MRI Driven Radiotherapy Treatment Planning
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Advantages of Magnetic Resonance Imaging (MRI)
• Superior soft tissue contrast
• Functional and physiological imaging
• Real time dynamic imaging
• No radiation imaging dose

MRI in RT planning
Used as secondary image in treatment planning.
Uncertainty in rigid image registration

CT/MRI images of the same patient sent to 45 institutions for image registration
Average error: 1.8mm

Uncertainty in deformable image registration

Additional planning margin is needed to account for the uncertainties in image registration

Other Challenges of using diagnostic MRI

- Diagnostic MRI is often imaged at:
  - different position than RT treatment simulation
  - limited field of view (FOV)
  - different organ filling
  - different respiration phase
- Insurance often reimburses for only one simulation
MRI driven treatment planning
• What CT brings to us for treatment planning?
  - Patient imaged in treatment position
  - Non obstructive imaging
  - High spatial integrity
  - Information for dose calculation
  - Treatment setup reference images

MRI imaging in treatment position
• Most commercial MRI scanners have smaller bore size than large bore CT
• MRI coil integrated with immobilization device
• Immobilization device:
  - MRI safe (i.e. Carbon fiber not MR safe)
  - Minimize image artifact and magnetic susceptibility
  - Coil attenuation consideration if used for treatment delivery guidance

Challenge – Spatial integrity
• MRI image distortion
  - Gradient non-linearity
  - Field inhomogeneity
  - Chemical shifts
  - Magnetic susceptibility

Scanner dependent
System dependent
Sequence dependent
Patient dependent
**Geometric distortion – System dependent**

- **Field inhomogeneity**
  - Inversely proportional to gradient strength
  - Compensated through shim coils
- **Gradient nonlinearity**
  - Usually the dominant factor
  - Gradient strength falls off at periphery of FOV => increased distortion at periphery

Increase with increasing FOV and $B_0$. Decrease with gradient field strength.

Can be assessed and corrected using geometric phantom.

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**Distortion – Assessment and correction**

- $B_0 = 0.35$T
- $B_0 = 1.5$T

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**Geometric distortion – Patient specific**

- **Magnetic susceptibility**
  - Proportional to magnet strength $B_0$
  - Determined by the susceptibility difference between tissues
  - Most pronounced at air-tissue interface
  - Patient dependent and difficult to assess and correct
**Geometric distortion – Planning Margin**

19 of 20 published reports are $\pm 2\text{mm}$

Weygand et al. IJRBP. V95(4) 2016

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**Challenge - Dose calculation**

- MRI does not provide information of electron densities of tissues which is required for heterogeneity correction

- **Solutions:**
  - Bulk density assignment
  - Atlas based segmentation
  - Direct voxel-wise conversion (Pseudo-CT or synthetic, substitute-CT)

Jonsson et al. Rad Onc 2010, 5:62
Challenge – Treatment setup reference
• Image guidance for patient treatment setup is primarily x-ray based
• Heavily relies on bony anatomy
• General MRI images do not have bony anatomy information

Reference image

Setup image

Ultrashort TE (UTE) image for bony anatomy reference image
MRI sequence selection

- MRI pulse sequence impacts the appearance of tissues on the MRI image
- Understand MR image artifacts

Contouring on MRI

- Useful references:
  - MRI section anatomy
  - MRI contour guidelines and atlas
  - Sun et al. Contour atlas for HN. Rad Onc V110, p390. 2014
  - MRI Prostate Anatomy Atlas: http://www.prostadoodle.com/
  - MRI Brain Atlas: http://headneckbrainspine.com/Brain-MRI.php
  - MRI axial cross sectional anatomy: https://mrimaster.com/index5.html

Considerations for MR guided treatment system – Impact of magnetic field

Lorentz force:

In homogeneous tissue, point spread kernel becomes asymmetric
Impact of magnetic field on dose distribution

- Significant dose increase at tissue-air boundaries due to secondary electrons returned back by the Lorentz force

Electron return effect (ERE)

Treatment Planning Considerations for ERE

- The ERE can be characterized by Monte Carlo simulation
- Treatment planning system should incorporate MC simulation to account for the ERE
  - Dose calculation
  - Dose optimization
Account for ERE - Low magnetic field

Single beam

Multiple beam

Account for ERE in dose optimization

Other practical considerations for planning

• Data transfer and management
• Adaptive treatment planning
• Motion management
  - Respiration motion
  - Peristaltic motion
• Functional imaging for treatment planning
Considerations for implementation of MRI driven treatment planning

- Imaging with coil and immobilization devices
- Spatial integrity / Geometric accuracy
- Imaging protocols/ sequences selection
- Information for dose calculation
- Reference image for treatment setup
- Dose distortion due to magnetic field

Summary

- MRI offers superior soft-tissue contrast for target delineation and patient setup
- Special efforts are needed to address issues such as geometric distortion, lack of electron density info and dose distortion due to magnetic field
- A rigorous QA program is essential for MR driven planning
- Personnel and staff training is also important