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# A MRI Simulator from Proposal to Operation

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# Acknowledgments

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## ➤ Siemens Research grant (Balter)



# Outline

- Advantages of MRI-based simulation
- Proposal and planning
- MRI safety
- QA program
- MRI protocol development and workflow for RT



# Advantages of MRI for RT

- Soft tissue contrast
- Multi-contrast
- Functional (Physiological) and metabolic imaging
  - Dynamic contrast enhanced (DCE) imaging
  - Diffusion weighted imaging (DWI)
  - Spectroscopy imaging
- Arbitrary slice orientation
- Respiratory Motion suppression
- Respiratory Motion management (4D MRI)





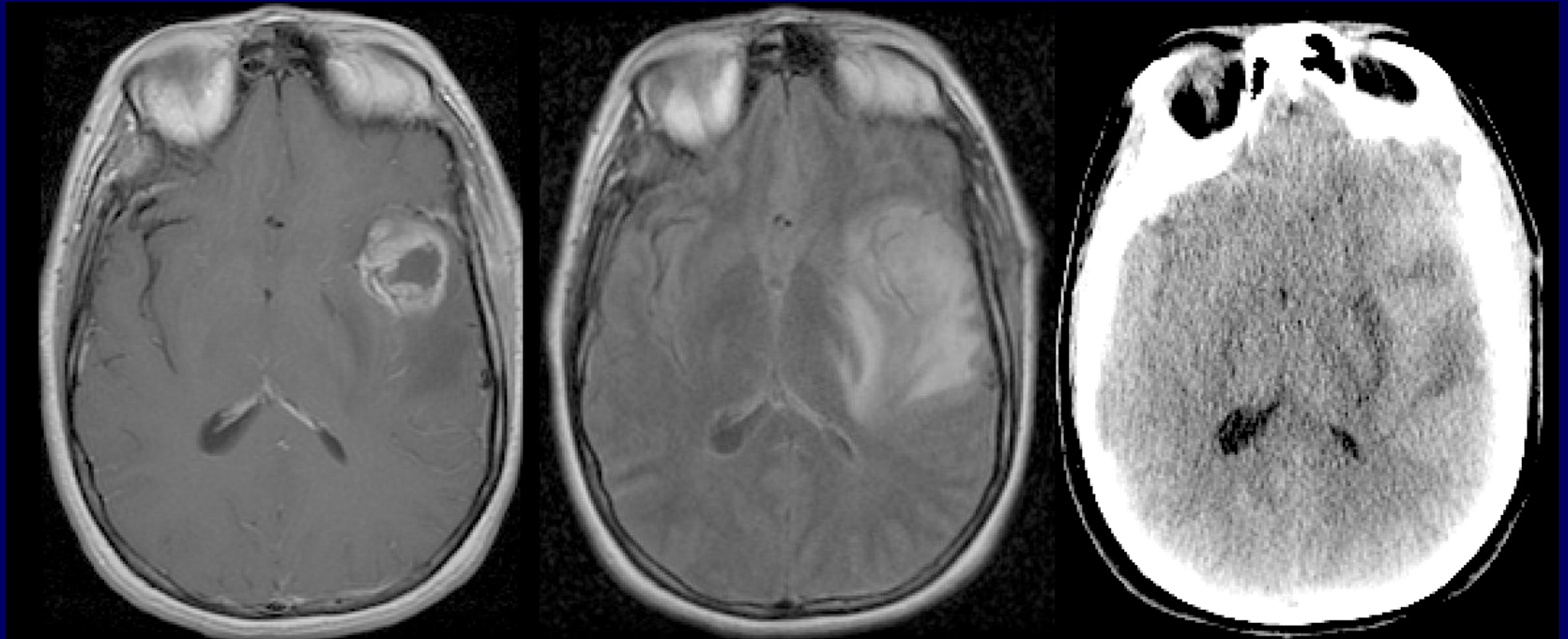
# MRI Simulation

- MRI Simulators have been in use in Radiation Oncology for over 12 years (early systems in FCCC, Hokkaido,...)
- Over 100 MRI scanners have been sold for primary/dedicated Radiotherapy use worldwide
- Rapid developments are happening to support broad use of MRI as a Simulator



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# Superior Soft Tissue Contrast



Post-Gd T1W

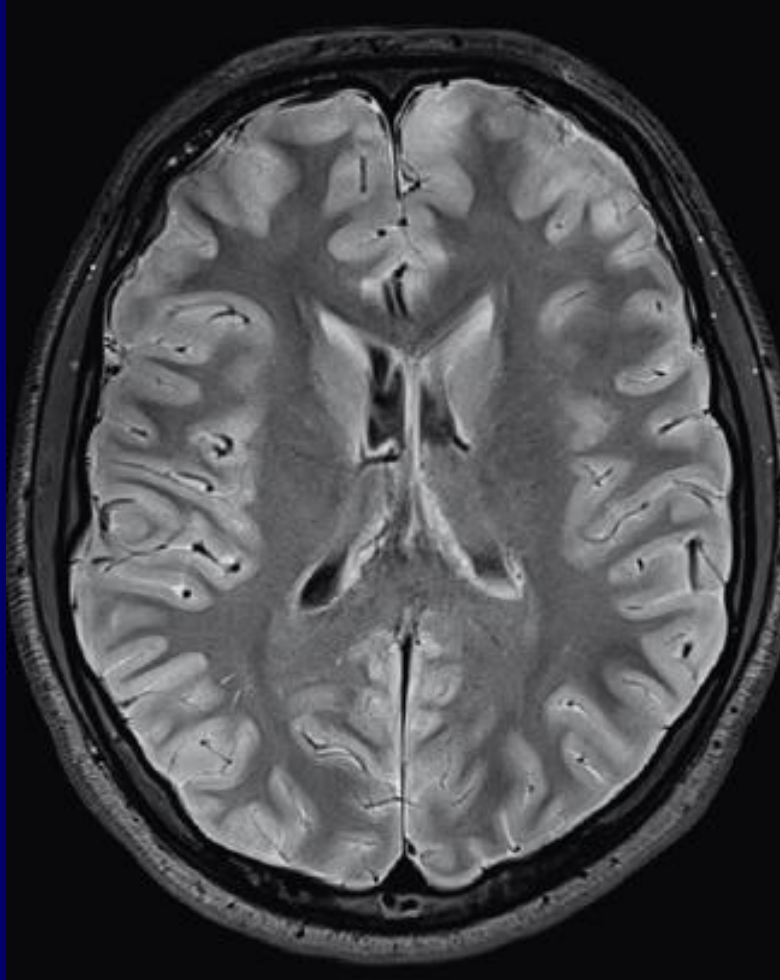
FLAIR

CT



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# Superior soft tissue contrast

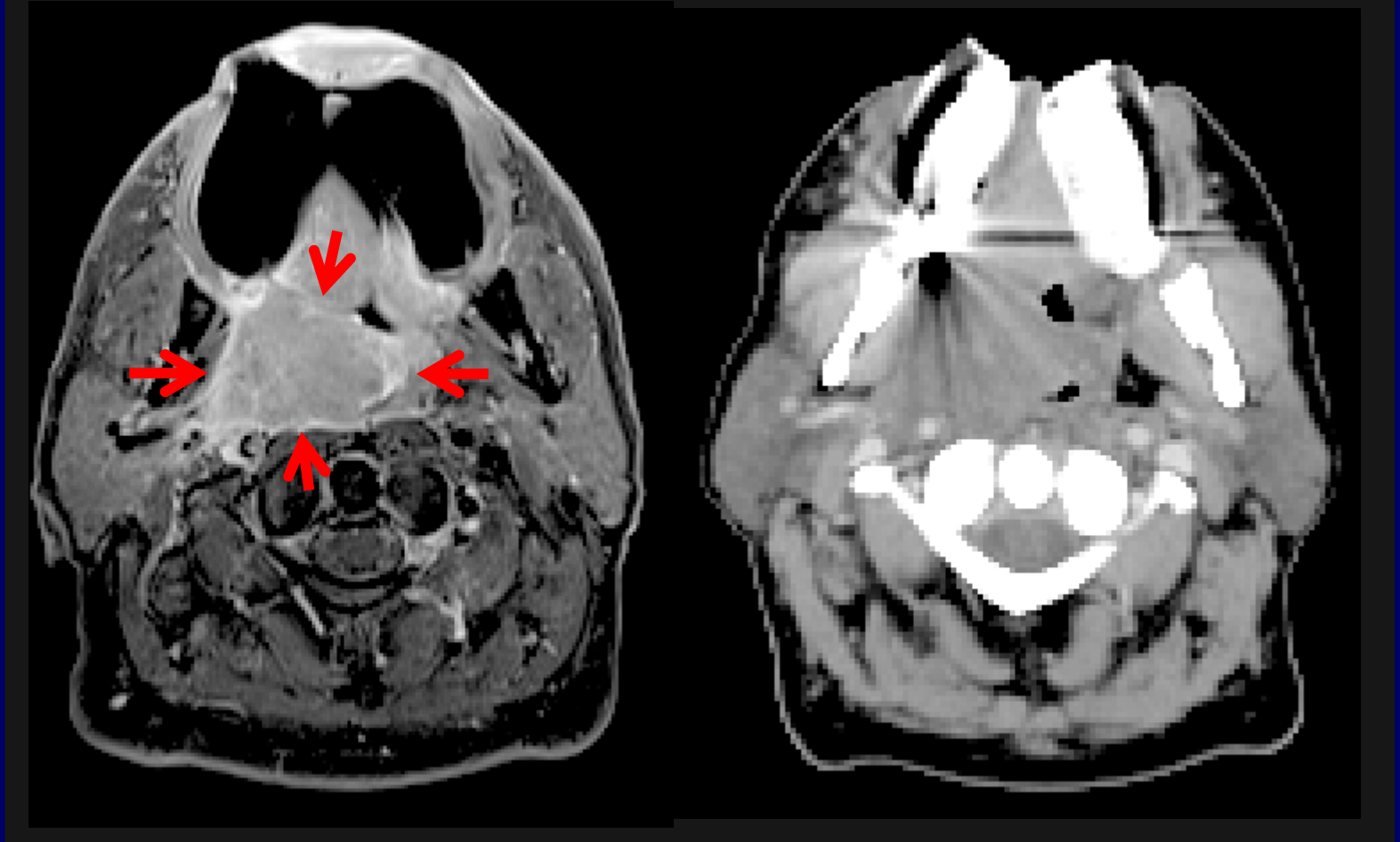


At high field



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# Tumor Definition



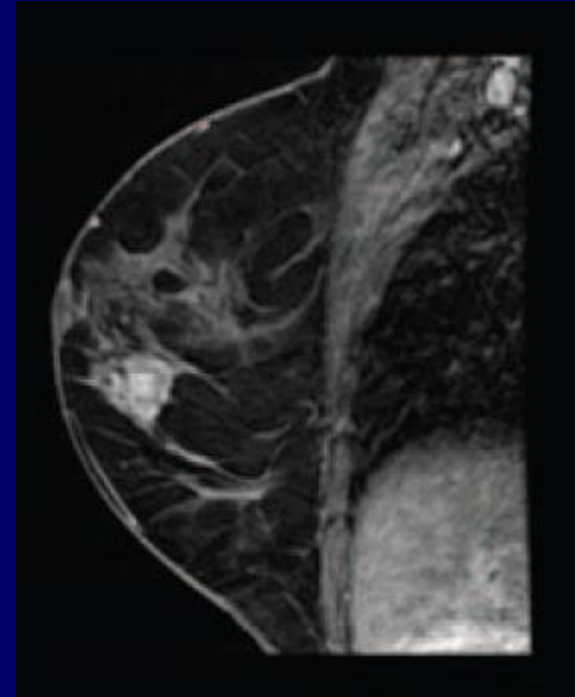


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# Superior Soft Tissue Contrast



CT

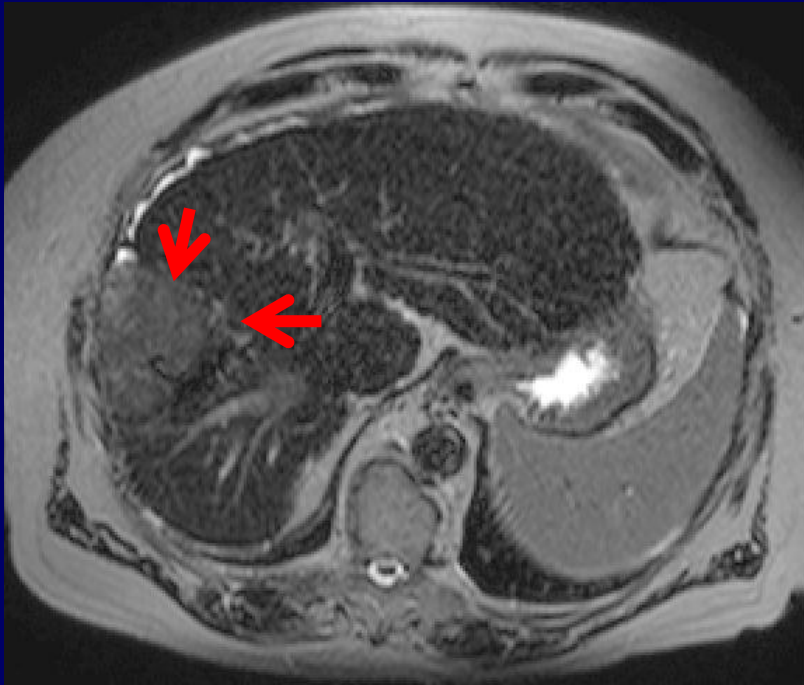


MRI

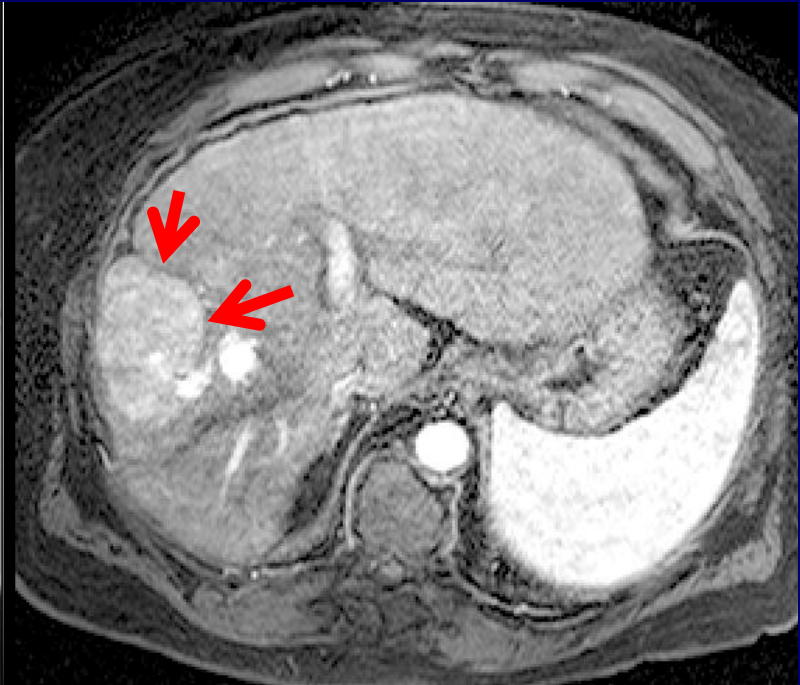


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# MRI: Multi-Contrast



T2WI



Arterial phase enhancement

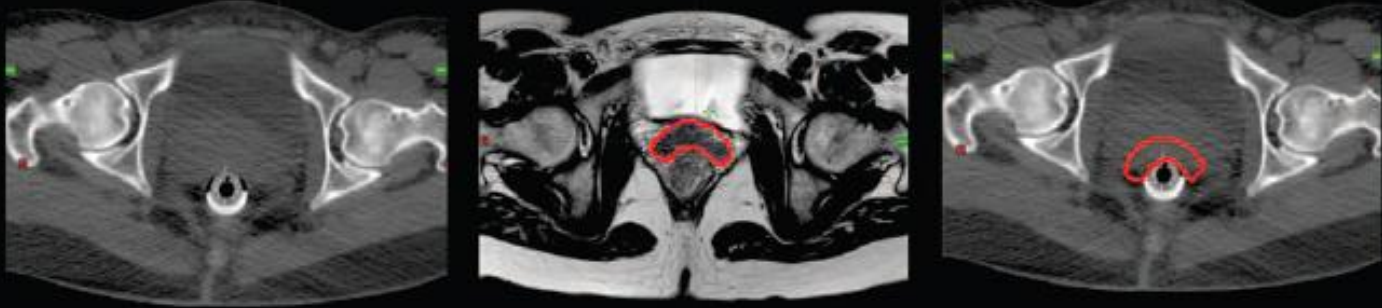




# Additional Cancer Sites

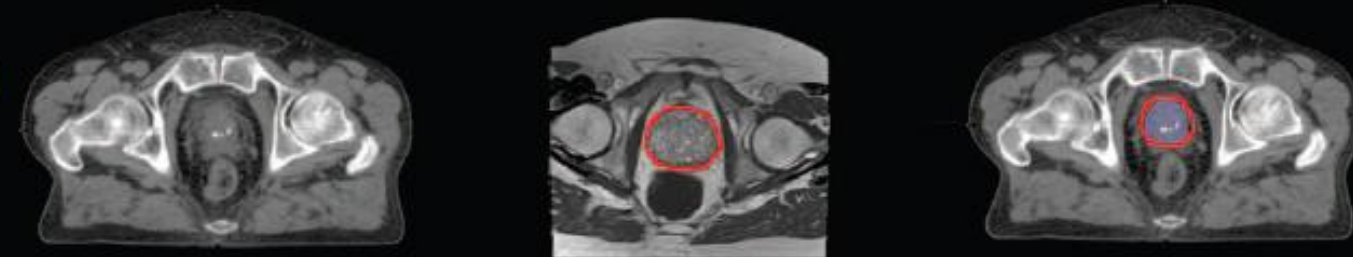
Rectal

(a)



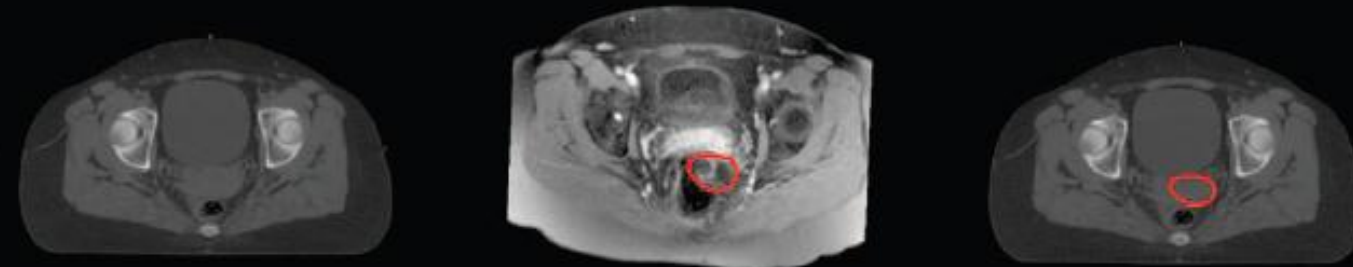
Prostate

(b)



GYN

(c)





# Cancer Sites Benefit from MRI Soft Tissue Contrast

- Brain primary tumors and metastases
- Nasopharyngeal cancers and other HN cancers
- Breast cancers
- Rectal cancers
- GYN cancers
- Prostate cancers
- Liver cancers



# Proposal and planning

- Basic equipment
- Specs for a MRI simulator
  - Advanced pulse sequences
- Site planning
- Staff training



# MRI for RT simulation

- Wide bore MRI Scanner
- Flat table top, immobilization devices and compatible RF coils
- Movable lasers
- Simulation workstation
- RT-sim MRI protocols
- QA
- Integration in RT workflow

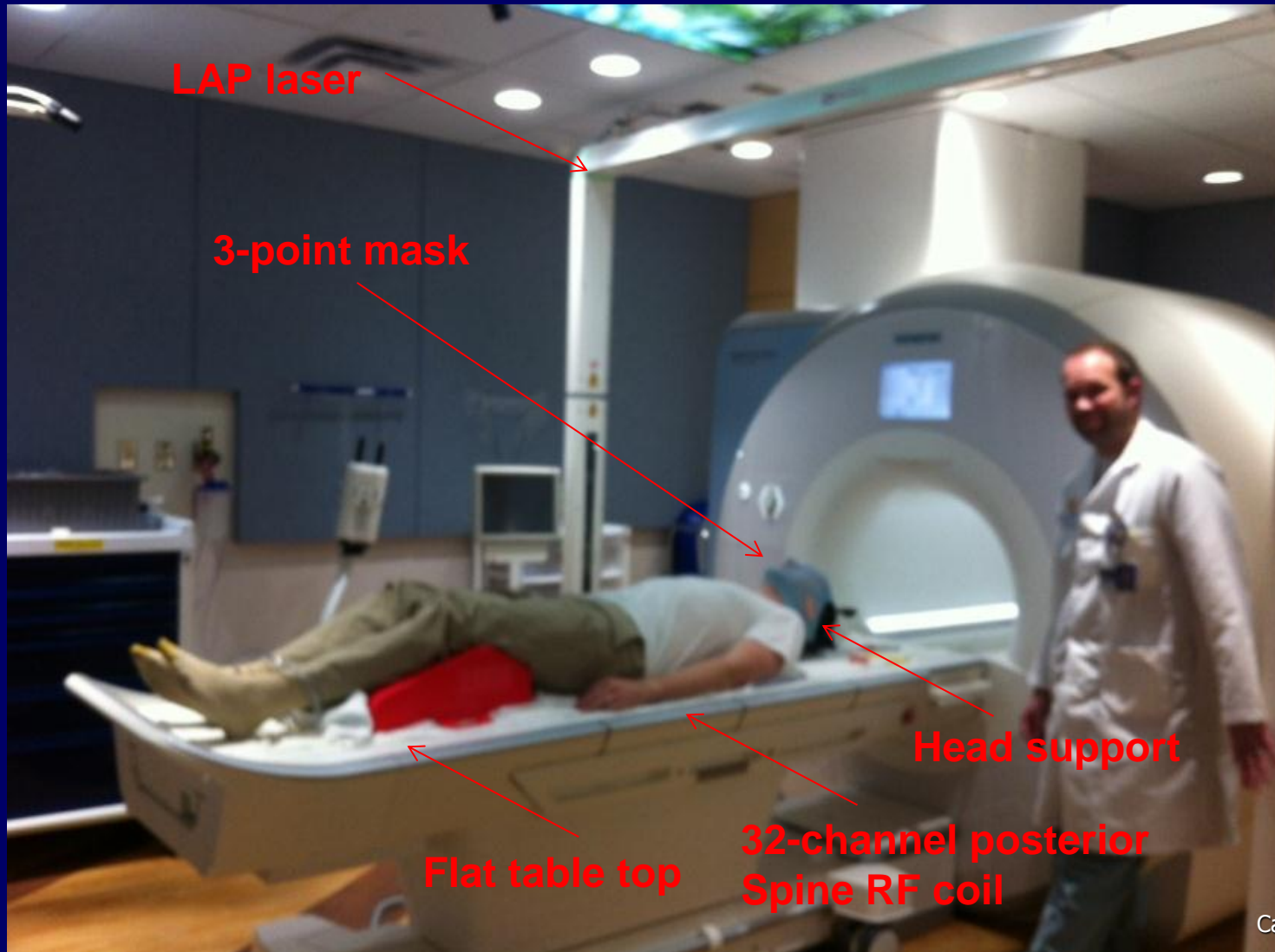


# MRI System at UM

- 3T wide bore scanner (Siemen SKYRA) with LAP laser system and simulation workstation (Varian)
- RF Coils:
  - 20 channel head/neck
  - 3 18 channel flex coils (“body 18” and “body 18 long”)
  - Two small and 1 large 4-channel flex coils
  - 2 detachable tabletops with 32-channel posterior spine coils
- MRI-compatible immobilization equipment (CIVCO)
- Various phantoms and test equipment



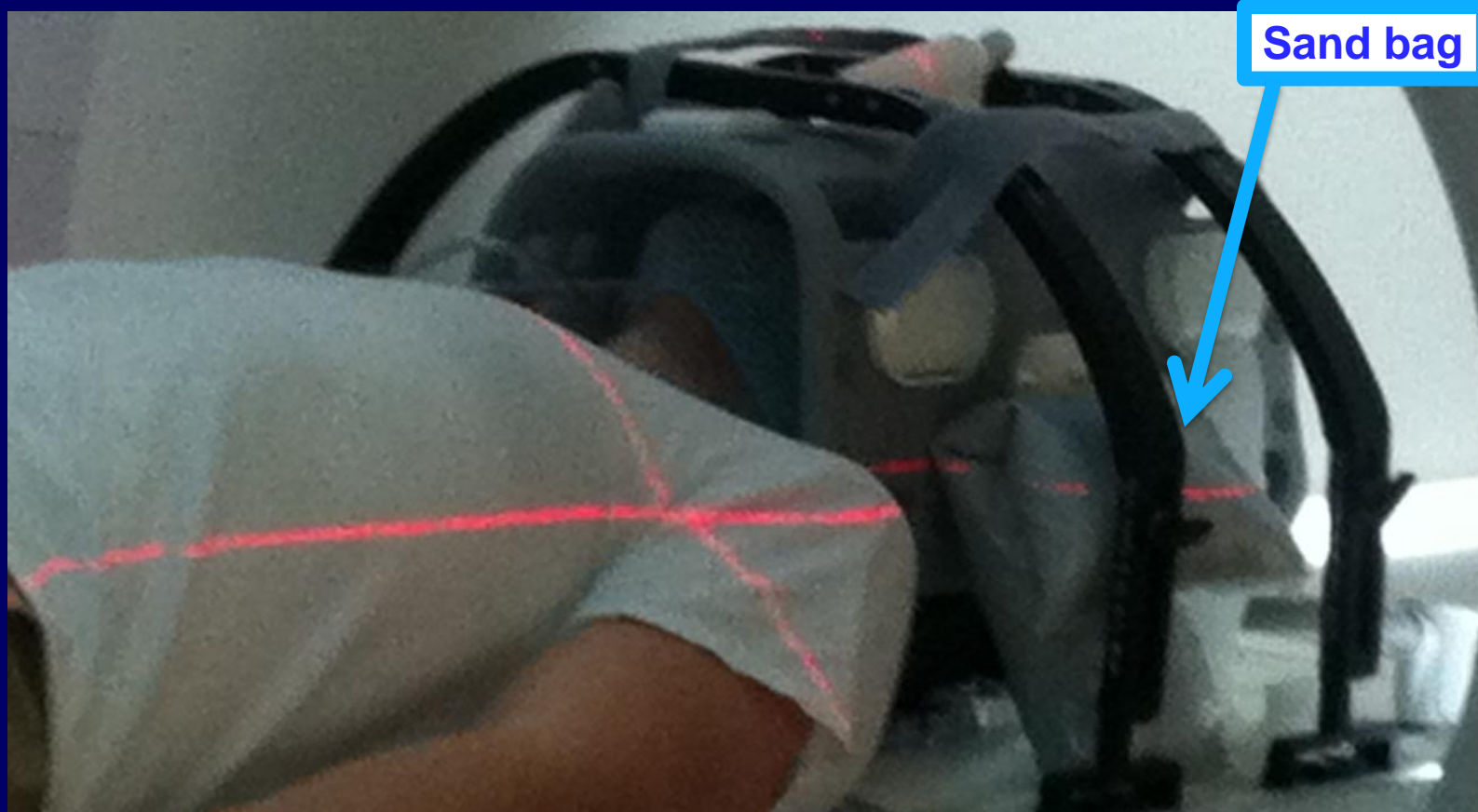
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# 3-point mask – Anterior 18-channel, posterior spine coil



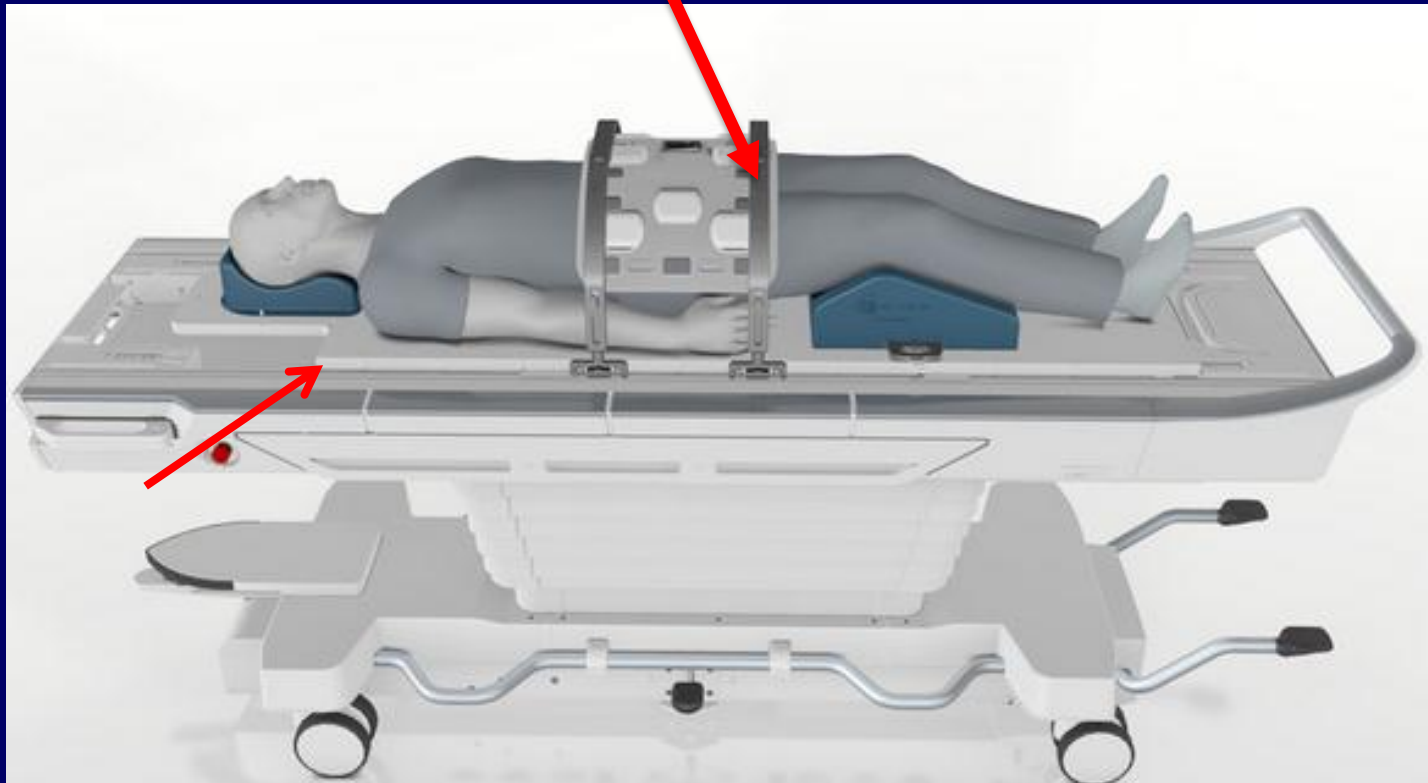
UM solution



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# Indexed MRI-compatible table top and coil holder

Bridge to hold coils slightly away from patient



Siemens / CIVCO

**Detach Table**

Cao 18



# Request for Proposal: **MRI Simulator for RT**

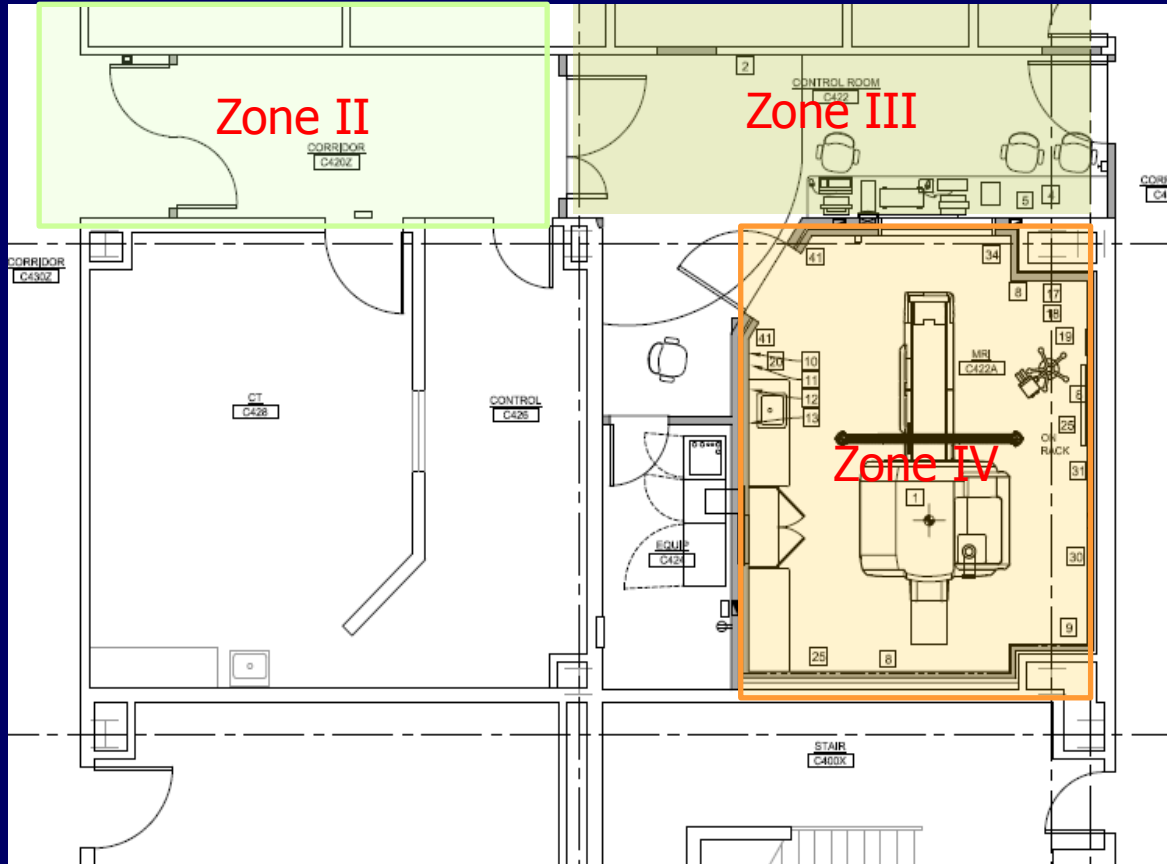
- System level geometric distortion
- B0 field homogeneity in a diameter of 30 cm and 40-50 cm
- Gradient non-linearity and correction
- Max field of view (50x50x45 cm or larger)
- Active shimming (any high order shimming)
  - Human subject changes the baseline B0 homogeneity
- Special pulse sequences and software for RT





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# Four-Zone Principle Design



Zone I: Universe

Zone II: Connected to MRI suite, accessible by patients and hospital staff

Zone III: Directly connected to the magnet room, accessible by screened patients and trained staff  
Field strength  $< 5$  Gauss

Zone IV: Magnet room, all ferromagnetic materials excluded, access controlled by level-2 safety officers

**MRI suite**

ACR recommended 2002

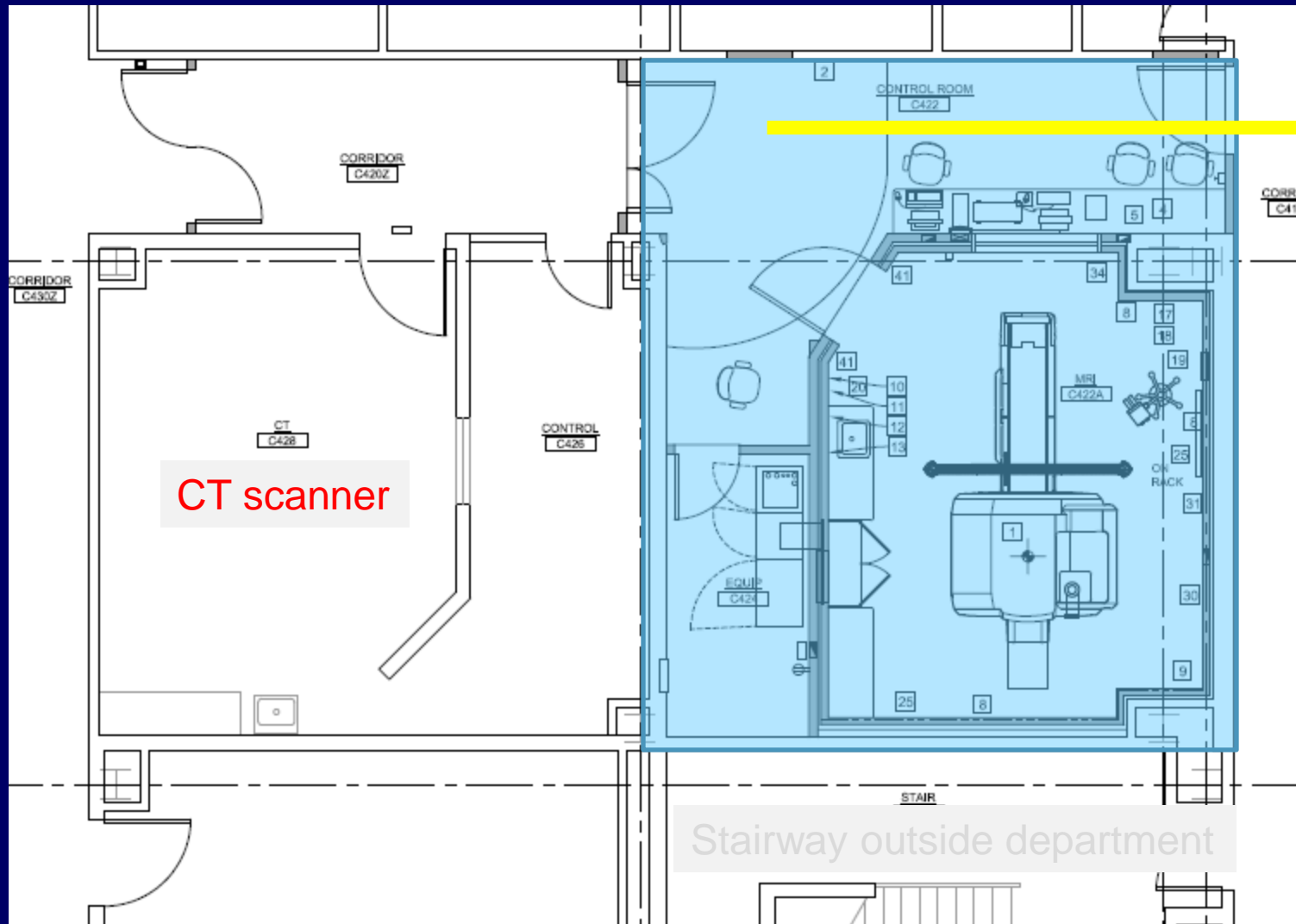
Cao 20





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# Site Planning

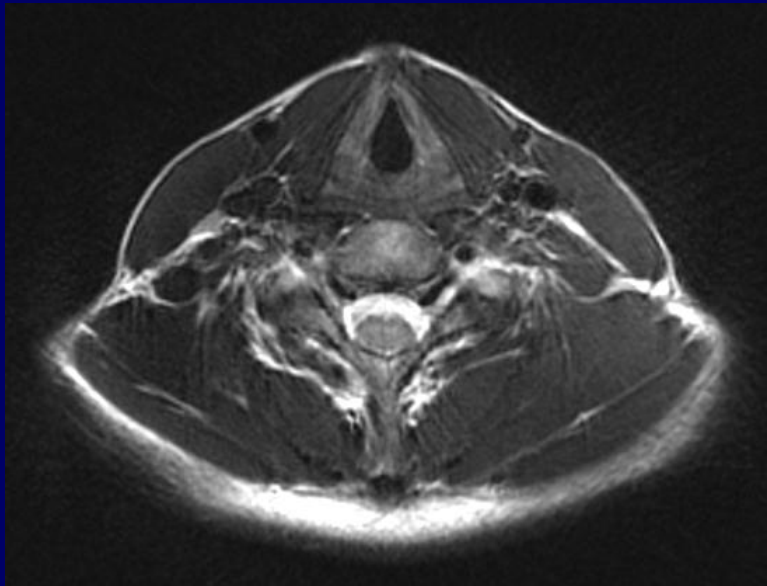


HDR Suite

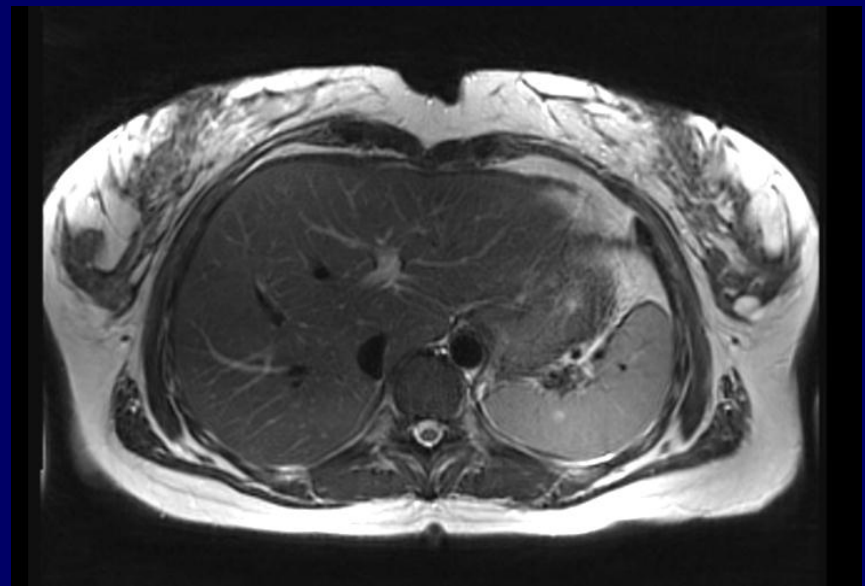


# Special Pulse Sequences for RT

- Motion Suppression
  - radial sampling, propelled sampling
  - triggering sampling



Swollen motion Free HN image

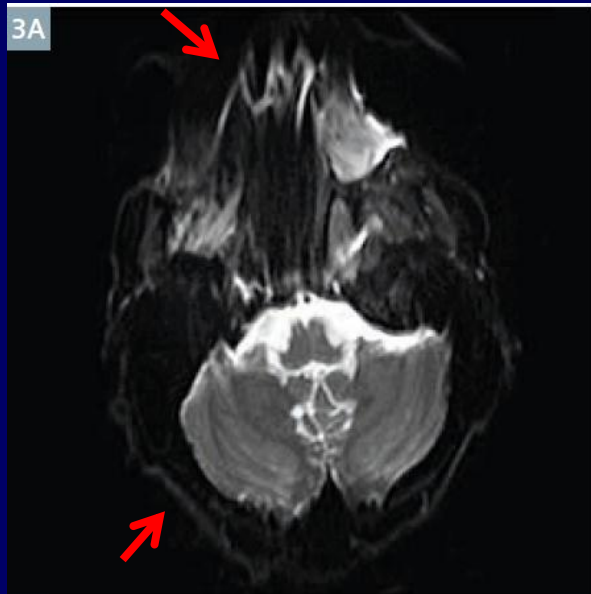


Free-breathing liver image



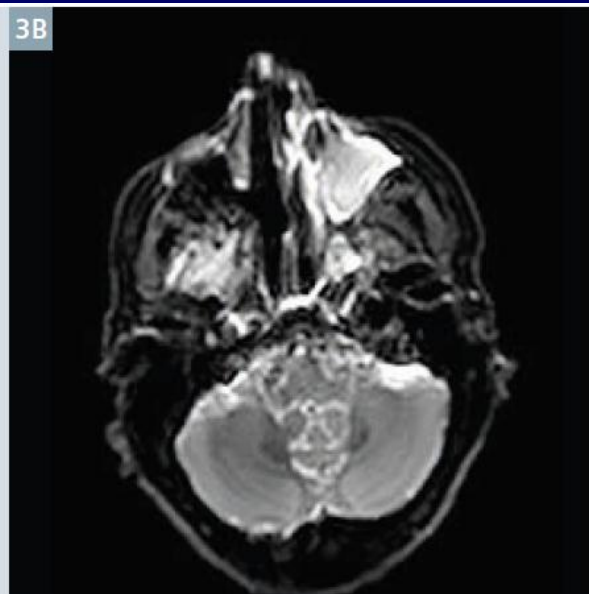
# Special Pulse Sequences for RT

- diffusion imaging sequence
  - High geometric accuracy, high quality, high resolution



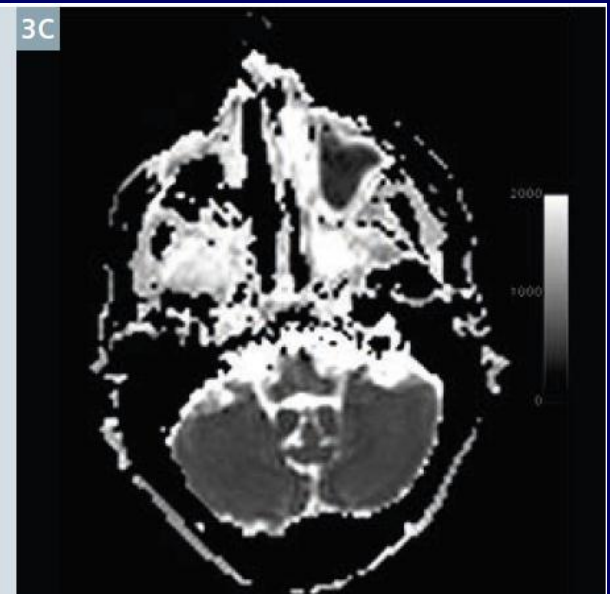
Standard DWI ( $b=0$ )

EPI



RESOLVE DWI ( $b=0$ )

RESOLVE

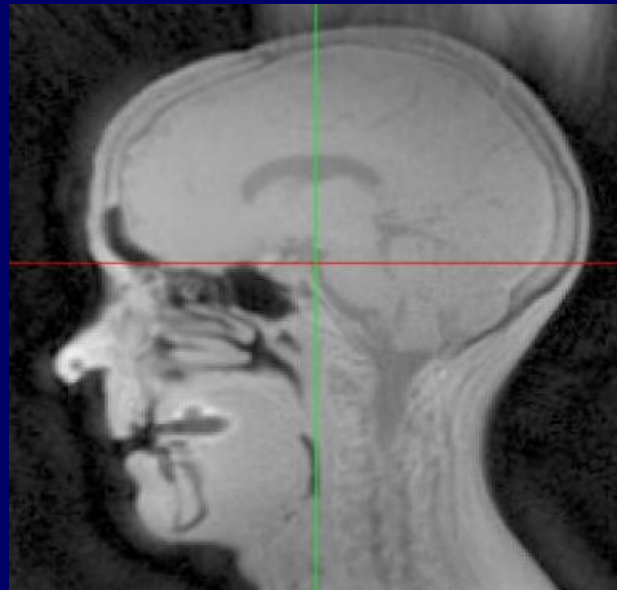


RESOLVE ADC



# Special Pulse Sequences for RT

- Ultra-short TE pulse sequence for bone imaging
  - Available in the quite suite



# Staff Training

- Cross-training
  - A MRI technologist can be cross-trained to become a RT sim therapist
    - Hiring a MRI tech prior to the MRI scanner installation and cross-training him/her for CT sim
  - A CT sim therapist is cross-trained for MRI sim
    - We have a limited success on simple protocols



# Challenges (opportunities?) – imaging of immobilized patients

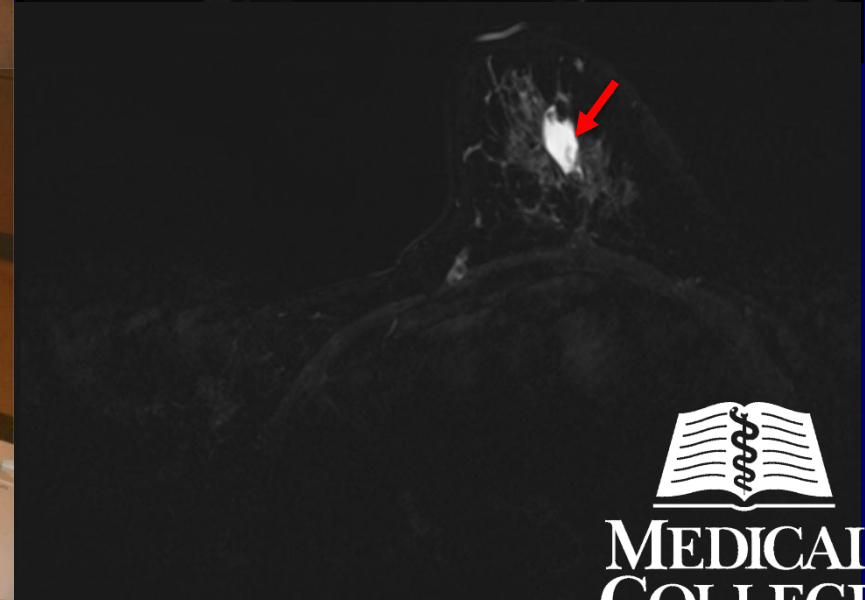
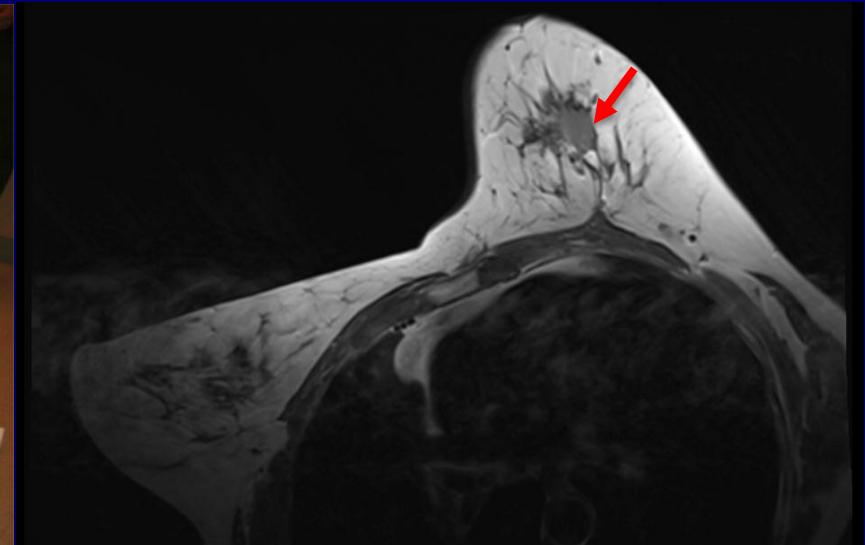
- A number of issues still impact image quality with off-the-shelf coils and standard immobilization materials
  - MRI-safe immobilization materials may still be suboptimal for scanning
  - Distance from coils to body due to table tops, immobilization equipment,...
  - Incompatible configurations for MRI and RT





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# Prone Breast scanning using a 4-channel coil



Paulson ES, et al, Med Phys (submitted)



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OF WISCONSIN



# MR Sim QA at UM

- Commissioning
  - Distortion across imaging field
  - Orientation labeling
- Daily
  - Uniformity tests
  - Rotate through coils
  - Disk space, helium level (stable)
- Weekly
  - ACR phantom imaged (analyzed monthly)
- Frequency being determined
  - LAP laser phantom

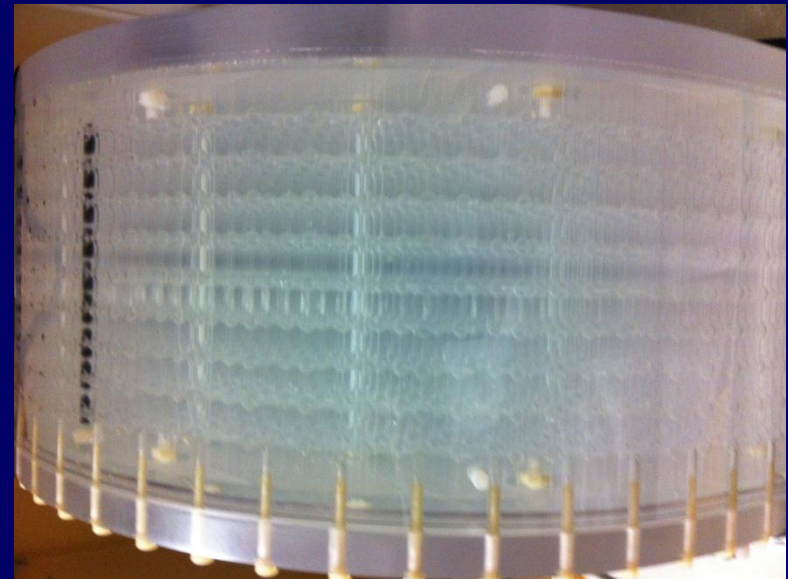




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# Geometric accuracy – phantom measurement

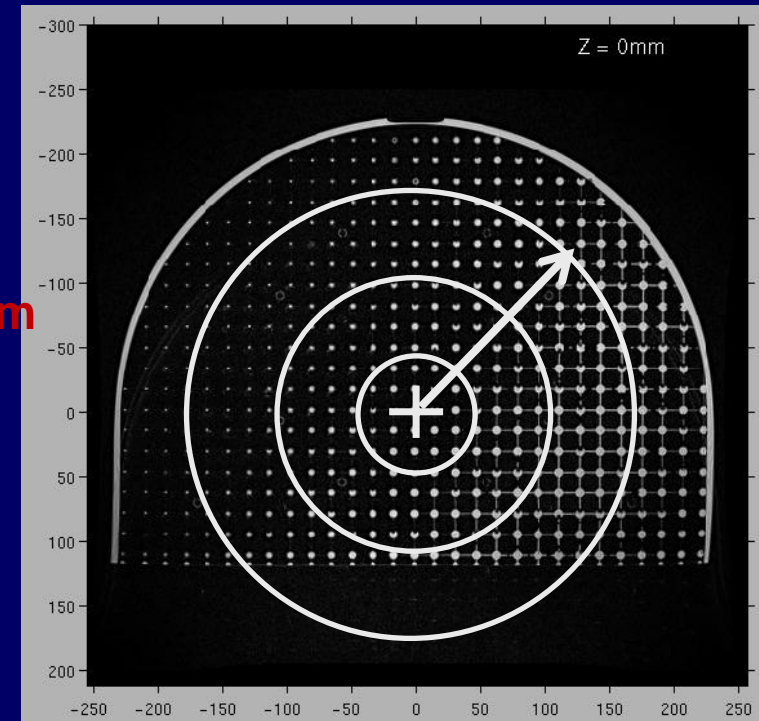
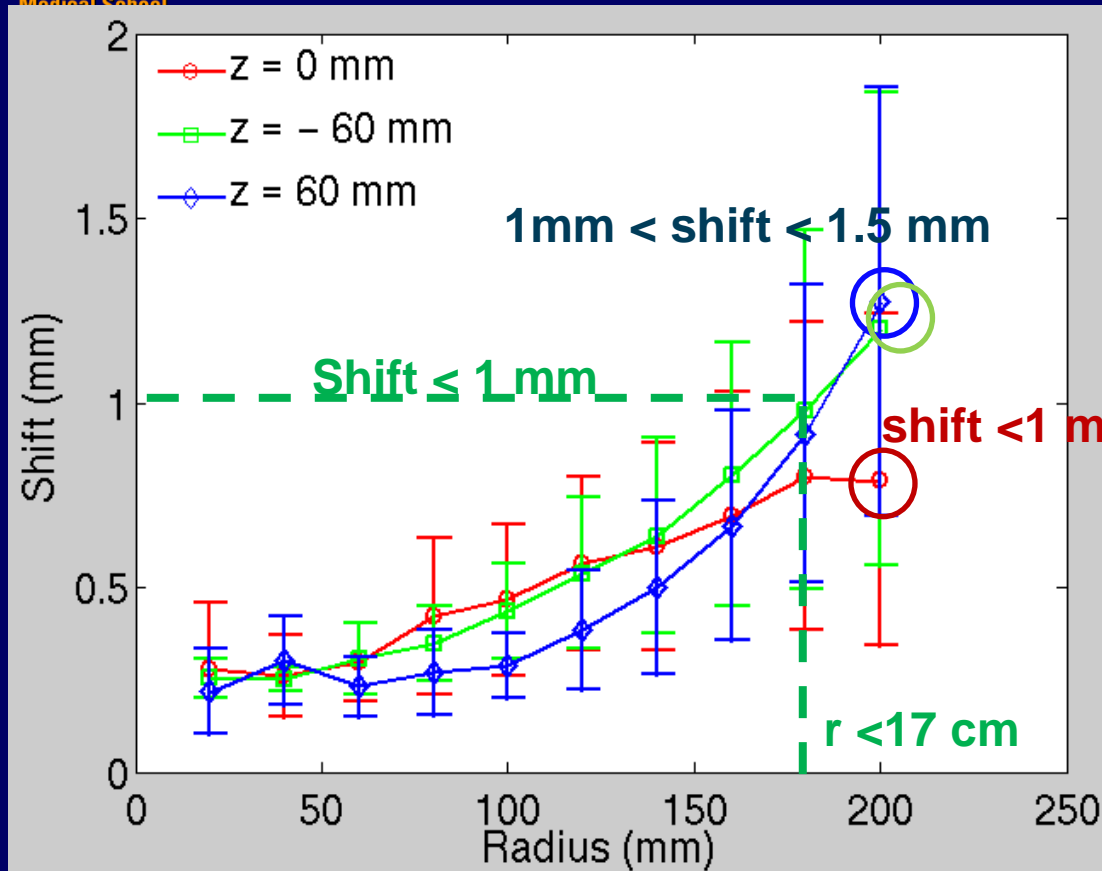
- Custom-designed large volume geometric distortion phantom (IMT and UM)





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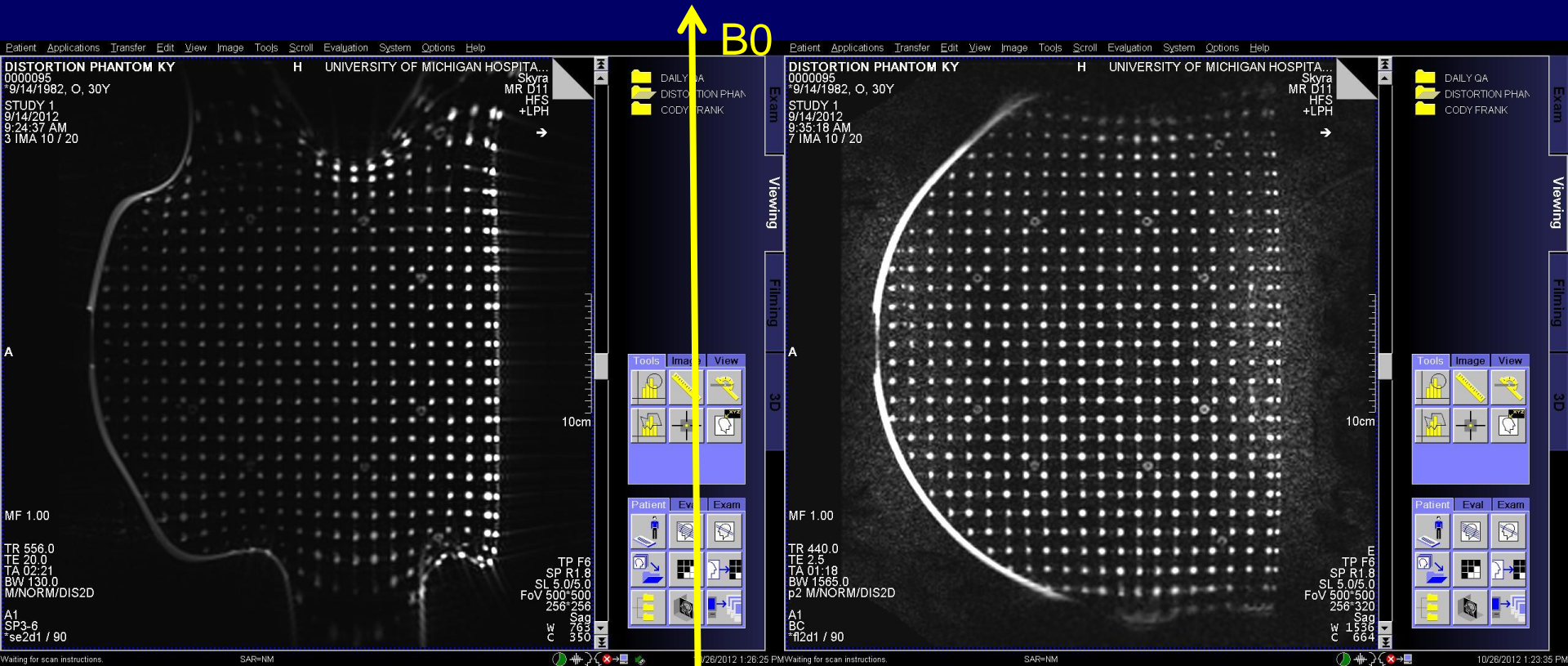
# Characterization of system-level distortion





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# Narrow vs Wide bandwidth



Narrow bandwidth

Wide bandwidth

$$x = x' + \Delta x \frac{\Delta B_0}{BW_f}$$



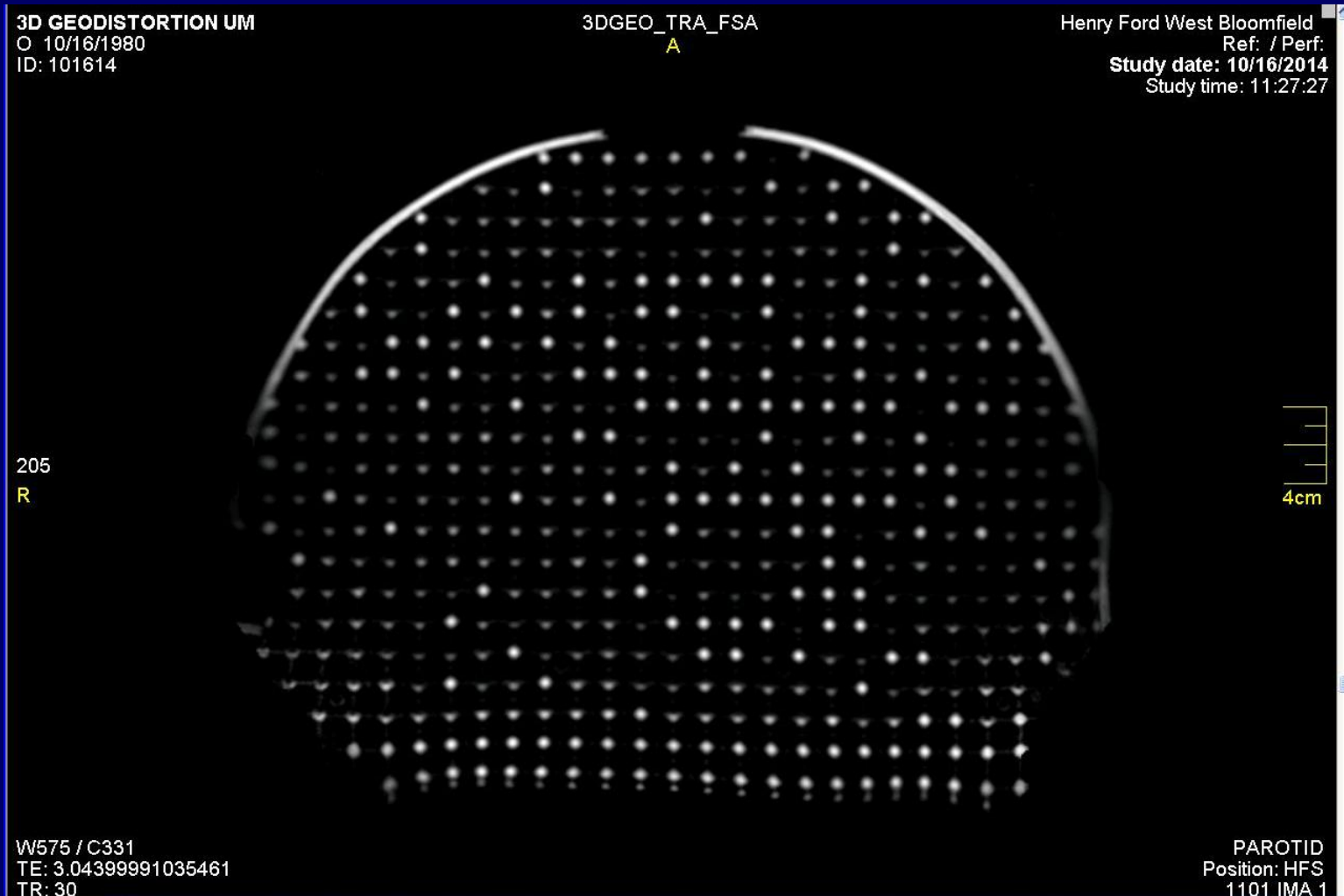
# Sources of Geometric Distortion

- System-level
  - B0 field inhomogeneity
  - Gradient non-linearity
- Patient-induced
  - B0 field inhomogeneity
  - Chemical shift effect



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# Image taken on a Panorama scanner



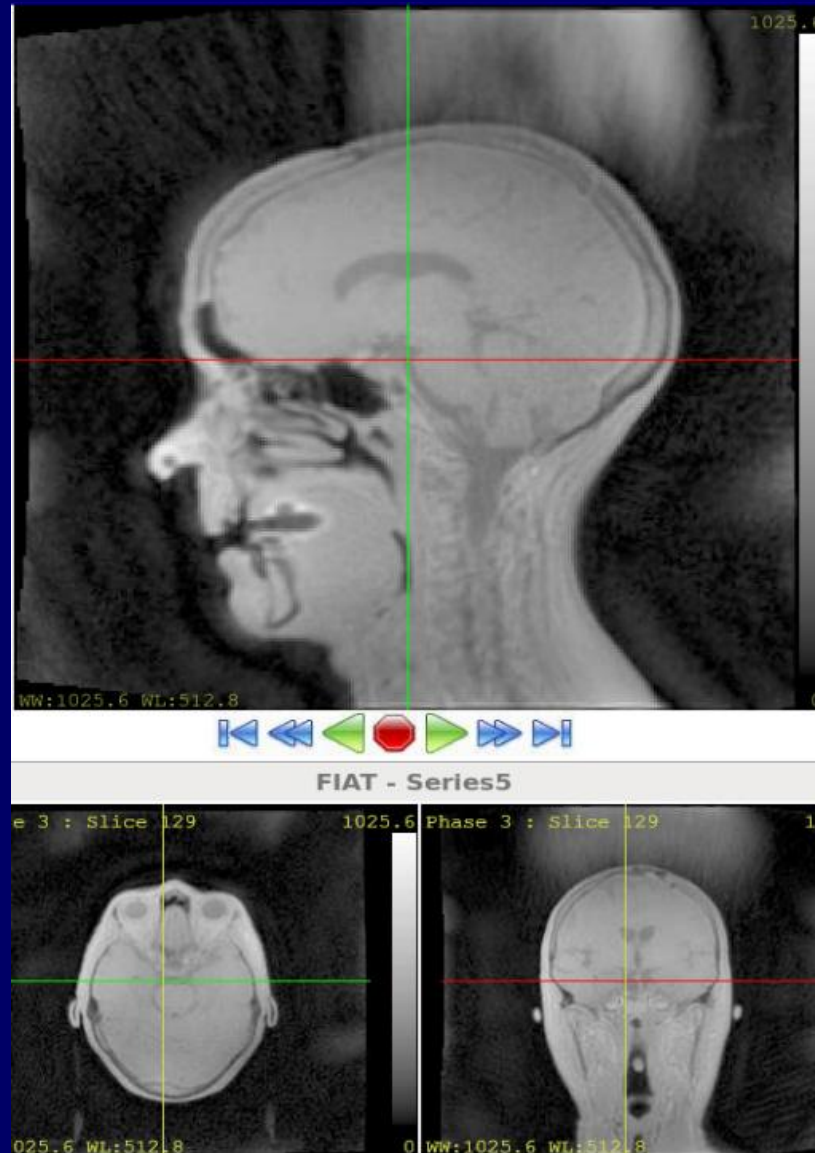
Slide courtesy of Henry Ford Hospital





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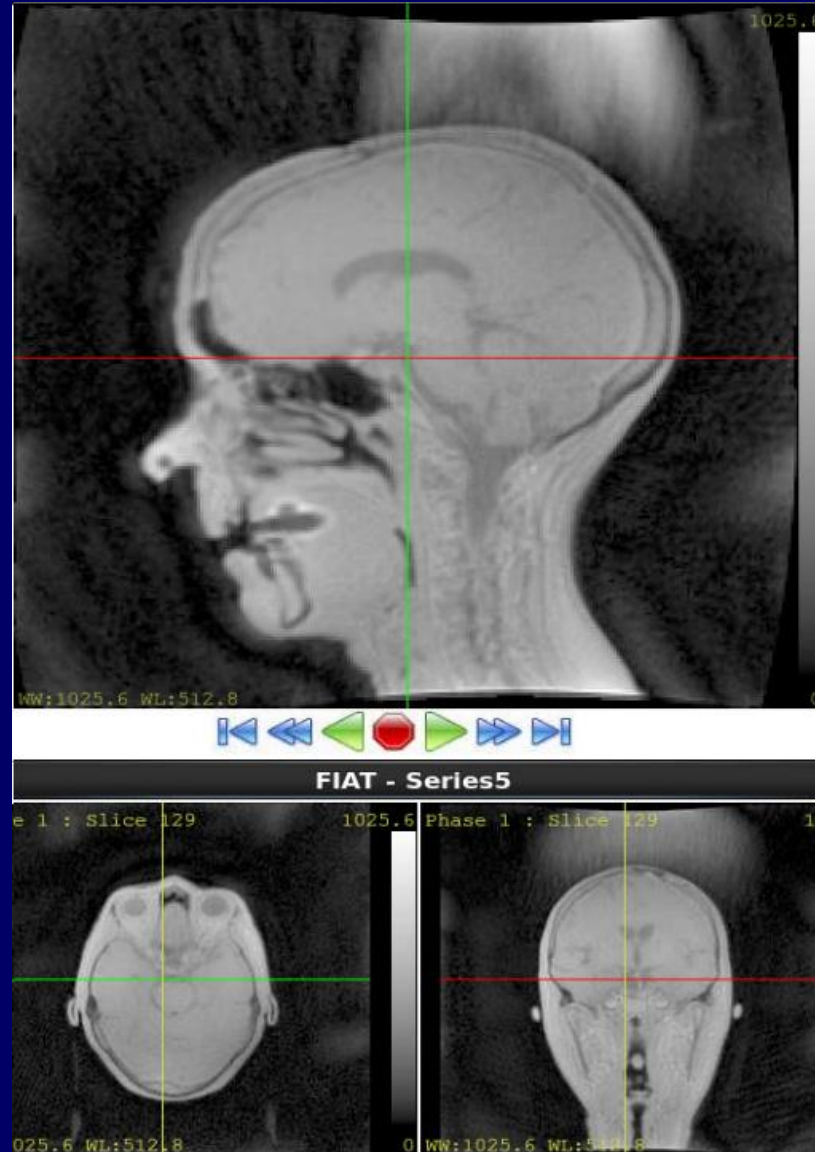
# PETRA with 3D Gradient non-linearity correction





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# PETRA without Gradient non-linearity correction





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# Laser QA

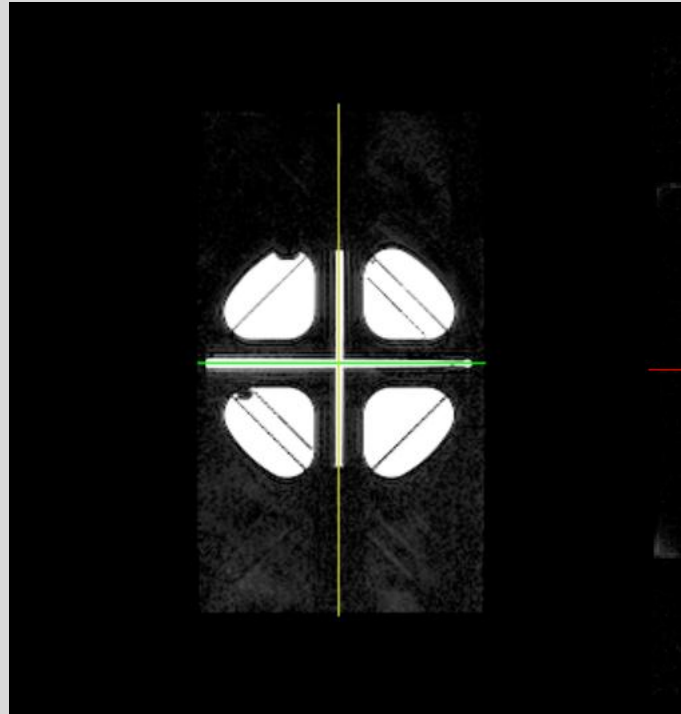




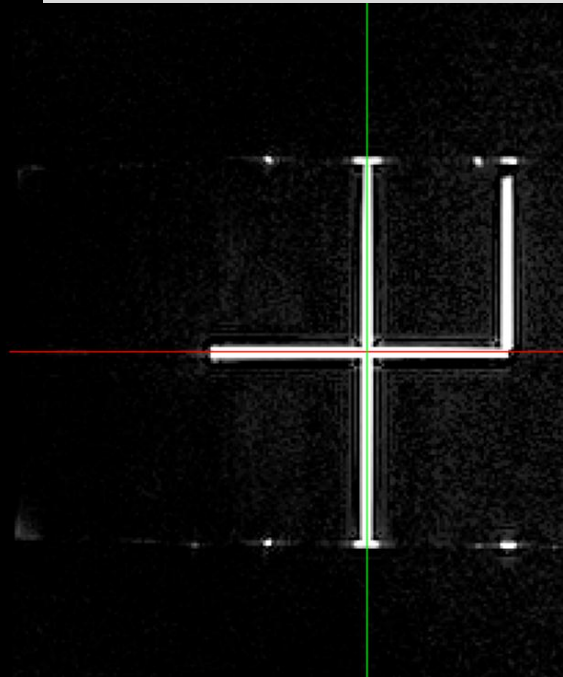


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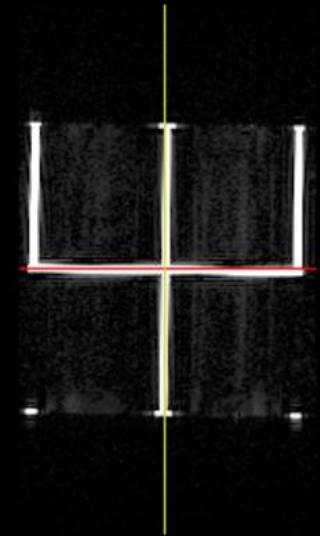
# Laser phantom images



axial



coronal



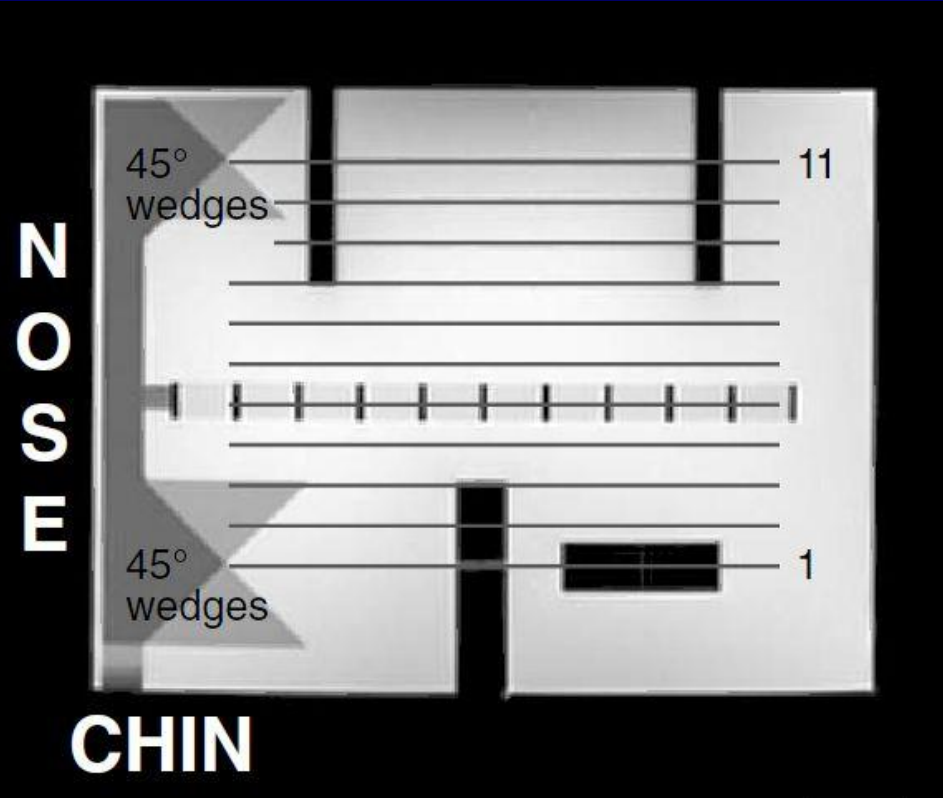
saggital

Error < 2 mm



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# ACR QA phantom





# ACR phantom tests

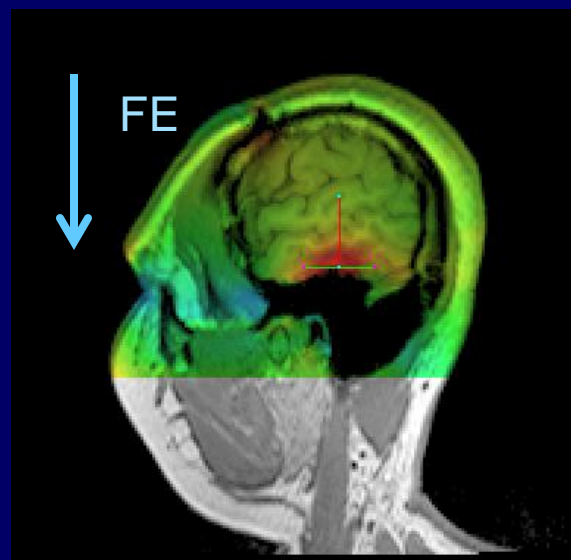
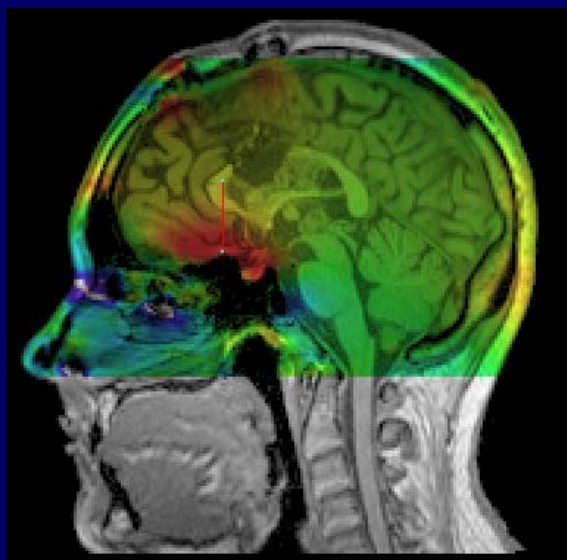
1. Geometry accuracy
2. High-contrast spatial resolution
3. Slice thickness accuracy
4. Slice position accuracy
5. Image intensity uniformity
6. Percent-signal ghosting
7. Low-contrast object detectability



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# Distortion from magnetic susceptibility differences

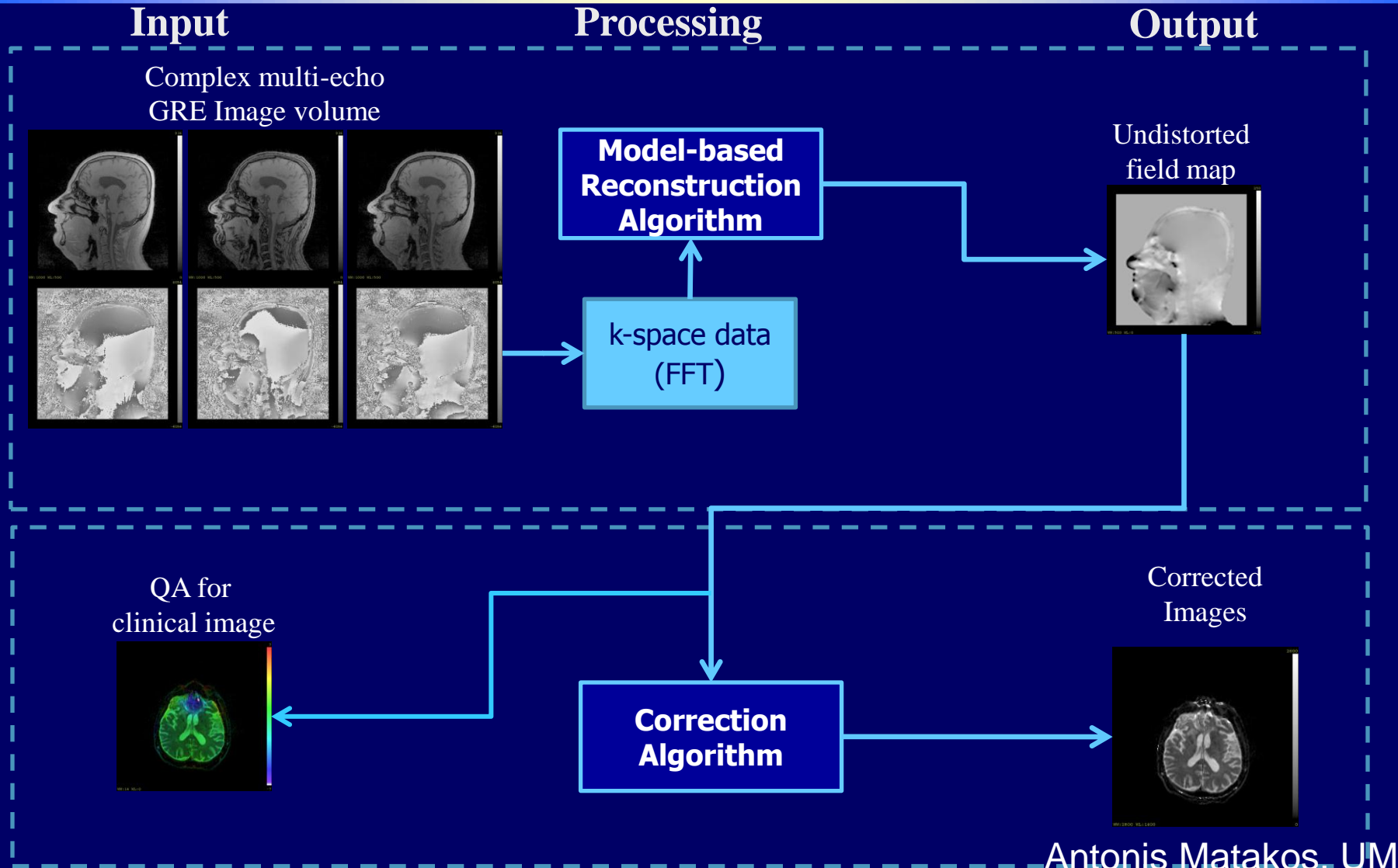
Patient-specific magnetic susceptibility can be mapped, and the related distortion can then be calculated and corrected for imaging sequences used





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# Patient-Specific Distortion Correction and QA





# MRI Safety

- Form a MRI safety committee
  - A MD as director, level-2 safety officers (physicists, MRI sim therapists...)
- Establish an education Program
  - All staff in the department has to pass education training annually
- Certify level-2 safety officers
- Control the access to the MRI suite





# MRI protocol development and workflow for RT

- Build a multi-disciplinary team per body site
  - Radiation oncologist, MRI/clinical physicist, dosimetrist, sim therapist, (radiologist)
- Understand intended use of MRI
  - Target and OAR delineation
  - Tumor invasion, tumor growth since diagnosis
  - Tx guidance
  - Dose planning, Dose coverage verification
  - Image registration, motion management
- Develop an imaging protocol and re-visit after a period of time (feedback)



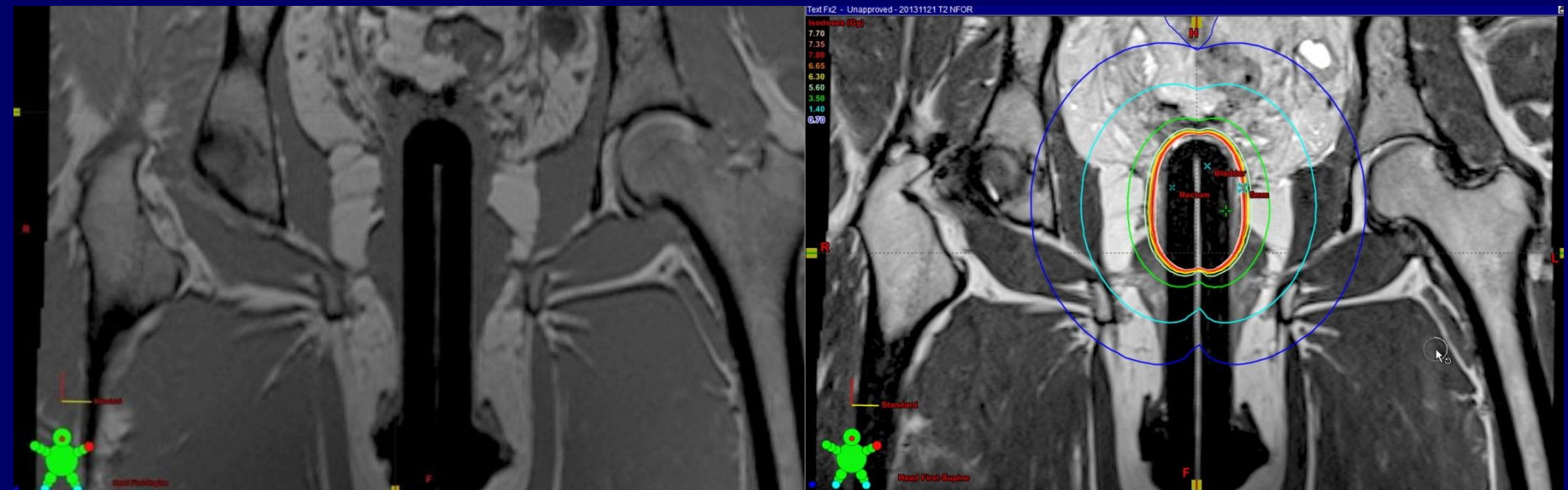
# Dedicated Protocol Development

- Optimize the number of sequences to meet multiple needs
- Shorten the scan time
- Lock shimming after individual patient shimming



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# MRI-based HDR using cylindrical applicators



T1-weighted image (applicator)

T2-weighted image (anatomy)

Slide courtesy of Joann Prisciandaro



# GYN HDR protocol

localizer 00:29

COVER FEMORAL HEAD TO FEMORAL H...

2 CM SUP TO CREST

t1\_ANGLE\_vibe\_COR\_SB\_p2\_SFOV... 01:24



t2\_2Dtse\_AX\_320\_SFOVp2\_STRAIG... 02:11



t2\_2Dtse\_SAG\_320\_SFOVp2\_STRAI... 02:11



**Scan time < 6min**



# HN protocol

localizer	00:13
t1_tse_tra_3mm_p2_top of FS to Man...	02:08
ep2d_diff_b50_400_800_tra_p2	05:01
t2_tse_tra_fs_320_top of FS to Mandi...	03:14
TWIST_3D_DCE_SAG_DRY RUN	00:47
Post Contrast	
TWIST_3D_DCE_SAG_inject_after_5	03:01
t1_tse_fs_tra_3mm_post_NASAL	05:35
t1_vibe_tra_1mm_320_FS	03:54

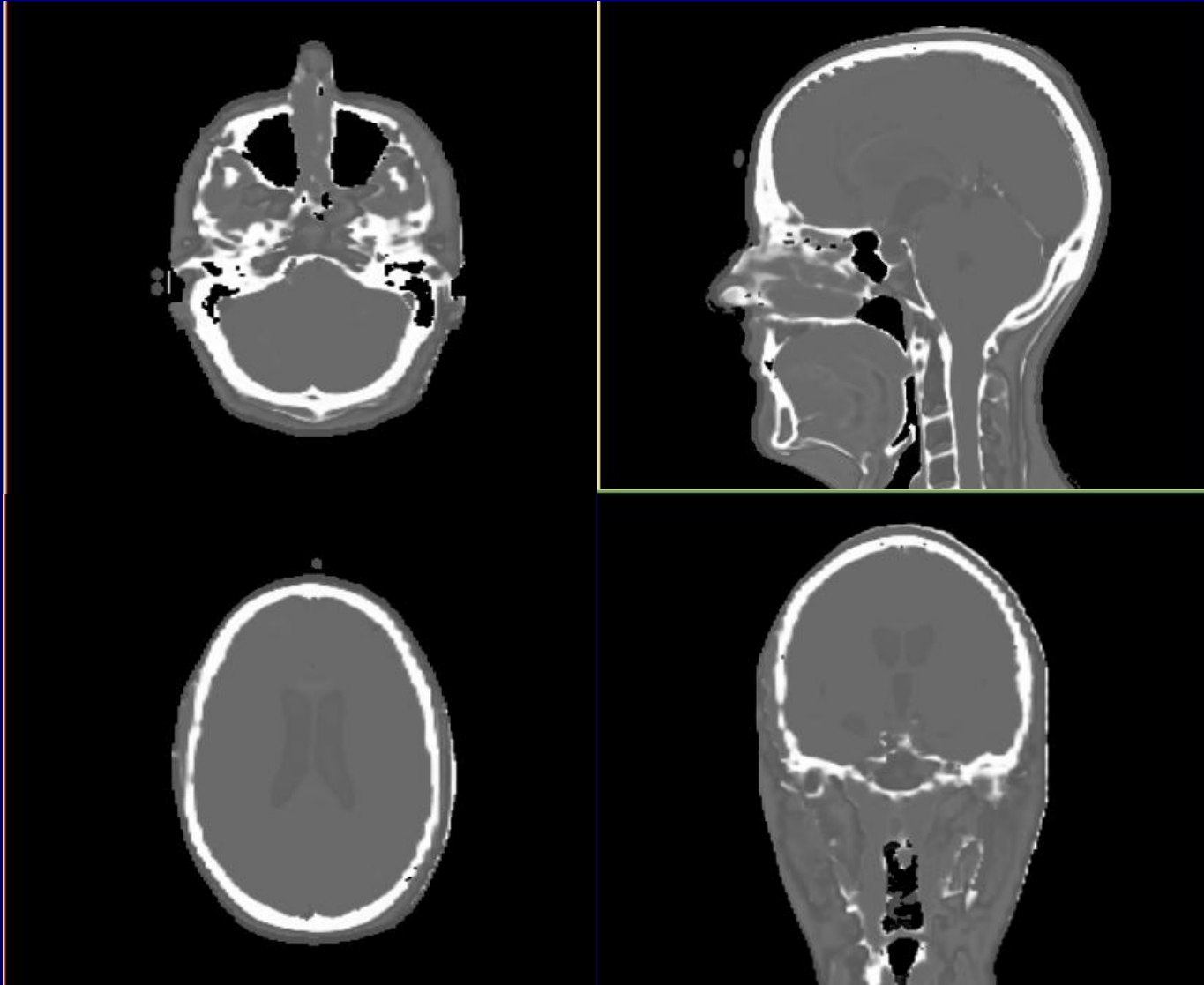
10 min

8 min



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# MRI alone simulation: Synthetic CT





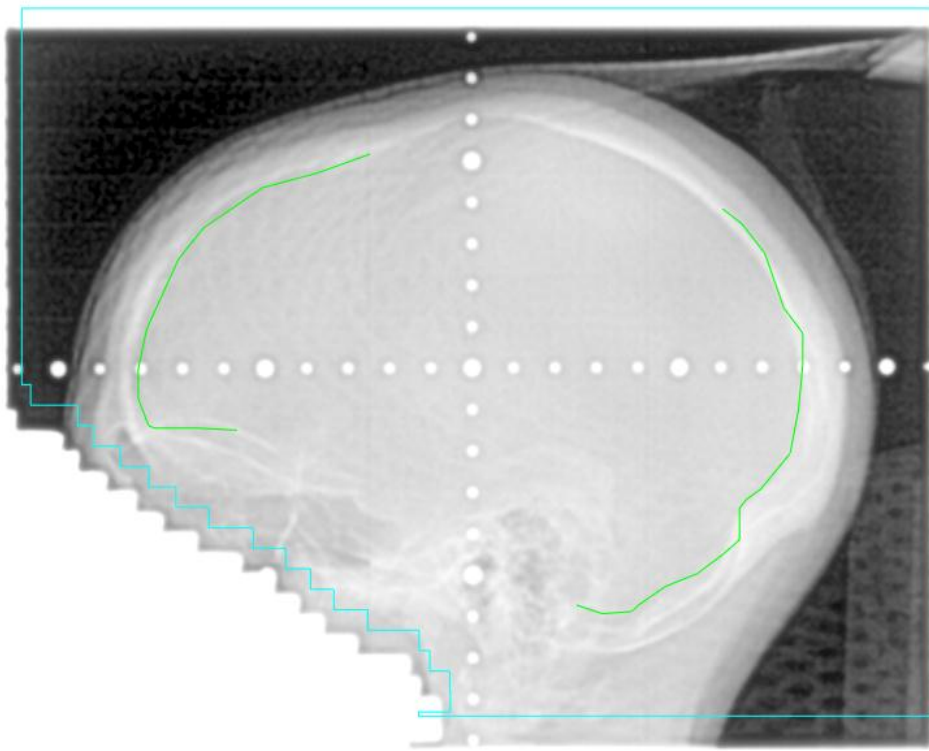


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# Whole brain setup verification – MV portal image aligned to MRCT-derived DRR

LLAT-DRR - LLAT-3\_1\_51 - 8/22/2013 16:26 - 90 deg

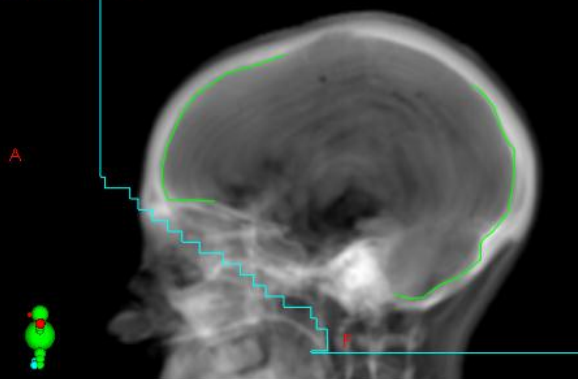
Field edge: Planned



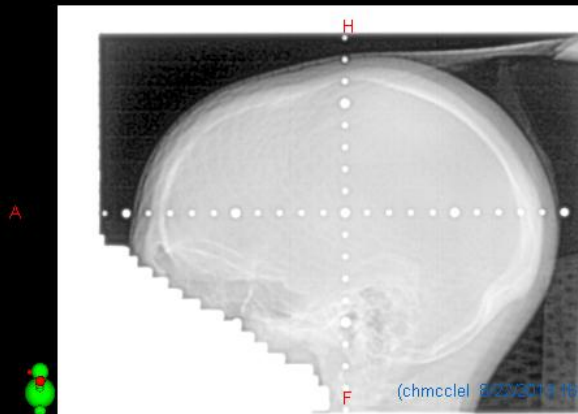
100 %

LLAT-DRR - 8/22/2013 11:02 - 90 deg

Field edge: Planned



LLAT-3\_1\_51 - 8/22/2013 16:26 - 90 deg

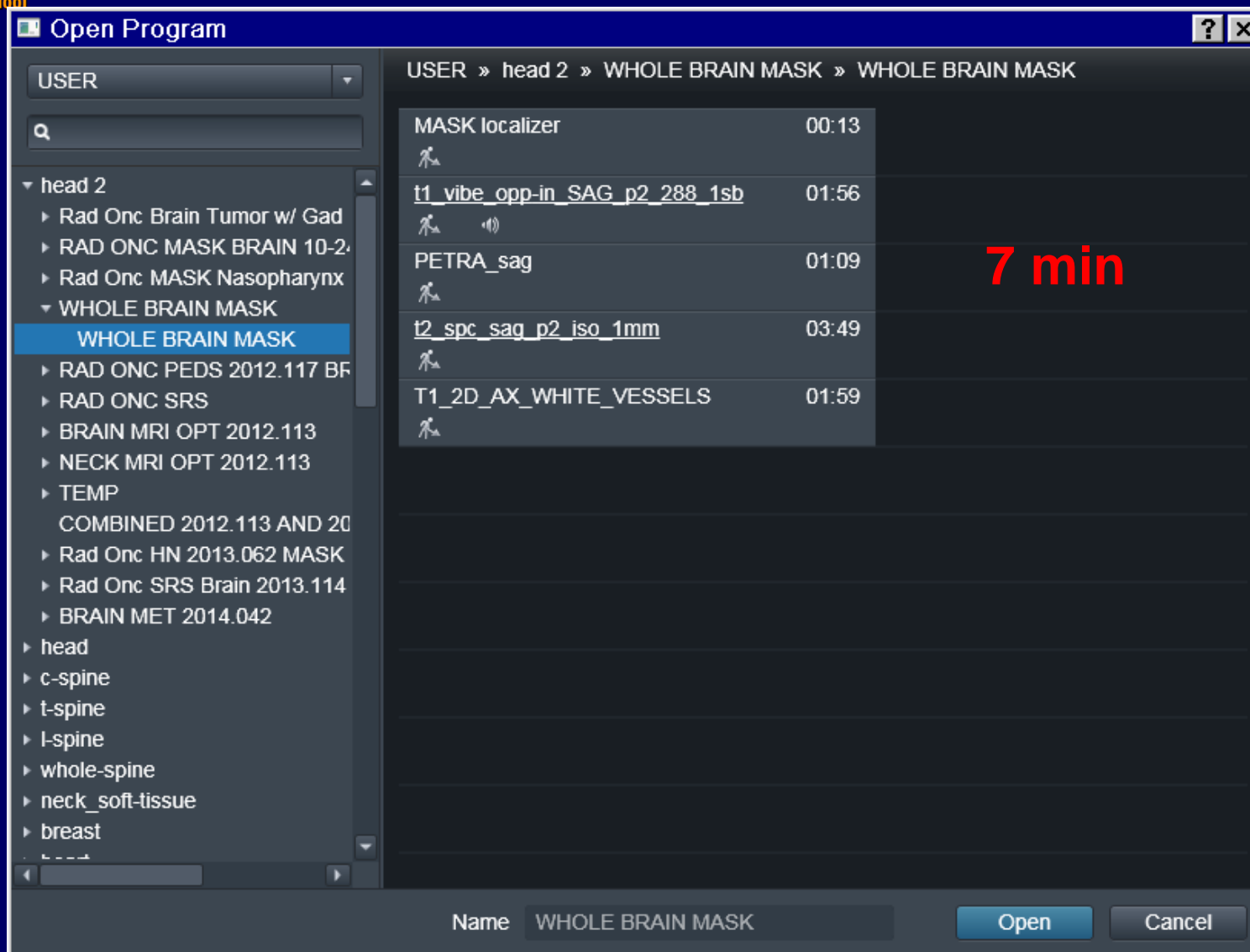


(chmcclel 8/22/2013 15:27)



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# Brain Sim MRCT Protocol





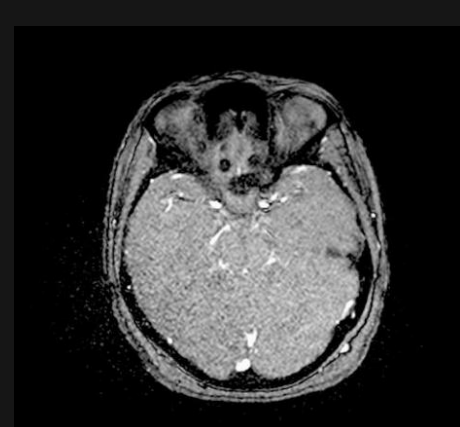
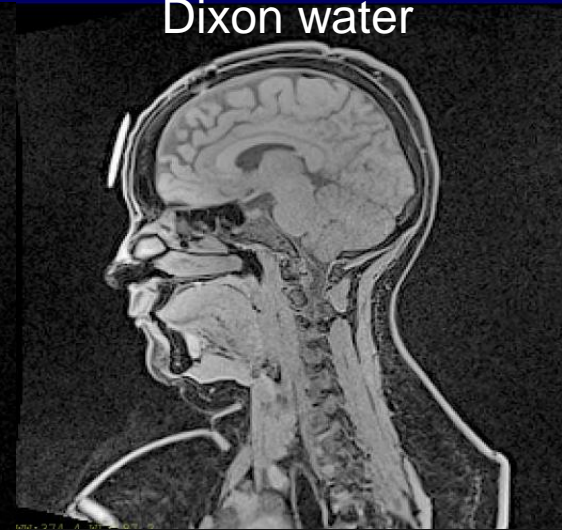
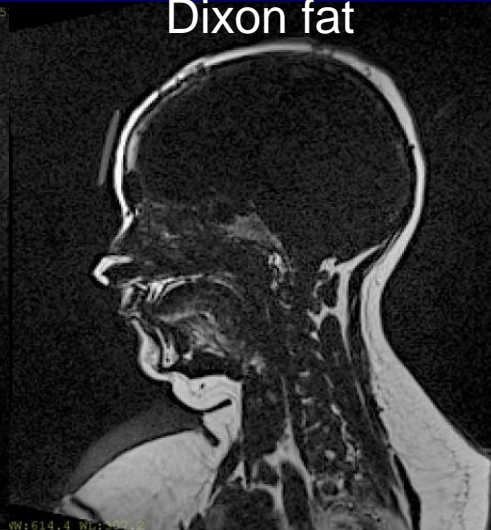
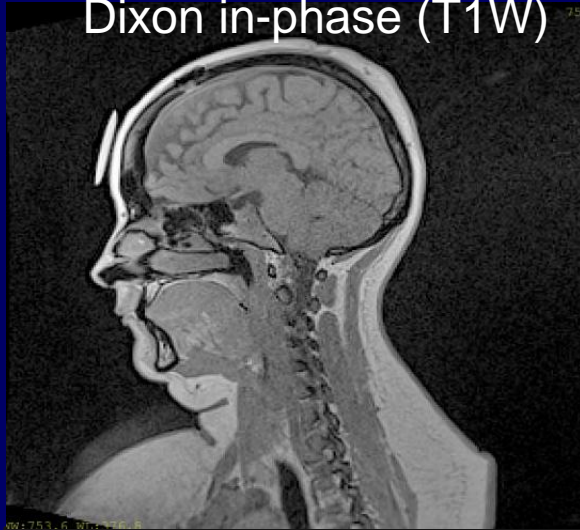
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# Example images used for tissue classification

Dixon in-phase (T1W)

Dixon fat

Dixon water



T2-weighted

UTE (PETRA)

Time of flight

Used for air mask

Used for vessel mask

# Summary

- RT simulation has different needs than diagnosis radiology for MRI
  - More concerns about small distortions, intensity uniformity

Describe these needs in the RFP  
and build the workflow in your  
program

- Anatomical extent
- Less critical for initial sensitivity/specificity