MRI for RT Treatment Planning
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MRI Advantages

- Soft tissue differentiation
- Multiple contrasts
  - Conventional contrasts
    - T1 contrast, T2 (or FLAIR) contrast, Post-Gd T1 contrast
  - Advanced contrasts
    - Susceptibility (T2*), water and fat images, cortical bone image
    - Molecular, metabolic and functional imaging
      - 1H, 31P and 13C spectroscopy imaging
      - DCE and DSC imaging
      - DW and DT imaging
      - Other contrast agents, e.g., SPIO, Eovist, Hyperpolatized 3He and 13C
- Localization, characterization and delineation of tumors and normal organs
  - beyond electron density (X-ray and CT)

Body Sites and Tumors

- Brain tumors
  - Primary and metastatic tumors
- Prostate cancers
  - Delineation of whole prostate gland
  - Localization and Delineation of dominant intra-prostatic lesion
- Cervical cancers
  - Brachy therapy
- Liver tumors
- HN tumors
  - Nasopharygeal cancer
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    - Molecular, metabolic and functional imaging
      - 1H, 1H, and 13C spectroscopy imaging
      - DCE and DSC imaging
      - DW and DT imaging
      - Other contrast agents, e.g., SPIO, Eovist, Hyperpolarized 3He and 13C
- Localization, delineation, and characterization of tumors and normal organs
- Integration of target definition and Tx assessment

**Technology Advancements**

- High field magnet
- Parallel imaging
- Large Bore size (70 cm)
- Multi-RF transmission
- RF-shimming
- RF coil array/TimCT
- Robust motion suppression pulse sequence

**RT Treatment Planning**

- Signals, fast acquisition, high resolution, 3D
- RT compatible, embolization equipment
- More uniform RF distribution, e.g., in the liver
- Uniform signal intensity
- Extended coverage and continuous scan like CT
- Better images for motion organ, e.g., liver, HN during swollen

**3D Volumetric T2W image**

1x1x1 mm³ resolution on 3T
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**Technology Advancements**

- High field magnet
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- Modular RF coil arrays/TimCT
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Motion Sensitive?

Motion Suppression

Can we plan solely on MRI?

What sources of geometric errors and solutions are?

**Issues:**
- Bore size
- Distortion
- Electron density
- IGRT support

**Sources of errors**
- System level
  - B0 field inhomogeneity
  - Gradient non-linearity

**Physics solutions**
- System level
  - Better magnet design
  - On-line gradient distortion correction (GDC)
  - Algorithms to further correct any errors in system level
Geometric Phantom to Map Homogeneity

Nina Hoven, Ulleval Hospital, Oslo, Norway

1.0T Philips panorama scanner
Distortion-free area:
Sagittal plane: 40 cm AP, 28 cm FH
Coronal plane: 34 cm FH, 36 cm LR
Transverse plane: 32 cm AP, 37 cm LR

Gradient Distortion Correction

L Chen, Fox Chase Cancer Center, AAPM Summer School 2006
0.3 T scanner

State-of-art 3T
Linear and high Orders correction

Geometric distortion

Sources of errors

- Patient-level
  - Susceptibility
  - Fat/water chemical shift effect
- Field strength
- k-space trajectory
- Gradient band width
- Region: air, tissue, & bone interface

Solutions

- Patient-level
  - Solutions:
    - B0 mapping
    - Rectification
    - Published 15-20 years ago
  - Sub-mm for small FOV and 1-2 mm for large FOV distortions for SE and GE
**Geometric Accuracy in Brain**

Gradient Echo T1W images from a 3T scanner
Registered to CT by rigid body transformation
Both superior and inferior portions of brain MRI are well registered to CT

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**How can you get electron density from MRI?**

- MR-CT alignment
- Atlas-based density insertion
- MR segmentation:
  - UTE imaging – attempts to directly visualize bone
  - Pattern learning to select candidate bone (versus air) features
- Hybrid approaches

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**MRI-based patient modeling for RT planning**

- Careful consideration of contrasts in MRI and human models permits image analysis to support:
  - Segmentation
  - Dose calculation
  - Image guided positioning

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**Molecular/Functional/Metabolic MRI**

- Molecular, metabolic and functional imaging
  - 1H, 31P and 13C spectroscopy imaging
  - DCE and DSC imaging
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**Caio AAPM 2011**
How to validate these imaging techniques for target definition?

- Pathological validation
  - Pathological specimen may not be easily obtained for certain organs, e.g., brain

- Pattern failure
  - Comparing the pattern pre RT with the recurrent pattern

- Prognostic and predictive factors
  - Via assessment of response or outcome to determine the subvolume of the tumor

Primary Brain Tumor: GBM

CT

Proton Spectroscopy Imaging in Glioma

- Metabolic Abnormality: CNI: Cho/NAA ≥ 2.0 SD

Cho/NAA Abnormality in GBM

- Metabolic Abnormality: CNI: Cho/NAA ≥ 2.0 SD
DCE and DSC MRI in GBM

Boost Volume

Vascular Permeability

subvolume of the tumor with abnormal CBV/CBF/vascular permeability

outcomes


High b-value DWI in GBM

Post-operative

b=1000

b=3000

b=5000

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Maier et al, NMR Biomed, 2010

Localization of Prostate Gland

CT

T2W MRI

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Localization of Intra-Prostatic Cancers by 3D MRSI

Abnormal metabolism: Cho+Cr/citrate ≥ 3SD

Scheidler, Radiology, 213:473,1999
Pathological Validation of 3D SI for Prostatic Tumor Localization

- UCSF study in 1999
  - 53 patients with biopsy-proved prostate cancer and subsequent radical prostatectomy with step-section histopathologic examination
  - T2W MRI:
    - sensitivity (77% and 81%), specificity (61% & 46%)
  - 3D MRSI (cho+Cr/citrate>3SD):
    - sensitivity (63%) specificity (75%)
  - MRI+3D MRSI:
    - sensitivity (95% either test), specificity (91%)

Validation of DCE and MRSI

  - Evaluate quantitative DCE MRI and 1H MRS for the detection of prostate cancers and the delineation of intra-prostate sub-volumes for IMRT
- Groenendaal et al, Int J Rad Onc Biol Phys, 2010

Delineation of Prostatic Cancers By DCE and MRS

- Schmuecking’s study in 2009
  - Comparing quantitative DCE MRI and 1H MRS with these intraprostatic subvolumes with histology and cytokeratin-positive areas in prostatectomy species
  - DCE MRI: (1) 82% of sensitivity and 89% of specificity for localization of prostate cancers in left, right or both lobes; (2) able to detect the lesions > 3mm and/or containing >30% tumor cells; (3) similar to choline PET/CT
  - 1H MRS: (1) 55%-68% for sensitivity and 62%-67% for specificity; (2) able to detect the lesions > 8mm and/or containing >50% tumor cells

DCE MRI Detection

**DCE MRI vs MRS Detection**

Prostate cancer with a lesion size of 9 mm x 3.7 mm


**Challenges of MRI for RT**

- **Electron density**
  - UTE MR imaging for bonny structures
- **Geometric accuracy**
  - System level
  - Patient-specific
  - Basic pulse sequences, e.g., GE and SE
  - QA/QC procedures
- **Choose spatial resolution and plane orientation**
- **Position patients in the configuration of RT**

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**Challenges of MRI for RT**

- **Sensitivity and specificity of each contrast or multiple contrasts for tumor delineation**
- **Reproducibility and uncertainty of metabolic and functional imaging**
  - Spatial and amplitude
- **Robustness of some of metabolic and functional imaging**
- **Optimize contrasts**
  - Tumor specific
  - Optimal combinations of contrasts

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**The Renaissance™ System 1000**

Not Approved for Human or Animal Use
Positive detection rates of 6 observers:
42–73% on T2WI alone
58–80% on T2WI plus DWI

KAJIHARA, Int J Rad Onc Biol Phys, 74:399-403, 2009

Groenendaal’s study
- Comparing the GTVs delineated on DW and DCE MRI by a rad oncologist with the lesions (22) on prostatectomy specimens by a pathologist
- 5 dominant intraprostatic lesions (>1cc) and 4 small lesions (>0.56 cc) detected by the Rad Oncologist based upon MRI
- MRI GTVs of 5 DIL cover 44-76% of pathological tumor volumes but have have 62-174% of the pathological tumor volumes

Sources of errors
- Registration
- Mis-matched characteristics between DW and DCE MRI (3 DIL), and negative on both DW and DCE MRI (1 DIL)
- Solution
  - add 5 mm margin to the MRI-GTVs to improve the tumor volume coverage
  - The MRI-GTVs are 2.5-3 times as large as the pathological tumor volumes

Wang, Eisbruch, Cao, AAPM 2009
Gradient Distortion Correction

L. Chen, Fox Chase Cancer Center, AAPM Summer School 2006
State-of-art 3T scanner

Soft Tissue Differentiation

CT
Post-Gd T1WI
Brain metastasis for SRS

CNI Abnormality vs Target in GKS of Recurrent GBM

>50% Overlap
Survival: 15.7 m
<50% Overlap
Survival: 10.4 m

Chan, J Neurosurg, 101:467, 2004

DCE MRI and MRS Detection


The small lesion was missed by both DCE MRI and 1H MRS