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 compatibility
- Conformal dose distributions
- Image guidance

**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

**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

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

MRI Concerns: Applicator Safety

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

Scanner Energy Deposition

Ionizing radiation
- slice thickness
- kV
- mA
- pitch

RF power
- heating patches
- metal objects - eddy currents

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
- ...

Weekly QA

- 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

MR QA
Quarterly QA
• Visual inspection (coils)
• Performance evaluation
• RF Noise
• Slice interference
• Field Homogeneity

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

Treatment Planning System
• Source decays
• Geometric accuracy
  — Slice thickness
• Dose calculations
  — Secondary calcs
  — Water universe
• Compatible with MR scans?
  — Obliques
  — spacing

Image Based Brachytherapy
• QA guidance
  — Imaging: without devices
  — Brachy: without MR
  — TPS: typically CT
• No guidance for a combined imaging brachytherapy process

Components of Brachytherapy
• Applicators or sources placed in patient
• Imaging with devices in place
• Applicators and anatomy localized
• Treatment planning in MR

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
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: Applicator/Anatomy
- Extended applicator make distortion a concern
- Fusion to CT allows evaluation of geometric distortions

Applicator Digitization,

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

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

T&x with needles

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

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
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

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

Future Trends
- Adaptive planning
- MR guidance
- Tracking tools

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?

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

MR Dosimetry Guided Implants

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

Dose Distributions Based on Source Locations

Preplan (Intraoperative)

Dosimetric Feedback

Preplan

Intermediate: with observed trajectories based on RT imaging

Final: intermediate + additional sources

Geometric vs Dosimetric

Preplan

Intermediate: with observed trajectories based on RT imaging

Dosimetric 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
MR guided brachytherapy efforts

• Improve physician access
• Improve catheter identification
• Improve imaging information

Improved Access: Development of MRI compatible robot

 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?

- Heterogeneity corrections
- Source decay correction
- Spatial Distortion
- Channel identification
- Generating setup DRR

Answer

- Brachytherapy 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 brachytherapy. 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?

- Image quality
- Patient energy deposition
- Coil wear
- Spatial accuracy
- Image resolution

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?

- CT: Anatomy; MR: Applicator Localization
- CT: Electron Density; MR: Spatial Accuracy
- CT: Spatial Accuracy; MR: Anatomy
- CT: Treatment Response; MR: Neutron Density
- CT: Electron Density; MR: Applicator Localization

Answer