In Memoriam of Lynn Verhey Clinical Physicists Must Know and Be Involved in Treatment Planning: Potential Issues with MRI

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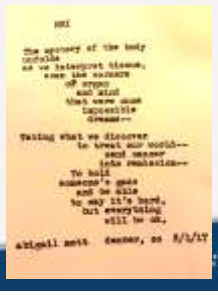
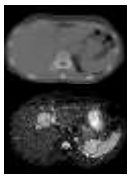
AAPM 2017: Denver, CO



MRI in Treatment Planning

- H&N:
  - Reduced inter-observer variability
- Brain:
  - MRI resolves tumor not resolvable on CT and identifies peritumoral edema
- Female pelvis:
  - RTOG consensus: "MRI provides precise delineation of uterus, cervix, S/I bladder extent"
  - GEC-ESTRO guidelines: "MRI provides most reliable delineation for gyn cancer"
- Prostate:
  - 3.5x reduction in inter-observer variability
  - ID prostate apex (high tumor incidence) and SVs

https://www.itnonline.com/content/pi-rads-named-best-clinical-research-paper-european-urology



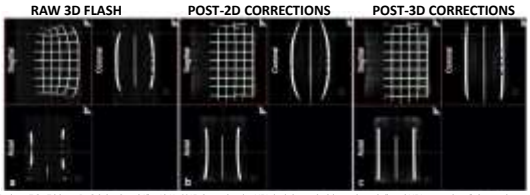
MRI is so beautiful & poetic…what could go wrong?

Different Requirements

Typical Diagnostic MRI	Needs for Rad Onc
Not skin-to-skin (reduced field of views)	Full FOV imaging
Thick (4-6 mm) Slices, Interslice spacing, Nonaxial/Oblique	Thin, Contiguous, Axial Slices
Radiologist can read through artifacts	Limit artifacts
Large field of view distortions not critical	Distortions quantified & mitigated
Auxiliary systems: i.e. Endorectal Coil	Mimic RT geometry
Bandwidth: tradeoff between SNR and fat/water shift	High bandwidth→reduce water/fat shift and susceptibility effects
Curved couch	Flat tabletop for immobilization devices
No Lasers	Lasers helpful for marking/leveling

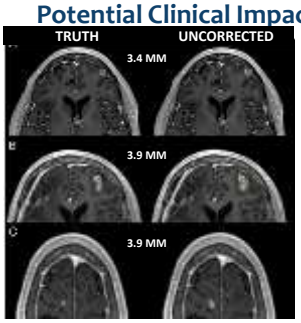
Pitfall: Gradient Non-linearity Distortion Not Managed

- Typically the **largest source** of MRI distortion **(SAMS ALERT)**
- Important: we require 3D Distortion Corrections to be enabled!



Paulson, E.S., Erickson, B., Schultz, C. and Allen Li, X., 2015. Comprehensive MRI simulation methodology using a dedicated MRI scanner in radiation oncology for external beam radiation treatment planning. Medical physics, 42(1), pp.28-39.

Potential Clinical Impact: GNL Distortions



- 28 SRS cases evaluated
- GTVs delineated on T1 Post-Gd, impact of no GNL vs. 3D correction assessed
- Median displacement = 1.2 mm
- 8 out of 28 = geometric miss
- Importantly, also compared 2D and 3D distortion corrections
- 2D: median reduction = 0.05 mm (only 2 cases reduced maximum distortion >0.5 mm)

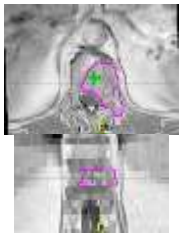
T. Seibert et al., Distortion inherent to magnetic resonance imaging can lead to geometric miss in radiosurgery planning, PRO, 2016

Pitfalls: Limited FOV, Status, Slice Thickness

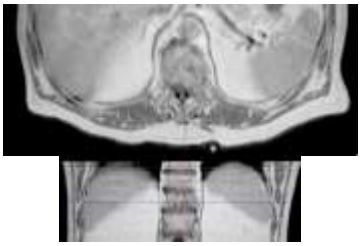
- T2 TSE, 0.5 mm inplane,
- 3.5mm slice thickness→artifacts
- Impact of bladder/rectal status on prostate location
- Limited FOV→initial bony fusion may be impacted

Diagnostic vs. MR-SIM Protocols

1.5 T, 5 mm slice thickness
Small FOV, 2 mm gap



1.0T, 3 mm slice thickness
Large FOV, no gap, in immobilization



Pitfall: Low Receiver Bandwidth (rBW) for Diagnostic MRI

- rBW is range of frequencies represented in image
- If rBW gets larger, number of Hz per pixel gets larger
- Assuming other parameters are fixed, water-fat shift (in pixels) is inversely proportional to rBW
- Diagnostic protocols:
  - Set as tradeoff between fat/water shift and signal to noise ratio

Clinical Impact: Chemical Shift

http://mriquestions.com/chemical-shift-artifact.html

What does this look like?

http://xrayphysics.com/chem_sh.html

So what can physicists do?

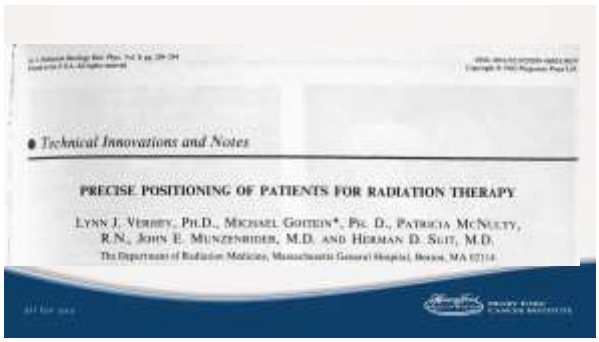
- Verify MRI protocols in your institution have 3D distortion corrections enabled
- Work with your Radiology colleagues to create RT-optimized protocols, particularly for high precision RT
  - -Watch out for:
    - Slice thickness, slice gaps, low bandwidths, oblique slices
- If you are importing an outside MRI, use a free DICOM header reader (e.g., KPACS) to better understand acquisition parameters

Patient QA: DICOM Header Screeners

- TPS Compatibility
- Distortions:
  - WFS
  - Susceptibility
  - GNL

Vendor	Private Tag	Value
Siemens	(0051,1016)	"DIS3D"
GE	(0043,102d)	"w"
Philips	(2005,10a9)	"3D"
Toshiba	(0008,0008)	"GDC"

Slide credit: Eric Paulson, PhD (MCW)



Technical Innovations and Notes

PRECISE POSITIONING OF PATIENTS FOR RADIATION THERAPY

Lynn J. Verhey, Ph.D., Michael Goitein*, Ph. D., Patricia McNulty, R.N., John E. Munzenrider, M.D. and Herman D. Suit, M.D.

or 3 mm between target and treatment volumes. Even in the absence of pretreatment radiographs, the careful use of secure immobilization devices would be expected to achieve improvements in tumor control probability.

Pitfall: Diagnostic MRI ≠ MRI in RT Position

- 20 patients, MR-SIM on flat couch, knee rests, leveling with lasers (MRI_{RT})
- Diagnostic (MRI_D): same scanner, curved couch, standard coils, no immobilization
- Automated rigid registration performed in Eclipse

Hanvey et al.,BJR, 85(2012).

Improved Bony & Tissue Registration w/ MR in RT position

Table 4. Quality of registration results, where the mean error is the distance from the centre of the CT structures to the centre of the MRI structures

Structure	CT to MRI_D mean (mm)	CT to MRI_{RT} mean (mm)
Left femoral head	3.0±2.2	2.0±1.6
Right femoral head	3.4±1.8	1.8±1.2
Symphysis pubis	5.2±3.0	1.8±1.1
Prostate	5.0±2.5	3.6±2.2
Prostate and seminal vesicles	5.2±2.3	4.1±2.6

MRI_D, diagnostic MRI scan; MRI_{RT}, MRI scan in the radiotherapy position; SD, standard deviation.

Hanvey et al.,BJR, 85(2012).

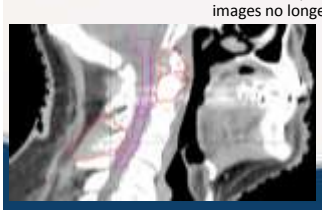
MR-Simulation (MR-SIM) for Treatment Planning

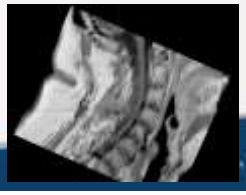
Flat indexed couches & coil bridges for flex coils

Challenges Facing MR in RT: Setup

Actual Physicist to Physician Correspondence for two-sited Spine SBRT

"C1 & C4 images were fused. Please note the curvatures are so different that I had to create separate registrations at C1 and C4, respectively. Still MRI at C4 is so curved that when you move down away from C4, the images no longer match."





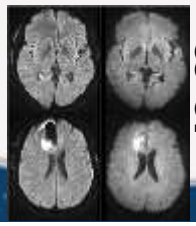
So what can physicists do?

- Understand the limitations/uncertainties that may arise due to different patient pose
- Discuss these with your physicians
- Be wary of the need to perform multiple registrations
- Ideally, image in the treatment position with proper equipment

High Performance MRI: Functional & MRI-only Planning

Functional Imaging: New Needs

- Echo-planar imaging (diffusion, perfusion) sensitive to off-resonance effects → severe geometric distortions



(Left) Single shot diagnostic DWI (b = 1000 s/mm)

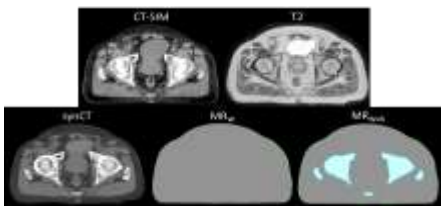
(Right) RadOnc DWI (multi-shot spiral) → reduced local susceptibility & signal pileup

Paulson et al., Med Phys (2016)

Synthetic CT (SynCT) Goals

- To use set of common clinical MRI sequences to generate synthetic CTs (synCT) to support MR-only treatment planning
- Used by a treatment planning system to produce electron density maps
- For accurate dose calculations and digitally reconstructed radiograph (DRR) generation

But do we need SynCT in Pelvis?

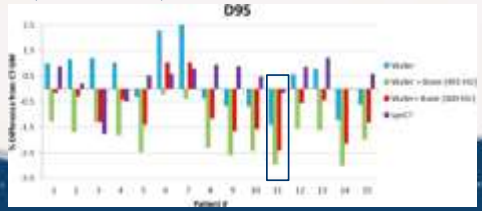


2 bone values tested: 491 HU (ICRU) and 300 HU (population n = 15)

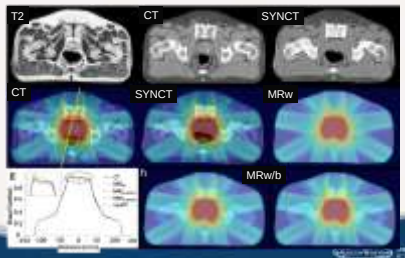
Kim, J., Garbarino, K., Schultz, L., Levin, K., Movsas, B., Siddiqui, M.S., Chetty, I.J. and Glide-Hurst, C., 2015. Dosimetric evaluation of synthetic CT relative to bulk density assignment-based magnetic resonance-only approaches for prostate radiotherapy. *Rad Onc 10*(1).

Dosimetric Comparison

- SynCT yielded smallest dosimetric differences from CT-SIM for target D95, D99, and mean dose (<0.7 Gy (1 %)), though not significant
- For bladder, synCT outperformed all others
- Rectum & penile bulb doses comparable



Differences w/Rectal Status



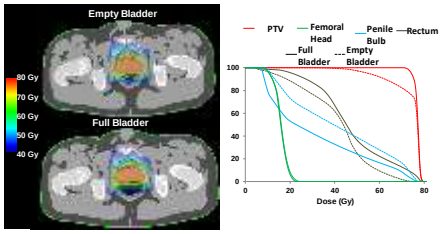
SAMS ALERT!

Clinically Available MR-only Prostate Planning Packages Available

Philips MR-CAT

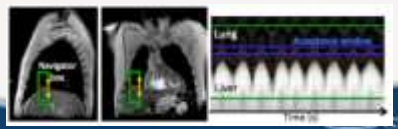
Spectronic MRI Planner

Status Changes in MR-CAT w/Rectal Air Override



Pitfall: Differences in Motion Management

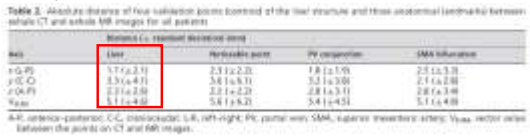
- Diagnostic MRI may trigger acquisition from:
  - External surrogate
  - Using an internal navigator
- Breath-hold (BH): can get you EE/EI, BUT…
  - Often deep inspiration/exhalation (not natural)
  - MRI scan times >>>CT scan times →many BHs for patients



Konik et al. Phys Med Biol. 2014 59(14)

Pitfall: Differences in Motion Management

- 53 HCC patients underwent 4DCT and T2-weighted respiratory gated MRI at end-exhale + external bellows belt
- Flat table top, aligned to lasers
- Bony fusion of end-exhale CT and T2 MRI conducted in TPS



- Ascites and pulmonary disease associated with distances >5mm

J. Yu et al. Evaluation of anatomical landmark position differences between respiration-gated MRI and 4DCT for radiation therapy in patients with HCC. Br J Radiol 2013

What can physicists do?

- Evaluate the uncertainties in new technology and develop procedures for effective implementation
- Share their experience with the community: through abstracts, publications, MedPhys Listserv, etc. so that we can all learn together

Take Home Messages

- MRI undoubtedly adds clinical value for many disease sites
- However, as a field, we need to optimize protocols to achieve high spatial fidelity and provide better correlates to RT-specific needs
- Know what images you have to better frame the scope of uncertainty
- Work closely with Radiology, MRI physicists, & vendor support to develop these RT-specific protocols