Clinical Implementation of an MR-Linac Program for Adaptive Radiotherapy

Christopher Williams, PhD

Dana-Farber Cancer Institute

BRIGHAM HEALTH
BRIGHAM AND WOMEN'S HOSPITAL

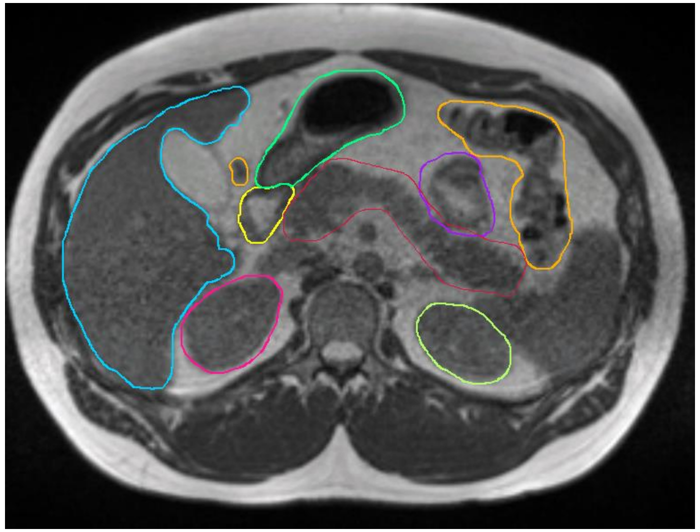
HARVARD MEDICAL SCHOOL

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

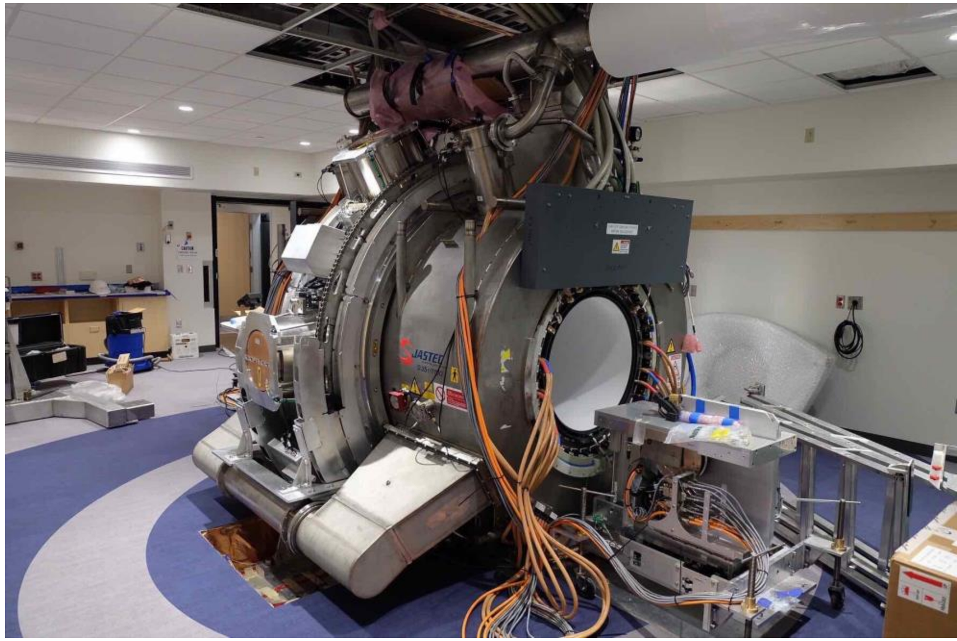
Need to adapt information from multiple sources to the capabilities of the machine and how it will be used

Outline For the Remainder

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

MR Linac Systems

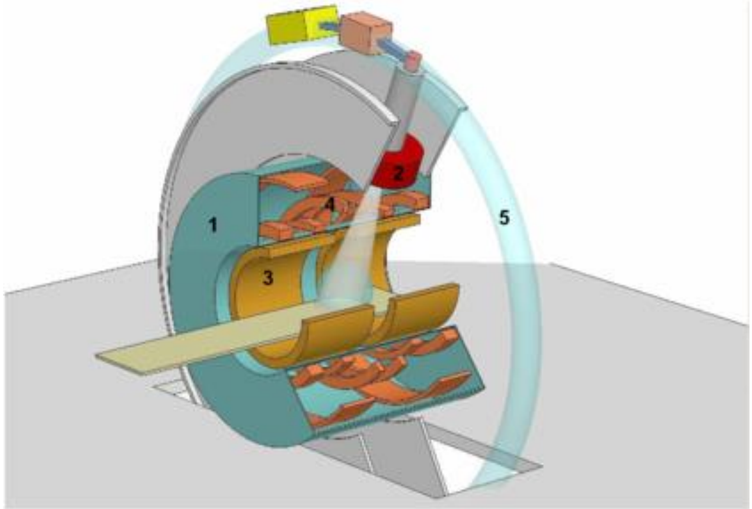
MR-Linac Systems



- 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

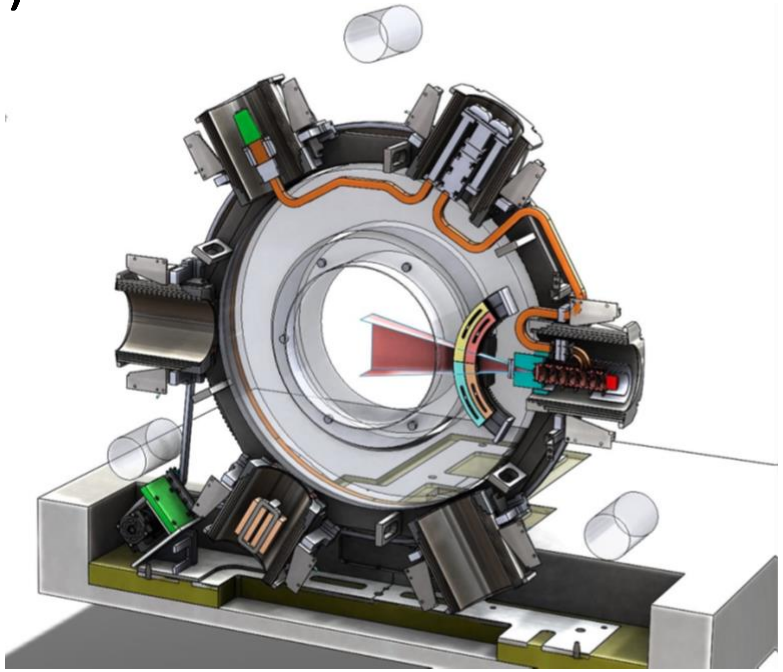
- Based on a 1.5T Philips MR (70 cm bore)
- 7MV Linac mounted outside the magnet cryostat (143 cm SAD, perpendicular to B field)
- Active shielding used to create a torus of low field for the linac components
- EPID imager and Agility MLC
- Plan adaptation for virtual patient shifts



Raaymakers *et al.*, Phys Med Bio., 2009 Jun 21;54(12):N229-37.

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)

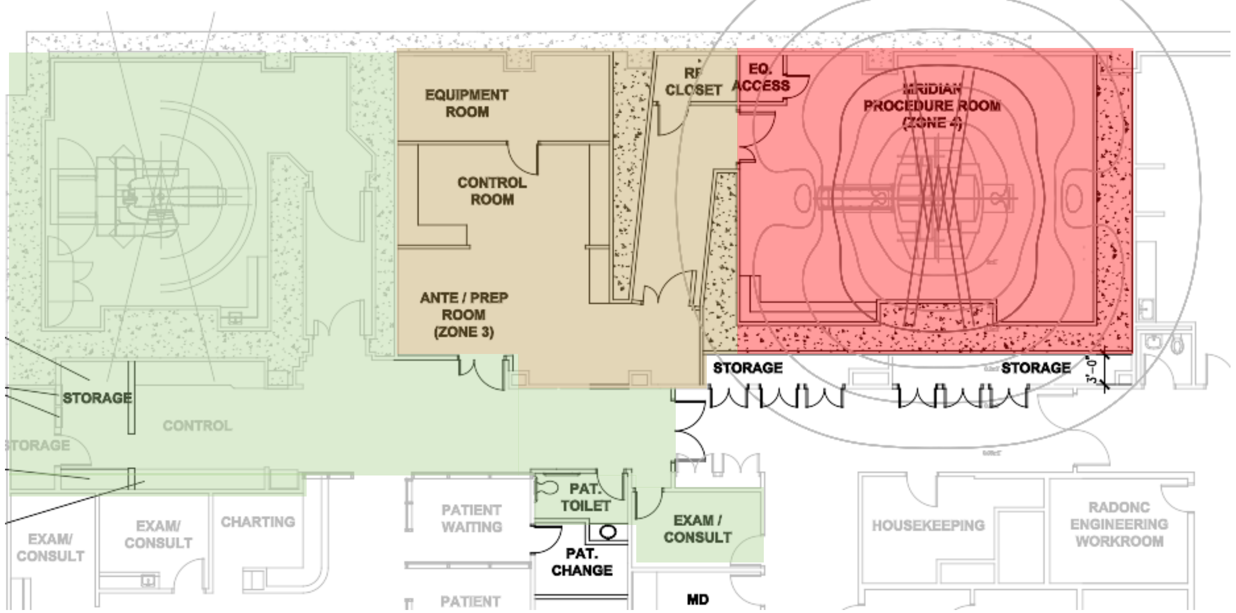


Facility and Safety Challenges

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)
https://www.acr.org/Clinical-Resources/Radiology-Safety/MR-Safety

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

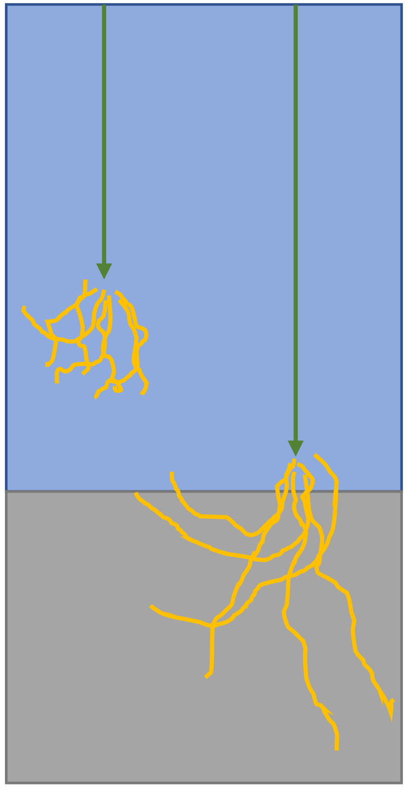
- *Cine* MR motion management
- Online adaptive radiotherapy

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"

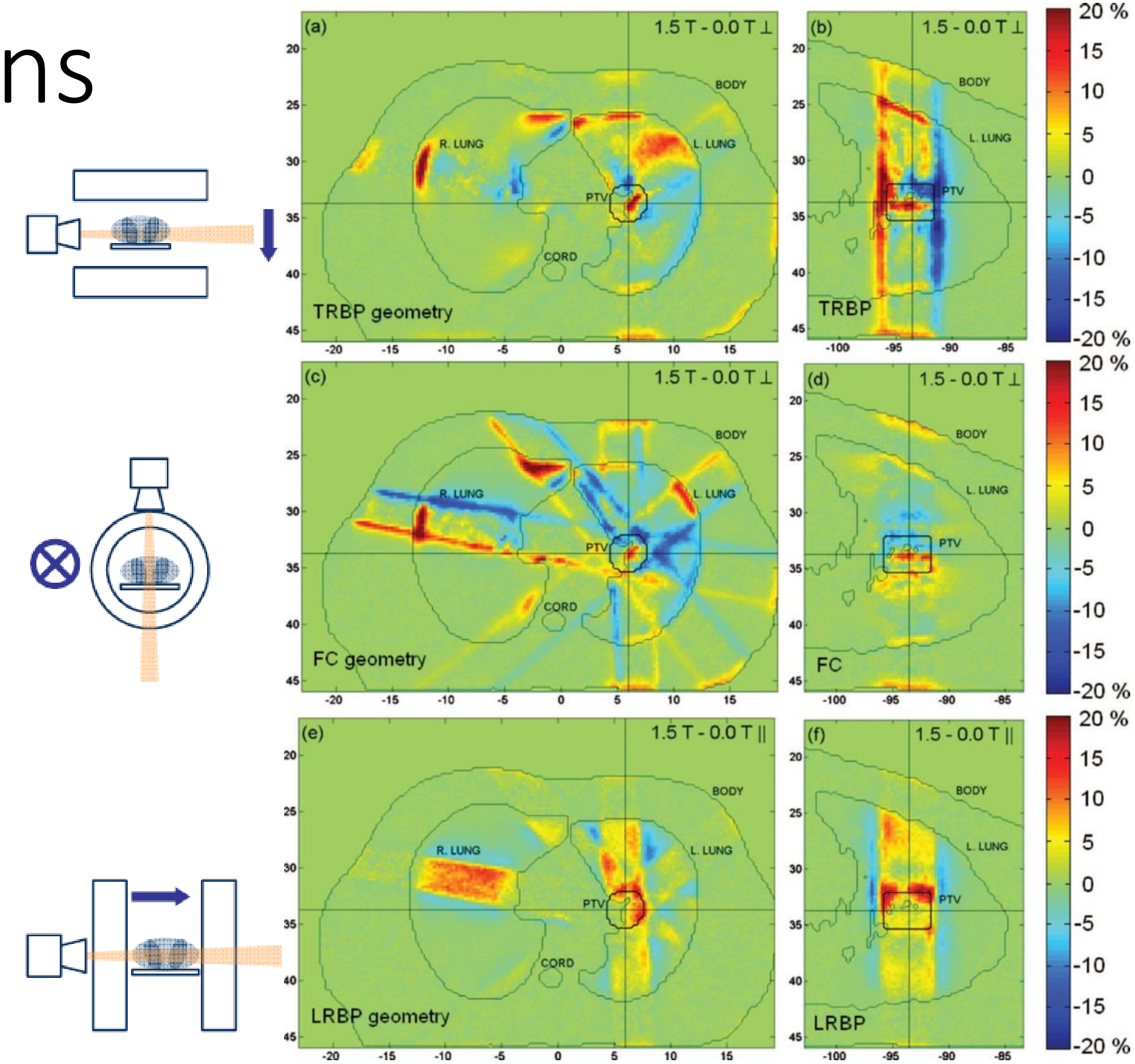


B=0
Perpendicular B Field

Raaijmakers *et al.* 2005 *Phys. Med. Biol.* **50** 1363-76

Impact on Treatment Plans

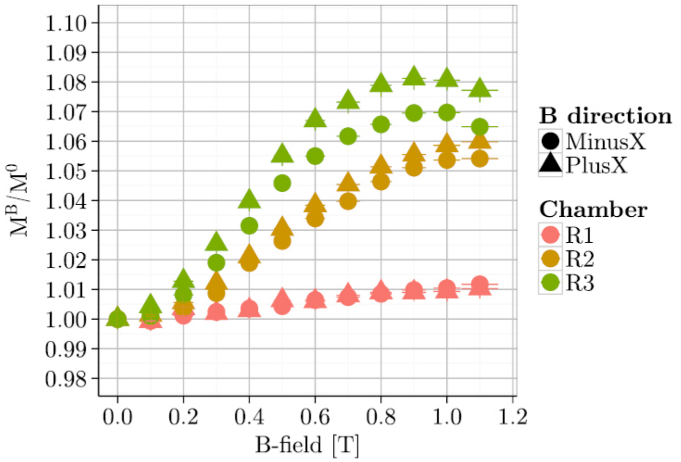
- The electron return effect may (or may not) impact treatment plans depending on:
  - Field Strength
  - Field Orientation
  - Patient anatomy
  - Plan Geometry
- <u>Need to verify the effect is accurately modeled in the TPS</u>

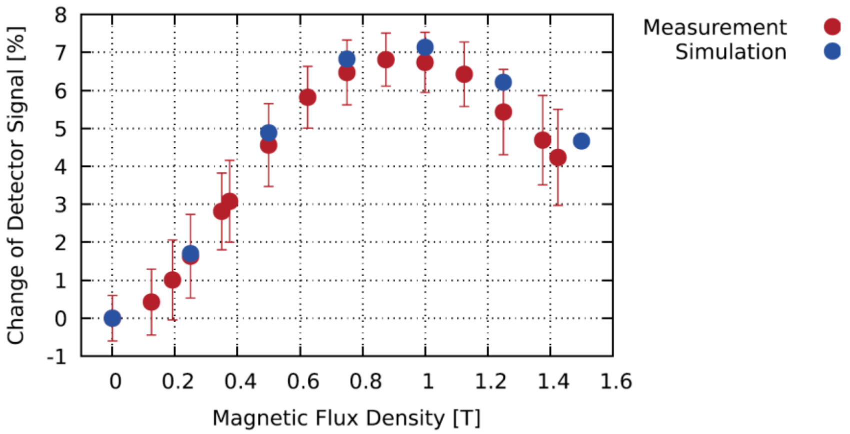


Kirkby *et al.* 2010 Med Phys 37(9):4722-32

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)
- <u>Need to use care in selecting an ionization chamber</u>

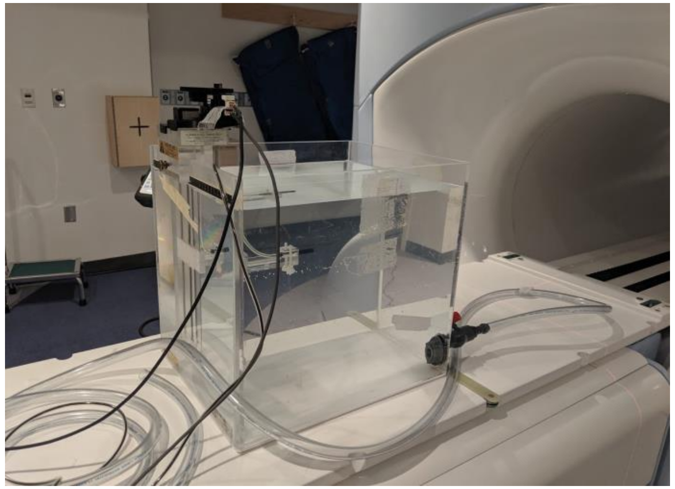




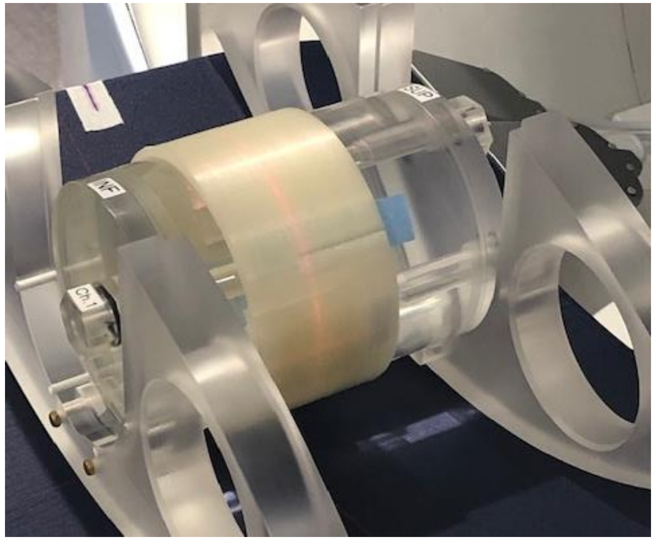
Spindeldreier *et al.* 2017 Phys. Med. Biol. 62 6708
Pojtinger et al 2018 Phys. Med. Biol. 63 11NT03

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)



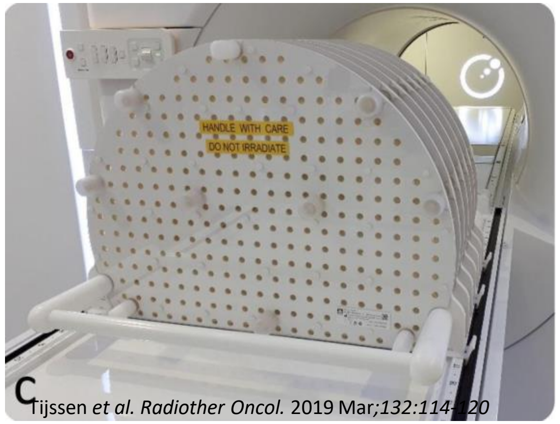
Open Source 1D Scanning Tank
See ePoster by Guthier *et al.* PO-GeP-T-104



Radiation/MR Isocenter check based on ViewRay Daily QA Phantom w/ 3D printed insert

MR QA Challenges

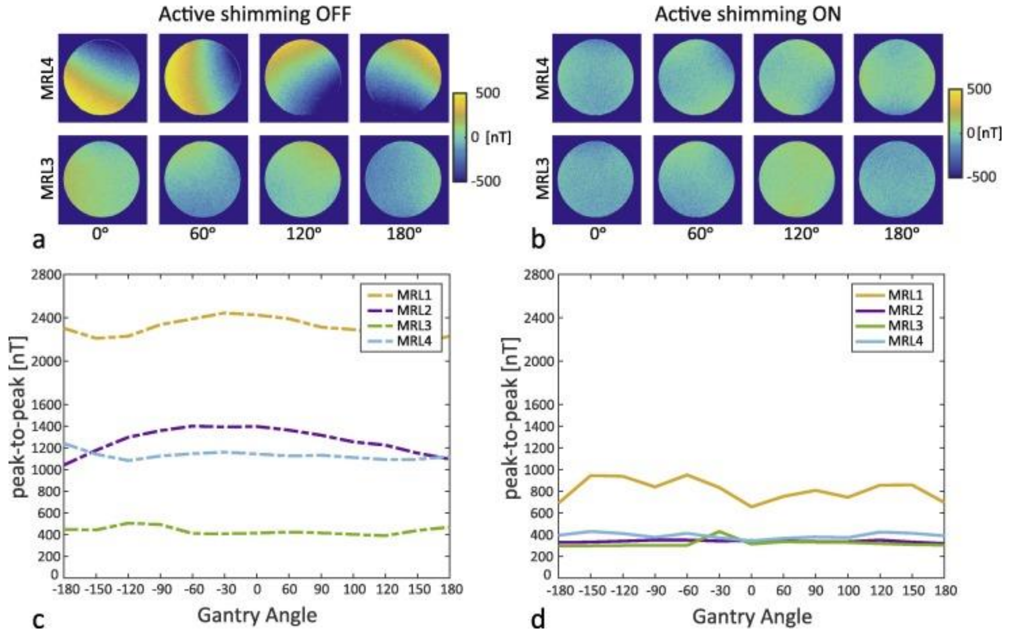
- MR-linacs often use a limited set of imaging sequences
  - Balanced SSFP (TrueFISP/FIESTA/b-FFE) is often used to maximize SNR
  - QA should reflect clinically used sequences
- Geometric accuracy and artifacts need to be assessed over a large field
  - Require specialized phantoms
- Need to evaluate motion compensation strategies
  - Breath hold, navigator, etc.

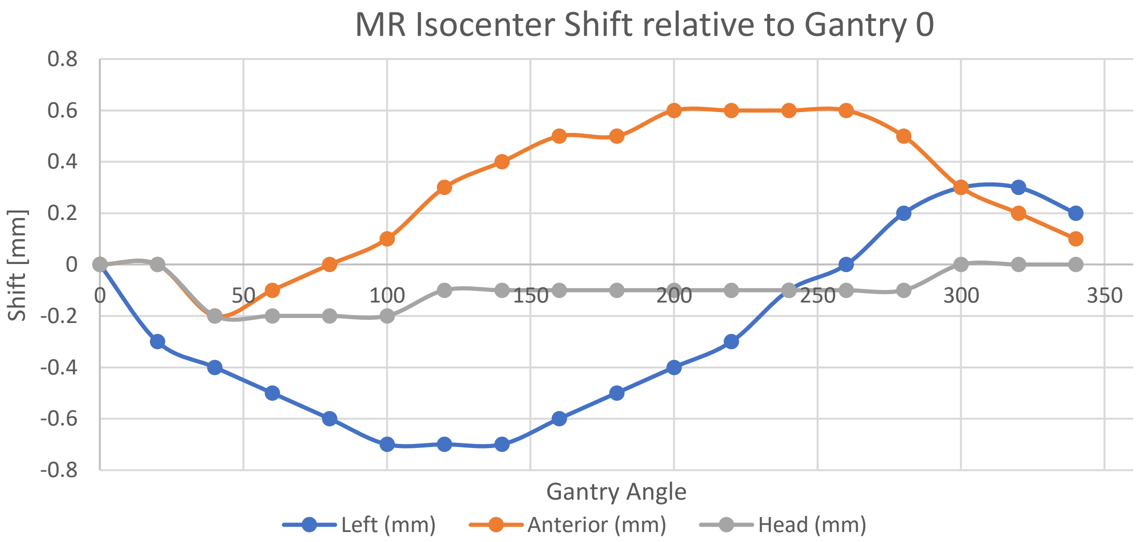


Tijssen *et al. Radiother Oncol.* 2019 Mar;*132:114-120*

Radiation Gantry Dependence

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





Tijssen *et al. Radiother Oncol.* 2019 Mar;*132:114-120*

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

Building an MR-Linac Adaptive Therapy Program

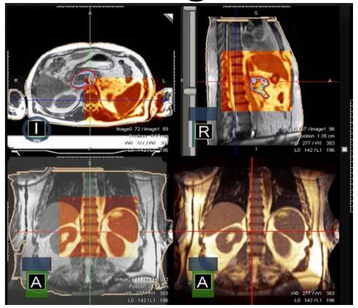
Commissioning Adaptive Radiotherapy

- 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

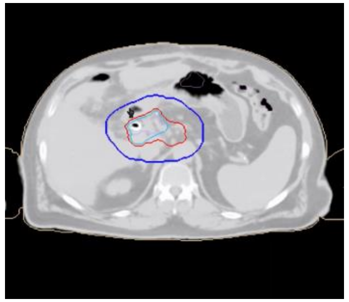
Set up patient to room lasers

Acquire 3D MRI image

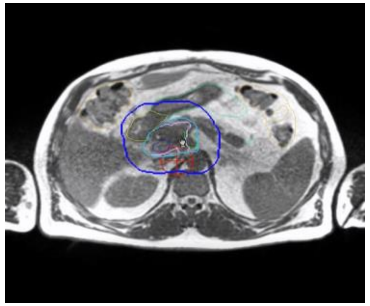


Automatically adapt contours to current anatomy

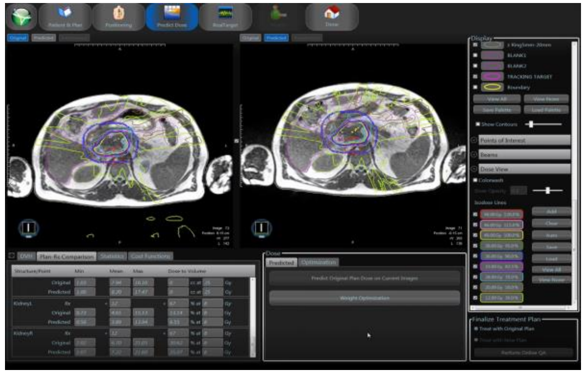
Adjust electron density



Physician verifies and modifies contours if necessary

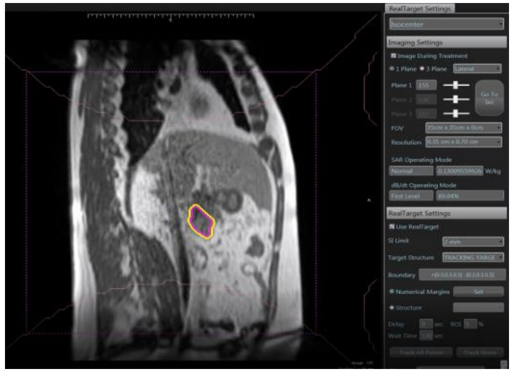


Plan is re-optimized

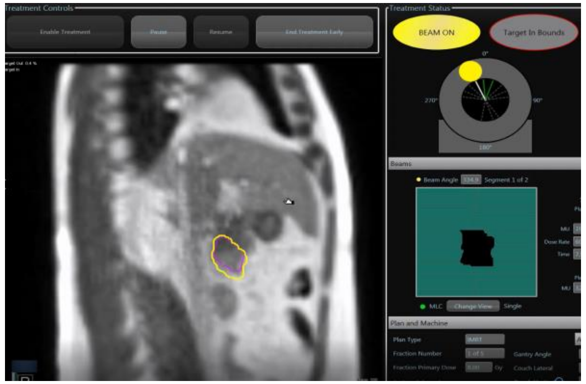


Physician and physicist approve and perform online QA of plan

Verify gating parameters



Treat while acquiring cine images



Total time for typical case: <u>40-90 minutes</u>

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

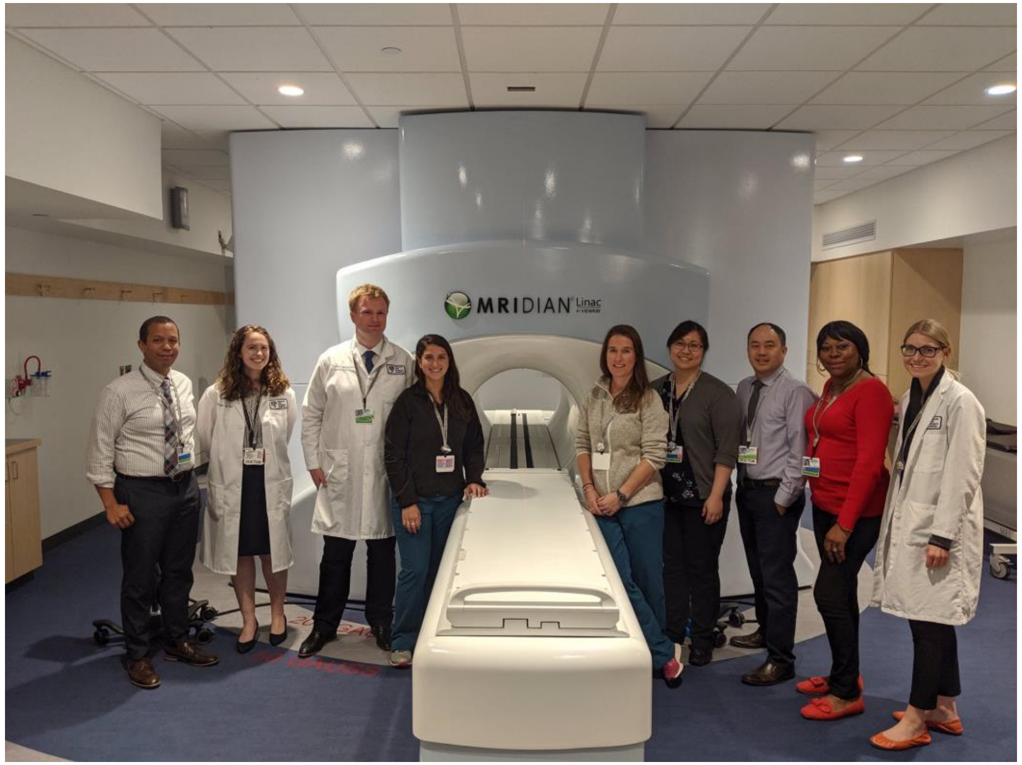
RT – Therapist MD – MR Physician P – Physicist

Pilot	Co-Pilot		Task	Specifics
RT		☐	Patient enters room	
RT	P	☐	Acquire initial MRI	
RT	P	☐	Rigid copy contours; Autocontour skin; Apply shift	Skin threshold: 40; Record shifts
RT	P	☐	Acquire high resolution MRI	
RT	P	☐	Rigid copy contours; Autocontour skin; Apply shift	If shift >5 mm, shift and acquire image
RT	P	☐	Get deformation and autocontour; Autocontour skin	
P	RT	☐	Evaluate electron density	
P	RT	☐	Adjust soft tissue and air override structures	
P	RT	☐	Clean up contours	
MD	P	☐	Edit target and OAR contours	Within 2 cm of PTV, correct contours
RT	P	☐	Clean up GTV/CTV	Remove islands only (0.2 cm^2)
RT	P	☐	Edit slice(s) of tracking target	Copy tracking to slices above and below based on boundary expansion
P	RT	☐	Apply all rules	If no vol. contour, uncheck that rule, record the contour on worksheet
P	RT	☐	Check applied rules structures	
P/MD	RT	☐	Final check of contours	Critical OARs, target structures and overlap regions
P	MD	☐	Predict original plan dose on current image	
P	MD	☐	Evaluate predicted dose	
P	MD	☐	Re-optimize plan	Remove no vol. contours from optimization
P	MD	☐	Evaluate re-optimized plan	

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!



Acknowledgements

- Elizabeth Huynh, PhD
- The BWH/DFCI MR Linac Team
- All of the MR Linac institutions helped us as we worked to install and commission our machine

The BWH/DFCI MR Linac Team

- Raymond Mak, MD
- Daniel Cagney, MD
- Lisa Singer, MD PhD
- Christopher Williams, PhD
- Elizabeth Huynh, PhD
- Evangelia Kaza, PhD
- Fred Hacker, PhD
- Zhaohui Han, PhD
- Emily Neubauer Sugar, MS
- Sara Boyle, CMD
- Noelle Lee, CMD
- Jennifer Campbell, RTT
- Jessica Penney, RTT
- Ashley Price, RTT
- Allison Madden, RTT