Clinical Implementation of an MR-Linac Program for Adaptive Radiotherapy

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Disclosures

• Research support from ViewRay Medical Systems
• My institution has recently commissioned a ViewRay MRIdian Linac
MR-Linac Systems

• Integrated MR-Linac systems are a rapidly emerging technology
  • First patient treatment in 2017
  • Today, over 40 centers treating patients with MR-Linac technology

• Benefits of on-board MRI include:
  • Improved soft tissue contrast
  • Motion management based off of real-time 3D imaging
  • Enables adaptive radiotherapy
  • Functional/biological image guidance and dose painting
The Challenge

• Building an implementing an MR-Linac program presents new challenges for radiation oncology departments and physicists:
  • Installation/siting
  • Machine commissioning
  • Building a program

• For many departments, installing an MR-Linac also means:
  • Starting an adaptive radiotherapy program
  • Performing new methods of motion management
  • Developing an MR safety infrastructure
Guidance to help us

- Linac Commissioning/Calibration Guidance
  - AAPM TG-142 Report
  - AAPM TG-51 Report
- MR Commissioning Guidance
  - AAPM MR TG-1 Report
  - ACR MRI Quality Control Manual
- Manufacturers tests
- Publications from early users
- AAPM TG-100 Report

Need to adapt information from multiple sources to the capabilities of the machine and how it will be used
Outline For the Remainder

• Introduction to Current MR-Linac Systems
• Facilities/Safety issues
• Commissioning Challenges
• Program Building
MR Linac Systems
MR-Linac Systems

• Two current commercially available systems
  • Elekta Unity
  • ViewRay MRIdian

• Several in development
  • MagnetTx
  • Australian MRI-Linac program

• Different design decisions between these systems
  • Field strength
  • Field orientation
  • Linac design
Elekta Unity

• Based on a 1.5T Philips MR (70 cm bore)
• 7MV Linac mounted outside the magnet cryostat (143 cm SAD, perpendicular to B field)
• Active shielding used to create a torus of low field for the linac components
• EPID imager and Agility MLC
• Plan adaptation for virtual patient shifts
ViewRay MRIdian

- Uses a 0.35T split magnet MRI (70 cm bore)
- 6MV FFF Linac mounted on gantry ring between magnet poles (90cm SAD, perpendicular to B field)
- Passive shielding sleeves
- 3 degree of freedom couch
- Double-focused double-stacked MLC (4.15mm effective leaf width)
Facility and Safety Challenges
Facility Concerns

• Need a room shielded for both MRI and Radiation Therapy (RF cage inside radiation bunker)
  • All connections (including physics QA) need to pass through an RF filter panel or waveguide

• Bunker needs to contain minimal ferrous material
  • Can impact MRI shimming
  • High density concrete often uses magnetite as an aggregate (ferromagnetic), so need to use alternatives (e.g. hematite)
  • Need to consider steel/rebar (use stainless steel or fiberglass near magnet)

• Need to plan a route for an MRI quench pipe
MRI Safety

• Defining MRI safety zones and access controls
  • Zone I: General public access
  • Zone II: Interface area
  • Zone III: Controlled access
  • Zone IV: Magnet room

• May impact other machines or areas of the clinic
  • Can lead to beam property changes (Perik et al. PhiRo 2017, Vol 4 P12-20 observed 4% symmetry changes)

• Need a program for staff, device and patient screening
  • Many implants or devices are not tested in MR-linac conditions (non-standard field strength, or cine scan length)

ACR Manual on MR Safety v1.0 (2020)
MR-Linac Commissioning
Key Differences

Compared to a standard linac:
- Different geometry/mechanical configuration
- Magnetic field impact on dosimetry
- Limitations on commissioning equipment

Compared to a standard MRI:
- Limited set of MR sequences
- Emphasis on geometric accuracy
- Impact of linac components on MR imaging system

New Capabilities
- *Cine* MR motion management
- Online adaptive radiotherapy
Mechanical

• Many standard linac commissioning tests won’t apply (e.g. couch rotation, collimator rotation, light field etc.)

• Non-standard SAD (90cm for MRIdian, 143 for Unity) and field sizes

• Will vary depending on the specific MR-linac model
Dosimetric Effects of the Magnetic Field

- Trajectories of secondary electrons are affected by the Lorentz force of the MR imaging system

- Depends on the magnetic field orientation

- Leads to a change in dose distribution, particularly at interfaces: the “Electron Return Effect”

Impact on Treatment Plans

• The electron return effect may (or may not) impact treatment plans depending on:
  • Field Strength
  • Field Orientation
  • Patient anatomy
  • Plan Geometry

• Need to verify the effect is accurately modeled in the TPS

Kirkby et al. 2010 Med Phys 37(9):4722-32
Impact on Detectors

• Readings from ionization chambers and diodes can also be impacted by the magnetic field
  • Both measured value and point of measurement

• Effect is greater for larger volume chambers, and depends on magnetic field

• Orientation dependent (relative to B field)

• Need to use care in selecting an ionization chamber

Equipment Limitations

• Standard QA equipment may not work or could be a safety hazard

• Some commercial MR-compatible QA devices are now available

• Solutions:
  • Develop processes for assessing equipment that may not be MR labeled
  • Budget for the purchase of MR-compatible QA equipment
  • Plan time for developing tests/re-purposing phantoms
  • Use alternative methods (e.g. film)
MR QA Challenges

• MR-linacs often use a limited set of imaging sequences
  • Balanced SSFP (TrueFISP/FIESTA/b-FFE) is often used to maximize SNR
  • QA should reflect clinically used sequences

• Geometric accuracy and artifacts need to be assessed over a large field
  • Require specialized phantoms

• Need to evaluate motion compensation strategies
  • Breath hold, navigator, etc.
Radiation Gantry Dependence

• The changing position of components in the RT gantry can cause changes in B0 homogeneity or gradient-induced eddy currents

See also: Latifi et al. Tech. Cancer Res. 2019; 18:1-6

Tijssen et al. Radiother Oncol. 2019 Mar;132:114-120
Building an MR-Linac Adaptive Therapy Program
Commissioning Adaptive Radiotherapy

• Online adaptive radiotherapy uses a pre-treatment 3D image to develop a new treatment plan based on the current patient anatomy

• Relies on a multi-disciplinary team
  • Physicists
  • Physicians
  • Dosimetrists
  • Therapists

• Quality control checks need to happen in real-time with the patient on the table
Online Adaptive Workflow

Set up patient to room lasers

Acquire 3D MRI image

Automatically adapt contours to current anatomy

Adjust electron density

Physician verifies and modifies contours if necessary

Plan is re-optimized

Physician and physicist approve and perform online QA of plan

Verify gating parameters

Treat while acquiring cine images

Total time for typical case: 40-90 minutes
Healthy volunteers for Workflow Commissioning

- MR Linacs offer unique opportunities to test image-guided workflows on healthy volunteers

- Set-up and immobilization
  - Use of vacuum bags vs no immobilization
  - Arms up vs down for greater patient comfort
  - Visual feedback
  - Breath hold coaching

- Team-based training
  - Dry run procedures to practice checklists and build familiarity with software
MR Linac Online Adaptive Treatment Roles

- Define who performs what roles at different stages of the adaptive process and who checks

- Cross-train across groups (physician/physics/therapy)
  - MR anatomy
  - Contouring
  - Planning
  - Respiratory management

- Train in a simulated time-pressured environment as a team
Summary

• MR-Linac systems have the potential to offer new capabilities for radiotherapy

• Commissioning these systems requires adapting guidance from both traditional linacs and MR systems within the context of how the MR-Linac will be used

• Building an MR-Linac based adaptive radiotherapy program involves commissioning both the machine and the adaptive process
Thank You!

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