Clinical Implementation of an MR-Guided Treatment Unit

Geoffrey S. Ibbott, Ph.D.
AAPM, August 2, 2017

Disclosures

My institution holds Research Agreements with Varian, Elekta, Philips and Sun Nuclear

I will be discussing devices that are not currently available for sale, and that do not have FDA clearance.

Objectives

- Review the current status of IGRT
- Review developments leading to MR-based simulation and planning, and MR image-guided radiation therapy
- Briefly describe patient imaging and treatment procedures possible with an MR-guided linac
- Discuss dosimetry issues in the presence of magnetic fields
- Present commissioning data for the Elekta MR-Linac
- Describe experience with use of commercial QA devices
Current Status of IGRT

- kV imaging widely used but relies on bony landmarks or fiducials
- CBCT IGRT has transformed RT practice and perception. Its potential may not have been fully exploited
- However, two issues remain...
  - Adequate soft tissue visualization particularly in abdomen and pelvic anatomy
  - Intrafraction motion
    - Long acquisition time of CBCT largely limits it to pre-treatment or periodic imaging

Clinical benefits of MR-IGRT

Soft-tissue visualization
- Difficult-to-image targets and critical structures become "easy"
- Improved ability to adapt treatment
- Ability to see the tumor not just the organ - GTV boost

Real-time 2D and 3D imaging
- Imaging simultaneous with irradiation
- Gating and tracking without surrogates
- No imaging dose
- Freedom to image at any time

Quantitative imaging
- Tumor treatment response assessment (inter- and intra-fractions)

4D-MRI: Volume Delineation of Moving Target in Abdomen

Courtesy of Jing Cai, PhD
What are the benefits of MR-Image Guided Radiation Therapy?

A. Imaging can be performed during treatment
B. Better soft tissue contrast than diagnostic CT
C. Able to stop motion better than CBCT imaging
D. Images can be manipulated to provide density data for heterogeneity corrections
E. All of the above

Answer: E. All of the above

Philips/Elekta Solution for MR-IGRT

Purpose
Treat the patient while simultaneously imaging with a 'conventional' 1.5T diagnostic MRI

How
1. Mount the linac on a rotatable gantry around the MRI magnet
2. Modify the linac to make it compatible with the MR environment
3. Modify the MRI system

G. Ibbott, AAPM, Denver, 2017
MR-Linac is a research programme. It is not available for sale and its future availability cannot be guaranteed.

**T2w 3D TSE**

- Imaging time: 2 min 12s
- Images courtesy of Philips

**MR-Linac**

- Diagnostic MRI
- Original axial
- Reformatted coronal

**T2w 3D TSE**

- Voxel size: 1.5 x 1.5 x 2 mm
- Imaging time: 4 min 10 s

Atlantic delivers high quality volumetric images.

Example volunteer images:

Atlantic can image and detect the target in real time simultaneous with irradiation:

- Localization results for Kidney
- Alternating axial, coronal and sagittal slices
- Acquired and processed in 200 ms
Influence of Magnetic Fields: Electron Return Effect

Electron Return Effect

- Simulation (GEANT4)

Small Air Gaps

Cannot avoid small air gaps in plastic phantoms

G. Ibbott, AAPM, Denver, 2017
Setup of water tank on couch

Elekta commissioning tank
- Marks on tank
  - $d_{10}$
  - $d_{20}$
  - $d_{max}$
  - Isocenter height
  - Ion chamber at isocenter

MDA calibration tank
- Marks on tank

Output measurements

$d_{max}$ vs field size
- For $B = 0$ T:
  - Differences with increasing field size
  - $e$ contamination from cryostat noticeable
- For $B = 1.5$ T:
  - $d_{max}$ more constant with increasing field size
  - $e$ contamination from cryostat diminished

Effective point of measurement for cylindrical ion chamber
- For $B = 0$ T: Photon beam $r = 0.6r_{cav}$
- For $B = 1.5$ T: offset is cut in about half but also has lateral shift [not to scale!]

Profiles
10 x 10 cm$^2$:
- Lateral shift removed for comparison
- Curves agree among most detectors

2x2 cm$^2$:
- Lateral shift removed for comparison
- Divergence detected for shielded diode

See AAPM presentation: "Dose Measurements" Session
O’Brien et al. Tuesday 2:45 pm
Measurements of beam profile

- Plastic scintillator
- Diode
- microDiamond
- Ion chamber array

Percent Depth Dose

With and without magnetic field

Percent Depth Dose

- Need correction for effective point of measurement
- 10 x 10 cm²: curves agree among most detectors
- 2 x 2 cm²: some divergence detected

Calibration – TRS398

Standard Imaging MR-compatible
Exradin A15LM ion chamber in water tank (B = 1.5 T)
Calibrated to 1 cGy = 1 MU at d_{50}

See AAPM presentation: TU-FG-205-7
O'Brien et al. Tuesday 2:45 pm
"Dose Measurements" Session
Which of the following dosimetry systems and conditions is likely to be most affected by the Electron Return Effect in an MR-Linac?

A. Polymer gel dosimeter immersed in a water phantom
B. Diode detector embedded in plastic matrix
C. Optically-stimulated luminescence detector (OSLD) sandwiched in bolus material
D. Ionization chamber in water-equivalent plastic phantom

Answer: D. Ionization chamber in water-equivalent plastic phantom

Reference dosimetry in magnetic fields: formalism and ionization chamber correction factors


Initial Testing of MR-Compatible ArcCheck QA Device

- Power supply moved away
- Must use MV beam to position
- Must calibrate in MR Linac
MR Imaging of Irradiated Gel

- Irradiated dosimeter with un-irradiated region shown below with $T_1$-weighted MR images in gray and RGB scale.

- Change in irradiated region during beam-on can be seen with $T_1$/$T_2$-weighted balanced-fast-field-echo (b-FFE) MR images.
MRI’s role is growing in Radiation Oncology

What precaution is required to use a diode array QA device with an MR-Linac?

A. The device must be wrapped in aluminum foil
B. The device must be immersed in a water phantom to eliminate air gaps
C. The power supply must be moved out of the high-strength magnetic field
D. The signal cable must be grounded externally

Answer: C. The power supply must be moved out of the high-strength magnetic field
Thank you for your attention!

Thanks to:
Hannah Lee, Yoonie Rhee, Kaine Choi, Ryan Lefrata,
Mitchell Carroll, Mamdooh Alqathami, Jihong Wang