Bridging the Knowledge Gap of MRI Implementation for HDR Brachytherapy

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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!

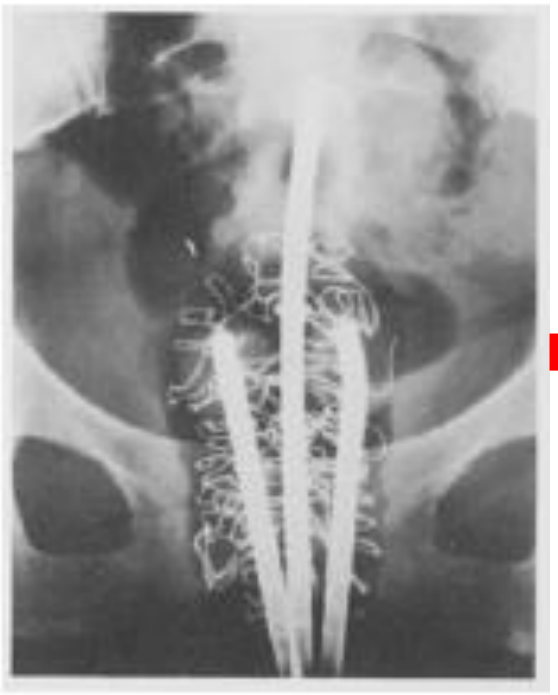
1. Firas Mourtada (Chair) – Christiana Care Hospital
2. Joann Prisciandaro (Vice-Chair) – University of Michigan
3. Gil'ad Cohen – Memorial Sloan Kettering Cancer Center
4. Robert Cormack – Brigham and Women's Hospital
5. Ken-Pin Hwang – MD Anderson
6. Perry Johnson – University of Miami
7. Yusung Kim – University of Iowa
8. Eric Paulson – Medical College of Wisconsin
9. William Song – Virginia Commonwealth University
10. Jacqueline Zoberi – Washington 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

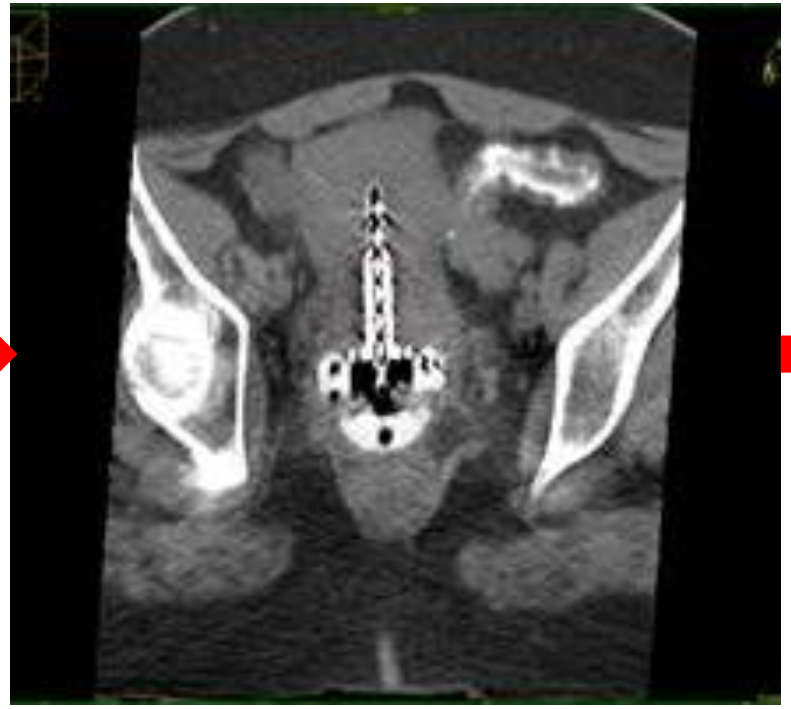
- Compared to CT and US, MR provides:
  - Superior soft tissue resolution
  - Clear distinction of target(s) from organs at risk
- Cervical BT
  - Ability to transition to volumetric based planning
  - Ability to develop conformal and adaptive plans
- Prostate BT
  - Ability to identify intraprostatic lesions and see functional anatomy adjacent to gland for sparing

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

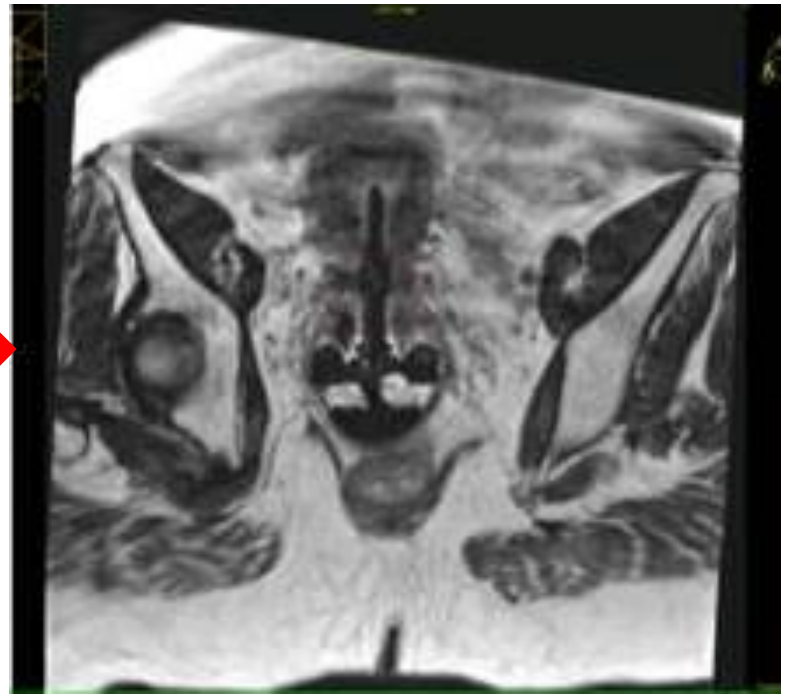
Imaging Modalities used for BT (GYN)



kV radiograph

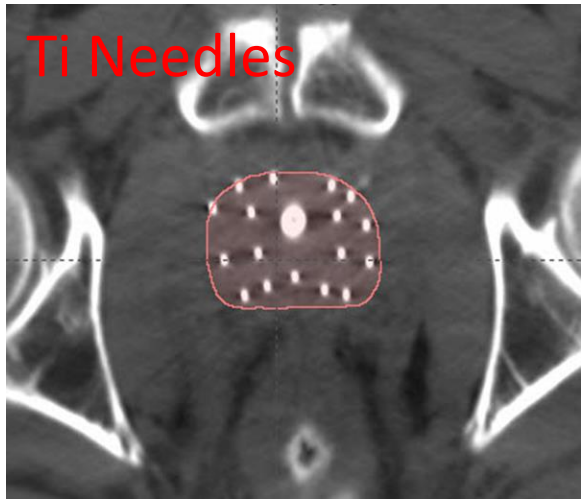


CT

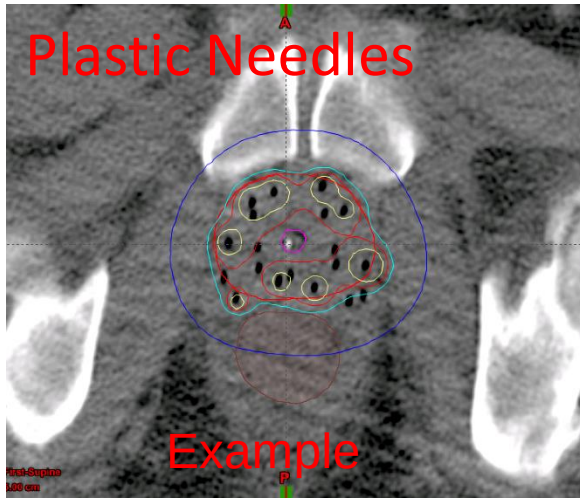


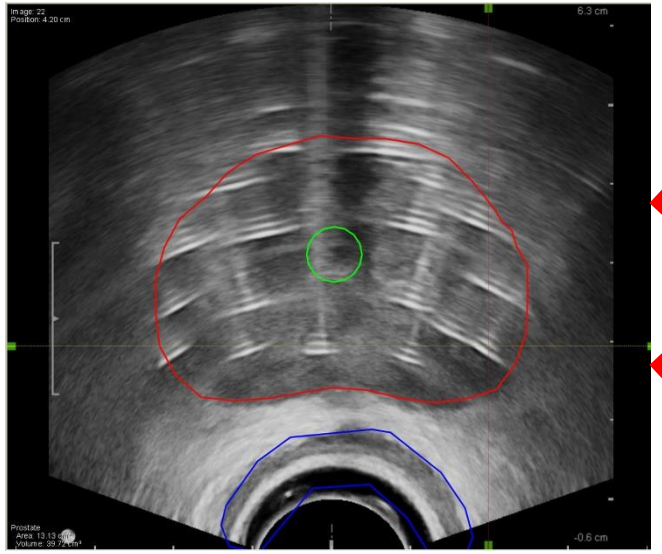
3D T2W MR (3T)

Imaging Modalities used for BT (Prostate)



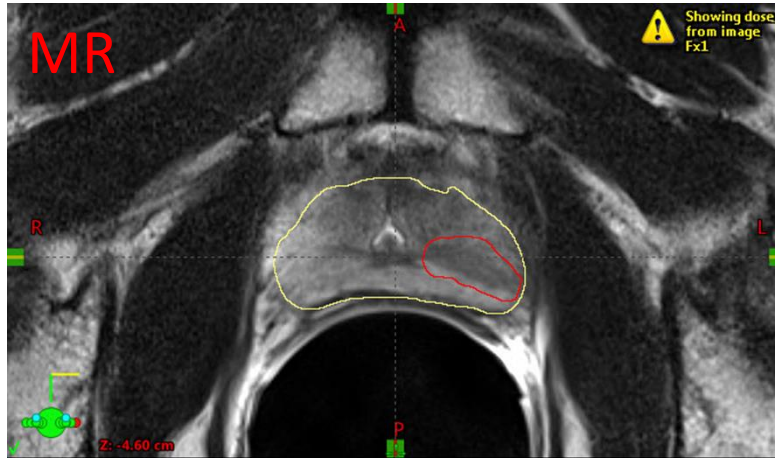
CT

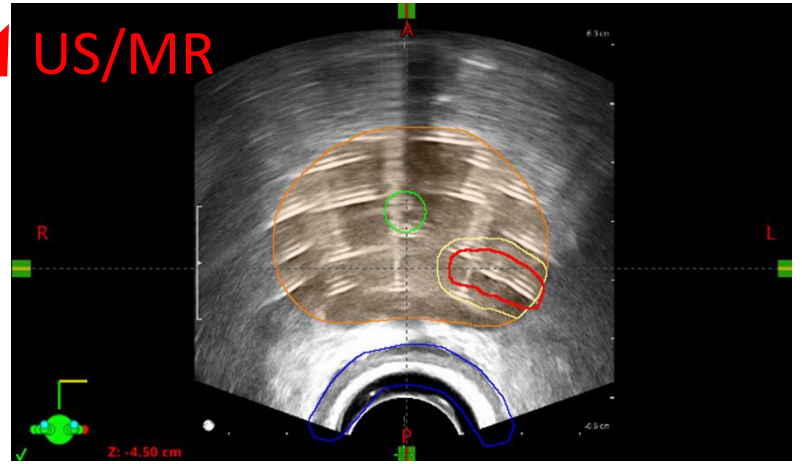




US

2D T2W MR (3T)

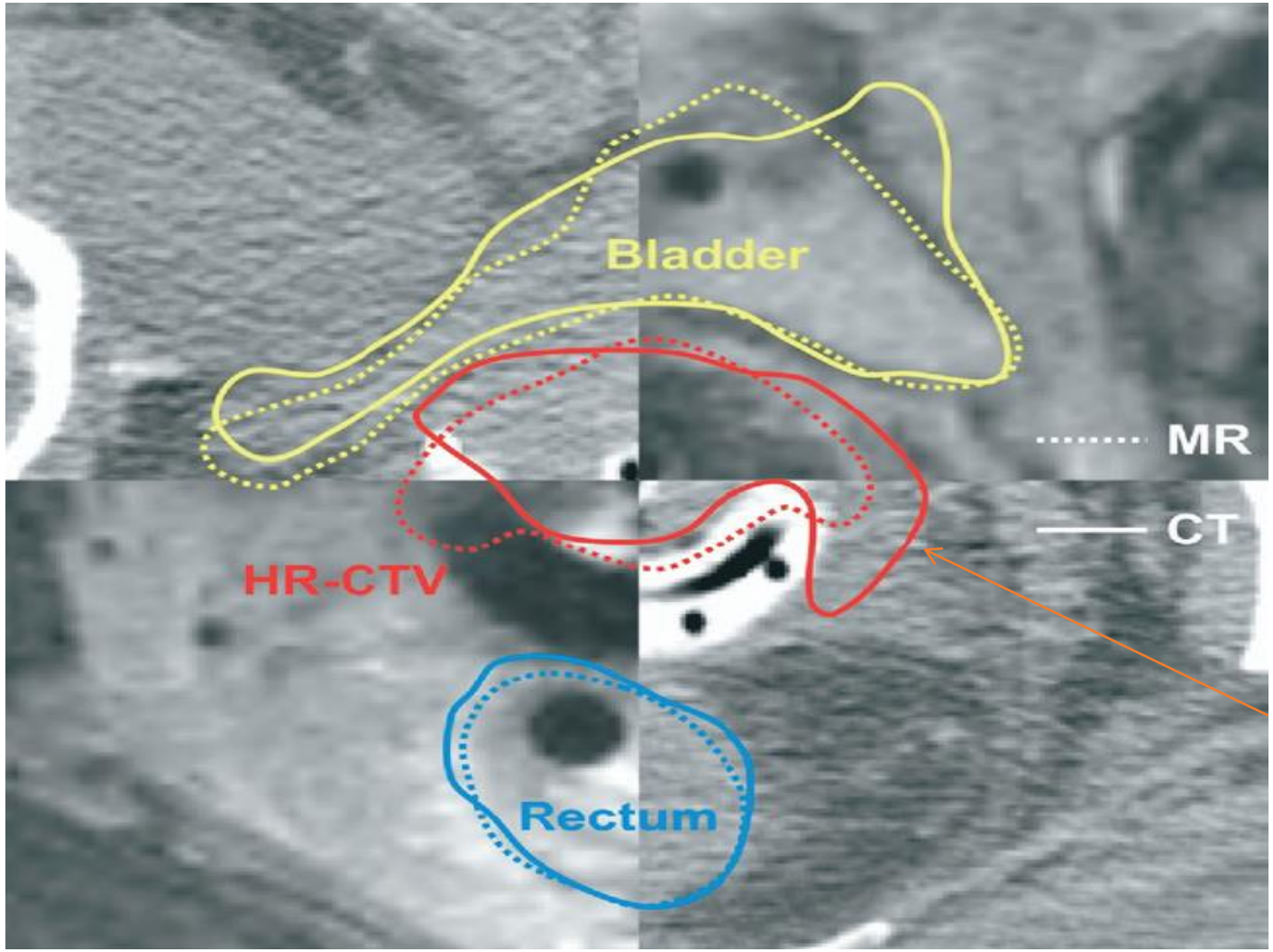




Courtesy of William Song, VCU, and Gil Cohen, MSKCC

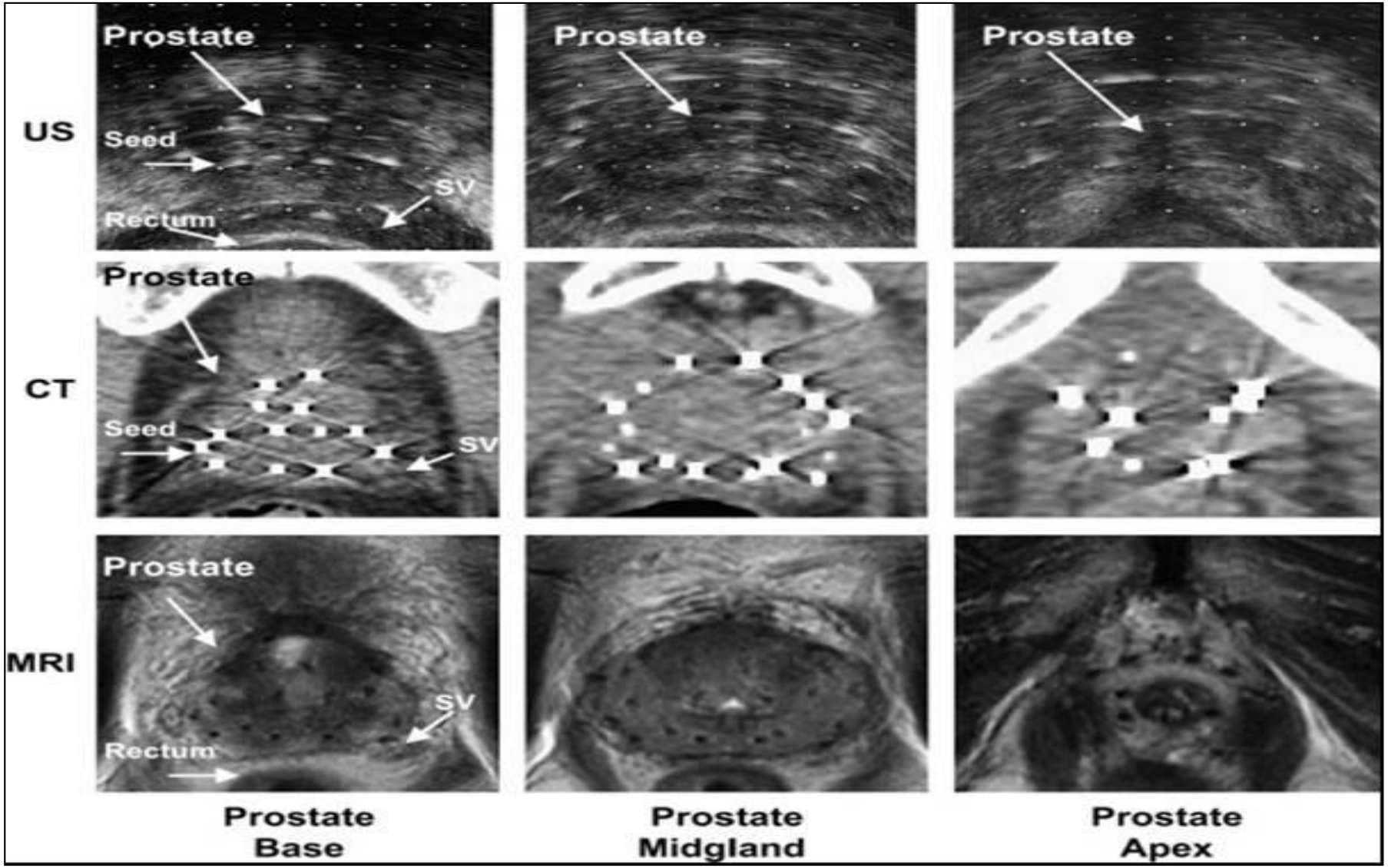
CT ROLE FOR OARs ASSESSMENT

No significant difference in volume or dose to OARs



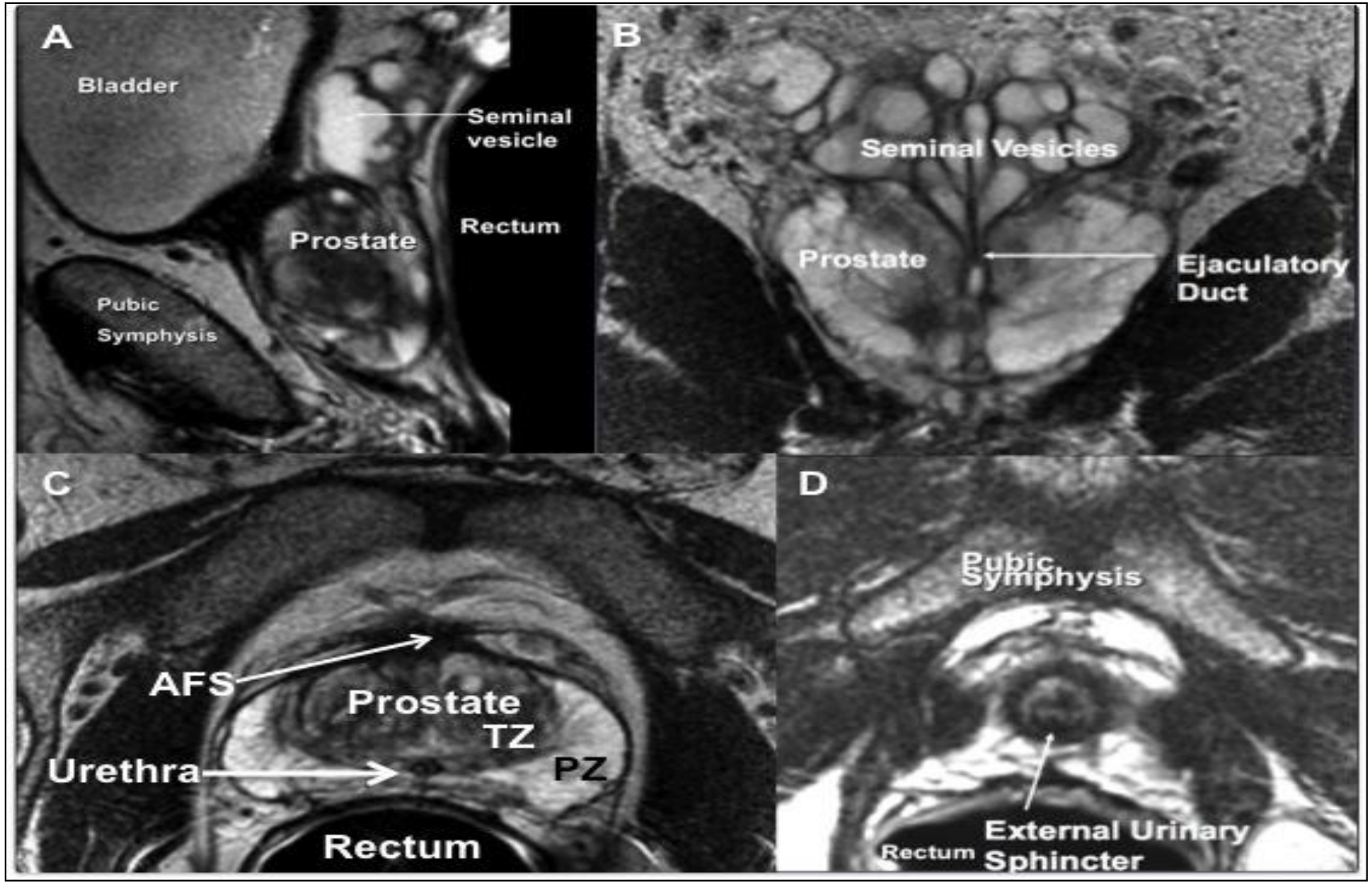
CT tumor contour width overestimated

Why MRI for the Prostate?



Frank et al. IJROBP 2008.

Pelvic anatomy on MRI, T2-weighted images (SAM)



Courtesy
Dr. Frank
MDACC

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

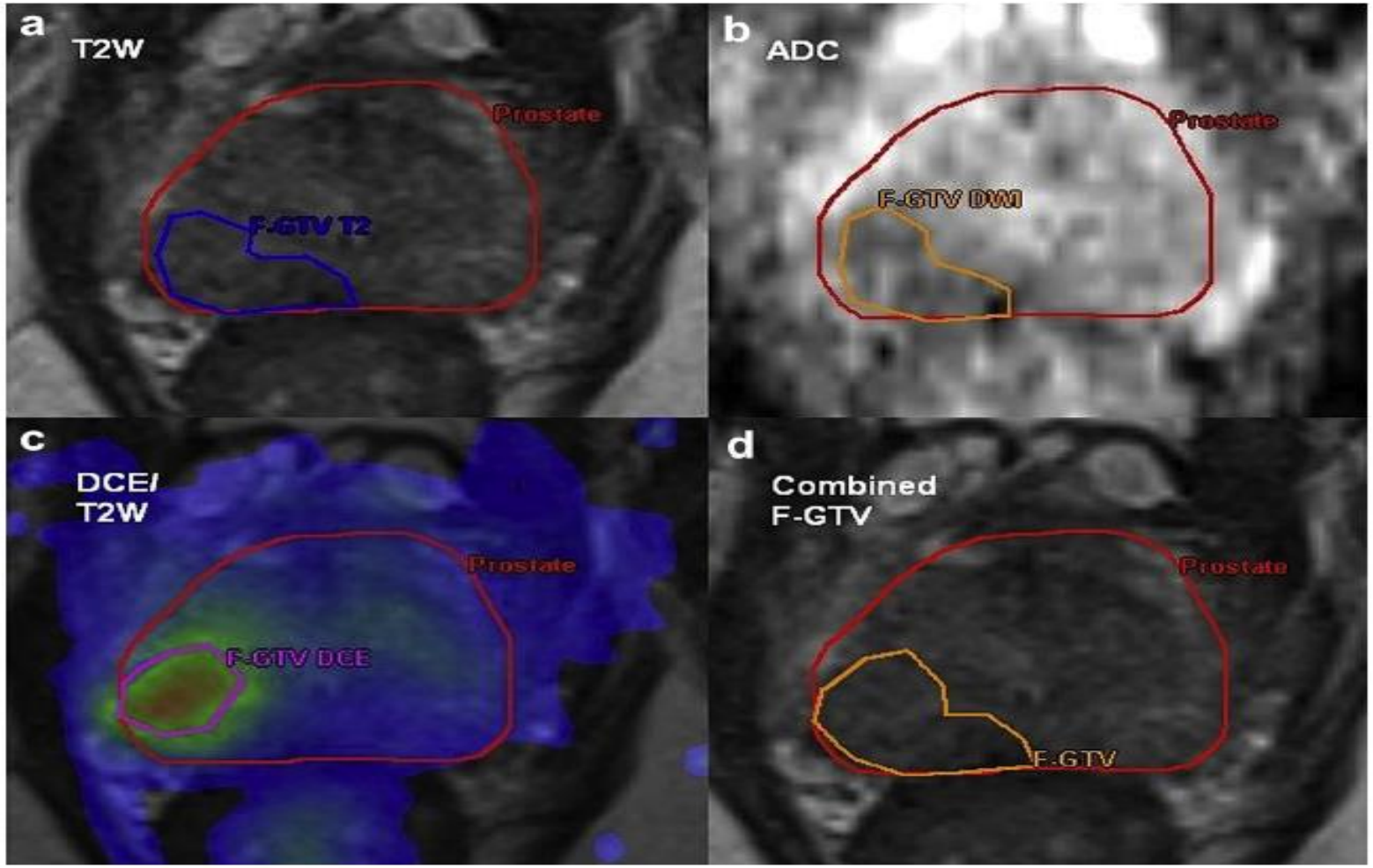


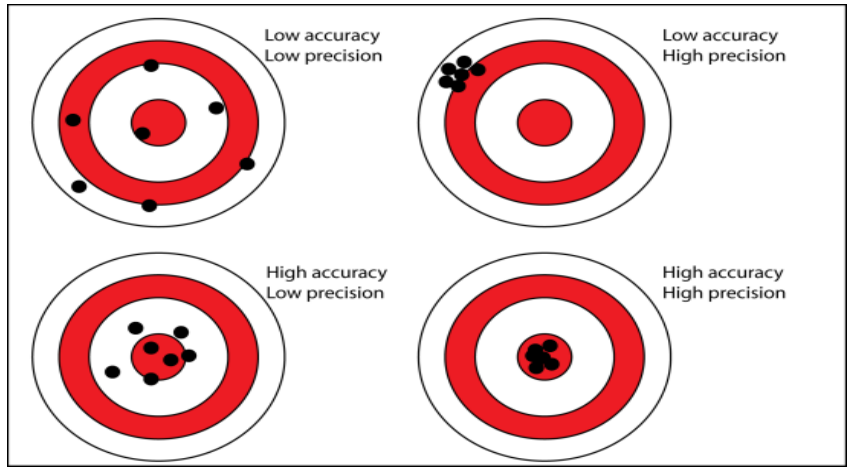
Fig. 2. Example of tumor delineation, showing the suspicious region delineated on (a) T2-weighted MRI, (b) ADC map, (c) Ktrans map. The union of suspicious areas was taken as the F-GTV for treatment, shown in (d).

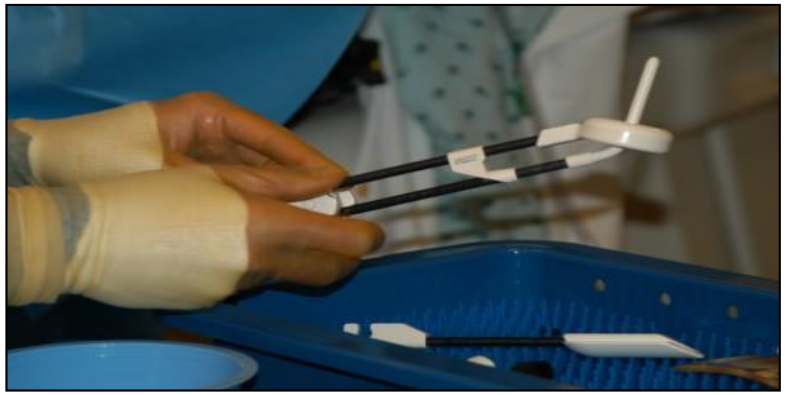
Multi-parametric MRI-guided focal tumor boost using HDR prostate brachytherapy

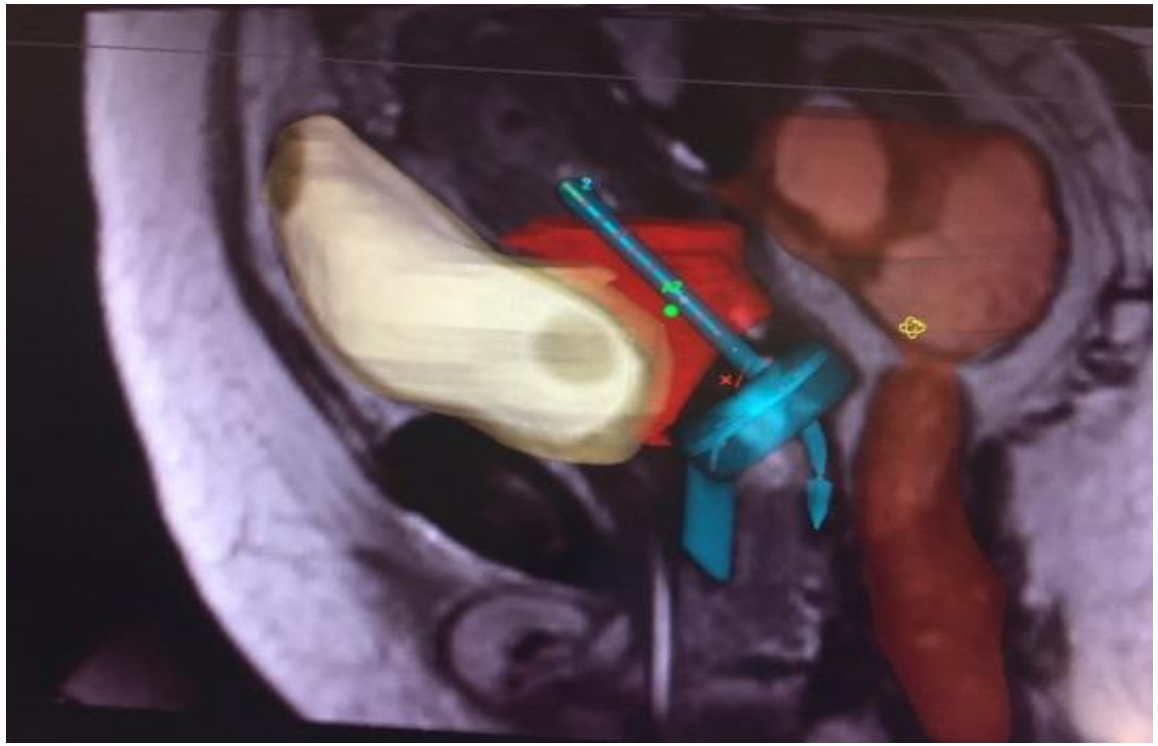
F. Mourtada

Brachytherapy 13 (2014) 137e145

MRI Target Precision for Treatment Planning for Brachytherapy







Solid evidence is here today

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.

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

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

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

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

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

Current Recommendations - GYN

- 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.

Current Recommendations - GYN

- 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.

Current Recommendations - GYN

- 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.

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

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

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.

Journal of ICRU 2013, 13 (1-2).

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

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

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

CT or US

Rodda et al, *ASCENDE-RT: An Analysis of Treatment-Related Morbidity for a Randomized Trial Comparing a Low-Dose-Rate Brachytherapy Boost with a Dose-Escalated External Beam Boost for High- and Intermediate-Risk Prostate Cancer, IJROBP,* 2017. **98**(2): p. 286-295

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
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15. Mo Kadbi – Philips Healthcare
16. Elena Nioutsikou – Siemens Healthcare

AAPM Task Group 303 - Charge

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.

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

- 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

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

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)

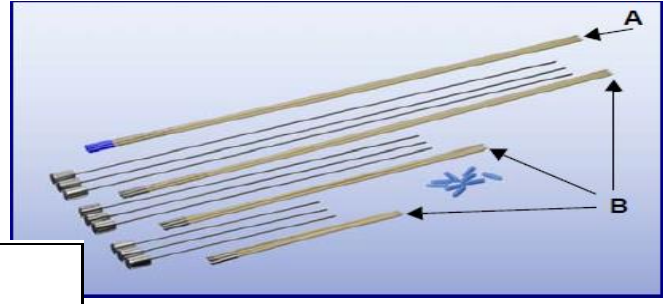
T.O. Woods, J Magn Reson Imaging 2007, 26: 1186 - 1189.

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 IFU



Compo							
Description					Manual Cleaning	Machine Cleaning	Autoclave	CT	MRI
Plastic needle, ø 2.0 mr					25	25	✓	✓	MR
with mandrin for 113 mr								-	MR
Plastic needle, ø 2.0 mr					25	25	✓	✓	MR
with mandrin for 200 mr								-	MR
Plastic needle, ø 2.0 mr					25	25	✓	✓	MR
with mandrin for 320 mr								-	MR
Plastic needle, ø 2.0 mr blunt tip					25	25	✓	✓	MR
with mandrin for 320 mr								-	MR

MRI Safety Information

MR

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.

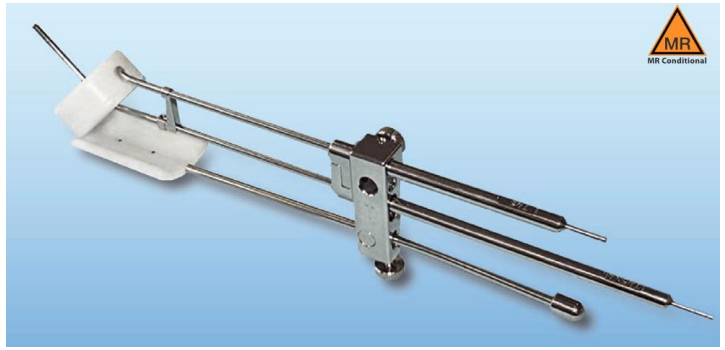
MRI Related Heating

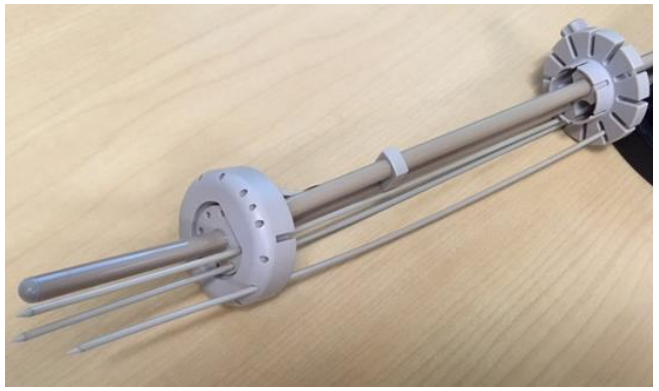
Under the scan conditions defined above, the Plastic Interstitial Needles are expected to produce a maximum temperature rise of less than 1.4° C after 15 minutes of continuous scanning.

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.

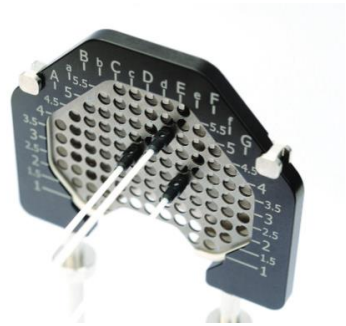
Example Applicator Options



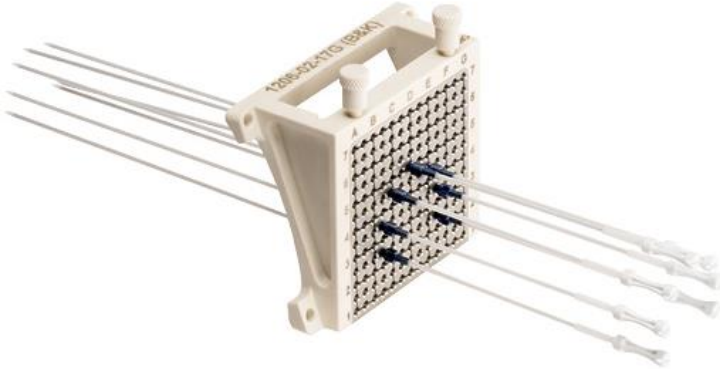


Varian Medical Systems

Elekta



Elekta



Eckert & Ziegler

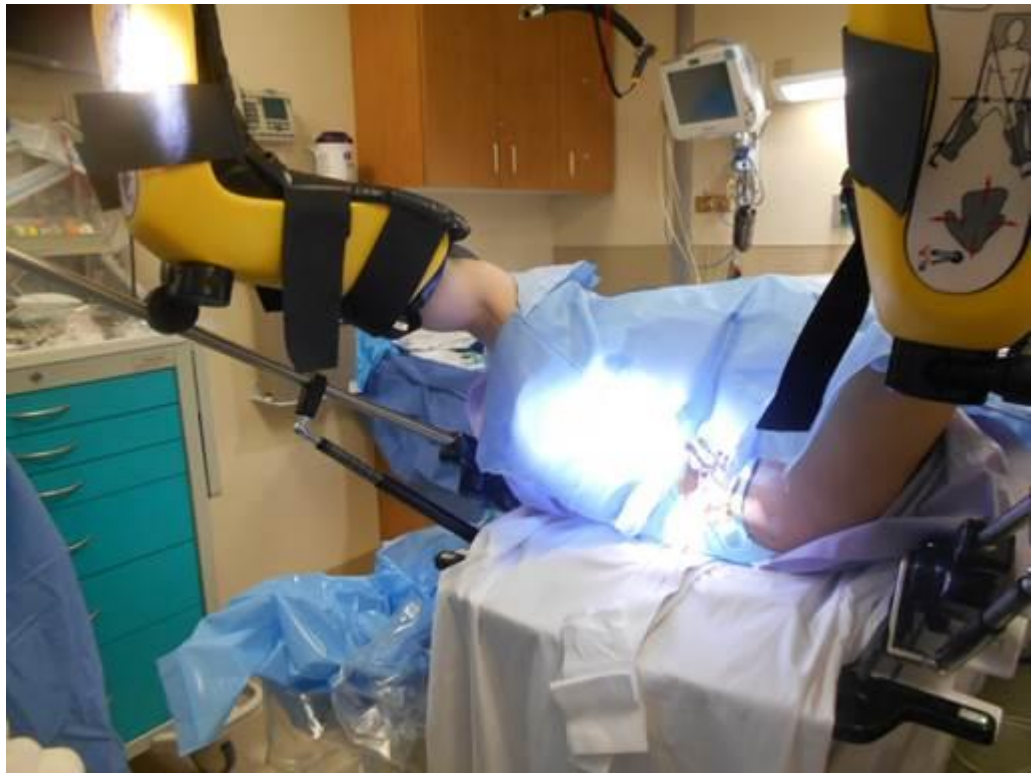
Ancillary Equipment

Siemens Tim Dockable Table

QFix Inc., Symphony System – Trolly 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

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

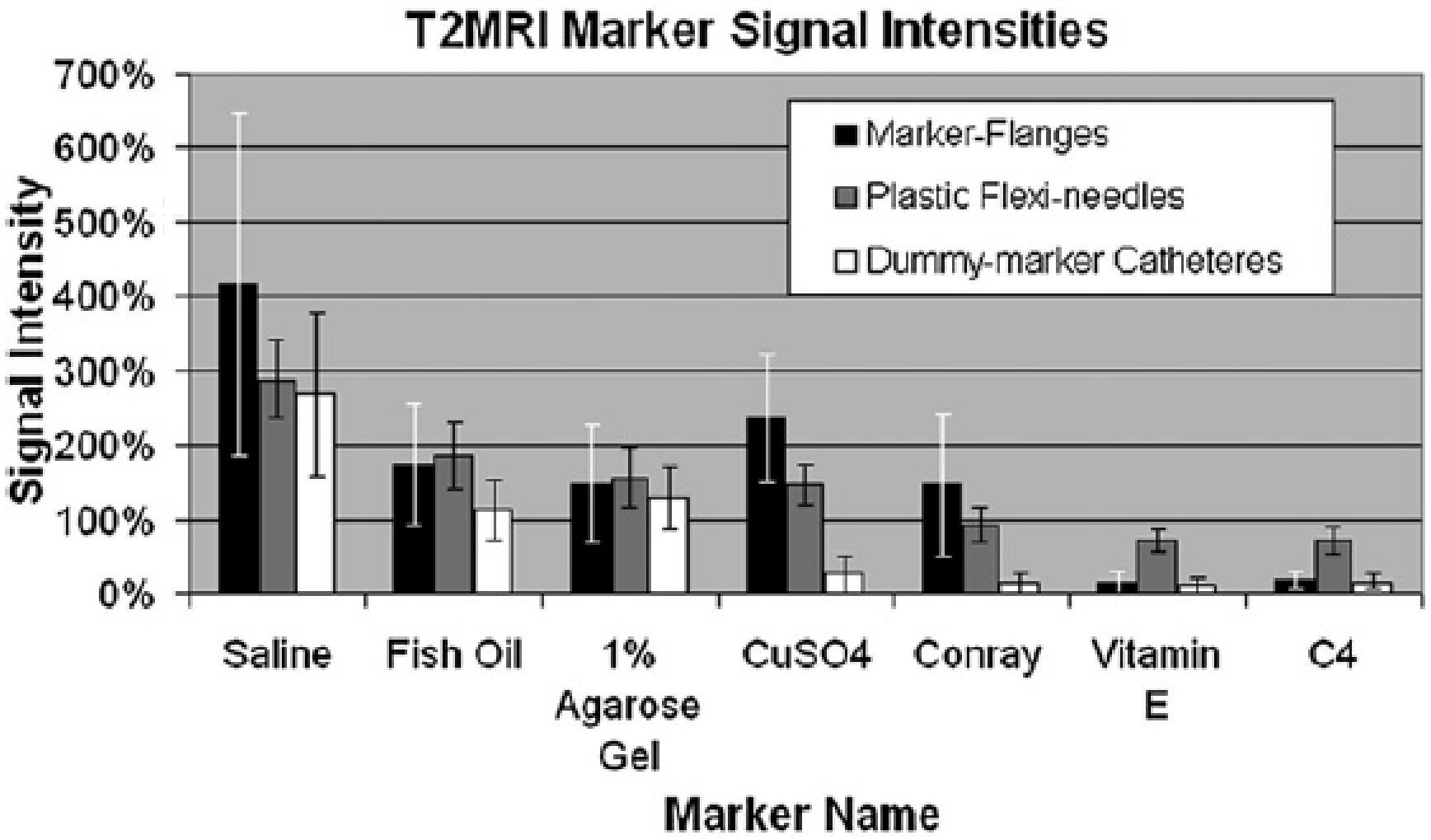
Commissioning

- 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



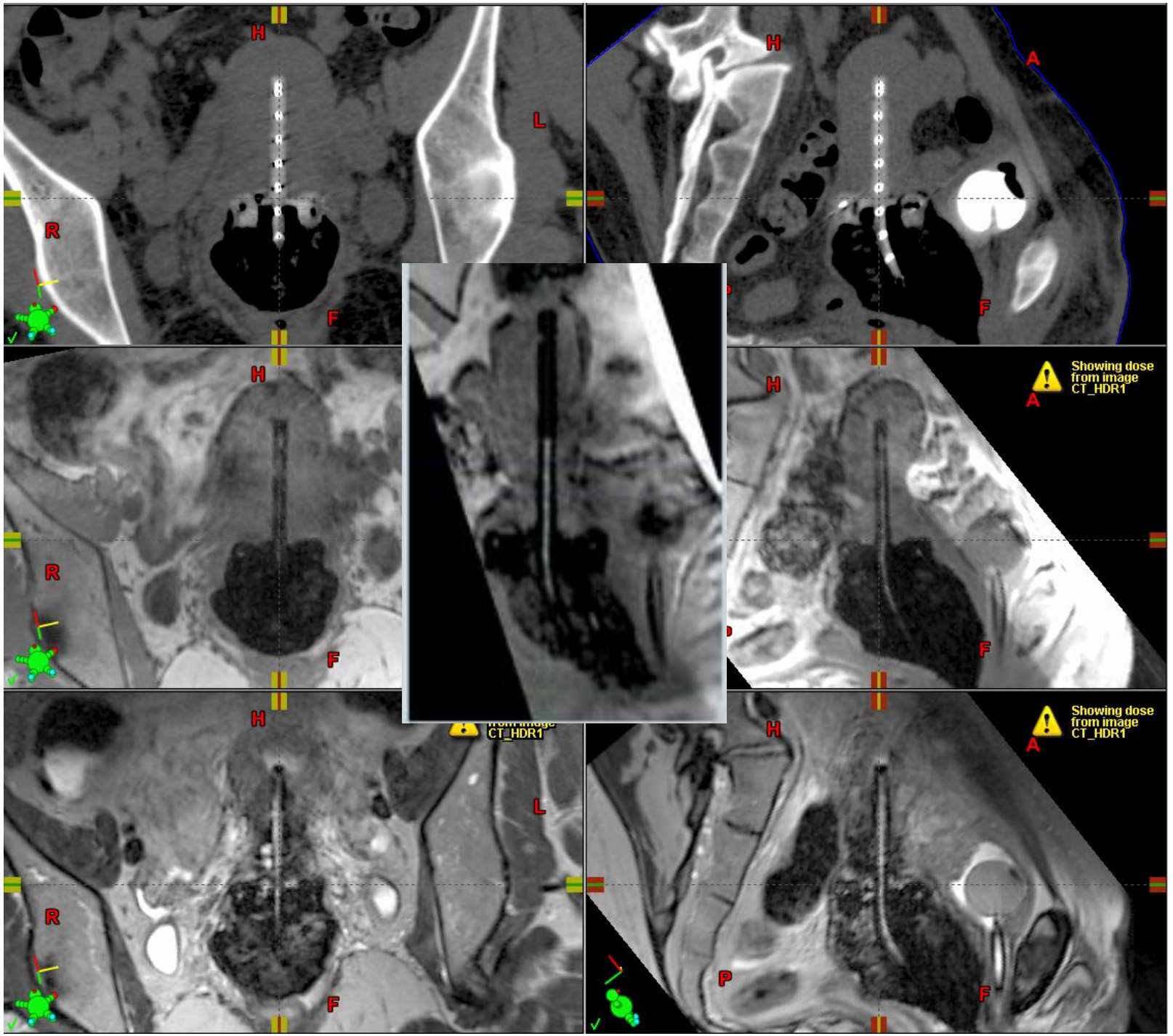
Schindel *et al.*, Int J Radiation Oncology 2013, 86(2): 387 – 393.

Plastic Applicators

CT

3D T1W
3T
Gd+H_2O

3D T2W
3T
H_2O



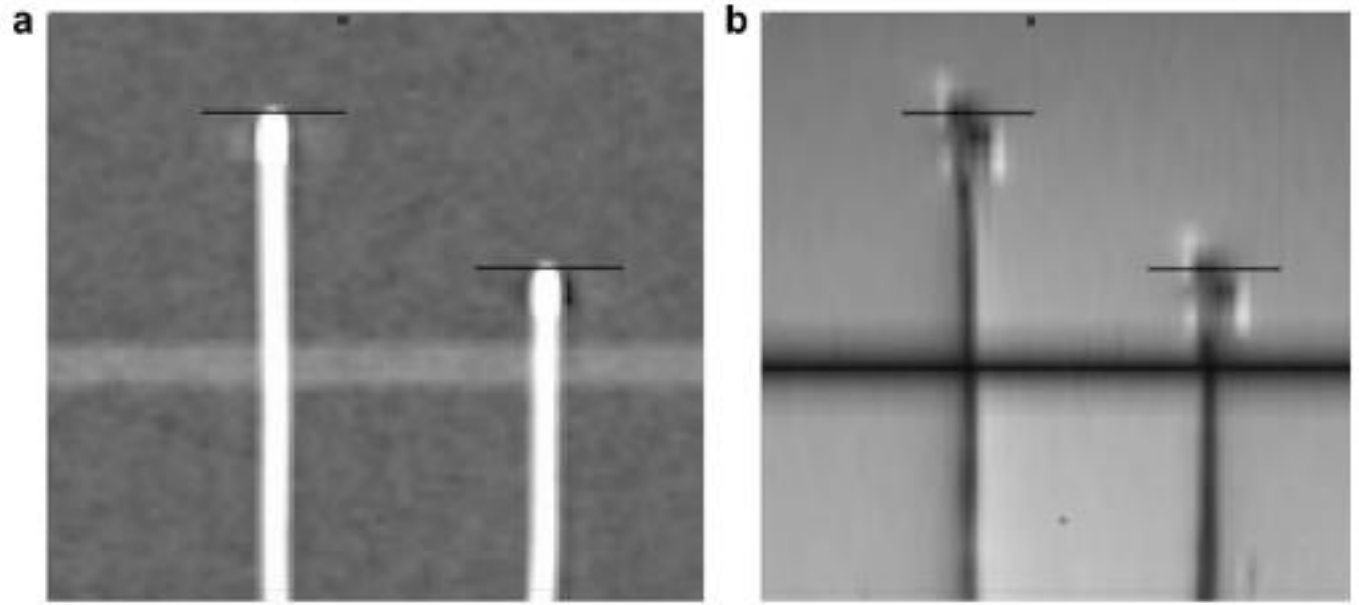
Applicator Reconstruction - Markers

- 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

Applicator Reconstruction – Direct Dig.



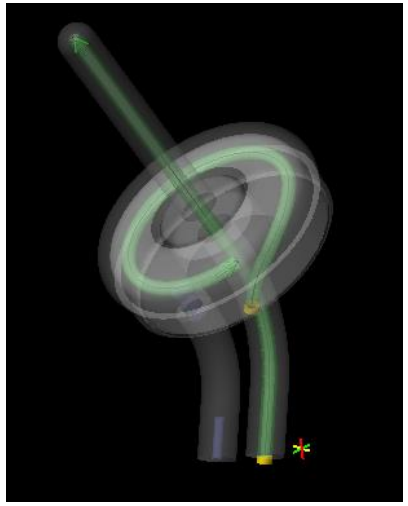
- Susceptibility related artifacts result in uncertainties in titanium applicator evaluation.
- Can be assessed by fusing CT and MR scans in phantom.
- Direct digitization is viable, but uncertainties need to be assessed.

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

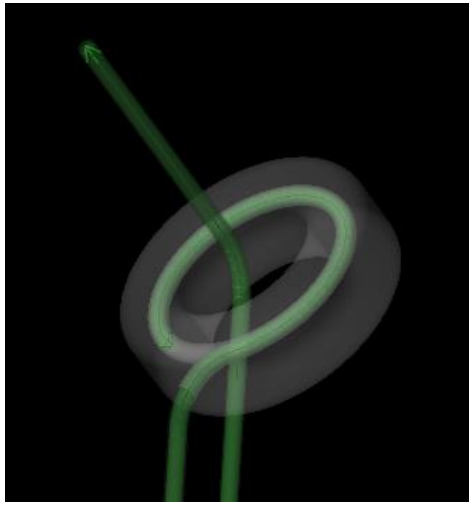
Applicator Reconstruction

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

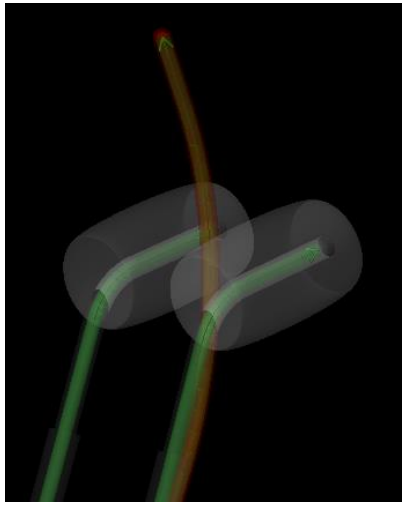
Example Applicator Models



CT/MR Titanium
R&T



CT/MR Plastic
R&T



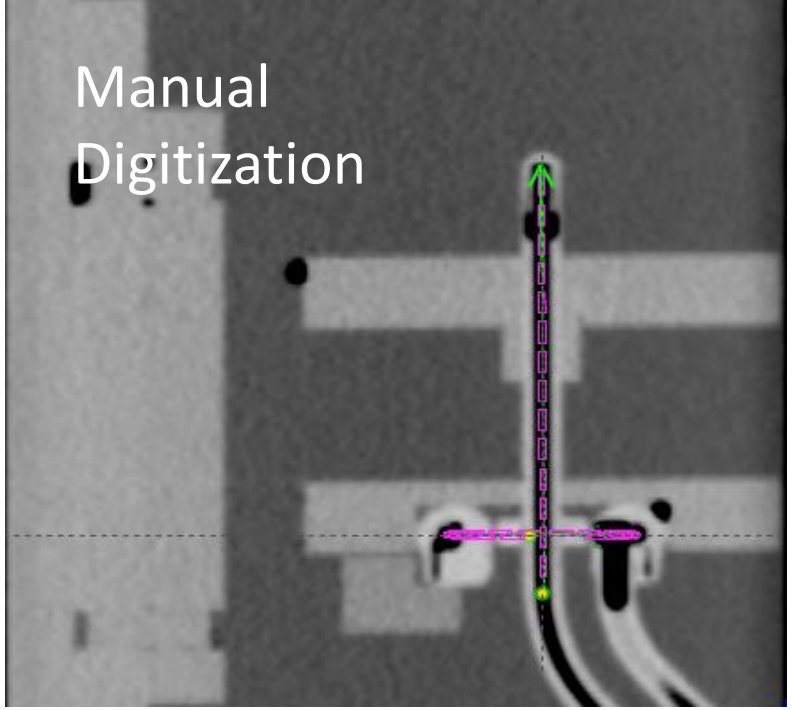
CT/MR Titanium
T&O (FSD)

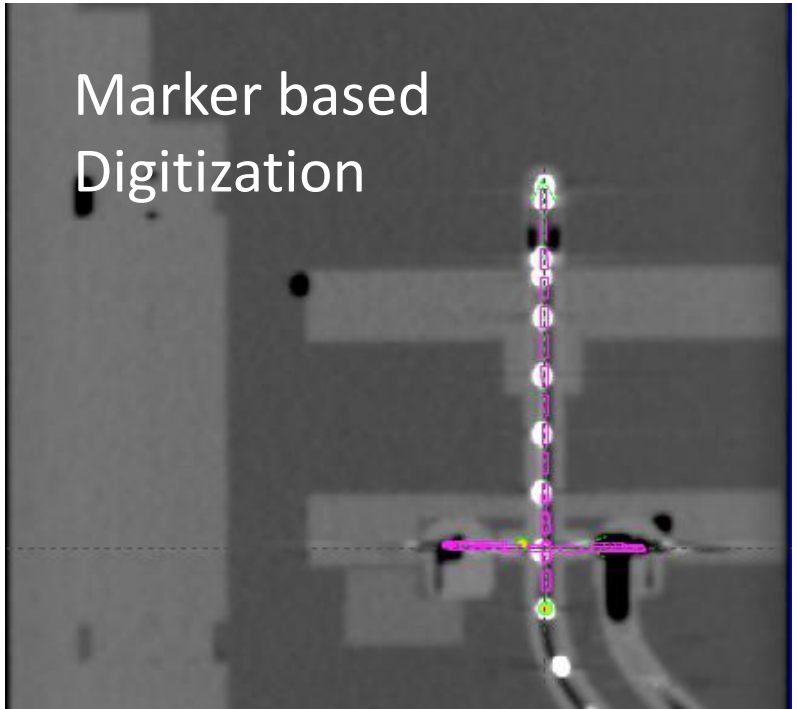
Varian Medical Systems

CT/MR Fletcher T&O
from Elekta Oncentra

Applicator Reconstruction

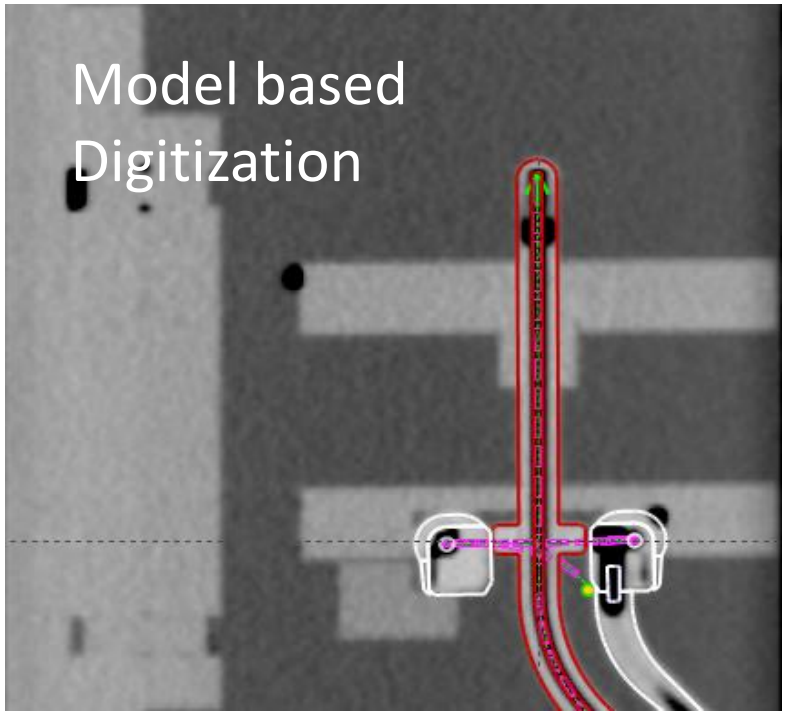
1. Evaluate the accuracy of the digitization compared with standard digitization technique on standard imaging modality.





Compare source positions defined on CT using manual or marker reconstruction to model-based reconstruction.

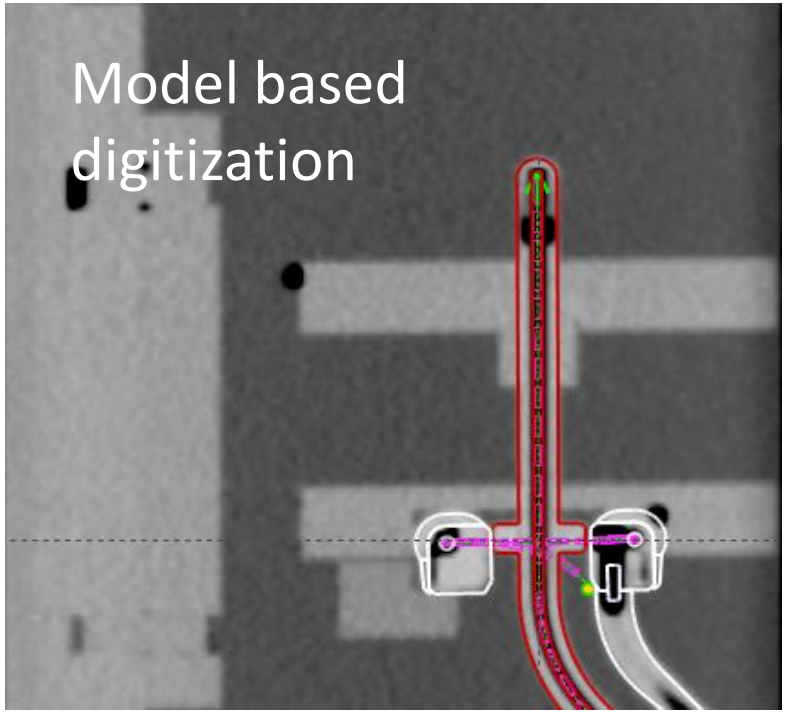
Versus



Applicator Reconstruction

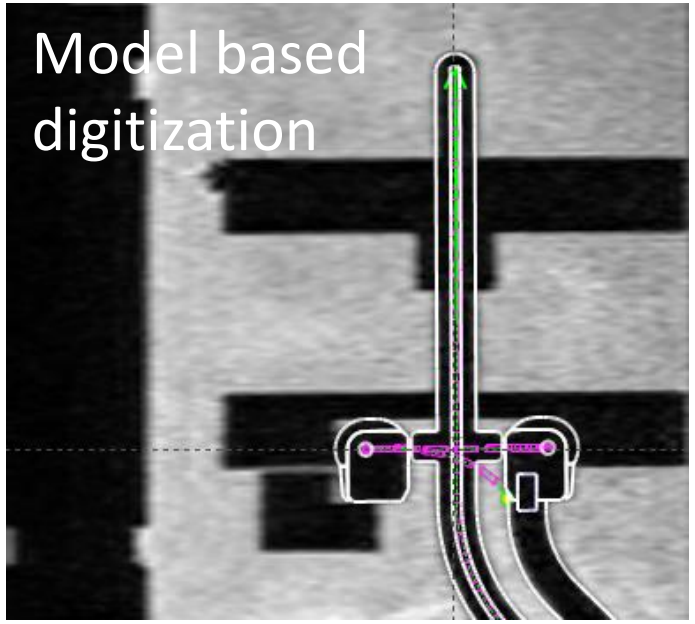
1. Evaluate the accuracy of the digitization compared with standard digitization technique on standard imaging modality.
2. Evaluate uncertainty of reconstruction using the models comparing institutional gold standard imaging modality (e.g., CT) with MR.

Compare source positions defined with model-based reconstruction between CT and MR.



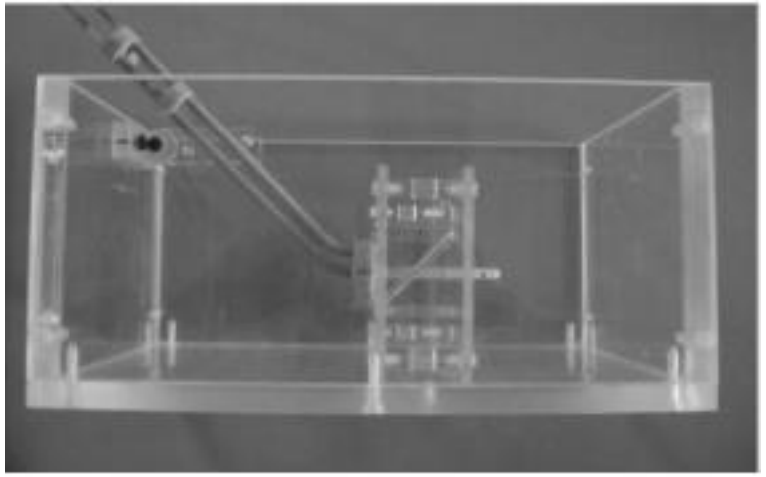
CT

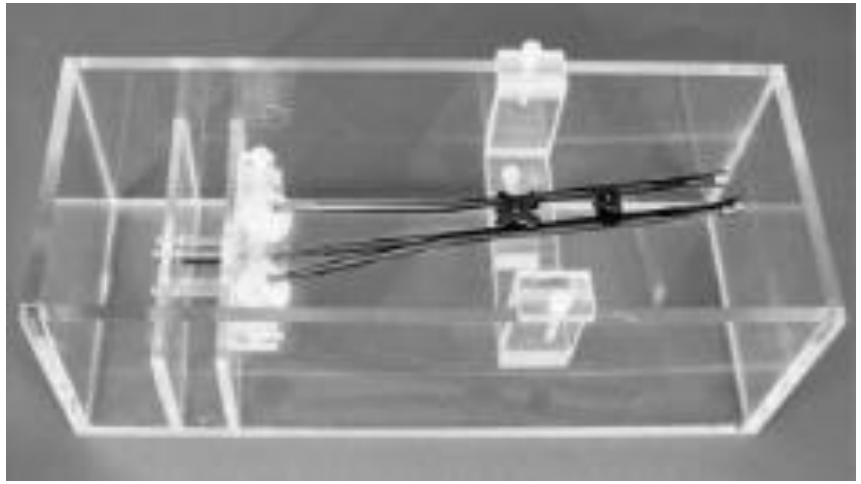
Versus

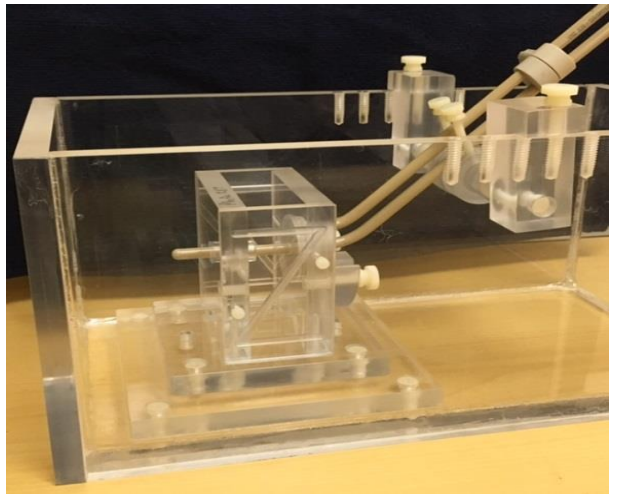


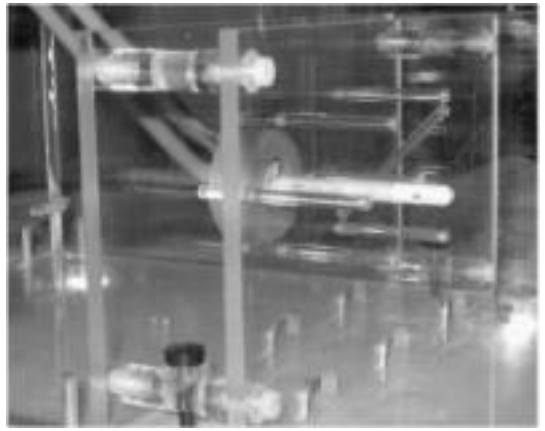
3D T1W MR (3T)

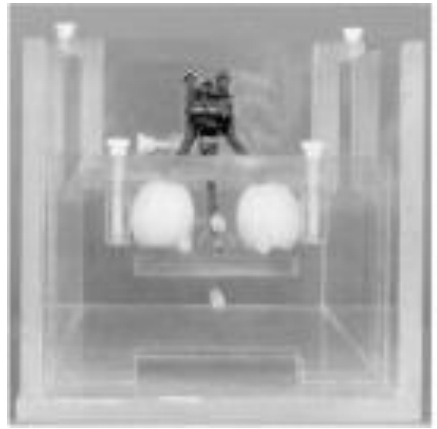
Commissioning Phantom (GYN)

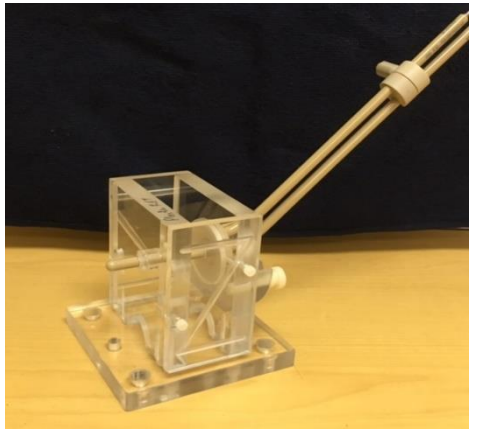










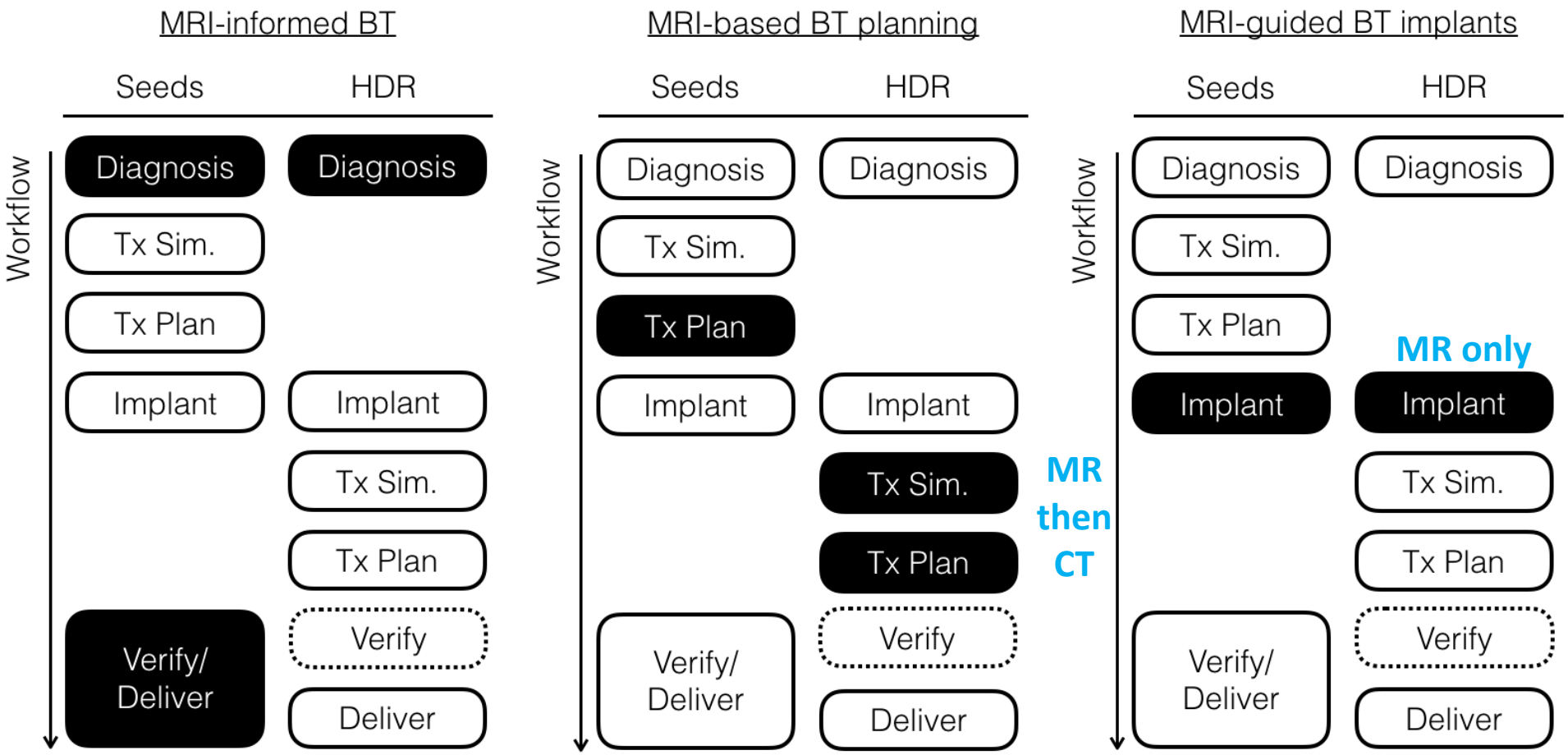


S. Haack *et al.*, Radiother Oncol 2009, 91(2): 187 – 193.
Y. Kim *et al.,* Int J Radiation Oncology 2011, 80(3): 947 – 955.

Commissioning

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

Different Workflows for MR integration



Workflows for Prostate but similar for GYN HDR

Wang et Al, Brachytherapy J, 2017.

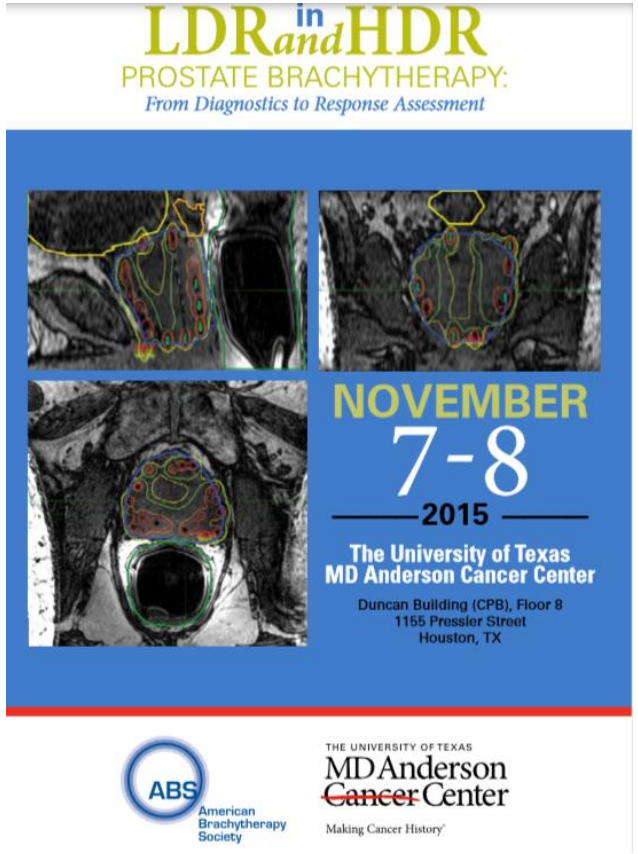
MR GYN BT Workflows

- 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

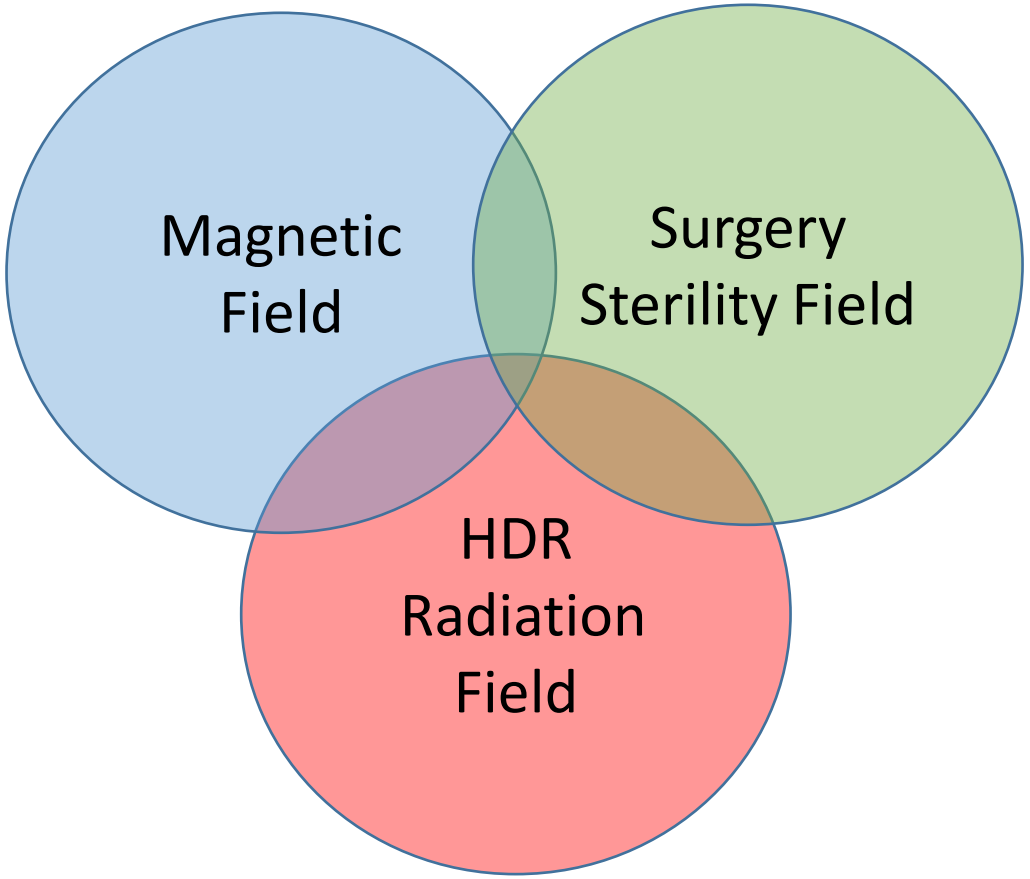
*Nesvacil N, Pötter R, Sturdza A, Hegazy N, Federico M, Kirisits C. Adaptive image guided brachytherapy for cervical cancer: a combined MRI-/CT-planning technique with MRI only at first fraction. Radiother Oncol. 2013 Apr; 107(1):75–81

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



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.