MRI for Diagnosis and Treatment of Cancer

Geoffrey Clarke & Niko Papanikolaou
Departments of Radiology and Radiation Oncology
University of TX Health Science Center
San Antonio, TX
Overview

- **Manipulating MR Image Contrast**
- Contrast-Enhanced Perfusion MRI
- Diffusion Weighted MR Imaging
- Magnetic Resonance Spectroscopy
- MR Image Registration Methods
- Clinical Examples of MRI Utility
MR Image Contrast

- Basic image contrast is affected by the amplitude and timing of the RF pulses used to excite the spin system.

- More advanced methods may use gradient pulses (to modulate motion) and alter tissue properties (T1, T2*) with exogenous contrast agents (such as Gd and high molecular weight)
MR Image Contrast

- RF Pulse basic functions (based on flip angle):
  - Excitation
  - Refocusing
  - Inversion

- Pulse timing determines contributions to contrast:
  - TR controls T1-weighting to overall contrast
  - TE controls T2-weighting to overall contrast
  - TI utilizes T1-weighting to exclude specific types of tissues (fat, CSF)
## Pulse Sequence Classifications

<table>
<thead>
<tr>
<th>Name</th>
<th>RF Pulses</th>
<th>Contrast Weighting</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gradient Echo</td>
<td>One</td>
<td>T1, T2*, T2/T1</td>
<td>Fast imaging (3DFT)</td>
</tr>
<tr>
<td>Spin Echo</td>
<td>Two or more</td>
<td>T1, PD or T2</td>
<td>Conventional</td>
</tr>
<tr>
<td>Inversion Recovery</td>
<td>Three</td>
<td>T1 and T2</td>
<td>Excludes certain tissues</td>
</tr>
</tbody>
</table>
Spin Echo Pulse Sequence

- RF\(_1\) (excitation)
- RF\(_2\) (rephasing)
- FID
- Spin Echo
- TE
- TR
T2 Weighting Enhances Lesions

Glioblastoma multiforme
T1-weighting better deliniates anatomy
T2-weighting naturally shows pathology

Runge VM. Top Magn Reson Imag 200; 12(4): 231-263
Gradient-Echo Imaging

- Uses gradient refocusing to create echo
- Faster method than spin echo
- Susceptibility artifacts occur because no refocusing RF pulse
- Contrast is a function of both pulse timing and flip angle
- Contrast relationships get complicated when TR<T2
Gradient Echo Pulse Sequence

RF
(<90° excitation)

TX

RX

G_x

FID

Gradient Echo

TE

TR

time

time

time
Low Grade Astrocytoma

Spin Echo (3 min scan)
TR/TE = 600/17

Gradient echo
(FLASH, 2.4 s scan)
TR/TE/flip = 40/12/50°
Cystic Mass

**Spin Echo**
- TR/TE = 2500/90
- NSA = 1
- 5 mm

**Gradient Echo**
- (FISP) TR/TE = 22/10
- NSA = 8
- 8 mm

**Gradient Echo**
- (True FISP) TR/TE = 16/6
- flip = 40°
- NSA = 8
- 5 mm

**Gradient Echo**
- (True FISP) TR/TE = 16/6
- flip = 70°
- NSA = 8
- 5 mm
Inversion Recovery Imaging

- Uses **THREE** rf pulses
- Is highly sensitive to T1, increases dynamic range of T1 contrast by manipulating signal phase AND amplitude
- Generally takes a longer time than simple SE or GE sequences
- When used with spin echo, is generally limited to specific niches
Inversion Recovery Pulse Sequence

- RF$_3$ (180° inversion)
- RF$_1$ (90° excitation)
- RF$_2$ (180° rephasing)
- RF$_3$ (180 degree inversion)

TX - time
RX - time
FID - time
TE - time
TR - time
TI - time
**T₁-Weighting with IR-MRI**

Positive and negative values refer to the phase of transverse magnetization.

- **Fat**
- **Muscle**

- **STIR = short TI Inversion Recovery**
- **Used to suppress lipid signals**

**Signal Nulling**

**Max contrast**
STIR (myxoid liposarcoma)

This lesion appears heterogeneous and does not resemble the intensity of the surrounding subcutaneous fat. Also notable is the significant amount of associated edema.

http://liddyshiversarcomainitiative.org/Newsletters/V01N05/Liposarcoma/liposarcoma.htm
Manipulating Contrast

What do I need to remember?

- The “weighting” of image contrast by T1, T2 etc.
- Gradient Echo – manipulating image contrast by varying the flip angle (fast imaging for showing anatomy)
- Spin Echo – manipulating image contrast with 180° refocusing pulses (T2-weighting shows pathology)
- Inversion Recovery – manipulating image contrast with 180° inversion pulses (eliminates fat and CSF)
Rules of Thumb

- TE controls T2 dependence
- TR controls T1 dependence
- T1 competes with T2 and proton density

“PD Weighted” = long TR, short TE
“T1 Weighted” = short TR, short TE
“T2 Weighted” = long TR, long TE
In which type of conventional MR images do most tumors appear most striking?

1. Those obtained with a short echo time (TE) and short pulse repetition time (TR)
2. Those obtained with a short TE and long TR
3. Those obtained with a long TE and short TR
4. Those obtained with a long TE and long TR
5. Those obtained with a short TE, a short TR and a very short inversion time (TI)
In which type of conventional MR images do most tumors appear most striking?

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1. T1-weighted images show morphology not so good at pathology
2. Proton density – high SNR
3. Low SNR – poor image quality
4. T2-weighted images show lesions well
5. STIR inversion recovery images useful for fat imaging
MAGNETIC RESONANCE IMAGING & SPECTROSCOPY

BIOLOGICAL EVENT
- ANGIOGENESIS
- TUMOR VOLUME
- TUMOR GROWTH
- THERAPEUTIC INTERVENTION

BIOLOGICAL ENDPOINT
- CELL KILL
  - TUMOR INCIDENCE & GROWTH RATES
  - ANIMAL SURVIVAL
  - PATIENT SURVIVAL & TUMOR RESPONSE

CELLULARITY
- DIFFUSION

PERFUSION & BLOOD VOLUME
- DIFFUSION

METABOLITE CONCENTRATION
- MRS

ANATOMICAL
- eg. TUMOR SIZE
- MRS

http://www.molecularimaging.com
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Gd-DTPA in Brain

- **Typical dose of ~0.1 mM/kg**
  - 550-600 Dalton

- **Shortens T1 relaxation times** of nearby $^1$H spins
  - Causes increased MR signal intensity on T1-weighted images

- **Nonuniform distribution of Gd-DTPA** increases magnetic susceptibility differences
  - Decreases MR signal on T2*-weighted images
Gadolinium Contrast Agents

Intra-axial Glioma: $T_1$-weighted Images

9 min post Gd contrast

Basic $T_1$-weighted

Post-Gadolinium T1-Weighted and T2-Weighted MR Images from Patients with Brain Metastases

Tissue Perfusion

Grey Matter

White Matter

http://www.fmrib.ox.ac.uk/~patricia/web_talk/index.htm
Perfusion Imaging – Methods

- **Phase-sensitive methods:**
  - Attempts to separate perfusion & diffusion
  - “Intravoxel incoherent motion”

- **T1/Inflow Methods:**
  - Measures inflow of magnetically saturated or inverted spins
  - “Arterial Spin Labeling”

- **Contrast Agent Uptake**
  - Dynamic Susceptibility Enhanced Contrast
Clinically available MRI contrast agents do not leak into the intracellular space.

\[ K_{\text{trans}} = \text{volume transfer constant of contrast agent leakage into the interstitial spaces} \]

**Phases of Contrast Enhancement**

**Uptake Phase:** signal intensity rises above baseline and there is a net leakage of contrast from the blood vessels into the interstitial space.

Phases of Contrast Enhancement

Plateau Phase: maximum enhancement with an equilibrium in the movement of contrast between the plasma and extracellular-extravascular space.

Phases of Contrast Enhancement

Washout Phase: contrast starts to leave tissue and goes back into blood vessels. Red part of graphs refer to phase in corresponding diagram showing movement of contrast.

Curves denote difference between uptake of normal glandular tissue (green) & lesion (blue).

High rate of uptake is linked to larger micro-vessel size and density.

Vlaardingerbroek & den Boer, 1999
Angiogenesis

- Angiogenesis is new blood vessel development, which can occur in the development of pathological states.
- Angiogenesis plays an important role in the growth and metastasis of tumors.
- A wide range of novel tumor therapies directed against angiogenesis have been developed.
- Perfusion MRI can assess hemodynamic parameters of tumors.
- Angiogenesis can be inferred from perfusion measurements from MRI.
DCE-MRI In a Patient with Partial Response to Monoclonal Antibody Rx

Inflammatory Breast Cancer

Bevacizumab (inhibits VEGF-A) + doxorubicin (chemo agent)

DCE-MRI: tumor enhancement outlined in red; contrast kinetics (black line)

DCE-MRI Summary

What do I need to remember?

- DCE-MRI with low molecular weight Gd contrast agents exploits the hyper-permeable nature of neoangiogenic tumor vessels.
- Rate of uptake is related to microvessel size & density
- A kinetic model can then be applied in order to derive parameters of permeability
- Most investigated method for imaging angiogenesis
Higher temporal resolution is desirable in contrast-enhanced breast MRI studies in order to improve evaluation of:

1. Lesion shape
2. Lesion margins
3. Size of necrotic region
4. Cell membrane integrity
5. Microvessel size and density
Higher temporal resolution is desirable in contrast-enhanced breast MRI studies in order to improve evaluation of:

1. Lesion shape
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4. Cell membrane integrity
5. Microvessel size and density

1. Determined from T1 & T2 images
2. See above
3. Determined from T2 images
4. Diffusion images
5. TRUE: Slope of uptake curve
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Diffusion Trajectory

MRI exploits phase losses in the signal due to diffusion of spins in a magnetic field gradient.
Crick Model

Apparent Diffusion Coefficient

One dimensional model.

- $\kappa \equiv$ permeability of membrane barriers
- $a \equiv$ distance between barriers
- $\text{ADC} \equiv$ diffusion coefficient of molecules in presence of barriers
- $D_0 \equiv$ diffusion coefficient of bulk fluid

- Time must large enough so there is time for particles to interact with barriers
- $D_0 > \text{ADC}$

The b-value

- Controls amount of diffusion weighting in image
- The greater the b-value the greater the area under the diffusion-weighted gradient pulses
  - longer TE
  - stronger and faster ramping the gradients
- Effect on contrast is analogous to TR and TE in conventional imaging
  - Involves timing of gradient pulses instead of RF pulses
Diffusion Weighted Imaging: Prototype Pulse Sequence

The greater the $b$-value, the more diffusion weighting you have but the smaller the overall signal becomes due to greater dephasing.

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

Diffusion EPI Pulse Sequence

- RF 90° 180°
- SS
- FE
- PE
- G_z, G_z, G_x, G_x, G_y, G_y
- MR signal
- Δ Δ δ
- ~100 ms
Diffusion Weighted Images

- Brighter regions indicate reduced diffusion values
- Different effect for different directions of the diffusion sensitizing gradients
- Splenium of the corpus callosum is aligned mainly with the x direction and has a large $D_{eff}$
- **Splenium is dark** when the gradients are in the x direction (upper left).

Diffusion Tensor

\[
\vec{D} = \begin{pmatrix}
D_{xx} & D_{xy} & D_{xz} \\
D_{yx} & D_{yy} & D_{yz} \\
D_{zx} & D_{zy} & D_{zz}
\end{pmatrix}
\]

- Directional dependence of diffusion coefficients are influenced by tissue perfusion and location of membranes and other biological barriers.
- The trace of the diffusion tensor is known as the *Apparent Diffusion Coefficient (ADC)*.
Changes in Tissue Cellularity are Related to Molecular Water Mobility

Biological processes proposed to be involved in therapeutic-induced changes in tumor ADC values along with a pictorial description of the fDM analytical process.
MRI of Patients with Oligodendrogliomas

7-week course of radiation therapy

DW-MRI of Glioblastoma Multiforme

7-week course of radiation therapy

Diffusion MR Imaging

What do I need to remember?

- Diffusion weighting (defined by the $b$-value) is accomplished by strong gradient pulses.
- Very fast *echo-planar imaging* is used to avoid artifacts from macroscopic motion.
- Tumor cell death is accompanied by an increase in the *apparent diffusion coefficient* (ADC).
- Early studies suggest that Diffusion MRI can be both *early marker of therapeutic response* and an effective biomarker when conventional imaging is ineffective.
Diffusion-weighted contrast in MR images depend on:

1. the chemical shift between water with a high apparent diffusion coefficient and those with a low apparent diffusion coefficient.
2. the microscopic motion of water in the during the time that gradient pulses are applied.
3. the change in the T1 relaxation time due to diffusion through a tissue.
4. multiple quantum coherences being established between diffusing spins.
5. the subtraction of two phase Fourier transform MR images.
Diffusion-weighted contrast in MR images depend on:

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4. multiple quantum coherences being established between diffusing spins.
5. the subtraction of two phase Fourier transform MR images.

1. Diffusion does not affect chemical shift
   - CORRECT
2. Diffusion effects T2*, not T1
3. Diffusion does not influence multiple quantum coherences
4. This is a method for imaging vessel flow, not diffusion
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In-Vivo Magnetic Resonance Spectroscopy

- Localize signal from ROI
- Maintain high magnetic field homogeneity in ROI
- Be able to select ROI over a reasonable range of volumes and positions
- Signal received shows distribution of chemicals in tumor
PRESS Pulse Sequence

**Point REsolved SpectroScopy**

Easy to incorporate localized imaging for spatial position check (see below)
PRESS Method

Diagram showing the PRESS Method with angles 90°, 180°, and 180° for the X, Y, and Z axes respectively.
The Proton MR Spectrum

- Components
  - Water (strongest signal needs to be eliminated)
  - Lipids (may obscure other important peaks)
  - Various metabolites (depends on tissue investigated)

- Relative Signal Strengths (quantification difficult)

- The Frequency Scale: \[ \text{ppm} = \frac{\text{freq.}}{\gamma \cdot B_0} \]

- Peak Positions
  - relative to water (4.2 ppm at 37° C)
Important Metabolites

- **In Brain:**
  - **Lactate** (@1.5 ppm) indicates anaerobic metabolism
  - **NAA** (N-acetyl aspartate @ 2.0 ppm) is evidence of neuronal integrity
  - **Choline** (@ 3.2 ppm) indicates membrane integrity

- **In Prostate:**
  - **Citrate** (@ ~2.6 ppm) The decrease in citrate with prostate cancer is due to changes in both cellular function and the organization of the tissue.

- **Creatine** (@ 3.0 ppm) used as internal reference
  - Brain Creatine Concentration ~ 20 mM
  - Water/Creatine > 5000
  - Water is the other internal standard
The “Good” Brain Spectrum

- Peak widths narrow
- Goodness of fit to Lorentzian lineshape
- Signal-to-noise ratio at least 10:1
1D-MRSI and 2D-MRSI

2D CSI – spectra from each strip (one slice)

3D CSI – spectra from each voxel (one slice)
GLIOMA

Ross B & Bluml S. Anat Rec (New Anat) 2001; 265: 54-84
Metabolite Maps with Anatomical & PET Correlation

T1W  GRE  FDG PET


Anaplastic Astrocytoma
Recurrent Anaplastic Astrocytoma

Following Gamma knife radiosurgery, choline intensities in the spectra decreased significantly by 1 month and even further by 5 months.

A

CE-MRI  FDG-PET

B

MR Spectra from 1 cm³ spectral voxel centered on the lesion

Prostate MRI and Histopathology

Low T2 signal intensity in the peripheral zone

Courtesy A. Jung, UTHSCSA Radiology
Prostate Metabolic Changes

Healthy voxel:
- **Citrate**
- **Creatine**
- **Choline**

Voxel size ~ 0.16 - 0.30 cc’s

Cancerous voxel:
- **Creatine**
- **Choline**
- **Citrate**

Screenshot courtesy A. Jung, UTHSCSA Radiology
Figure 1

Courtesy A. Jung, UTHSCSA Radiology
MR Spectroscopy

What do I need to remember?

- Clinical MRS is difficult to implement but shows promise at $B_0$ field $\geq 3.0$ Tesla
- Neuronal activity is indicated by NAA peak
- Lactate reveals dead tissue
- A big citrate peak is an indication of healthy prostate gland tissue
- MRS can improve specificity of diagnosis and provide early indications of treatment response
Which of the following chemical peaks in the hydrogen-1 MR spectrum is most important for the diagnosis of prostate cancer?

0%  1. Creatine
0%  2. Choline
0%  3. Citrate
0%  4. N-acetylaspartate
0%  5. Lipid
Which of the following chemical peaks in the hydrogen-1 MR spectrum is most important for the diagnosis of prostate cancer?

1. Creatine
2. Choline
3. Citrate
4. N-acetylaspartate
5. Lipid

1. Sometimes useful as an internal reference
2. Found in brain
3. Correct
4. Indicates neuronal viability
5. Can obscure other peaks
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Multimodality Imaging Challenges

- Increased acquisition time
- Efficiency and automated delineation
- Co-registration and fusion of MR image data
  - Segmentation
  - Co-registration
Registration of DCE-MRI w/ T1-MRI

Melbourne A. Phys Med Biol 2007; 52: 5147-5156
Co-Registration Methods

Determining the mapping between two images of the same object, similar objects, the same region or similar regions

- **Rigid**
  - Translations and Rotations

- **Non-rigid (deformable)**
  - Normalized mutual information (NMI)
  - Demons algorithm
Image Fusion

- Image registration is the process of determining the geometric transformation $T$ that relates the spatial coordinates of corresponding points in two imaging studies.

- Using this transformation, information derived from one imaging study, such as tumor outlines or computed doses can be transferred to the other.

- This transformation can also be used to reformat the images of one study to account for changes in patient orientation or anatomy between studies.

- Data fusion is the process of combining data from one imaging study with data mapped or reformatted from another.

Balter J. et al, JCO Vol25(8), 2007
Image Fusion

Volumes drawn on two series of magnetic resonance (MR) images and then mapped to the treatment planning computed tomography (CT).

Registration Frame Work

- Fixed Image
- Moving Image
- Metric
- Interpolator
- Optimizer
- Parameters
- Transform
- Resampler
- Moving Registered
Rigid Transformation

\[
\begin{pmatrix}
    x' \\
    y' \\
    z' \\
    1
\end{pmatrix}
= \begin{bmatrix}
    R_{11} & R_{12} & R_{13} & T_{11} \\
    R_{21} & R_{22} & R_{23} & T_{21} \\
    R_{31} & R_{32} & R_{33} & T_{31} \\
    a_{11} & a_{12} & a_{11} & 1
\end{bmatrix}
\begin{pmatrix}
    x \\
    y \\
    z \\
    1
\end{pmatrix}
\]
S-Scaling

Scale down 50%
R-Rotation

Rotate right 10 degree
T-transform

Transfer right 5 cm and down 2.5 cm
$a$-Shearing Component

$\left( x, y \right) \rightarrow \left( x + ay, y \right)$
Rigid registration

- 10 unknowns maximum
- Usually less than 10 equations are needed
- Immobilization device can be used to define feature points (e.g., Gamma knife frame)
- Easy and quick to compute
- Not accurate for deformable organs (liver, lung)
Deformable Registration

- **Feature-based algorithms**
  - Match contours, fiducial points or landmark points and lines in the deformed image with the same features in the reference image either manually or automatically.
  - Potential errors in feature detection may be carried over into the deformable image registration process.
  - In addition, extra time for extracting features before image registration may be needed (for example, manual delineation of feature points can be time consuming).

Greyscale image-based algorithms

- use pixel or voxel data directly, assuming that image intensities alone contain enough information for image registration.
- Usually, the feature-based algorithms are faster than image intensity based algorithms when performing image registration because they usually operate on a sparse set of features.
- However, the time spent on feature extraction can be significant and error prone.

CT images:

- are used in calculating radiation doses because Hounsfield units (CT pixel values) are calibrated to the attenuation coefficient of water and therefore the pixel values are well defined.
- Because of the consistency in CT image intensities, it is advantageous to use a greyscale image-based algorithm for radiotherapy applications.
Mutual Information

More possible pairs
Intuitive Notion of Joint Entropy

The More Pairs Exist
The Larger the Joint Entropy
Mutual Information

Reduction of Number of Pairs

Reduction of Joint Entropy
Mutual Information MI

\[ MI = \text{Joint Entropy(Image A, Image B)} - \text{Entropy ImgA} - \text{Entropy ImgB} \]
The method uses gradient information from a static reference image to determine the ‘demons’ force required to deform the ‘moving’ image. This may not be efficient, especially when the gradient on the reference image is low. Conceptually, the diffusing model assumes that local ‘demons’ at every voxel location are applying invisible ‘forces’ that push the voxels of the moving image into matching up with the reference (static) image.
Demons theory

\[ \frac{m - f}{v} = \frac{\| \nabla f \|}{1} \]

\[ \vec{v} = \frac{m - f}{\| \nabla f \|} \]

\[ \vec{v} = \frac{(m - f) \| \nabla f \|}{\| \nabla f \|^2} \]

\[ \vec{v} = \frac{(m - f) \| \nabla f \|}{\| \nabla f \|^2 + (m - f)^2} \]

\( v \downarrow 0, m \rightarrow f \) until \( v = 0, m = f \)
Rigid registration is applicable for organs that do not deform and are well defined in both the respective imaging modalities they are derived from (e.g., brain/cranium).

Image registration is a critical component of contour definition in radiation oncology as we try to capitalize on the advantages of each imaging modality to define the target.

Deformation vectors allow us to map for the same patient an imaging study to the reference image set, but can also be used to map other things such as contours and the dose matrix back to the reference image.
For tumor localization and image-guided treatment planning, MRI is considered superior to ________ because ___________.

1. X-ray CT; it can produce superior soft tissue contrast for delineating tumor margins.
2. PET; it produces biochemical images with higher spatial resolution.
3. SPECT; most MR contrast agents are compounds that are normally found in the human body.
4. Ultrasound; it has lower radiation dose to the patient.
5. Digital planar x-ray imaging; it has lower total monetary cost.
For tumor localization and image-guided treatment planning, MRI is considered superior to ___________ because ______________.

1. X-ray CT; it can produce superior soft tissue contrast for delineating tumor margins.  
   1. Correct

2. PET; it produces biochemical images with higher spatial resolution. 
   2. PET resolution is better than MRS

3. SPECT; most MR contrast agents are compounds that are normally found in the human body. 
   3. MR contrast agents must be chelated to limit toxicity

4. Ultrasound; it has lower radiation dose to the patient. 
   4. Neither US nor MRI give radiation to patient

5. Digital planar x-ray imaging; it has lower total monetary cost. 
   5. MRI costs more than digital x-rays and US, but less than PET and SPECT
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MRI Artifacts

Machine dependent
MR Field inhomogeneities
gradient field artifacts (eddy currents)
surface coil artifacts
radiofrequency artifacts

Patient related artifacts
ghost images
blood flow

Signal processing dependent artifacts
chemical shift
Gibbs phenomenon (ringing artifact)
wrap around artifact
partial volume
Defining the Target Volume with MRI imaging

- Ghilezan showed that “perfect” targeting of the prostate permitted an average increase in dose of 13% while maintaining equivalent risk of rectal toxicity.

- More importantly, the spread of individual gains through image-guided radiation therapy (IGRT) varied by more than 30%, indicating that patient-specific geometric factors weigh heavily on the actual benefit of image guidance.

Gamma Knife Treatment Planning

- Typically, MRI acquisitions for Gamma Knife treatment planning are performed after the injection of contrast agents (Gd).
- A rigid frame attached with screws in the patient’s cranium, enables very accurate rigid transformation for isocenter localization during treatment planning.
- Volume acquisitions are usually performed (spgr) to minimize image distortion artifacts.
- MRI alone is used for planning, assuming negligible effect of tissue inhomogeneities in brain.
Real-Time MR Image Guided Therapies

- Prostate brachytherapy
- Focused US
- Cobalt arc therapy - Renaissance unit
- Integrated MRI and Linac unit
Prostate Brachytherapy

Menard et al., IJROBP, Vol. 59, No. 5, pp. 1414–1423, 2004
MRI-Guided Focused US

- The ultrasound waves are directed from a transducer into a small focal volume.

- The cone-shaped ultrasound beam penetrates through soft tissue and produces well defined regions of protein denaturation, irreversible cell damage, and coagulative necrosis, at specific target locations.

- Tight focusing is designed to limit the ablation to the targeted location.

- Treatments consist of multiple exposures of focused energy or sonications.
Temperature maps display the relative tissue temperature as a color map superimposed on an anatomical MR image.

This allows the physician to observe temperature changes in real time during treatment.

Based on these observed temperature changes, treatment parameters can be adjusted to ensure safe and effective thermal ablation.

T1 weighted MR images with Gadolinium contrast enable the physician to immediately assess the outcome and determine which regions are non-perfused (ablated).
MRI-Guided Cobalt Arc therapy

- A low Tesla MRI scanner is coupled with a three-head Cobalt source mounted on a circular slip ring, similar to a CT scanner.

- Real time imaging and delivery of radiation is realized
Integrated MRI and Linac Unit

- A design has been developed at the University of Utrecht, in collaboration with Elekta (Crawley, UK) and Philips (Hamburg, Germany) to integrate a high-field MRI system with a linear accelerator.

- The design is an accelerator mounted in a ring around the mid-transverse plane of a 1.5 Tesla MRI.

- Superconducting MRI coil are adapted to minimize the magnetic coupling between the MRI and the accelerator.

- By synchronizing the accelerator pulses and the MRI radiofrequency pulses radiofrequency interference between the accelerator and the MRI is minimized.

Electrons and MRI

- The challenging issue of electron transport in a magnetic field needs to be addressed for these emerging technologies.

- At tissue-air interfaces, electrons travel in a circular path through the air, reentering tissue and increasing dose.

- In a similar manner, the curved trajectory of secondary electrons decreases the buildup depth in skin.

- The influence on electron transport is reduced with lower field strengths, although with significant impact on the signal-to-noise ratio of the MRI data.

- This may hinder some of the applications for which MRI is advantageous, such as localized MRS, diffusion and dynamic blood flow studies.

Balter J. et al, Sem Rad Onc 2007
Clinical Example: Brain

Left – T1W, pre-contrast
Right – post-contrast reveals homogeneous enhancing mass
**Clinical Example: Brain**


<table>
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<tr>
<th>AX T1W</th>
<th>AX T2W</th>
<th>FLAIR</th>
<th>Diffusion</th>
<th>Gadolinium</th>
<th>Perfusion</th>
</tr>
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**FLAIR**
- eliminates CSF

**T2W**
- shows edema associated with tumor
Clinical Example: Brain


Perfusion Perfusion Vessel Size Map from slope of uptake curve

Permeability calculated $K^{\text{trans}}$ map
Clinical Example: Brain


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Water mobility determined with ADC Map

Diffusion tensor imaging can be used to produce white matter fiber tract image.
Clinical Examples: Liver

AX FSE  AX EPI  AX T1W  Ferumoxide

• T2-Weighted FAST SPIN ECHO is often used to reduce motion artifact & scan time
Clinical Examples: Liver

- Echo planar is the fastest imaging sequence and can be used to minimize motion artifacts.
- Long TE Gradient Echoes produce T2* contrast to identify tumors.

Increasing the number of shots increases imaging time but decreases geometric distortions.

Mehdi P-A et al. Radiographics 2001; 21:767
**Clinical Examples: Liver**

<table>
<thead>
<tr>
<th>AX T2W</th>
<th>AX EPI</th>
<th>AX T1W</th>
<th>Ferumoxide</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image A" /></td>
<td><img src="image2.png" alt="Image B" /></td>
<td><img src="image3.png" alt="Image C" /></td>
<td><img src="image4.png" alt="Image D" /></td>
</tr>
</tbody>
</table>

Explanted liver from 47-YO man with cirrhosis secondary to chronic hepatitis C infection with a mixed micronodular and macronodular pattern.

**T2W FSE**

<table>
<thead>
<tr>
<th>T2W</th>
<th>T1W</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image5.png" alt="Image B" /></td>
<td><img src="image6.png" alt="Image C" /></td>
</tr>
</tbody>
</table>

**T1W**

Clinical Examples: Liver

AX T2W  AX EPI  AX T1W  Ferumoxide

Super Paramagnetic Iron Oxide is the contrast agent of choice in liver imaging

T2W Fast Spin Echo  T2*W Gradient Echo
Clinical Examples: Breast

- T1-weighted
- T1-weighted w/ FatSat
- T2-weighted
- Late Enhancement

Courtesy Qi Peng, UTHSCSA
Summary

- RF pulse timing (TE, TR & TI) manipulates soft tissue $T_1$ and $T_2$ contrast in MRI
- Inversion recovery MRI can be used to eliminate signal from fat or CSF
- Conventional MR images can be used to evaluate tumor size, histological composition
- Contrast agents can be used to reduce tissue $T_1$ and/or $T_2^*$ for dynamic contrast enhanced perfusion imaging (DCE-MRI)
Summary

- MRI perfusion imaging can be used to evaluate angiogenesis
- MR diffusion imaging relies on diffusion-weighting gradients
- Diffusion MRI is used to evaluate tumor cell integrity
- MR spectroscopy can help in the staging of cancers (brain, prostate …)
References for SAMS


