2020 NCC 의학물리 아카데미 교육프로그램

Physics of MRI Clinical Applications

Haijo Jung, Ph. D.
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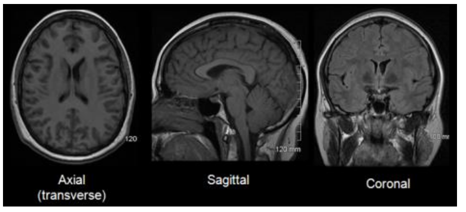
haijo5864@naver.com

General MRI Images

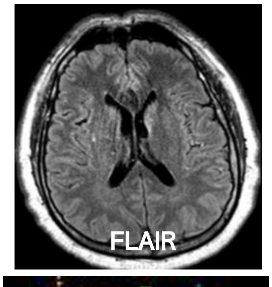
- Water is distributed throughout the body and organs.
- The water content of various organs depends on their composition, and ranges from 83% in blood to only 10% in adipose tissue .
- General MRI represents the black and white contrast with the water distribution of body (i.e. proton density)

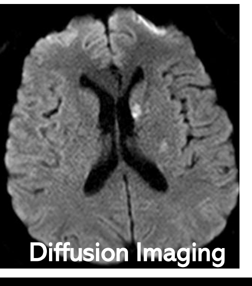
General MRI Images

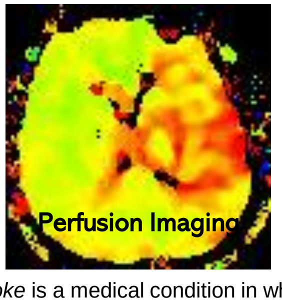


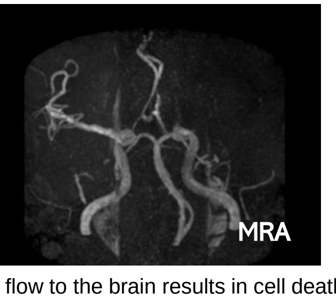
- MRI is a relatively new diagnostic imaging technique that has substantially affected the diagnosis of a multitude of disease.
- It has became the imaging modality of choice for a number of pathologic process, especially in the central nervous system.
- Also, It has became the useful imaging modality in Radiotherapy Treatment Planning field.

Stroke Images in MRI









A *stroke* is a medical condition in which poor blood flow to the brain results in cell death.

What is Angiography?

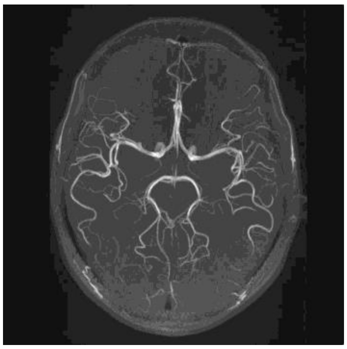
- Angiography is a medical imaging technique used to visualize the inside of blood vessels and organs of the body, with particular interest in the arteries, vein, and heart chambers.
  - Strokes
  - Aortic coarctation
  - Carotid artery disease
  - Heart disease
  - Other blood vessel issues

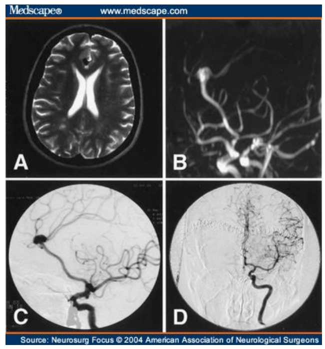
Angiographies

- Angiography is performed using:
  - Fluoroscopy (x-rays) to help the interventional radiologists place catheters into blood vessels of the body.
  - Computed Tomography (CT)
  - Magnetic Resonance Imaging (MRI)
    - MRA dose not use ionizing radiation (x-rays)
    - MRA may be performed with or without contrast material, if needed, the contrast materials is usually administered through a small intravenous (IV) catheter in a vein in your arm.
    - Unlike CT angiography, MRA is not able to see and capture images of calcium deposits within the blood vessels.

MR Angiography

- MRA (Magnetic Resonance Angiography) evaluate diseases of blood vessels and help identify abnormalities or diagnose atherosclerotic (plaque) disease.
- MRA is noninvasive vascular imaging exam and furthermore, provide the merit of functional information.

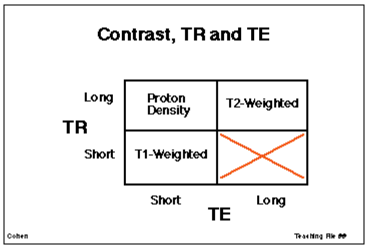


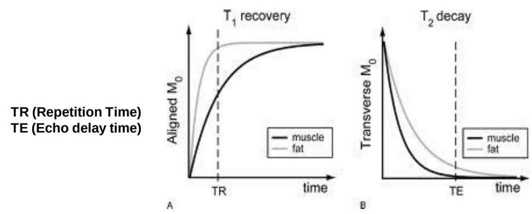


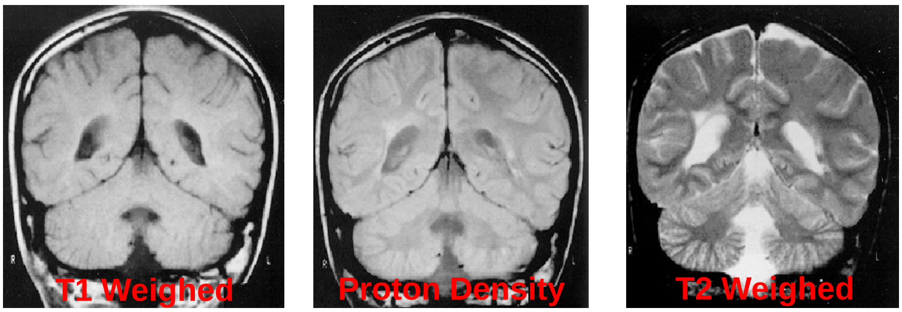
MRI and MRA Risks

- Heating of the body.
- Skin burns from radiofrequency.
- Magnetic reactions from (ferrous) objects with your body
- Hearing damage.
- Risk associated with the injection of intravenous contrast agent.
- Health risks are very rare with MRIs and MRAs, the FDA receives roughly 300 reports a year out of millions of MRI scans performed.)

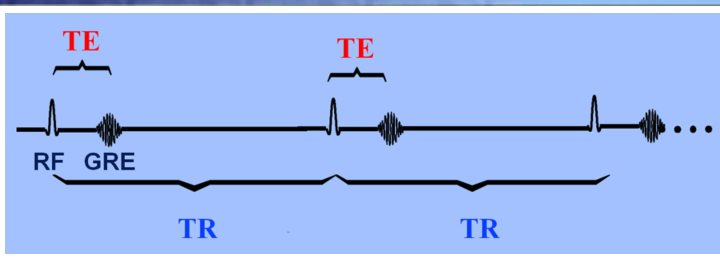
T1/Proton Density/ T2 Weighed Images







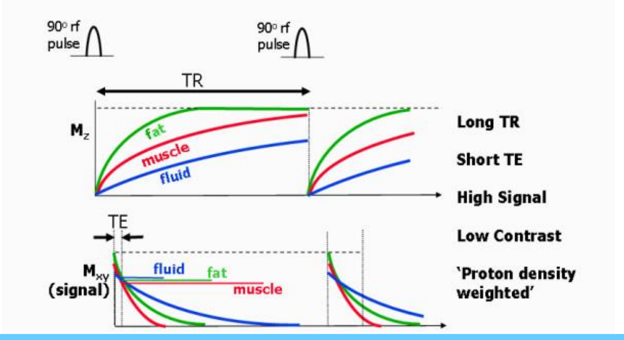
What are TR and TE?



- ***TR*** and ***TE*** are basic pulse sequence parameters and stand for ***repetition time*** and ***echo time*** in the unit of milliseconds (ms), respectively.
- The ***Echo Time (TE)*** represents the time from the center of the RF-pulse to the center of the echo.
- The ***Repetition Time (TR)*** is the length of time between corresponding consecutive points on a repeating series of pulses and echoes.

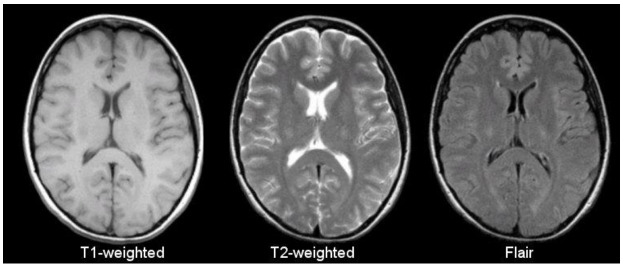
Spin Echo Imaging

The value of the repetition time (TR) and echo time (TE) can be varied to control contrast in spin echo imaging.



For example:
TR=2000 sec TE=20 msec [Proton Density Weighted]
TR=2000 sec TE=80 msec [T2 Weighted]
TR=600 sec TE=20 msec [T1 Weighted]

Comparison of T1 vs. T2 vs. Flair (Brain)

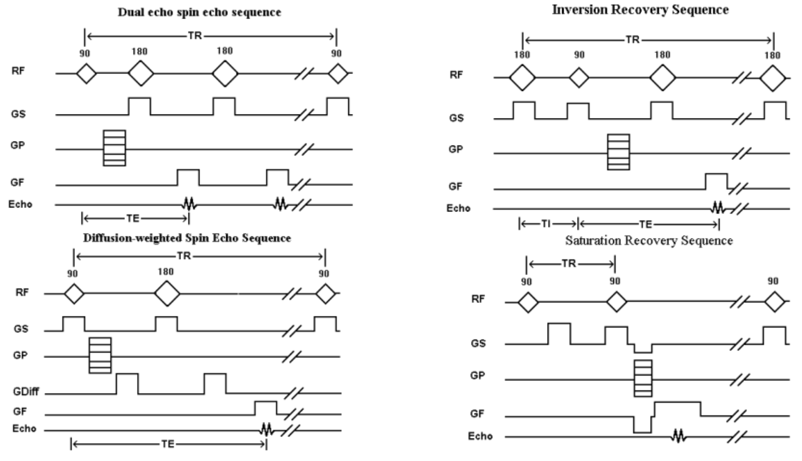


Tissue	T1-Weighted	T2-Weighted	Flair
CSF	Dark	Bright	Dark
White Matter	Light	Dark Gray	Dark Gray
Cortex	Gray	Light Gray	Light Gray
Fat (within bone marrow)	Bright	Light	Light
Inflammation (infection, demyelination)	Dark	Bright	Bright

CSF: Cerebrospinal Fluid

MRI Pulse Sequences

There are many pulse sequences available for imaging (spectroscopy).
(Listed below are some of the commonly used pulse sequences in MRI.)



New Methods of MRI Imaging

Diffusion Weighted Imaging (DWI) is a form of MR imaging based upon **measuring the random Brownian motion of water molecules** within a voxel of tissue.

Perfusion Weighted Imaging is a term used to denote a variety of MRI techniques able to give insights into the **perfusion of tissues by blood**.

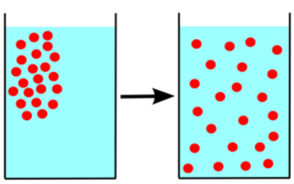
Functional MRI (**fMRI**) is a functional neuroimaging procedure using MRI technology that **measures brain activity** by detecting changes associated with blood flow.

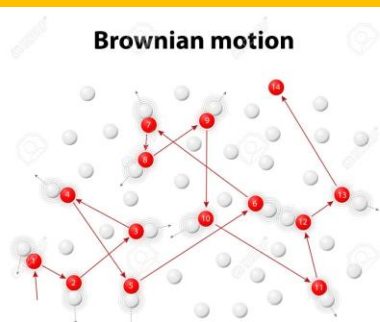
DWI: Diffusion Weighted Imaging

- DWI is a form of MR imaging based upon measuring the random Brownian motion of water within a vessel of tissue.
- In general simplified terms, highly cellular tissue of those with cellular swelling exhibit lower diffusion coefficient.
- Water molecules diffuse relatively freely in the extracellular space; their movement is significantly restricted in the intracellular space.
- Diffusion is particularly useful in tumor characterization and cerebral ischemia.

What is Diffusion?

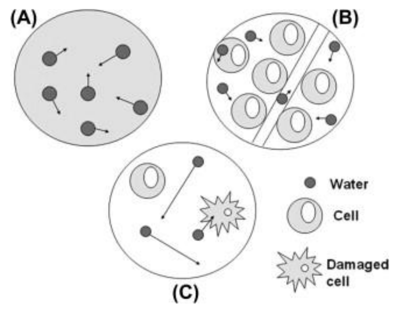
- Diffusion is the net movement of molecules or atoms from a region of higher concentration(or high chemical potential) to a region of lower concentration (or low chemical potential).
- Diffusion is a driven by a gradient in chemical potential of the diffusing species.





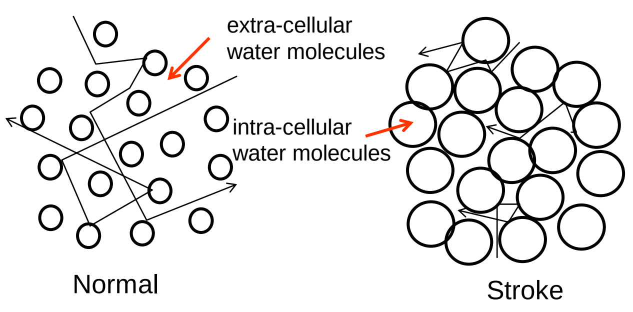
Diffusion Weighted Imaging

- There is diffusion motion in a living body, however, its extent is different between each organs
- Minute signal changes by the diffusion are maximized, and the diffusion difference between organs are imaged.
- The extent of diffusion effects on the intensity of signal, unlike general MR techniques determined by T_1, T_2 relaxation times of organ



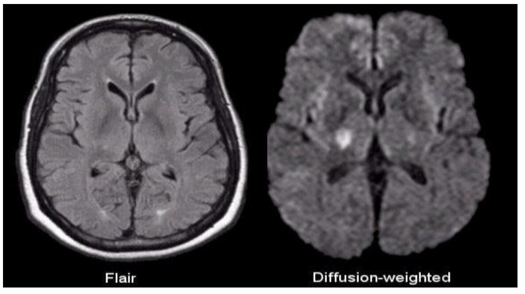
Schematic illustrating water molecule movement.
In (A) water molecules in a container alone move randomly (**Brownian motion**).
In (B) highly cellular tissue impedes the movement of water molecules. Their movement can be categorized as intravascular, intracellular, or extracellular.
In (C) tissue of low cellularity or with defective cells permits greater water molecule movement.

Diffusion Motion in the Human Body



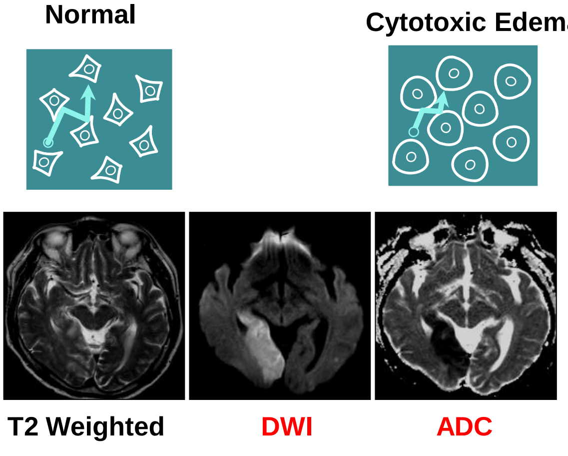
Clinical Applications of DWI

- Each organs in living body has different diffusion coefficients by its intrinsic environments.
- Clinical application filed of DWI: acute cerebral infarction, brain tumor, brain white matter disease, pathology decision of cyst, brain membrane diffusion, etc. (Among these, acute cerebral infarction is most important disease within 5 ~ 6 hours after the attack.



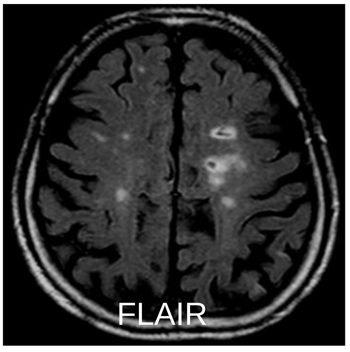
Comparison of Flair vs. Diffusion-weighted

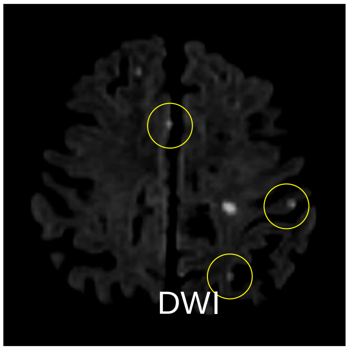
Early Detection of Acute Infarction



Detection of Small Acute Infarction

Multiple Embolic Infarcts



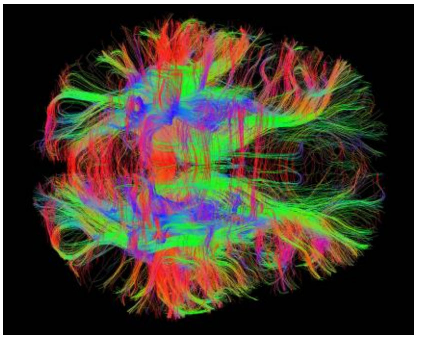


White Matter Fiber Tracts (Diffusion Tensor Imaging)

Diffusion Tensor Imaging (DTI) is an MRI-based neuroimaging technique which makes it possible to estimate the location, orientation, and anisotropy of the brain's **white matter tracts**.

DTI has become one of the most popular MRI techniques in brain research, as well as in clinical practice.

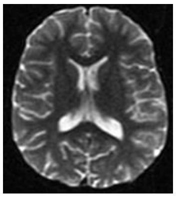
DTI is used to study white matter architecture and integrity of normal and diseased brains (multiple sclerosis, stroke, aging, tumors, dementia, schizophrenia, etc.)

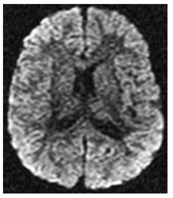


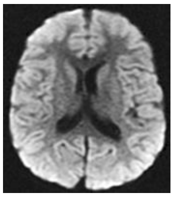
White matter fiber tracts in the adult human brain. Image: Zeynep Saygin - See more at: http://mcgovern.mit.edu/news/newsletter/summer-2013/attachment/image7lr/#sthash.pg3YZMQp.dpuf

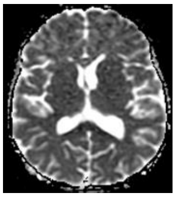
Generating DT Image processes

“b-zero” image that are T2-weighted and will serve as a baseline for later calculated maps.


bo image

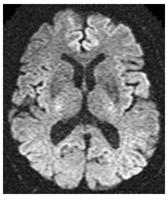

Source DW image

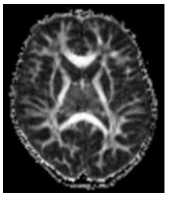

Trace DW image

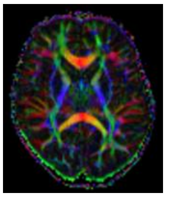

ADC map

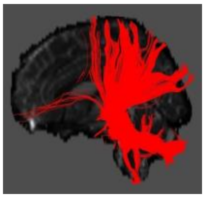
The **DW source images** are combined to produce a set of **Trace DW image**.

An **Apparent Diffusion Coefficient (ADC)** map is then calculated using the data form b0 and source image .


Exponential ADC map


Fractional Anisotropy map

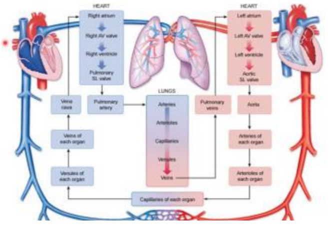

Principal Diffusion Direction map


Fiber Tracking map

Further advanced processing can be optionally perform, creating additional calculated image set for analysis.

What is Perfusion???

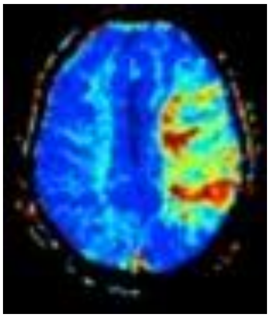
Perfusion



- Perfusion is the passage of fluid through the circulation system or lymphatic system to an organ or a tissue, usually referring to the delivery blood to capillary bed in tissue.
- Perfusion is measured as the rate at which blood is delivered to tissue, or volume of blood per unit time (blood flow) per unit tissue mass.

PWI: Perfusion Weighted Imaging

- PWI is perfusion scanning by the use of a particular MRI sequence.
- The acquired data then post processed to obtain perfusion maps with different parameters, such as blood volume (BV), blood flow (BF), mean transit time (MTT), and time to peak (TTP) .
- Perfusion is to acquire the functional information, that is, the circulation phenomenon of blood in a capillary vessel.



MRI perfusion showing a delayed time-to-maximum flow (T_{max}) in the penumbra in a case of occlusion of left middle cerebral artery.

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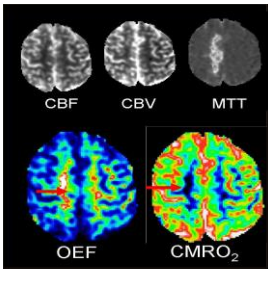
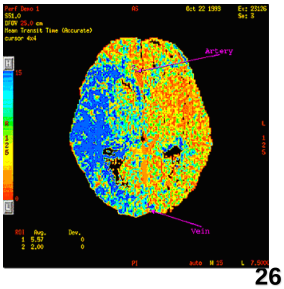
Generating PWI

- After intravenous (IV) bolus of paramagnetic contras media (gadolinium, iron oxide etc.), a dynamic scan is performed, → then, image of regional cerebral blood flow (rCBF) is acquired as signal intensity of blood region is decreased because shortening of T2* due to the difference of magnetization rate.
- To get this PWI, equipment, which give strong gradient magnetic field during a short time, is essential.





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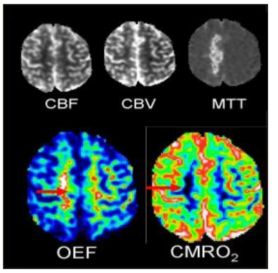
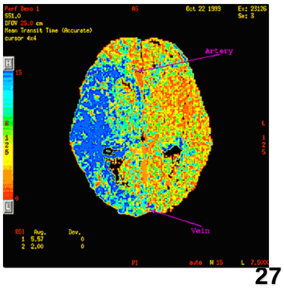
Generating PWI

- Because requirement for control other motions except diffusion, the mage should be acquired with minimizing unnecessary movements so far as in short time by using cardiac gating etc. including patient compliances.





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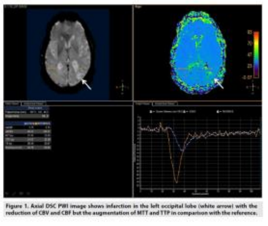
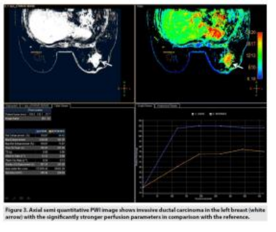
Clinical Applications of PWI

- Perfusion is one of the most important parameters affected on the diagnosis, treatment planning, and disease response to therapy.
- In cerebral infarction, the penumbra has decreased perfusion. Another MRI sequence, diffusion weighted MRI, estimates the amount of tissue r that is already necrotic, and the combination of sequence can therefore be used to estimate the amount of brain tissue that is salvageable by thrombolysis and/or thrombectomy.



Axial DSC PWI images shows infraction in the left occipital lobe (white arrow) with the reduction of CBV and CBF but the augmentation of MTT and TTP in comparison with the reference.



Axial semi PWI images shows invasive ductal carcinoma in the left breast (white arrow) with the significantly stronger perfusion parameters in comparison with the reference.

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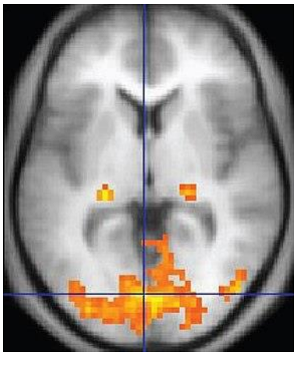
Development of f(Functional)MRI

- Researches have been progressed to express the region of its function as images after inducing the localized nerve activation in brain and the research area of functional MR imaging were developed together with technical developments.
- fMRI is not only *excellent in spatial and temporal resolutions* but also have a *merit that can do repeatedly perform the exam* because the unnecessary of radioisotope injection.

Introduction to fMRI

- fMRI measures brain activity by detecting changed associated with blood flow.
- This technique relies on the fact that cerebral blood flow and neuronal activation are coupled.
- When an area of the brain is in use, blood flow to that region also increased.



An fMRI image with yellow areas show increased activity compared with a control condition (to measure brain activity detecting changes due to blood flow.).

Generating fMRI

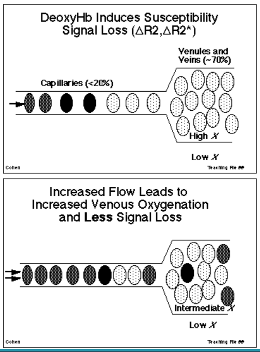
- The primary form of fMRI uses the Blood Oxygen Level-Dependent (BOLD) contrast.
- This is a type of specialized brain and body scan used to map neural activity in the brain or spinal cord of humans or other animals by imaging the change in blood flow (hemodynamic response) related to energy use by brain cells.
- The increment of regional blood flow due to brain activation means the increment of oxygen's amount supplied to brain tissue, and in this time, increased oxygen's amount increase oxyhemoglobin's amount existed in capillary vessel and vein, and as a result, the concentration of deoxyhemoglobin's amount is decreased.

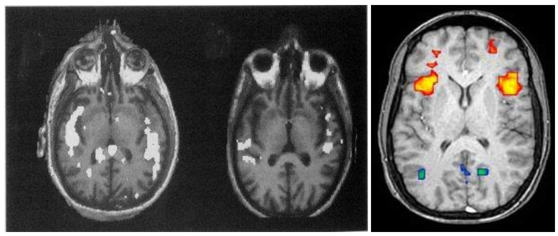
Generating fMRI

- Because deoxyhemoglobin is paramagnetic material to shorten T_2 or T_2* relaxation time, the deduction of this material cause the signal increase in T_2* weighted image.
- The fMRI technique is to sensitively examine this T_2* effect.

Application of fMRI

- In early stage, fMRI imaged the functions of basic visual cortex and motor cortex. In recent years, fMRI image reorganization functions including language function.
- So far, even in clinical application step, It is helpful in localized brain surgery, and could be used to predict the damages due to surgery.



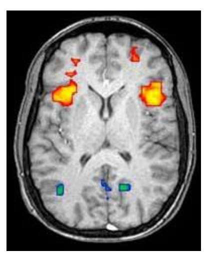


Images acquired with Functional Imaging

Application of fMRI

Functional Brain Mapping
i.e. what regions of the brain are responsible for what

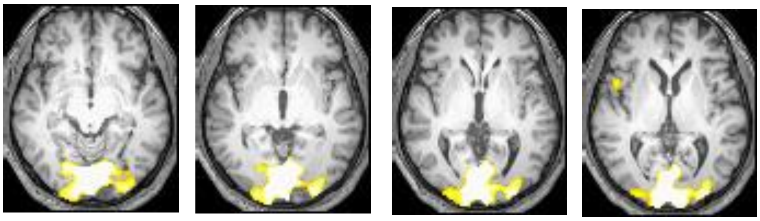
Women “hear” with both sides of the brain,
men only use one side.



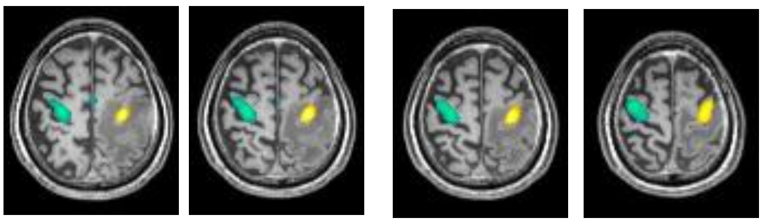
Expose subject to a particular stimulus and then look for regions of activations

Visual and Motor fMRI Tasks

Visual Task Regions



Motor Task Regions



Use of MRI in RT

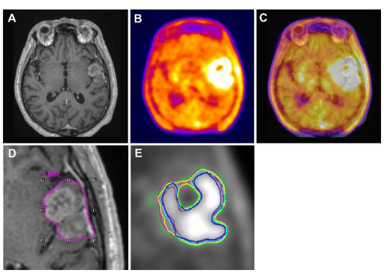
The British Journal of Radiology, 79 (2006), S2–S15

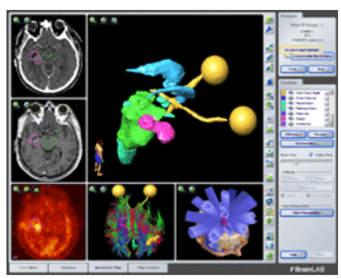
New developments in MRI for target volume delineation in radiotherapy

[1,2]V S KHOO, FRACR, FRCR, MD and [3]D L JOON, FRACR

[1]*Royal Marsden Hospital, Institute of Cancer Research, Fulham Road, London SW3 6JJ, [2]University of Manchester, Manchester, UK and [3]Austin Health Radiation Oncology Centre, Heidelberg Repatriation Hospital, Victoria, Australia*

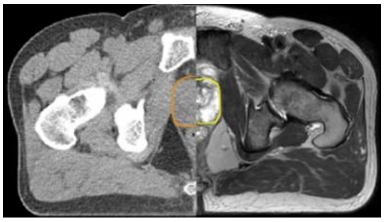
ABSTRACT. MRI is being increasingly used in oncology for staging, assessing tumour response and also for treatment planning in radiotherapy. Both conformal and intensity-modulated radiotherapy requires improved means of defining target volumes for treatment planning in order to achieve its intended benefits. MRI can add to the radiotherapy treatment planning (RTP) process by providing excellent and improved characterization of soft tissues compared with CT. Together with its multiplanar capability and increased imaging functionality, these advantages for target volume delineation outweigh its drawbacks of lacking electron density information and potential image distortion. Efficient MR distortion assessment and correction



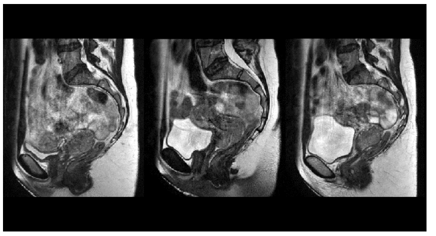


Benefits of MRI for RT

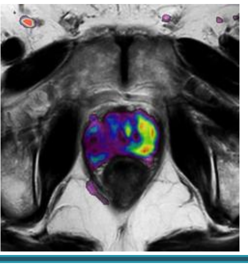
Excellent soft-tissue contrast



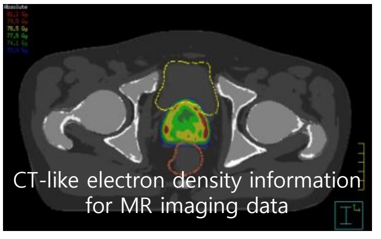
No ionizing radiation



Functional Imaging



Density information for dose calculation



Benefits of MRI for RT

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A New Era of Image Guidance with Magnetic Resonance-guided Radiation Therapy for Abdominal and Thoracic Malignancies

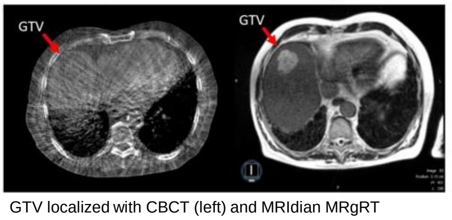
Kathryn Mittauer [1], Bhudatt Paliwal [1], Patrick Hill [1], John E. Bayouth [1], Mark W. Geurts [1], Andrew M. Baschnagel [1], Kristin A. Bradley [1], Paul M. Harari [1], Stephen Rosenberg [1], Jeffrey V. Brower [2], Andrzej P. Wojcieszynski [3], Craig Hullett [1], R A. Bayliss [1], Zacariah E. Labby [1], Michael F. Bassetti [1]

1. Department of Human Oncology, University of Wisconsin - Madison, Madison, USA 2. Radiation Oncology, Wentworth Douglas Hospital, Seacoast Cancer Center, Dover, USA 3. Department of Radiation Oncology, University of Pennsylvania, Philadelphia, USA

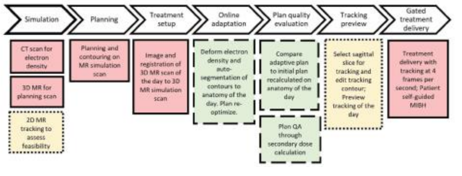
Abstract

Magnetic resonance-guided radiation therapy (MRgRT) offers advantages for image guidance for radiotherapy treatments as compared to conventional computed tomography (CT)-based modalities. The superior soft tissue contrast of magnetic resonance (MR) enables an improved visualization of the gross tumor and adjacent normal tissues in the treatment of abdominal and thoracic malignancies. Online adaptive capabilities, coupled with advanced motion management of real-time tracking of the tumor, directly allow for high-precision inter-/intrafraction localization. The primary aim of this case series is to describe MR-based interventions for localizing targets not well-visualized with conventional image-guided technologies. The abdominal and thoracic sites of the lung, kidney, liver, and gastric targets are described to illustrate the technological advancement of MR-guidance in radiotherapy.

CBCT   MRgRT



GTV localized with CBCT (left) and MRIdian MRgRT setup scan (right) for fraction 2 and fraction 1, respectively, for patients undergoing liver stereotactic body radiation therapy for hepatocellular carcinoma.

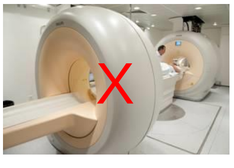


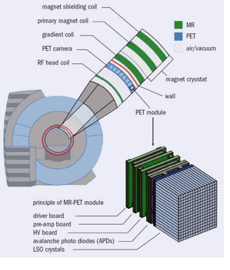
Clinical MRgRT workflow with workflow details unique to gating denoted in dotted outline and online adaptive in dashed outline

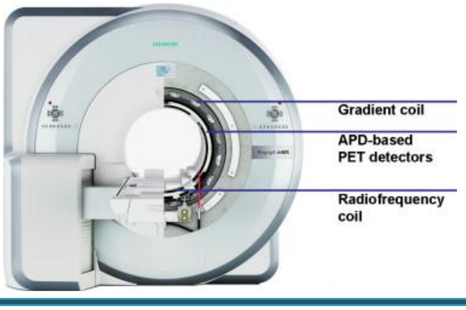
MR Simulator

Simulation	Registration	Contouring	Dose planning	Treatment	Follow-up
MR /CT imaging in the treatment position	Registration of MR and CT datasets	Contouring target and organs at risk	Dose calculation aiming high dose on target, while sparing critical structures	Radiation therapy delivery in multiple fractions	Follow-up and response assessment

Simultaneous MRI-PET



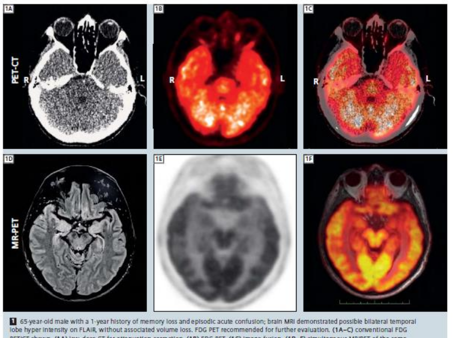




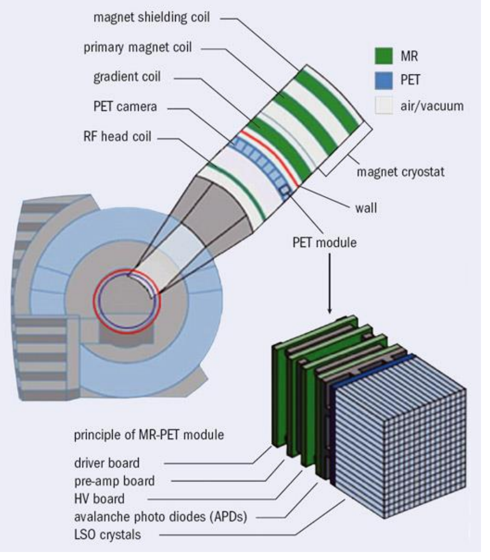
Clinical Experience with Simultaneous MR-PET Acquisition: Developing Optimal Protocols for Anatomically Focused and Whole-Body Examinations

Kathryn Fowler, M.D.[1]; Farrokh Dehdashti, M.D.[1]; Tammie L.S. Benzinger, M.D., Ph.D.[1]; Michelle Miller-Thomas, M.D.[1]; Jonathan McConathy, M.D., Ph.D.[1]; Matthew Parsons, M.D.[1]; Vilaas Shetty, M.D.[1]; Constantine Raptis, M.D.[1]; Perry Grigsby, M.D.[1]; Pamela K. Woodard, M.D.[1]; Richard Laforest, Ph.D.[1]; Robert J. Gropler, M.D.[1]; Vamsi Narra, M.D.[1]; Barry A. Siegel, M.D.[1]; John Kotyk, Ph.D.[1]; Agus Priatna, Ph.D.[2]; Robert McKinstry, M.D., Ph.D.[1]

[1]Mallinckrodt Institute of Radiology, Washington University School of Medicine, St Louis, MO, USA
[2]R&D Collaborations, Siemens Healthcare, St Louis, MO, USA



1 65-year-old male with a 1-year history of memory loss and episodic acute confusion; brain MRI demonstrated possible bilateral temporal lobe hyper intensity on FLAIR, without associated volume loss. FDG PET recommended for further evaluation. **(1A–C)** conventional FDG PET/CT shown: **(1A)** low-dose CT for attenuation correction, **(1B)** FDG PET, **(1C)** image fusion; **(1D–F)** simultaneous MR/PET of the same patient: **(1D)** FLAIR, **(1E)** FDG PET data, **(1F)** overlay of metabolic information.



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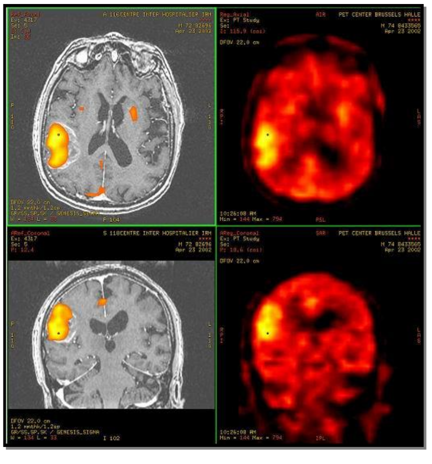
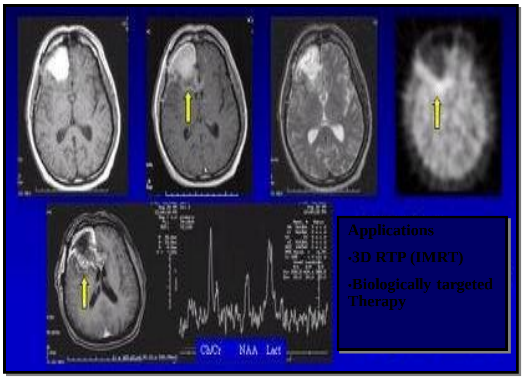
Multi Fusion Imaging (MRI-PET)

Tumor Define & Analysis
MRI + F-18 FDG PET + MRS





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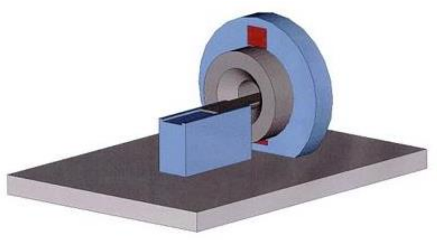
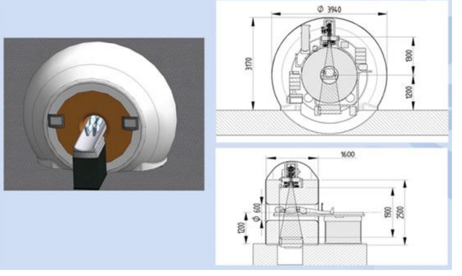
MRI guided RT (MRIgRT)

Schematic design of the MRI accelerator combination.
Blue is the accelerator section, **grey** the 1.5 T MRI.
Red is the collimator section.





Precise, soft-tissue based, on-line position verification and treatment monitoring is a prerequisite for image guided radiotherapy (IGRT). In order to obtain on-line MRI guidance for radiotherapy we are constructing a 1.5 T MRI scanner integrated with a 6 MV radiotherapy accelerator. Basically, the design is a modified 1.5 T Philips Achieva MRI scanner with a small, single energy (6 MV) accelerator rotating around it

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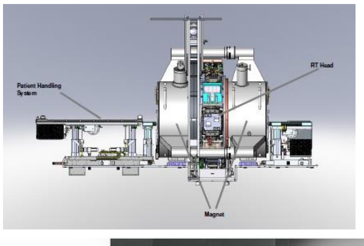
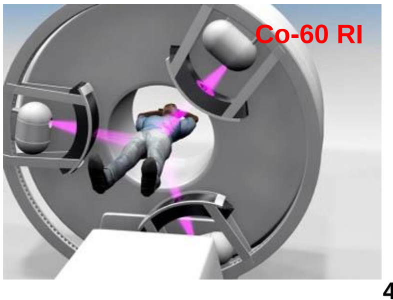
In-room MRI-guided Radiotherapy





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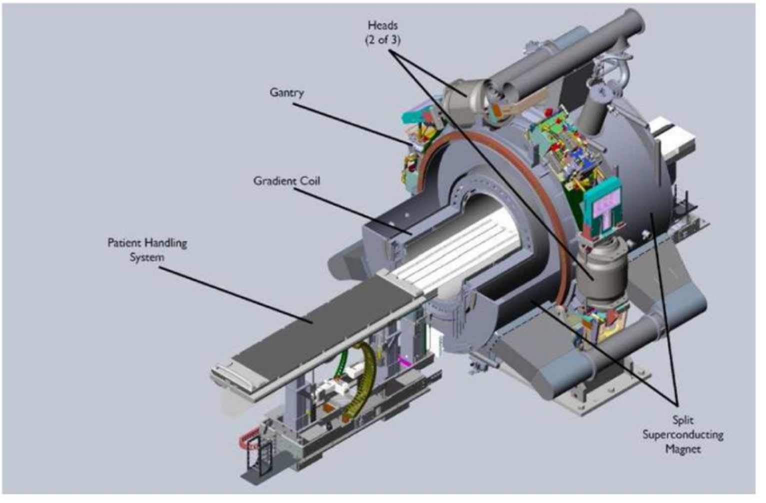
ViewRay
MRI-guided Radiotherapy



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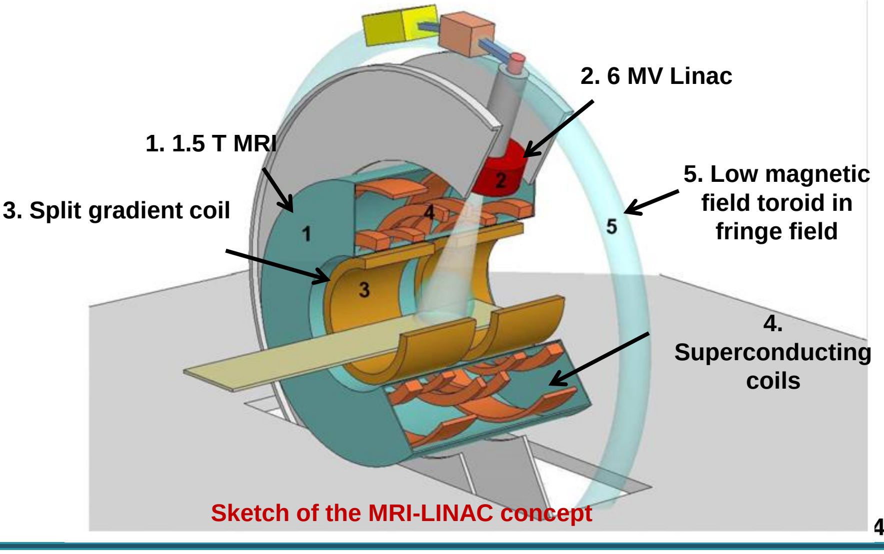
MRI (Supercon)-LINAC ???

University Medical Center Utrecht, The Netherlands



Sketch of the MRI-LINAC concept

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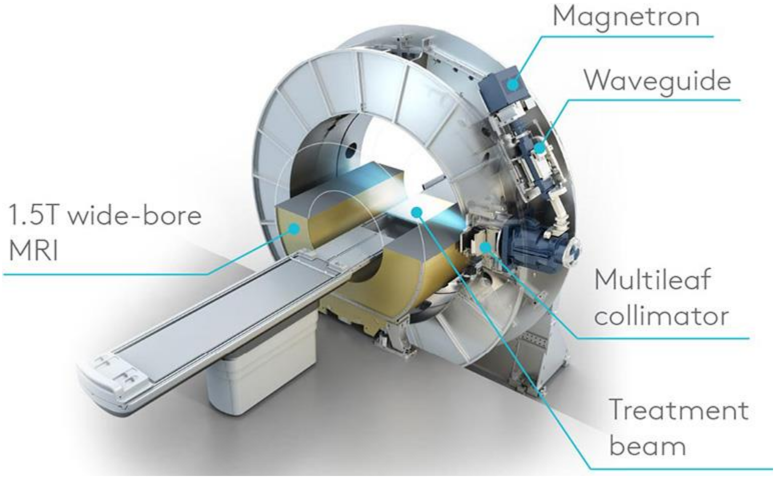
MR-LINAC

The MR-LINAC aims to provide soft tissue imaging during radiation therapy while adapting treatment delivery in real-time for precise cancer treatments. (Source: Elekta.)

(Elekta)
High Field MR-LINAC System




THANK
YOU