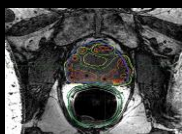
MRI-based Treatment Planning for Prostate HDR



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AAPM 2016 JUL 31–AUG 4
COMMUNICATING OUR VALUE
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58TH ANNUAL MEETING & EXHIBITION | WASHINGTON, DC

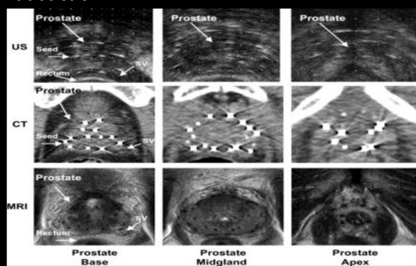
DISCLOSURE

None

Talk Objectives

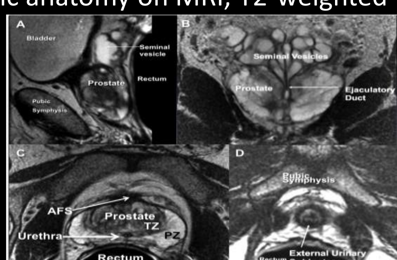
- Review prostate HDR techniques based on MRI
- Discuss the challenges and pitfalls introduced by MRI for prostate HDR brachy planning
- Review the QA process and learn about the development of clinical workflows for MRI
  - TPS

Why MRI?



Frank et al. IJROBP 2008.

Pelvic anatomy on MRI, T2-weighted images

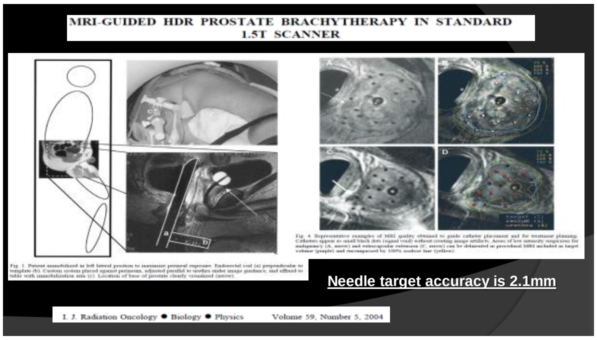


Courtesy
Dr. Frank
MDACC

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

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


MRI-GUIDED HDR PROSTATE BRACHYTHERAPY IN STANDARD 1.5T SCANNER
Needle target accuracy is 2.1mm
I. J. Radiation Oncology ● Biology ● Physics Volume 59, Number 5, 2004


Large Bore MR for RT: 1.5T or 3.0T
1A
1B
Siemens' recommended MR systems supporting RT imaging. (1A) 1.5T MAGNETOM Aera and (1B) 3T MAGNETOM Skyra with the MAGNETOM Combi Suite Radiation Therapy.

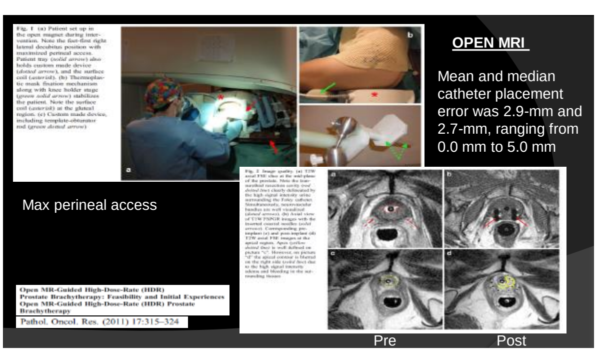
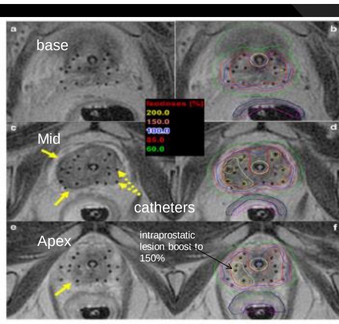

OPEN MRI
Mean and median catheter placement error was 2.9-mm and 2.7-mm, ranging from 0.0 mm to 5.0 mm
Max perineal access
Open MR-Guided High-Dose-Rate (HDR) Prostate Brachytherapy: Feasibility and Initial Experiences
Open MR-Guided High-Dose-Rate (HDR) Prostate Brachytherapy
Pathol. Oncol. Res. (2011) 17:315–324
Pre
Post

Fig. 3 Individualized dose distribution with simultaneous integrated boost. Representative MR slices at the base-, mid- and apical plane showing anatomy (a,c,e) with structures and isodose lines (b,d,f) in patient with cT3a prostate cancer. Note the posterolaterally bulging tumor on the right side involving the apical region also (*solid arrows* on c,e). Plastic catheters are clearly defined as small black dots (*dotted arrows*) without compromising target definition. Clinical target volume (*red*) and intraprostatic lesion (*light green*) covered by 100% (*dark blue*) and 150% (*pink*) isodose lines



Visual QA- non quantitative

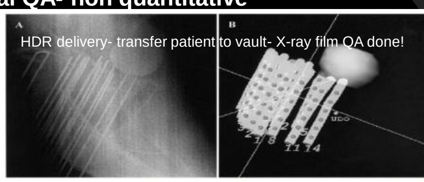


Fig. 3. (a) Diagnostic portable X-ray showing relationship between Foley balloon and brachytherapy catheters acquired immediately before radiotherapy delivery and compared with (b) surface-rendered image generated from treatment planning MRI. No appreciable motion of catheters was noted.

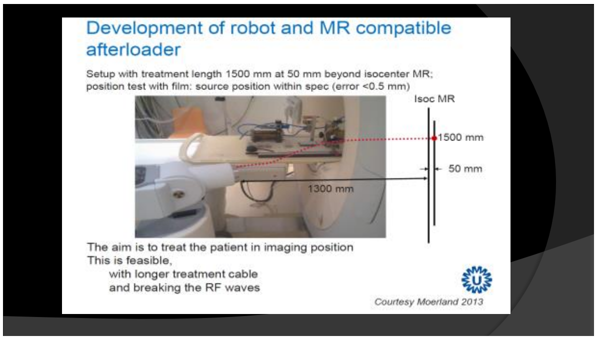
"Great care was taken to prevent pelvic movement with the transfer, and immobilization was maintained"

In Foley MRI contrast replaced with Xray contrast

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 afterloader (without cover) at 30 mT line

- 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
    - vendor software for correction
- 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

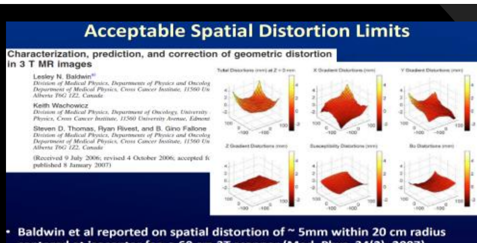
Residual distortion Is evident

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



5-mm spatial distortion might not be acceptable for brachytherapy!
Be careful going to 3T

MRI scan protocols considerations for brachytherapy planning

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

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

Brachytherapy TPS Prerequisites Specific to MRI

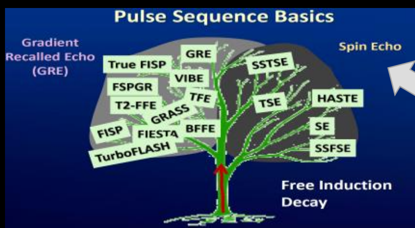
- High fidelity images with acceptable image contrast and resolution
  - Delineate Prostate and OARs
- Which pulse sequences to use?

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

Most common sequences

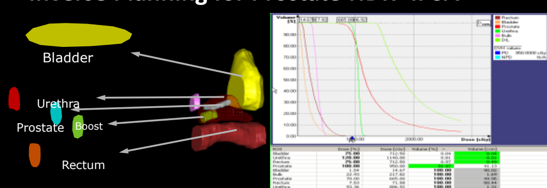
Sagittal T2	Delineation of rectum and bladder
Axial T2	Delineation of prostate gland and extracapsular disease (dark)
Axial fat-suppressed T2	Delineation of intracapsular disease (dark); lymph nodes (bright)
Axial T1	Detection of postbiopsy hemorrhage (bright)

Pulse Sequence for prostate brachy?



McGee, AAPM 2015 MRI Basics II: MR Imaging for treatment planning

Inverse Planning for Prostate HDR- IPSA



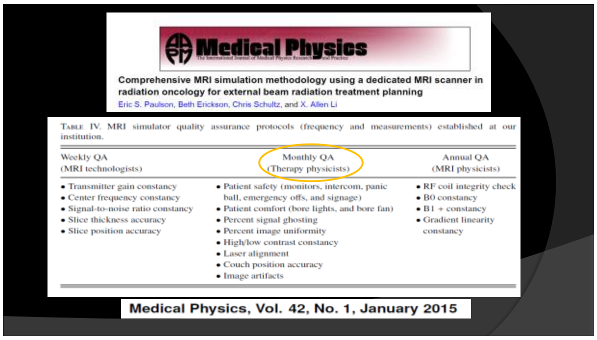
Dose Objectives: Courtesy of University of California, San Francisco

ROI	Usage	Margin		Surface				Volume			
		Dose	Activ.	Weight	Min (cGy)	Max (cGy)	Weight	Weight	Min (cGy)	Max (cGy)	Weight
Bladder	Organ	0	0			475	40				
Bulb	Organ	0	0			475	20			475	20
DIL	Target	0	0	100	1045	1425	30	100	1045	1425	5
Prostate	Ref Target	0	0	100	950	1425	80	100	950	1425	30
Rectum	Organ	0	0			475	40				
Urethra	Organ	0	0	100	950	1140	30	100	950	1140	40

Med Phys. 2001 Lessard E, Pouliot J.

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



Medical Physics

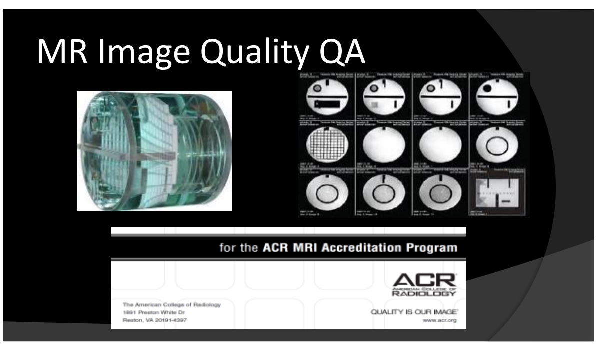
Comprehensive MRI simulation methodology using a dedicated MRI scanner in radiation oncology for external beam radiation treatment planning

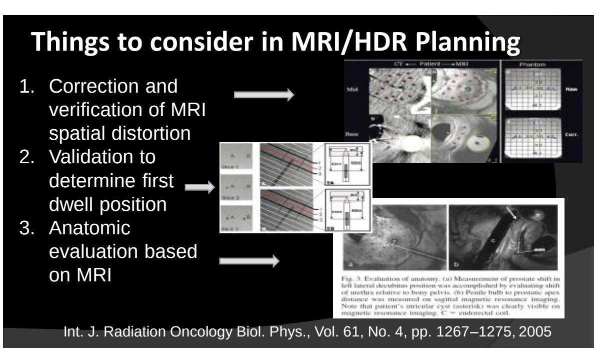
Eric S. Paulson, Beth Erickson, Chris Schultz, and X. Allen Li

TABLE IV. MRI simulator quality assurance protocols (frequency and measurements) established at our institution.

Weekly QA (MRI technologists)	Monthly QA (Therapy physicists)	Annual QA (MRI physicists)
• Transmitter gain constancy • Center frequency constancy • Signal-to-noise ratio constancy • Slice thickness accuracy • Slice position accuracy	• Patient safety (monitors, intercom, panic ball, emergency offs, and signage) • Patient comfort (bore lights, and bore fan) • Percent signal ghosting • Percent image uniformity • High/low contrast constancy • Laser alignment • Couch position accuracy • Image artifacts	• RF coil integrity check • B0 constancy • B1 + constancy • Gradient linearity constancy

Medical Physics, Vol. 42, No. 1, January 2015





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.

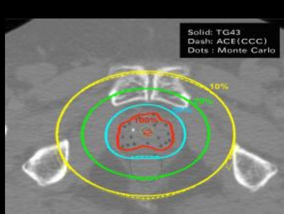
Clinical Outcome Quality?

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

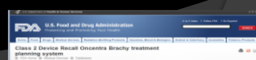
HDR Prostate implants



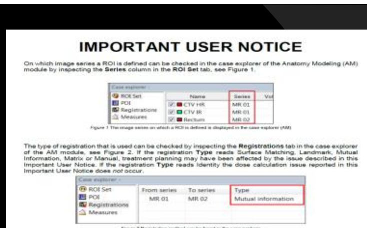
17 catheters; rectum set to air!

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.



IMPORTANT USER NOTICE

On which image series a ROI is defined can be checked in the case explorer of the Anatomy Modeling (AM) module by inspecting the **Series** column in the **ROI Set** tab, see Figure 1.

Name	Series
CTV HR	MR 01
CTV IR	MR 01
Rectum	MR 02

Figure 1 The image series on which a ROI is defined is displayed in the case explorer (AM)

The type of registration that is used can be checked by inspecting the **Registrations** tab in the case explorer of the AM module, see Figure 2. If the registration **Type** reads Surface Matching, Landmark, Mutual Information, Matrix or Manual, treatment planning may have been affected by the issue described in this Important User Notice. If the registration **Type** reads Identity the dose calculation issue reported in this Important User Notice does *not* occur.

From series	To series	Type
MR 01	MR 02	Mutual information

Figure 2 Registration method can be found in the case explorer

Function	When applied to:	
	ROIs defined on Primary Image Series	ROIs defined on Secondary Image Series
DVH graph values	Not affected	Affected (Brachy Planning only)
DVH table values	Not affected	Affected (Brachy Planning only)
Dose statistics in case explorer	Not affected	Affected (Brachy Planning only)
IPSA	Not affected	Turned off
HIPO	Not affected	Affected (Brachy Planning only)

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