MRI-based Treatment Planning for Prostate HDR
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Talk Objectives
- Review prostate HDR techniques based on MRI
- Discuss the challenges and pitfalls introduced by MRI for prostate HDR brachy planning
- Review the QA process and learn about the development of clinical workflows for MRI
  - TPS

DISCLOSURE
None
Why MRI?

Frank et al. IJROBP 2008.

Pelvic anatomy on MRI, T2-weighted images

Courtesy Dr. Frank MDACC

MRI Guidance in HDR Prostate

- Real-time
  - Close Bore
    - 1.5T or higher → good/excellent image quality
    - 60 cm bore → tricky to implant
    - Newer 70 cm dia. bore available
  - Open Bore
    - Lower field strength (0.2-0.5T) → poor image quality
    - Easier access to place needles
- Fuse pre-diagnostic MRI to real-time US
  - Issues with image registration; two imaging sessions
Needle target accuracy is 2.1mm

Large Bore MR for RT: 1.5T or 3.0T

Mean and median catheter placement error was 2.9 mm and 2.7 mm, ranging from 0.0 mm to 5.0 mm
Base Mid Apex

Catheters

HDR delivery - transfer patient to vault - X-ray film QA done!

“Great care was taken to prevent pelvic movement with the transfer, and immobilization was maintained.”

In Foley MRI contrast replaced with X-ray contrast

Visual QA - non quantitative

HDR Afterloading & MRI

There is no afterloader today that is MRI compatible

Hence, fraction delivery must be done in a separate vault

- Not efficient
- Implant motion between MRI and Delivery?

MR-compatible mobile table
Elekta testing: Flexitron afterloader MR conditional

- Flexitron fully operational; not affected by magnetic and RF fields of 1.5T MRI
- Highest field strength for reliable operation at 30 mT line
- Machine hardly attracted by MRI, no securing needed
- MRI imaging and treatment delivery not possible, as RF emissions of afterloader disrupt MR image quality.
  - Machine needs to be moved out of the room.

Please note that the MR capability of Flexitron has not been 510(k) cleared yet - test results need to be submitted to FDA.
Potential sources of error in MRI

- Spatial distortion
  - Due to $B_0$ inhomogeneity
    - Passive and active shimming methods
    - and gradient non-linearity
  - RF non-uniformity
  - Susceptibility induced distortion
  - Motion and organ filling (MRI→HDR Vault)
  - Metal Implants (needles, hip prosthesis)
  - Treatment Planning tools validity

Gradient Nonlinearity-induced geometric distortions

Uncorrected 3D FLASH Images
2D Distortion Corrected (vendor software)
3D Distortion Corrected (vendor software)

Paulson et al.: Comprehensive MRI simulation methodology for external beam RTP. Med Phys, Jan., 2015

Acceptable Spatial Distortion Limits

- Baldewin et al reported on spatial distortion of ~5 mm within 20 cm radius centered at isocenter for a 60 cm 3T scanner (Med. Phys. 34(2), 2007)

5-mm spatial distortion might not be acceptable for brachytherapy! Be careful going to 3T.
MRI scan protocols considerations for brachytherapy planning

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Diagnostic Radiology</th>
<th>Brachytherapy</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOV</td>
<td>Reduced FOV toward ROI</td>
<td>Larger FOV to include OARs, body contours if MBDCA* used</td>
</tr>
<tr>
<td>Readout bandwidth (RBW)</td>
<td>Set w trade off fat/water shift and SNR</td>
<td>Set high to minimize chemical shift and susceptibility induced spatial distortions</td>
</tr>
<tr>
<td>Slice thickness</td>
<td>4-5mm</td>
<td>2mm contiguous, better DRR quality</td>
</tr>
<tr>
<td>Geometric distortion</td>
<td>tolerated</td>
<td>&lt;2mm in all planes</td>
</tr>
<tr>
<td>Image Intensity Nonuniformity</td>
<td>tolerated</td>
<td>Minimal for image registration and segmentation accuracy</td>
</tr>
</tbody>
</table>

* AAPM TG-186. MBDCA = Model-based Dose Calculation Algorithms

Brachytherapy TPS
Prerequisites Specific to MRI

- High fidelity images with acceptable image contrast and resolution
  - Delineate Prostate and OARs
- Which pulse sequences to use?

Superior MRI soft tissue contrast will eventually replace CT-based planning

Most common sequences

- Sagittal T2: Delineation of rectum and bladder
- Axial T2: Delineation of prostate gland and extracapsular disease (dark)
- Axial fat-suppressed T2: Delineation of intracapsular disease (dark); lymph nodes (bright)
- Axial T1: Detection of postbiopsy hemorrhage (bright)
Pulse Sequence for prostate brachy?

Inverse Planning for Prostate HDR- IPSA

QA Procedures for MRI

- ACR MR QC program
  - Well defined tolerances and limits
- Insure PM is done on scanner
- Additional phantoms needed, specific to brachytherapy planning
- Currently, there is a void in MRI QA for brachytherapy for robust planning
  - AAPM TG is pending
Things to consider in MRI/HDR Planning

1. Correction and verification of MRI spatial distortion
2. Validation to determine first dwell position
3. Anatomic evaluation based on MRI

Int. J. Radiation Oncology Biol. Phys., Vol. 61, No. 4, pp. 1267–1275, 2005
Few TPS factors impacting clinical outcome quality

- Image modality quality
- ROI contouring accuracy
- Applicator registration accuracy
- HDR source registration accuracy
- Dose model assumptions
- Source decay, etc.

Clinical Outcome Quality?

Commission Work Guideline

- AAPM TG-53: Quality Assurance for Clinical Radiotherapy Treatment Planning
- AAPM TG-40: Comprehensive QA for Radiation Oncology
- AAPM TG-56: Code of Practice of Brachytherapy Physics
- AAPM TG-43: Dosimetry of interstitial Brachytherapy sources
- Acceptance Testing, Commissioning, Data Entry, and QA for Brachytherapy Treatment Planning Systems, M. J. Rivard, AAPM 2008

Newly AAPM TG for MRI Brachytherapy is in the works

HDR Prostate implants

17 catheters; rectum set to air!
Why need to commission TPS tools?

- Incorrect dose calculation for Regions of Interest (ROIs) defined on a secondary image series
  - Example: CT is primary, MR is secondary
- Impact: The magnitude of the dose calculation error depends on the registration transformation and can vary between 0 and 100% of the correct dose value.

Issue occurs because the registration transformation is not applied to the dose sampling points.

Conclusions

- Improves the accuracy of target and OAR delineation, dose prescription and reporting
- Potential to define prostate sub-volumes and dominant lesions to allow for dose administration reflecting the differential risk of recurrence.
- Key issue for safe dissemination and implementation is establishment of qualified multidisciplinary teams and strategies for training and education
Conclusions:
- To start your MR-based HDR Program
  - need to establish QA/QC program
  - Set standards and tolerances to meet ACR MR QC
- Make sure to perform end to end tests and define baselines and tolerances
- Systematic evaluation of image spatial integrity for MRI-based planning is essential
- Other factors such as image fidelity and delineation uncertainty should be considered to further reduce uncertainty in planning