CONNECTING LIFE AND SCIENCE

MRI-Guided Radiotherapy Systems

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Conflict of Interests

- I don't have personal conflict of interests.
- Washington University has research and service agreements with Viewray Inc.

Objectives

- Motivation for MRI guided radiotherapy system
- What are the technical challenges?
- What is the status of current developmental work?
- How do each radiotherapy system addresses those technical challenges?

Background

- Radiation therapy
  - One of the most important cancer treatment types
  - About 50% of cancer patients will receive radiation therapy
  - Contribute to approximately 40% of curative treatment
- Radiation is a double-edged sword
  - Kill tumors
  - Damage healthy tissues

Background

- Radiotherapy treatment planning
  - CT simulation
  - Tumors and organ-at-risk delineation
  - Calculate radiation dose distribution
  - Beam optimization based on the prescription dose to the PTV and the constraint doses to the OARs
  - Beam setups are transferred to the radiotherapy system for patient treatment.
  - Highly conformal dose delivery is feasible with conformal RT or IMRT

Background

- Prerequisites for a successful radiotherapy treatment
  - Patient setup is exactly the same between treatment and simulation
  - Patient anatomy does not change between treatment and simulation
  - Internal organs and tumor does not move during radiation dose delivery
- Margin is used to compensate for localization errors
  - Small margin → insufficient tumor coverage
  - Large margin → normal tissue toxicity

Background

- Techniques to reduce localization errors
  - Surface and skin markers
  - Portal imaging
  - Cone beam CT
  - Megavoltage CT
- Techniques to reduce motion induced errors
  - Fiduciary markers
  - Optical tracking
  - Respiratory surrogates
  - Electromagnetic transponders
  - MRI

Motivation

- Advantages of using MRI as the On-board imaging unit for radiotherapy system
  - No ionizing radiation
  - Good soft tissue contrast
  - Capable of real time tracking
  - Better suitable for gated radiotherapy

Technical Challenges

- MRI system → Radiotherapy system
  - Beam generation
  - Beam penetration
  - Scatter caused by beam penetration through MRI system
  - Impact of Lorentz force on secondary electrons
- Radiotherapy system → MRI system
  - Magnetic field homogeneity
  - Radiofrequency interference

Current Developmental Efforts

- MRI-guide radiotherapy systems
  - MRI on rail
  - Viewray
  - Bi-planar Linac-MR
  - MR-XRT at 1.5T

MRI on Rail

- Princess Margaret Hospital (Dr. Jaffray)

Jaffray, ASTRO 2012 spring refresher course

MRI on Rail

- Mobile 1.5T MRI unit + LINAC
  - Interference between the two systems is minimal.
  - During treatment, the MRI unit moves out of the treatment room so it has no effect on LINAC operation.
  - For imaging, the MRI unit will be moved into the treatment room.
  - No real time imaging during radiotherapy dose delivery.

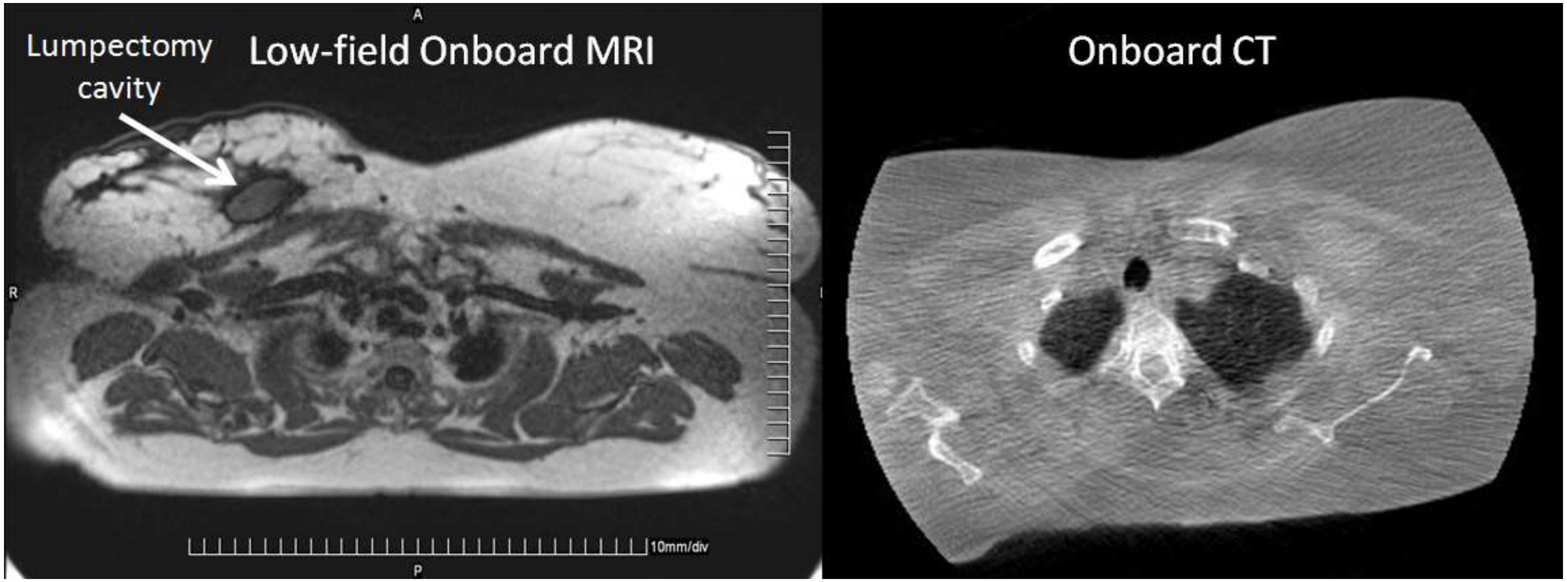
The ViewRay^{TM} System

- Washington University in Saint Louis (Dr. Mutic)

The ViewRay^{TM} System

- 0.35T MRI scanner + ^{60}Co radiotherapy system
  - Split magnet design to allow beam penetration and reduce scatter radiation.
  - Radiation produced by ^{60}Co is not affected by magnetic field.
  - At low magnetic field strength, effect of magnetic field on dose distribution is negligible.
  - At low magnetic field strength, spatial integrity is great.
  - Three symmetrically located ^{60}Co sources reduce the effect of gantry rotation on magnetic field.

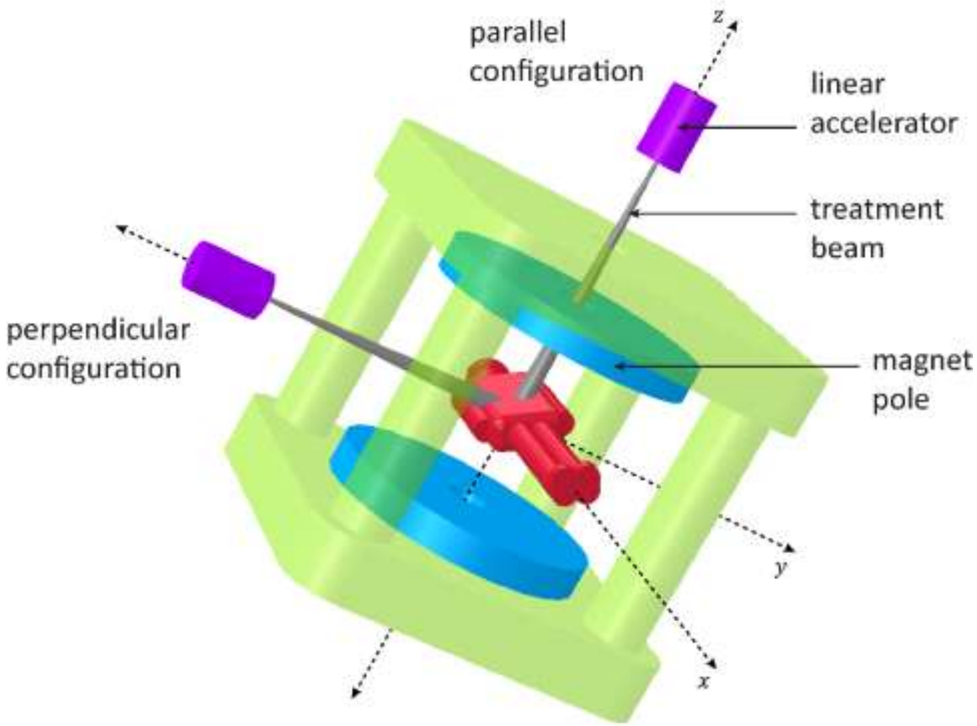
The ViewRay^{TM} System



The ViewRay^{TM} System

Bi-Planar Linac MR

- Cross Cancer Institute (Dr. Fallone)



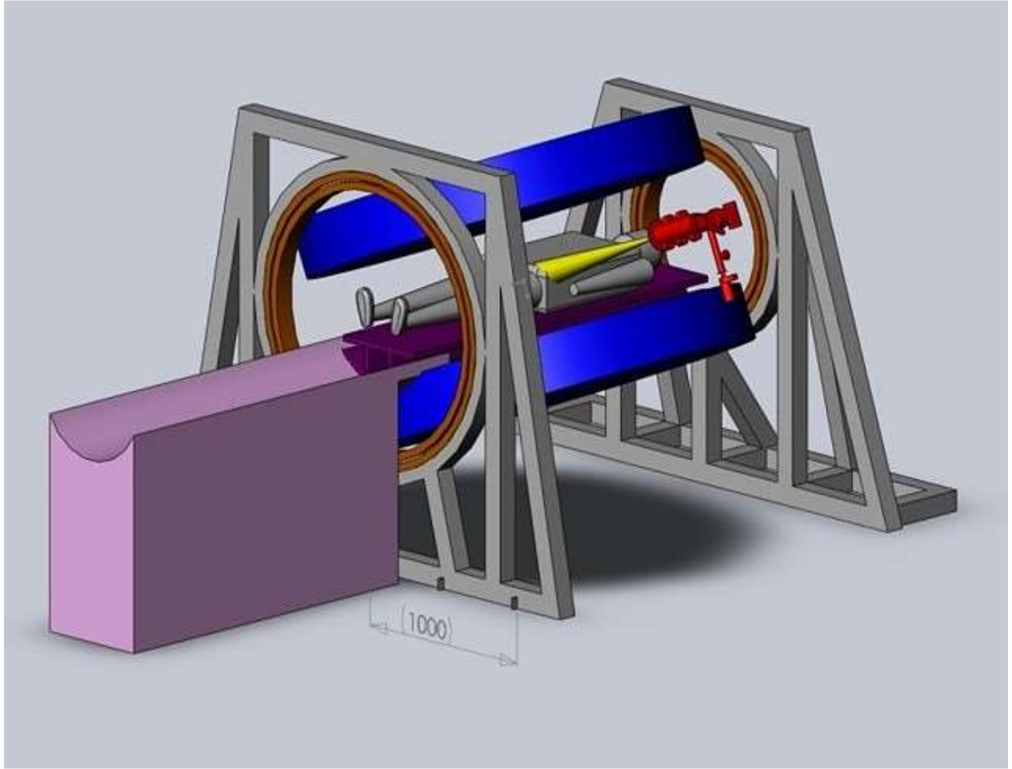
Courtesy of Dr. Gino Fallone

Bi-Planar Linac MR

- 0.5T Bi-polar MRI imager + 6 MV LINAC
  - Bi-polar MRI provides tunnel for radiation beam, solving the beam penetration and scatter issue.
  - Either passive or active magnet shielding can be used to minimize the effect of magnetic field on LINAC.
  - Bi-polar MRI allows parallel orientation of magnetic field to LINAC axis to reduce electron return effect.
  - Low field strength has better spatial integrity.
  - Rotation of LINAC with MR has less effect on MR performance.

Bi-Planar Linac MR

- System integration



Courtesy of Dr. Gino Fallone

Bi-Planar Linac MR

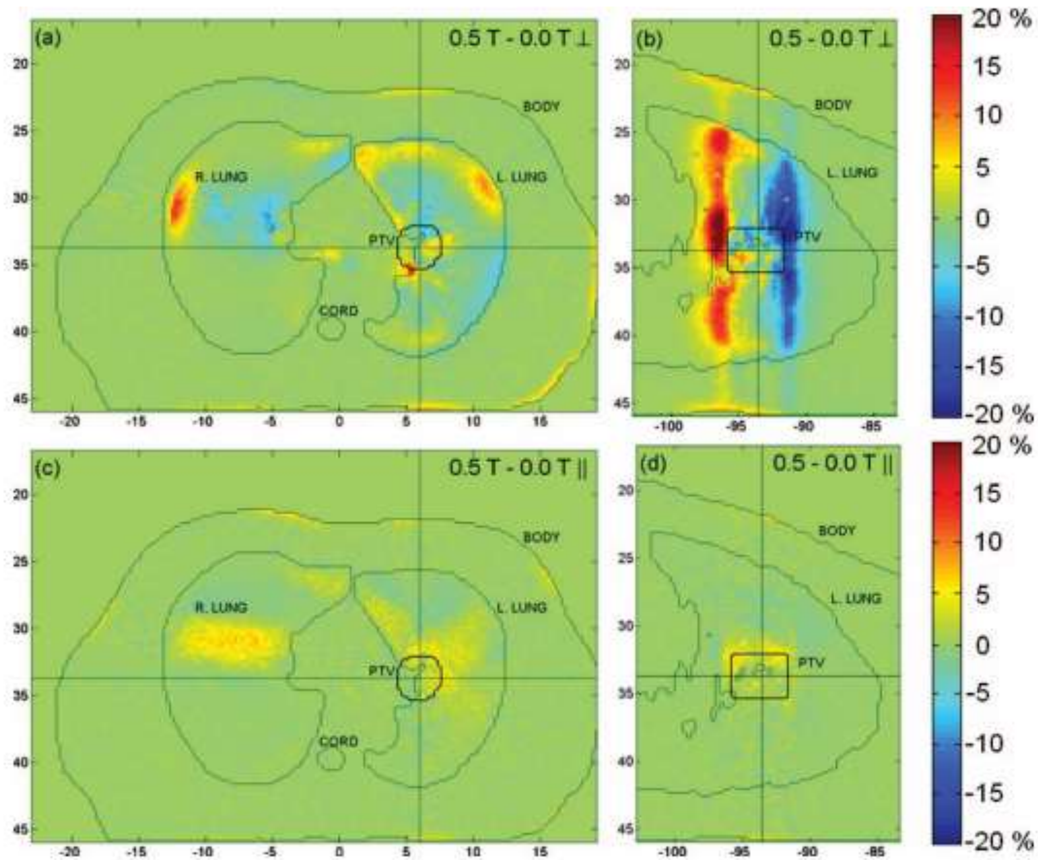
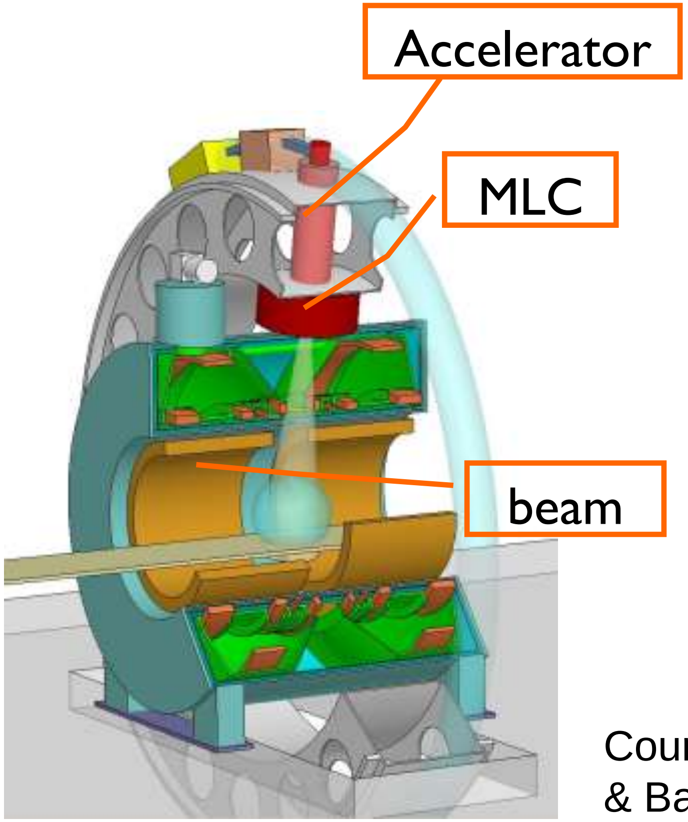


FIG. 6. Relative dose differences for the five field plan at 0.5 T. With the increased field strength tissue interface effects begin to manifest in the transverse geometry. Dose shift inside the lungs becomes more prominent with extreme differences at ±20% in the lung tissue. In the longitudinal geometry differences from the zero field case remain below ~5%.

Kirby et al Med Phys 37 (2010) 4722

MR-XRT at 1.5T

- UMC Utrecht (Dr. Jan Lagendijk)



Courtesy of Dr. Jan Lagendijk & Bas Raaymakers

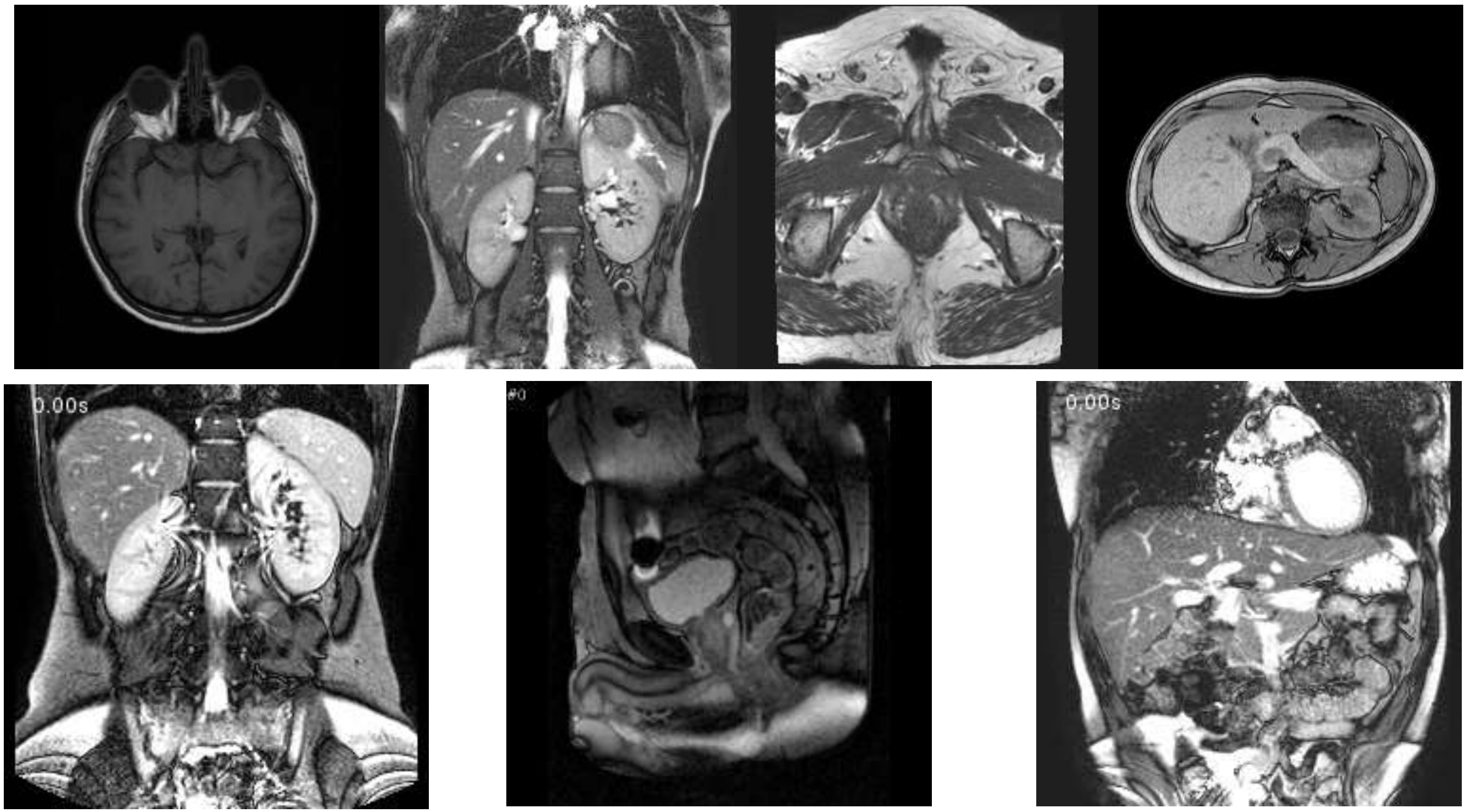
MR-XRT at 1.5T

- 1.5T MRI scanner + 6 MV LINAC
  - Active magnetic shielding creates B=0 at accelerator gun and minimal magnetic field at accelerator tube.
  - The superconducting coils are put aside and the gradient coil is split to allow beam passage.
  - Close bore does increase scatter.
  - Additional magnetic sources are added to the rotating LINAC structure to create a combined magnetic effect independent of LINAC position.
  - Correction schemas for gradient nonlinearity and B0 inhomogeneity to improve spatial integrity.

MRI with ring gantry

Courtesy of Dr. Jan Lagendijk & Bas Raaymakers

MR-XRT at 1.5T



Courtesy of Dr. Jan Lagendijk & Bas Raaymakers

Summary & take home points

- MRI guided radiotherapy systems have good soft tissue contrast and no ionizing radiation from imaging unit.
- MRI guided radiotherapy systems are well suited for real time tracking and gated radiotherapy.
- MRI guided radiotherapy systems has great potential for adaptive radiotherapy.
- MRI guided radiotherapy systems are still in development stage but getting closer to clinical evaluation.

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