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

**Carri Glide-Hurst, PhD, DABR, FAAPM**
Director of Translational Research, Radiation Oncology, Henry Ford Health System
Associate Professor FTA, Wayne State University



## Disclosures

- Research funding provided by:
  - NIH R01CA204189
  - 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-Co$^{60}$ Clinical since Jan, 2014

advances in radiation oncology

Scientific Article

**Two-and-a-half-year clinical experience with the world's first magnetic resonance image guided radiation therapy system**

Benjamin W. Fischer-Valuck MD [a,1], Lauren Henke MD [a,1], Olga Green PhD [a], Rojano Kashani PhD [a], Sahaja Acharya MD [a], Jeffrey D. Bradley MD [a], Clifford G. Robinson MD [a], Maria Thomas MD, PhD [a], Imran Zoberi MD [a], Wade Thorstad MD [a], Hiram Gay MD [a], Jiayi Huang MD [a], Michael Roach MD [a], Vivian Rodriguez PhD [a], Lakshmi Santanam PhD [a], Harold Li PhD [a], Hua Li PhD [a], Jessika Contreras MD [a], Thomas Mazur PhD [a], Dennis Hallahan MD [a], Jeffrey R. Olsen MD [a], Parag Parikh MD [a], Sasa Mutic PhD [a], Jeff Michalski MD, MBA [a,*]

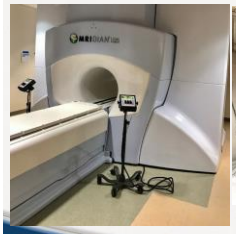
[a] Washington University, Department of Radiation Oncology, St. Louis, Missouri
[b] University of Colorado, Department of Radiation Oncology, Aurora, Colorado

Received 20 March 2017; received in revised form 21 May 2017; accepted 25 May 2017

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



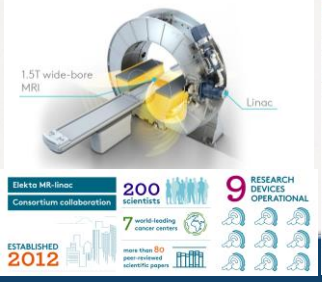
## ViewRay MRIdian Linac Design



- 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




May 25, 2017

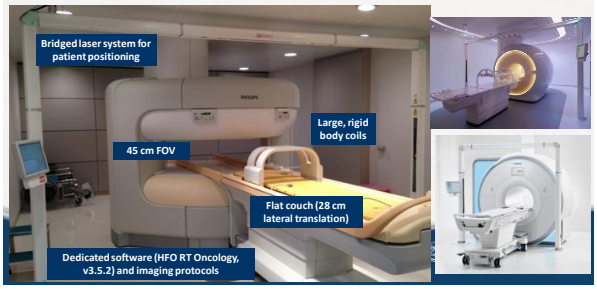
**First patient treated on the Unity MRI-linac**

The recent ESTRO 36 meeting saw Elekta officially release the Unity MRI-linac, an MRI-guided radiotherapy system that integrates a diagnostic quality 1.5 T MR scanner with an advanced linear accelerator. Now the team at UMC Utrecht, where this technology was first envisioned, has performed the first patient treatment using the Unity system.

UMC Utrecht team with the Unity MRI-linac

This landmark treatment, on a patient with spinal bone metastases, took place last Friday afternoon. According to Bas Raaymakers, professor of experimental clinical physics in UMC

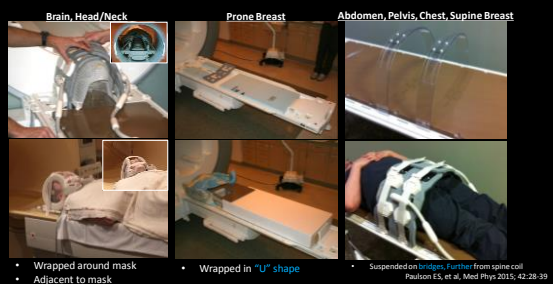
## MR Simulators (MR-SIM)



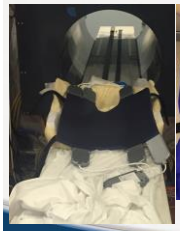

## Different Imaging Requirements

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

## Coil Configurations + Immobilization



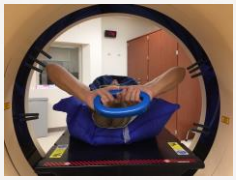
## Site-specific Coil/Immobilization Optimization



6 Element Torso Receive Coils (X2)



## MR-guided RT Requires Creative Solutions!

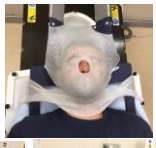


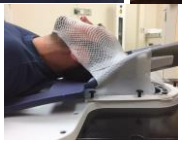
Paul Jackson, RTT
Solution to bore geometry differences (85 cm vs. 70 cm):
NERF DARTS!

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 (X2)**

## Immobilization Devices: MR optimal

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

all for you

HENRY FORD CANCER INSTITUTE

## Operational Models for MR in RadOnc

| *Operational Model* | *Definition* | *Potential Roles* | *Advantages* | *Disadvantages* |
|---|---|---|---|---|
| Traditional | Personnel work in professional training capacities | • ARRT-certified MR technologist operates MR scanner<br>• ARRT-certified radiation therapist performs patient immobilization and setup<br>• MRI physicist performs acceptance, commissioning, and ongoing QA | • Level 2 personnel requirements met using dedicated MRI staff<br>• Personnel comfortable in standard roles<br>• Formal didactic training programs completed<br>• MRI expertise established | • If MR-SIM is a dedicated resource, may not require full FTEs<br>• Training required for diagnostic staff to understand simulation objectives |
| Specialized | Personnel given didactic and practical training to operate independently | • ARRT-certified MR technologist taught simulation and immobilization<br>• ARRT-certified radiation therapist operates MRI scanner<br>• Radiation oncology physicist performs acceptance, commissioning, and ongoing QA | • More efficient use of resources<br>• Staff receives necessary training to work in MRI without reliance on external support | • Optimal with dedicated staffing<br>• Requires substantial training for radiation therapists and therapy physicists to learn MRI<br>• Special cases (implanted devices, complex imaging) require additional physics support |

TG-284, under review

all for you

HENRY FORD CANCER INSTITUTE

## Dedicated MR-linac Clinical Team

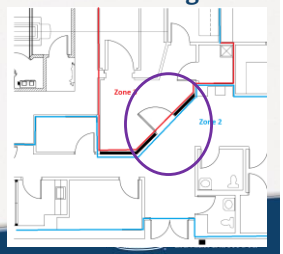
| Staff Member | Full-time Effort (FTE) | Primary Responsibilities |
|---|---|---|
| Radiation Therapists (RTTs) | 2.5 | Daily QA, Treatment, Simulation, MR Screening, Patient Instruction |
| RT Physicists | 2* | PSQA, Procedure Development, Daily coverage, Chart checks, QA (*2 FTE covered by 4 primary physicists) |
| Dosimetrist | 0.5 | All conventional & SBRT Treatment Planning |
| Physician | 1 | Daily coverage |

all for you

HENRY FORD CANCER INSTITUTE

## 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




all for you

## 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

all for you

ACR Guidance Document on MR Safe Practices: 2013

HENRY FORD CANCER INSTITUTE

## 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 Technologist** – 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

**Patient Consult**
- Initial MR Eligibility Screening (Nursing)
- Implant Review

**CT-SIM**
- MR-compatible immobilization devices
- Isocenter selection by physician
- 2nd MR screening (Radiation Therapist)

**MR-SIM**
- Final MR Screening before entering Zone 3 (Radiation Therapist)
- MR-SIM Time Out Procedure

## MR-Safety Screening

all for you

HENRY FORD CANCER INSTITUTE

## 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

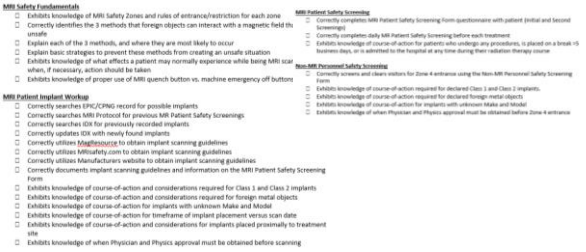
- **Investigation is critical**

all for you

HENRY FORD CANCER INSTITUTE

Slide Credit: A Doemer, HFCI

## Key Component: Demonstrating Proficiency



**MRI Safety Fundamentals**

- ☐ Exhibits knowledge of MRI Safety Zones and rules of entrance/restriction for each zone
- ☐ Correctly identifies the 3 methods that foreign objects can interact with a magnetic field th unsafe
- ☐ Explain each of the 3 methods, and where they are most likely to occur
- ☐ Explain basic strategies to prevent these methods from creating an unsafe situation
- ☐ Exhibits knowledge of what effects a patient may normally experience while being MRI scar when, if necessary, action should be taken
- ☐ Exhibits knowledge of proper use of MRI quench button vs. machine emergency off button

**MRI Patient Implant Workup**

- ☐ Correctly searches EPIC/CPNG record for possible implants
- ☐ Correctly searches MRI Protocol for previous MR Patient Safety Screenings
- ☐ Correctly searches IDX for previously recorded implants
- ☐ Correctly updates IDX with newly found implants
- ☐ Correctly utilizes MagResource to obtain implant scanning guidelines
- ☐ Correctly utilizes MRIsafety.com to obtain implant scanning guidelines
- ☐ Correctly utilizes Manufacturers website to obtain implant scanning guidelines
- ☐ Correctly documents implant scanning guidelines and information on the MRI Patient Safety Screening Form
- ☐ Exhibits knowledge of course-of-action and considerations required for Class 1 and Class 2 implants
- ☐ Exhibits knowledge of course-of-action and considerations required for foreign metal objects
- ☐ Exhibits knowledge of course-of-action for implants with unknown Make and Model
- ☐ Exhibits knowledge of course-of-action for timeframe of implant placement versus scan date
- ☐ Exhibits knowledge of course-of-action and considerations for implants placed proximally to treatment site
- ☐ Exhibits knowledge of when Physician and Physics approval must be obtained before scanning

**MRI Patient Safety Screening**

- ☐ Correctly completes MRI Patient Safety Screening Form questionnaire with patient (Initial and Second Screenings)
- ☐ Correctly completes daily MR Patient Safety Screening before each treatment
- ☐ Exhibits knowledge of course-of-action for patients who undergo any procedures, is placed on a break >5 business days, or is admitted to the hospital at any time during their radiation therapy course

**Non-MR Personnel Safety Screening**

- ☐ Correctly screens and clears visitors for Zone 4 entrance using the Non-MR Personnel Safety Screening Form
- ☐ Exhibits knowledge of course-of-action required for declared Class 1 and Class 2 implants.
- ☐ Exhibits knowledge of course-of-action required for declared foreign metal objects
- ☐ Exhibits knowledge of course-of-action for implants with unknown Make and Model
- ☐ Exhibits knowledge of when Physician and Physics approval must be obtained before Zone 4 entrance

Credit: P Jackson/A Doemer HFCI



## 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

all for you

Henry Ford Health System — Henry Ford Cancer Institute

Slide Credit: A Doemer, HFCI

## Clinical Example #1

| | | |
|---|---|---|
| **Type**: Aortic Valve | **Location**: Aorta | **Class**: Class 2 |
| **Date Implanted**: 6/23/2017 | **Make/Model**:<br>Make: Medtronic / Model: Corevalve Evolut R Bioprosthesis; Model #: EVOLUTR-34-US<br>Generic: Heart valve | |

**Scanning Guidelines/Implant Information**:
Material: Porcine, Nitinol
Summary: MR Conditional - See Reference Max. Field: 1.5, 3 Tesla

Note: Evolut™ R bioprosthesis is MR Conditional. A patient with this device can be safely scanned in an MR system meeting the following conditions:
- Static magnetic field of 1.5 T and 3.0 T
- Maximum spatial field gradient of 2,500 gauss/cm (25 T/m)
- Maximum MR system reported, whole body averaged specific absorption rate (SAR) of 2.0 W/kg (Normal Operating Mode)

Based on nonclinical testing and modeling, under the scan conditions defined above, the Medtronic CoreValve™ Evolut™ R bioprosthesis is expected to produce a maximum in vivo temperature rise of less than 4.0°C after 15 minutes of continuous scanning.

| MRI PARAMETER TYPE | VIEWRAY SPECIFICATION | IMPLANT DEVICE CONDITIONS |
|---|---|---|
| Static Magnetic Field | 0.35 T | 1.5 T to 3.0 T |
| Max Spatial Field Gradient | 7 T/m (700 Gauss/cm) | 25 T/m |
| Max dB/dt | 383 T/sec | N/A |
| Maximum Slew Rate | 200 T/m/sec | N/A |
| Maximum SAR | < 1.2 W/kg (in Normal Operating Mode) | 2.0 W/kg |
| Cine imaging | First Level Operating Mode | N/A |

0.35T Volumetric imaging: Usually **Normal Mode**, sometimes **First Level Controlled Operating Mode** (alerted by pop-up)
Cine imaging: always operating in **First Level Controlled Operating Mode**

Credit: J Kim, HFCI

## Clinical Example #2

| Type: TIPS Stent | Location: Liver Portal Vein | Class: Class 2 |
|---|---|---|
| Date Implanted: Prior to 2010 TIPS stent (Viatorr) placement | Make/Model: Make: Boston Scientific / Model: WALLSTENT™ RP Endoprosthesis (Transhepatic Biliary; Tracheobronchial; TIPS; Venous) | |
| Scanning Guidelines/Implant Information: Non-clinical testing has demonstrated that WALLSTENT TIPS is MR Conditional for single and overlapping lengths up to 94 mm. A patient with this stent can be scanned safely, immediately after placement, under the following conditions:<br>• Static magnetic field of 1.5 Tesla or 3.0 Tesla<br>• Highest spatial gradient magnetic field of 19 Tesla/m (1900 Gauss/cm) or less<br>• Maximum MR system reported, whole body averaged specific absorption rate (SAR) of ≤2 W/kg<br>RF Heating<br>Under the scan conditions defined above, WALLSTENT TIPS is expected to produce a maximum in-vivo temperature rise of 0.64°C after 15 minutes of continuous scanning | | |

| MRI PARAMETER TYPE | VIEWRAY SPECIFICATION | IMPLANT DEVICE CONDITIONS |
|---|---|---|
| Static Magnetic Field | 0.35 T | 1.5 T to 3.0 T |
| Max Spatial Field Gradient | 7 T/m (700 gauss/cm) | 19 T/m |
| Max dB/dt | 383 T/sec | N/A |
| Maximum Slew Rate | 200 T/m/sec | N/A |
| Maximum SAR | < 1.2 W/kg (in Normal Operating Mode) | 2.0 W/kg |
| Cine imaging | First Level Operating Mode | N/A |

Credit: J Kim, HFCI

## Clinical Example #3

| Type: Loop recorder | Location: Left chest | Class: Class 2 |
|---|---|---|
| Date Implanted: | Make/Model: Reveal LINQ Insertable Cardiac Monitor MRI Conditions for Use:<br>A patient with a Reveal LINQ device can be safely scanned in an MR system that meets the following conditions with no post-insertion waiting required. Failure to follow these conditions for use may result in a hazard to the patient during an MRI scan:<br>• Horizontal cylindrical bore magnet, clinical MRI systems with a static magnetic field of 1.5 Tesla (T) or 3.0 T must be used.<br>• Hydrogen proton MRI equipment must be used.<br>• Maximum spatial gradient of the static magnetic field specification must be ≤25 T/m (2500 gauss/ cm).<br>• Whole body gradient systems with gradient slew rate specification must be ≤200 T/m/s per axis.<br>• The Whole Body Specific Absorption Rate (WB-SAR) as reported by the MRI equipment must be ≤4.0 W/kg; the head SAR as reported by the MRI equipment must be ≤3.2 W/kg.<br>•*****Do not use local transmit coils on the chest, trunk, or shoulder region.<br>•*****There are no restrictions on the placement of receive-only coils, and there are no restrictions on the use of local transmit or receive coils for imaging of the head or extremities. | |

| MRI PARAMETER TYPE | VIEWRAY SPECIFICATION | IMPLANT DEVICE CONDITIONS |
|---|---|---|
| Static Magnetic Field | 0.35 T | 1.5 T to 3.0 T |
| Max Spatial Field Gradient | 7 T/m (700 Gauss/cm) | 25 T/m |
| Max dB/dt | 383 T/sec | N/A |
| Maximum Slew Rate | 200 T/m/sec | ≤ 200 T/m/s |
| Maximum SAR | < 1.2 W/kg (in Normal Operating Mode) | W. Body ≤ 3.0 W/kg<br>Head ≤ 3.2 W/kg |
| Cine imaging | First Level Operating Mode | N/A |

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

**TG-284, under review**

**MR Sim Patient QA Checklist**

Patient Name: _____ MRN: _____

| | | Therapist Checklist |
|---|---|---|
| *Setup* | Patient screened for MRI Safety | |
| | Patient changed into gown | |
| | Organ at risk (OAR) filling protocol administered (if applicable) | |
| | IV access obtained and contrast injector loaded (if applicable) | |
| | Prior images of patient reviewed on PACS system | |
| | Flat table overlay positioned on MRI couch | |
| | Immobilization devices fit within MRI bore and RF coil plugs have access to terminals | |
| | External lasers reset (zeroed) prior to setting up patient | |
| | Ear plugs or headphones placed on patient | |
| | RF coils secured on bridges or with brackets and positioned close to patient surface | |
| | Antiperistalic agent administered (if applicable) | |
| | Emergency panic ball positioned in patient hand | |
| *Localizers* | External lasers turned off | |
| | OAR filling matches planning CT (if applicable). If not, wait or intervene. | |
| *Acquisition* | Center of prescription volume set to move to isocenter | |
| | High order shim volume optimized and copied to each series | |
| | Intensity uniformity correction enabled (Pre-Scan Normalize/CLEAR/PURE) | |
| | Navigator position optimized at dome of liver (if applicable) | |
| | Breath holds acquired at respiratory phase matching RT delivery (if applicable) | |
| | Receiver bandwidths optimized per disease site (or 440/880 Hz/pixel at 1.5T/3T) | |
| | Prescribed image volume/plane compatible with delineation software | |
| | Metal artifact reduction sequences used for metallic implants (e.g., hip prostheses) | |
| | 3D GNL distortion correction enabled (3D Distortion/3D Correction/3D GradWarp) | |
| | Images screened for artifacts. If necessary, resolve artifact source and re-acquire. | |

## MR-Safe/Conditional Equipment List

| Equipment |
| --- |
| • Exradin A26 MR-Compatible Chamber (0.015 cc) |
| • Exradin A12 MR-Compatible Chamber (0.65 cc) |
| • Gafchromic EBT Film + In-house software |
| • 1D Medtech mechanically driven water tank |
| • SunNuclear MR-Compatible Arc Check |
| • SunNuclear MR-Compatible IC Profiler |
| • JM Specialty Parts, ACR Large MRI Phantom |
| • In-house large field of view distortion phantom |

-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.