# Basic and advanced principles of Diffusion Weighted Images (DWI) - 2


Speaker: Yung-Chieh Chang

Date : 106.07.22

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## Outline

- Basic and advanced principles of Diffusion Weighted Images (DWI) - 1
  1. Echo Planar Imaging **(EPI)**
  2. Diffusion weighted imaging **(DWI)**
- Basic and advanced principles of Diffusion Weighted Images (DWI) – 2
  1. Diffusion-weighted whole-body imaging with background body signal suppression **(DWIBS)**
  2. Intravoxel Incoherent Motion **(IVIM)**
- Dynamic Contrast enhanced MRA
- Preliminary conclusions and discussion

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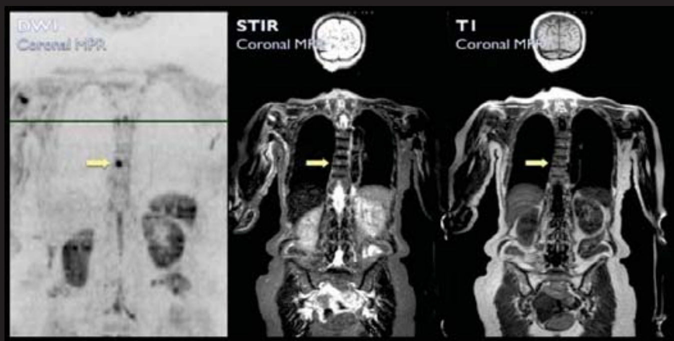
## DWIBS

### Diffusion-weighted whole-body imaging with background body signal suppression




Breast carcinoma: DWI helps detecting a small vertebral metastasis (arrow)

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- DWIBS be used on clinical
- Fat suppression
- Preliminary experiment discussion for neck DWI
- Note about DWIBS image post-processing steps

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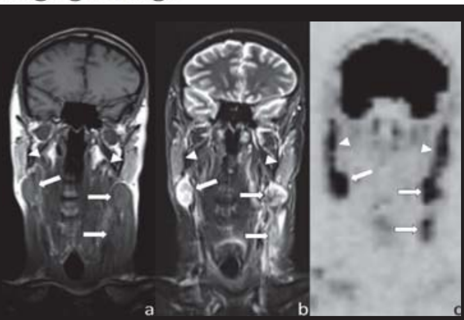
**Whole body MRI with DWIBS in oncology: an overview of imaging findings**




parotid glands(腮腺)

cervical lymphadenopathy (淋巴結腫大)

Fig : 59-year-old man with cervical lymphadenopathy (arrows) of squamous cell carcinoma (unknown primary location). a.T1, b.STIR and c.DWIBS.
The parotid glands also show physiological signal on DWIBS (arrowheads).

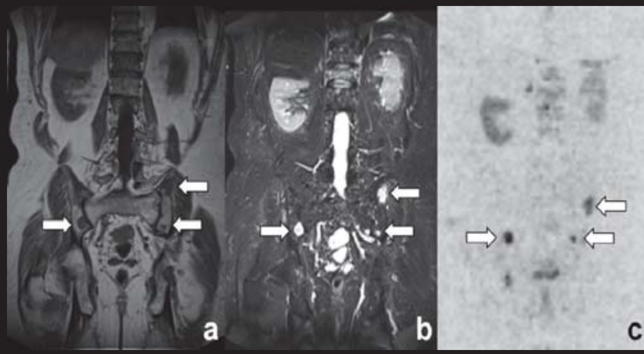



Fig. 4:
a.T1, b.STIR and c.DWIBS in a 71-year old man with several multiple myeloma (多發性骨髓瘤) lesions in pelvis.

ELSEVIER
Clinical Imaging 34 (2010) 298–301
CLINICAL IMAGING

Diffusion-weighted whole-body imaging with background body signal suppression facilitates detection and evaluation of an anterior rib contusion

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Received 20 June 2009; accepted 20 July 2009

Diffusion-weighted whole-body imaging with background body signal suppression (DWIBS) was introduced ,which has various applications in oncological imaging .However, DWIBS may also be useful in nononcological applications, such as in the case of traumatic musculoskeletal injuries.

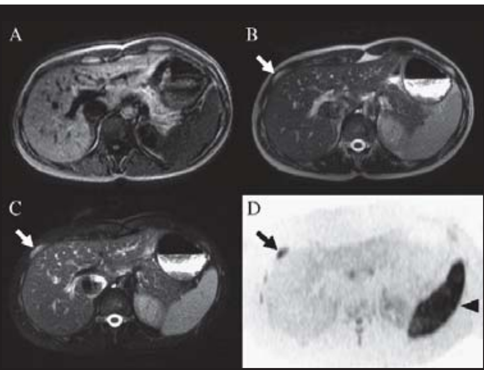



Fig. 1.
Axial T1-weighted (A), T2-weighted (B), fat-saturated T2-weighted (C), and (grayscale inverted) DWIBS images (D) at the same level.

(B) and (C) show a hyperintense signal in one of the right lower right ribs (white arrows). The lesion is highlighted at DWIBS (D, black arrow).
Also note the normal high signal intensity of the spleen at DWIBS (D, arrowhead).

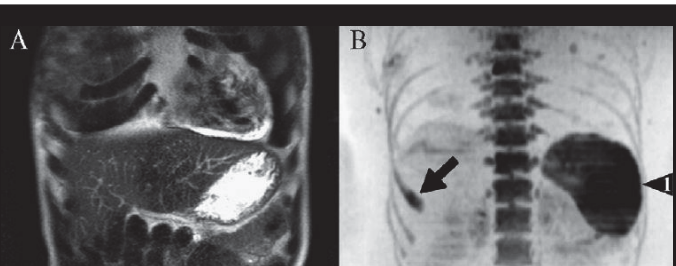
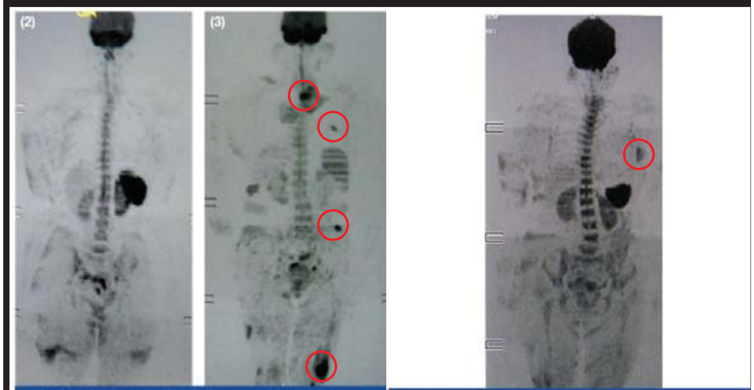



Fig. 2. Coronal T2-weighted image (A) at the level of the suspected injury does not clearly detect the lesion. On the other hand, coronal entire volume MIP DWIBS image (B) clearly shows a lesion of the right anterior eight rib and its extent (black arrow).

The addition of DWIBS to the routine protocol may allow an easier and more straightforward detection, localization, and assessment of costal (cartilage) abnormalities than (fat-suppressed) T2-weighted images. because of the high lesion-to-background contrast in a 3D manner.

Original Article

## DWIBS Imaging: Modifying MRI to Monitor Metastases




**[Table/Fig-1 & 2]:** (1) DWIBS image in a normal healthy volunteer (2) DWIBS image in a patient operated earlier for carcinoma cervix shows metastases in the sternum, left hemi thorax, left iliac blade and left femur.

**[Table/Fig-5]:** DWIBS image in a patient operated earlier for carcinoma breast and now presented with back ache. Multiple vertebral and left axillary metastases are seen.

Original Article

## DWIBS Imaging: Modifying MRI to Monitor Metastases

| S No. | Criteria | Bone Scan | PET Scan | DWIBS MRI |
|---|---|---|---|---|
| 1 | Availability | Less | Lesser | More |
| 2 | Prior preparation | Needed | Needed | Unnecessary |
| 3 | Scan Time | More | More | Less |
| 4 | Radiation Exposure | Yes | Yes | No |
| 5 | Repeatability | Limited | Limited | Unlimited |
| 6 | Usage in Pregnant patients | No | No | Unlimited |
| 7 | Usage in Pediatric patients | Limited | Limited | Unlimited |
| 8 | Cost of study | More | More | Less |

[Table/Fig-6]: Comparative analyses of various imaging techniques for evaluating skeletal metastases

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## Pitfalls of DWIBS: possible false positive findings

Lymph nodes :

Normal lymph nodes have a relatively restricted diffusion because of their high cellular density. Metastatic lymph nodes have increased cellular density and may have necrotic areas. However it is still unknown whether it is possible to differentiate benign lymphadenopathy from malignant nodes using DWIBS.

Normal tissues with high signal on DWIBS

Besides lymph nodes, also some other tissues represent high signal in DWIBS, like the brain, spinal cord, peripheral nerves, salivary glands , spleen, gallbladder, kidneys and ureters, intestines, bone marrow. To prevent misinterpretation of these areas with T2 penetration effect and missing obscured lesions in these areas, DWIBS should be combined with an anatomical sequence.

Artifacts due to moving organs:

Artifacts due to movement of imaged organs may occur, mainly around the diaphragm and bowel.

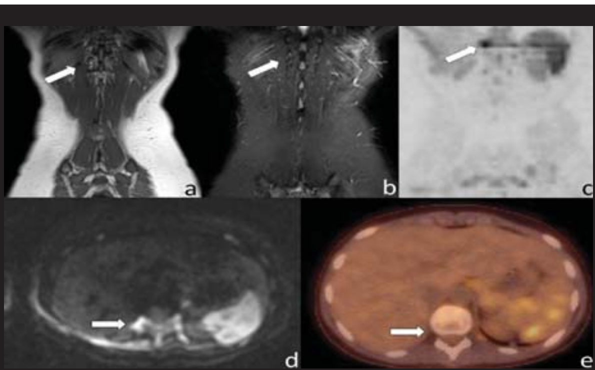


Fig. 8: Artifact near the diaphragm in a 15- year old girl with Hodgkin lymphoma stage IV. a.T1, bSTIR, c.DWIBS, d.axial DWI b-1000 (source image for DWIBS) and e.fused 18F-FDG-PET-CT image. The right paravertebral high signal on DWI just below the diaphragm on DWIBS (arrow) was not identified on anatomic MR-images and 18F-FDGPET- CT. Possibly this artifact is due to movement, although the cause of this artifact is not entirely clear.

Eur Radiol (2008) 18: 1937–1952
DOI 10.1007/s00330-008-0968-z

MAGNETIC RESONANCE

Thomas C. Kwee
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**Diffusion-weighted whole-body imaging with background body signal suppression (DWIBS): features and potential applications in oncology**

In 2004, Takahara et al. reported a unique concept of whole-body DWI, called "diffusion-weighted whole-body imaging with background body signal suppression" (DWIBS).

They extended the possibilities of DWI: scanning time is no more limited (as in breathhold scanning) and image acquisition time is no more confined to a particular phase of the breathing cycle (as in respiratory triggered scanning), images with multiple b-values including high b-values around 1,000 s/mm2 can be acquired, thin slices can be obtained, and multiple signal averaging is possible.

Furthermore, these advances enable volumetric [three-dimensional (3D)] image processing, including maximum intensity projections (MIPs), and multiplanar reformatting (MPR) in any plane.

**DWIBS = DWI + Fat sat (IR)+ thin slice + no gap + Invert Grayscale + MIP and MPR**

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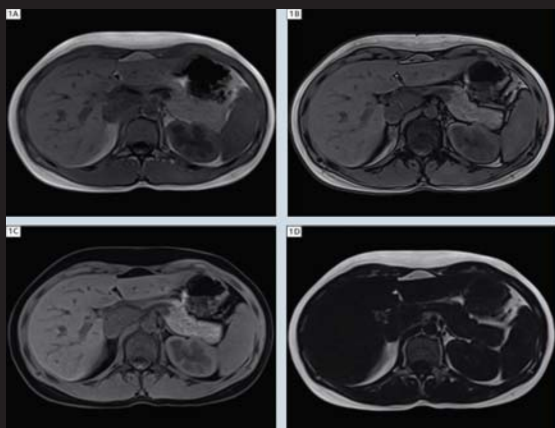
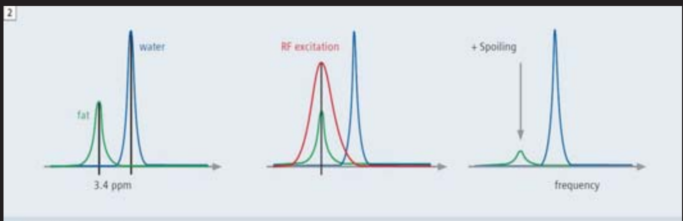
## Fat Suppression Techniques – DIXON




1 Dixon technique (VIBE). Four contrasts generated in one breathhold:
1A: in-phase
1B: opposed-phase
1C: water image
1D: fat image

# Spectral fat saturation



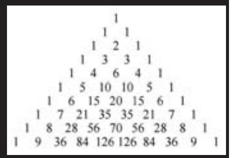

2 Spectral fat saturation.

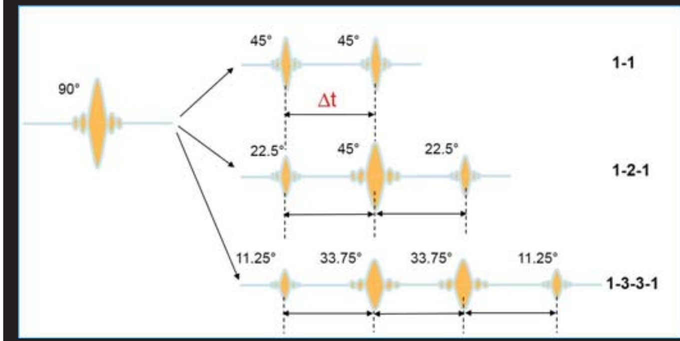
Water and Fat have different resonant frequencies (3.4ppm)

# ProSet

A technique that selectively excites water or fat

Excitation pulse is split in sub-pulses (巴斯卡三角形)



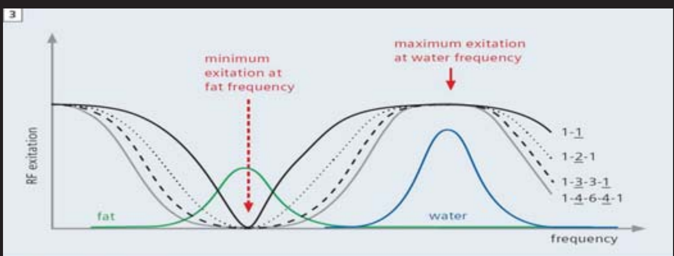




# ProSet-
# PRinciple Of Selective Excitation Technique

Water Excitation (Fat sat) or Fat Excitation

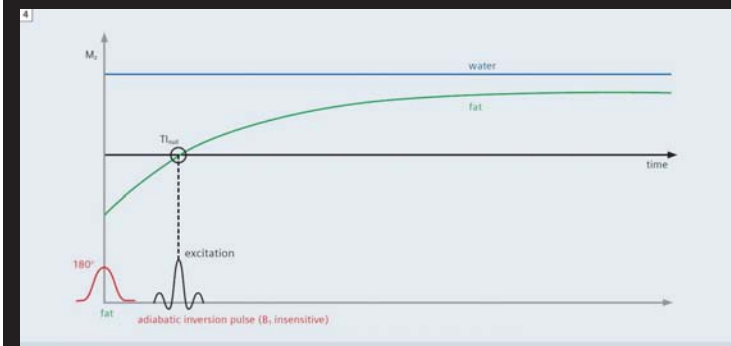
Binomial Pulse (二項式脈衝)

1:1, 1:2:1, or 1:3:3:1



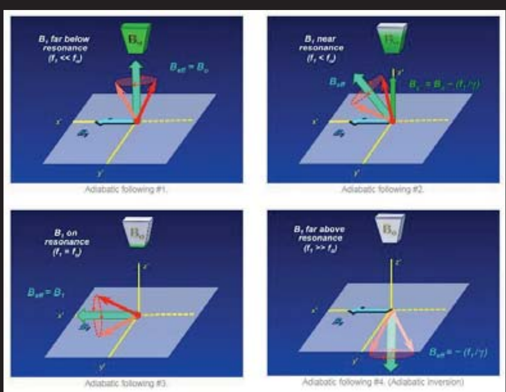

3 Water Excitation.

# SPAIR technique (Spectrally Adiabatic Inversion Recovery)

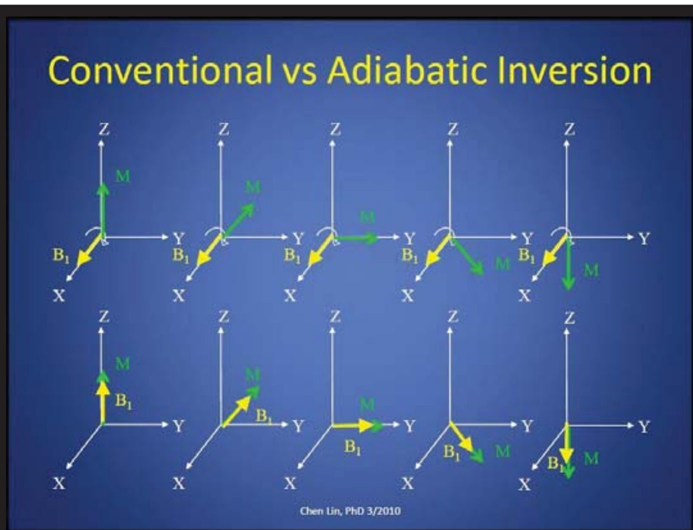



4 SPAIR technique.

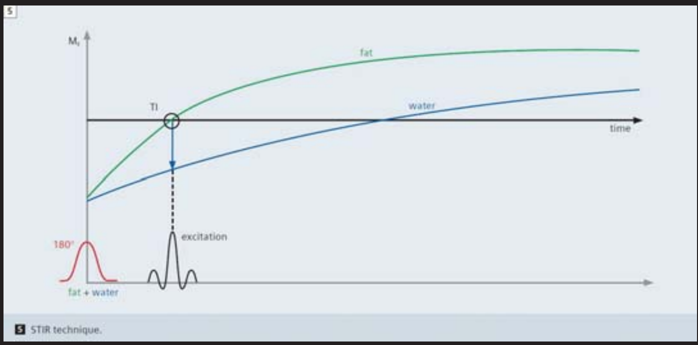
# Adiabatic Excitation



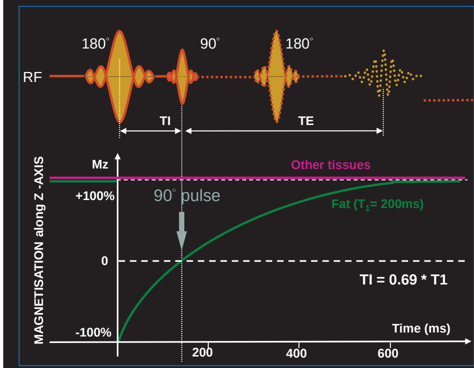

Adiabatic excitation is a special type of RF-stimulation . An additional required concept (presented here for the first time) is of continuous wave (CW) excitation.



# STIR
## (Short TI Inversion Recovery)



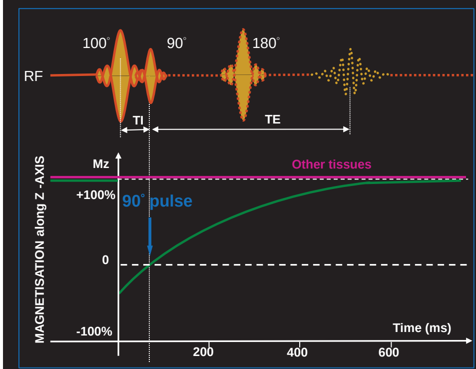

# SPAIR - SPectral Attenuated Inversion Recovery




Frequency selective inversion pulse

Based on the differences in $T_1$ relaxation time and resonant frequency of fat and water

# SPIR- Spectral Presaturation Inversion Recovery




Frequency selective saturation pulse

Sensitive to B0 and B1 field

Inversion time as short as possible

Based on the differences in resonant frequency of fat and water.

# Fat Suppression Techniques

| Name of Technique | Method | Time Penalty | SAR | Sens. To $B_0$ | Sens. to $B_1$ |
|---|---|---|---|---|---|
| CHESS/ Fat-Sat | Chemical Shift | Small | Med | High | High |
| Dixon | Chemical Shift | Large | Low | Low | Low |
| Water excitation | Chemical Shift | Small | Low | High | Low |
| STIR | T1 | Large | High | Low | Low |
| SPIR | Hybrid | Med | Med | High | High |
| SPAIR | Hybird | Large | High | High | Low |

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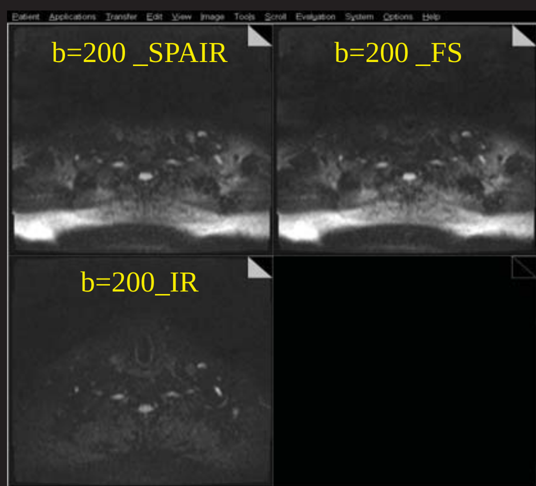
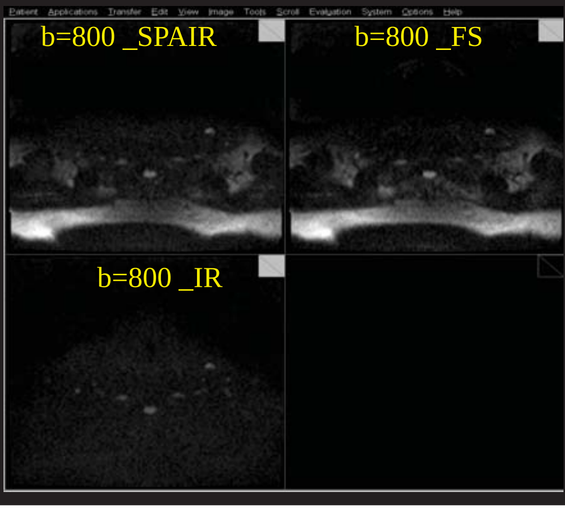
## Preliminary experiment discussion for neck DWI



## Preliminary experiment discussion for neck DWI

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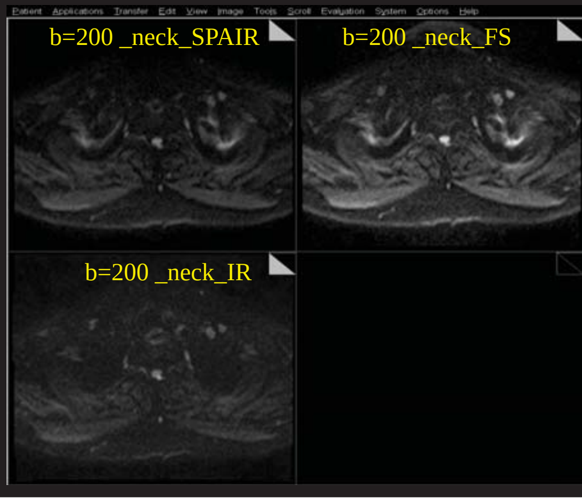


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*Thank you for your attention*

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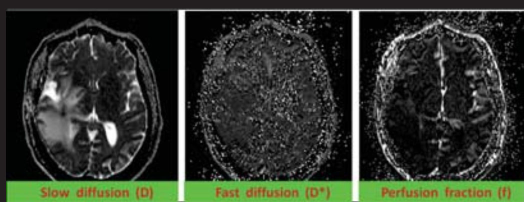
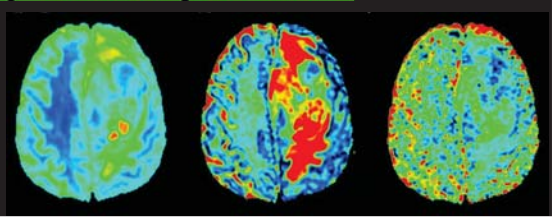
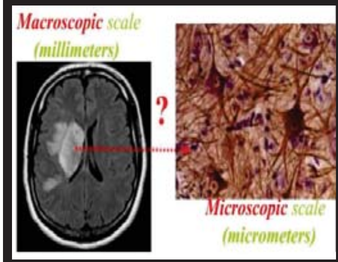
# IVIM

## Intravoxel Incoherent Motion

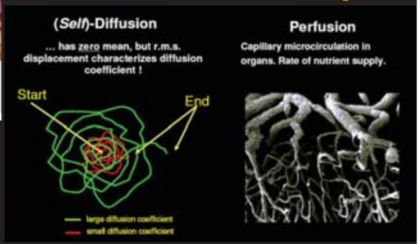


# From macro to micro world
## Diffusion vs. Perfusion

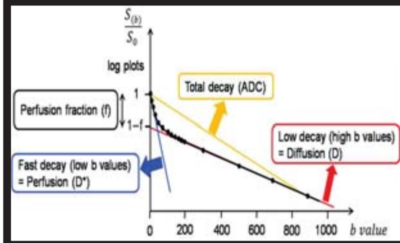



**Capillary perfusion and water diffusion in the extracellular extravascular space.**




*Department of Radiology, Taichung Veterans General Hospital*

# Intravoxel Incoherent Motion (IVIM)

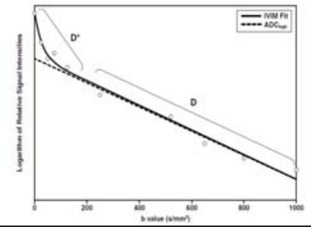



- $S_b = S_0 \exp(-b\ ADC)$
- $S_b/S_0 = (1\text{-PF})\exp(\text{-bD}) + \text{PF}\exp(\text{-bD}^*)$
- $\text{PF} = (S_0 - S_{int})\ /\ S_0$

- $S_b$ is the measured signal intensity with a gradient sensitivity factor b.
- $S_0$ is the measured signal intensity with a gradient sensitivity factor b=0.
- D is the molecular diffusion coefficient.
- D* is assumed to be the pseudo-diffusion coefficient associated with microvascular flow.
- PF is the volume fraction of microvasculature.

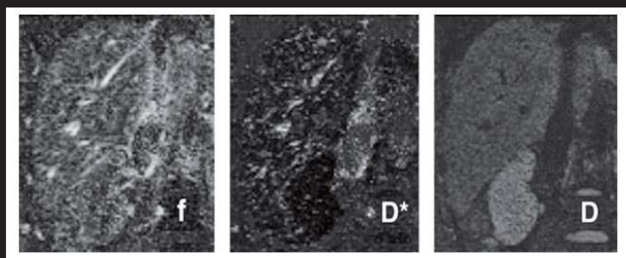
# Intravoxel Incoherent Motio
# Journal Review

$$I = I_0(f\exp(-b[D^* + D_{\text{molecular}}]) + (1-f)\exp(-b D_{\text{molecular}}))$$




- $I$ is the measured signal intensity with a gradient sensitivity factor $b$.
- $I_0$ is the measured signal intensity with a gradient sensitivity factor $b = 0$.
- $D_{\text{molecular}}$ is the molecular diffusion coefficient $D^*$ is assumed to be the pseudo-diffusion coefficient associated with microvascular flow. Even though considered as a perfusion index, this is not a 'real' parameter and cannot be measured in any other way.
- $f$ is the volume fraction of microvasculature within the voxel and may be used as a perfusion index. When $f = 0$ or 1, the expression reduces to a single exponential form; if $f = 0$, $D_{\text{measured}} = D_{\text{molecular}}$ and if $f = 1$, $D_{\text{measured}} = D^* + D_{\text{molecular}}$.

# Intravoxel Incoherent Motio




(Fraction) Pseudo-diffusion(perfusion) (Diffusion)

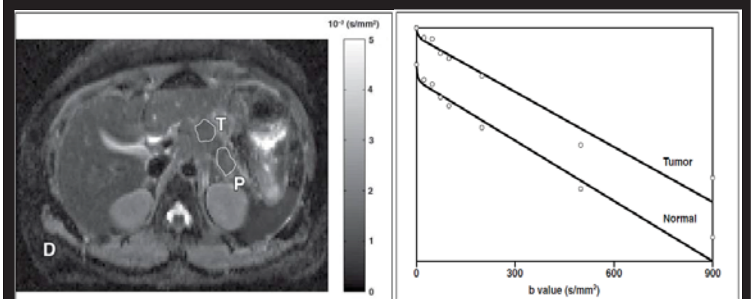
AJR2011; 196:1351–1361
0361–803X/11/1966–1351

AJR:196, June 2011

**Intravoxel Incoherent Motion in Body Diffusion-Weighted MRI: Reality and Challenges**

Dow-Mu Koh[1]
David J. Collins[1,2]
Matthew R. Orton[2]

**OBJECTIVE.** Diffusion-weighted MRI is increasingly applied in the body. It has been recognized for some time, on the basis of scientific experiments and studies in the brain, that the calculation of apparent diffusion coefficient by simple monoexponential relationship be-




AJR2011; 196:1351–1361
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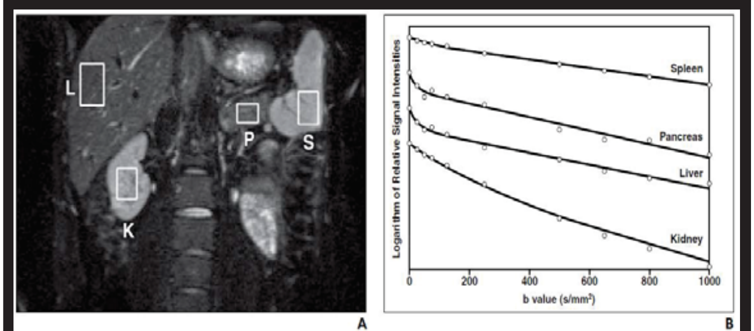

Magnetic Resonance in Medicine 65:1437–1447 (2011)

## Intravoxel Incoherent Motion Imaging of Tumor Microenvironment in Locally Advanced Breast Cancer

E. E. Sigmund,[1]* G. Y. Cho,[1] S. Kim,[1] M. Finn,[1] M. Moccaldi,[1] J. H. Jensen,[1] D. K. Sodickson,[1] J. D. Goldberg,[2] S. Formenti,[3] and L. Moy[1]

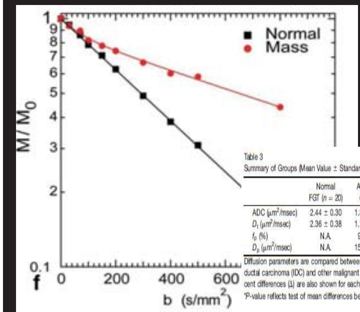



Table 3
Summary of Groups (Mean Value ± Standard Deviation) from IVIM Analysis of DWI ROI Data in the Cohort of Breast Patients

| | Normal FGT ($n$ = 20) | All lesions ($n$ = 24) | Δ(%) FGT/all | $P$* FGT/all | IDC ($n$ = 19) | Δ(%) FGT/IDC | $P$* FGT/IDC | OT ($n$ = 5) | Δ(%) FGT/OT | $P$* FGT/OT | Δ(%) IDC/OT | $P$* IDC/OT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ADC ($\mu m^2$/msec) | 2.44 ± 0.30 | 1.34 ± 0.39 | 58.5 | <0.01 | 1.35 ± 0.36 | 57.1 | <0.01 | 1.29 ± 0.52 | 61.6 | <0.01 | 4.2 | 0.83 |
| $D_1$ ($\mu m^2$/msec) | 2.36 ± 0.38 | 1.15 ± 0.35 | 69.0 | <0.01 | 1.14 ± 0.32 | 68.8 | <0.01 | 1.18 ± 0.52 | 66.7 | <0.01 | −3.3 | 0.88 |
| $f_p$ (%) | N.A. | 9.8 ± 4.8 | N.A. | N.A. | 10.5 ± 5.0 | N.A. | N.A. | 6.9 ± 2.9 | N.A. | N.A. | 41.4 | 0.06 |
| $D_p$ ($\mu m^2$/msec) | N.A. | 15.1 ± 10.4 | N.A. | N.A. | 14.9 ± 11.4 | N.A. | N.A. | 16.1 ± 5.7 | N.A. | N.A. | −7.5 | 0.75 |

Diffusion parameters are compared between normal fibroglandular tissue (FGT) and lesion groups (all, IDC, and OT) via two-sided $t$-tests. Within the lesion group, the subtypes invasive ductal carcinoma (IDC) and other malignant (OT) lesions are compared in the same way. Note that quantification of the perfusion parameters $f_p$ and $D_p$ is only possible within lesions. Percent differences (Δ) are also shown for each group comparison.
*$P$-value reflects test of mean differences between groups using paired or unpaired $t$-tests as appropriate (see text).

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Original Research

## Hepatocellular Carcinoma: Short-Term Reproducibility of Apparent Diffusion Coefficient and Intravoxel Incoherent Motion Parameters at 3.0T

Table 2
Test-Retest Reproducibility of IVIM Parameters and ADC in HCC and Liver Parenchyma

| | | D | D* | PF | ADC-16b | ADC-4b |
|---|---|---|---|---|---|---|
| HCC ($n$ = 15) | Test | 1.07 ± 0.21 | 28.2 ± 20.0 | 17.4 ± 9.3 | 1.33 ± 0.25 | 1.27 ± 0.30 |
| | Retest | 0.96 ± 0.18 | 34.5 ± 55.5 | 20.9 ± 9.5 | 1.30 ± 0.20 | 1.13 ± 0.21 |
| | $P$* | 0.076 | 0.620 | 0.158 | 0.653 | **0.010** |
| | CV (range) | 19.7 (2.5–54.5) | 60.6 (12.2–141.4) | 37.3 (12.8–96.7) | 15.6 (3.5–27.9) | 12.6 (0.2–40.8) |
| | BA-LA | −57.4–36.3 | −161.6–135.3 | −66.2–101.0 | −38.2–17.4 | −37.1–34.1 |
| Liver ($n$ = 11) | Test | 1.02 ± 0.16 | 70.6 ± 70.0 | 16.7 ± 5.6 | 1.15 ± 0.12 | 1.10 ± 0.20 |
| | Retest | 0.99 ± 0.08 | 47.6 ± 35.6 | 15.4 ± 5.7 | 1.03 ± 0.14 | 1.10 ± 0.09 |
| | $P$* | 0.563 | 0.182 | 0.361 | 0.315 | 0.100 |
| | CV (range) | 13.2 (1.2–28.5) | 59.0 (2.4–121.3) | 25.3 (9.3–84.9) | 8.8 (0.3–29.0) | 9.1 (0.4–28.3) |
| | BA-LA | −32.8–28.4 | −151.2–132.7 | −74.6–56.4 | −28.7–15.7 | −29.0–20.9 |

Mean/range of coefficients of variation (CV in %) and Bland-Altman limits of agreements (BA-LA, in %) are shown.
*Paired $t$-test, bolded when significant ($P < 0.05$).
D: true diffusion coefficient (x$10^{-3}$ mm²/sec), D*: pseudodiffusion coefficient (x$10^{-3}$ mm²/sec), PF: perfusion fraction (%), ADC-4b: apparent diffusion coefficient using 4 b-values (x$10^{-3}$ mm²/sec), ADC-16b: apparent diffusion coefficient using 16 b-values (x$10^{-3}$ mm²/sec).

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Original Article

## Intravoxel incoherent motion MRI for liver fibrosis assessment: a pilot study

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Table 2. Summary of the DW image parameters according to the hepatic fibrosis stage.

| Hepatic fibrosis stage | ADC (× $10^{-3}$ mm²/s) | $D_{slow}$ (× $10^{-3}$ mm²/s) | $f$ | $D_{fast}$ (× $10^{-3}$ mm²/s) | $f \cdot D_{fast}$ (× $10^{-3}$ mm²/s) |
|---|---|---|---|---|---|
| Fibrosis stage ≤2 | 1.163 ± 0.108 | 0.981 ± 0.103 | 0.318 ± 0.047 | 74.26 ± 10.702 | 23.98 ± 6.931 |
| F0 | 1.161 ± 0.109 | 0.988 ± 0.110 | 0.3 | | |
| F1–2 | 1.170 ± 0.114 | 0.960 ± 0.078 | 0.3 | | |
| Fibrosis stage ≥3 | 1.073 ± 0.086 | 0.938 ± 0.0813 | 0.2 | | |
| F3 | 1.064 ± 0.055 | 0.921 ± 0.062 | 0.2 | | |
| F4 | 1.076 ± 0.094* | 0.943 ± 0.087 | 0.2 | | |
| P values‡ | 0.013, 0.001 | 0.300, 0.084 | < | | |

*Post hoc analysis revealed a statistically significant difference compared with F0.
†Post hoc analysis revealed a statistically significant difference compared with F1-
‡The first P values are obtained from the comparison of the parameter values
repeated-measures ANOVA test and the second P values from the comparison of
using the independent sample t-test.
Data are mean ± standard deviation.

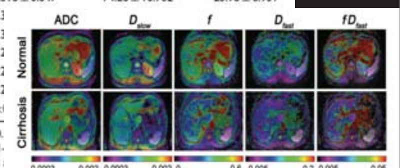


Fig. 1. ADC and IVIM parametric maps of a 40-year-old woman with normal liver (upper row) and a 62-year-old man with hepatitis B viral liver cirrhosis (lower row). ADC, $f$, $D_{slow}$ and $fD_{fast}$ maps show lower values in the patient with liver cirrhosis (lower row) than in the patient with normal liver (upper row), while no obvious difference is noted in the $D_{slow}$ maps.

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DIAGNOSTIC NEURORADIOLOGY

## Intravoxel incoherent motion perfusion imaging in acute stroke: initial clinical experience

C. Federau · S. Sumer · F. Becce · P. Maeder · K. O'Brien · R. Meuli · M. Wintermark

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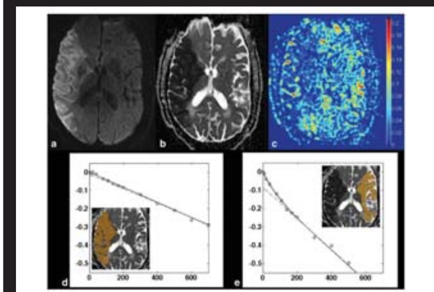


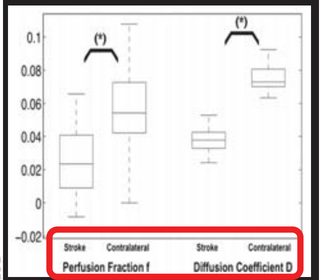


Eur Radiol
DOI 10.1007/s00330-014-3511-4

ONCOLOGY

## The Histogram Analysis of Diffusion-Weighted Intravoxel Incoherent Motion (IVIM) Imaging for Differentiating the Gleason grade of Prostate Cancer

Yu-Dong Zhang · Qing Wang · Chen-Jiang Wu · Xiao-Ning Wang · Jing Zhang · Hui Liu · Xi-Sheng Liu · Hai-Bin Shi

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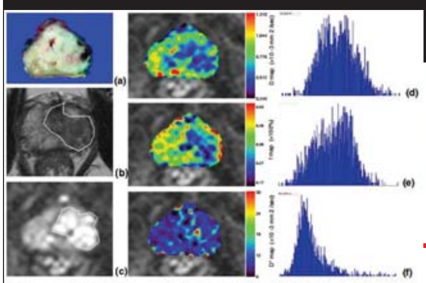



Fig. 1 A representative PCa with Gleason score of 4+4 for the introduction of metrics for histologic-radiologic correlation, and histogram analysis of DW imaging measures.

### Conclusion

Our results suggest that diffusivity $D$ derived from IVIM can be a useful tool for discriminating low-grade tumour foci from intermediate/high-grade tumour foci in patients with PCa; and the $f$ and $D^*$ contribute little to the diffusivity for predicting the tumour grade. The histogram analysis is helpful to reflect the varieties of biologic behaviour in tumour foci.

# Conclusions and discussion

## Introduction about Intravoxel Incoherent Motion (IVIM)

- Blood flow effect analysis
- Pseudo-different process from movement of the blood in the microvassulature

## Biexponential model

- slow and fast diffusion
- intra-cellular and extra-cellular compartment

$$I = I_0(f\exp(-b[D^* + D_{molecular}]) + (1-f)\exp(-bD_{molecular}))$$

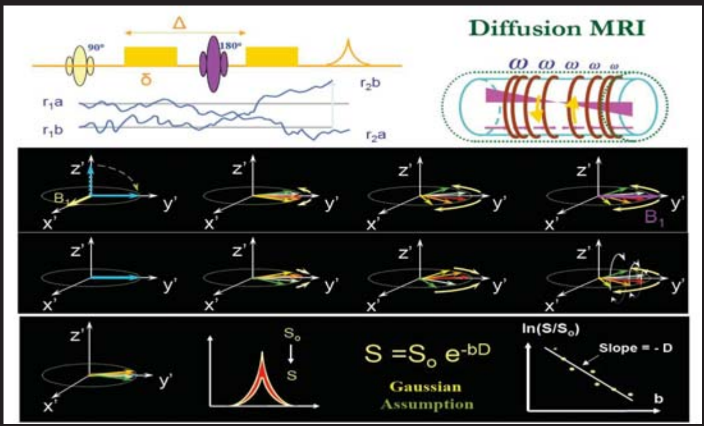
# Conclusions and discussion

Clinical application

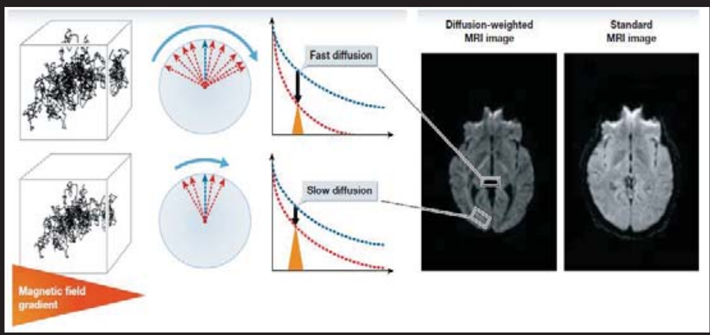
- Tissue characterization (benign or malignant)
- Tumor staging
- Predicting treatment outcomes (treatment guidelines)
- Monitoring treatment response after chemotherapy or radiation
- Detecting recurrent cancer

*Thank you for your attention*

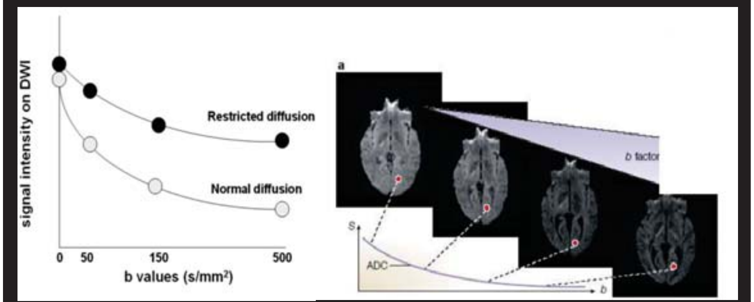
# Conventional DWI




# Principles of DWI




# Diffusion image v.s b-value




# MRI signal