MRI簡介與成像原理
MR PET Breast Cancer

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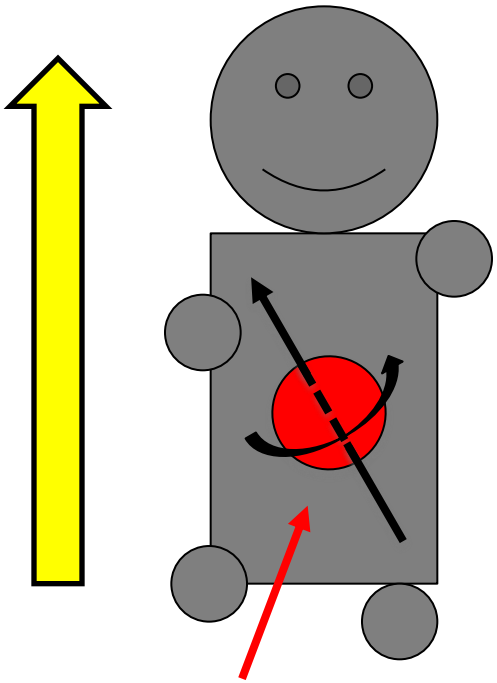
MRI之理論基礎

磁 振 造影

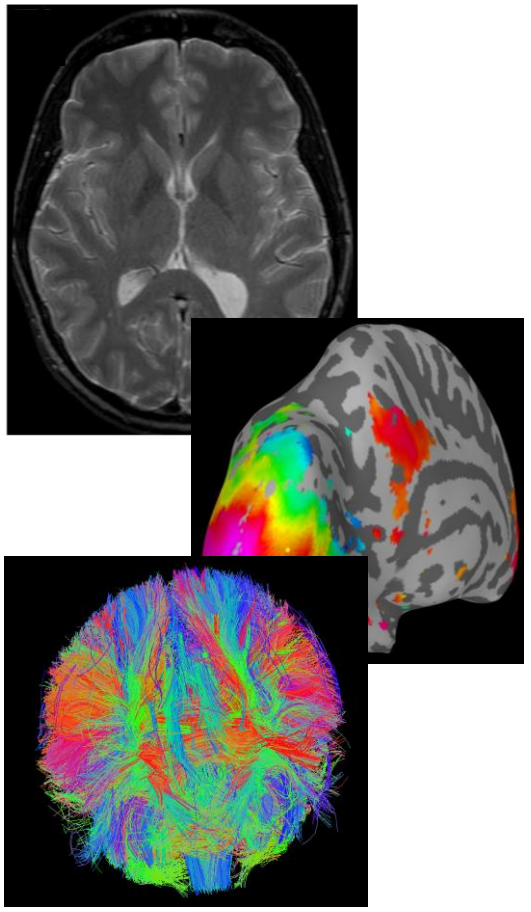
M = Magnetic R = Resonance I = Imaging

Magnetic field direction



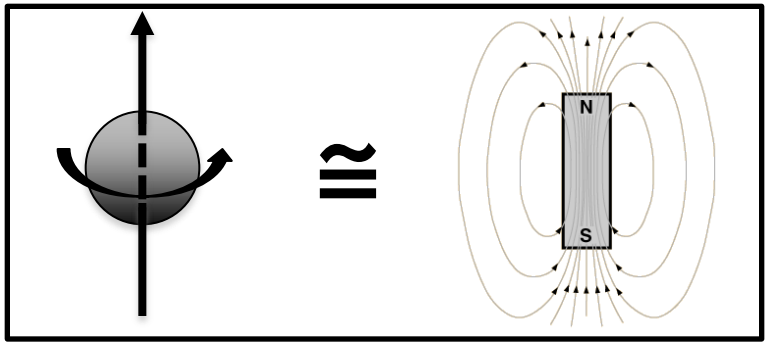
Proton: like a small magnet
Water: 70% of human body

Same frequency

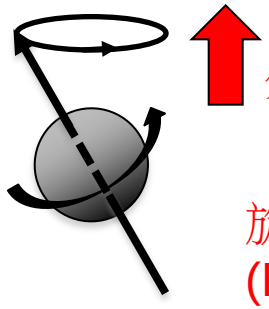


MRI的理論基礎 - NMR

- NMR?
  - Nuclear Magnetic Resonance (核磁共振)



原子核帶電 + 自旋 = 小磁鐵



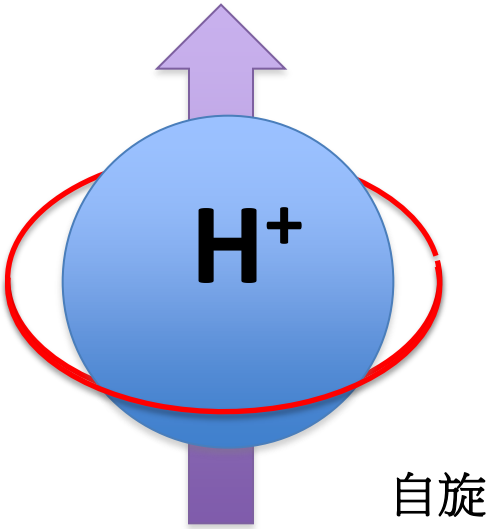
外加磁場 (B_0)

旋進頻率正比於B_0
(E.g. 64MHz for 1.5 Tesla)

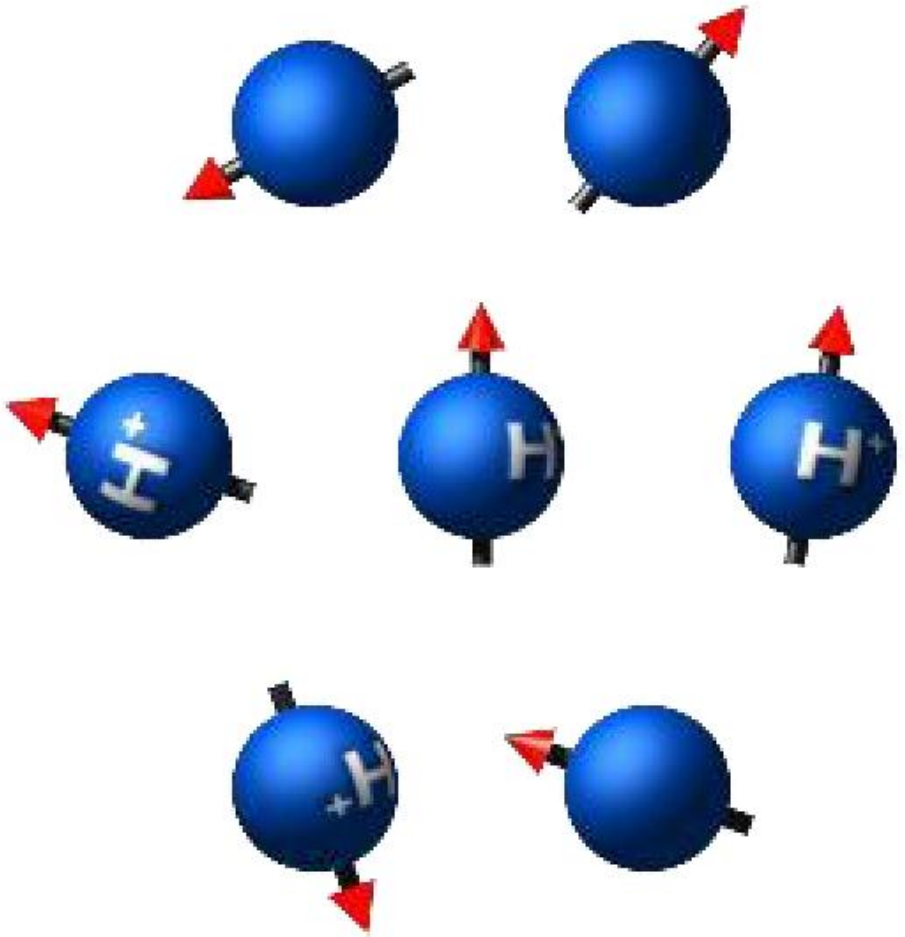
- 何謂MRI?
  - Magnetic Resonance Imaging (磁振造影)
    - 因為增加了梯度磁場，使得外加磁場在空間中有了變化，能夠編碼磁旋在空間中之位置，產生影像

Hydrogen nuclei (protons)

- 氫原子核是具有磁性的，我們稱為nuclear spin(核自旋)
- 這些氫原子核就像是小小旋轉磁鐵，我們可以用一個向量來描述其磁性方向

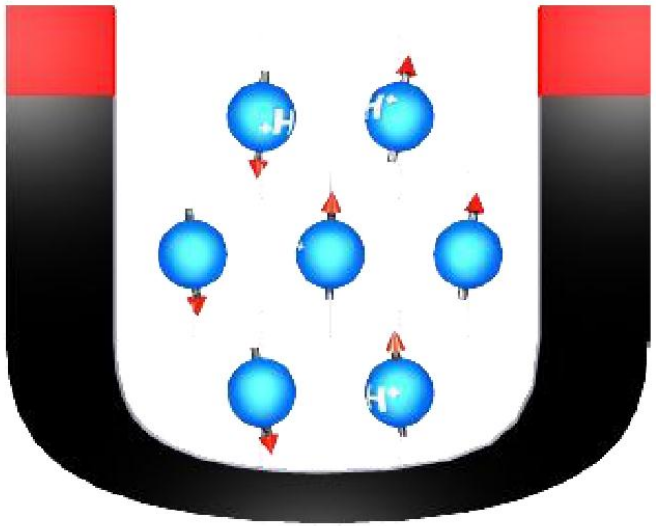


一般情況下

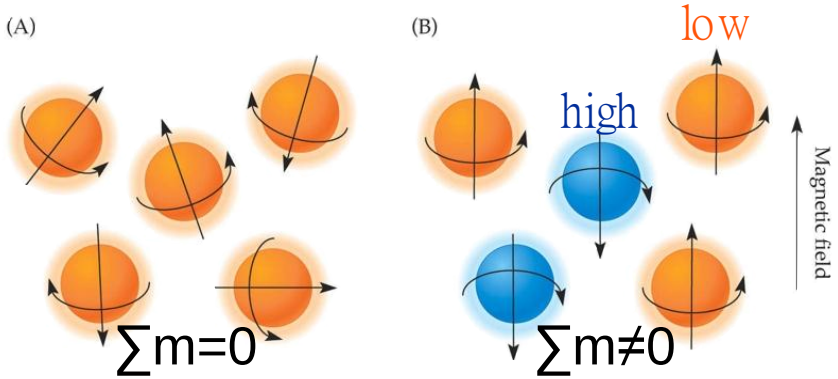


- 氫原子們散亂無章朝隨機方向，因此靜磁矩(net magnetization)為零

如果是在一個外加磁場下呢？



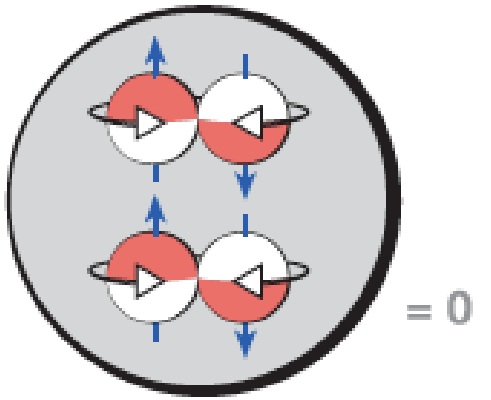
- 氫原子們受到外加磁場(B_0)影響，所以其磁性向量會與磁場方向平行(parallel)或反平行(anti-parallel)



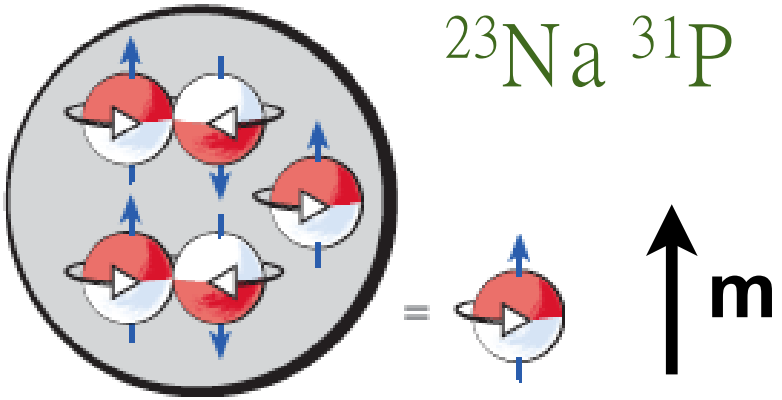
Which atom has spin?

Anyone which has **uneven** number of protons / neutrons

^{16}O
^{12}C

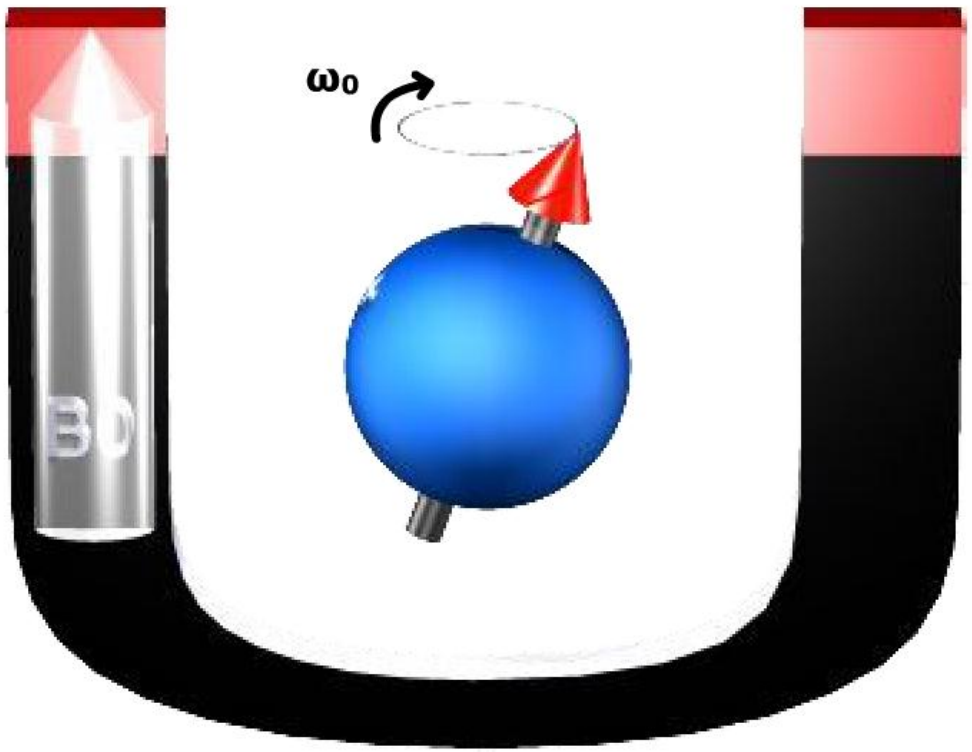


^{13}C ^{19}F
^{23}Na ^{31}P



其實氫原子很好動

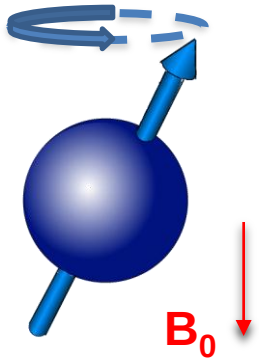
- 不只自旋，還會旋進(precession)
- 旋進軸即為磁性方向



旋進頻率(Larmor frequency, ω_0) =gyromagnetic ratio 與外加磁場強度的乘積

$$\omega_0 = \gamma B_0$$

Larmor Frequency



$$\omega_0 = \gamma B_0$$

γ : Gyromagnetic ratio(磁旋比)

γ=42.58 MHz/T @ B0=3 Tesla

H原子的Larmor Frequency=127.74 MHz

	^{1}H	^{13}C	^{19}F	^{31}P
g (MHz/T)	42.58	10.71	40.05	17.23
W_0 @ 3T (MHz)	127.74	32.13	120.15	51.69

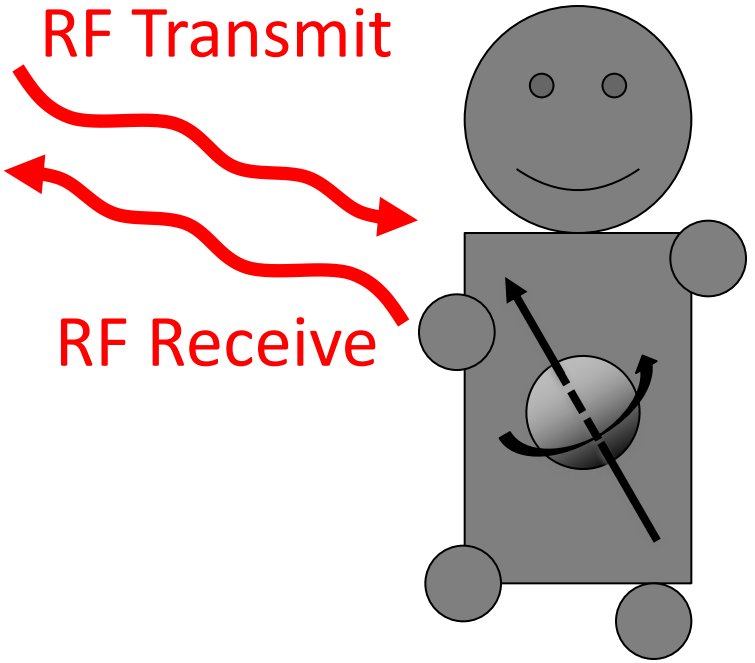
那1.5T呢？ 42.58 x 1.5= 63.87 MHz →Radio Freq.

如何得到NMR之信號?

- 射頻(Radio-Frequency, RF)之激發與接收

表面線圈

頭部線圈



- Images from ***DotyNMR*** and ***Siemens AG***

如何接收NMR信號?

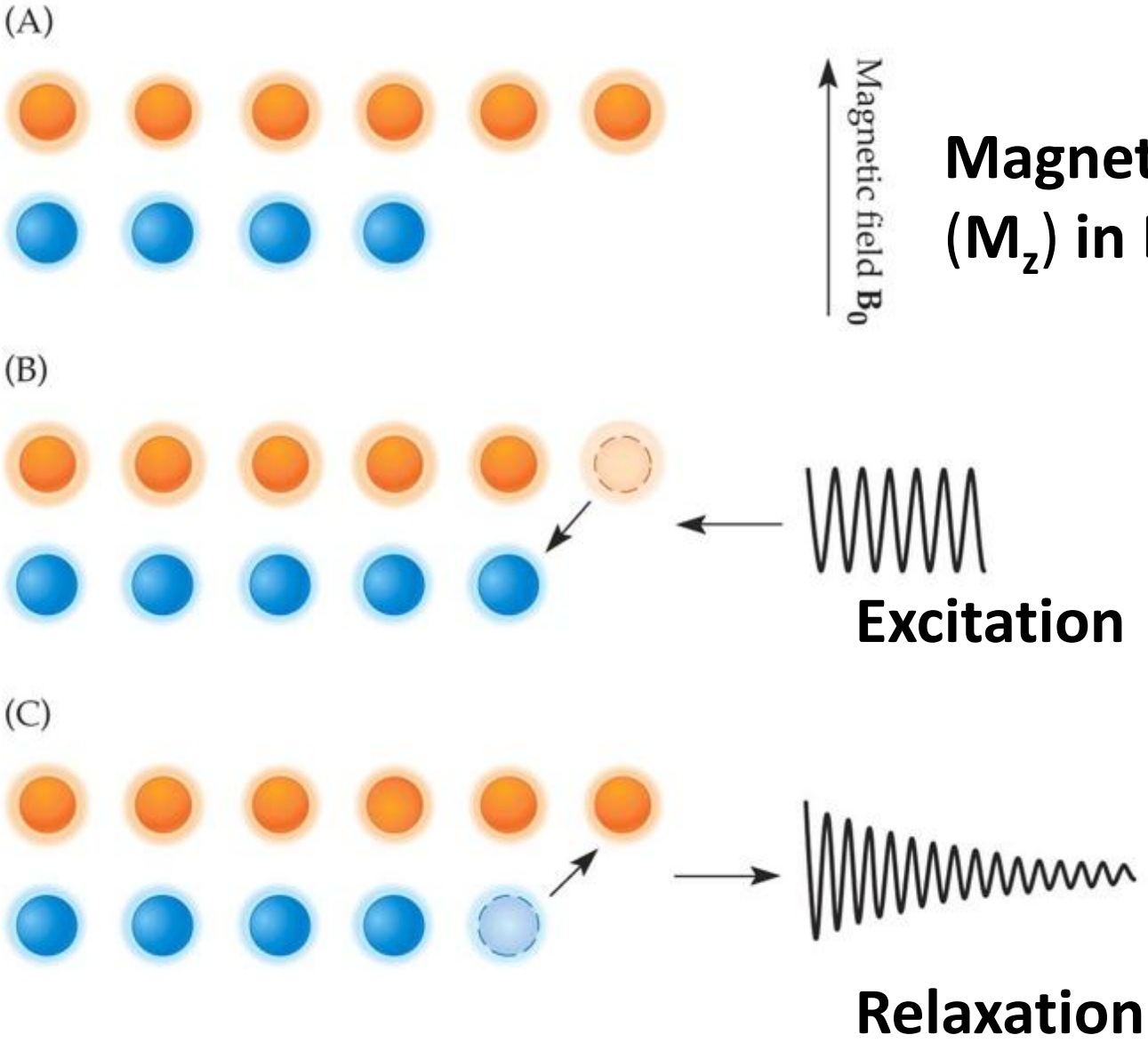
- 根據法拉第定律－動磁生電
  - 變化中的磁場輻射出電磁波，電路感應後產生電流
- 與線圈面垂直的磁場變化才會受感應
- 感應電動勢之大小與磁場變化速度(Larmor Frequency)成正比
- 線圈必須與磁旋共振－相同頻率

想像是在聽廣播...

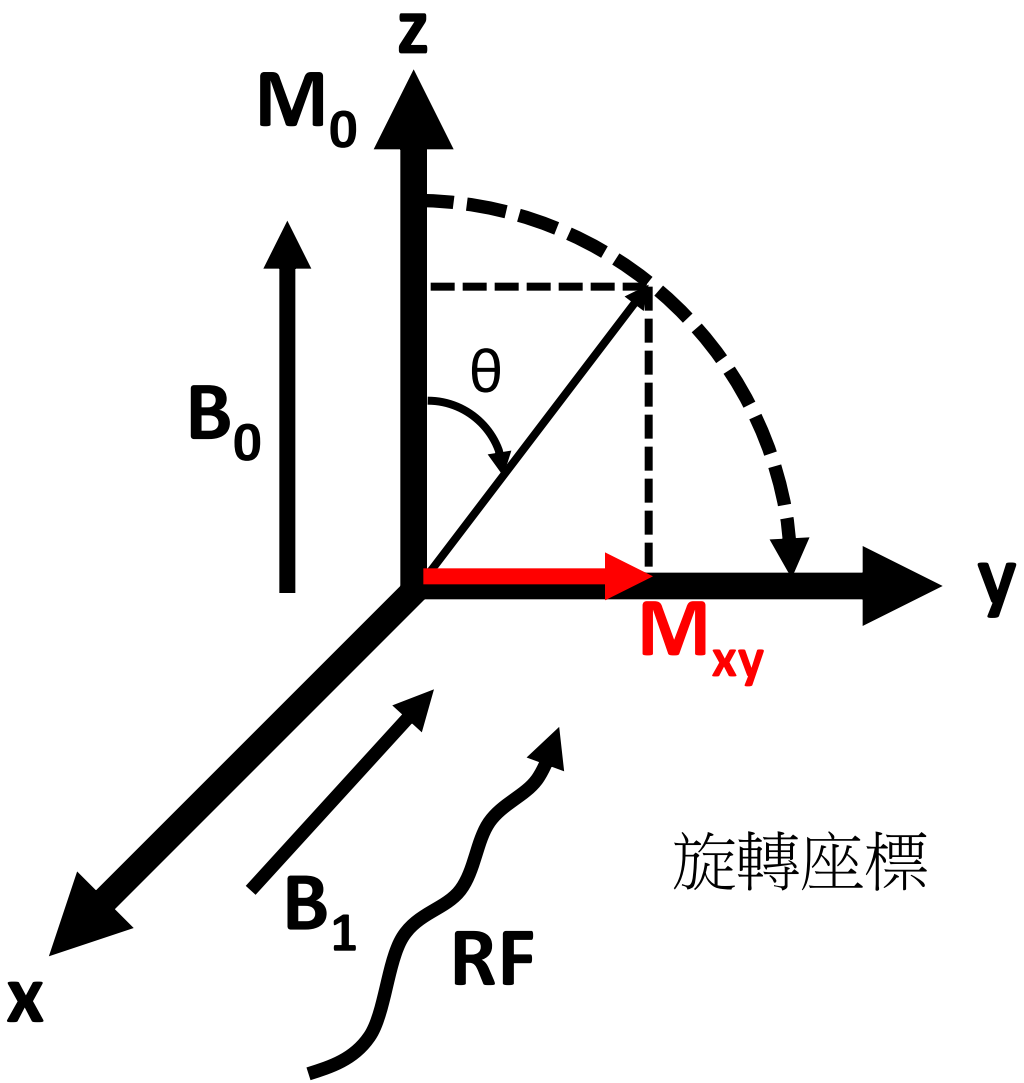
磁旋(釋放電磁波)

共振(某特定頻率)

線圈(接收信號)


(A)
Magnetic field B_0
Magnetization (M_z) in B_0
(B)
Excitation
(C)
Relaxation

射頻激發(Excitation)



旋轉座標

$q = \gamma B_1 t$

$M_{xy} = M_0 \sin q$

γ: gyromagnetic ratio

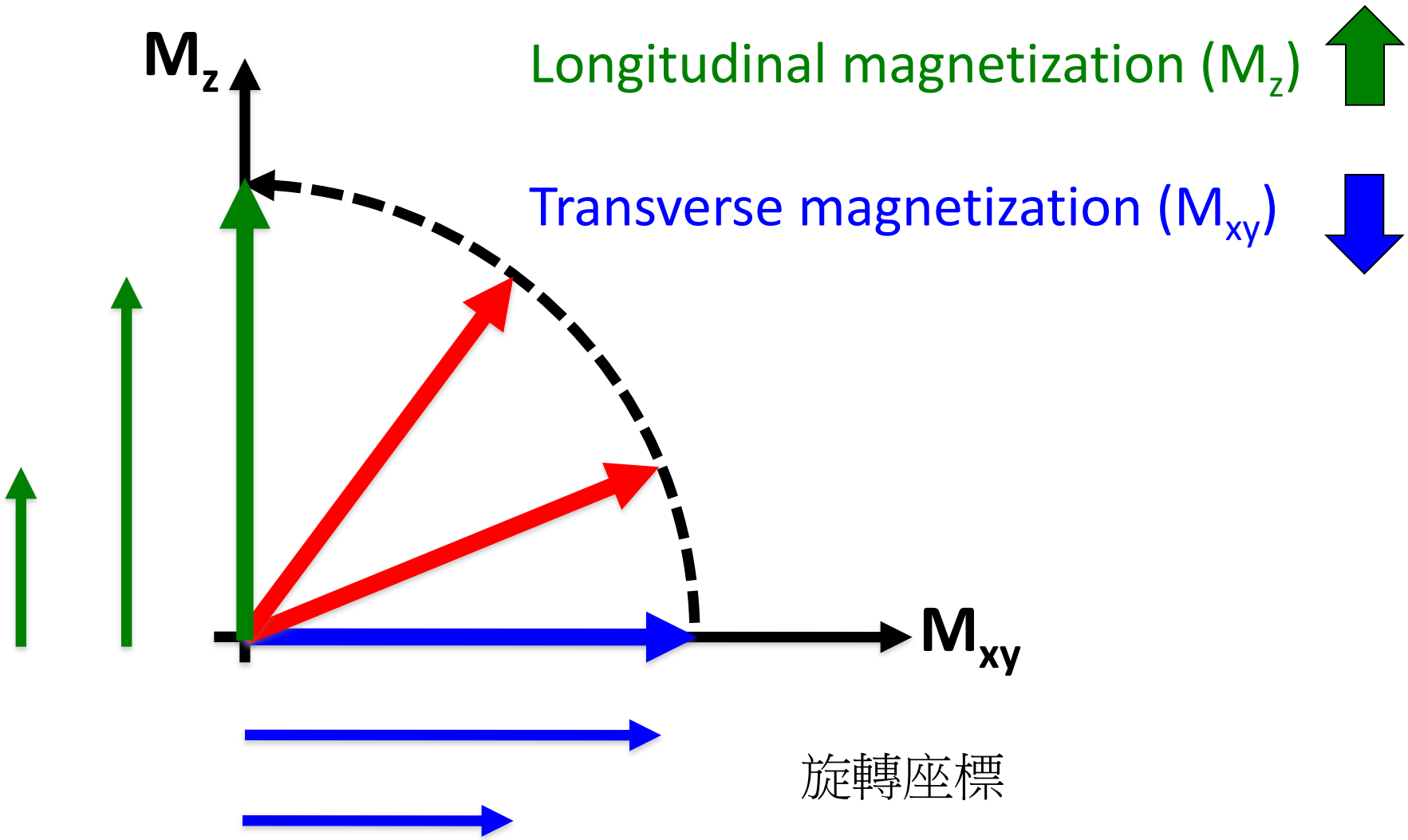
B_1 : RF pulse strength

t : RF pulse duration

M_0 : net magnetization along z-axis

q: flip angle

RF激發之後，開始回復


M_z
Longitudinal magnetization (M_z)
Transverse magnetization (M_{xy})
M_{xy}
旋轉座標

T1 Recovery and T2 Decay

Relaxation

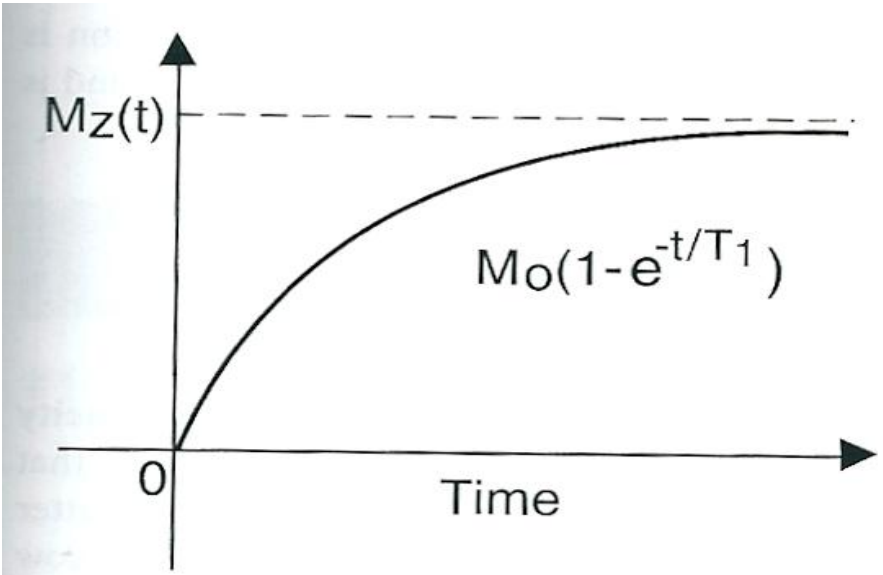


Figure 4-3. The graph of recovery of longitudinal magnetization with the growth rate of T1.

T1 recovery

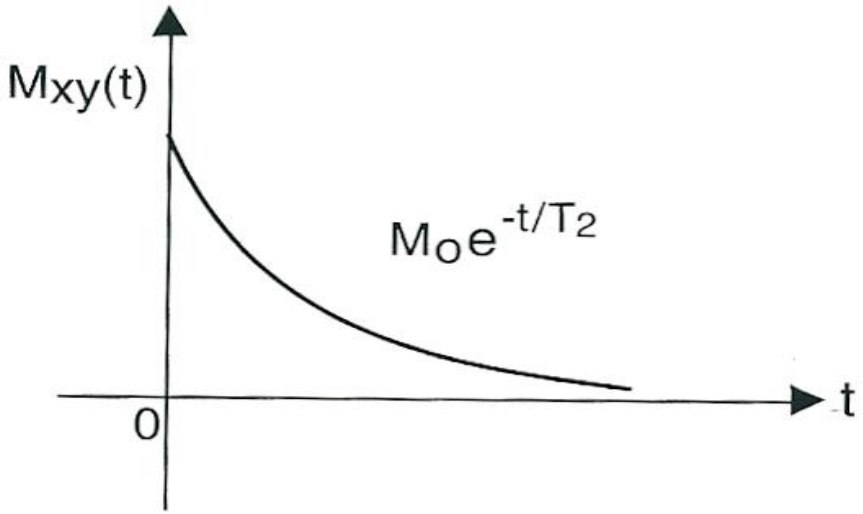


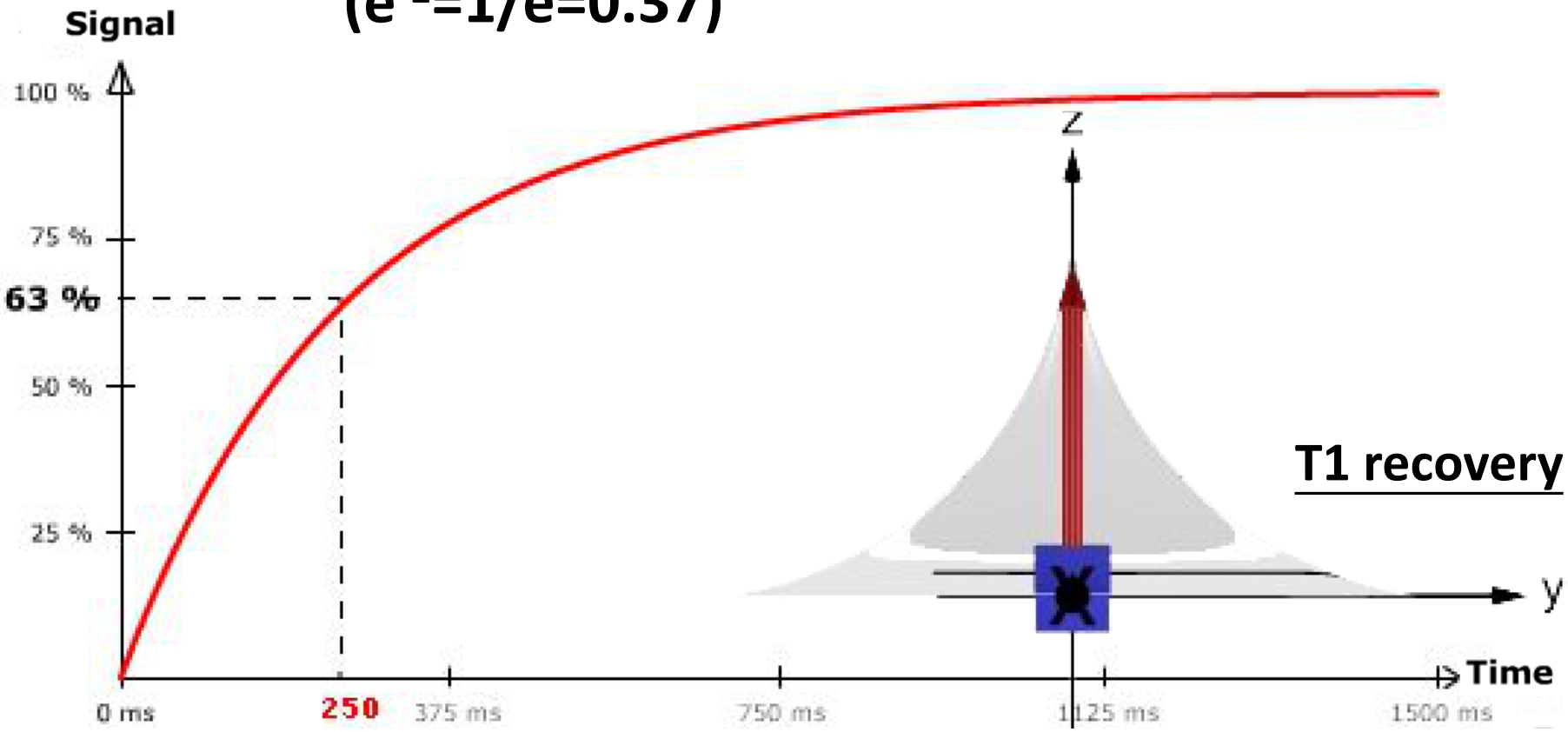
Figure 4-4. The graph of transverse magnetization with the decay rate of T2 and RF off.

T2 decay

- Hashemi et al., MRI the basics, p41.

T1 Recovery

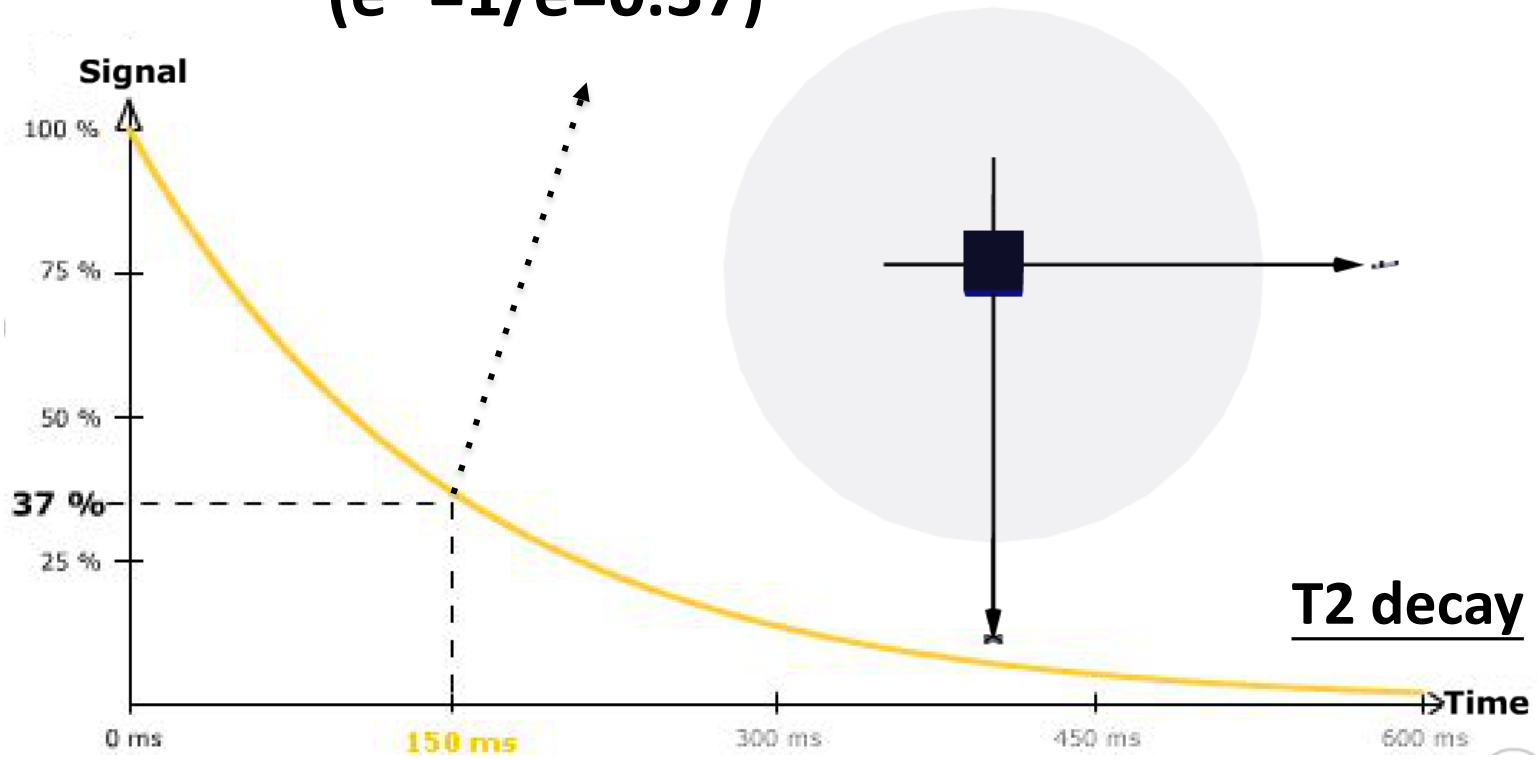
當t=T1時，$M_z=M_0(1-e^{-t/T1})=0.63M_0$
($e^{-1}=1/e=0.37$)



可推論出特定組織T1時間

T2 Decay

當t=T2時，$M_{xy}=M_0e^{-t/T2}=0.37M_0$
($e^{-1}=1/e=0.37$)

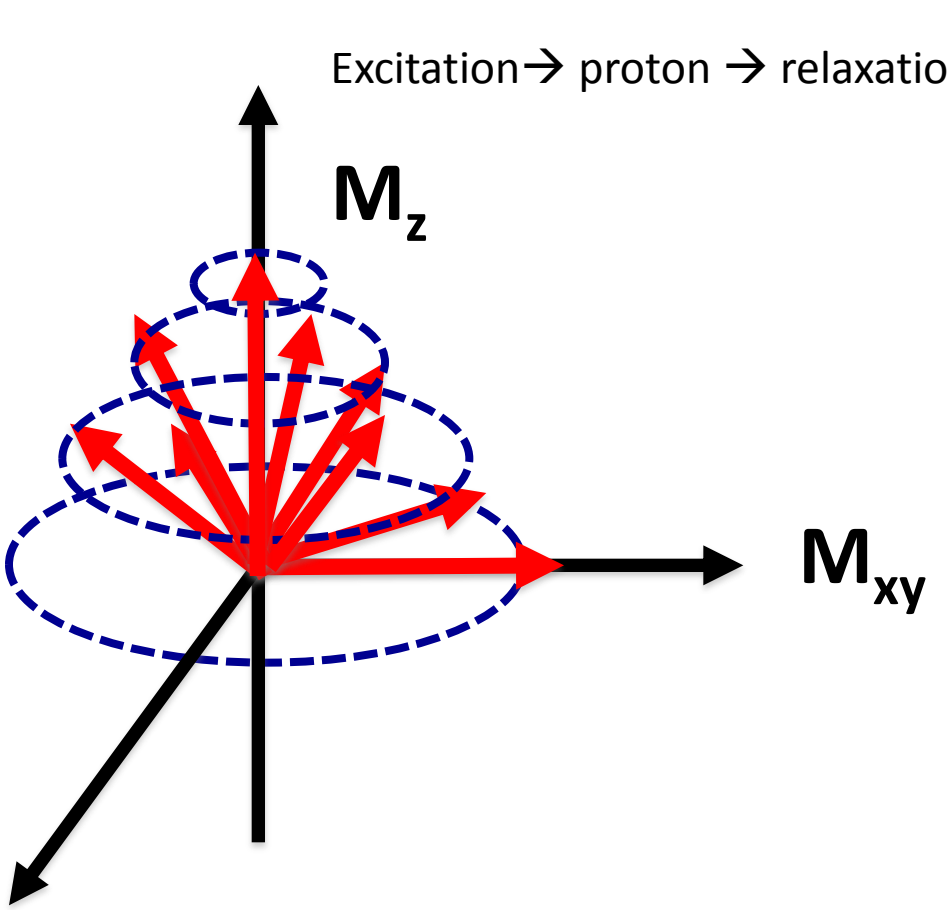


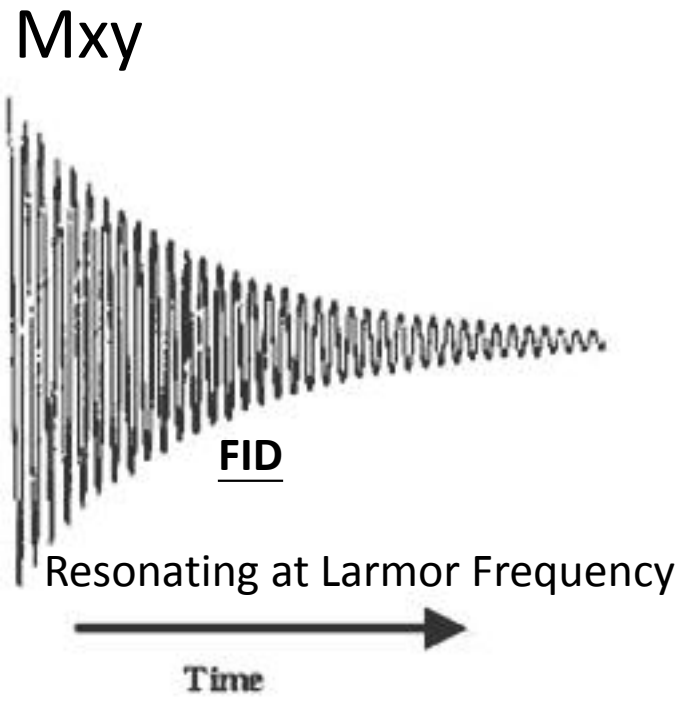
可推論出特定組織T2時間

T2 is tissue-specific and is always shorter than T1

NMR信號是什麼樣子?

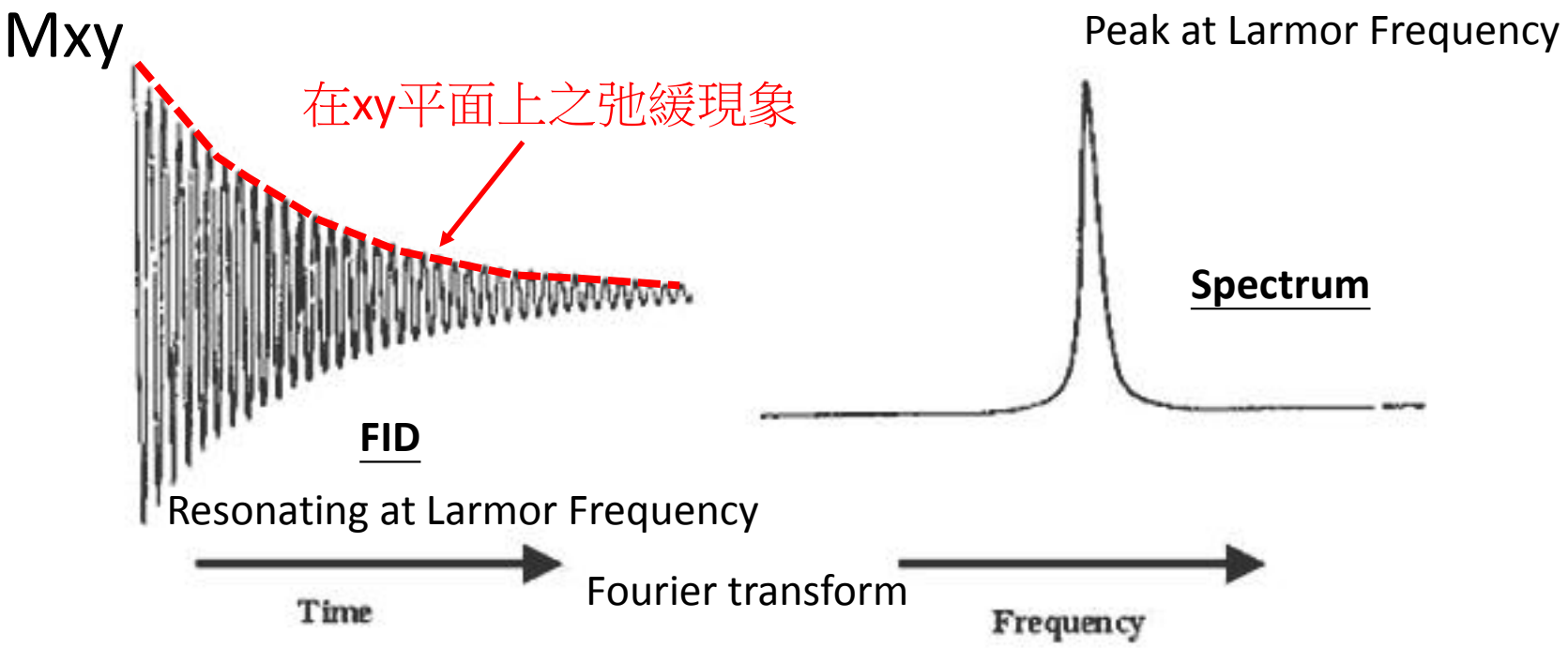
- Free Induction Decay (FID)





NMR信號是什麼樣子?

- **F**ree **I**nduction **D**ecay (FID)



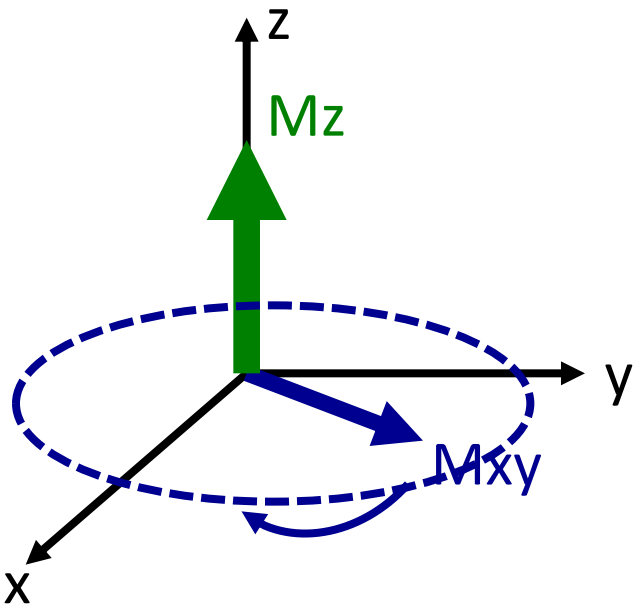
Relaxation time (弛緩時間)

- T1 (z-axis)
  - Longitudinal relaxation time (縱向)
  - Spin-lattice relaxation time (自旋-晶格)

- T2 (x-y plane)
  - Transverse relaxation time (橫向)
  - Spin-spin relaxation time (自旋-自旋)

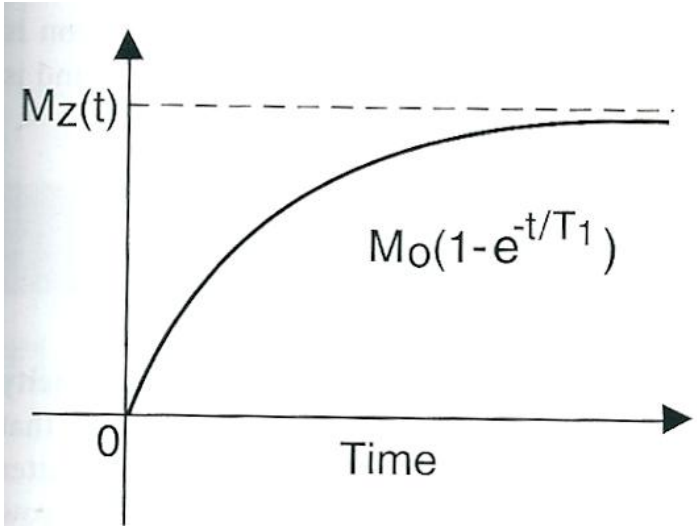
自旋-晶格弛緩 (T1)

- z方向上信號(Mz)恢復之時間快慢
- 自旋(spin)與周遭環境(lattice)進行能量交換，釋放出能量以恢復熱平衡狀態



自旋-晶格弛緩 (T1)

- M_0: 初始之淨磁矩
- Mz(t): 時間t時之磁矩大小



- T1為信號回復約63%時所需要的時間
- 信號完全回復需要約**五倍T1**之時間
- Relaxation rate (R1) = 1/T1
- T1(數百～數千ms) > T2(數十～數百ms)

常見組織T1

- 不同組織有不同T1，可利用此產生信號之對比度

組織	脂肪	肝臟	腎臟	肌肉	白質	灰質	腦脊髓液
T1@1.5 T (ms)	250	490	650	860	780	920	3000
T1@1.0 T (ms)	220	420	590	730	680	810	2500

影響T1之因素

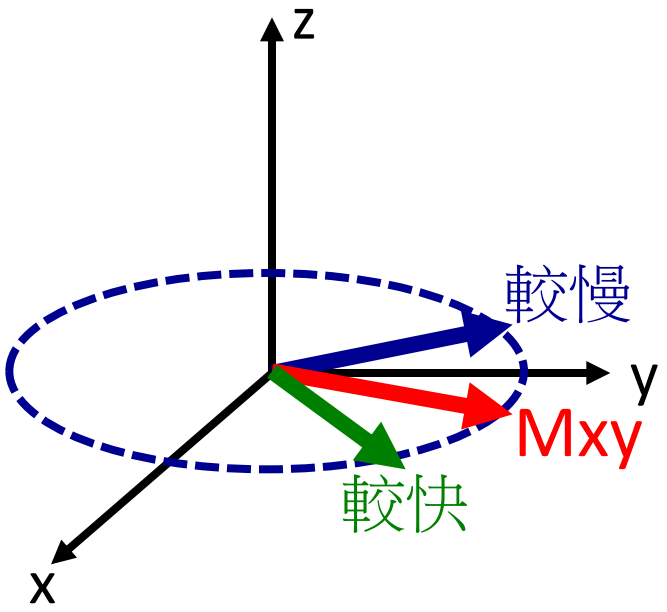
- 小磁鐵與周遭環境的聯結(coupling)
  - 聯結越緊密，能量釋放越快(T1短)
  - 固體T1 < 液體T1
- 分子之大小
  - 分子振動(tumbing)的頻率與Larmor frequency越接近，越能促進能量釋放 (T1越短)
  - 分子越小，振動越快
  - 中型分子(如脂肪)振動與Larmor frequency較近

影響T1之因素(續)

- 主磁場強度
  - 分子振動頻率離Larmor freq.越遠，高磁場下T1變長
- 順磁性離子或分子
  - 具有不成對電子，產生局部擾動，使磁旋不易維持在高能階 (T1縮短)
  - Mn^{2+}, Cu^{2+}, Fe^{2+}, Fe^{3+}, Gd^{3+}, 自由基
- 溫度
  - 溫度降低，分子運動變慢，T1變短

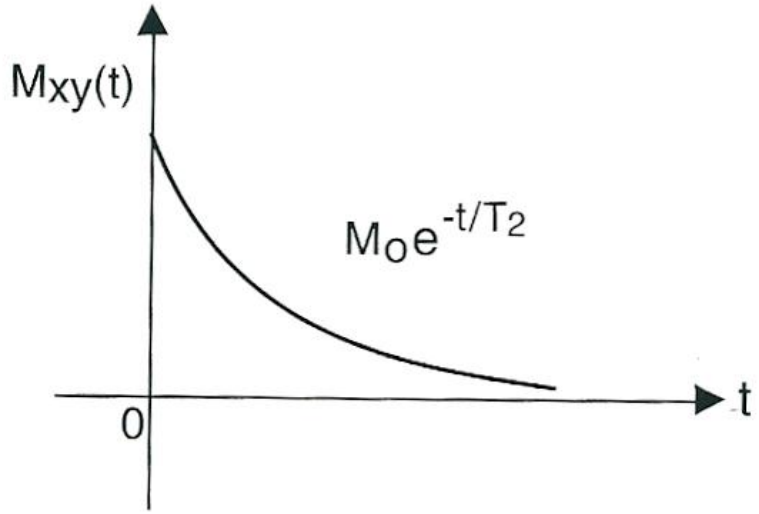
自旋-自旋弛緩 (T2)

- xy平面上磁矩(Mxy)衰減的時間快慢
- 每個自旋旋進速度不一致(相位差)，以致於相互抵消使淨磁矩變小



自旋-自旋弛緩 (T2)

- M0: 初始的淨磁矩
- Mxy: 時間t時之磁矩大小

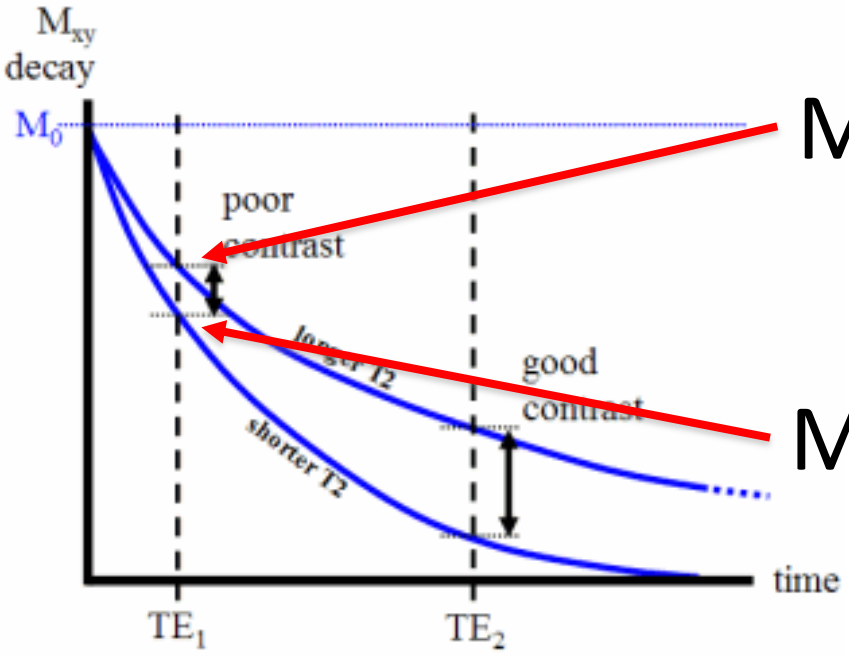


- T2為信號衰減約63%所需之時間
- 信號完全消失約需五倍之T2
- Relaxation rate (R2) = 1/T2

常見組織T2

- 不同組織有不同T2，可利用此產生信號之對比度

組織	脂肪	肝臟	腎臟	肌肉	白質	灰質	腦脊髓液
T2 (ms)	**80**	**40**	**60**	**50**	**90**	**100**	**1400**



$$M_{xy(long)}=M_0e^{-TE1/T2(long)}$$

$$M_{xy(short)}=M_0e^{-TE1/T2(short)}$$

影響T2之因素

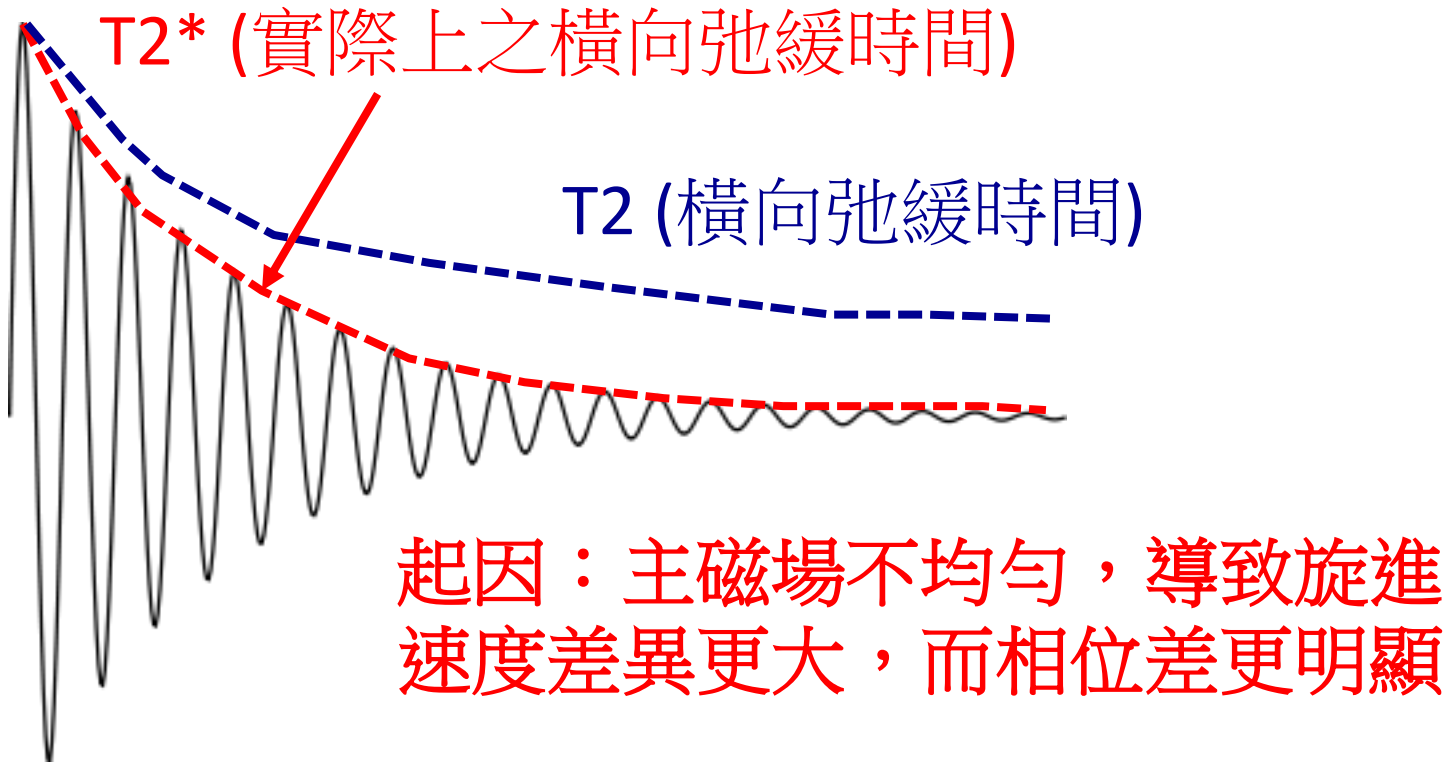
- 組織造成的局部磁場擾動
  - 移動性(mobility)
    - 移動性越低的分子產生之局部磁場擾動越強，使T2縮短，如固體T2<<液體T2 (難怪CSF是長T2)
    - 分子越大移動性越低，T2越短，如蛋白質
  - 等向性(isotropy)
    - 等向性越低，局部磁場擾動越大

影響T2之因素(續)

- 其他來源造成之局部擾動
  - 順磁性物質(去氧血紅素)
- 主磁場強度
  - 使T2縮短，但影響較小
- 溫度
  - 溫度降低，分子運動變慢，T2變短
- 水分子擴散(diffusion)

T2*

- 實際上，FID觀察到的變化不是T2，而是T2*



T2*

$$\frac{1}{T2^*} = \frac{1}{T2} + \gamma \Delta B$$

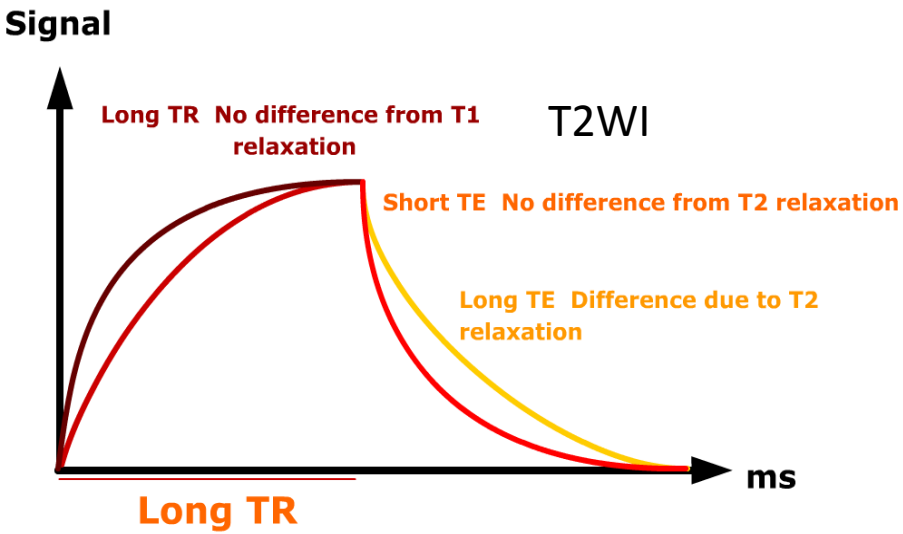
磁場不均勻

- 來源
  - 主磁場無法完全均勻
  - 梯度磁場會使主磁場不均勻
  - 物體也會擾動主磁場之均勻度

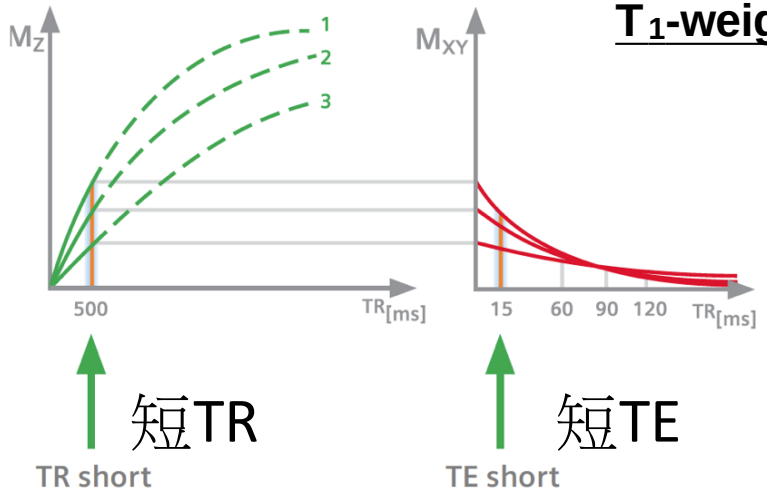
參數調整與信號對比度

- 經由調控TR以及TE，可以得到組織間不同之信號對比度
  - T1權重: Short TR / Short TE
  - T2權重: Long TR / Long TE
  - PD權重: Long TR / Short TE

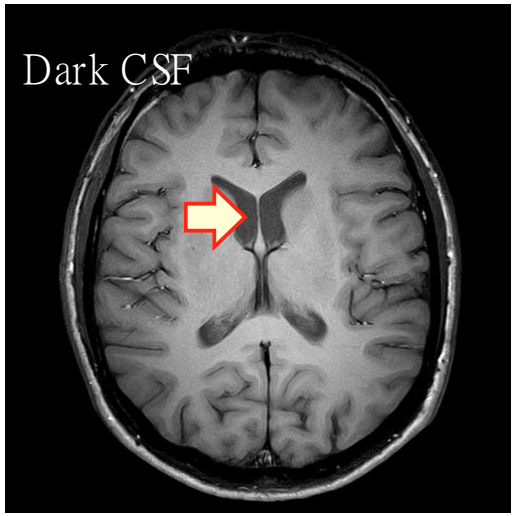
Signal= $M_0(1-e^{-TR/T1})*(e^{-TE/T2})$

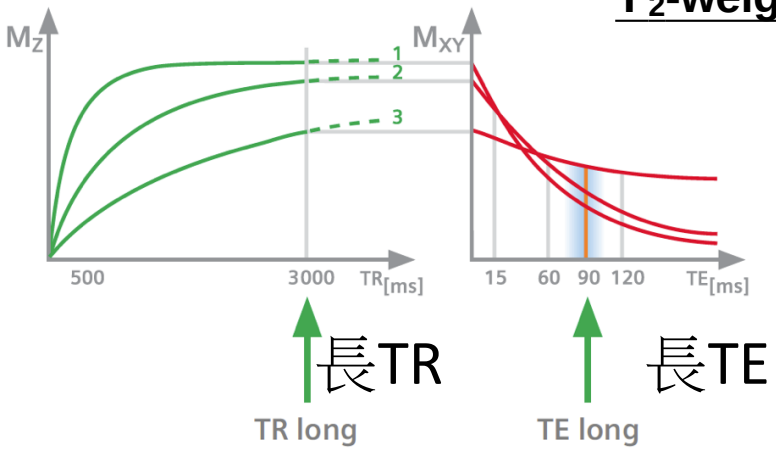


參數調整與信號對比度

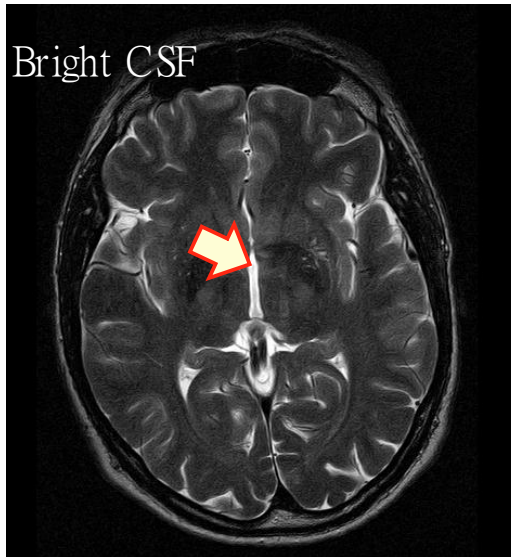


T_1-weighted Image

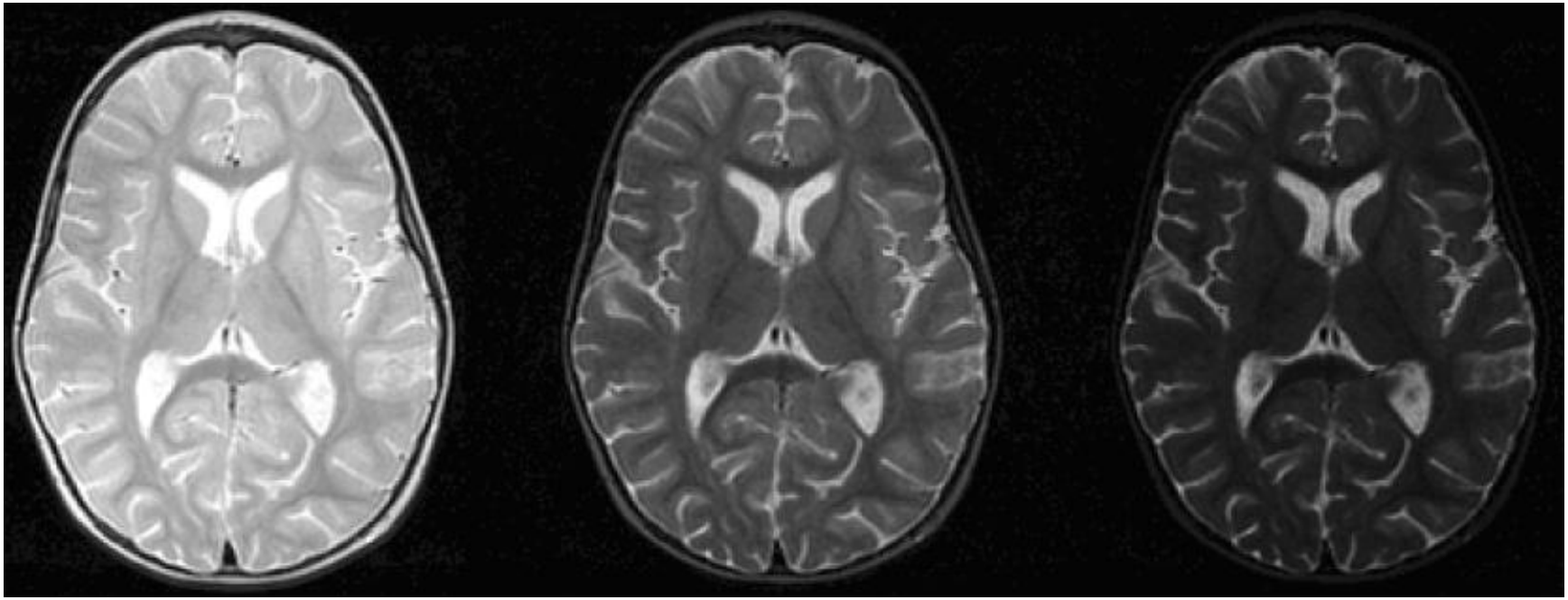




T_2-weighted Image



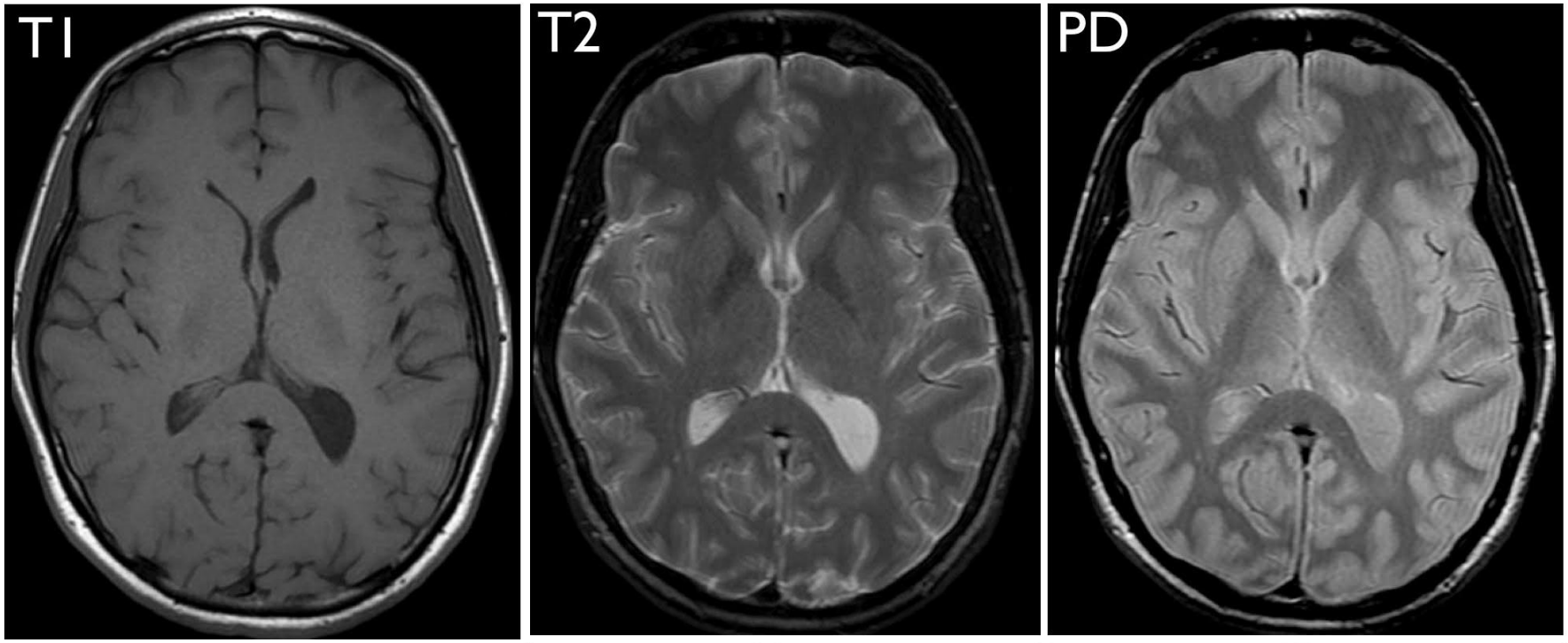
Effects of TE on T2 contrast



TE = 30ms TE = 90ms TE = 150 ms

所以短T2的白質很快就沒有訊號了
而長T2的腦脊髓液可以撐比較久！

T1/T2/PD權重影像

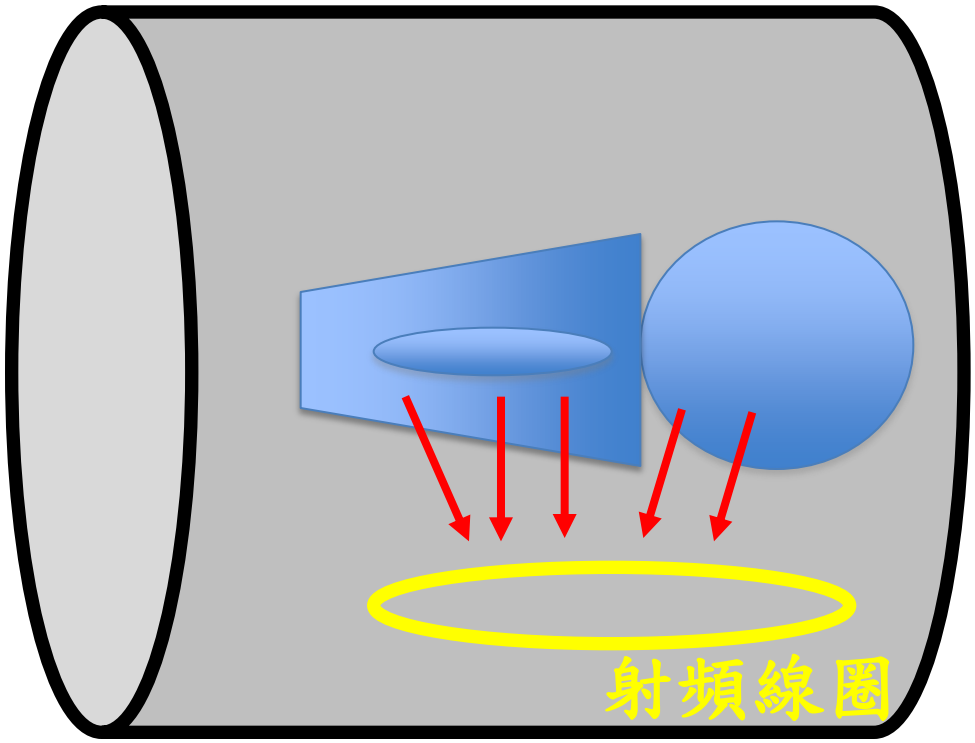


Short TR / Short TE　　LongTR / Long TE　　LongTR / Short TE

- http://knol.google.com/k/brain-ct-mri#

MRI之成像原理

如何將NMR信號變成影像?

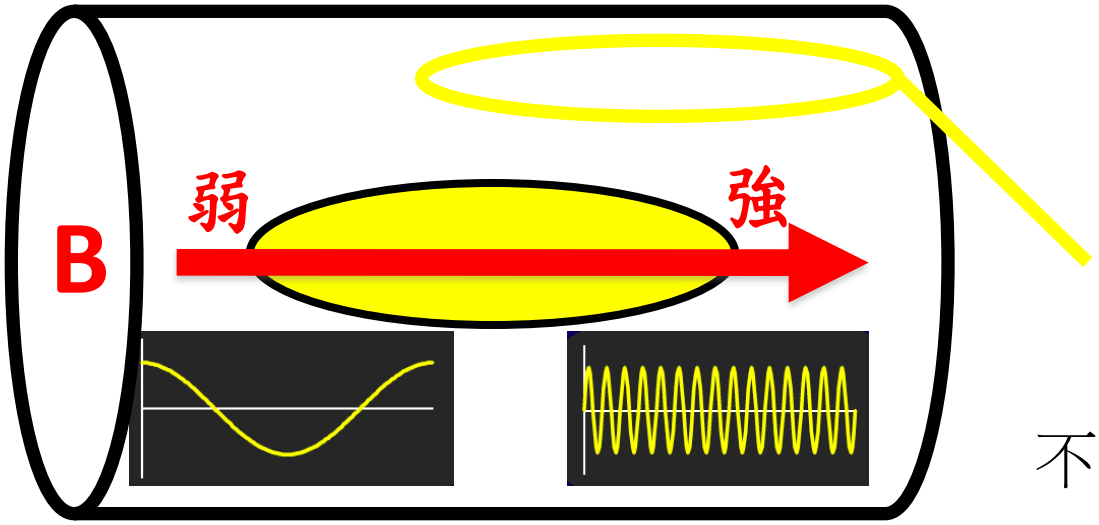


信號混在一起了，要如何將其分開，並獲得空間中之資訊呢?

我們所收到之信號包含了所有被激發的磁旋

影像空間編碼基本原理

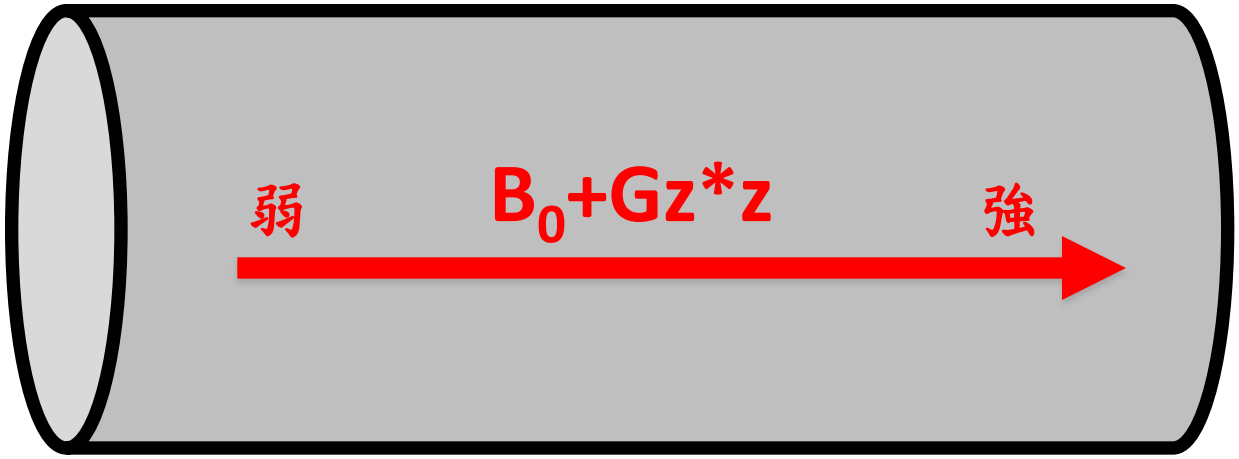
- 在不同的空間位置中創造不同的旋進頻率
  - 讓空間位置中有不同的磁場強度B
  - 因為ω = γB，共振頻率隨位置而異
  - 信號中不同頻率的成份即代表來自不同位置的信號



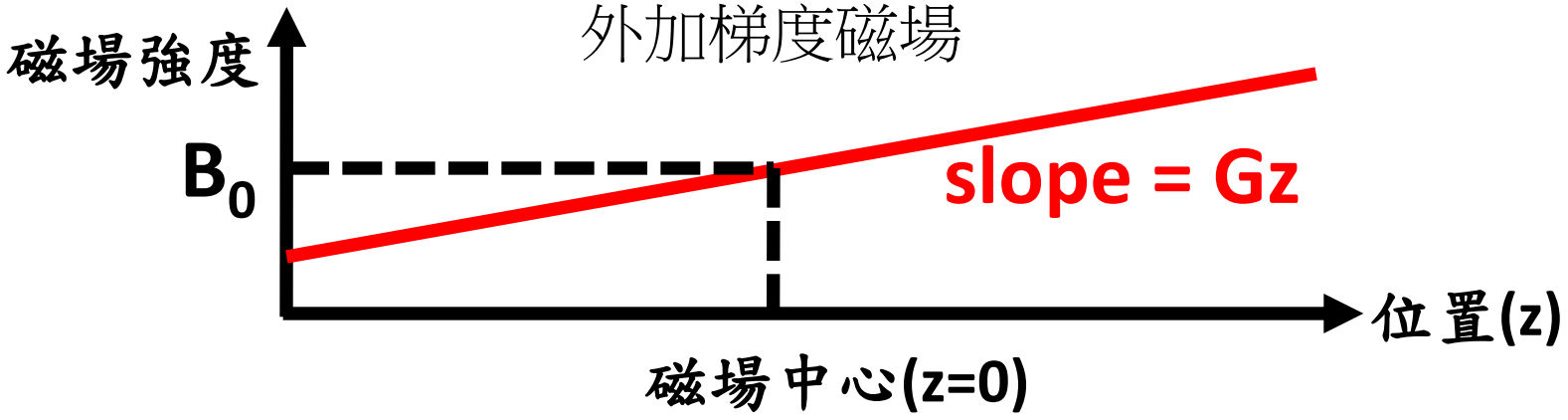
不同頻率加成的RF訊號

梯度磁場(以z方向為例)

- 梯度磁場 (Magnetic field gradient)

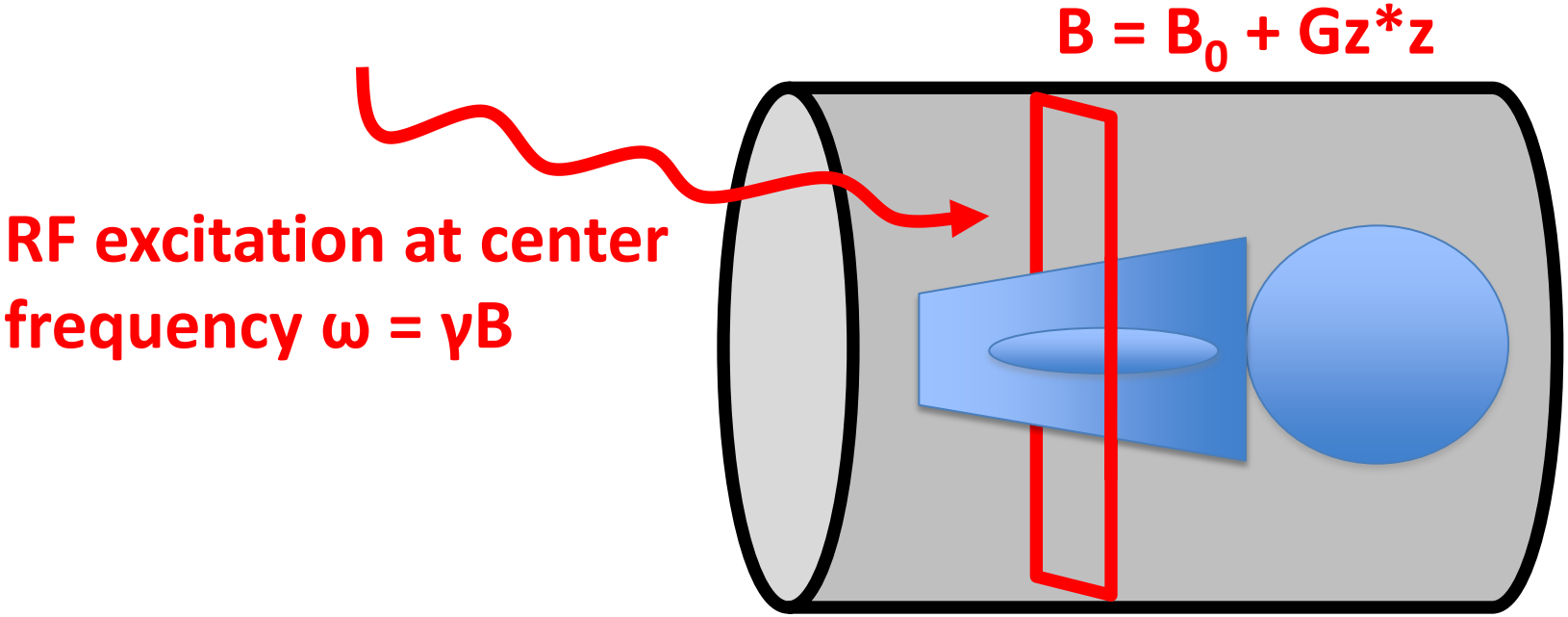


外加梯度磁場

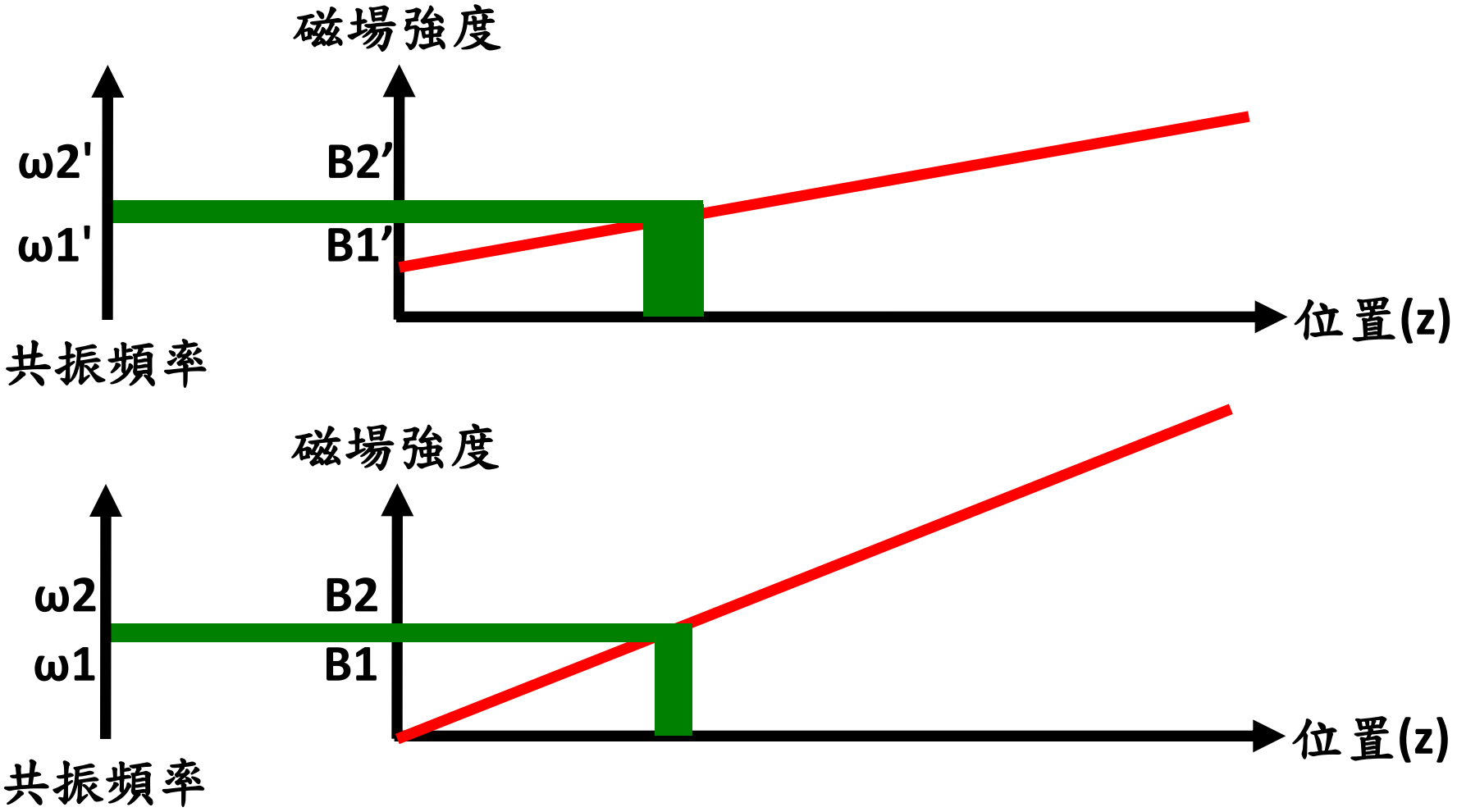


切面選擇性激發

- Slice-selective excitation
- 概念 - 在梯度磁場開啟的同時，只激發對應某一截面之頻率範圍(bandwidth, BW)



切面解析度與梯度磁場間的關係

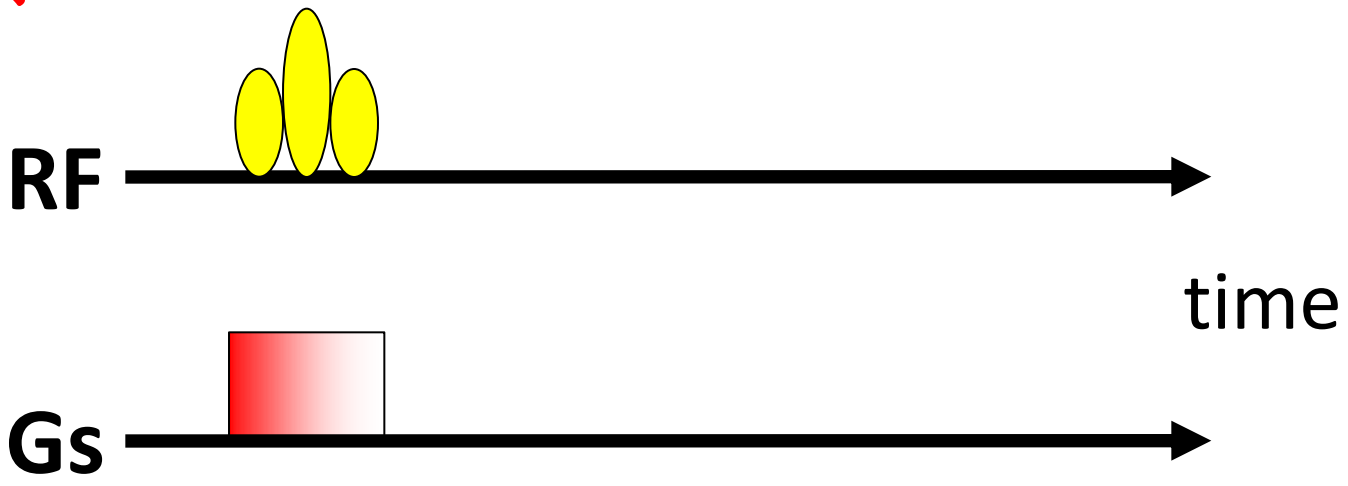


切面方向(slice orientation)

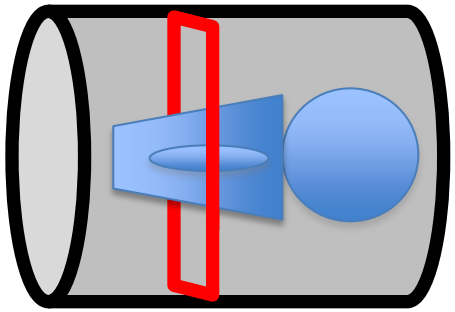
- 切面可為任意方向
  - **Axial (Gz), Coronal (Gx) and Sagittal (Gy)**
- 且可為任意角度(Oblique)
  - **同時打開兩個方向之梯度磁場**
- 亦可作非選擇性之激發
  - **激發時不開梯度磁場即可**

脈衝序列

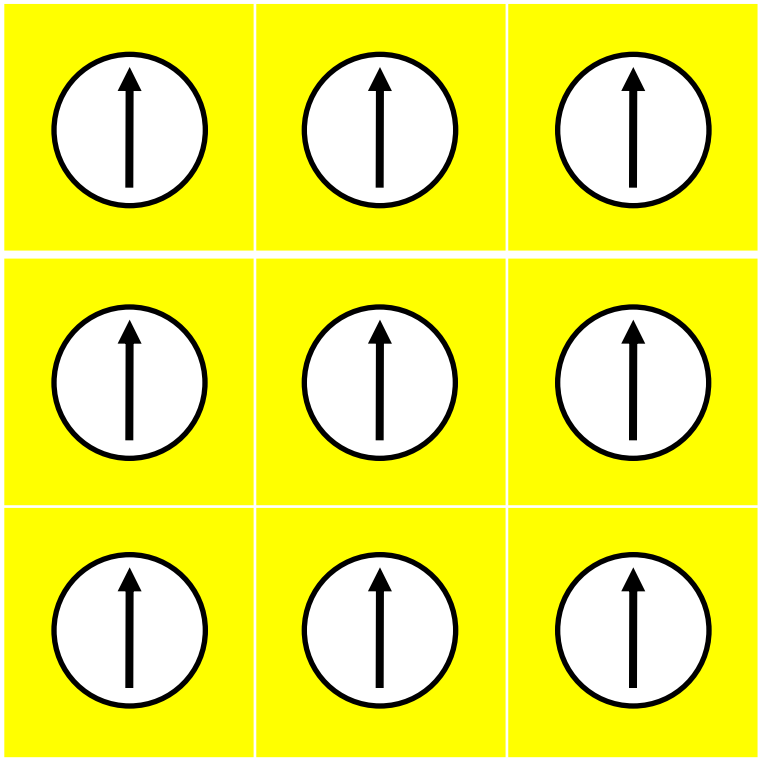
- **P**ulse **S**equence **D**iagram (PSD)
- 脈衝序列
  - 控制磁振造影系統如何執行射頻激發以及梯度磁場開啟之時序、強度、時間以及資料擷取之程序



範例:切面



原始影像強度

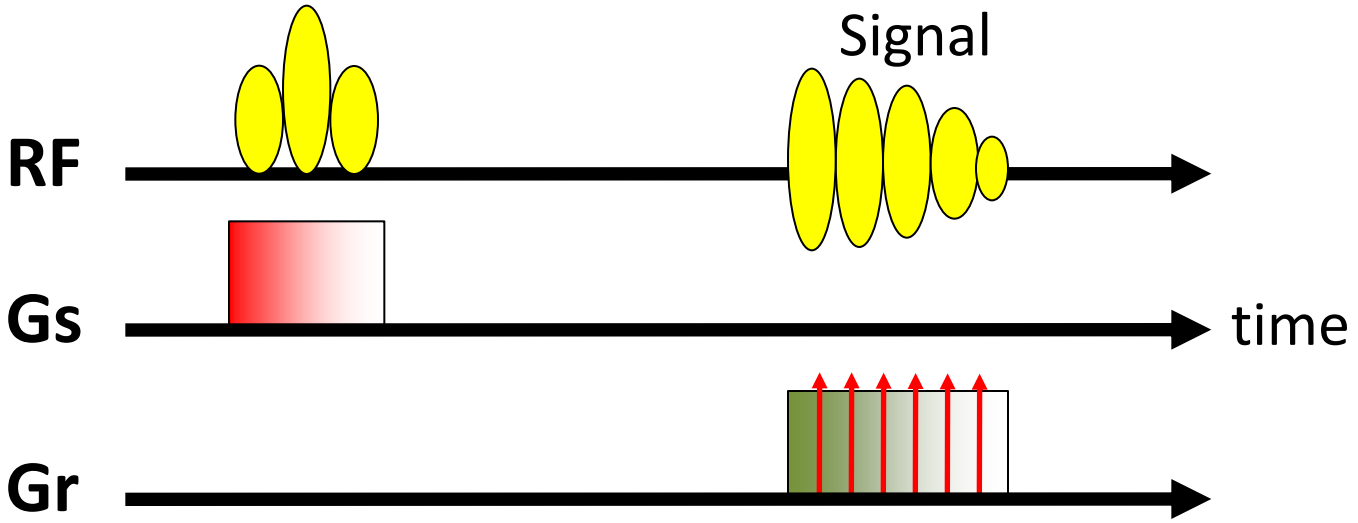


Assign frequency ω

- Hashemi et al., MRI the basics

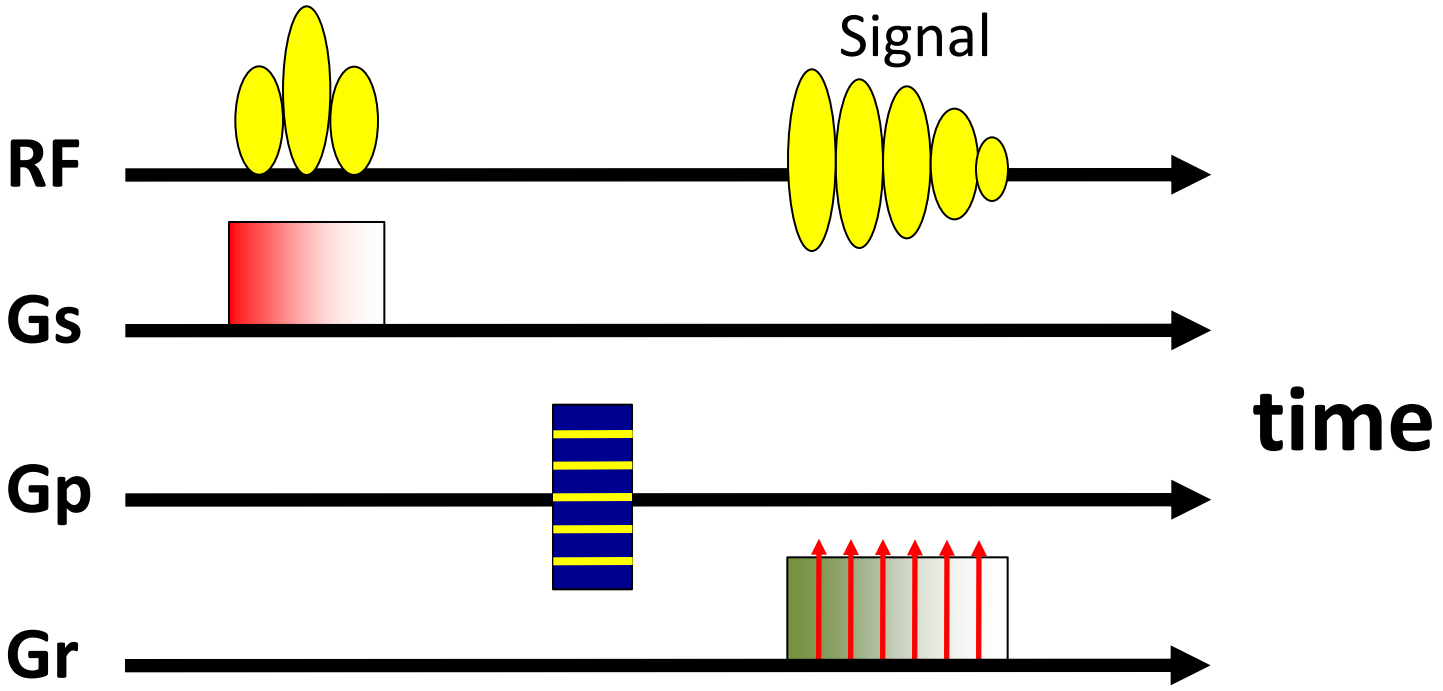
頻率編碼

- 想法
  - 在採集訊號的時候，打開頻率編碼方向之梯度磁場(Gr)，一樣利用梯度磁場造成readout方向上之磁場強度變化

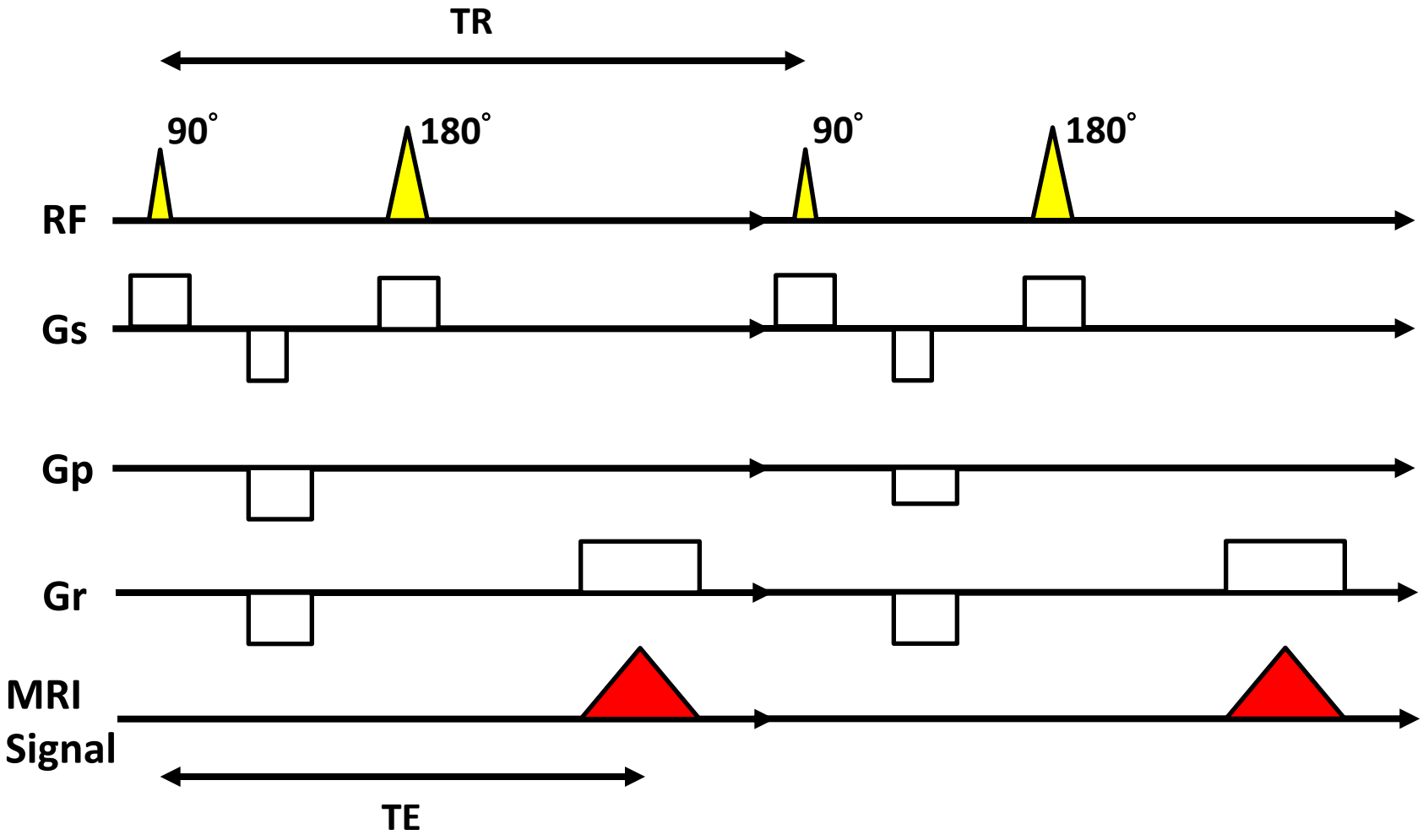


相位編碼

- 想法
  - 在頻率編碼開始之前，開啟一相位編碼方向之梯度磁場(Gp)，沿此方向，讓不同位置的磁旋有不同的起始相位，藉此製造空間中之差異性



一個完整的MRI成像序列

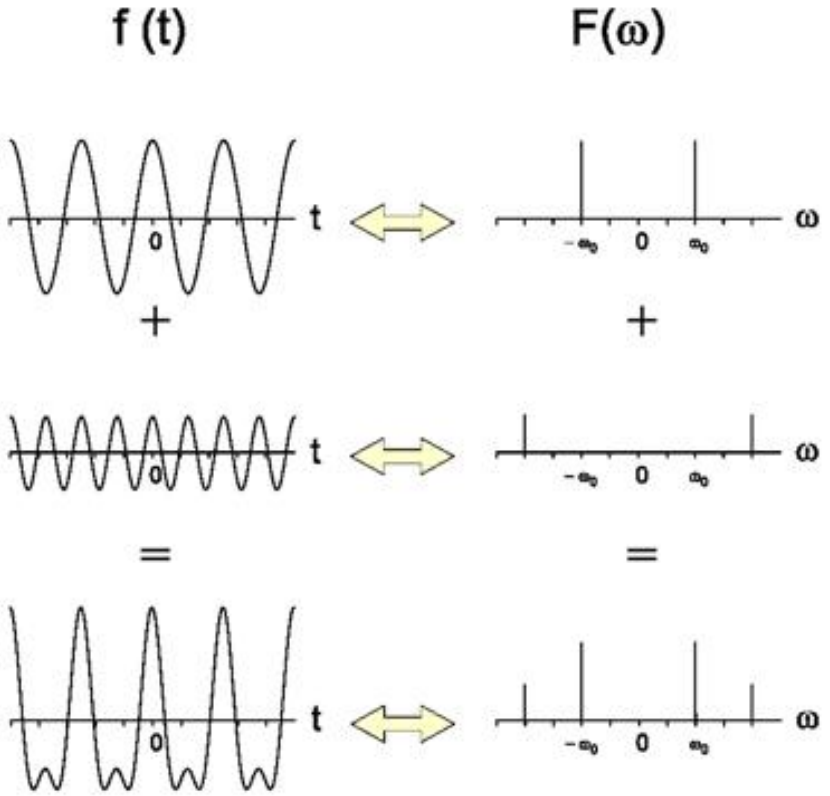


What is k-space?

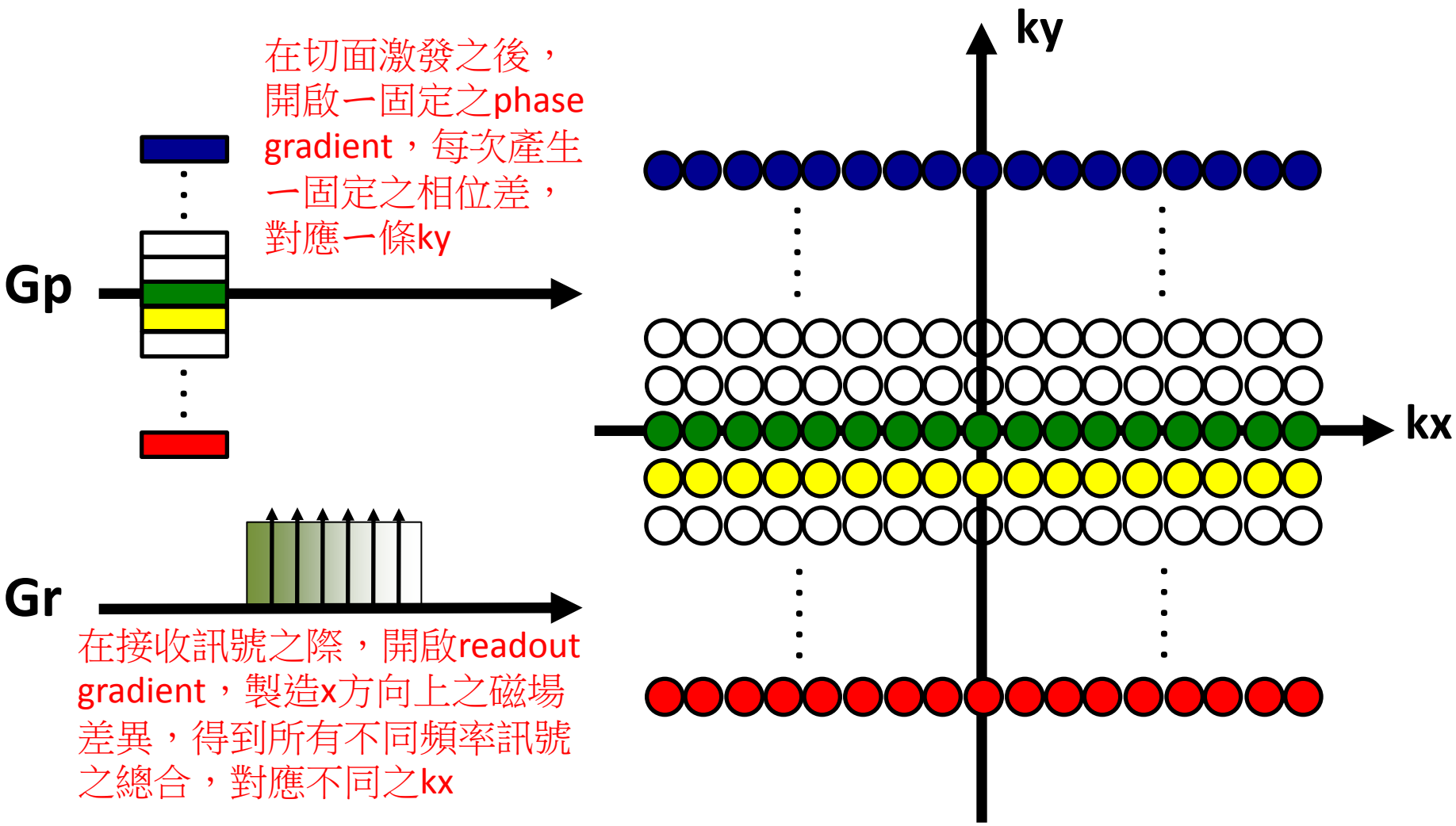
- 有了各方向之編碼方式之後，便能夠將所採集的資料填到適當的空間中產生影像，此空間即為k-space
- 平常所看到的影像與k-space為一傅立葉共軛空間對(Fourier pair)
  - 經由傅立葉轉換可將k-space資料轉換為影像
- 實驗中採集到的資料為複數(complex)之k-space資料，並非為常見之影像強度(magnitude)

Fourier Transform

- 可分解訊號中所含不同頻率成份之強度
- 時域 (time) *vs.* 頻域 (frequency)



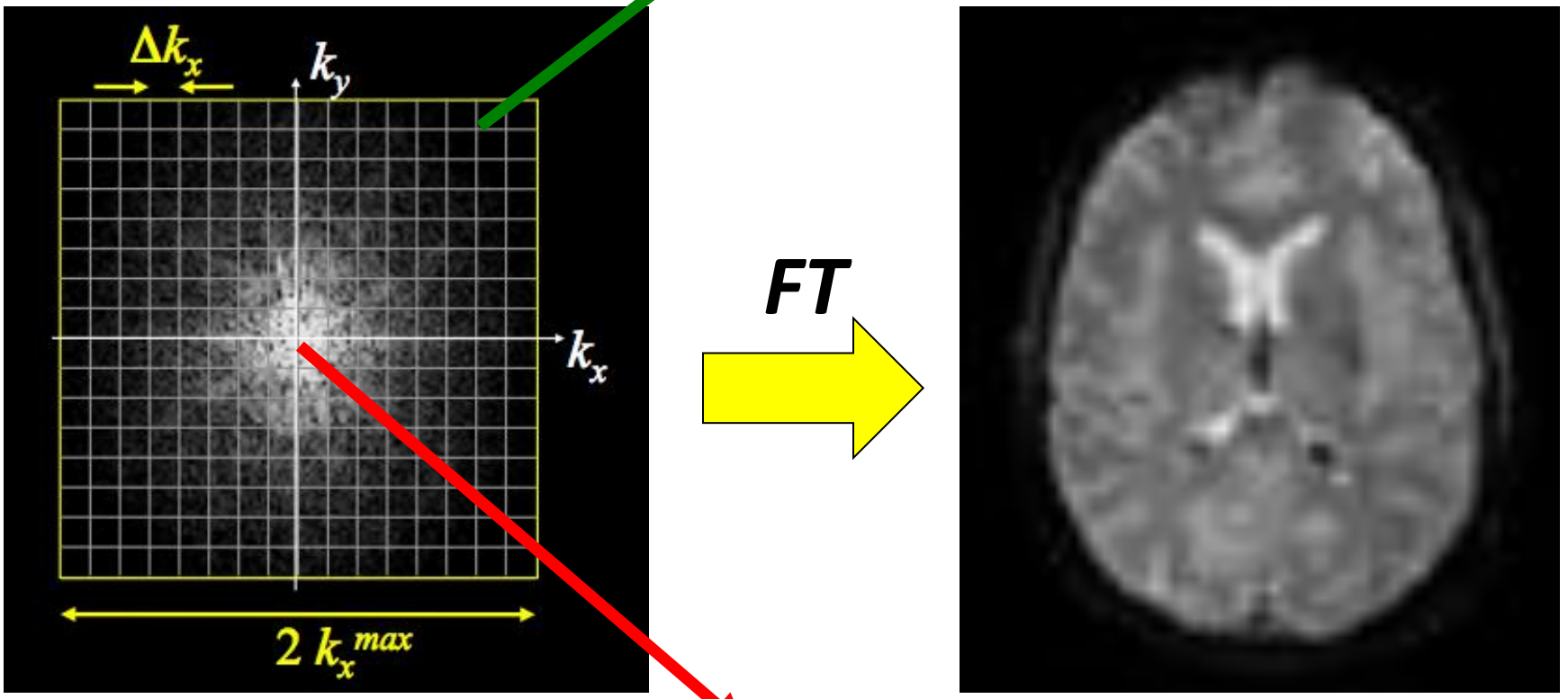
How to fill k-space?



Contrast and Detail

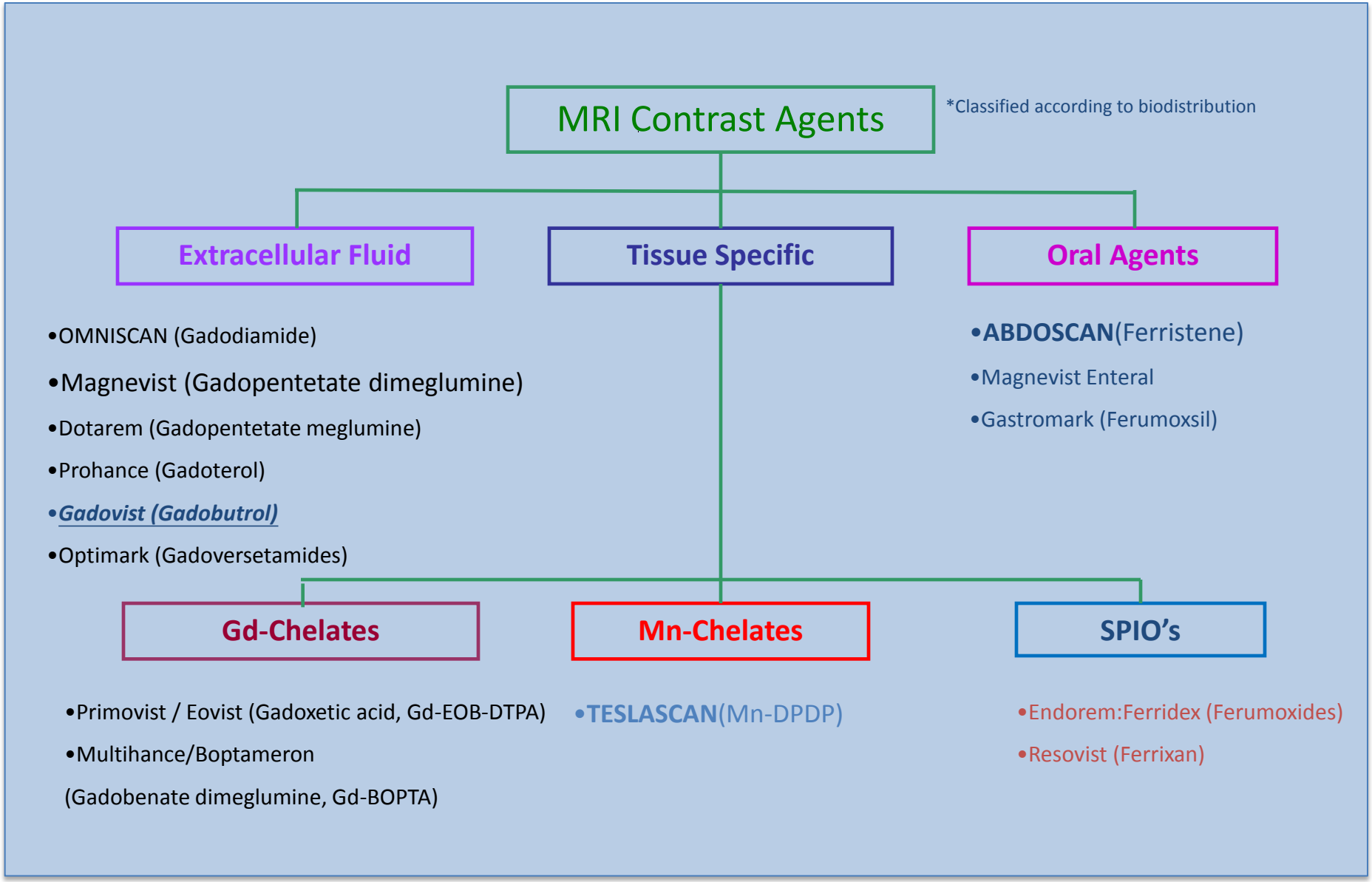
- http://practicalfmri.blogspot.com

Transform k-space to image



- *http://practicalfmri.blogspot.com*

MRI CM 的分類: 依據生體分佈的特性



Brand name	Chemical name	Structure	Comments
Magnevist®	gadopentetate (Gd-DTPA)	linear ionic	Oldest agent (FDA approved 1988) with historically largest world-wide market share and clinical experience; below average relaxivity; probable ↑risk NSF
MultiHance®	gadobenate (Gd-BOPTA)	linear ionic	Highest relaxivity of all extracellular gadolinium agents due to transient protein binding; 3-5% hepatocyte uptake; competitive inhibitor for cMOAT drugs (tamoxifen, methotrexate, cisplatin); QT prolongation
Omniscan™	gadodiamide (Gd-DTPA-BMA)	linear nonionic	Low thermodynamic stability; disproportionately ↑risk NSF; may interfere with serum Ca^{++} measurements
Optimark™	gadoversetamide (Gd-DTPA-BMEA)	linear nonionic	Low thermodynamic stability; probable ↑risk NSF; may interfere with measurements of serum Ca, Fe, Cu, and Zn
Dotarem®	gadoterate (Gd-DOTA)	macrocyclic ionic	One of oldest agents with largest market share in Europe; most recent entry (2013) into US market
ProHance®	gadoteridol (Gd-HP-DO3A)	macrocyclic nonionic	Lowest osmolality and viscosity of all agents; below average relaxivity
Gadavist®	gadobutrol (Gd-BT-DO3A)	macrocyclic nonionic	Highest viscosity due to 1.0M formulation (all others 0.5M); above average relaxivity; marketed as Gadovist® outside the US
Eovist® (USA) Primovist®	gadoxetate (Gd-EOB-DTPA)	linear ionic	Designed for liver imaging; ~50% uptake by hepatocytes after initial extracellular phase; joint renal & biliary excretion; very high relaxivity due to size and transient protein binding; may interfere with serum Fe measurements; QT prolongation
Ablavar®	gadofosveset (Gd-DTPA-DCHP) (MS-325)	linear ionic	Highest relaxivity of any agent due to reversible albumin binding; intended for MRA; steady-state blood pool imaging 20 min – 4 hrs after injection; long elimination half-life (16+ hrs); QT prolongation

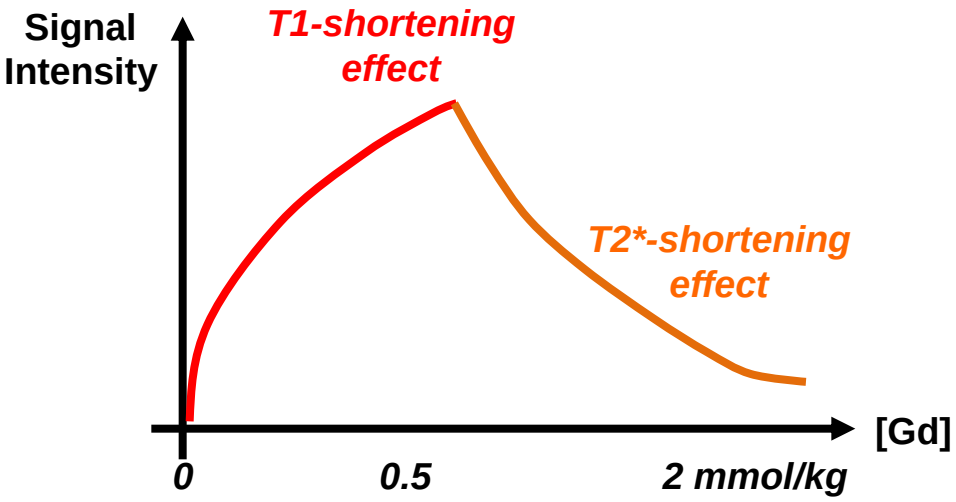
http://mri-q.com/so-many-gd-agents.html

Brand Name	Osmolality (mOsm/kg)	Viscosity (cP)	Stability (log K_{eq})	T1 Relaxivity (L/mmol-s)	Elimination Half-Life (hr)	Dose (mmol/kg)
Magnevist®	1960	2.9	22.5	4.1	1.6	0.1
MultiHance®	1970	5.3	22.6	6.3	1.6	0.1
Omniscan™	789	1.4	16.9	4.3	1.30	0.1
Optimark™	1110	2.0	16.6	4.7	1.73	0.1
Dotarem®	1350	2.4	25.8	3.6	1.6	0.1
ProHance®	630	1.3	23.8	4.1	1.57	0.1
Gadavist®	1603	5.0	21.8	5.2	1.81	0.1
Eovist®	688	1.2	23.5	6.9	0.93	0.025
Ablavar®	825	2.7	22.1	16	16.3	0.03

http://mri-q.com/so-many-gd-agents.html

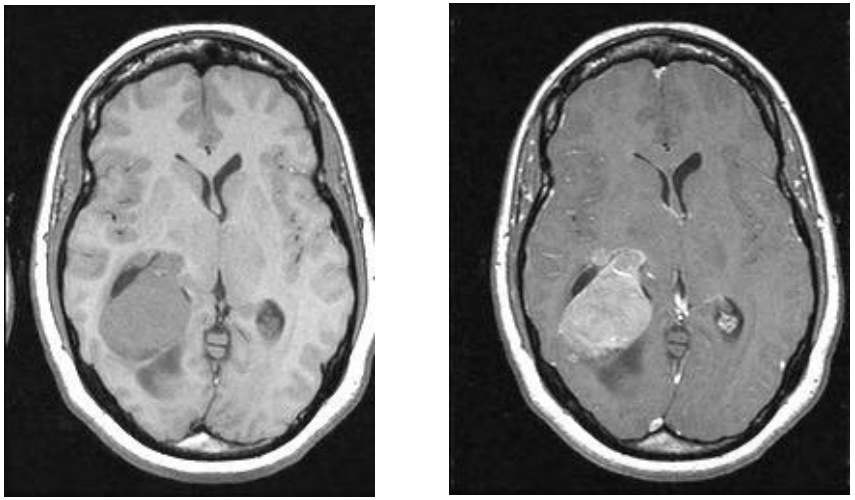
MRI Contrast Agent

- Paramagnetic agents (with unpaired electrons), e.g. Gd-DTPA
  - ***Gd has 7 unpaired electrons, fluctuating around metal and creating dipole-dipole effects – to promote T1 relaxation***
- Gadolinium shortens both T1 and T2 $S = S_0(1 - e^{-TR/T1}) \times e^{-TE/T2}$
  - ***T1-shortening effect is dominant***
  - ***T2-shortening effect is observed around where high concentrations exist***
- $1/T1_{observed} = 1/T1_{tissue} + 1/T1_{contrast}$



- Moseley, 2005; Brown and Semelka, 2003

T1-weighted spin-echo images (a) before and (b) after administration of gadolinium-chelate contrast agent



(a) (b)

Gadolinium

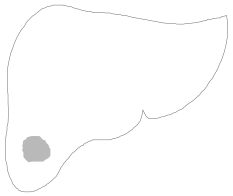
- Shortening of both T1 and T2 tissue relaxation time
- Extracellular gadolinium-containing contrast agents
- With ability to visualize vascular perfusion
  - To detect and characterize focal liver lesions

Liver specific contrast media

- Iron oxide-based
  - Specific for **RES** (ReticuloEndothelial System): Kupffer cells in liver
  - Superparamagnetic iron oxides (SPIO)
  - Signal loss in T2WI
    - ferumoxides (Endorem®)
    - ferucarbotran (Resovist®)

T2WI

- Manganese-based or Gadolinium-based
  - Specific for Hepatocytes
  - Signal rise in T1WI
    - Manganese-based: Mn-DPDP (Teslascan®)
    - Gadolinium-based: Gd-BOPTA (Multihance®), Gd-EOB-DTPA (Primovist®)

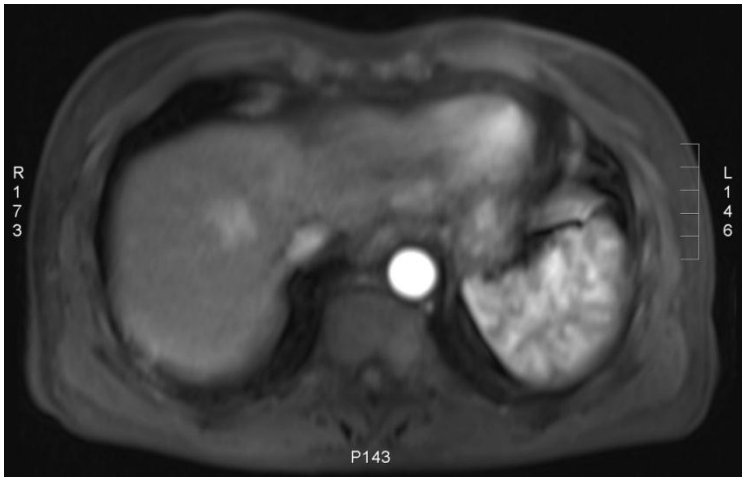


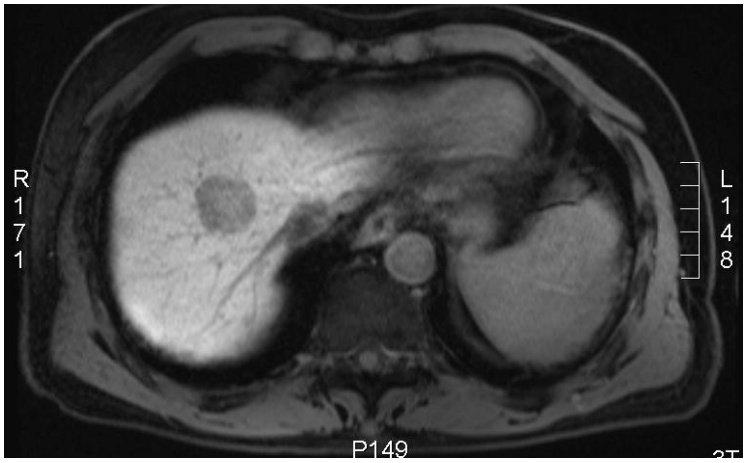
T1WI

Primovist®-enhanced MRI

Dynamic Vascular Phase + Hepatocyte-specific Late Phase

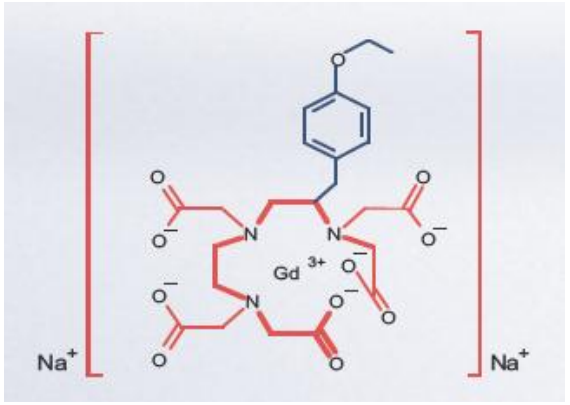
- Dynamic perfusion information comparable to extracellular Gd-containing contrast media (ECCM)
  - lesion characterization ↑
- Highly hepatocyte-specific phase in T1W imaging: improved signal-to-noise ratio and contrast-to-noise ratio
  - lesion detection ↑
  - lesion characterization (specific enhancement pattern) ↑
- Information on vasculature and tumor/vascular – relationship
  - pre-operative planning ↑



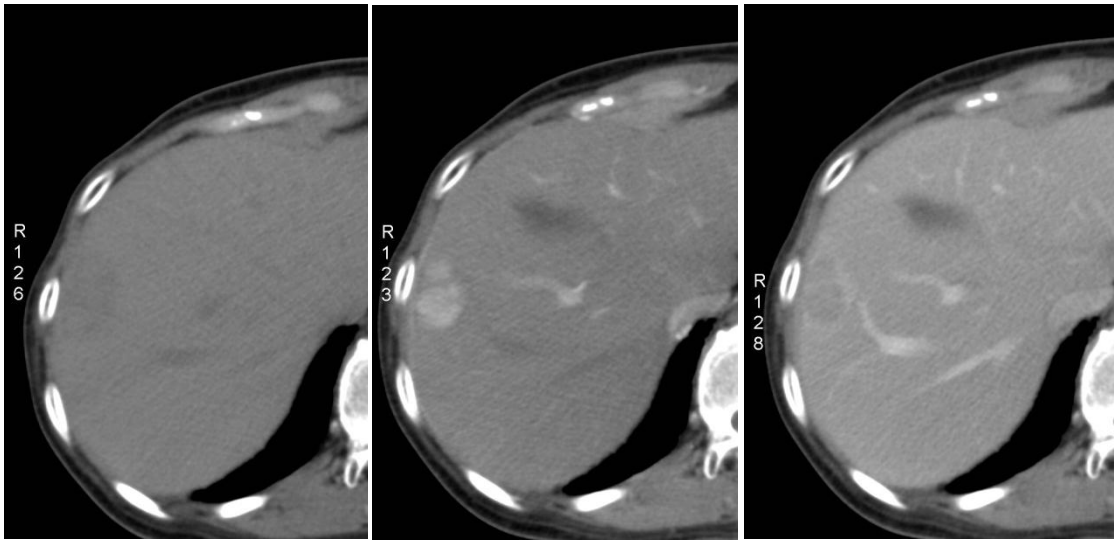


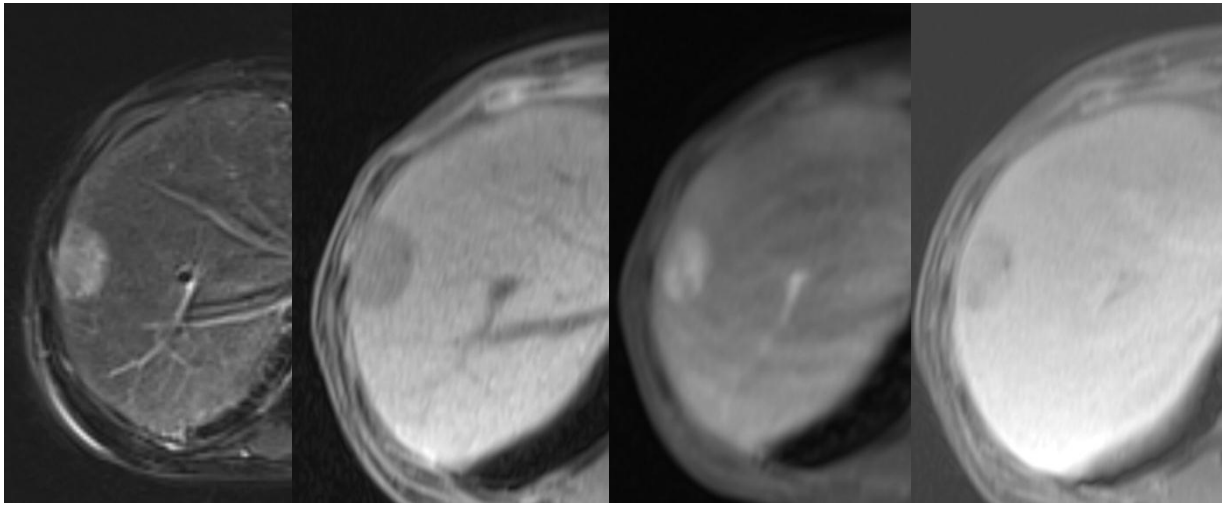
Primovist® – Gd-EOB-DTPA – Product Features

- Gadoxetic acid disodium salt, Gadoxate disodium, Gd-EOB-DTPA, Primovist, Eovist
- Gd: paramagnetic component
- EOB: lipophilic Ethyl-Oxy-Benzyl
  - Biliary excretion
  - High protein binding: ~10%

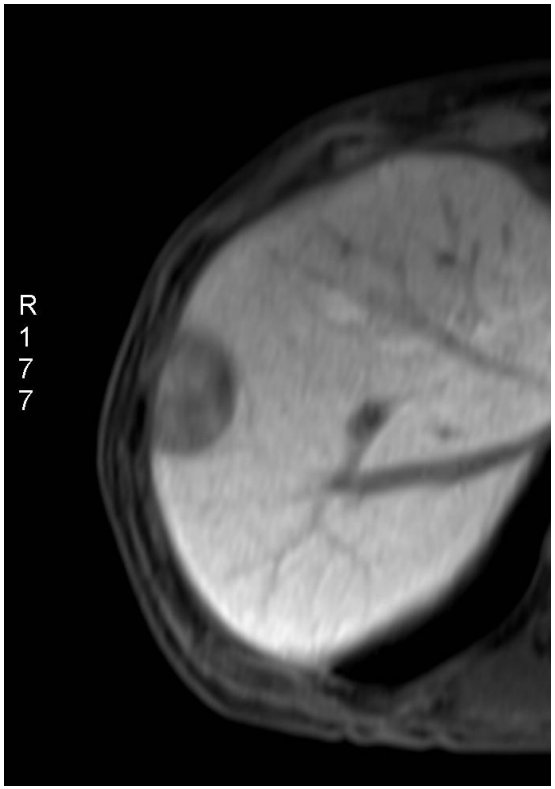


66F





Typical HCC

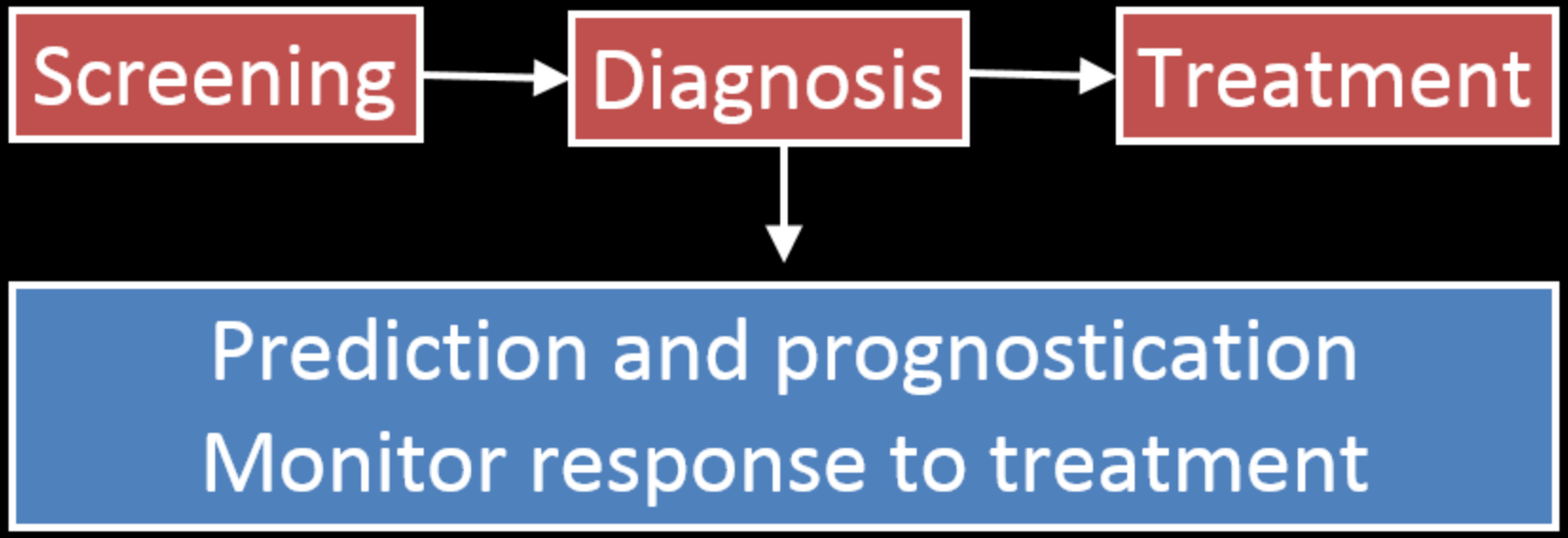


S/P OP: Gr.2 HCC

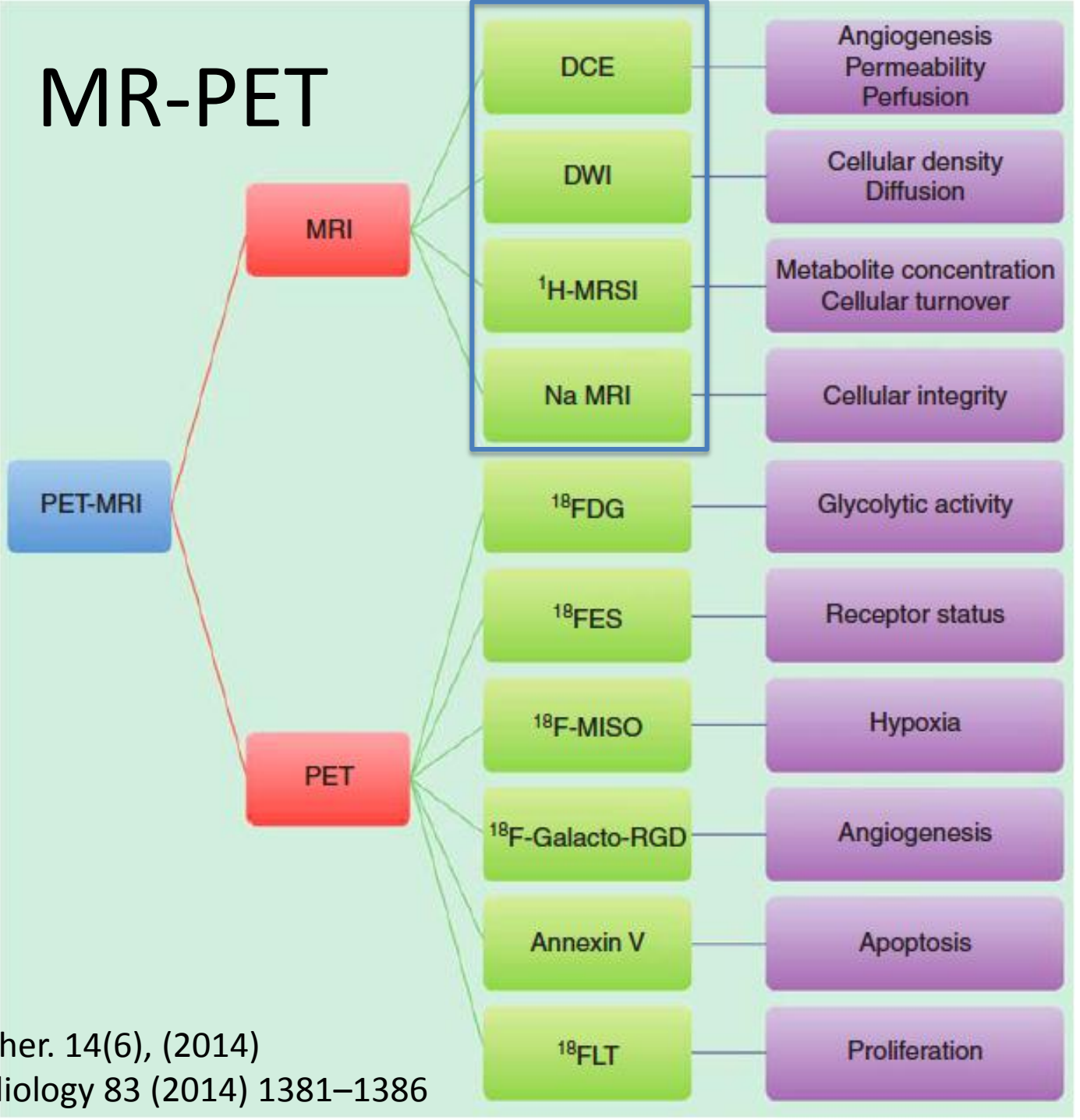
Biograph mMR

- Simultaneous acquisition of MR and PET
- Fully integrated PET detector architecture
- Largest PET FOV in the industry
- Powerful 3T MRI
- Faster exams through simultaneous acquisition

Role of MR PET imaging in breast cancer



MR-PET



Medicine 93(22):e115
Expert Rev. Anticancer Ther. 14(6), (2014)
European Journal of Radiology 83 (2014) 1381–1386

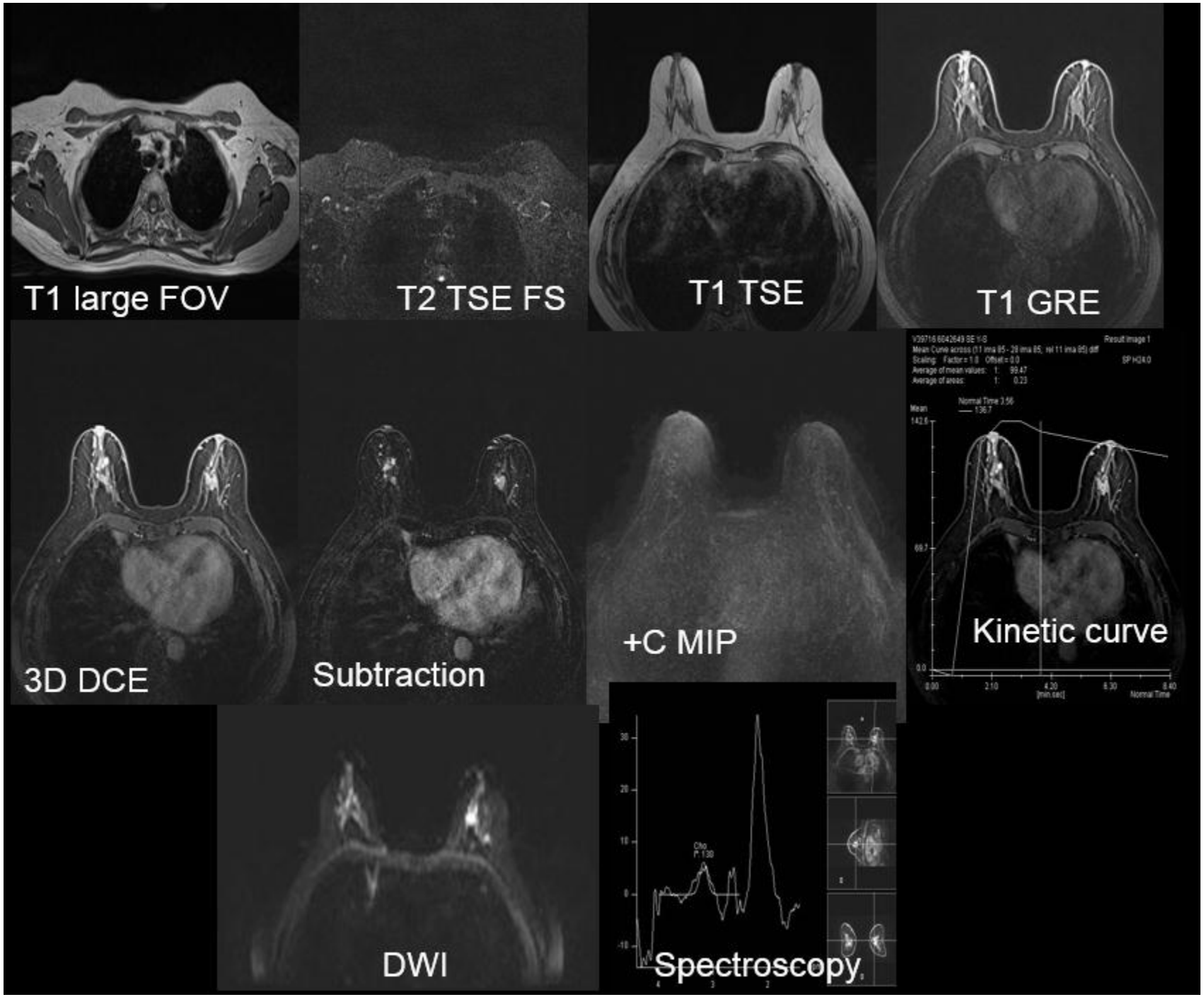
Protocol

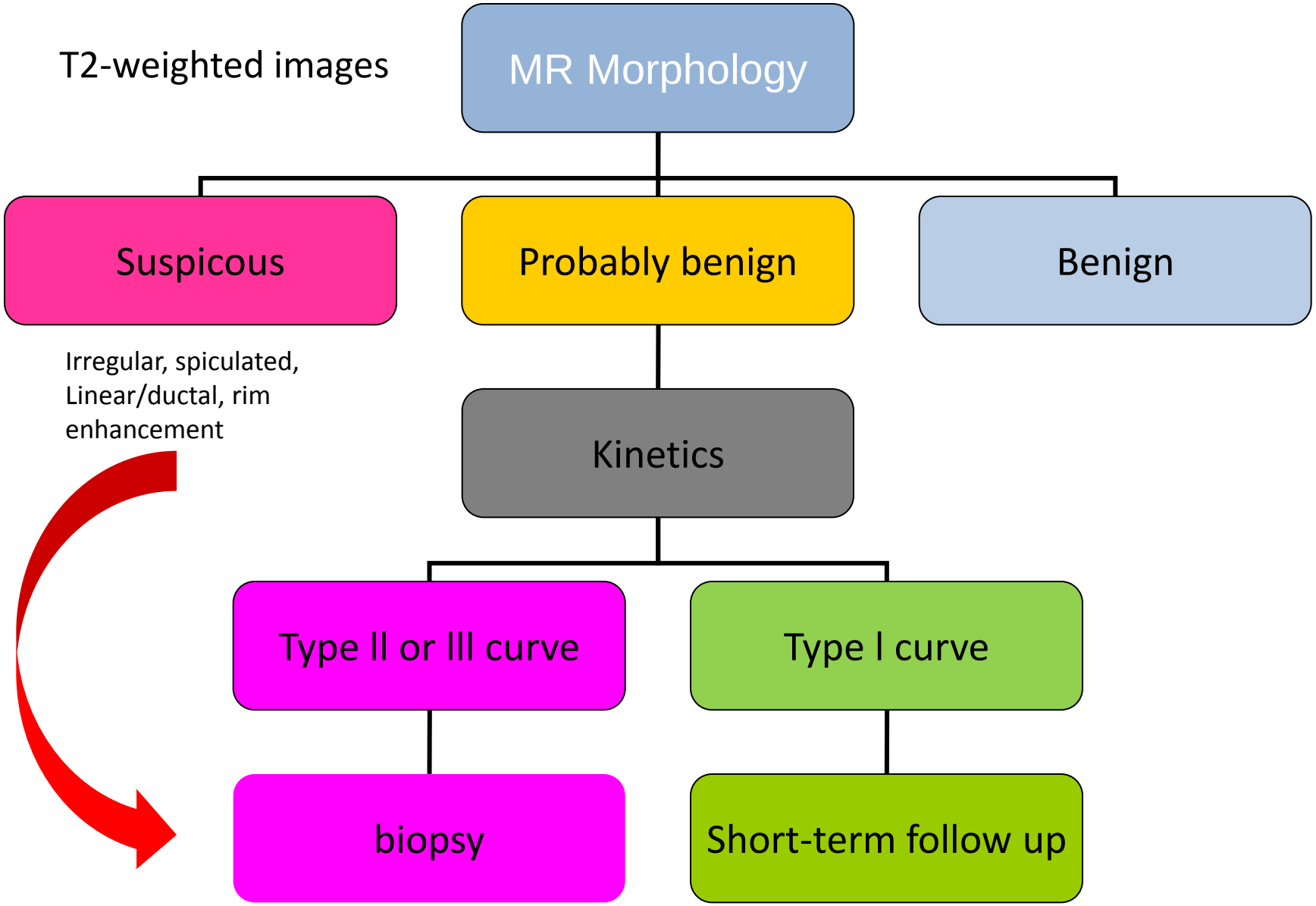
400 ± 56 MBq
18F-FDG
injection

Gd injection

Total time: 64.6 min

MR	Breast		Whole body (head-thigh)
	AC for breast (DIXON) Ax T2 TSE fs Ax T1 TSE Ax DWI/ADC (b0, 50, 600, 1000) +/- MRS	Ax DCE (4+2)	AC for WB (DIXON) Cor VIBE fs Ax VIBE fx Cor STIR Ax HASTE fs AC for brain Ax FLAIR, VIBE for brain
PET	1 bed 8min		4 bed 3min/bed
Position	Prone		Supine


T1 large FOV
T2 TSE FS
T1 TSE
T1 GRE
3D DCE
Subtraction
+C MIP
Kinetic curve
DWI
Spectroscopy

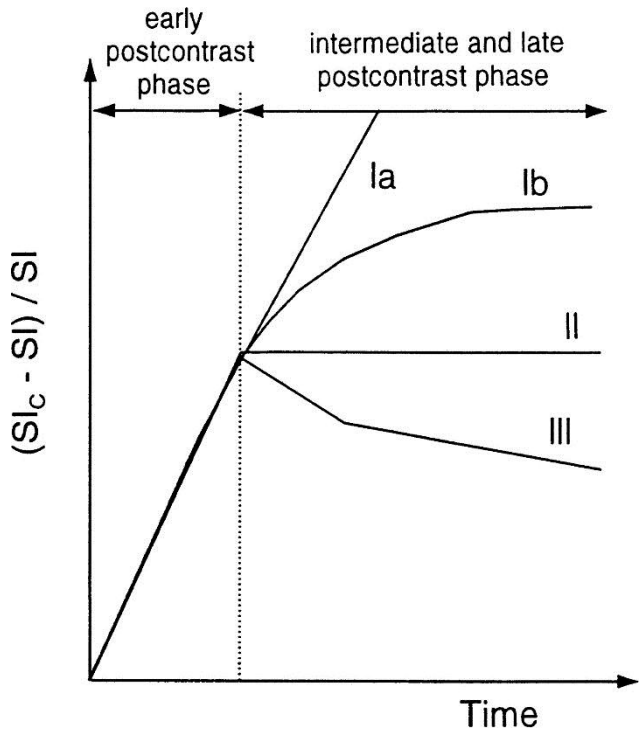


Morris EA, Liberman L. Breast MRI 2005, p77

Multi-parametric imaging

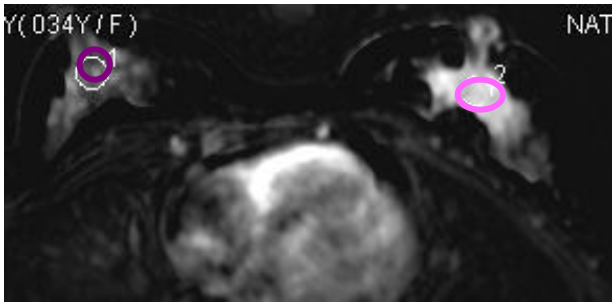
- DCE MRI
  - Ktrans,kep, ve, vp
  - IAUC
- Diffusion weighted (DW) MRI
  - Water restriction
  - ADC
  - IVIM (intravoxel incoherent motion)
- Metabolism
- PET (FDG18 or other tracers)

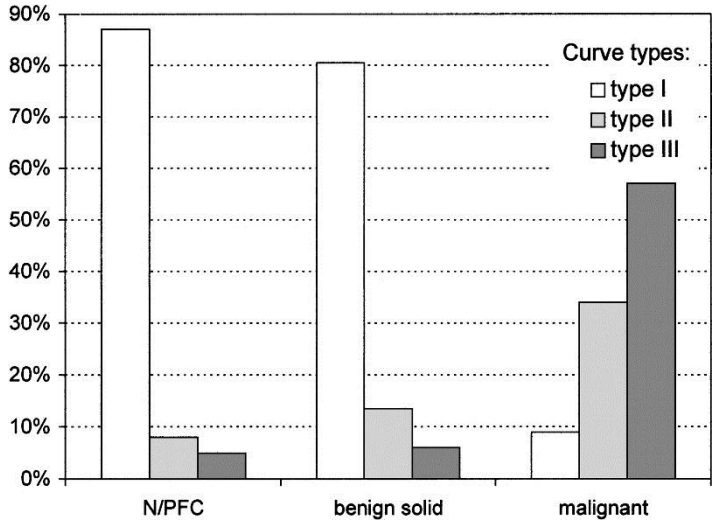
Time signal curve in DCE MRI



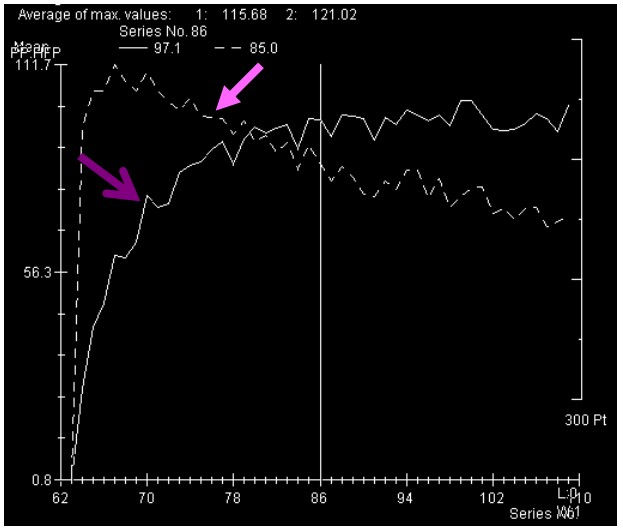
Fibrocystic change vs. Breast cancer

Right normal Left cancer





signal



time

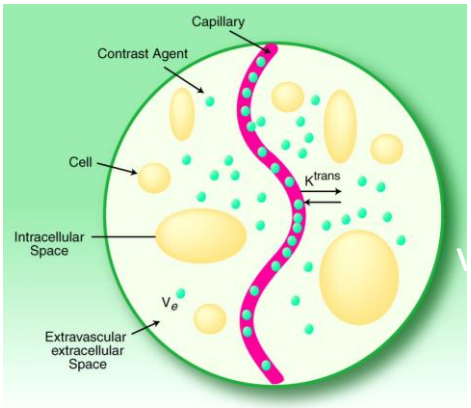
Kuhl, C. K. et al. Radiology 1999;211:101-110

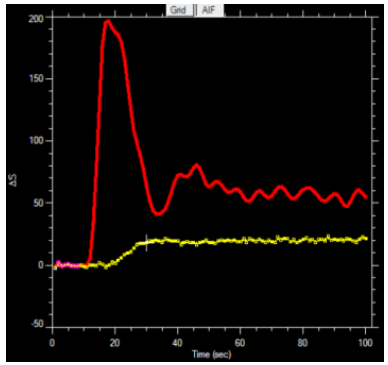
Two-compartment model

$$C_t(t) = K^{trans} \int_0^t C_p(T) e^{\frac{-K^{trans}}{v_e}(t-T)} d(T) + v_p C_p(t)$$

,

$$k_{ep} = \frac{K^{trans}}{v_e}$$





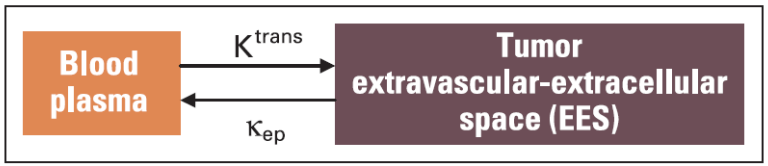


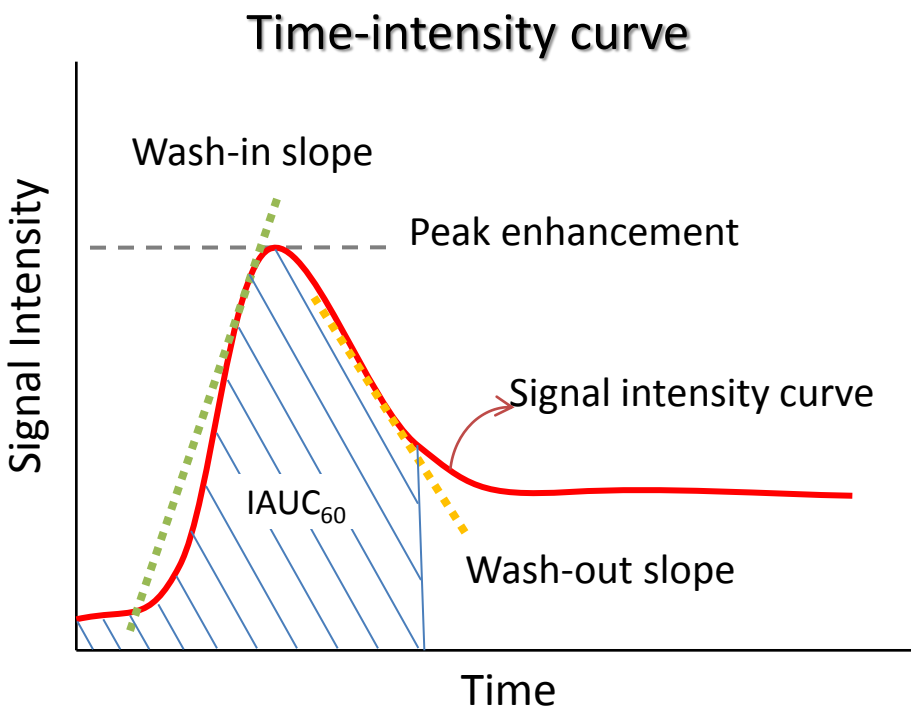
Fig 1. A generalized tracer kinetic model applied to dynamic gadolinium-enhanced magnetic resonance imaging (MRI) is used to estimate three physiologic parameters: (a) volume transfer constant (K^{trans}) between the blood plasma and EES, (b) volume of EES per unit volume of tissue (υ_e), and (c) flux rate constant between the EES and plasma, κ_{ep} ($\kappa_{ep} = K^{trans}/\upsilon_e$).

Jackson A et al. Clin Cancer Res 2007;13:3449
Tofts PS. J Magn Reson Imaging 1999;10:223.
Hylton N. J Clin Oncol 2006; 24: 3293

K^{trans}	Volume transfer constant between plasma and EES	min^{-1}
k_{ep}	Rate constant between EES and plasma	min^{-1}
C_p	Tracer concentration in arterial blood plasma	mmol/L
$C(t)$	Concentration of contrast agent at time t in each voxel	mmol/L
V_e	Volume of EES per unit volume tissue	None
V_p	Blood plasma volume	None

Contrast agent/ dynamic T1-weighted imaging

Conventional Curve Analysis



1. Maximum peak enhancement
2. First transit slope(wash-in slope)

Represent the mean velocity of increased intensity per second from contrast agent entry time to early peak.

3. Washout phase (wash-out slope)

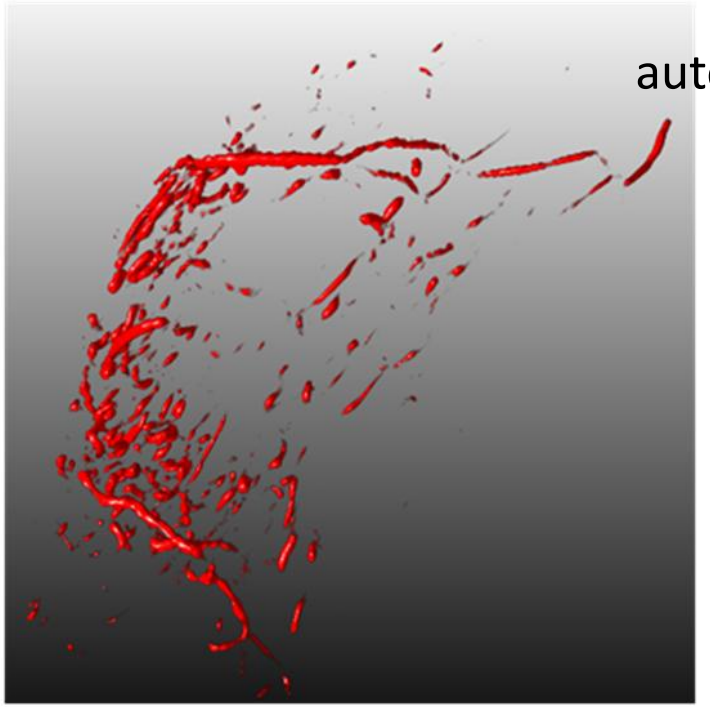
Assess the changes in intensity per second after the early peak.

4. Initial area under curve ($IAUC_{60s}$): First 60s integral of the contrast-enhancement time curve. One of the indices of tissue perfusion.
5. Mean enhancement

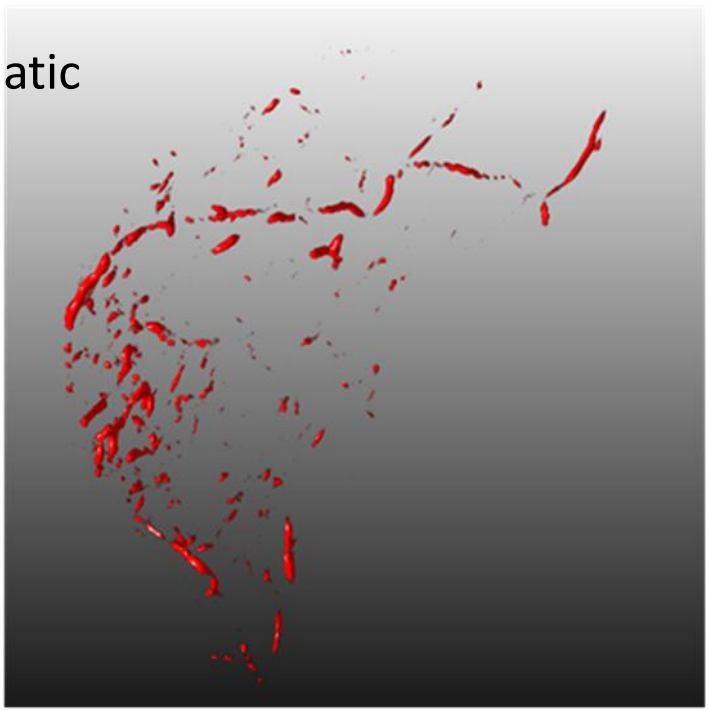
AUC: a mixed parameter, correlating with K^{trans}, v_e and v_p, and ultimately has an intractable relationship with all three. Not significantly affected by AIF

Vascular map from DCE MRI

automatic



Before chemotherapy



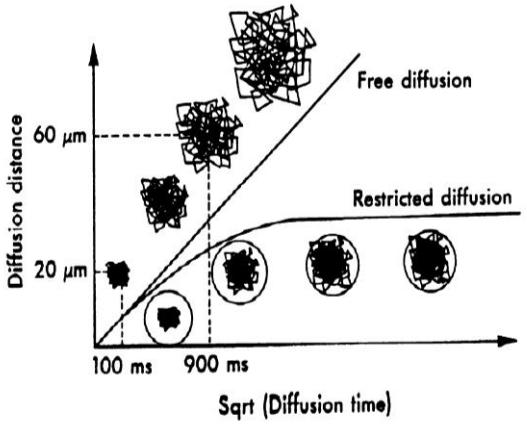
After chemotherapy

Breast segmentation
Line filter: Hessian matrix
Vessel skeleton after thinning
Vascular feature extraction

Combined vessel features and tumor size can provide the best diagnostic performance with accuracy, sensitivity and specificity improved to 83.87% (26/31), 88.24% (15/ 17), and 78.57% (11/14)

Courtesy from Professor Ruey-Feng Chang, NTU

Tissue cellularity vs. ADC (water mobility)



$$S = S_0 e^{-bD}$$

$$b = \gamma^2 g^2 (\Delta - \frac{\delta}{3})$$

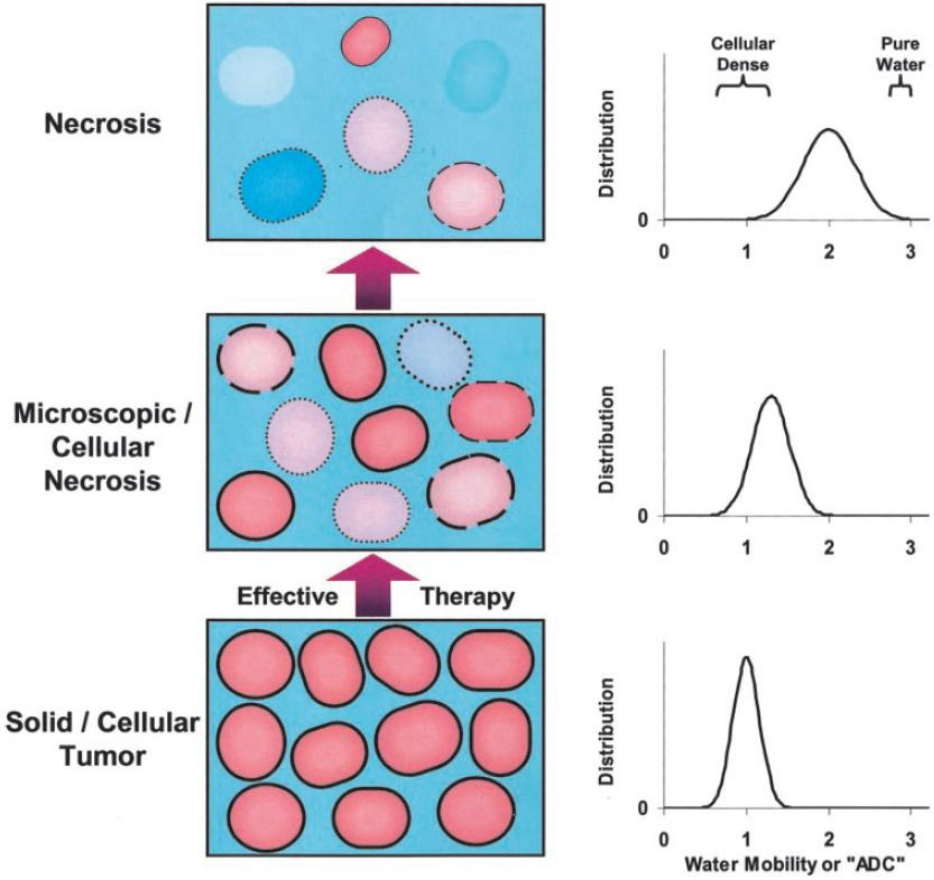
S_o: Reference signal; S: Diffusion signal

b: b value

D: Apparent Diffusion coefficient

g: diffusion gradient; δ: diffusion duration

Δ: diffusion time



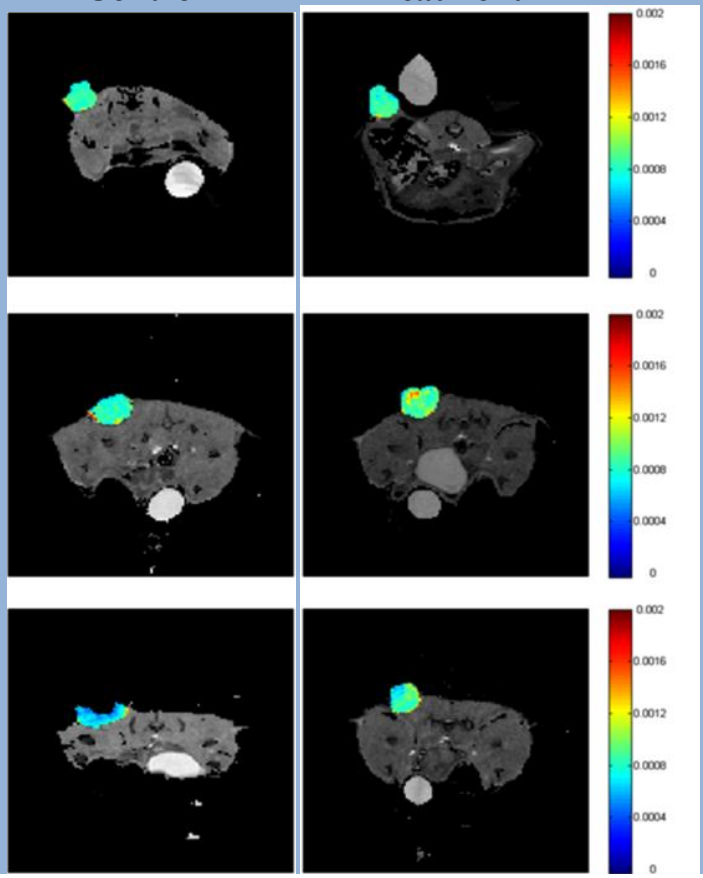
Ross BD, et al. Mol Cancer Ther 2003;2:581-587

ADC change during treatment

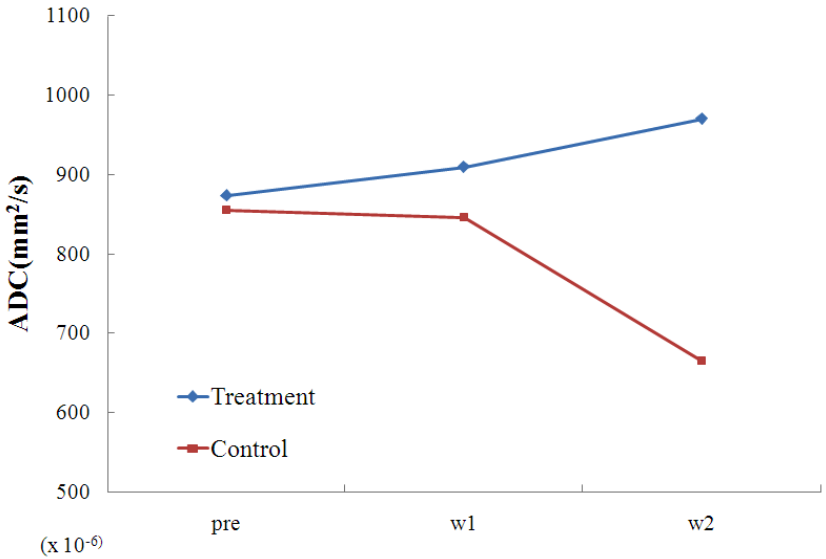
■ ADC map

■ ADC value

a)



b)



- Method: DW EPI
- TR: 3000ms
- TE: 29.5ms
- FOV: 4 X 4 cm
- MTX: 128 X128
- TA: 4mins
- Segment: 4
- B value: 1924.53 s/mm^2
- Average: 5

PET

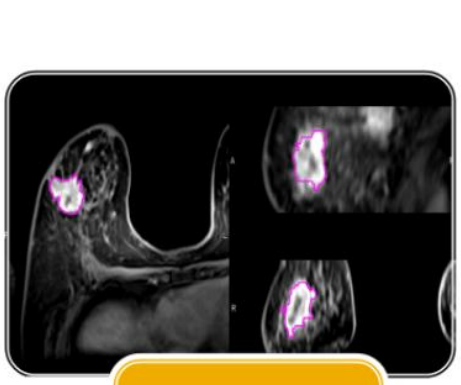
- SUV (standard uptake value)

$$\mathrm{SUV} = \frac{\text{tissue activity concentration(MBq/mL)}}{\text{injected dose(MBq)/ body weight(g)}} \times \frac{1}{\text{decay factor of } {}^{18}F}$$

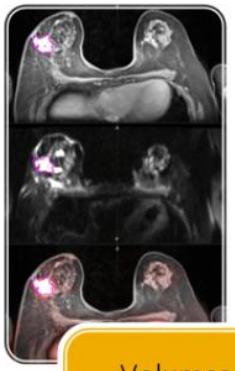
- MTV (metabolic tumor volume)
- TLG (Total lesion glycolysis)

$$\mathrm{TLG} = \mathrm{SUV}_{\mathrm{mean}} \times \mathrm{VOI}_{\mathrm{PET}}$$

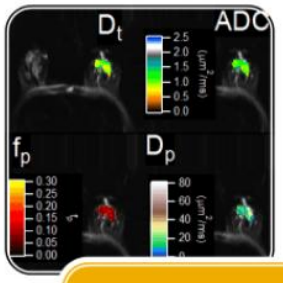
- DWI-PET registration to T1 VIBE
  - spatial distortion in DWI and small shifts in patient position over the scan (mean 5.6mm for DWI, 3.7mm for PET)



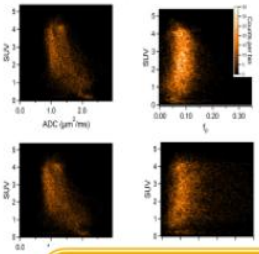
Index lesion contoured over its volume on T1 post (MIM)



Volumes co-registered using rigid body translation (MIM) and resampled to T1 resolution



ADC, IVIM, and co-registered SUV maps created (IGOR Pro)



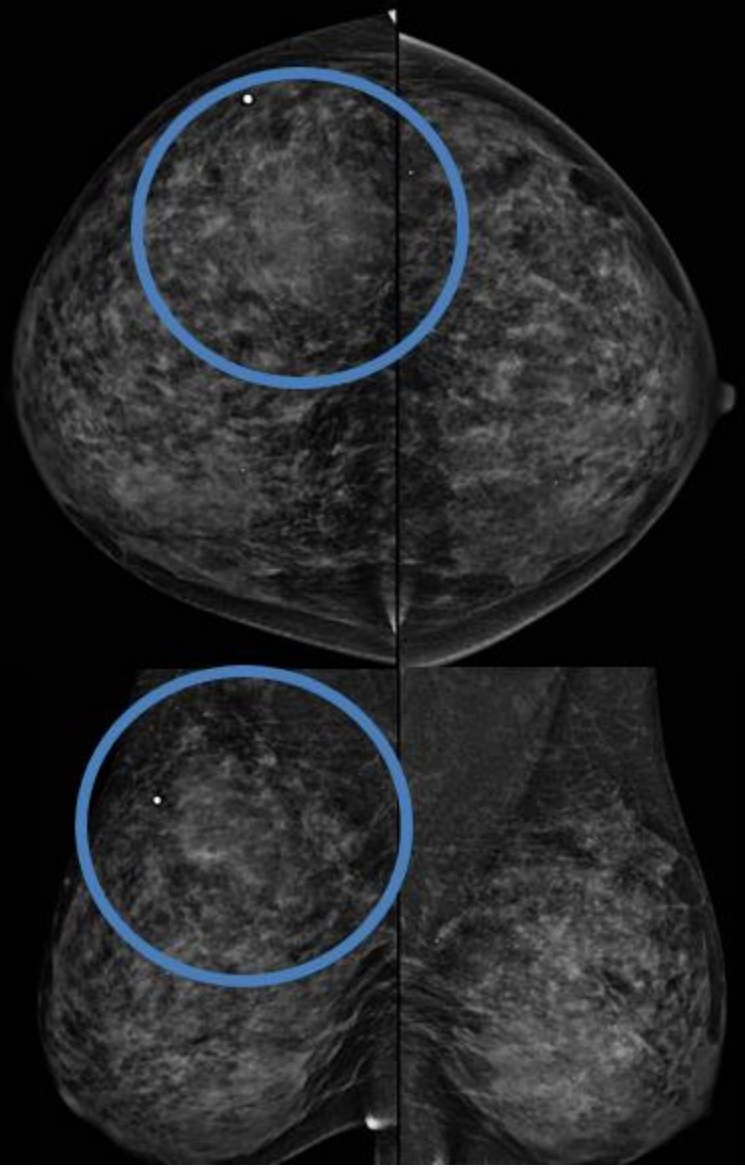
Two-dimensional (joint) histograms created between SUV and IVIM parameters (IGOR Pro)

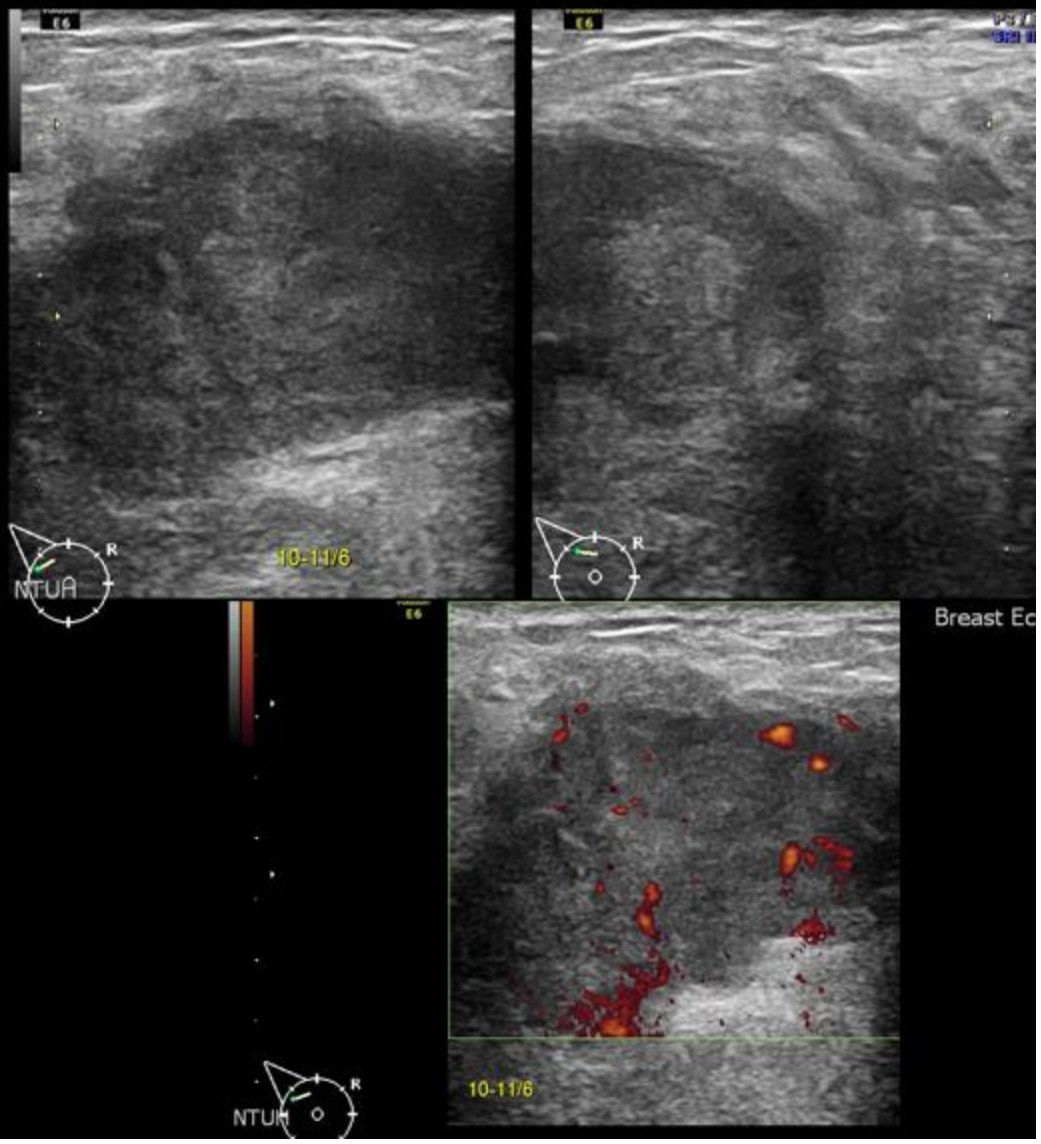
[1]NYU Langone Medical Center, Department of Radiology

- Emerging MRI techniques
  - DCE pharmacokinetic model- K^{trans}, k_{ep}, v_e , v_p
  - Voxel-based parametric map analysis
  - Texture analysis

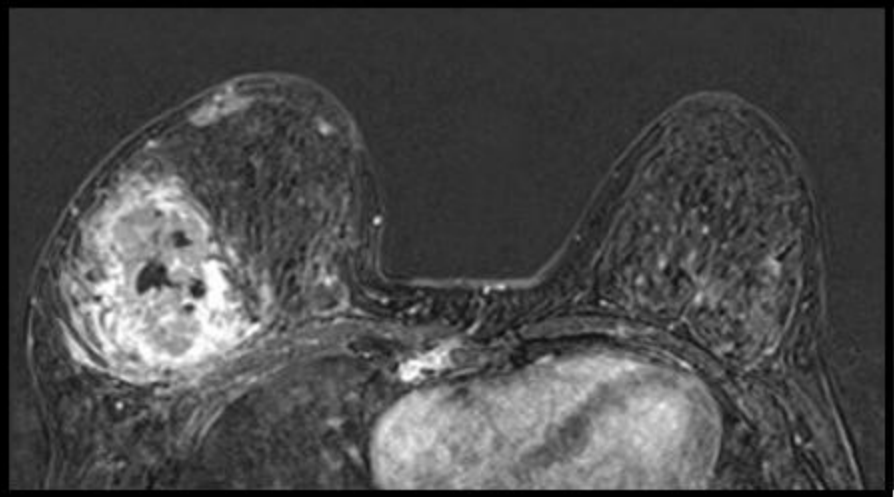
- New PET biomarkers
  - Receptor expression for metastatic heterogeneity- ER, PR, Her2
  - Cell proliferation for treatment response- FLT
  - Anti-angiogenesis- [18F]galacto-RGD

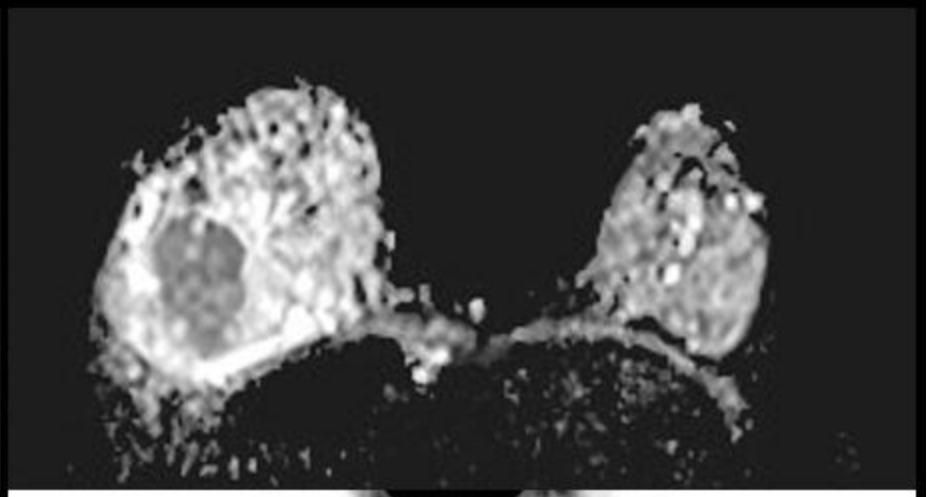
MMG, Echo

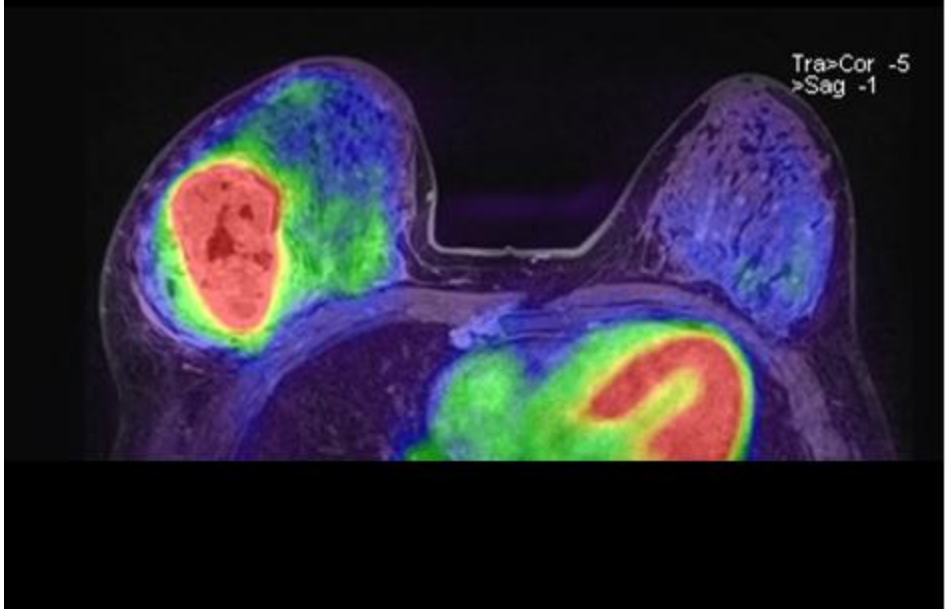


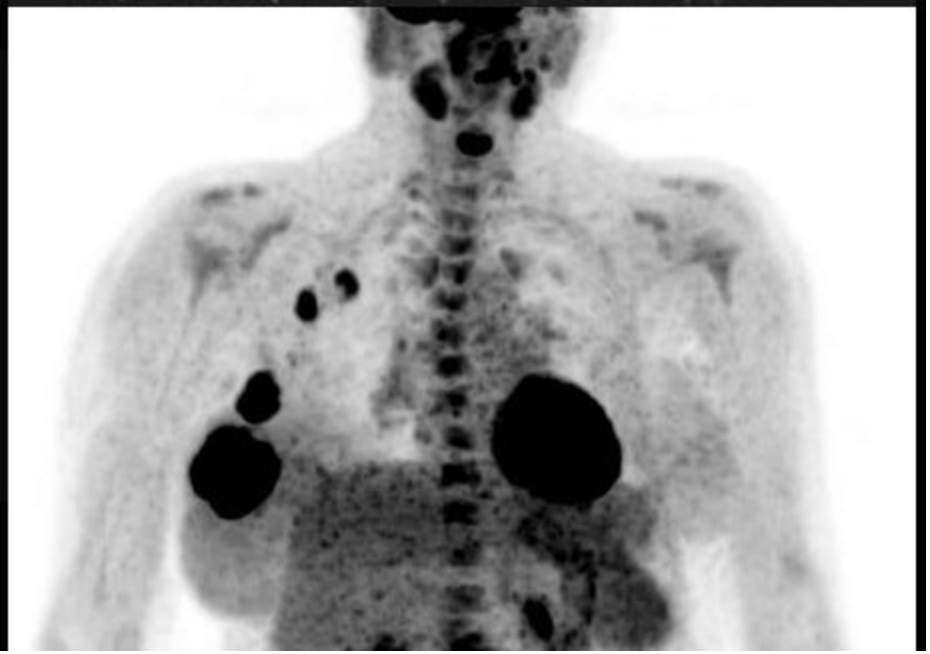


Before NAC

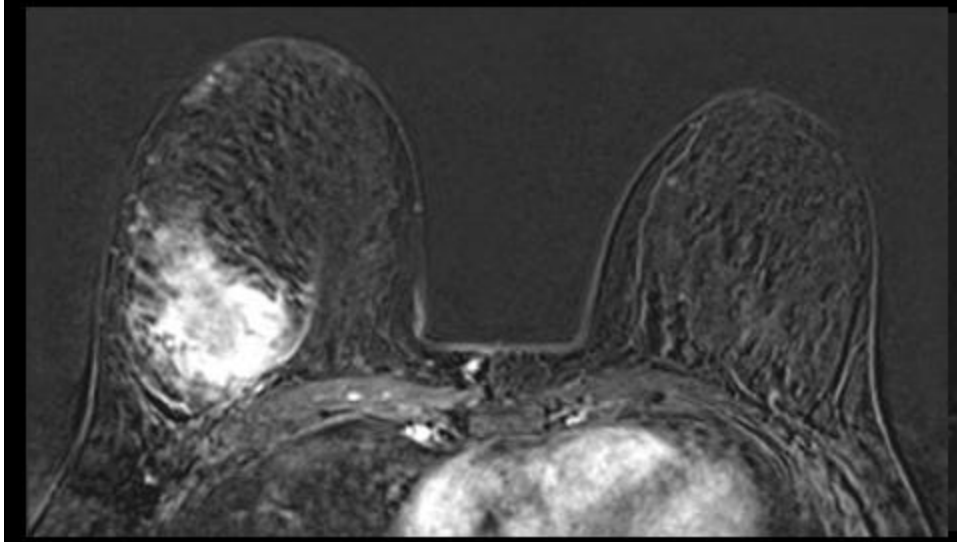


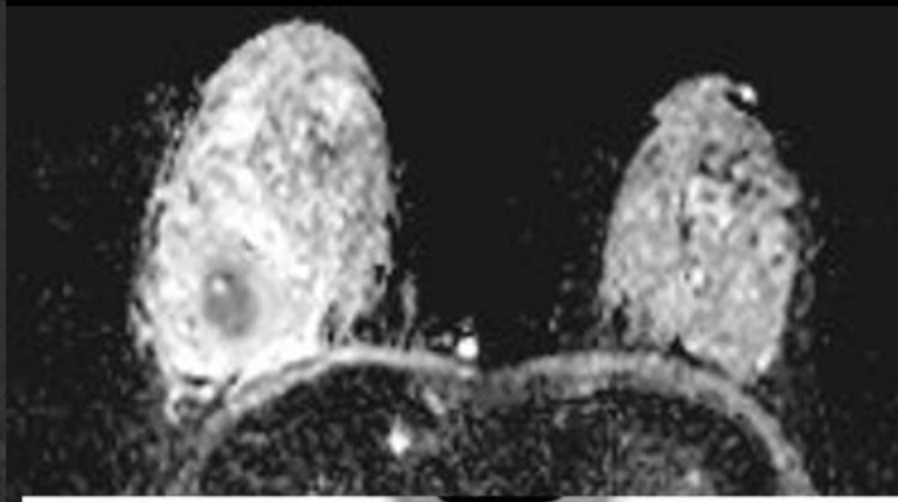


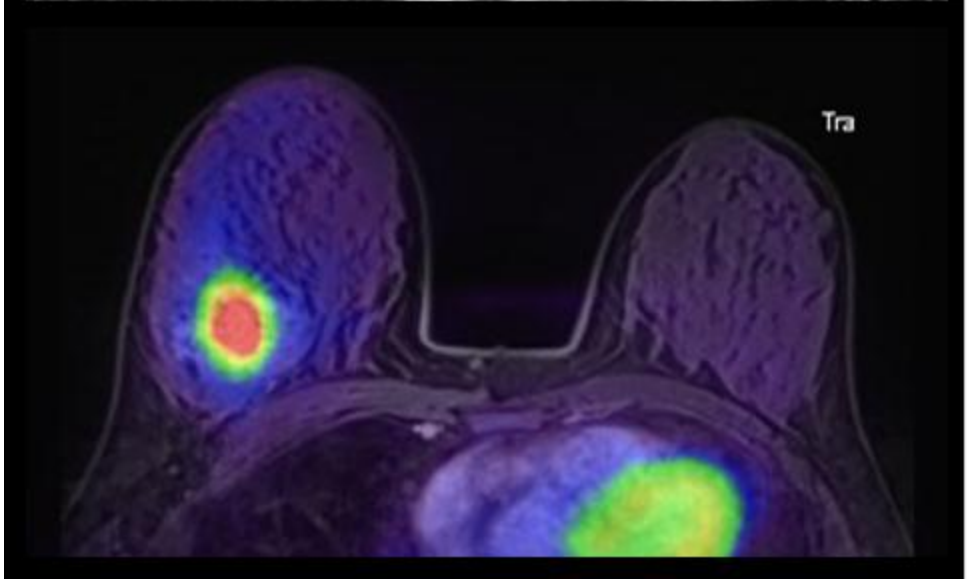


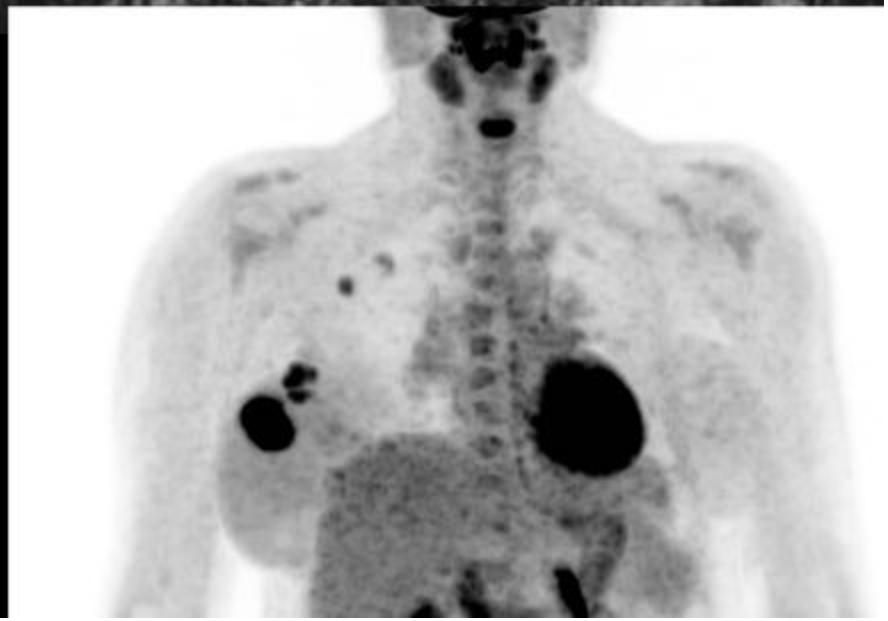


After 1st NAC

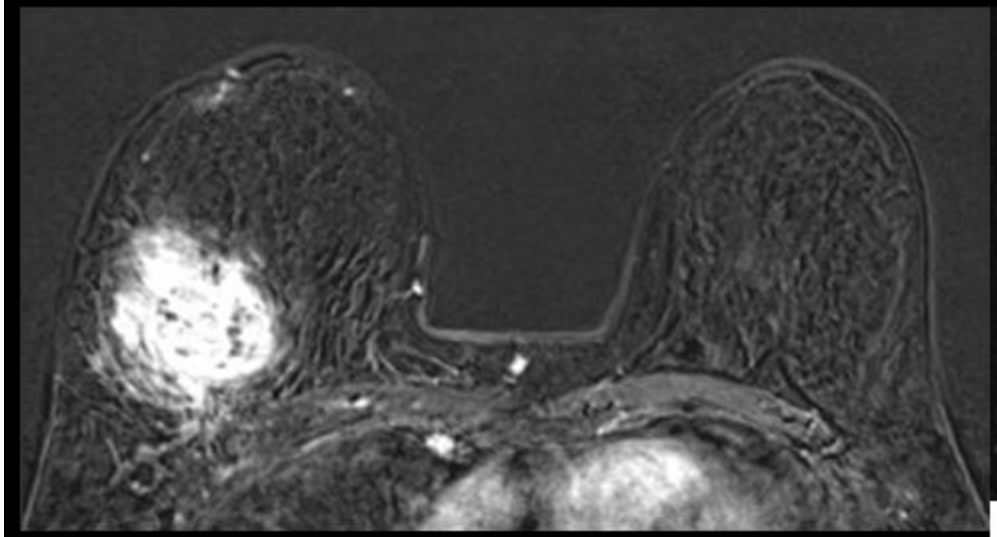


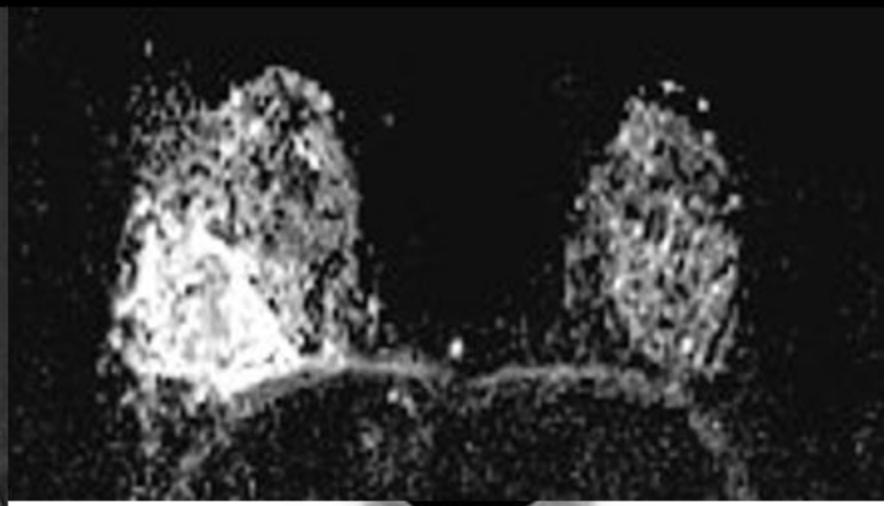


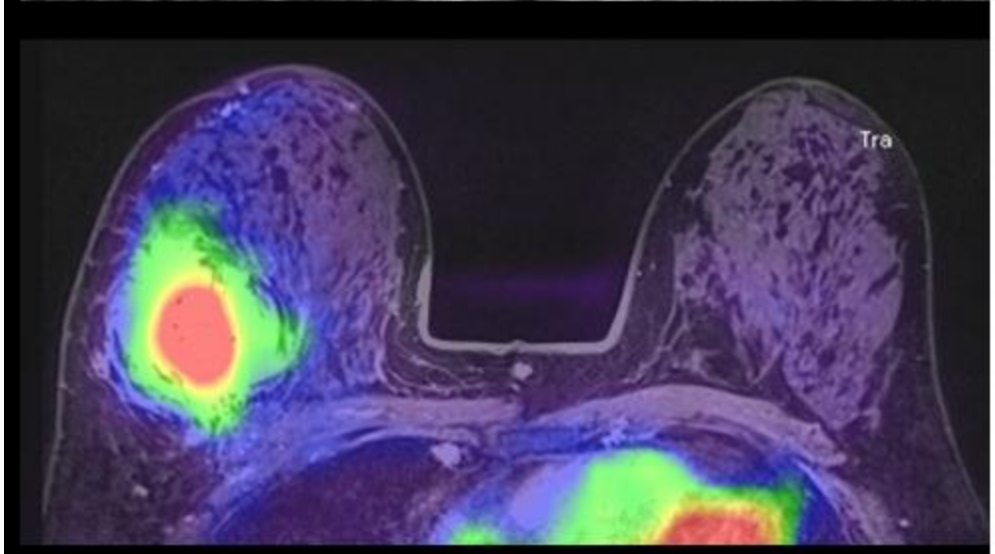


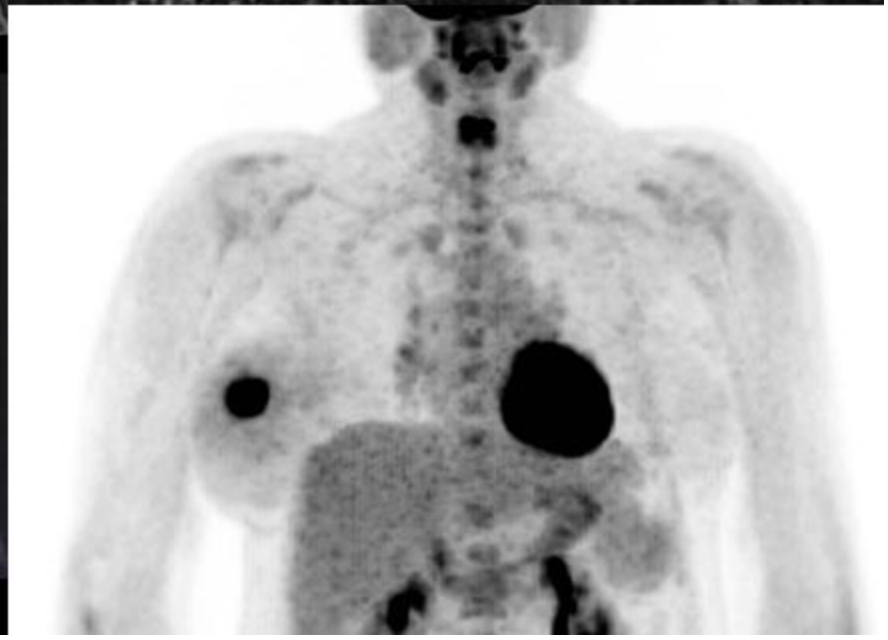


After NAC

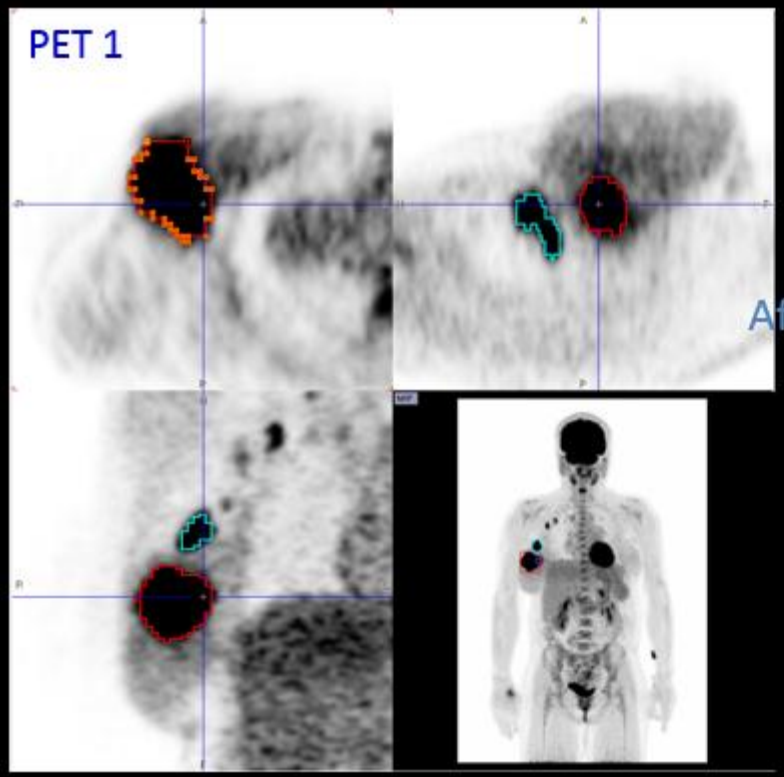




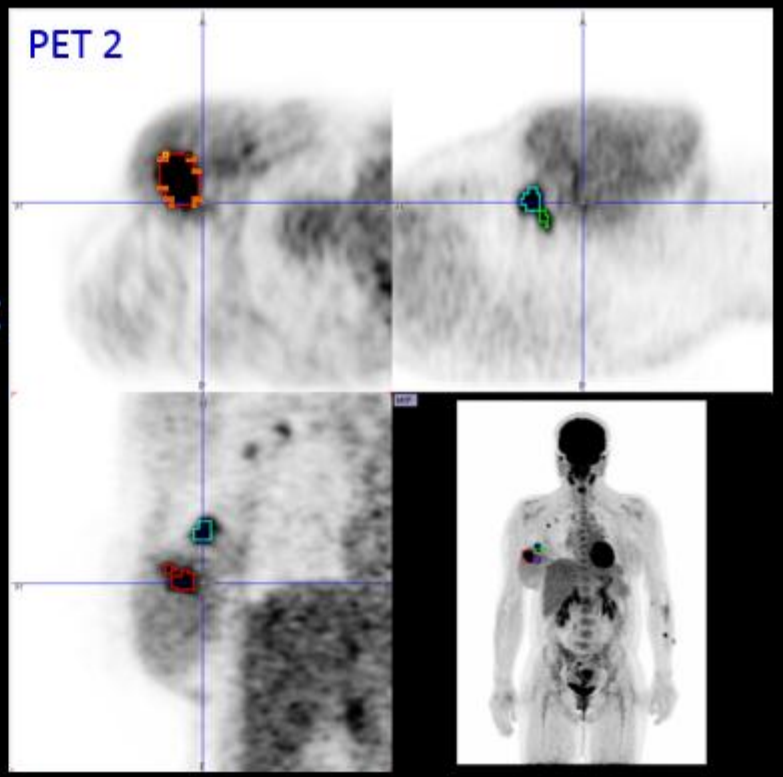




Glycolysis changes in PET



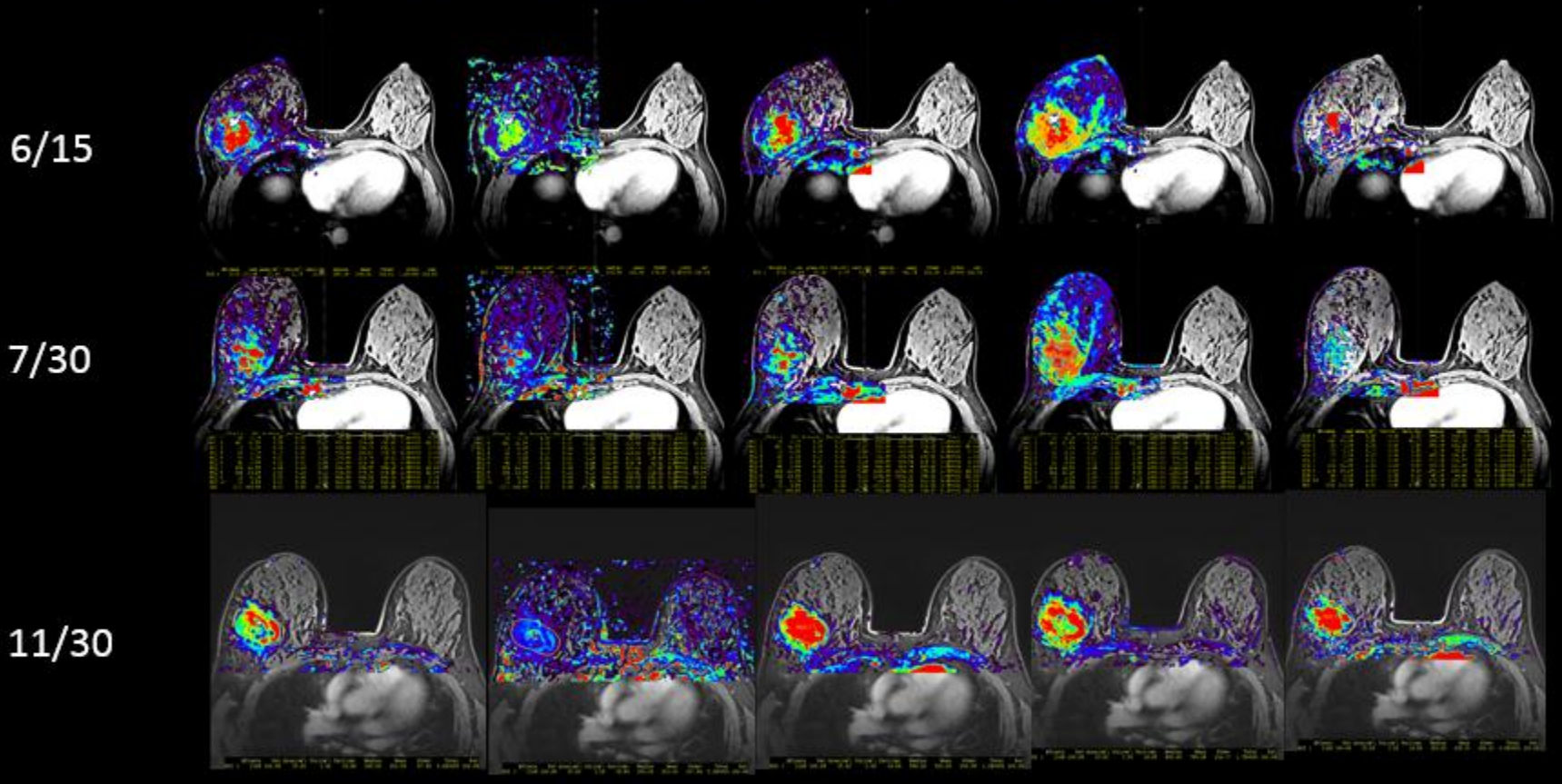
After 1st NAC



Regions	SUV_{max}	SUV_{mean}	MTV (cm^3)	TLG
main T(PET_1)	33.92	11.03	100.75	1111.51
Lymph Node(PET_1)	7.15	4.21	11.92	50.17
main T(PET_2)	17.10	6.42	25.85	165.89
Lymph Noses(PET_2)	4.60	3.40	3.18	10.83

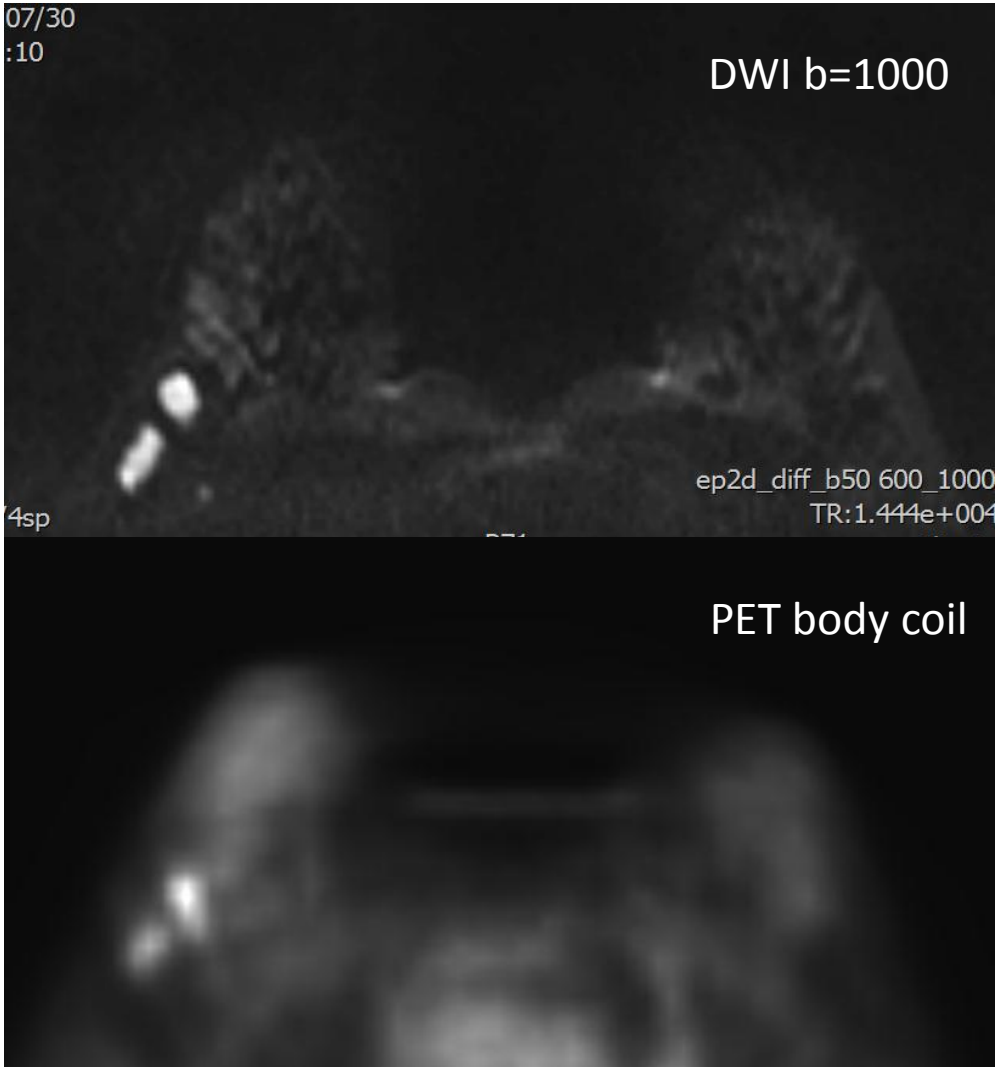
Regions	SUV_{max}	SUV_{mean}	MTV (cm^3)	TLG
main T(PET_3)	13.8	8.41	6.79	57.10
Lymph Node(PET_3)	-	-		

Changes in parameters of dynamic contrast-enhanced MRI



Date	Ktrans	kep	iAUC	rve	rvp
6/15	611	767	637.905	450.165	299.177
7/30	583	786	423.233	748.857	78.53
11/30	477	909	593.688	789.08	228.334

Right axillary lymphadenopathy



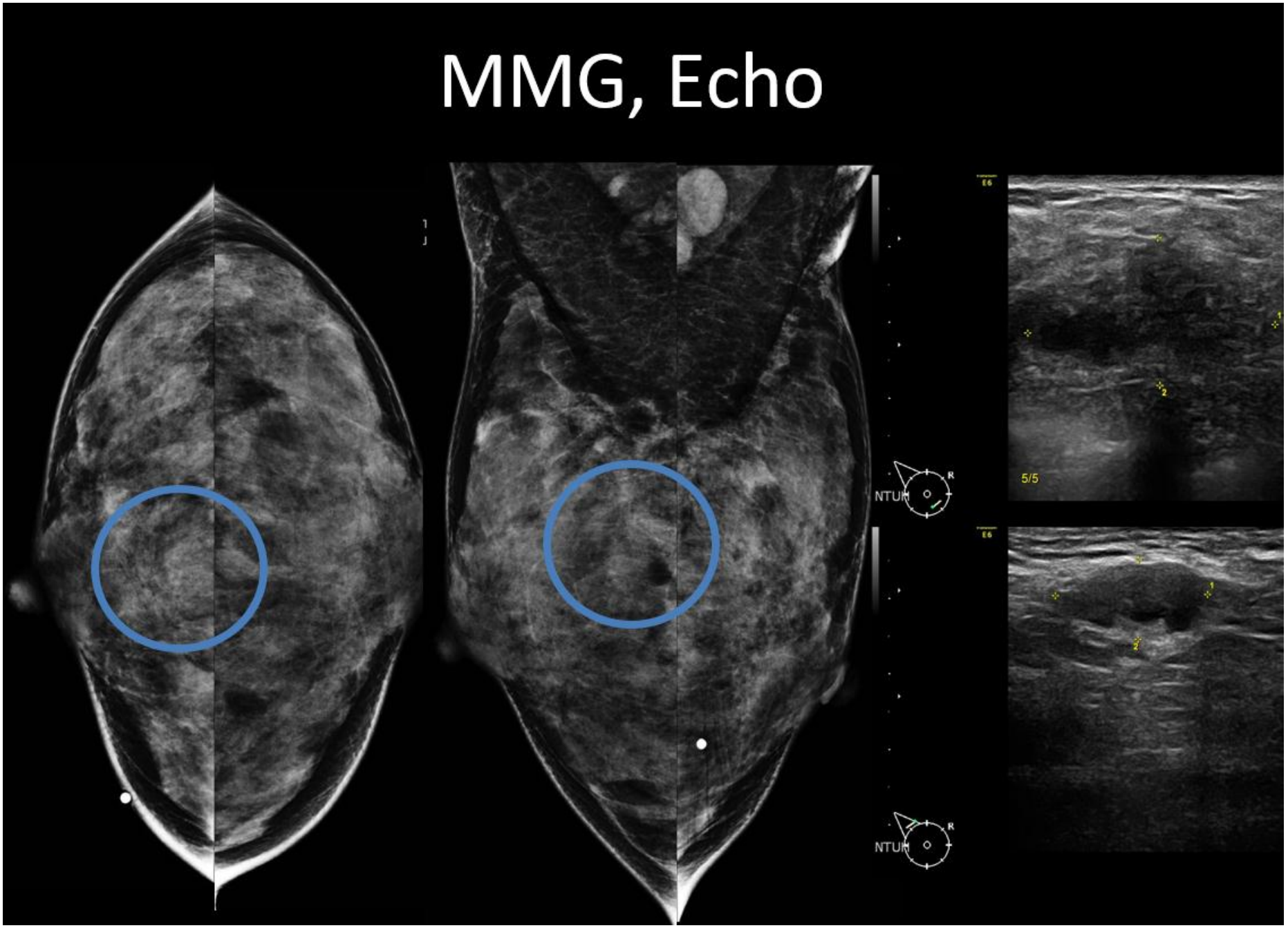
Pathology

an invasive carcinoma of no special type with marked nuclear hyperchromasia, pleomorphism, high nuclear-cytoplasmic ratio and brisk mitotic activity arranged in solid pattern with marked necrosis.

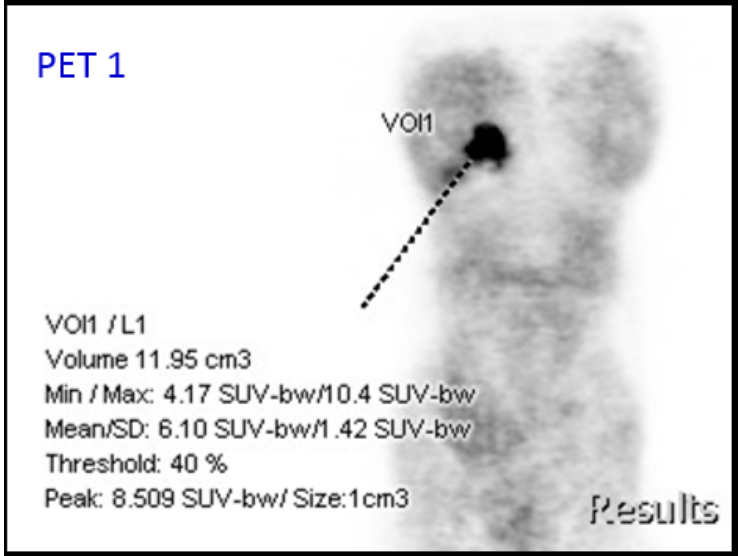
LN (-)

Response to neo-adjuvant therapy: Partial response to therapy, ＞50% of tumor cellularity remains evident, although some features of response to therapy present

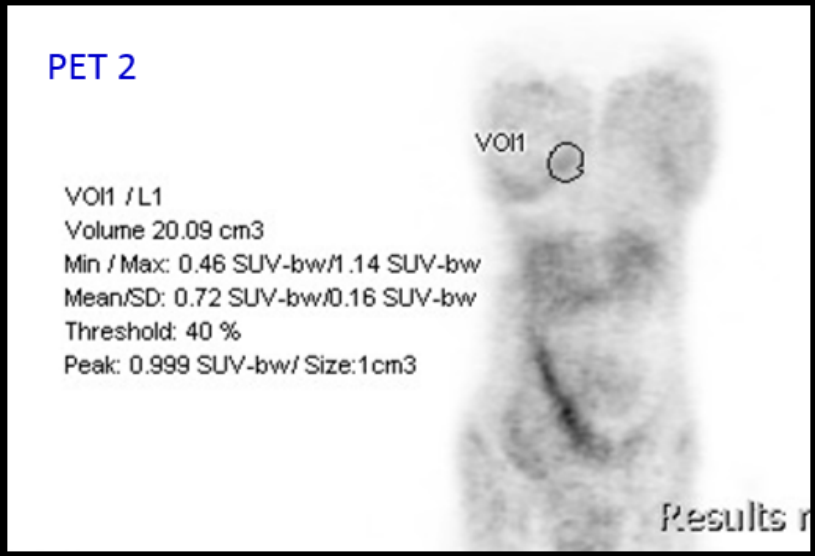
MMG, Echo



Glycolysis changes in PET



After 1st NAC



Regions	SUV_{max}	SUV_{mean}	MTV (cm^3)	TLG
main T(PET_1)	10.4	6.10	11.95	72.90
main T(PET_2)	1.14	0.72	20.09	14.46

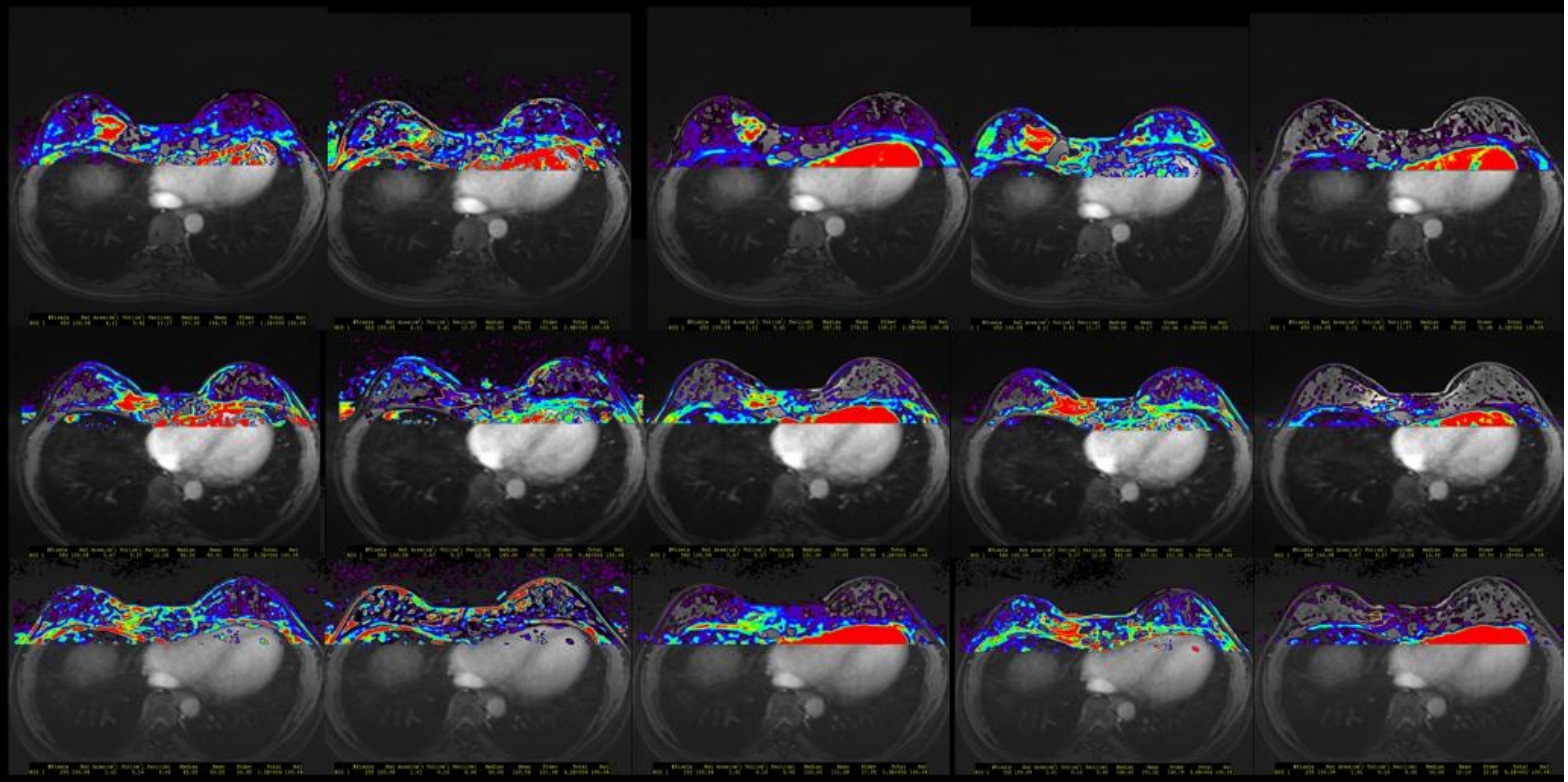
Regions	SUV_{max}	SUV_{mean}	MTV (cm^3)	TLG
main T(PET_3)	-	-		

Changes in parameters of dynamic contrast-enhanced MRI

6/16

7/27

12/10



Date	Ktrans	kep	iAUC	rve	rvp
6/16	194.737	436.149	378.02	514.171	93.231
7/27	90.907	162.707	157.984	537.009	38.078
12/10	50.255	165.584	131.478	351.024	32.102

2016/01/15 modified radical mastectomy

small residual foci of carcinoma in the lymphatics as emboli. No other residual tumor is noted in the breast parenchyma. Post-treatment effect is evident. The section margins are free.

The level I axillary tissue shows micrometastatic carcinoma in two lymph nodes, and a small focus of metastatic carcinoma in the soft tissue. Level II axillary tissue is not involved.

Thank you for your attention!