MR Safety in a Hybrid Environment: MR-Linac

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Disclosures

- Henry Ford Health System holds research agreements with Varian Medical Systems, Philips Healthcare, ViewRay, Inc., and Modus Medical.
- I'm not a MR scientist.

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MR Safety in MR Linac

- The good/bad news - worried about all of the same magnetic effects that are common in traditional MR environment.
- Some subtle considerations will go a long way to ensuring a safety environment for operating both the MRI and the Linear Accelerator.

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MR Linac

Seminars in RADIATION ONCOLOGY
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Introduction: Systems for Magnetic Resonance Image Guided Radiation Therapy

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Table 1

Authors	Jaffray et al	Mutic et al	Fallone	Keall et al	Lagendijk et al
Field strength (Tesla)	1.5	0.35	0.56	1	1.5
Radiation source	6 MV	Co-60	6 MV	6 MV	6 MV
In-line imaging	No	Yes	Yes	Yes	Yes
Clearance	70-cm bore	70-cm bore	85-cm open bore	82-cm open bore	70-cm bore
Install requirement	Adjacent MRI suite	Conventional bunker	Conventional bunker	Conventional bunker	Conventional bunker

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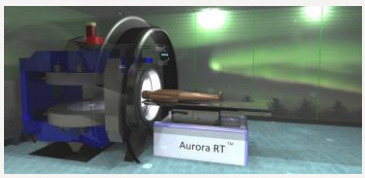
Rotating Biplanar MR Linac



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http://www.magnettx.com/index.php/category/products/

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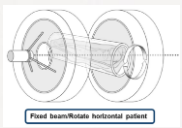
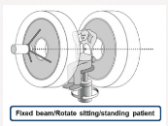
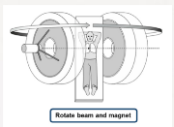
Australian MR Linac







The Australian Magnetic Resonance Imaging–Linac Program

Paul J. Keall, PhD,*† Michael Barton, FRANZCR,‡ Stuart Crozier, PhD, DEng§
On behalf of the Australian MR-Linac Program, including contributors from the Ingham Institute, Illawarra Cancer Care Centre, Liverpool Hospital, Stanford University, Universities of Newcastle, Queensland, Sydney, Western Sydney, and Wollongong

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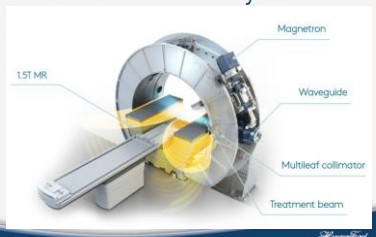
Elekta Unity



https://mrrt.elekta.com/elekta-mr-linac/

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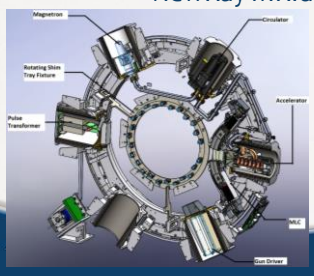
ViewRay MRIdian Linac



- 0.35 T field strength
- Gantry ring is in between two cylindrical torus magnets
- Only one clinical sequence is usable (can only adjust image resolution and FOV)

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MR Linac at HFCI


Henry Ford to Acquire ViewRay MRIdian Linac Research System

Henry Ford Health System to be Among the First in the World to Evaluate ViewRay's Linear Accelerator Technology

CLEVELAND: September 1, 2016 – ViewRay, Inc. (Nasdaq: VRAY) announced today that Henry Ford Health System will acquire ViewRay's linear accelerator technology and plans to conduct studies using this innovative linear accelerator-based radiotherapy technology. Henry Ford is the second center in the world, along with the Washington University School of Medicine in St. Louis, and first in Michigan to order ViewRay's MRIdian Linac research system.

SEARCH

medical physicsweb

Henry Ford treats first patients with MRIdian Linac

ViewRay's MRIdian Linac received FDA approval in February of this year. Now a team at Henry Ford Cancer Institute has become the first in the world to treat patients with this new MR-guided radiotherapy system.

Henry Ford received the MRIdian linac earlier this year, with ViewRay dedicating and validating the system from about February to June. Henry Ford began treating patients in July. So far, two cases involved Intensity-modulated radiotherapy (IMRT) for prostate cancer, and one case involved stereotactic body radiotherapy (SBRT).

"Once the physicians got a chance to see what they could do with this treatment system, we immediately prepared for using SBRT," explained Carri Glide-Hurst, director of translational research and senior staff physicist at Henry Ford Cancer Institute.

Elekta

CIRS

RaySearch

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So what were we doing for that year?

- Retrofitting an existing linac vault to take this new system
- Developing strategies to use immobilization devices in this new environment
- Personnel planning
- MRI safety considerations were a substantial point of emphasis during our installation process

MR Safety

ACR Guidance Document on MR Safe Practices: 2013

- As someone working in Radiation Oncology, MR Safety is a new paradigm that requires as much attention as all other safety considerations that have been classically considered in Radiation Oncology.
- For those that are new to the topic, there are many resources available to review:
  - ACR Guidance document on MR Safe Practices: 2013
  - ISMRM recommended responsibilities for MR safety management
  - Online safety modules
  - Safety courses
  - Your own hospital policies

Guidelines for MR Staffing

- ISMRM Safety Committee
  - MR Medical Director
    - Ultimate operational responsibility
    - Responsible for safe execution of the MR exam on each and every patient/human subject
    - Ensures that appropriate investigation is performed for each reported MR safety adverse event
  - MR Safety Officer
    - Responsible for ensuring that policies and procedures are being enforced
    - Developing, documenting, and introducing, in conjunction with and under the authority of the Medical Director
  - MR Expert
    - Serves as a resource for the MR Medical Director and/or MR Safety Officer
    - Provides high-level advice on the engineering, scientific, and administrative aspects of the safe use of MR equipment
    - Provide safety advice on the modification of MR protocols

Guidelines for MR Staffing

- ACR Guidance
  - Non-MR personnel
    - Those that have not within the previous 12 months undergone the designated formal training in MR safety.
    - Should be accompanied by, or under the immediate supervision of and in visual/verbal contact with one specifically identified Level 2 person for the entirety of their duration in Zone 3 and 4.
  - Level 1 Personnel
    - Those who have passed minimal safety educational efforts to ensure their own safety as they work within Zone 3.
    - Permitted to work unaccompanied through Zone 3 and 4, but are not permitted to directly admit or be responsible for non-MR personnel in Zone 4.
  - Level 2 Personnel
    - Those that have had extensive training and educated in broader aspects of MR safety.
    - Responsible for supervision of non-MR personnel needing to work in Zone 4.

HFCI Personnel Training to work/screen in MR Environment

- All personnel that can work in Radiation Oncology will minimally have basic MR safety training.
  - Facilities/Maintenance
  - Housekeeping
- Radiation Oncology staff will have more in depth lectures, and an annual proficiency exam.
  - Physicians, Physicists, Dosimetrists, Therapists, Nurses, CSRs
- Personnel that can work unaccompanied in Zone 3 & 4 need to complete:
  - 80 hours of time with trained staff in both Radiology and Radiation Oncology.
  - Demonstrate proficiency performing screening of patients, non-MR personnel, etc.

Differences in Screening in Radiology vs. Radiation Oncology

- Radiology can see patients for a variety of indications, including orthopedic, cardiovascular, neurological, and cancer diagnosis and staging.
- Patients that come to Radiation Oncology will have had a substantial track record of procedures, including imaging.
  - Pro: This means that our ability to screen patients can be improved due to the amount of imaging and documentation that's available
  - Con: Patient's are less likely to be aware of all markers placed by surgeons, meaning we have to rely on information other than what is provided by the patient – investigation is a critical component

Screening Form Components

- Expansive list of possible implants/devices/markers/etc. to ask about
- Any biological conditions to consider during scanning (piercings/tattoos, adverse effects of contrast injection, claustrophobia, etc)
- Documentation of specific implant and scanning guidelines
- Checklist of investigation for implants patient did not disclose
  - Checking surgical notes, EMR keyword search, diagnostic images(!)
- Rescreening information
  - Radiation Oncology patients will have anywhere between ~ 4 and 40 total times to enter the magnet environment
  - Due to their condition, interventional procedures during treatment course are not rare, and complete screening process needs to occur

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HFCI RadOnc Personnel/Duties for Screening

- Nurses perform initial screening over the phone when scheduling patient for consultation/simulation.
- Radiation therapists will take initial screening, investigate/summarize any findings
- Present information to Physics for evaluation, additional workup
- Present any information necessary for physician approval

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HFCI RadOnc Personnel/Duties for Screening

- Sounds easy, but if there is any hold up in the process, it will impact the ability for the initial MR simulation to be performed, and a procedural hard stop should be considered to ensure safety.
  - If screening documentation is unsatisfactory the day before MRSIM, that portion of imaging is cancelled until resolved.
- By also performing the CT simulation, this can provide a good information in determining whether further workup is needed regarding whether something will pose a risk in the magnet environment.

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HFCI Peer to Peer Model for Screening

- A peer to peer model for learning the proper process for screening patient can help the Radiation Oncology department get comfortable with screening processes already in practice in Radiology

Radiation Therapist/Lead → MRI Technologist/Lead
↓
Therapy Medical Physicist → Diagnostic Physicist/MR Scientist
↓
Radiation Oncologist → Radiologist

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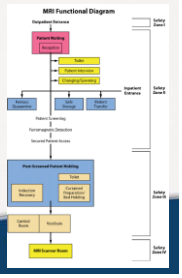
ACR Guidelines for Safety Zones

- Zone 1: region includes all areas that are freely accessible to the general public.
- Zone 2: area that is an interface between publically accessible, uncontrolled Zone 1, and the strictly controlled Zone 3 & 4.
- Zone 3: region in which free access by unscreened non-MR personnel or ferromagnetic objects/equipment can result in serious injury or death. Zone 3 regions should be physically restricted from general public access (by key lock, passkey locking, or another reliable physically restricting method that can differentiate between MR personnel and non-MR personnel.
- Zone 4: Area synonymous with the MR scanner magnet room itself.



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Implementing Safety Zones in RadOnc

- Zone 4 will be typically represented by the RF shielding door. This door can be locked with a physical key and secured when Zones 3 and 4 will be unoccupied.
- Zone 3's distance outward can vary depending on space considerations and interest in keeping MR-specific equipment (stretchers, wheelchairs, screening equipment, etc.) separate from not MR Safe equipment.
- Zone 2 will typically represent any area a patient should be traveling with assistance or supervision from staff. May require more badge locking of department access points.
- Zone 1 is the lobby and areas outside of Radiation Oncology.

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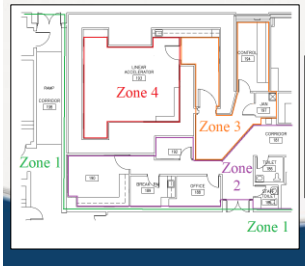
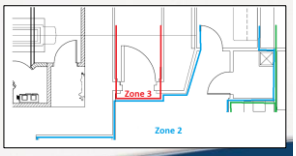
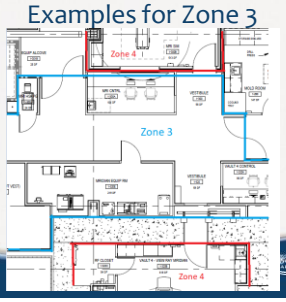
Examples for Zone 3



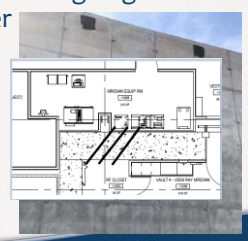


Examples for Zone 3



Things to Consider When Designing a New Center

- MRI cables need to travel less than 50 feet in total length from coils to computers.
- Require substantial space considerations and possibly penetrations in the secondary barrier.
- May require creative conduit construction and additional shielding (discussed in NCRP 151).



RadOnc Equipment needed in MR Environment

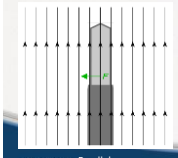
- Screening equipment
  - Strong permanent magnet
  - Metal detector (wand or walk through)
- MR safe versions of stretcher, wheelchair, and fire extinguishers
- Immobilization devices
  - MR safe
  - Need to not impact image quality
  - Need to be usable in bore smaller than typically used in RadOnc
- Radiation detectors
  - MR Safe
  - Absolute dose chamber
  - Small volume chamber for patient specific QA
  - 2D/3D arrays for beam profiles and patient specific QA
- Ancillary equipment like Solid water, MR safe tools

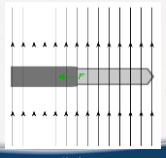
How do the MRI and Linac Affect One Another

- Linear accelerators require the production of high powered RF
  - If not properly shielded, this RF will seep into the image and degrade image quality
- The presence of a strong magnetic field has the possibility to affect multiple aspects of treatment delivery
  - Perturbing the electron paths and thus the dose deposition
  - Absolute dose calibration
- These are all issues that need to be mitigated to ensure safe treatment delivery.

Absolute Dose Calibration

- Magnetic field corrections for 1.5T field can be upwards of 4% for directions clockwise and counterclockwise to the direction of the magnetic field.
- Corrections are smallest for a chamber direction parallel to the magnetic field (<1%).





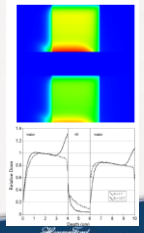
Detector	$k_{B,M}^{Q_{msr},Q_0}$	$k_{B,\parallel}^{Q_{msr},Q_0}$	$k_{B,\perp}^{Q_{msr},Q_0}$	Uncertainty (%)
PTW 30013	0.994	0.961	0.976	0.15
PTW 30012[a]	0.992	0.958	0.970	0.25
PTW 30011[a]	1.000	0.958	0.968	0.25
PTW 30010[a]	0.996	0.961	0.975	0.25
NE2571[a]	1.003	0.962	0.973	0.20
NE2571	1.001	0.962	0.973	0.15
Exradin A19	1.005	0.962	0.956	0.25

[a]Chambers modeled with a 1 mm-thick layer of PMMA representing a water-proof sleeve.

Parallel
Clockwise
O'Brien et al. Med Phys 2016

Electron Return Effect





Bielajew Med Phys 1993

Raaijmakers AJ et al PMB 2005

Electron Return Effect

- At 1.5T (Raaijmakers AJ et al PMB 2005)
  - Depth to dose maximum (dmax) will decrease by 5mm
  - Penumbra will increase by 1mm
  - 50% isodose line with shift laterally 1mm.
  - Large dose enhancement seen at air cavity interfaces
- Dosimetric consequences can be lessened by:
  - Using lower magnetic field strength
  - Using multiple treatment fields (likely in clinical practice)
  - Modeling magnetic field in treatment planning system (monte carlo based)
  - Beam path parallel to magnetic field direction

Artifacts Effect on Tumor Tracking

Conclusion

- Securing the magnet environment and making that area safe for all of those coming in to the magnet area is just as important to Radiation Oncology as it is to Radiology.
- Hopefully those in Radiation Oncology endeavoring with MR Linacs that may not have resources to teach/train/advice on safety matters will reach out to Radiology colleagues for guidance.
  - There's no need to reinvent this particular wheel
- There are some more nuances regarding safety in a MR Linac environment. They can be managed.

Thank You!

Radiation Oncology
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