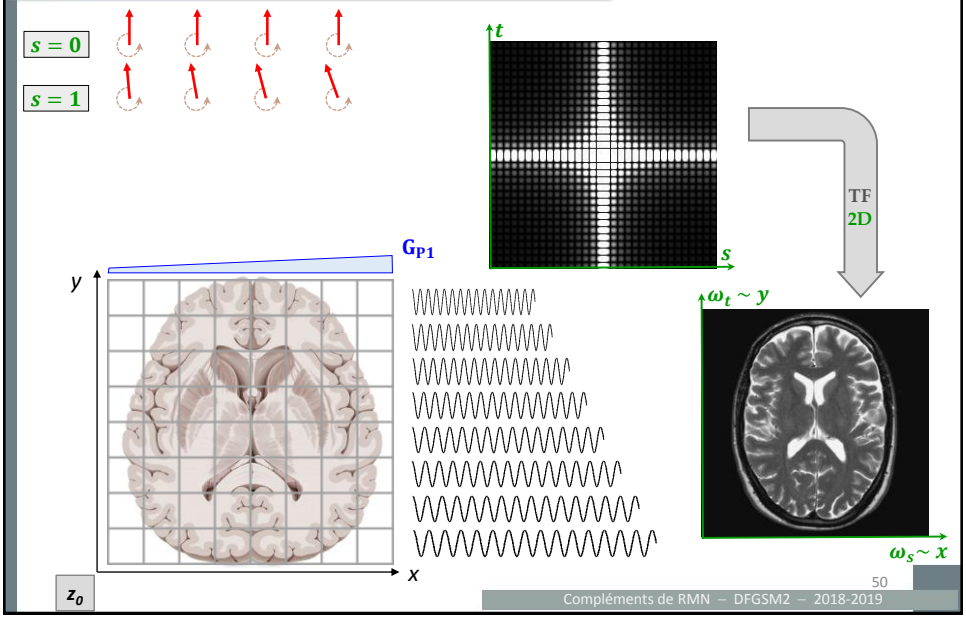

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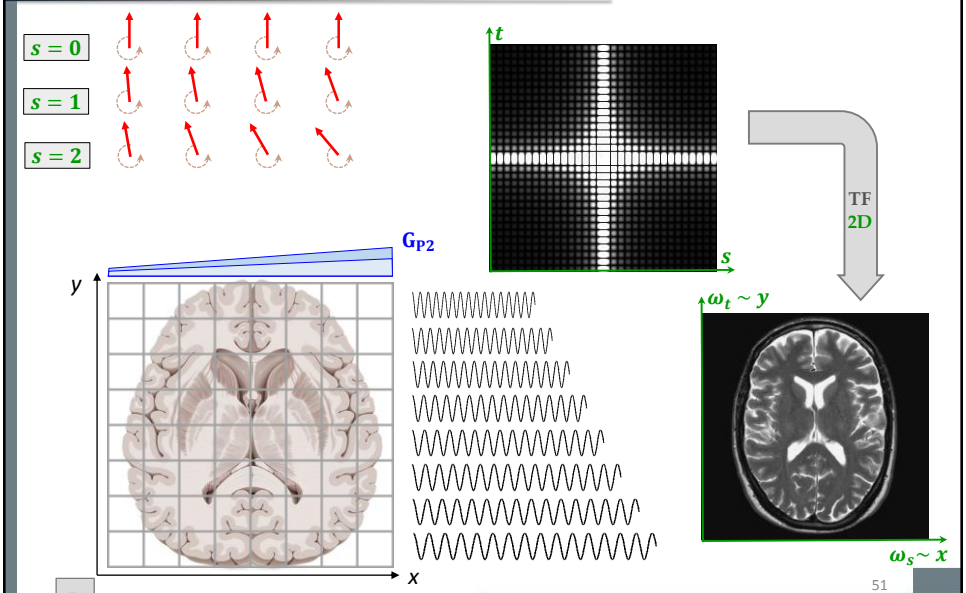

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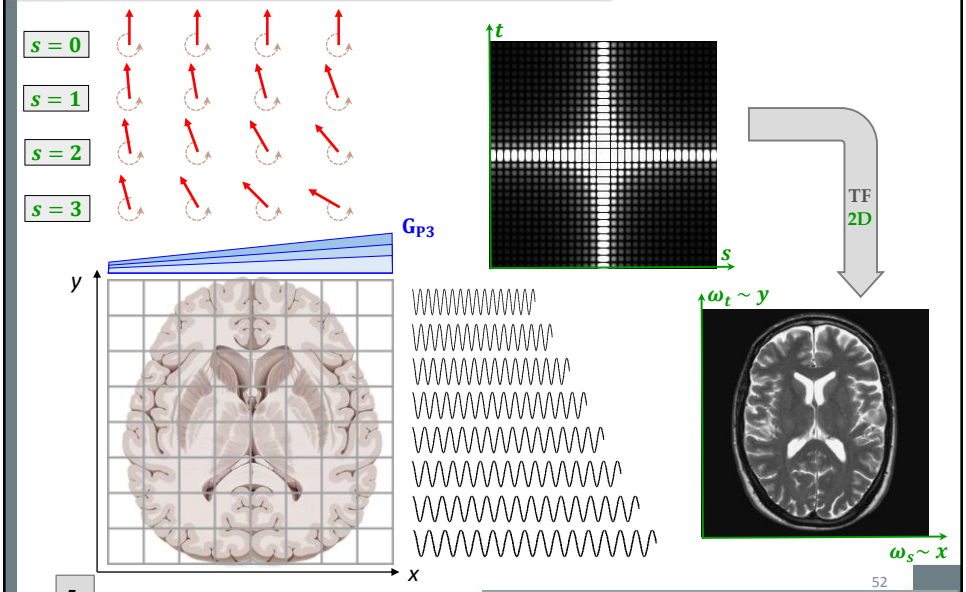

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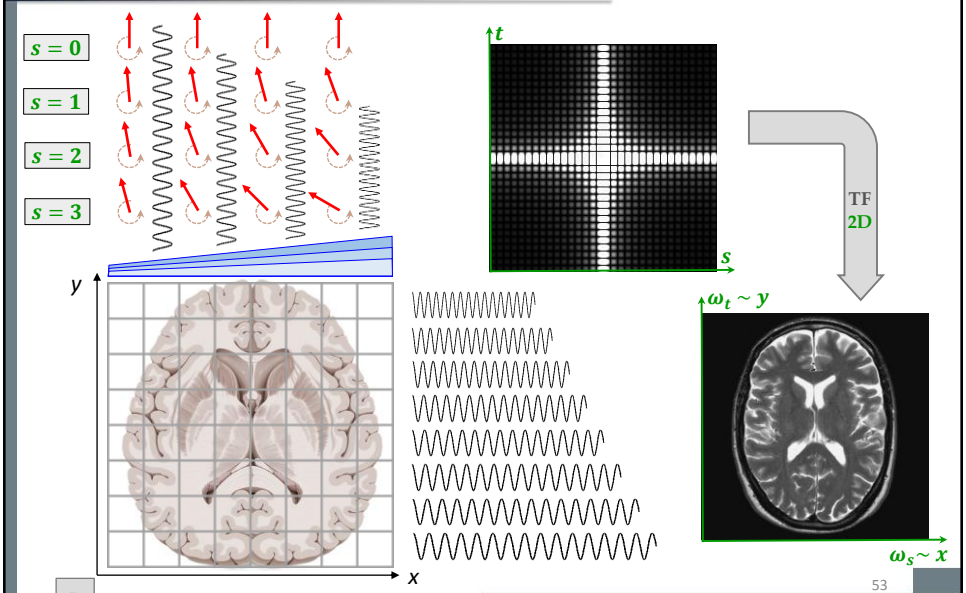

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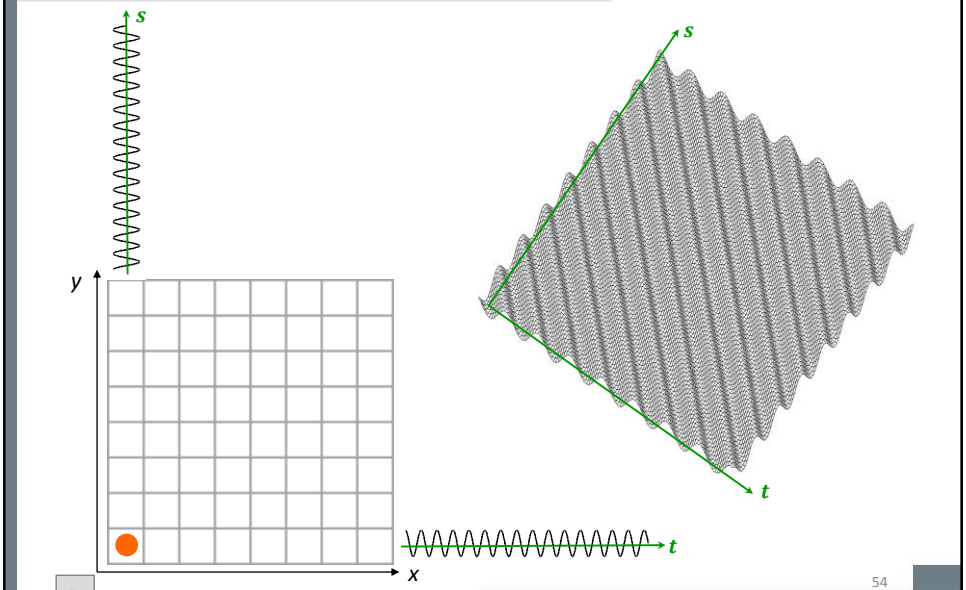

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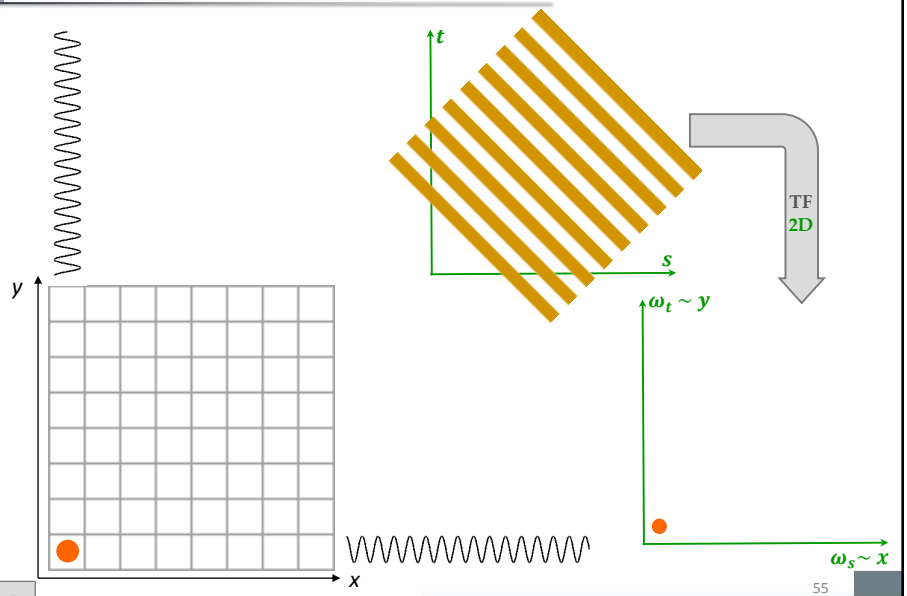

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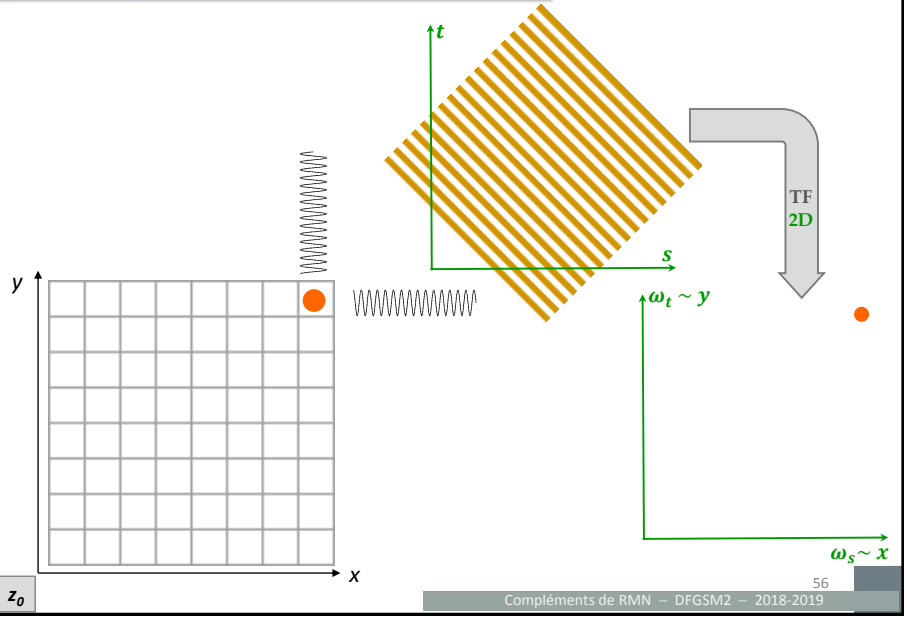

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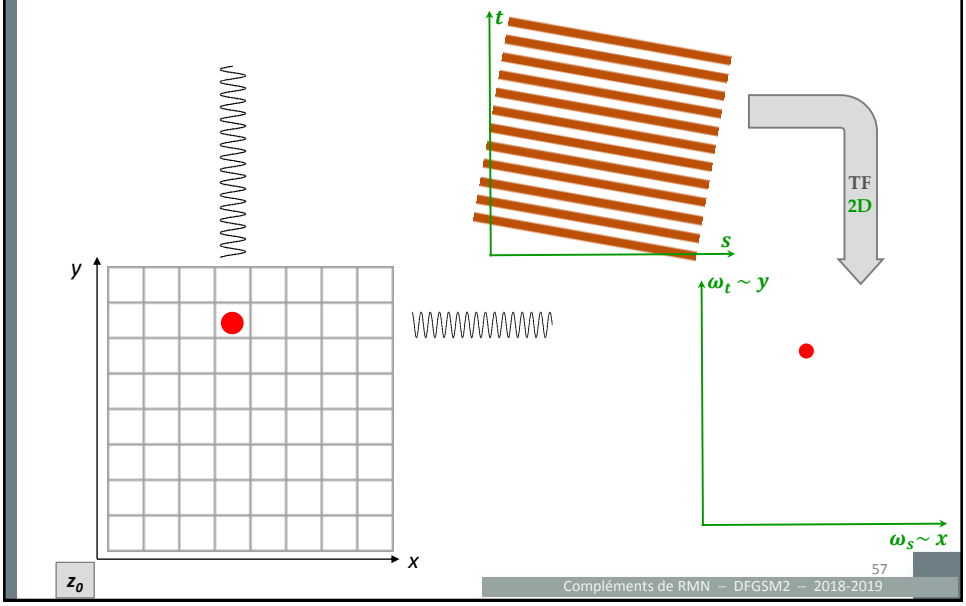

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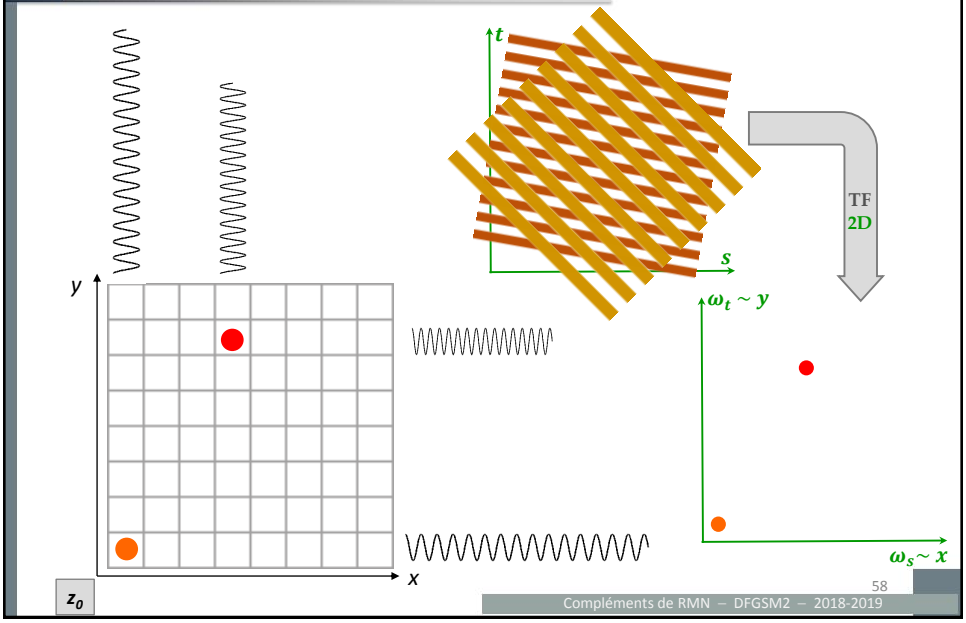

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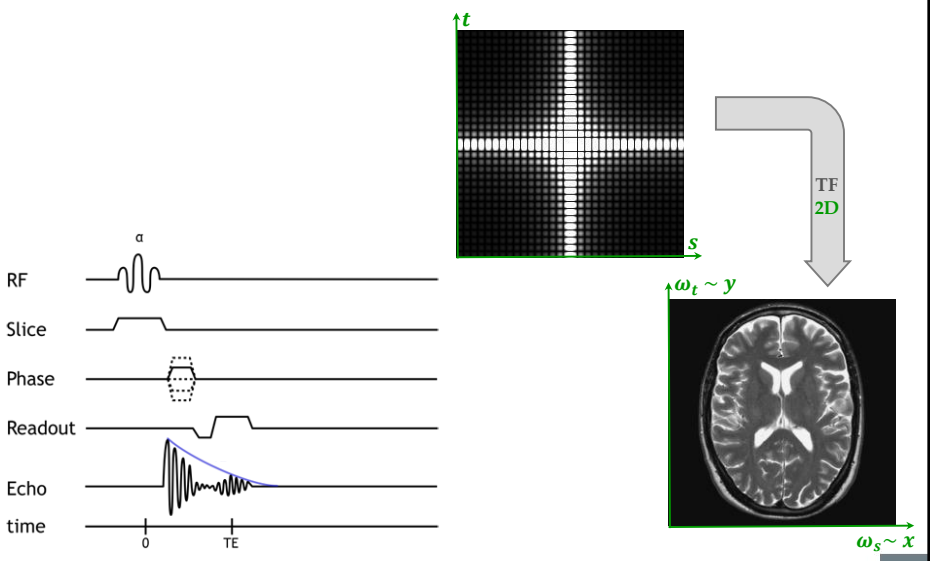
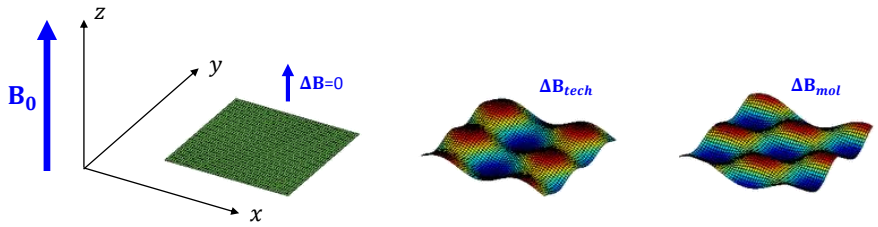


Séquences d'acquisition

Relaxation T_2

T_2 : environnement moléculaire : ΔB_{mol}

T_2^* : environnement moléculaire & inhomogénéités de champ : $\Delta B_{mol} + \Delta B_{tech}$

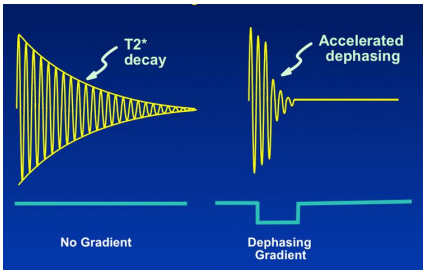


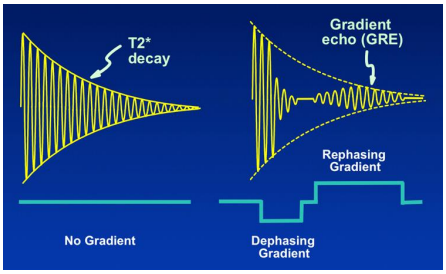
Séquences d'acquisition

Echo de gradient

T_2 : environnement moléculaire

T_2^* : environnement moléculaire & inhomogénéités de champ





Susceptibilité magnétique :

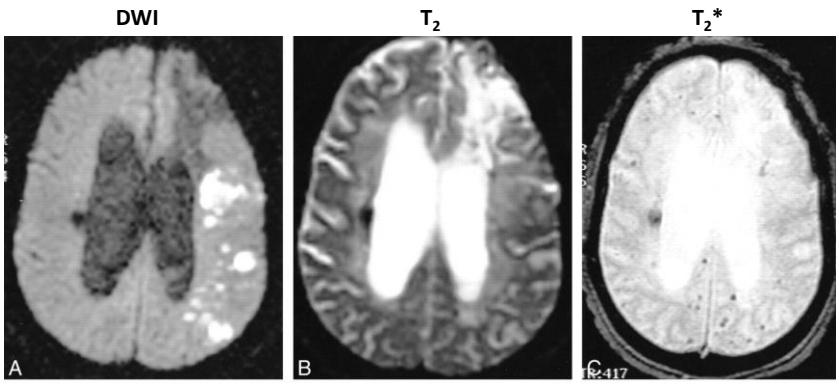
- Calcium ($\chi < 0$)
- Produits de dégradation de l'hémoglobine ($\chi > 0$)

Séquences d'acquisition

Echo de gradient

T_2 : environnement moléculaire

T_2^* : environnement moléculaire & inhomogénéités de champ



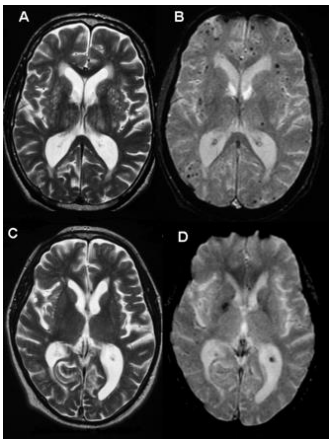
Lin et al. Am J Neuroradiol 2001

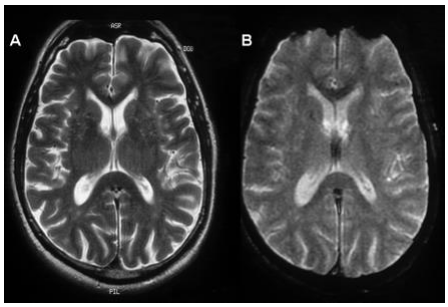
Séquences d'acquisition

Echo de gradient

T_2 : environnement moléculaire

T_2^* : environnement moléculaire & inhomogénéités de champ





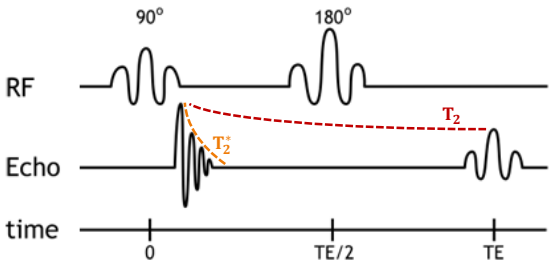
Werring et al. Brain2004

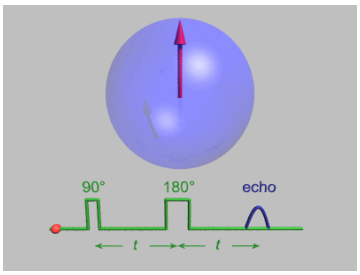
Séquences d'acquisition

Echo de spin

T_2 : environnement moléculaire

T_2^* : environnement moléculaire & inhomogénéités de champ



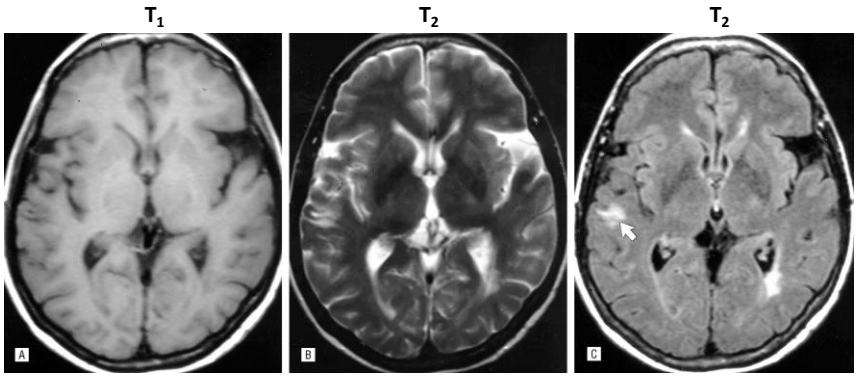


Séquences d'acquisition

Echo de spin

T_2 : environnement moléculaire

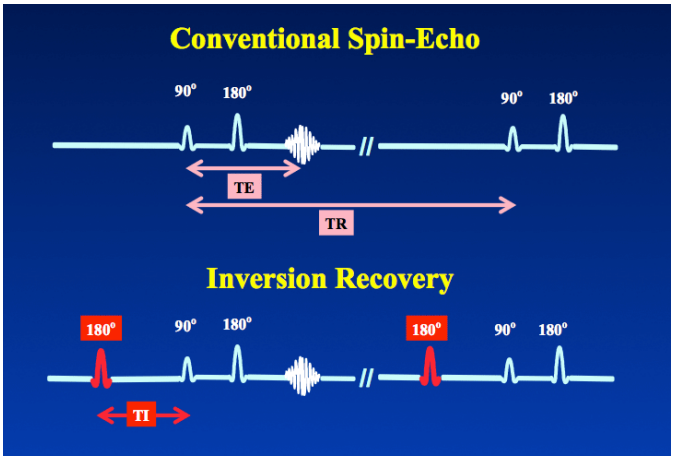
T_2^* : environnement moléculaire & inhomogénéités de champ



Bakshi et al. Arch Neurol 2001

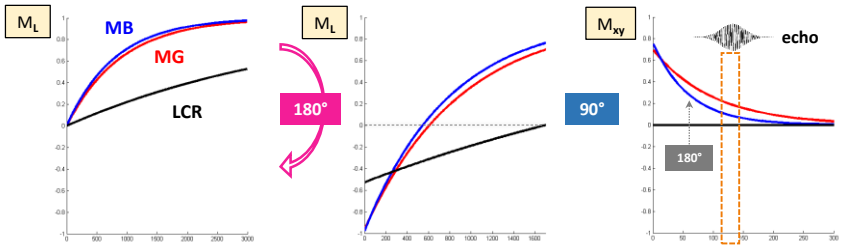
Séquences d'acquisition

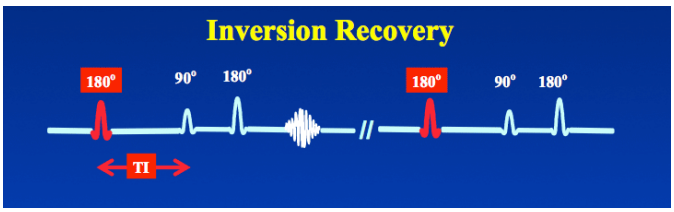
Inversion - récupération



Séquences d'acquisition

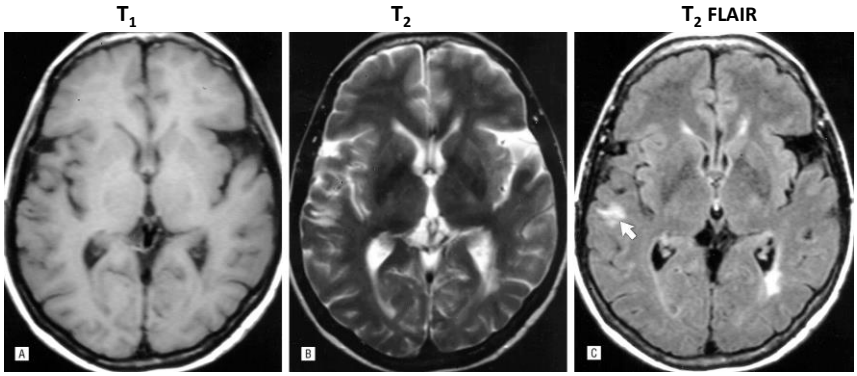
Inversion - récupération
FLAIR : FLuid Attenuated Inversion Recovery





Séquences d'acquisition

Inversion - récupération
FLAIR : FLuid Attenuated Inversion Recovery



Séquences d'acquisition

Inversion - récupération
FLAIR : FLuid Attenuated Inversion Recovery

RECOMMANDATIONS DE BONNE PRATIQUE

Accident vasculaire cérébral : prise en charge précoce (alerte, phase préhospitalière, phase hospitalière initiale, indications de la thrombolyse)

RECOMMANDATIONS

Mai 2009

4.3 Quels patients justifient d'une hospitalisation en UNV ?

Tout patient ayant un AVC doit être proposé à une UNV.

4.2 Imagerie cérébrale et vasculaire

Les patients suspects d'AVC aigu doivent avoir un accès prioritaire 24 h/24 et 7 j/7 à l'imagerie cérébrale. Des protocoles de prise en charge des patients suspects d'AVC aigu doivent être formalisés et contractualisés entre le service accueillant ces patients et le service de radiologie (accord professionnel).

L'IRM est l'examen le plus performant pour montrer précocement des signes d'ischémie récente, et elle visualise l'hémorragie intracrânienne. Il convient de la réaliser de façon privilégiée.

Si l'IRM est possible comme examen de première intention, elle doit être accessible en urgence et elle doit privilégier des protocoles courts incluant les séquences suivantes : diffusion, FLAIR, écho de gradient (grade B).

En cas d'impossibilité d'accéder en urgence à l'IRM, il convient de réaliser un scanner cérébral. Cet examen ne montre qu'inconstamment des signes d'ischémie récente, mais permet de visualiser une hémorragie intracrânienne.

L'exploration des artères intracrâniennes est effectuée par ARM cérébrale, angioscanner ou Doppler transcrânien (accord professionnel).

Une exploration des artères cervicales doit être réalisée précocement devant tout accident ischémique cérébral. Celle-ci est urgente en cas d'AIT, d'infarctus mineur, d'accident ischémique fluctuant ou évolutif. L'examen de première intention peut être un écho-Doppler, une ARM des vaisseaux cervico-encéphaliques avec injection de gadolinium ou un angioscanner des troncs supra-aortiques (grade B).

5.1 Thrombolyse intraveineuse

► **Indications**

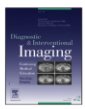
La thrombolyse intraveineuse (IV) par rt-PA des IC est recommandée jusqu'à 4 heures 30 (hors AMM, *voir annexe 2*) (accord professionnel). Elle doit être effectuée le plus tôt possible (grade A).

La thrombolyse IV peut être envisagée après 80 ans jusqu'à 3 heures (accord professionnel).

Séquences d'acquisition

Inversion - récupération
FLAIR : FLuid Attenuated Inversion Recovery

Diagnostic and Interventional Imaging (2014) 95, 1135–1144



CONTINUING EDUCATION PROGRAM: FOCUS...

Patient ''candidate'' for thrombolysis: MRI is essential

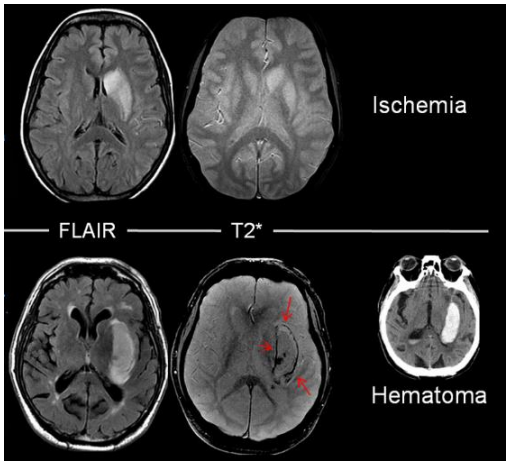
M. Tisserand, O. Naggara, L. Legrand, C. Mellerio, M. Edjlali, S. Lion, C. Rodriguez-Régent, R. Souillard-Scemama, C.-F. Jbanca, D. Trystram, J.-F. Méder, C. Oppenheim*

Objectifs primaires
- Confirmer l'AVC ischémique
- Exclure l'hémorragie
- Exclure les diag. diff.

Objectifs secondaires
- Dater l'AVC
- Localiser l'occlusion
- Evaluer la pénombre (pron.)

Séquences d'acquisition

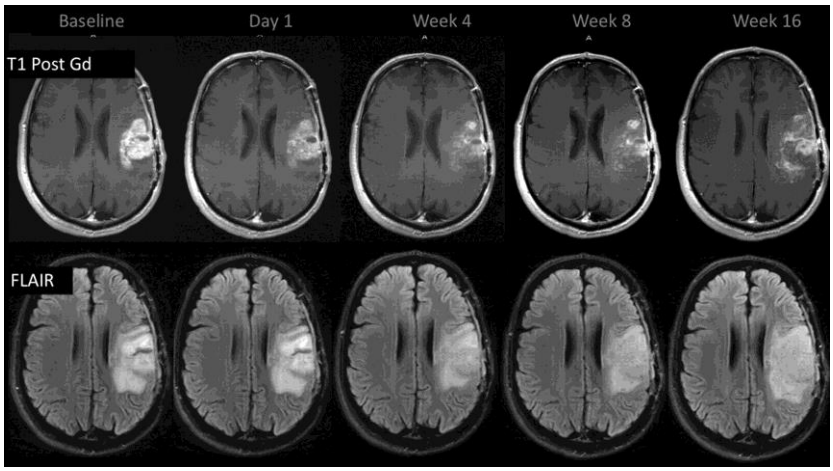
Inversion - récupération
FLAIR : FLuid Attenuated Inversion Recovery



Tisserand et al. Diag Interv Imaging 2014

Séquences d'acquisition

Inversion - récupération
FLAIR : FLuid Attenuated Inversion Recovery



Hygino da Cruz et al. Am J Neuroradiol 2011

Séquences d'acquisition

Inversion - récupération
FLAIR : FLuid Attenuated Inversion Recovery

THE LANCET
Neurology

REVIEW | VOLUME 15, ISSUE 3, P292-303, MARCH 01, 2018

MRI criteria for the diagnosis of multiple sclerosis: MAGNIMS consensus guidelines

Prof Massimo Filippi, MD • Maria A Rocca, MD • Prof Olga Ciccarelli, PhD • Nicola De Stefano, MD • Nikos Evangelou, PhD • Prof Ludwig Kappos, MD • et al Show all authors • Show footnotes

***Panel 2:* Recommended 2016 MAGNIMS MRI criteria to establish disease dissemination in space in multiple sclerosis**

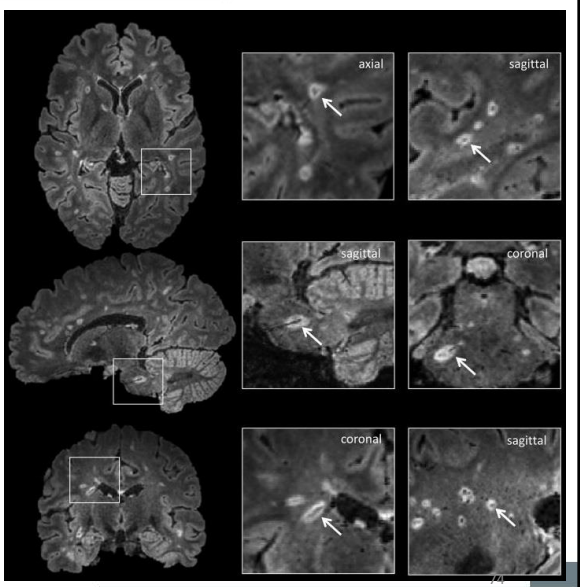
Dissemination in space can be shown by involvement* of at least two of five areas of the CNS as follows:

- Three or more periventricular lesions
- One or more infratentorial lesion
- One or more spinal cord lesion
- One or more optic nerve lesion
- One or more cortical or juxtacortical lesion†

*If a patient has a brainstem or spinal cord syndrome, or optic neuritis, the symptomatic lesion (or lesions) are not excluded from the criteria and contribute to the lesion count. †This combined terminology indicates the involvement of the white matter next to the cortex, the involvement of the cortex, or both, thereby expanding the term juxtacortical lesion.

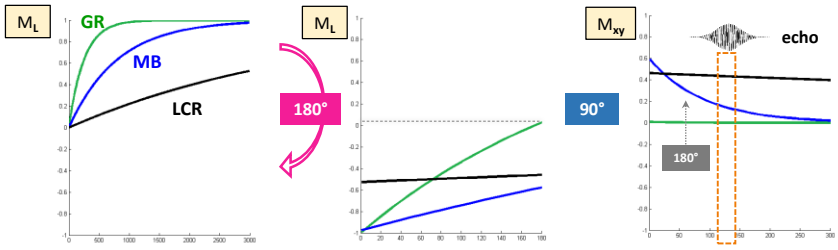
Séquences d'acquisition

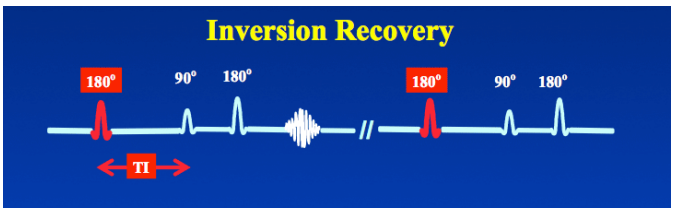
Inversion - récupération
FLAIR : FLuid Attenuated Inversion Recovery



Séquences d'acquisition

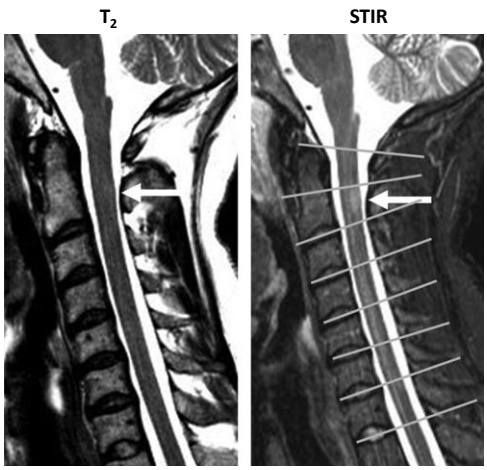
Inversion - récupération
STIR : Short Ti Inversion Recovery





Séquences d'acquisition

Inversion - récupération
STIR : Short Ti Inversion Recovery



Alcaide-Leon et al. Am J Neuroradiol 2016

Séquences d'acquisition

Inversion - récupération
STIR : Short Ti Inversion Recovery

Salinas et al. ECR 2017

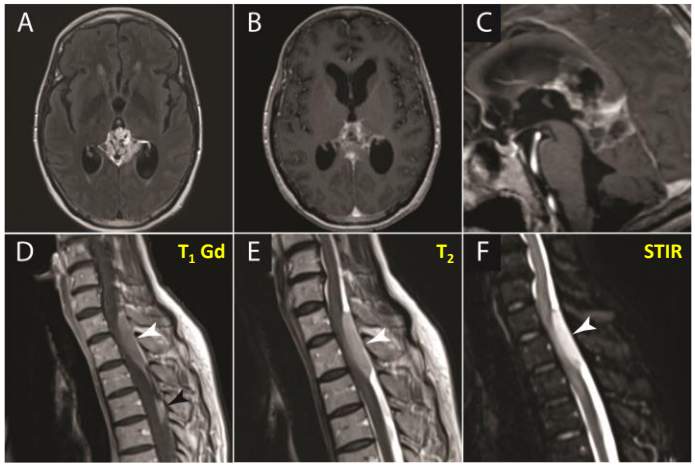
Séquences d'acquisition

Inversion - récupération
STIR : Short Ti Inversion Recovery

Salinas et al. ECR 2017

Séquences d'acquisition

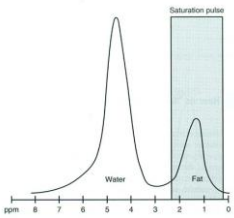
Inversion - récupération
STIR : Short Ti Inversion Recovery

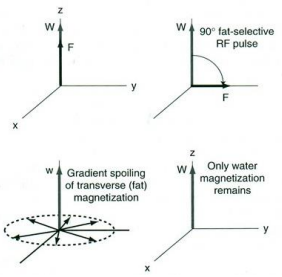


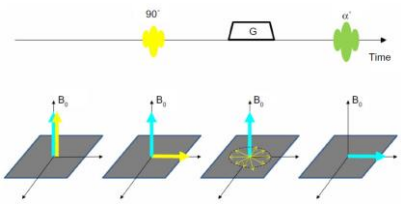
Ben Bouallègue et al. Clin Nucl Med 2018

Séquences d'acquisition

Techniques de saturation
FAT-SAT

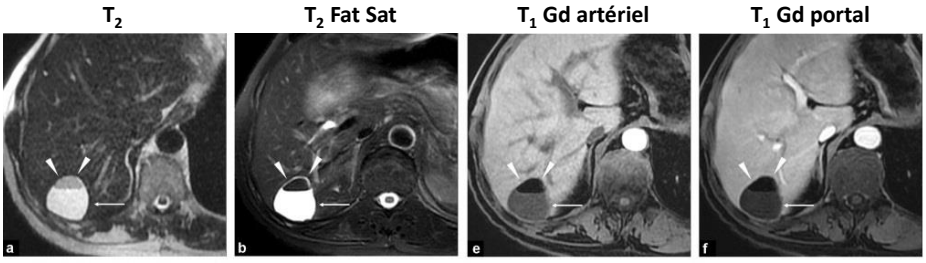






Séquences d'acquisition

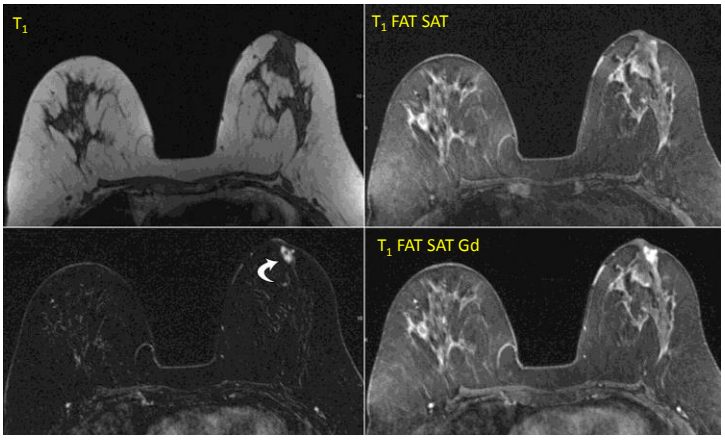
Techniques de saturation
FAT-SAT



Tekath et al. Diag Interv Imaging 2015

Séquences d'acquisition

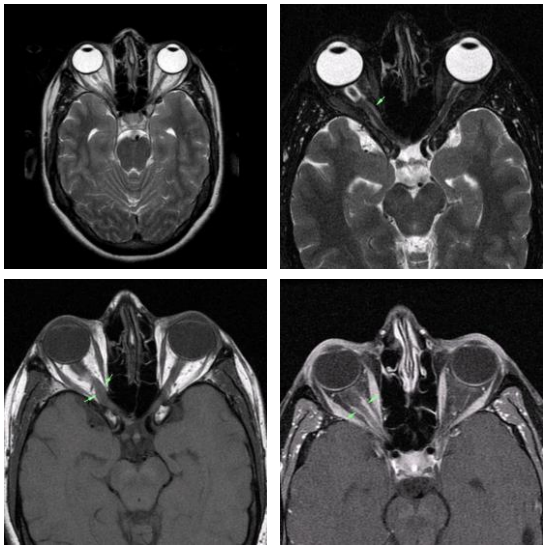
Techniques de saturation
FAT-SAT



Daly et al. AJR 2008

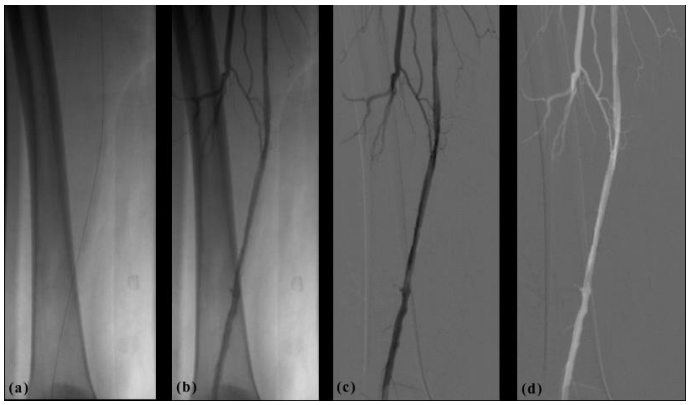
Séquences d'acquisition

Techniques de saturation
FAT-SAT



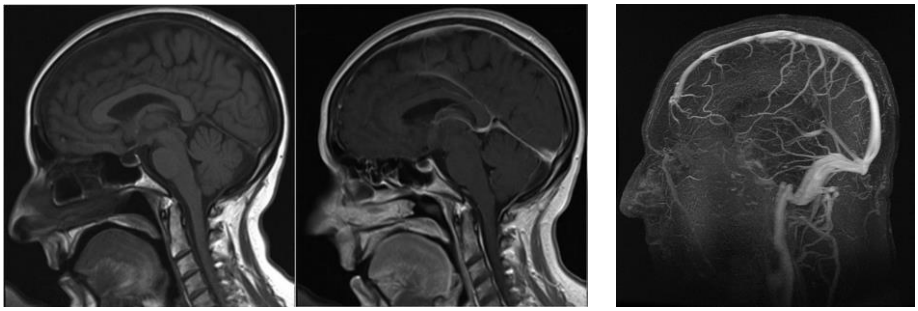
Séquences d'acquisition

Angiographie IRM
Contraste



Séquences d'acquisition

Angiographie IRM
Contraste



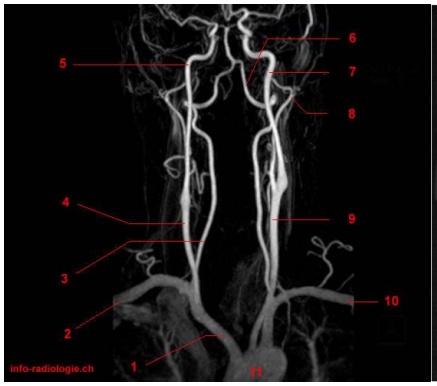
Currie et al. Postgrad Med J 2013

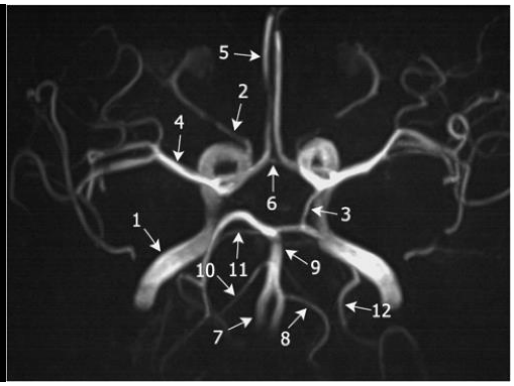
Séquences d'acquisition

Angiographie IRM
Contraste

Séquences d'acquisition

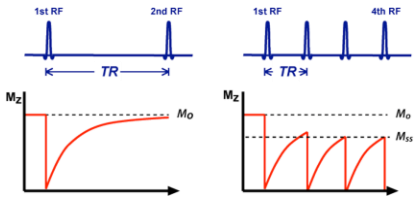
Angiographie IRM
Contraste

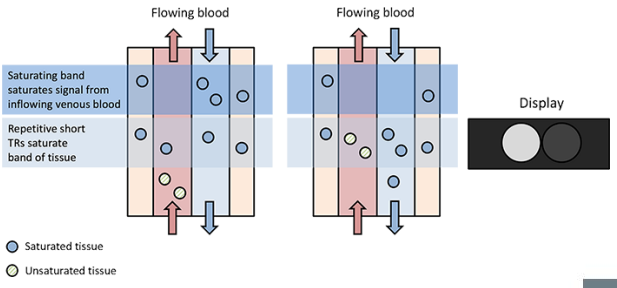




Séquences d'acquisition

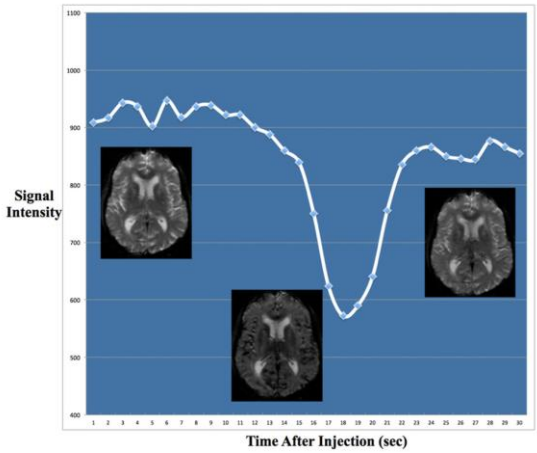
Angiographie IRM
TOF (temps de vol)





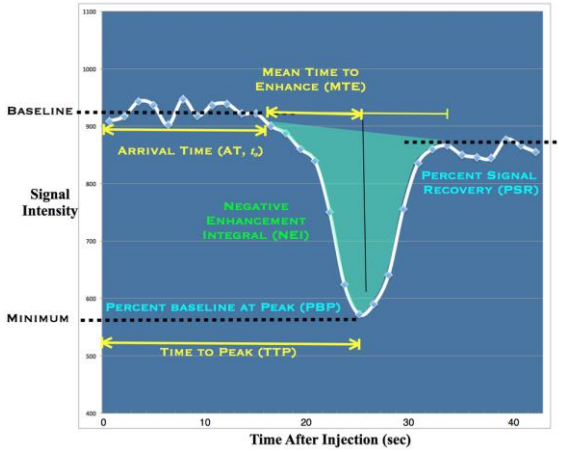
Séquences d'acquisition

IRM de perfusion
Contraste
DSC (dynamic susceptibility contrast, T_2)



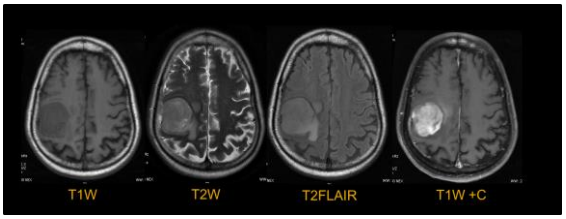
Séquences d'acquisition

IRM de perfusion
Contraste
DSC (dynamic susceptibility contrast, T_2)

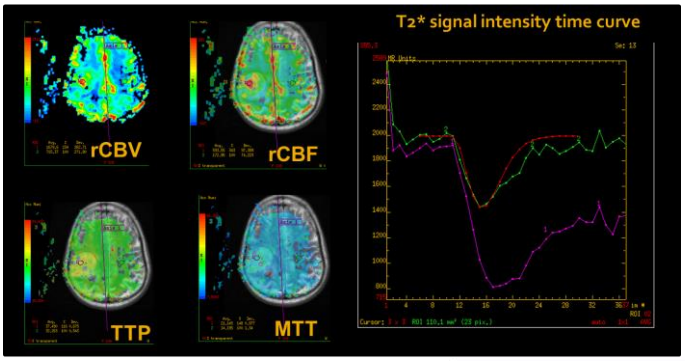


Séquences d'acquisition

IRM de perfusion
Contraste
DSC (dynamic susceptibility contrast, T_2)

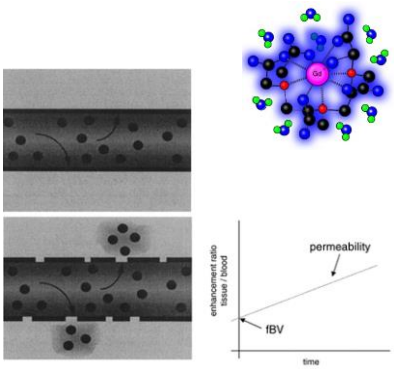


Udare et al. ECR 2014

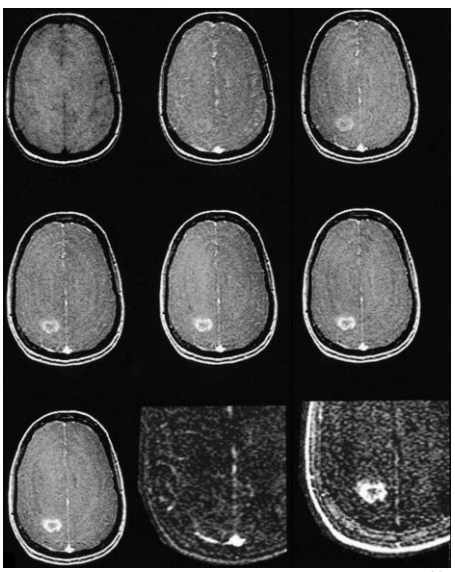


Séquences d'acquisition

IRM de perfusion
Contraste
DCE (dynamic contrast enhanced , T_1)

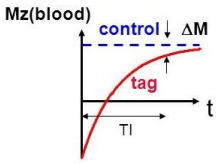


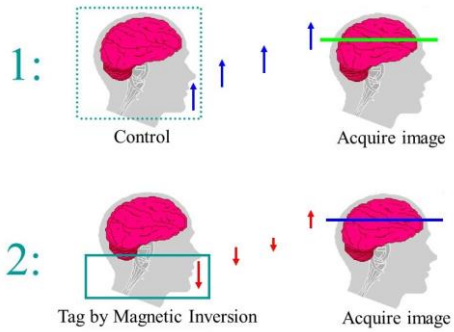
Roberts et al. AJNR 2000



Séquences d'acquisition

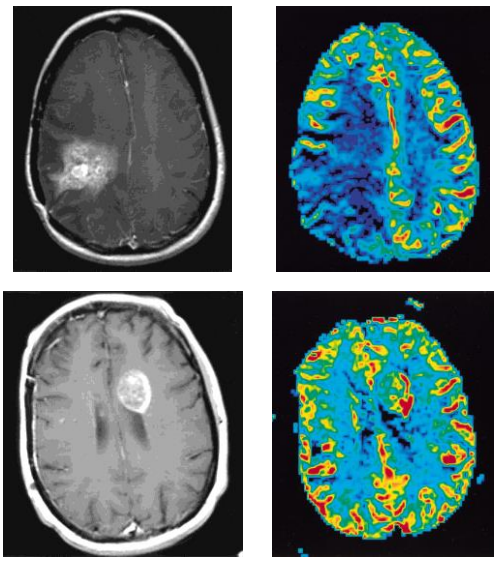
IRM de perfusion
ASL (arterial spin labeling)





Séquences d'acquisition

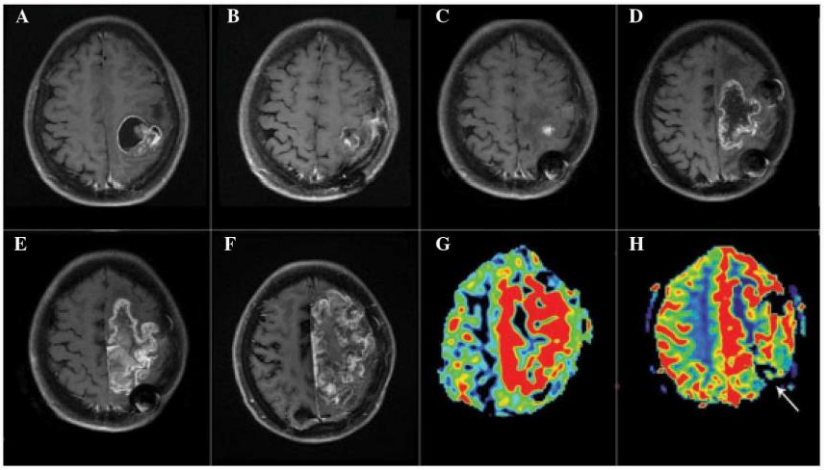
IRM de perfusion
Applications



Petrella et al. AJR 2000

Séquences d'acquisition

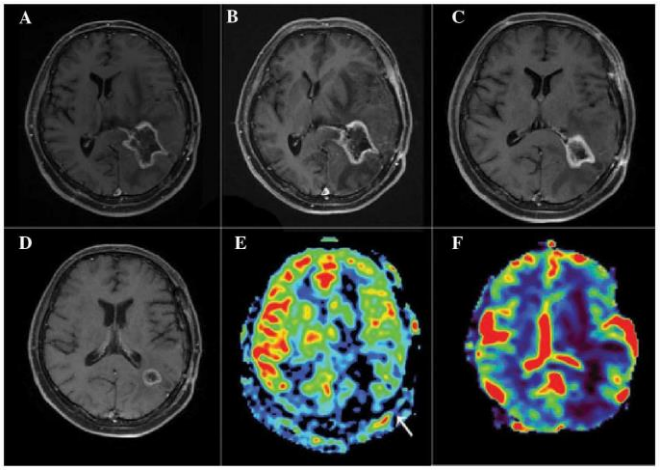
IRM de perfusion
Applications



Ye et al. Exp Ther Med 2016

Séquences d'acquisition

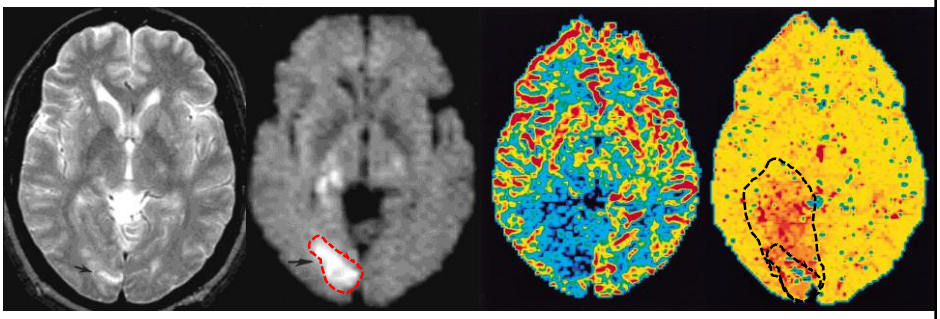
IRM de perfusion
Applications



Ye et al. Exp Ther Med 2016

Séquences d'acquisition

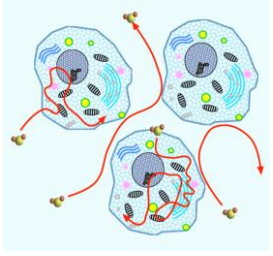
IRM de perfusion
Applications

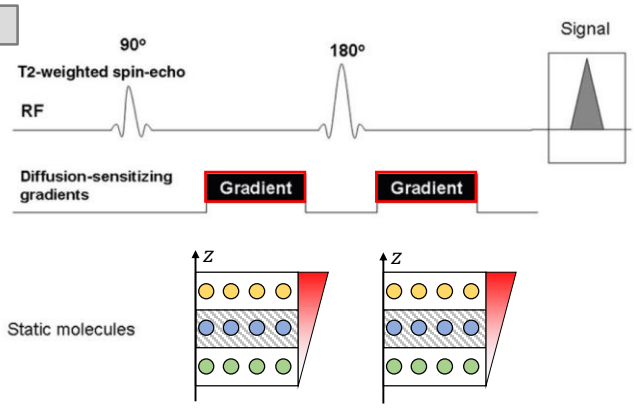


Petrella et al. AJR 2000

Séquences d'acquisition

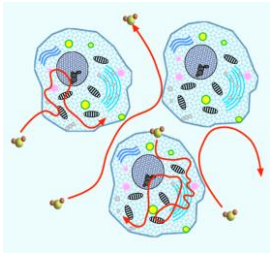
IRM de diffusion : DWI

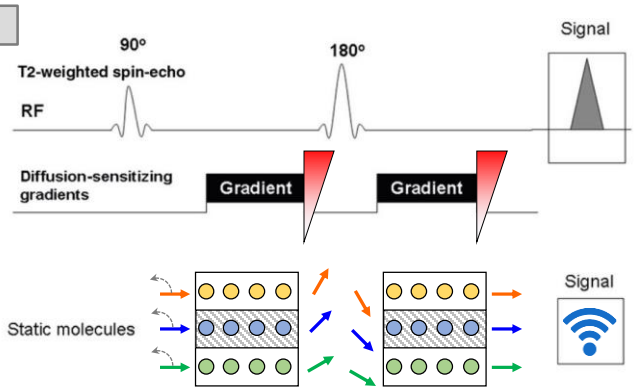




Séquences d'acquisition

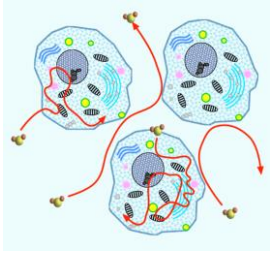
IRM de diffusion : DWI

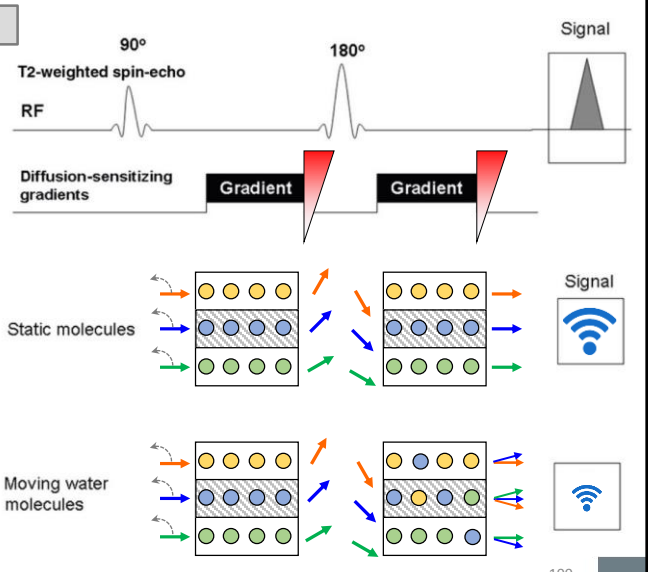




Séquences d'acquisition

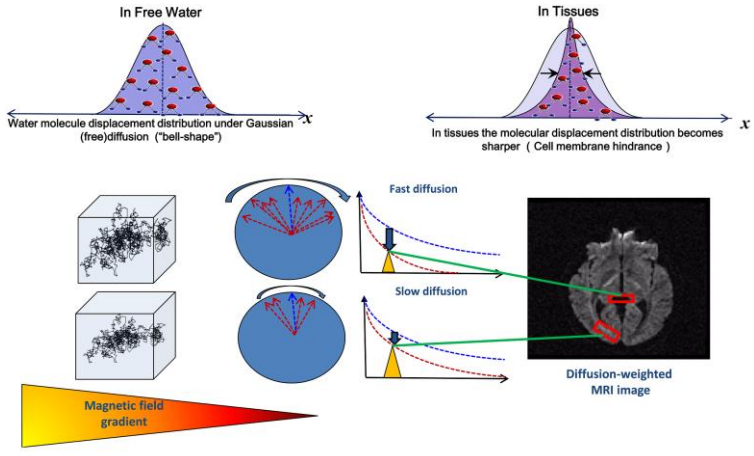
IRM de diffusion : DWI





Séquences d'acquisition

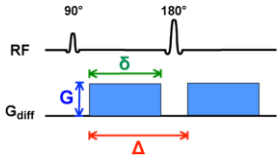
IRM de diffusion : DWI



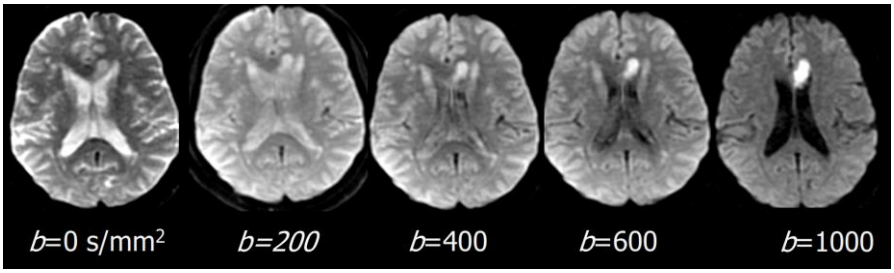
Le Bihan et al. Plos One 2015

Séquences d'acquisition

IRM de diffusion : DWI

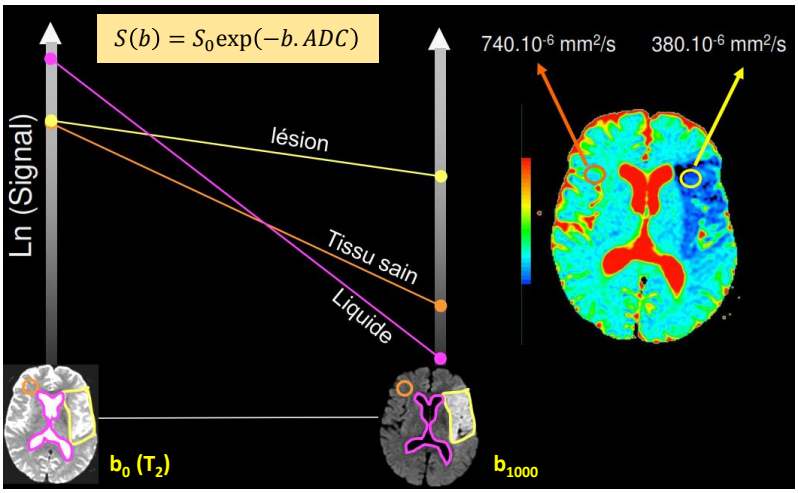


$$b = G^2\gamma^2\delta^2\left(D - \frac{\delta}{3}\right)$$



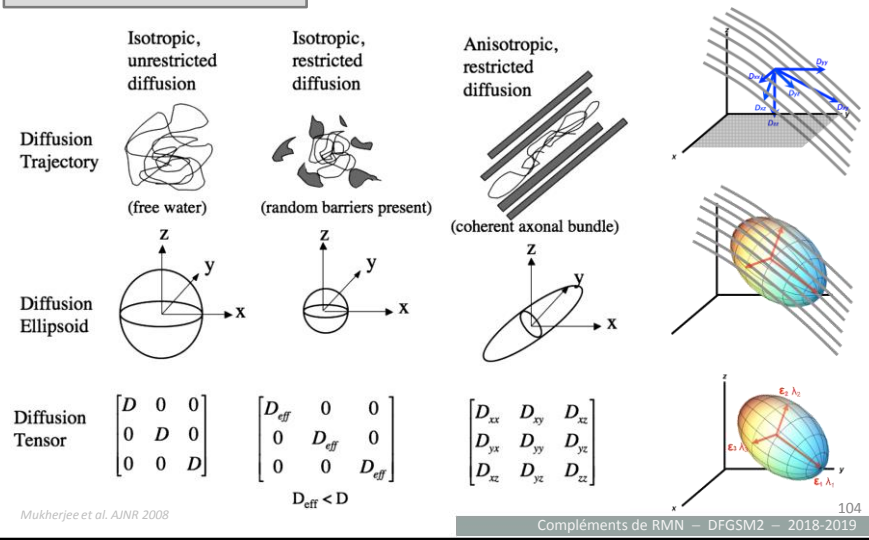
Séquences d'acquisition

IRM de diffusion : DWI



Séquences d'acquisition

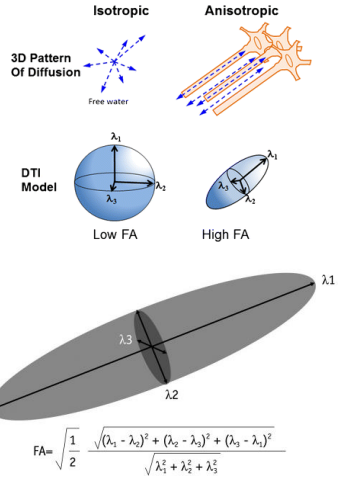
IRM de diffusion
DTI (tractographie)

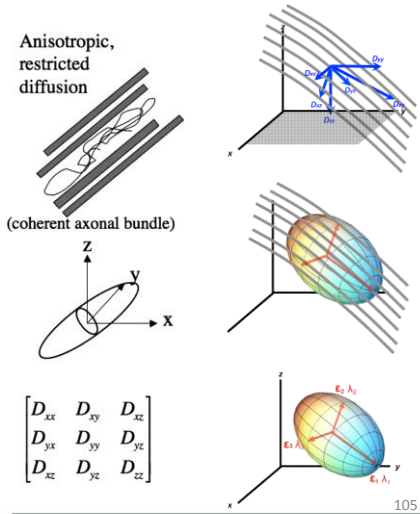


Mukherjee et al. AJNR 2008

Séquences d'acquisition

IRM de diffusion
DTI (tractographie)

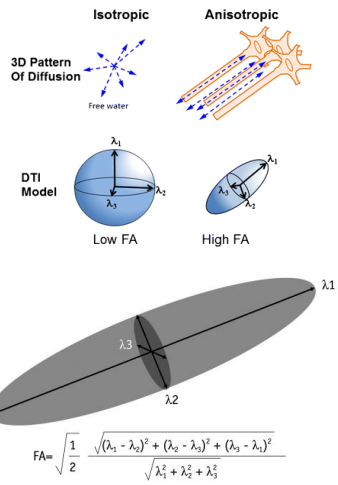


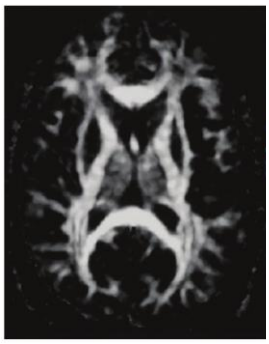


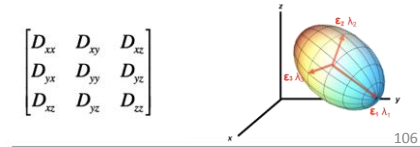
$$\begin{bmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{yx} & D_{yy} & D_{yz} \\ D_{xz} & D_{yz} & D_{zz} \end{bmatrix}$$

Séquences d'acquisition

IRM de diffusion
DTI (tractographie)



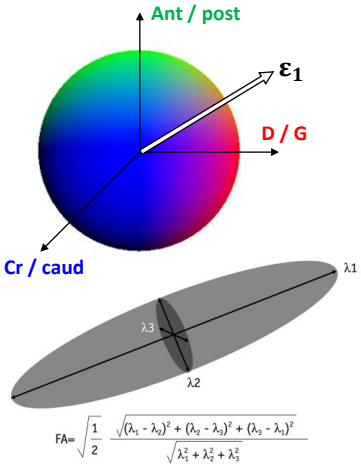


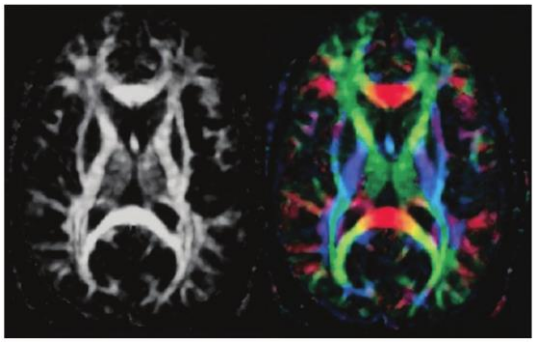


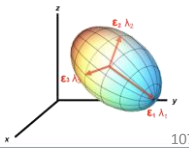
$$\begin{bmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{yx} & D_{yy} & D_{yz} \\ D_{xz} & D_{yz} & D_{zz} \end{bmatrix}$$

Séquences d'acquisition

IRM de diffusion
DTI (tractographie)



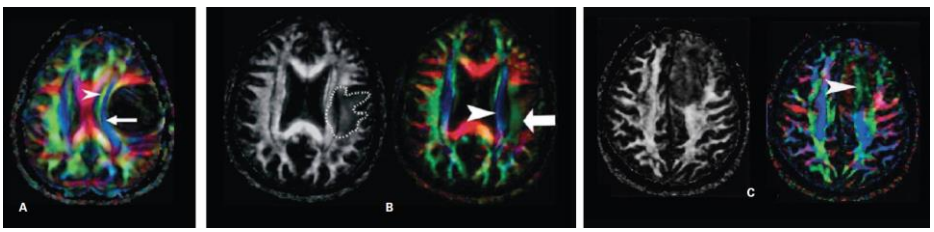




Séquences d'acquisition

IRM de diffusion
DTI (tractographie)

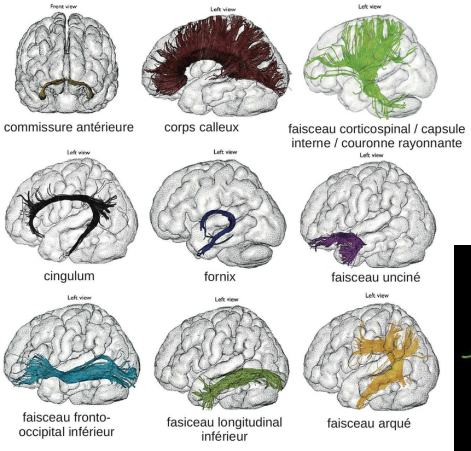
Astrocytome kystique | Métastases | Astrocytome infiltrant



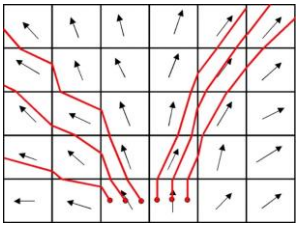
Guillevin et al. Neurologie.com 2010

Séquences d'acquisition

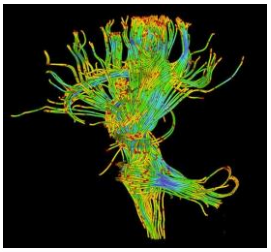
IRM de diffusion
DTI (tractographie)

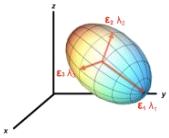


Adapted from Catani et al. Cortex 2008



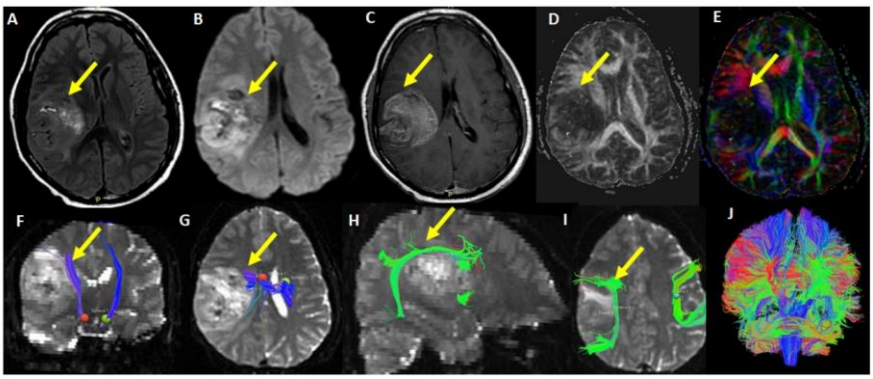
Mukherjee et al. AJNR 2008





Séquences d'acquisition

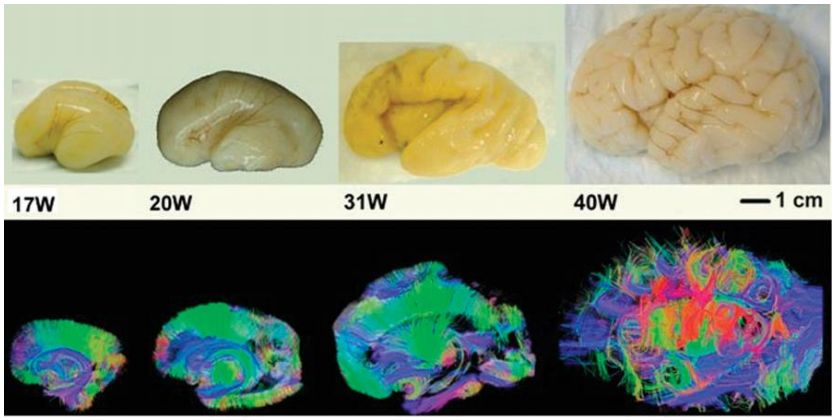
IRM de diffusion
DTI (tractographie)



Soni et al. Cureus 2017

Séquences d'acquisition

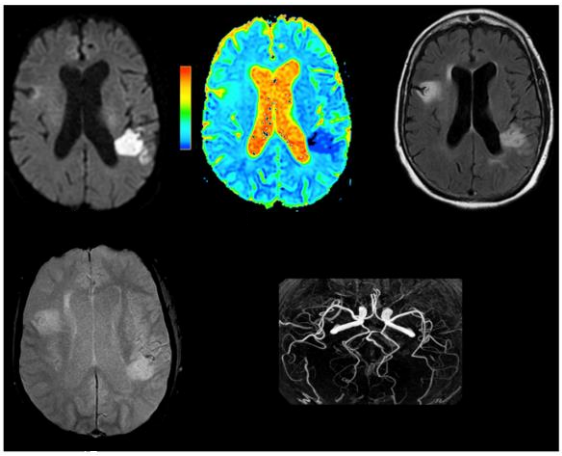
IRM de diffusion
DTI (tractographie)



Takahashi et al. Cereb Cortex 2012

Séquences d'acquisition

Cas clinique



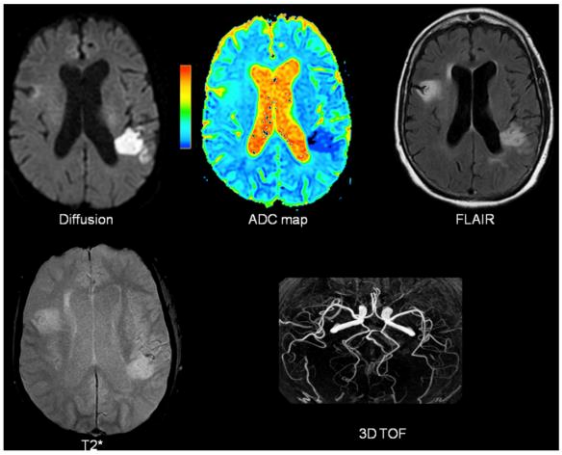
Tisserand et al. Diag Interv Imaging 2014

Séquences d'acquisition

Cas clinique

Questions

1) What is the diagnosis?
   A. Multiple hematomas.
   B. Infarctions of different ages.
   C. Metastases.
   D. Abscess and pre-suppurative lesion.
2) Describe the appearances of the different lesions.
3) What does the left posterior insular T2* hypointensity represent?
4) Should thrombolysis be performed in this patient?



Tisserand et al. Diag Interv Imaging 2014