MR Safety in Radiation Oncology (and Lower Field Strengths < 1.5T)

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  - Philips Healthcare
  - HFHS A-Grant
- Research Collaborations with Modus Medical Devices, ViewRay, Inc, MedSpira

MR-guided Radiation Therapy (MRgRT)

- MRgRT brings powerful soft-tissue contrast into the treatment room
- Enables real-time gating/monitoring
- Facilitates adaptive radiation therapy
MR-Co60 Clinical since Jan, 2014

- January 2014 - June 2016, 316 patients treated
- Online ART MR-IGRT (6 mos)
- Cine gating (9 mos)

ViewRay MRIdian Linac Design

- Split bore 0.35T MRI
- 6XFFF magnetron powered linac
- No bending magnet
- 4,000 lbs (mostly steel sleeves)
- Components separated & shielded
  - RF interference
  - Impact of magnet on beam

1.5T Unity MR-linac, Philips/Elekta Consortium

1.5T wide-bore MRI

Research & Development

200 Research Resources

9 Research Centers

2012
**MR Simulators (MR-SIM)**

- Bridged laser system for patient positioning
- 45 cm FOV
- Large, rigid body coils
- Flat couch (28 cm lateral translation)

**Dedicated software (HFO BT Oncology, v3.5.2) and imaging protocols**

**Different Imaging Requirements**

<table>
<thead>
<tr>
<th>Typical Diagnostic MR</th>
<th>Needs for Rad Onc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not skin-to-skin (coned down field of views common)</td>
<td>Full FOV imaging</td>
</tr>
<tr>
<td>Thick (4-6 mm) Slices, Oblique</td>
<td>Thin, Axial Slices</td>
</tr>
<tr>
<td>Radiologist can read through artifacts</td>
<td>Limit artifacts</td>
</tr>
<tr>
<td>Large field of view distortions not critical</td>
<td>Distortions quantified &amp; mitigated</td>
</tr>
<tr>
<td>Bore size flexible</td>
<td>Large bore size helpful</td>
</tr>
<tr>
<td>Curved couch</td>
<td>Flat tabletop for immobilization devices</td>
</tr>
<tr>
<td>No Lasers</td>
<td>Lasers helpful for marking/leveling</td>
</tr>
</tbody>
</table>

**Coil Configurations + Immobilization**

- Brain, Head/Neck
- Prone Breast
- Abdomen, Pelvis, Chest, Supine Breast

* Wrapped around mask
* Adjacent to mask
* Wrapped in “U” shape
Site-specific Coil/Immobilization Optimization

6 Element Torso Receive Coils (X2)

MR-guided RT Requires Creative Solutions!

Paul Jackson, RTT
Solution to bore geometry differences (85 cm vs. 70 cm):
NERF DARTS!

UW Madison trick:
Pool noodle to suspend coil from breast—avoid deforming external anatomy

Brain/H&N Mockups: Trial #1,345,324

Earphones: Attenuating
Ear buds: Require cutouts
5 Element H&N Receive Coils (K2)
Immobilization Devices: MR optimal

- Not just MR-safe
- Should not:
  - Introduce unnecessary susceptibility artifacts,
  - Produce undesired signal,
  - Increase safety profile/risk,
  - Be compatible with RF coil systems used for signal reception.

Operational Models for MR in RadOnc

<table>
<thead>
<tr>
<th>Operational Model</th>
<th>Definition</th>
<th>Potential Risks</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional</td>
<td>Prevents contamination of patient</td>
<td>Unnecessary susceptibility artifacts, unwanted signal, increased safety profile/risk, not compatible with RF coil systems</td>
<td>More efficient use of equipment, fewer errors of commission, reduced costs, increased accuracy, increased physician performance, increased efficiency</td>
<td>Not fully optimised for MR compatibility, may not support dedicated MR-based therapy, training required for integrated care, limited integration with conventional treatment planning systems</td>
</tr>
<tr>
<td>Specialised</td>
<td>Prevents contamination of patient and staff</td>
<td>Unnecessary susceptibility artifacts, unwanted signal, increased safety profile/risk, not compatible with RF coil systems</td>
<td>More efficient use of equipment, fewer errors of commission, reduced costs, increased accuracy, increased physician performance, increased efficiency</td>
<td>Not fully optimised for MR compatibility, may not support dedicated MR-based therapy, training required for integrated care, limited integration with conventional treatment planning systems</td>
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Dedicated MR-linac Clinical Team

<table>
<thead>
<tr>
<th>Staff Member</th>
<th>Full-time Effort (FTE)</th>
<th>Primary Responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation Therapists (RTTs)</td>
<td>2.5</td>
<td>Daily QA, Treatment, Simulation, MR Screening, Patient Instruction</td>
</tr>
<tr>
<td>RT Physicists</td>
<td>2</td>
<td>PSQA, Procedure Development, Daily coverage, Chart checks, QA (*2 FTE covered by 4 primary physicists)</td>
</tr>
<tr>
<td>Dosimetrist</td>
<td>0.5</td>
<td>All conventional &amp; SBRT Treatment Planning</td>
</tr>
<tr>
<td>Physician</td>
<td>1</td>
<td>Daily coverage</td>
</tr>
</tbody>
</table>
Lesson Learned: Following ACR MRI Safety Zoning Recommendations for Room Design

- Added badge-protected sliding door to partition Zone 3
  - Restricted area, controlled/supervised by MR personnel
  - Restricted from public access (key locks, badge swipe, etc.)
  - Follows our hospital MR Safety Policy
- Zone 4: MR scanner room

Who are MR personnel?

**LEVEL 1**
- Passed minimal safety education
- Ensure own safety while in Zone III
- Examples: MRI office staff, patient aides

**LEVEL 2**
- More extensive training (i.e. SAR, burns, neuro stimulation)
- Determined by MR Medical Director
- Examples: MRI technologist, radiologist, radiology nursing staff

MR-Safety in Hybrid Environment

- MRI Patient Safety screening: @ Consult (trained RN), implants investigated and documented, handed off to RTT for 2nd check, physics consult as needed
- Critical training piece for RNs/RTTs. We consult diagnostic physicist regularly
- Amended HFHS System-wide MRI safety policy


MR Personnel Level 2 Definitions

MR Technician - Meets Personnel Qualifications for ACR MRI Accreditation Program
MR Therapy Technologist - is ARRT certified, has completed an MRI safety course as approved by the MRI safety officer and has completed 80 contact hours of experiential training in MRI under the supervision of Level 2 personnel.
MR Physicist - Meets Personnel Qualifications for ACR MRI Accreditation Program
MR Therapy Physicist - is board eligible in Therapeutic Medical Physics by the American Board of Radiology, has completed an MRI safety course as approved by the MRI Safety Officer and has completed 80 contact hours of experiential training under the supervision of Level 2 personnel.
MR Radiologist - Meets Personnel Qualifications for ACR MRI Accreditation Program
MR Researchers - Physicians and others who are involved with conducting specific projects as approved by the
Typical MR Screening Clinical Workflow

- Initial MR Eligibility Screening (Nursing)
- Implant Review
- MR-compatible immobilization devices
- Incenter selection by physician
- 2nd MR screening (Radiation Therapist)
- Final MR Screening before entering Zone 3 (Radiation Therapist)
- MR-SIM Time Out Procedure

Patient Screening in Radiology vs. RadOnc

- Radiology can see patients for a variety of indications, including orthopedic, cardiovascular, neurological, and cancer diagnosis and staging.
- RadOnc patients generally have 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 available
  - Con: Patients less likely to be aware of all implants placed by surgeons, meaning we have to rely on information other than what is provided by the patient

- Investigation is critical

MR-Safety Screening

Slide Credit: A Doemer, HPCI
Key Component: Demonstrating Proficiency

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

Clinical Example #1

<table>
<thead>
<tr>
<th>3D/4D Image Type</th>
<th>Description</th>
<th>Code</th>
<th>Code Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mammography</td>
<td>Usually Normal Mode, sometimes First Level Controlled Operating Mode (alerted by pop-up)</td>
<td>First Level Controlled Operating Mode</td>
<td>3D imaging</td>
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Credit: J Kim, HFCI
Clinical Example #2

<table>
<thead>
<tr>
<th>MRI Scan Parameters</th>
<th>ViewRay</th>
<th>Specification</th>
<th>Implant Device</th>
<th>Condition</th>
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<tbody>
<tr>
<td>Static Magnetic Field</td>
<td>0.35 T</td>
<td>1.5 T to 3.0 T</td>
<td>N/A</td>
<td></td>
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<tr>
<td>Max Spatial Gradient</td>
<td>7 T/m (700 Gauss/cm)</td>
<td>25 T/m</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Max dB/dt</td>
<td>383 T/sec</td>
<td>N/A</td>
<td></td>
<td></td>
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<tr>
<td>Maximum Slew Rate</td>
<td>200 T/m/sec</td>
<td>≤ 200 T/m/s</td>
<td>N/A</td>
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<tr>
<td>Maximum SAR</td>
<td>&lt; 1.2 W/kg (in Normal Operating Mode)</td>
<td>2.0 W/kg</td>
<td>W. Body ≤ 3.0 W/kg, Head ≤ 3.2 W/kg</td>
<td></td>
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Cine imaging: First Level Operating Mode

NOTE: In this example, the Slew Rate for this implant is close to specification, but still safe to be scanned on ViewRay.

Risk/benefit must be assessed by physician, Radiology consulted as needed, and formally documented

Credit: J Kim, HFCI

Clinical Example #3

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**MR-Safe/Conditional Equipment List**

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<th>Remarks</th>
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<tr>
<td>Exradin A26 MR-Compatible Chamber (0.015 cc)</td>
<td></td>
</tr>
<tr>
<td>Exradin A12 MR-Compatible Chamber (0.45 cc)</td>
<td></td>
</tr>
<tr>
<td>Gafchromic EBT Film + In-house software</td>
<td></td>
</tr>
<tr>
<td>1D Medtech mechanically driven water tank</td>
<td></td>
</tr>
<tr>
<td>SunNuclear MR-Compatible Arc Check</td>
<td></td>
</tr>
<tr>
<td>SunNuclear MR-Compatible IC Profiler</td>
<td></td>
</tr>
<tr>
<td>JM Specialty Parts, ACR Large MRI Phantom</td>
<td></td>
</tr>
<tr>
<td>In-house large field of view distortion phantom</td>
<td></td>
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- Equipment log maintained
- All objects shall be affixed with labels using standard FDA labeling criteria for “MR safe” (wholly non-metallic objects), “MR-conditional,” and “MR unsafe” materials following guidelines outlined in Kanal et al., 2013.

**Conclusions**

- MR safety in hybrid environments present new challenges in personnel/staffing
- Equipment/immobilization add complexity
- Implant workup needs to be tailored to the specific equipment and planned operating modes/time of operation
- Multidisciplinary approach is essential.