QA Concerns in MR Brachytherapy

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- MR guided
  - Permanent prostate 1997
  - Prostate biopsy 1999
  - Cervix 2002
  - TPS 2012
  - Robotic assistance 2014
  - Tracking 2013

Learning Objectives

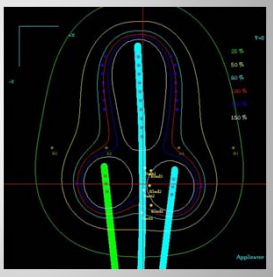
- Review QA concerns for MR imaging in brachytherapy
- Review QA concerns for devices in MR brachytherapy
- Review QA concerns for MR based treatment planning
- Discuss technical challenges
  - MR based planning
  - MR guided implants
- Indicate current developments & efforts

Traditional T&O

- Tandem and ovoids
  - Tandem length
  - Ovoid separation & diameter
- Imaging
  - Orthogonal x-rays
- Planning
  - Variable loading
  - Reference point dosimetry

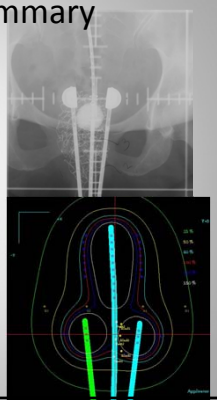
Dose calculation

- Dose reported wrt applicator & os
- Rx dose
  - Report A, B
  - Ovoid surface dose
  - Bladder: foley
  - Rectum: packing



Traditional Summary

- Imaging: x-ray
- Simple metal sturdy applicators
- Sources
- QA
  - X-ray & film
  - Applicator & shielding
  - Source
  - TPS



HDR Suite

- Shielding
- Radiation detectors & monitors
- Imaging
  - Fluoro
  - CT
  - TRUS
  - MR
- Afterloader

Evolution of Brachytherapy

- 3D image based CT/MR
  - Anatomic structures (MR)
  - Source localization (CT)
- HDR afterloading
- Applicator development
  - Geometry
  - Image compatablity
- Conformal dose distributions
- Image guidance

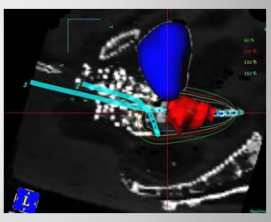


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Image Based Brachytherapy Process

- Place applicator
- Image patient with applicator
- Planning
  - Identify anatomy
  - Localize applicator
  - Calculate dose
- Treat

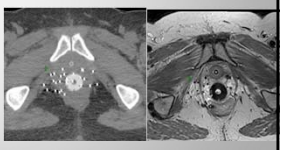
Why MRI?

Prostate

- **Visualization of capsule and substructure: T1, T2**
- **Identification of primary tumor: MRS, DCE, DWI**
- **Normal tissues**

Gyn

- **Target visualization**
- **Normal structures**
- **Target definition guidelines**



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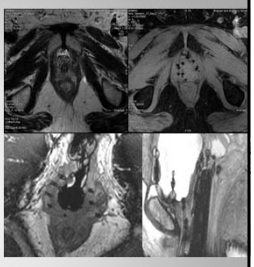
MR Scanners

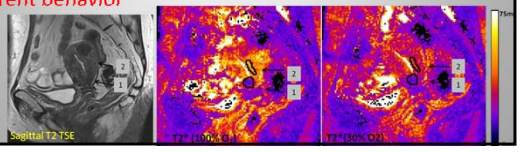
0.3 T
0.5 T

1.5 T
3.0 T

MR Pulse Sequences

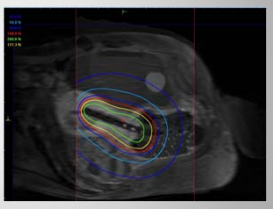
- T1 applicators
- T2 anatomy
- Diffusion
- Hypoxia
- Metal enhancement
- Common coordinate system?
- Different behavior





QA Concerns

- Patient safety
- Imaging device
- Applicators
- Afterloader
- Sources
- TPS
- Secondary calc



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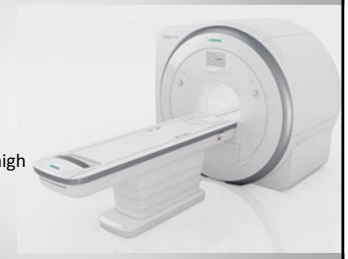
MRI Concerns: General Safety

- MR safe vs MR compatible
- Boy, 6, Dies of Skull Injury During M.R.I.
  - Controlled access
  - Device check using high strength magnets
  - Patient screening
  - Implanted devices



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Scanner Energy Deposition

Ionizing radiation
- slice thickness
- kV
- mA
- pitch

Rf power
- heating
- patches
- metal objects - eddy currents

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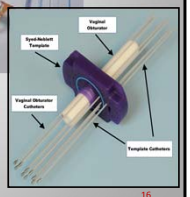
MRI Concerns: Applicator Safety

Applicators
- Magnetic safety
  - Plastics
  - Some metals
- Reports of excessive heating with Ti applicators at 3T



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MR QA

- Scanner QA similar to CT-Sim QA
- Guidance from Joint Commission and ACR
  - Annual (quarterly)
  - Weekly
  - Daily
- Involve an MR physicist

Joint Commission Requirements for MRI
- …
- Image uniformity for all RF coils used clinically
- Signal-to-noise ratio for all coils used clinically
- Slice thickness accuracy
- Slice position accuracy
- Alignment light accuracy
- High contrast resolution
- Low-contrast resolution
- Geometric or distance accuracy
- Magnetic field homogeneity
- Artifact evaluation
- …

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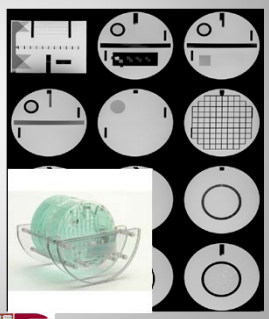
MR QA

Weekly QA

MR Technologist:
- ACR phantom images acquired @ sites.
  - Images transferred to central server.
  - Measurements made on phantom images.
  - Electronic QA form filled.

MR Physicist:
- Update database and run automated analysis (twice weekly)
- Review warnings on performance limits and messages from site technologists.
- Respond to warnings and messages and document.
- Interact with sites as needed.



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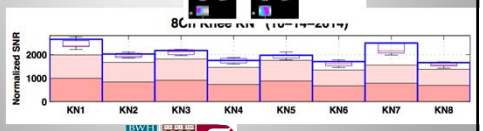
Quarterly QA

- Visual inspection (coils)
- Performance evaluation
- RF Noise
- Slice interference
- Field Homogeneity



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Afterloader and Source QA

- Afterloader and sources used outside MR environment. Covered by AAPM guidance
- Monthly QA
  - Source calibration
  - Timer accuracy
  - Positional accuracy
  - Interlocks
  - Safety features
    - Batteries
    - Detectors

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Treatment Planning System

- Source decays
- Geometric accuracy
  - Slice thickness
- Dose calculations
  - Secondary calcs
  - Water universe
- Compatible with MR scans?
  - Obliques
  - spacing

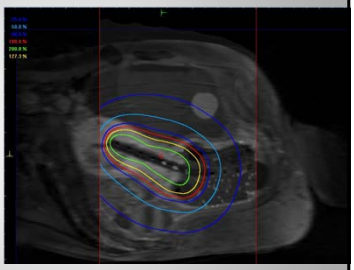

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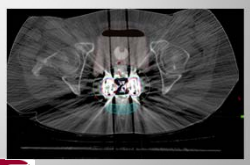
Image Based Brachytherapy

- QA guidance
  - Imaging: without devices
  - Brachy: without MR
  - TPS: typically CT
- No guidance for a combined imaging brachytherapy process
- Goals
  - Applicator localization (CT>MR)
  - Anatomy identification (MR>CT)



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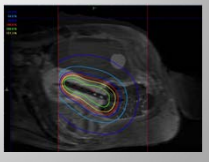
Components of Brachytherapy

- Applicators or sources placed in patient
- Imaging with devices in place
- Applicators and anatomy localized
- Treatment planning in MR



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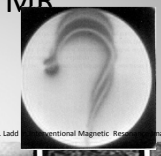
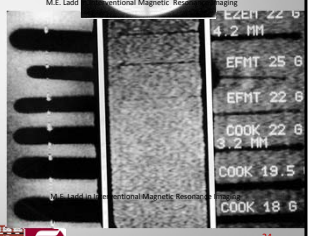
Devices in MR

- Safe vs. compatible
- HDR applicators offered in MR versions
- Accessories may be safe but not compatible
- Compatibility may be pulse sequence dependent
- Image with devices in scanner





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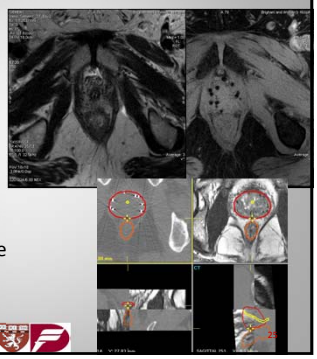
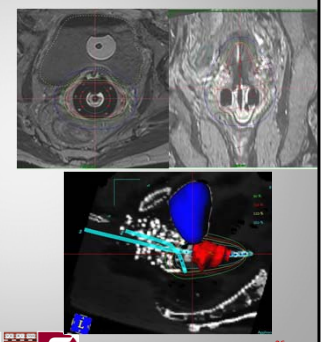
MR Based planning: Multiple pulse sequences

- Example Image guided prostate implant
- Multiple MR sequences
  - Anatomy T2
  - Sources T1 (artifacts merge)
  - Coordinate system
- CT source identification
- Implanted objects provide means of registration



MR Based planning: T&R,T&O

- MR target definition: GEC-ESTRO HR CTV
- MR compatible applicator differences: diameter, shielding
- Applicator enable fusion
- Multiple sequences : Appliactor/Anatomy
- Extended applicator make distortion a concern
- Fusion to CT allows evaluation of geometric distortions



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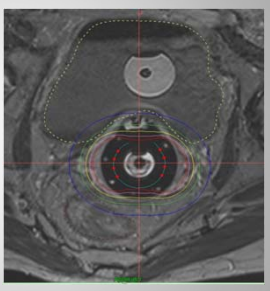
Applicator Digitization,

- T&X have significant artifacts
- Thick slices increase uncertainty
- MR ~3mm vs CT ~1mm
- No 'dummies'
- No independent verification (scout)



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Model Based Applicator Digitization

- Validate model
- Geometry in model
- Can be used to visually detect distortions
- No channel ambiguity
- Challenges
  - Uncoupled components
  - Needles
- Coronal/sagittal may provide complimentary information

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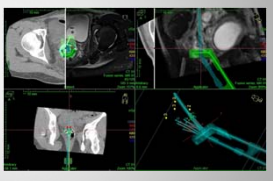
T&x with needles

- Addition of interstitial needles complicates issues
  - Needle localization
    - Artifact crossing
    - Tip localization
  - Needle identification



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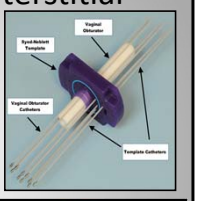
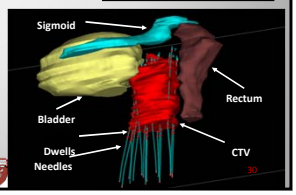
MR Based Planning: Interstitial

- 10-30 needles
- Assume HDR with post-implant planning
- Most devices plastic, **!NOT QUITE!**
- Gyn: large irregular targets
- Prostate: small regular targets





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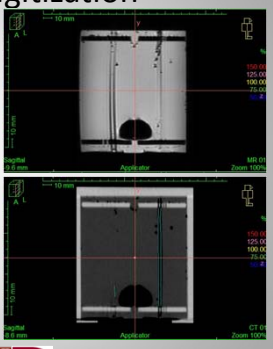
Needle Digitization

- Enhanced T&x or Interstitial
- Needle digitization
  - Tip identification
  - Channel confusion
- Distortion vs curvature
  - MR scanner corrections
- Distortions affect dose calculation. Not present in CT
- MR corrections



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Needle Localization

- MR artifacts larger/ambiguous compared to x-ray or CT
- MR dummies not readily available
- CT with multiple scans /dummies and fuse
- RF Trackers
- Phantoms to evaluate artifacts

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Future Trends

- Adaptive planning
- MR guidance
- Tracking tools

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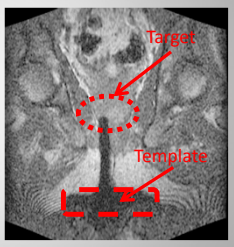
MR Guided Brachytherapy

- Brachytherapy is dominated by placement
- Optimization can make a good implant better but cannot make a poor implant good
- Placement is controlled at a distance
- How do we use MR to improve placement?



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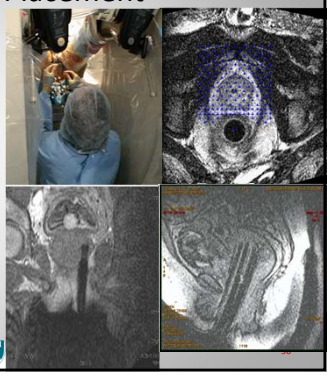
Insertion under MR guidance

- Magnet design
  - Open
  - Closed
- Interstitials
  - Geometry

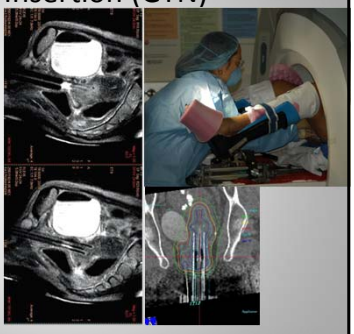
0.5T Open Magnet MR Guided HDR Needle Placement

- MR guided targeting
  - Biopsy
  - Brachytherapy
  - 0.25 fps
- Requires localization of needle guidance device
  - Template
  - Image based
  - External system
    - Optical
    - Mechanical
    - Physician



3T Closed-bore MR Guided HDR Needle Insertion (GYN)

- Real time imaging 4f/s
- Pt repositioning between group needle placement
- Needles degrade image
- Target shifts
- Tends to focus on needle not configuration
  - Catheter spacing
  - Multiple depths
- Allows easier needle placement



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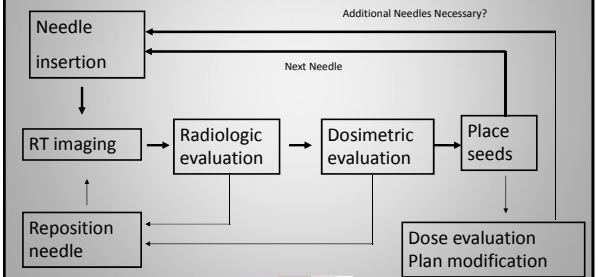
MR Dosimetry Guided Implants

- Permanent implants
  - Seed identification challenging
  - Needles as surrogates
- No repositioning of pt
- Scanner coordinate system
- Template/robot registration



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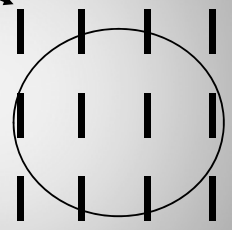
Dose Distributions Based on Source Locations

Preplan (Intraoperative)



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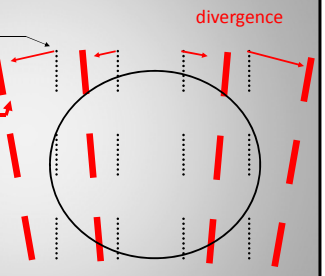
Geometric vs Dosimetric

Preplan

Intermediate: with observed trajectories based on RT imaging



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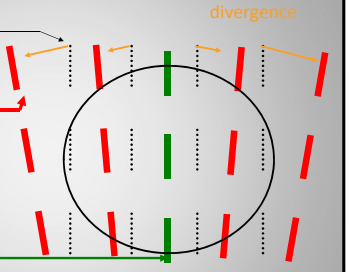
Dosimetric Feedback

Preplan

Intermediate: with observed trajectories based on RT imaging

Final: intermediate + additional sources



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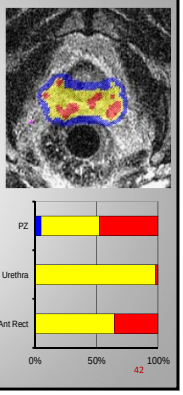
Dosmetric Feedback & Adaptive Planning

- Permanent prostate implants
- Single visit implant
- Open magnet
- No patient repositioning
- MR target definition
- Optical template registration
- Adaptive planning
  - Needle artifact captured in TPS
  - Dose updated in real time
- Initial underplanning



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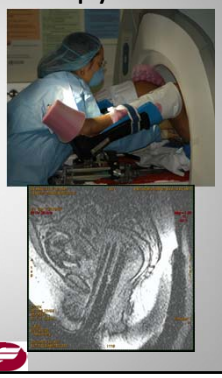
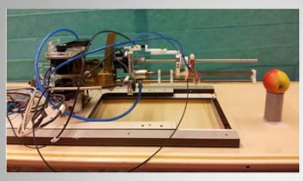
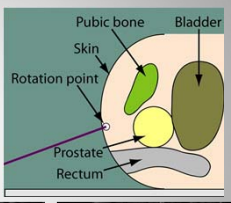
MR guided brachytherapy efforts

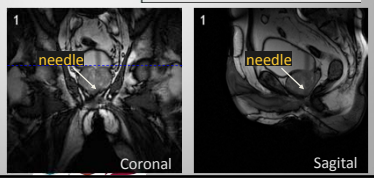
- Improve physician access
- Improve catheter identification
- Improve imaging information



Improved Access: Development of MRI compatible robot



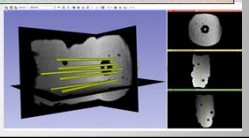




Utrecht robot courtesy of M Moerland

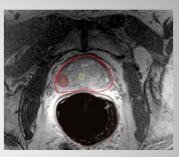
Improved Needle Identification: Active MR Tracking

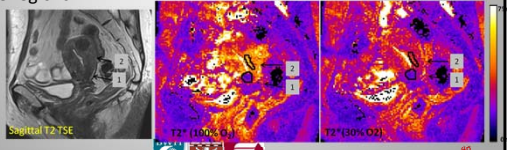
- PC coils mounted on stylet
- Capture location along length of needle
- User identifies channels
- Controls MR scan plane through tip of needle.



Improved Information: Personalized Planning

- Multiparametric MR
- Hypoxia imaging
- Patient management
  - Sub-volume implant without constraining follow up.
  - Controlled placement of high dose regions





Conclusions

- MR is an ideal image modality for image based or image guided brachytherapy with outstanding visualization of pelvic anatomy
- MR can be involved in brachytherapy at various levels of complexity
- MR brachytherapy provides a number of opportunities to improve process and treatments, but introduces a number of challenges
- Image based brachytherapy is a process. Its QA involves more than the QA of the individual components.

Questions

What is a concern for MR brachy planning dose calculation that is not for CT?

20% 1. Heterogeneity corrections
20% 2. Source decay correction
20% 3. Spatial Distortion
20% 4. Channel identification
20% 5. Generating setup DRR

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Answer

- Brachytherpy dose calculations assume a universe of water, source decay corrections and channel identification is a QA concern independent of planning modality. Set up DRRs are not routinely used for brachythearpy. Spatial distortion is a concern for MR imaging. Cormack RA. Quality assurance issues for computed tomography-, ultrasound-, and magnetic resonance imaging-guided brachytherapy. *Int J Radiat Oncol Biol Phys* 2008;**71**(1 Suppl), S136-141:doi 10.1016/j.ijrobp.2007.07.2389.

What MR scanner QA is not shared by CT QA?

20% 1. Image quality
20% 2. Patient energy deposition
20% 3. Coil wear
20% 4. Spatial accuracy
20% 5. Image resolution

10

Answer

- Visual inspection of RF coils on a regular basis is indicated by AAPM report 100. RF coils are used in MR but not in CT

Using CT-MR fusion is used to merge what information?

20% 1. CT: Anatomy ; MR: Applicator Localization
20% 2. CT: Electron Density ; MR: Spatial Accuracy
20% 3. CT: Spatial Accuracy ; MR: Anatomy
20% 4. CT: Treatment Response ; MR: Neutron Density
20% 5. CT: Electron Density ; MR: Applicator Localization

10

Answer

- MR is the preferred imaging modality for identifying pelvic anatomy. CT has excellent spatial accuracy. Cormack RA. Quality assurance issues for computed tomography-, ultrasound-, and magnetic resonance imaging-guided brachytherapy. *Int J Radiat Oncol Biol Phys* 2008;**71**(1 Suppl), S136-141:doi 10.1016/j.ijrobp.2007.07.2389.