Overview of MRI for HDR Brachytherapy in the Treatment of Gynecologic and Prostate Cancer

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Disclosures

• None



Learning Objectives

- 1. Understand the rationale for transitioning to MR based brachytherapy (BT) for gynecologic and prostate cancers.
- 2. Understand the process of commissioning, QA, and clinical implementation of MR based BT.
- 3. Discuss workflow options for implementing MR based BT for gynecologic and prostate cancers.



Imaging Modalities used for BT (GYN)



kV radiograph

СТ

3D T2W MR (3T)



Imaging Modalities used for BT (Prostate)



Courtesy of William Song, VCU, and Gil Cohen, MSKCC



- 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

S.J. Frank and F. Mourtada, Brachytherapy, 2017, 16: 657 – 658.



 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.

S. Grover et al., Int J Radiation Oncol Biol Phys 2016, 94(3): 598 – 604.



- 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%
 - Preliminary results suggest there is an advantage to limiting bladder D2cc ≤ 80 Gy

R. Pötter *et al.*, ctRO 2018, 9: 48 - 60.



- 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 \ge 85Gy_{$\alpha/\beta=10$} delivered in 7 weeks resulted in a 3-year local control rate of:
 - ≥ 94% in small targets (CTV_{HR}(BT)< 20cm³)
 - > 93% in intermediate size targets (CTV_{HR}(BT) 20-30cm³)
 - > 86% in large targets (CTV_{HR}(BT) up to 70cm³)
 - Overall survival benefit of 10% compared to historical cohorts

R. Pötter *et al.*, ctRO 2018, 9: 48 - 60.



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

C. Haie-Meder *et al.*, Radiotherapy Oncology 2005, 74: 235 – 245.



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

R. Pötter *et al.*, Radiother Oncol 2006, 78: 67 – 77.



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

T. Hellebust *et al.*, Radiother Oncol 2010, 96: 153 – 160.



- 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

J.C.A. Dimopoulos *et al.*, Radiother Oncol 2012, 103: 113 – 122.



- 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.

Journal of ICRU, Radiotherapy Oncology 2013, 13.



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, prostatebladder interface, prostate-rectal interface, neurovascular bundles, and genitourinary diaphragm

T.J. Pugh and S.S. Pokharel, Brachytherapy 2017, 16(4):659 - 664.



However...

- 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



AAPM Task Group 303

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
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- 14. Cristina Cozzini GE Healthcare
- 15. Mo Kadbi Philips Healthcare
- 16. Elena Nioutsikou Siemens Healthcare



AAPM Task Group 303 - Charge

- 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.



AAPM Task Group 303 – Charge (cont.)

- 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

- 1. Access to MRI scanner
- 2. MR safety
- 3. Optimized clinical workflow
- 4. Developed and documented procedures, appropriate staff training



Access to MRI

- Diagnostic MRI
- Dedicated Radiation Oncology MRI Simulator



MR Safety Considerations

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



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

J.G. Delfino and T.O. Woods, Curr Radiol Rep 2016, 4(6): 28



Classification of Passive Implants



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

MR

- 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

T.O. Woods, J Magn Reson Imaging 2007, 26: 1186 - 1189.



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)

T.O. Woods, J Magn Reson Imaging 2007, 26: 1186 - 1189.



Example Applicator Options



Example IFU

MRI Safety Information



Comp

Description

- Plastic needle, ø 2.0 mr
- with mandrin for 113 mr

Plastic needle, ø 2.0 mr

with mandrin for 200 mr

Plastic needle, ø 2.0 mr

with mandrin for 320 mr

Plastic needle, ø 2.0 mr

blunt tip

with mandrin for 320 mr

Varian Medical Systems

RADIATION ONCOLOGY

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.



B

10750



Ancillary Equipment



Siemens Tim Dockable Table





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



HoverMatt[®]







Commissioning

- Staff training (equipment, MR safety, etc.)
- Optimization of MR scan sequences
 - MR expertise critical (radiologists, MR physicists, vendor)
 - –Need to assess sequences for:
 - 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 Phantom (GYN)













S. Haack *et al.*, Radiother Oncol 2009, 91(2): 187 – 193.
Y. Kim *et al.*, Int J Radiation Oncology 2011, 80(3): 947 – 955.



Applicator Reconstruction

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



MR Compatible Markers



T2MRI Marker Signal Intensities

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

RADIATION ONCOLOGY

MICHIGAN MEDICINE

Plastic Applicators

3D T2W 3T H₂O

3D T1W 3T Gd+H₂O

СТ



Applicator Reconstruction

- Applicator can be reconstructed based on markers
- However,
 - Commercially available MR markers limited, and prone to errors
 - Additional uncertainties introduced if multiple images are fused



Titanium Applicators

3D T1W 3T 2D T2W 3T

СТ

Showing dos from image HDR FX#5 howing dose rom image IDR FX#5 rom image IDR FX#5

Applicator Reconstruction



- 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.

T.P. Hellebust *et al.*, Radiother Oncol 2010, 96: 153 – 160.



Example Applicator Models



CT/MR

Titanium R&T



Varian Medical Systems

CT/MR Plastic R&T



CT/MR Titanium T&O (FSD)



CT/MR Fletcher T&O from Elekta Oncentra



Applicator Reconstruction

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.



Applicator Reconstruction

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



3D T1W MR

(3T)

Commissioning

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



MR BT Workflows

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



MR BT Workflows

- Hybrid approach (MR/CT, MR/US)
 - MR-informed BT placement of BT applicator(s)/needles based on pre-implant MRI data
 - MR-guided BT MR imaging used to guide the physical placement of the applicator(s)/needles
 - MR-based BT utilizes an MRI dataset registered to a planning CT or US to aid in the delineation of the target and/or critical structures.
 - Need to determine timing and frequency of MRIs

J. Wang *et al.*, Brachytherapy 2017, 16(4): 715 - 727.



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
 - Due to steep brachy dose gradients, reconstruction errors can produce significant deviations in doses to target(s) and OARs



Commissioning

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



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
- Per-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.



Special thanks to TG 303 members!

- 1. Firas Mourtada (Chair) Christiana Care Hospital
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Thank you!

