Bridging the Knowledge Gap of MRI Implementation for HDR Brachytherapy

Firas Mourtada, Ph.D., FAAPM
Christiana Care Health System, Newark, DE
Disclosure

None
Learning Objectives

➢ Understand the rationale for MR for gyn and prostate brachytherapy

➢ Realize the different workflows for MR

➢ Update on TG303 work in progress
  Review process of commissioning, QA, MR safety, and clinical implementation
Special thanks to TG 303 members!

1. Firas Mourtada (Chair) – Christiana Care Hospital
2. Joann Prisciandaro (Vice-Chair) – University of Michigan
3. Gil’ad Cohen – Memorial Sloan Kettering Cancer Center
4. Robert Cormack – Brigham and Women’s Hospital
5. Ken-Pin Hwang – MD Anderson
6. Perry Johnson – University of Miami
7. Yusung Kim – University of Iowa
8. Eric Paulson – Medical College of Wisconsin
9. William Song – Virginia Commonwealth University
11. Sushil Beriwal – University of Pittsburgh
12. Beth Erickson – Medical College of Wisconsin
13. Christian Kirisits – Medical University of Vienna
14. Cristina Cozzini – GE Healthcare
15. Mo Kadbi – Philips Healthcare
16. Elena Nioutsikou – Siemens Healthcare
Rationale to Transition to MR-based BT

• Compared to CT and US, MR provides:
  • Superior soft tissue resolution
  • Clear distinction of target(s) from organs at risk

• Cervical BT
  • Ability to transition to volumetric based planning
  • Ability to develop conformal and adaptive plans

• Prostate BT
  • Ability to identify intraprostatic lesions and see functional anatomy adjacent to gland for sparing

Imaging Modalities used for BT (GYN)

- kV radiograph
- CT
- 3D T2W MR (3T)
Imaging Modalities used for BT (Prostate)

- CT
- US
- MR
- US/MR

Example

Ti Needles
Plastic Needles

2D T2W MR (3T)

Courtesy of William Song, VCU, and Gil Cohen, MSKCC
CT ROLE FOR OARs ASSESSMENT

No significant difference in volume or dose to OARs

CT tumor contour width overestimated
Why MRI for the Prostate?

Frank et al. IJROBP 2008.
Pelvic anatomy on MRI, T2-weighted images (SAM)

AFS, anterior fibromuscular stroma; TZ, transition zone; PZ, peripheral zone

Courtesy Dr. Frank MDACC
Fig. 2. Example of tumor delineation, showing the suspicious region delineated on (a) T2-weighted MRI, (b) ADC map, (c) Ktrans map. The union of suspicious areas was taken as the F-GTV for treatment, shown in (d).

Multi-parametric MRI-guided focal tumor boost using HDR prostate brachytherapy
MRI Target Precision for Treatment Planning for Brachytherapy

Solid evidence is here today

F. Mourtada
Rationale to Transition to MR-based BT

• Based on the American Brachytherapy Society practice pattern survey of cervical brachytherapy, there has been an increased in utilization of MR with brachytherapy from 2% in 2007 to 34% in 2014.

Rationale to Transition to MR-based BT

• Based on EMBRACE I (accrual of ~ 1400 patients),
  • Rectum D2cc ≤ 75 Gy reduced incidence of fistulae to ≤ 2.7%
  • Rectum D2cc ≤ 65 Gy reduced rate of G2 toxicity and proctitis to ≤ 5.2% and 4.6%, respectively
  • Preliminary results suggest there is an advantage to limiting bladder D2cc ≤ 80 Gy

Rationale to Transition to MR-based BT

- Based on EMBRACE I (accrual of ~ 1400 patients)
- A retrospective study of 852 patients from 12 centers was also conducted, retroEMBRACE. Study demonstrated that D90 of the high risk CTV ≥ 85Gy<sub>α/β=10</sub> delivered in 7 weeks resulted in a 3-year local control rate of:
  - ≥ 94% in small targets (CTV<sub>HR(BT)< 20cm³</sub>)
  - > 93% in intermediate size targets (CTV<sub>HR(BT) 20-30cm³</sub>)
  - > 86% in large targets (CTV<sub>HR(BT) up to 70cm³</sub>)
  - Overall survival benefit of 10% compared to historical cohorts

Current Recommendations - GYN

• GEC ESTRO Report I
  • Definition of a common language and means of delineating the target volumes

Current Recommendations - GYN

- GEC ESTRO Report I
- GEC ESTRO Report II
  - 3D dose-volume parameters for brachytherapy of cervical carcinoma

Current Recommendations - GYN

- GEC ESTRO Report I
- GEC ESTRO Report II
- GEC ESTRO Report III
  - Issues related to applicator reconstruction

Current Recommendations - GYN

- GEC ESTRO Report I
- GEC ESTRO Report II
- GEC ESTRO Report III
- GEC ESTRO Report IV
  - Suggestions on MR imaging sequences to utilize for treatment planning

Current Recommendations - GYN

- ICRU 89 Report – Prescribing, recording, and reporting BT for cancer of the cervix
  - Committee consisted of members from ABS and GEC-ESTRO
  - Provides description of current use of volumetric imaging for the cervix with the addition of 4D adaptive target concepts, updated radiobiology, and DVH parameter reporting for target and OARs.
However… (SAM)

- GYN – Recommendations are based on experience of a few key European institutions using magnetic field strengths that did not exceed 1.5T
- Prostate – No national/international recommendations, still investigational
Current Recommendations - Prostate

- Reported application is limited, however, there is interest in MRI integration for prostate BT
  - Improved soft tissue resolution
  - Localization of intra-prostatic lesions
  - Improved visualization of the prostate apex, prostate-bladder interface, prostate-rectal interface, neurovascular bundles, and genitourinary diaphragm

Pivotal Prostate Trial- ASCENE-RT

• “Androgen Suppression Combined with Elective Nodal and Dose Escalated Radiation Therapy” trial demonstrated an unequivocal improvement in biochemical control rates for intermediate to high risk patients treated with an LDR BT

• But, Grade 3 late GU toxicities of 18.4% - half of which were urethral strictures, many of which resolved over time with a prevalence rate of 8.6% at 5 years

MRI Guidance in HDR Brachytherapy - Considerations from Simulation to Treatment

1. Firas Mourtada (Chair) – Christiana Care Hospital
2. Joann Prisciandaro (Vice-Chair) – University of Michigan
3. Gil’ad Cohen – Memorial Sloan Kettering Cancer Center
4. Robert Cormack – Brigham and Women’s Hospital
5. Ken-Pin Hwang – MD Anderson
6. Perry Johnson – University of Miami
7. Yusung Kim – University of Iowa
8. Eric Paulson – Medical College of Wisconsin
9. William Song – Virginia Commonwealth University
11. Sushil Beriwal – University of Pittsburgh
12. Beth Erickson – Medical College of Wisconsin
13. Christian Kirisits – Medical University of Vienna
14. Cristina Cozzini – GE Healthcare
15. Mo Kadbi – Philips Healthcare
16. Elena Nioutsikou – Siemens Healthcare
1. Develop recommendations for the commissioning, clinical implementation, and on-going quality assurance (QA) for MRI-guided HDR brachytherapy including:
   a. Considerations for brachytherapy-specific image parameters (e.g., frequency of imaging, evaluation of geometric and dosimetric uncertainties, use of contrast, and workflow),
   b. Equipment and applicator selection considerations,
   c. MR safety awareness for patient and staff when using HDR applicators and tools,
   d. Logistical and economic considerations for initial program development and maintenance.
2. Describe workflow processes for MRI-guided HDR brachytherapy from simulation to delivery for common treatment sites such as GYN and prostate based on:
   a. Open bore MRI scanners,
   b. Closed bore MRI scanners,
   c. Hybrid methods using, for instance, CT/MR and US/MR.
Requirements for Implementing MR-based BT

• Access to MRI scanner
  • Diagnostic MRI
  • Dedicated Radiation Oncology MRI Simulator

• MR safety

• Optimized clinical workflow

• Developed and documented procedures, appropriate staff training
MR Safety Considerations

• Beyond the standard MRI patient safety questionnaire, need to ensure the safety of the:
  • Instruments used to deliver treatment – applicator(s)/needles
  • Accessories (e.g., immobilization and transport devices)
  • Anesthesia equipment (e.g., cart, gas tank(s), monitors, epidural introducers)
Concerns with Implants - Applicator

- MR presents a hazard of damage to tissue due to:
  - Movement of the device due to displacement force due to the Bo
  - Torque of the device due to the Bo
  - Vibrations of the device due to gradient fields
  - Heating produced by gradient and RF fields
- Image artifacts

Classification of Passive Implants (SAM)

- MR safe
  - An item that poses no known hazards in all MRI environments (e.g., nonconducting, nonmagnetic items) such as a plastic

- MR conditional
  - An item that has demonstrated no known hazards in an MR under specific conditions

- MR unsafe
  - An item that is known to pose hazards in all MRI environments (e.g., magnetic items)

Classification of Passive Implants (cont.)

• Caution - A medical device that is deemed MR Conditional under one environment may not be safe to scan in another. This includes changes in:
  • Field strength
  • Spatial gradient
  • dB/dt (time rate of change of the magnetic field)
  • RF fields
  • Specific absorption rate (SAR)

Example IFU

MRI Safety Information

Non-clinical testing and MRI simulations were performed to evaluate the Plastic Interstitial Needles. Non-clinical testing demonstrated that the Plastic Interstitial Needles are MR conditional. A patient with this device can be scanned safely in an MR system immediately after placement under the following conditions:

- Static magnetic field of 1.5 Tesla and 3 Tesla only.
- Maximum spatial gradient magnetic field of 10,000 Gauss/cm (100T/m) or less.
- Maximum MR system reported, whole body averaged specific absorption rate (SAR) of 2.0 W/kg for 15 minutes of scanning (i.e., per pulse sequence) in the Normal Operation Mode of the MR system.
- All stainless steel parts (such as obturators/mandrins, marker wires, length gauges, etc.) must be removed prior to entering the MR environment.

MRI Related Heating

Under the scan conditions defined above, the Plastic Interstitial Needles are expected to produce a maximum temperature rise of less than 1.4°C after 15 minutes of continuous scanning.

Artifact Information

In non-clinical testing, the image artifact caused by the Plastic Interstitial Needles extends approximately 5 mm from this device when imaged using a gradient echo pulse sequence and a 3 Tesla MR system.
Example Applicator Options

Varian Medical Systems

Elekta

Eckert & Ziegler
Ancillary Equipment

Siemens Tim Dockable Table

QFix Inc., Symphony System – Trolley and brachy transfer device

HoverMatt®
HDR Applicator Insertion @ MR Prep Room

MR Prep Room Procedure with Qfix Symphony Transport System

Siemens TIM Dockable MR Table

F. Mourtada
Commissioning

• Staff training (equipment, MR safety, etc.)
• Optimization of MR scan sequences
  • MR expertise critical (radiologists, MR physicists, vendor)
• Need to assess sequences for:
  • Visualization of anatomy
  • Distortions and susceptibility artifacts introduced by the applicator
Commissioning

• Staff training (equipment, MR safety, etc.)
• Optimization of MR scan sequences

• Applicator reconstruction
  • Scan applicator(s) in a fixed orientation on MR and standard imaging system (e.g., CT)
  • Assess accuracy of digitization on MR compared to institutional gold standard
Commissioning: Applicator Reconstruction

• Digitization of tip and inner lumen of applicator in software (TPS)
  • Markers (plastic applicators)
MR Compatible Markers

Schindel et al., Int J Radiation Oncology 2013, 86(2): 387 – 393.
Plastic Applicators

CT

3D T1W
3T
Gd+H₂O

3D T2W
3T
H₂O
Applicator Reconstruction - Markers

• Applicator can be reconstructed based on markers

• However,
  • Commercially available MR markers limited
  • Prone to errors
Applicator Reconstruction

• Digitization of tip and inner lumen of applicator in software (TPS)
  • Markers (plastic applicators)
  • Direct digitization
• Susceptibility related artifacts result in uncertainties in titanium applicator evaluation.

• Can be assessed by fusing CT and MR scans in phantom.

• Direct digitization is viable, but uncertainties need to be assessed.

Applicator Reconstruction

- Digitization of tip and inner lumen of applicator in software (TPS)
  - Markers (plastic applicators)
  - Direct digitization
  - Fusing multiple image sets
  - Applicator models
Example Applicator Models

Varian Medical Systems

CT/MR Titanium R&T
CT/MR Plastic R&T
CT/MR Titanium T&O (FSD)

CT/MR Fletcher T&O from Elekta Oncentra
1. Evaluate the accuracy of the digitization compared with standard digitization technique on standard imaging modality.
Compare source positions defined on CT using manual or marker reconstruction to model-based reconstruction.

**Manual Digitization**

**Marker based Digitization**

**Model based Digitization**

**Versus**
Applicator Reconstruction

1. Evaluate the accuracy of the digitization compared with standard digitization technique on standard imaging modality.

2. Evaluate uncertainty of reconstruction using the models comparing institutional gold standard imaging modality (e.g., CT) with MR.
Compare source positions defined with model-based reconstruction between CT and MR.
Commissioning Phantom (GYN)

Commissioning

• Staff training (equipment, MR safety, etc.)
• Optimization of MR scan sequences
• Applicator reconstruction
• Development of workflow
Different Workflows for MR integration

MRI-informed BT

Seeds
- Diagnosis
- Tx Sim.
- Tx Plan
- Implant

HDR
- Diagnosis
- Implant
- Tx Sim.
- Tx Plan
- Verify/Deliver

MRI-based BT planning

Seeds
- Diagnosis
- Tx Sim.
- Tx Plan
- Implant

HDR
- Diagnosis
- Implant
- Tx Sim.
- Tx Plan
- Verify/Deliver

MRI-guided BT implants

Seeds
- Diagnosis
- Tx Sim.
- Tx Plan
- Implant

HDR
- Diagnosis
- Implant
- Tx Sim.
- Tx Plan
- Verify/Deliver

Workflows for Prostate but similar for GYN HDR


F. Mourtada
MR GYN BT Workflows

• Hybrid approach (MR/CT) - or US/CT
  • MR-informed BT - placement of BT applicator(s)/needles based on pre-implant MRI data
    • Cognitive fusion ...
    • Most us have done this for a while on diagnostic MR series
  • MR-based BT - utilizes an MRI for first fraction only and fusion to subsequent fractions CT*
    • Contour the HR CTV “target”
    • For subsequent fractions using image fusion for target
    • CT is reliable and accurate of OARs

MR Only Workflow for GYN Brachy

• Guiding both implant insertion and volumetric image series for treatment planning
• New concept introduced has been proposed
  • MR assisted radiosurgery (MARS)- MD Anderson
  • Interventional Radiation Oncology (IRO)- Hopkins
• Even better if the HDR unit is inside MR vault
  • After all, MR linacs technology is proven now
  • Integrate afterloader inside MR-Linac vault
MR vs. Sterility vs. Radiation Fields

- Magnetic Field
- Surgery Sterility Field
- HDR Radiation Field
MR BT Workflows

• MR only
  • MR guided BT – guiding both implant and planning
• Challenging:
  • Location of MR (i.e., outside of department)
  • Logistical issues
  • Required MR time
  • Reimbursements
Commissioning

- Staff training (equipment, MR safety, etc.)
- Optimization of MR scan sequences
- Applicator reconstruction
- Development of workflow
- Development of documentation
Treatment Planning Consideration

• Additional time is required when MR is integrated into the BT workflow
  • Longer acquisition time compared to CT and US
  • Volume based plans require target(s) and OARs to be delineated
    • Training is necessary to ensure structures are appropriately contoured on MR
  • Applicator reconstruction is challenging on MR
Quality Assurance

• Standard screening of patient and equipment prior to MR
• Inspection of marker integrity, if applicable
• Independent review of applicator reconstruction
• Independent review of multi-modality registration
• Verification of applicator/needle positions prior to treatment – visual inspection or repeat imaging
Patient Setup Verification

• Single implant, multiple fractions – repeat imaging (e.g., CT, MR, CBCT) should be performed and registered to planning scan to ensure plan can be decayed and treated

• Pre-treatment verification – due to length of planning process and/or patient transfers, in room imaging (e.g., CBCT, MV, kV, MR, CT) may be performed to verify applicator/needle positions
Summary

• MR based BT is viable, and allows for the visualization of targets, opportunity to conform dose to the target volume, and spare normal tissues.

• The goal of TG 303 is to provide recommendations to the medical physics community to safely and efficiently integrate MR into the HDR clinical workflow.