

MR-Only Simulation

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Conflicts of Interest

- Scientific Advisory Board: ViewRay

MRI in RT Departments

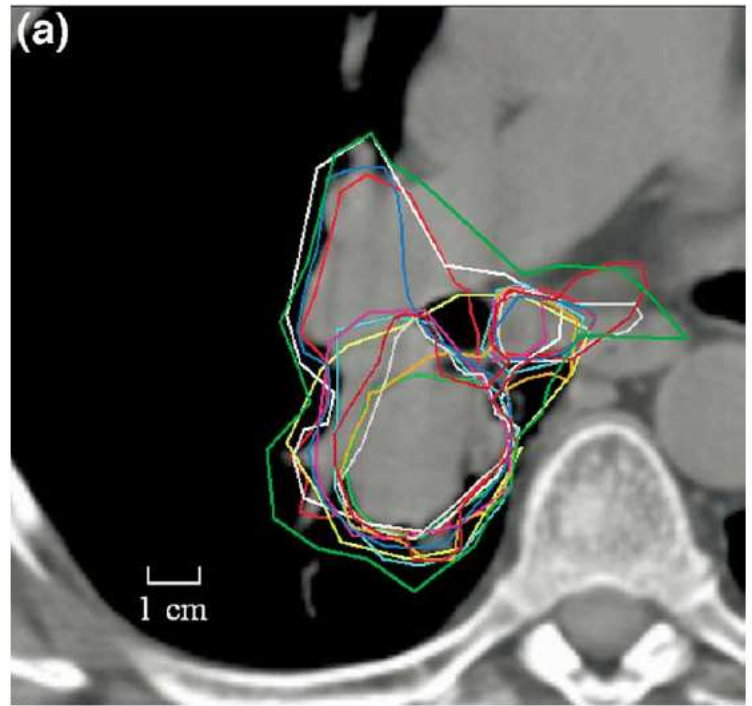
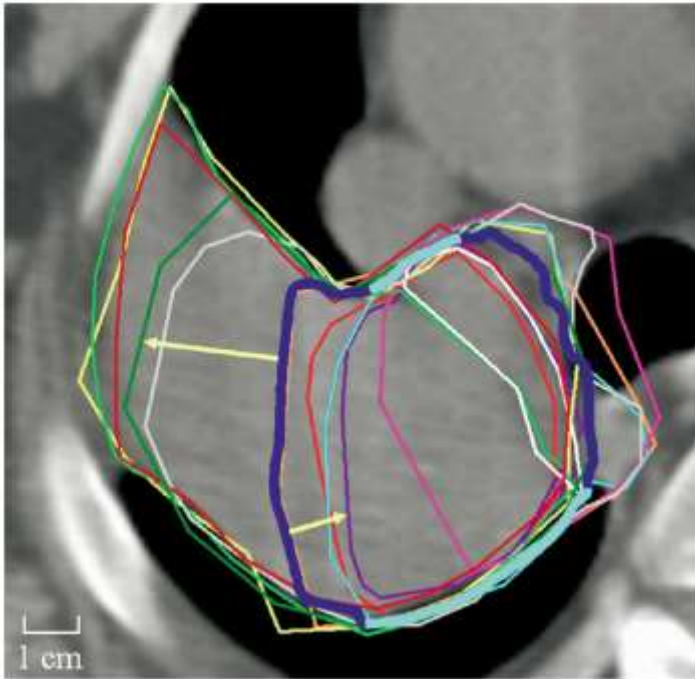
- Workshop in 2012 November 1, Brigham Women's Hospital
 - U Penn
 - Wake Forest
 - Beaumont
 - U Michigan
 - Princess Margaret
 - Hopkins
 - Duke
 - U Iowa
 - Fox Chase
 - Mayo
 - Wash U
 - Harvard
 - Medical College Wisconsin
 - Wake Forest
 - St. Jude
 - UCLA



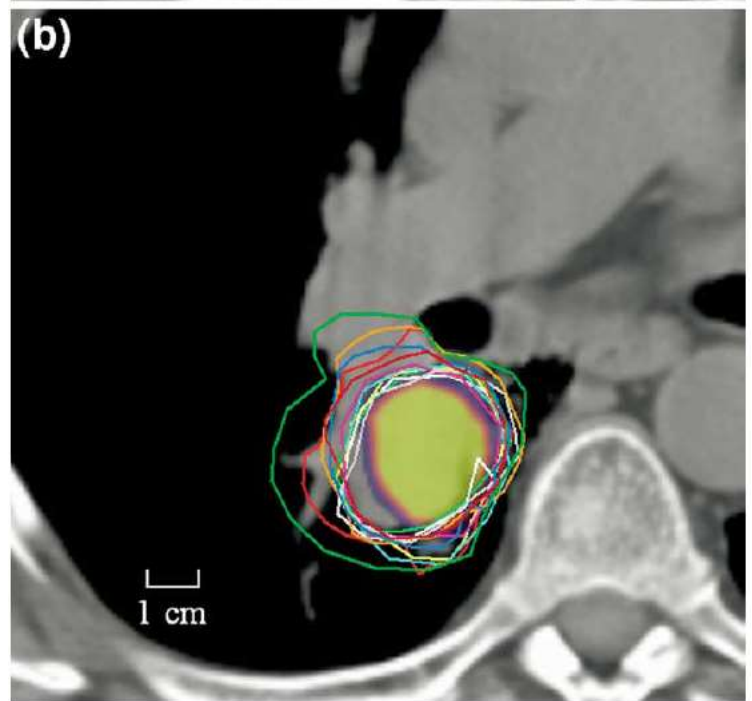
Why MR Sim?

- Hypothesis: We are very precise, but not so accurate with radiation therapy
- Precision comes from accurately knowing the dose within the patient
- However, tumor segmentation is often unreliable, so dose is inaccurately optimized
- MR Sim will improve accuracy

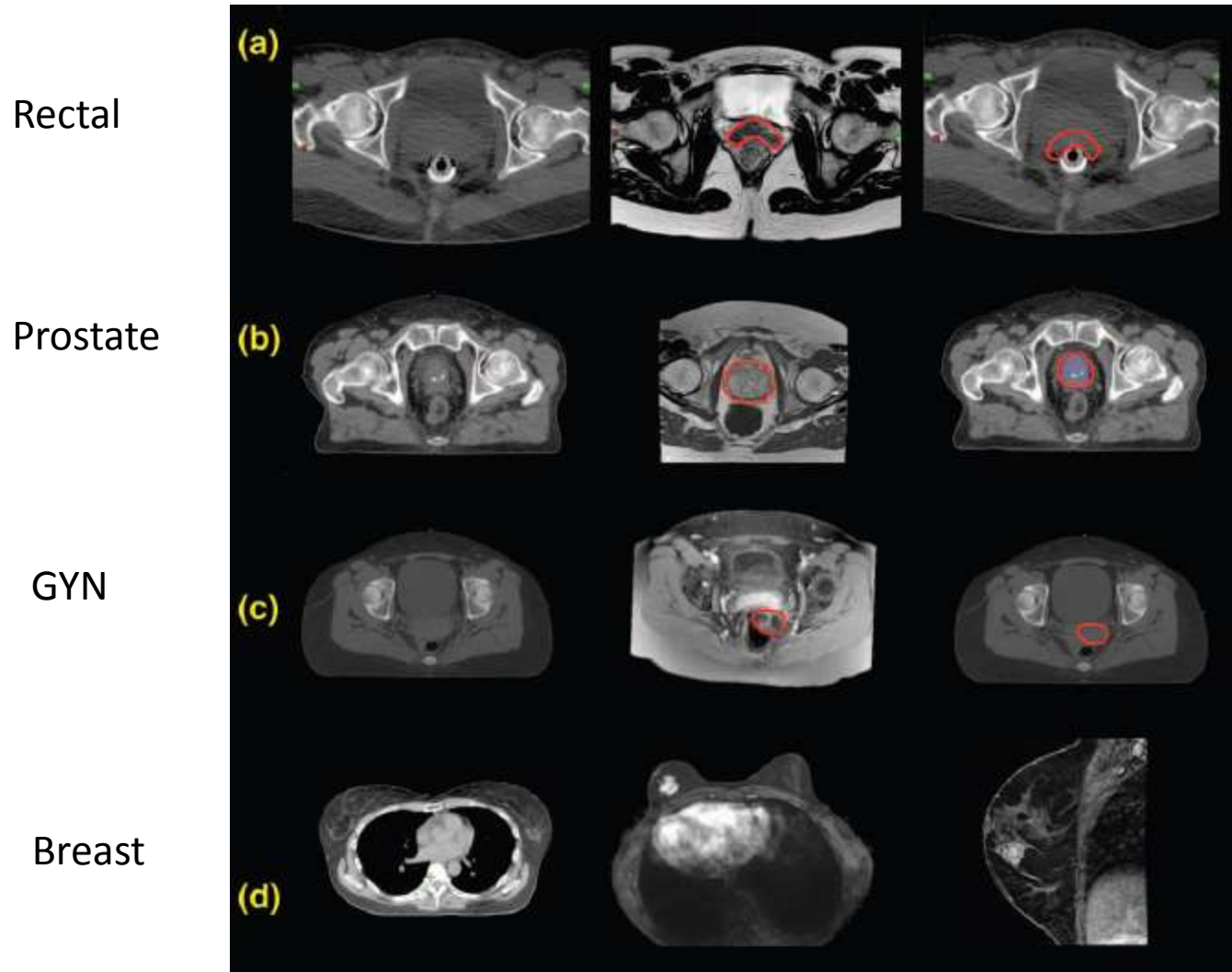
No PET



With PET



Sites

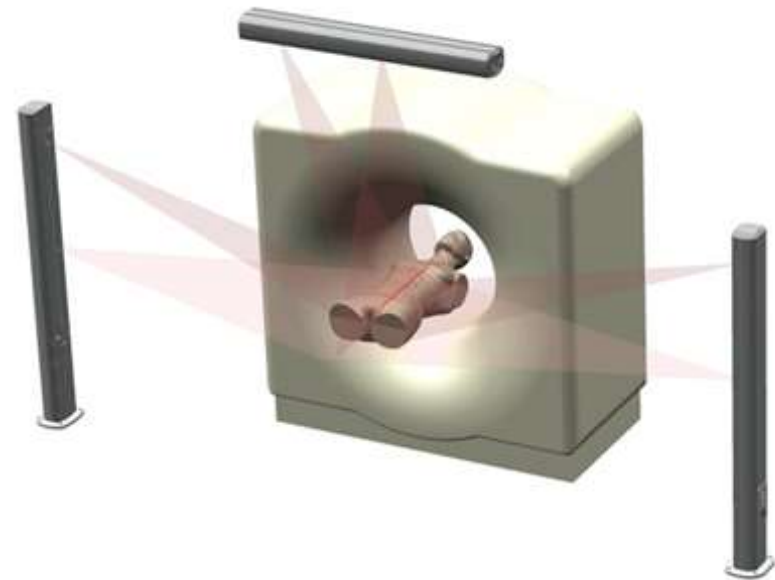


Why not BOTH MR and CT Sim?

- Reimbursement for one sim only
- No widespread demonstration of clinical need
- Solution: MR Sim only?
- MR Sim only will increase accuracy, but degrade precision (dose will be less accurately known)

MR Simulation

- MR providing primary or sole 3D imaging information
- What does CT give us that we need to replace or manage?
 - Bigger bore (85-90 cm vs 70 cm)
 - Unobtrusive imaging setup (coils)
 - Flat couches
 - Spatial integrity
 - Electron density (from HU)
 - Reference kV images (e.g. DRRs)
 - 4D imaging
 - Lung cancer imaging
 - Training



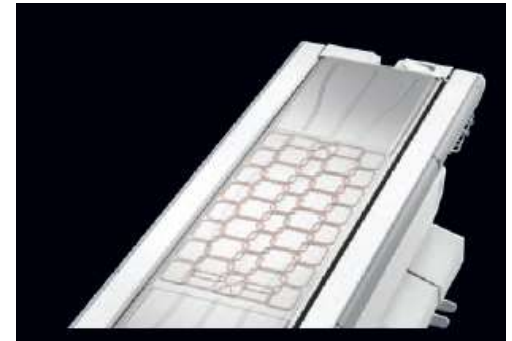
Smaller Bore

- 70 cm bore: Modify immobilization and patient setup
- Back to old days with smaller bore
- Modify patient positioning
- Modify immobilization systems



Obtrusive Imaging

- MR requires coils placed near the anatomical sites of interest
- Potential for distorting anatomy
 - Floating
 - Rigid immobilization
 - Built-in coils



Spatial Integrity

- Most modern MRI scanners shim so they are within 2 mm in a ~ 40 cm diameter sphere
- Multiple sweet spots can be chained together by abutting image acquisitions

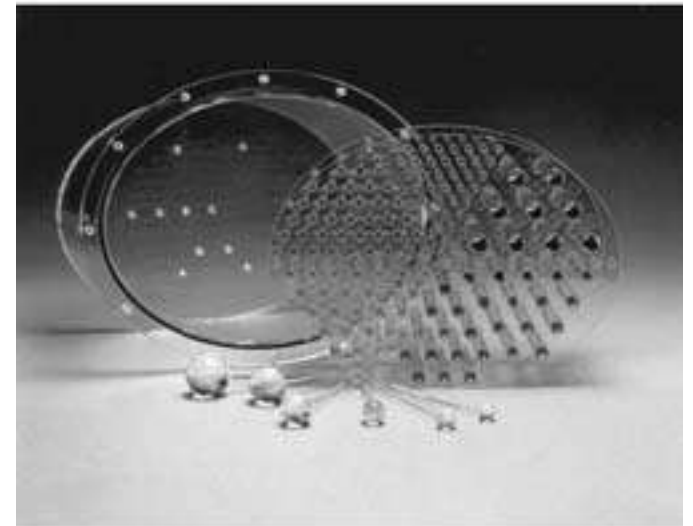
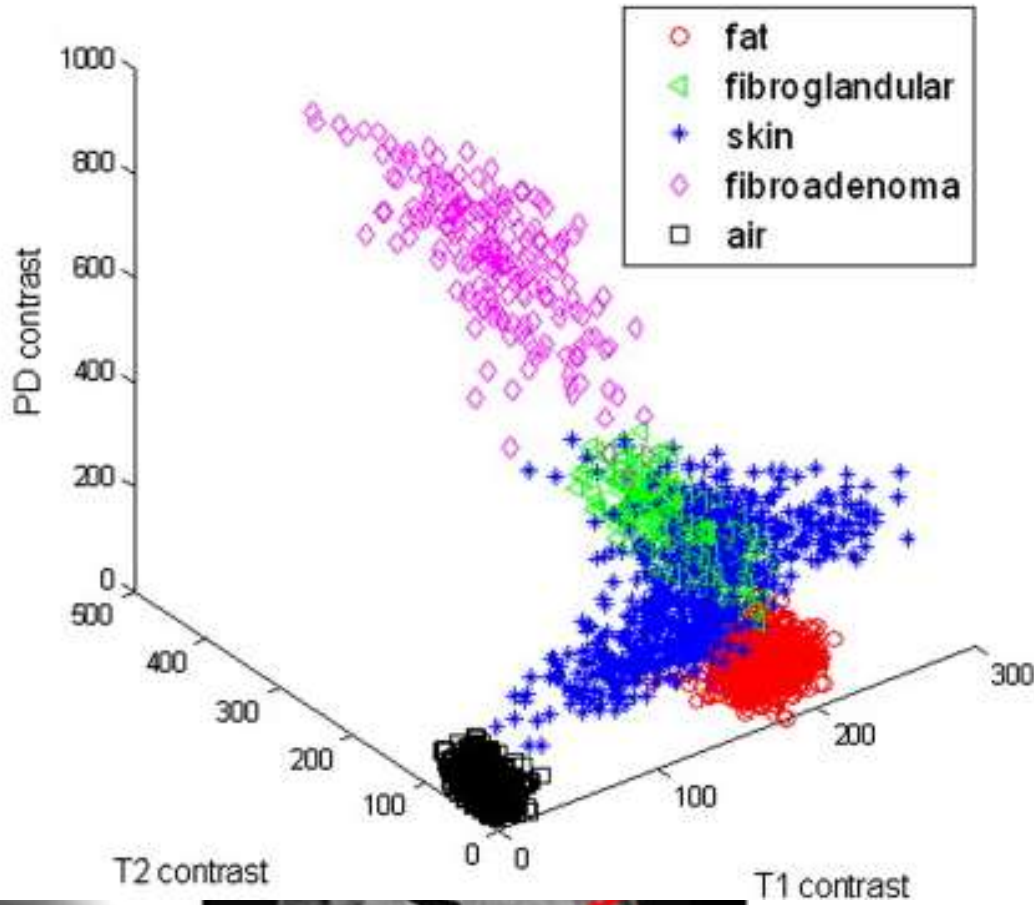


Image Series'

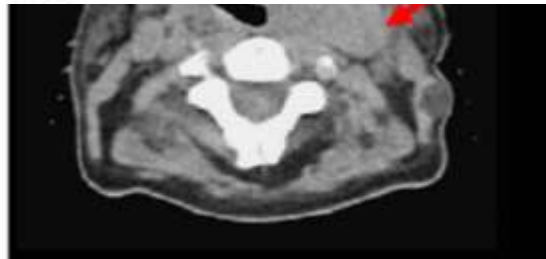
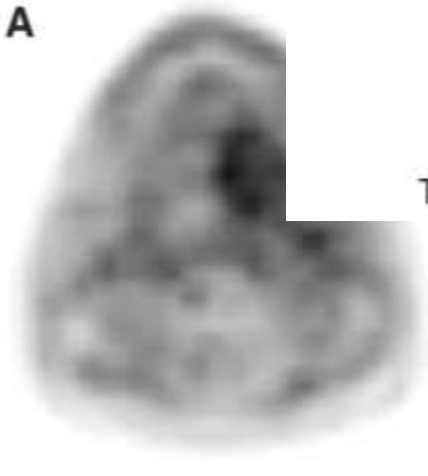
- Manual (functional)
 - Developmental and
 - Regional



and use

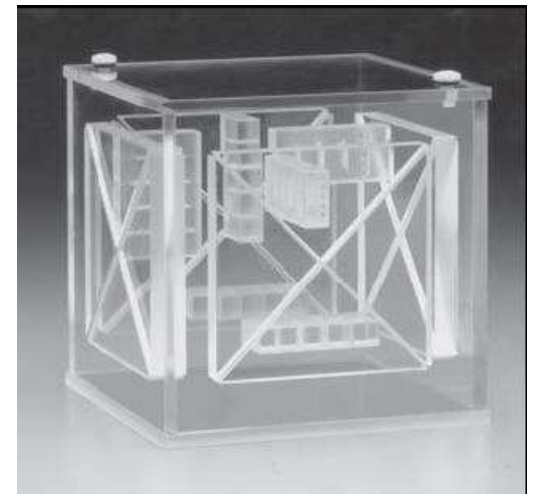
the images

A



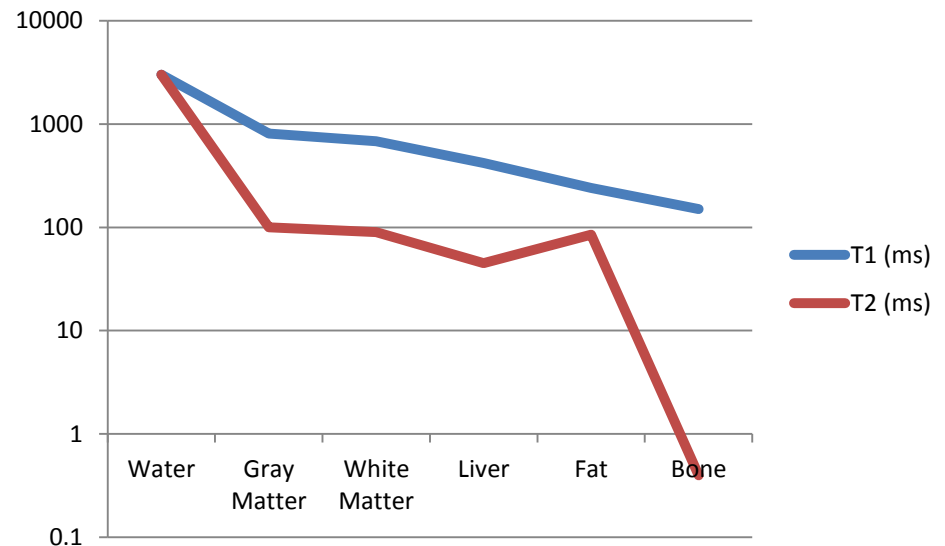
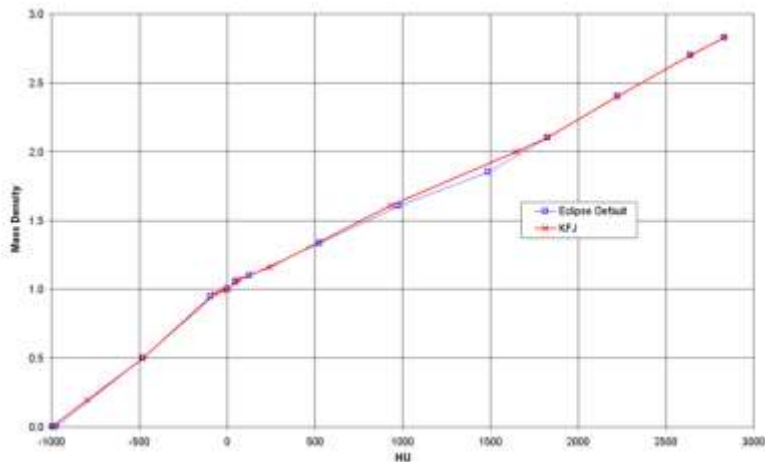
Spatial Accuracy

- Need to have validation on per-patient basis that images are spatially robust
 - Daily may be insufficient
 - Patient-based distortions: chemical and metal
 - Machine-based distortions: Permanent markers?



Electron Density

- Used for dose calculation
- CT: Essentially is free due to physics of attenuation coefficients of 120 kV and electron density



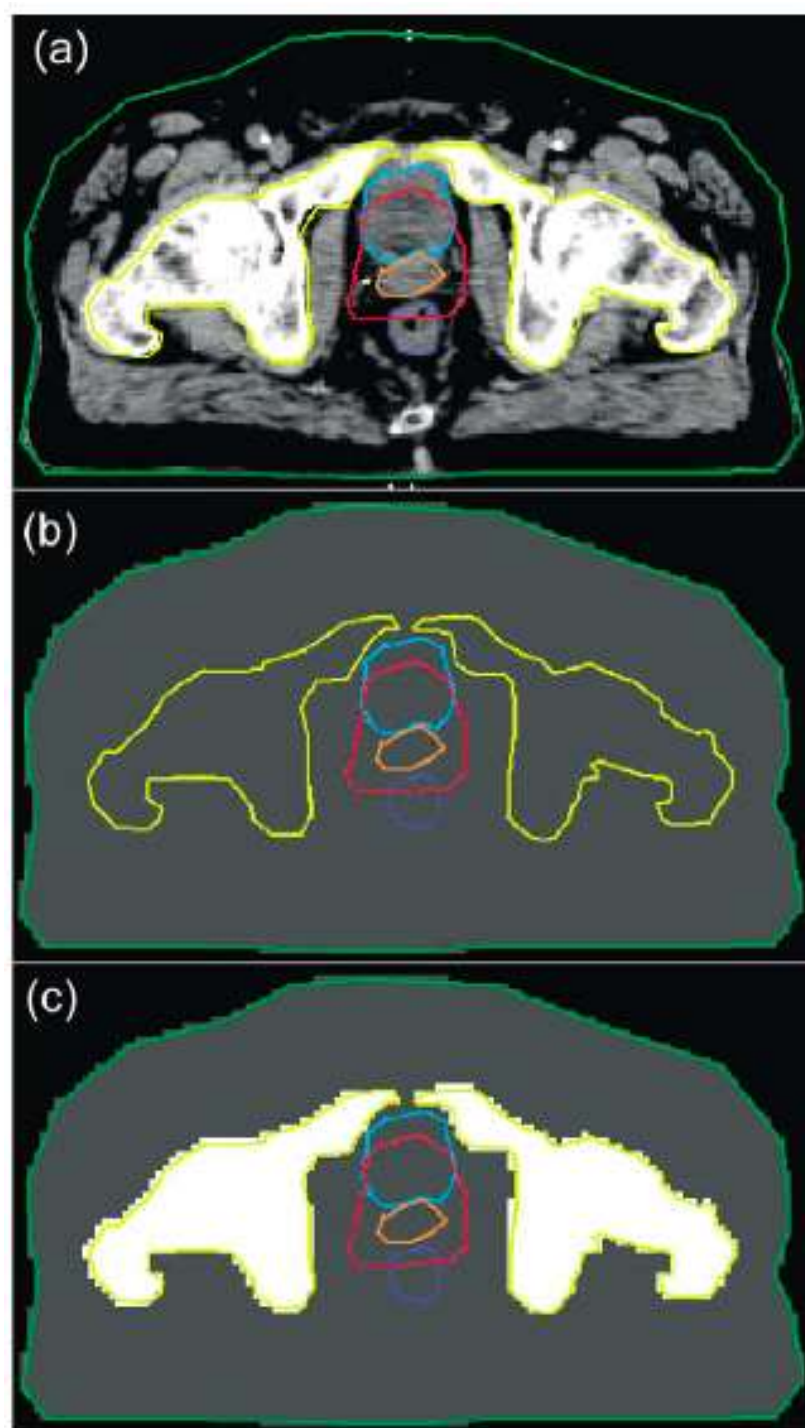
Solutions?

- Water
- Bulk density assignments
- Brain: 2-3% differences heterogeneities on vs off
(Ramsey and Oliver, MP 25 (1998) 1928)
- Head Neck: CT vs Water vs 3 levels (bone, air, tissue) bulk assignment.
Water = 4%-5%, bulk = 2%
(Karotki et al, JACMP 12 (2011) 97)

Prostate

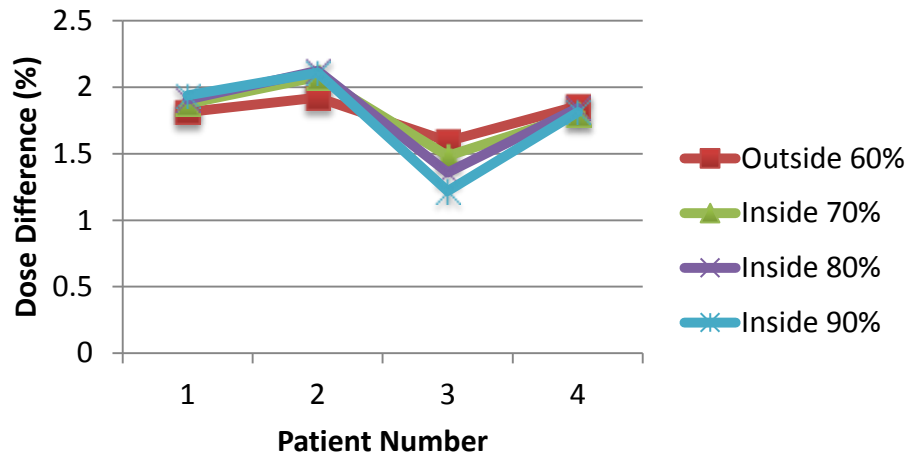
- Lee et al (Green J 66, 203, 2003)
- Water, bulk density, original CT
- 4 patients
- 64 Gy Rx

$$\%diff_{(D_{CT}-D_x)_i} = \frac{D_{CT_i} - D_{x_i}}{D_{CT_i}} \times 100$$

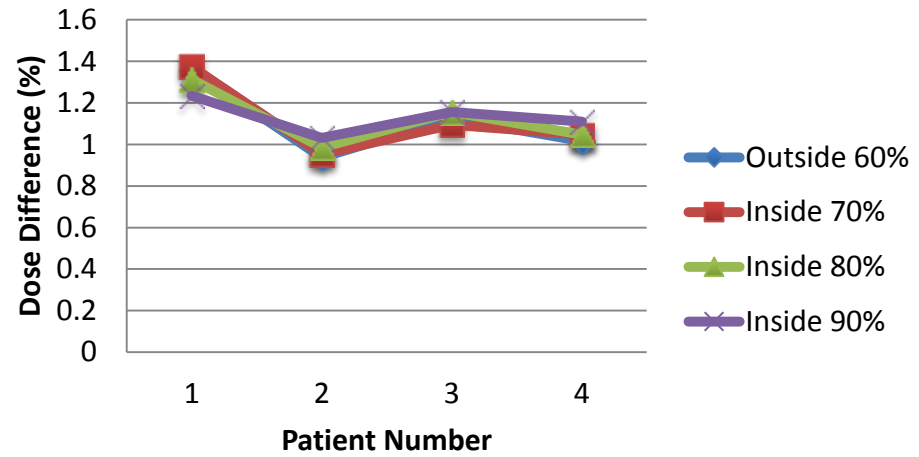


Results

Water vs CT



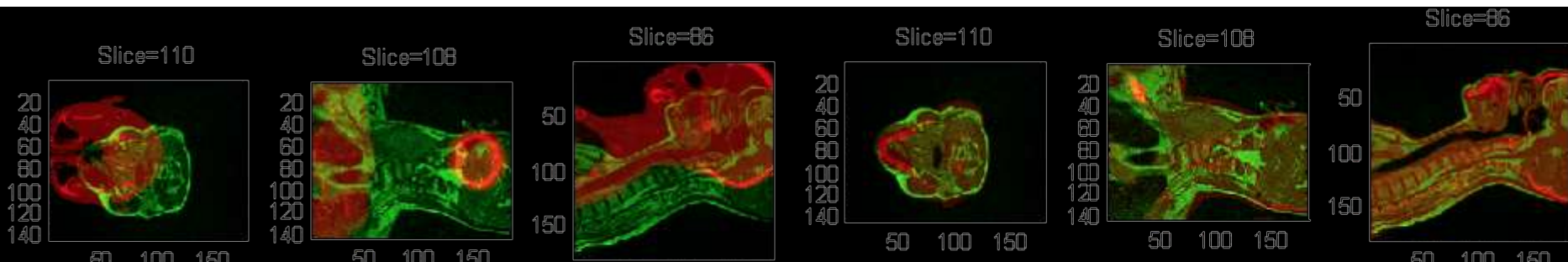
Bulk vs CT



Reference Images

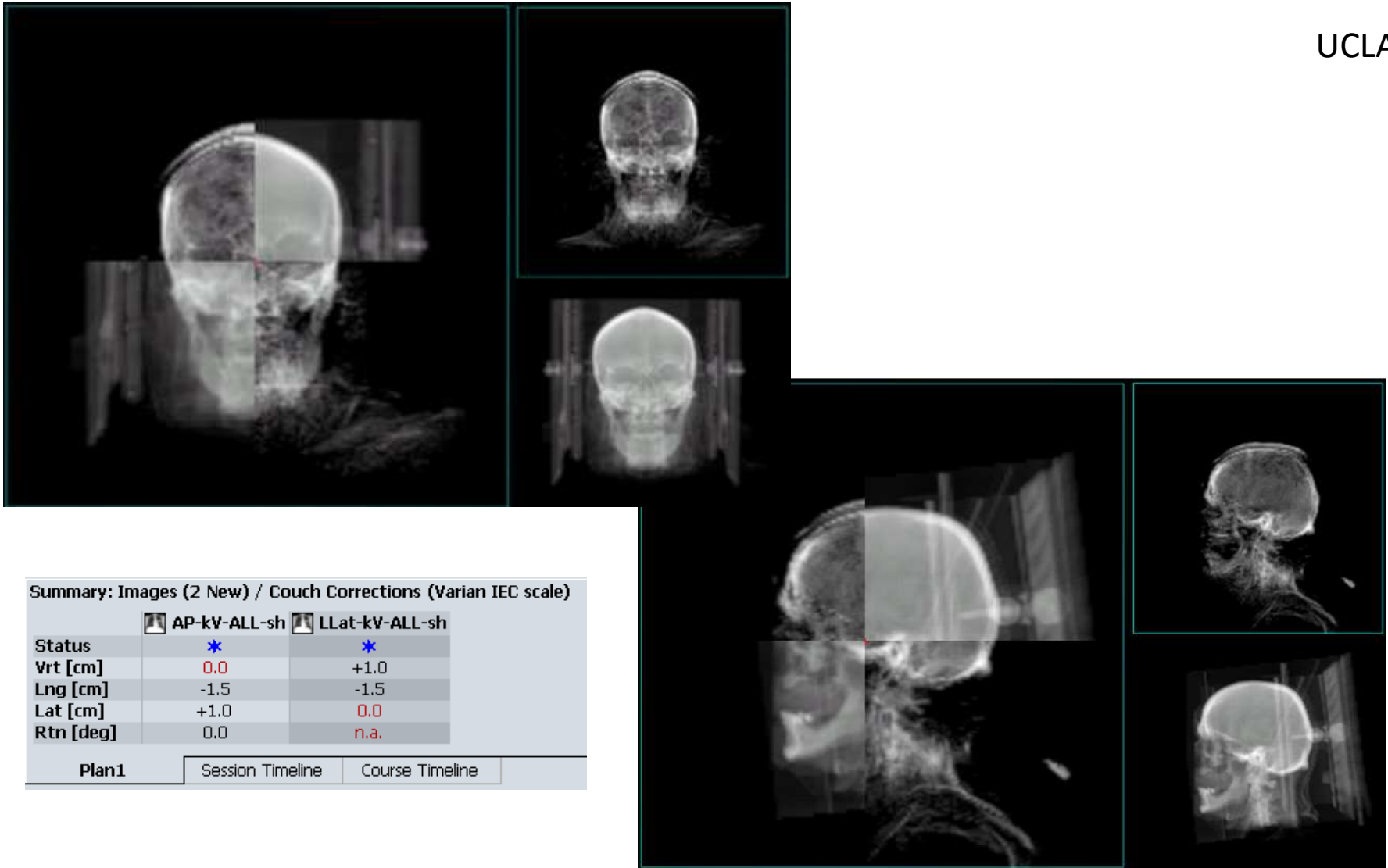


- 3D: Possible to use MR directly using mutual information
- 2D: Need projection DRR for comparison
 - Develop quasi-HU image
 - Mostly bone and air contrasts
 - Atlas-based mapping of MR images to CT
 - UTE imaging for bone imaging



UTE bone imaging _____ patient setup simulation

UCLA



Managing MR Simulation

- Tissue classification via Dixon MR (water-fat imaging) techniques (Helle et al, Proc Int Soc Mag Reson 21 (2013))

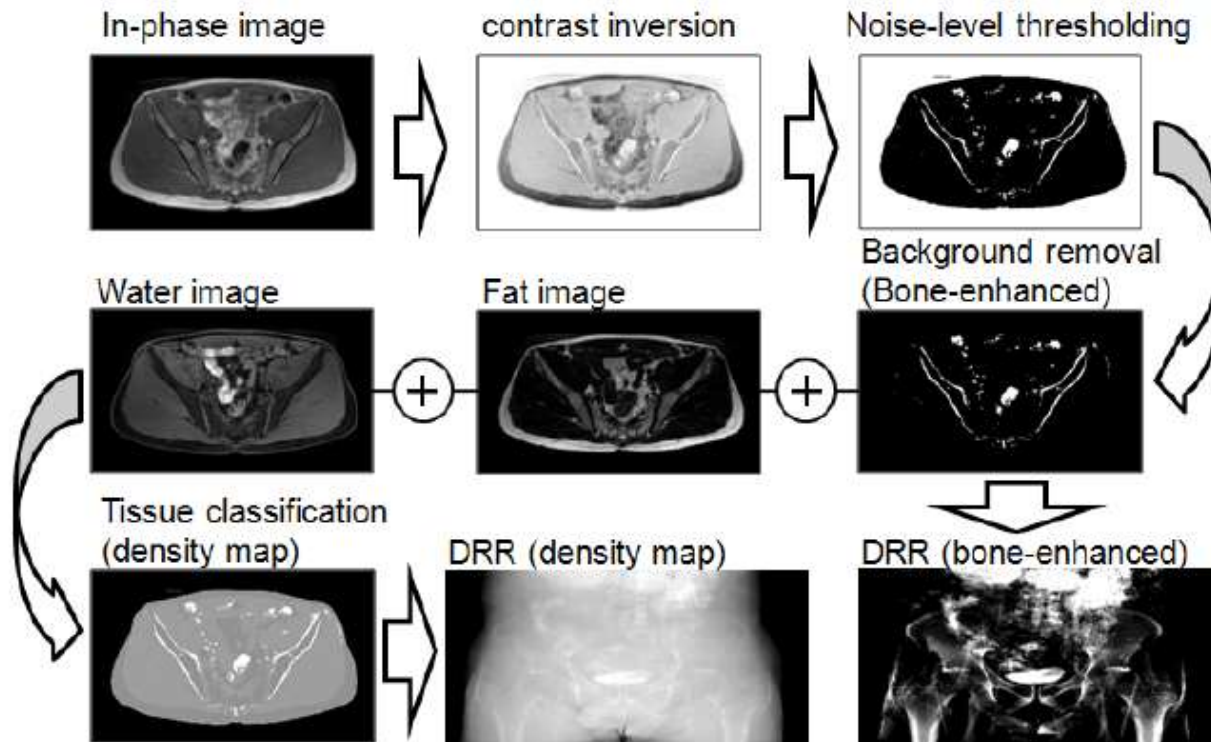
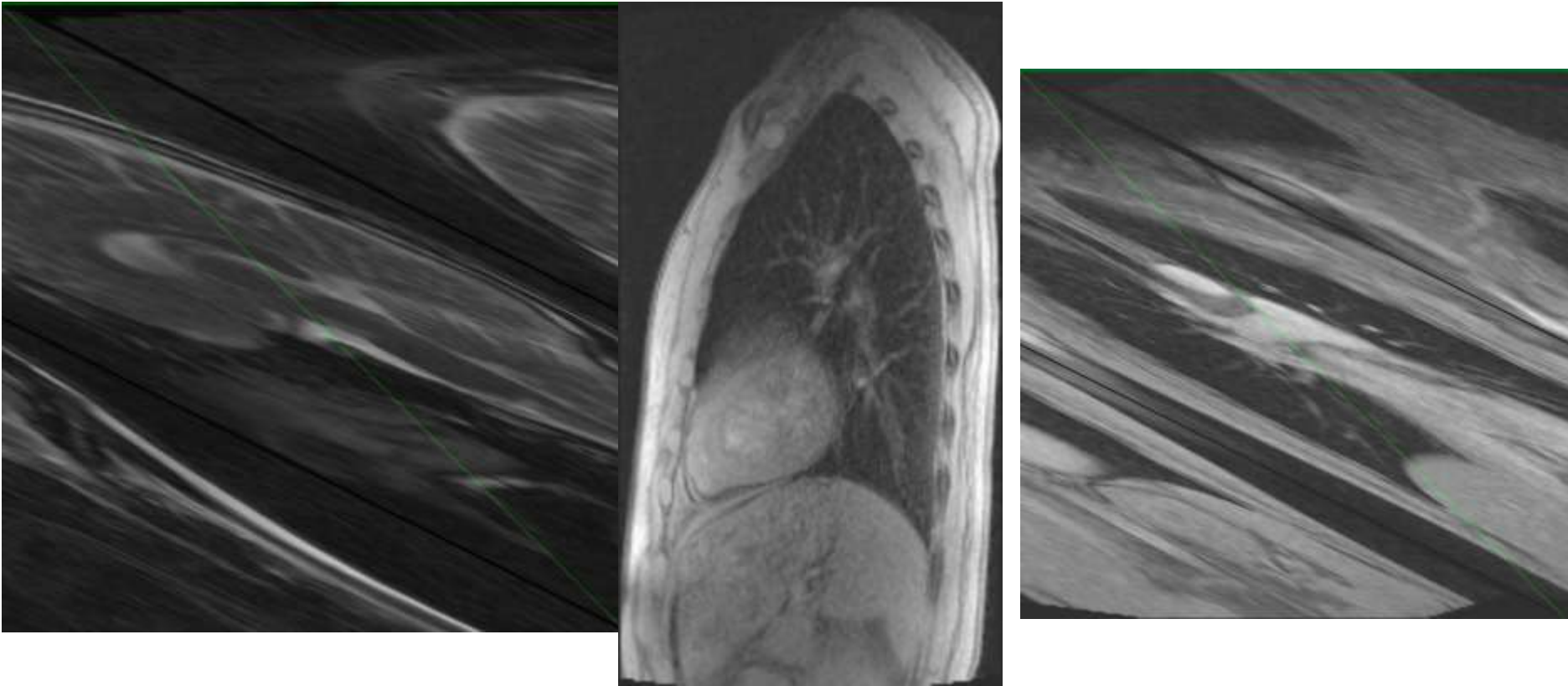


Figure 1: Workflow for generation of bone-enhanced images and tissue-classification for a Cartesian T1-Dixon sequence.

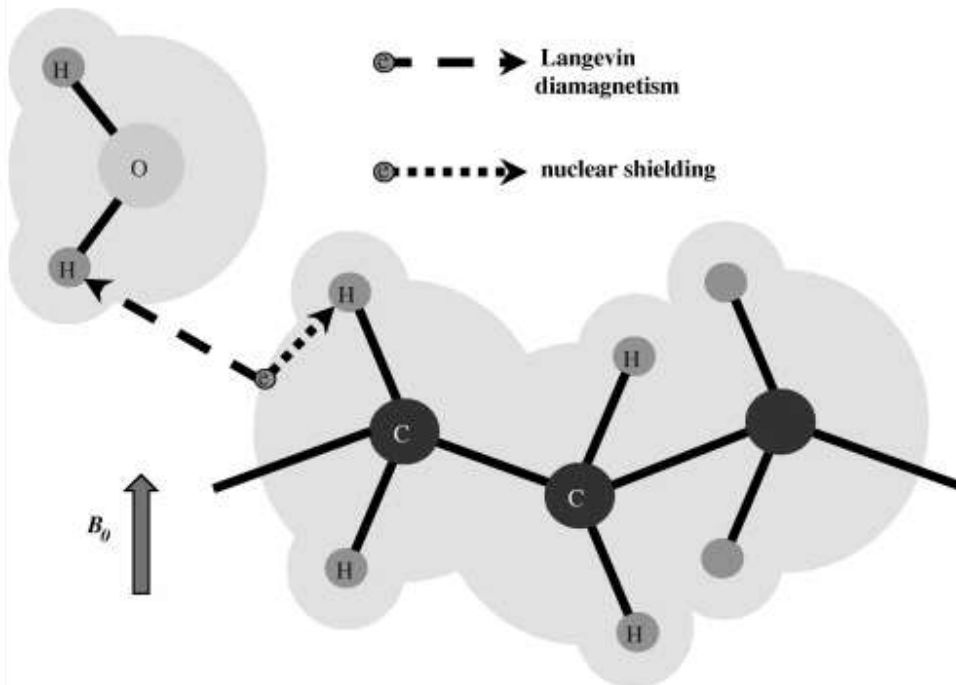
4D Imaging (Planar)

- 2-20 fps, low latency



Magnetic Susceptibility

- Electron clouds perturbed by asymmetric molecules and nearby atoms
- Perturbation changes local magnetic field



Paramagnetism



Diamagnetism

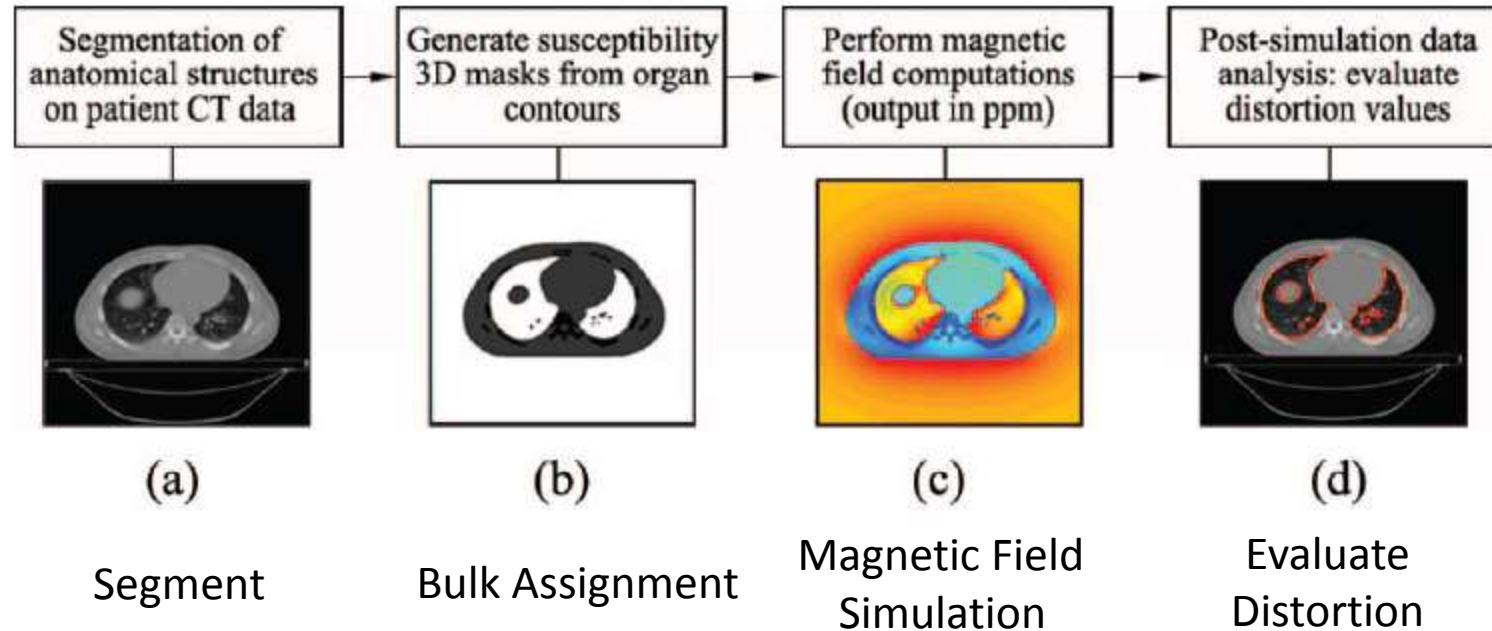


Ferromagnetism



Local field change = positioning error (distortion)

MR Susceptibility

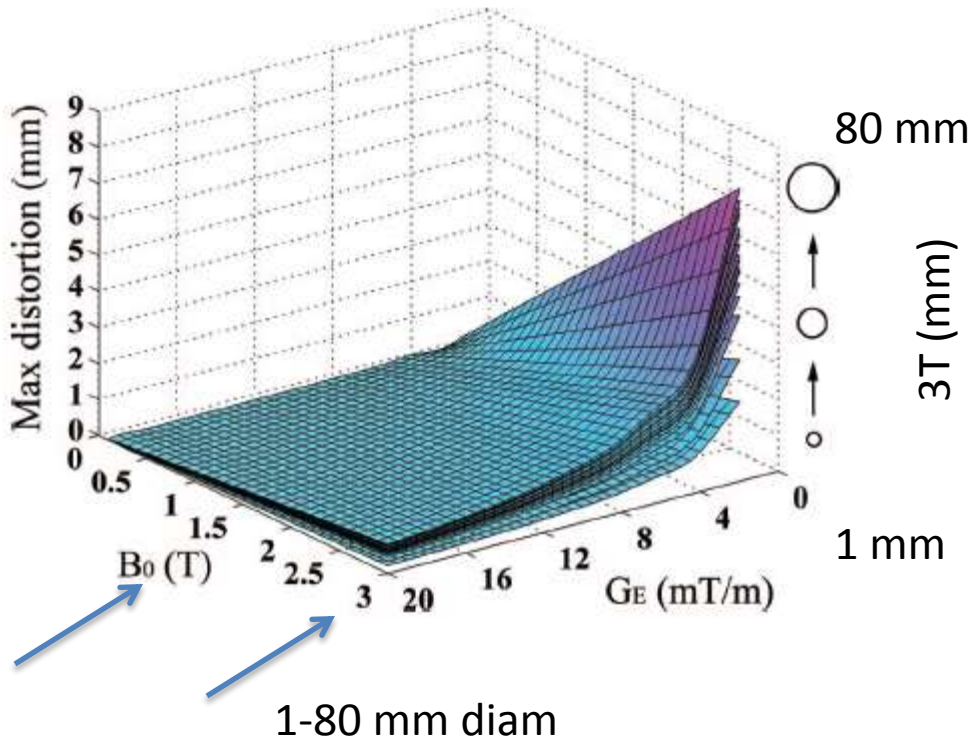


B_0 orientation
0-3T
Cavity Size
Ge

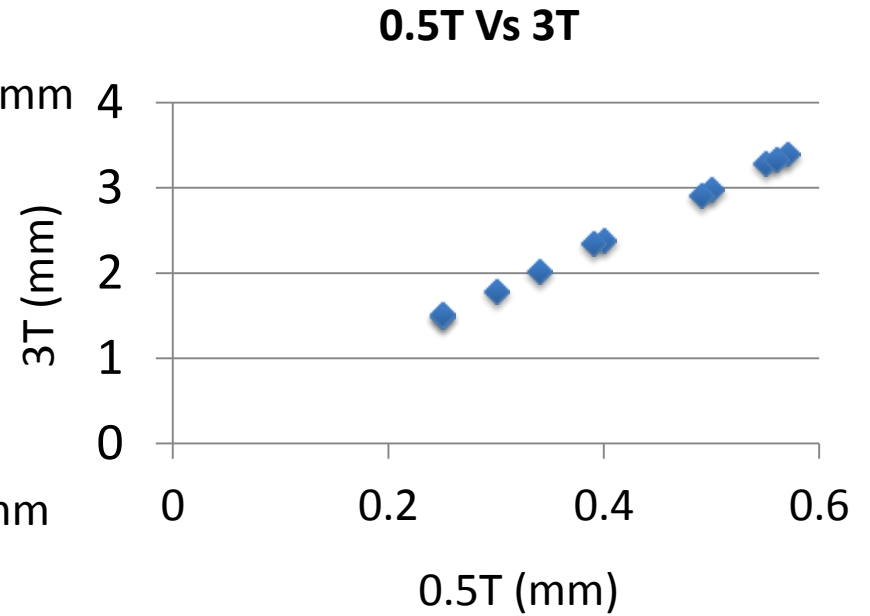
Susceptibility = Degree of magnetization of a material in response to applied magnetic field

Results: Air Cavity

Susceptibility: Air Cavity



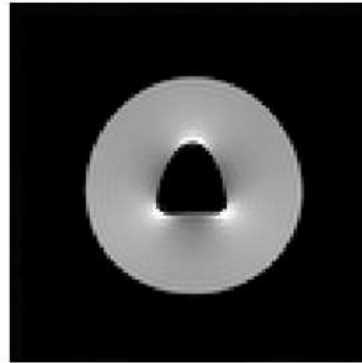
Chemical Shifts: Human Tissues



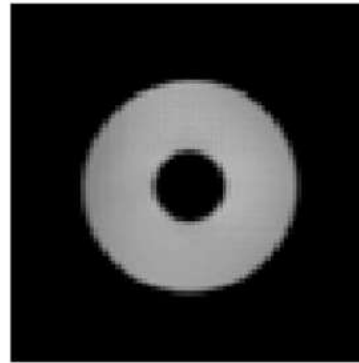
Improving Spatial Integrity

- Crijns et al, PMB 57 (2012) 1349
- Use only phase-encoding
- Undersample and regularize to reduce imaging time and improve patient stability
- Compare spin-echo to phase encoded sequences
Phase encoded sequences were spatially accurate
- Acceleration factor of 4 yielded spatially accurate images

Results



(a) SE

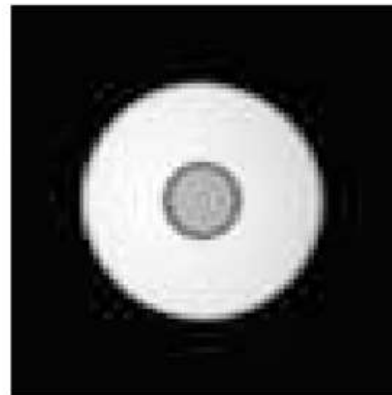


(b) SPI

Water/Air Susceptibility



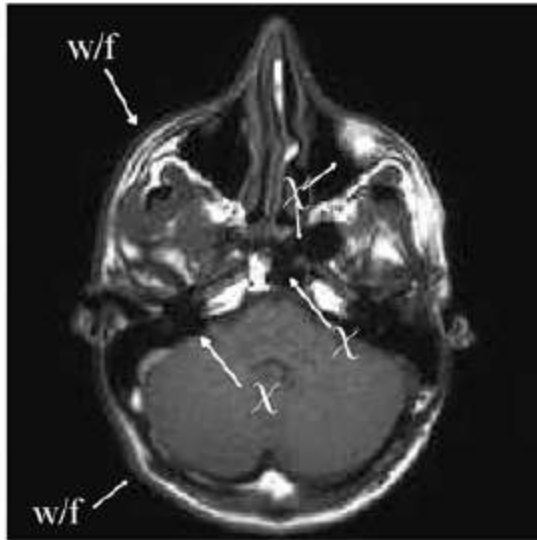
(a) SE



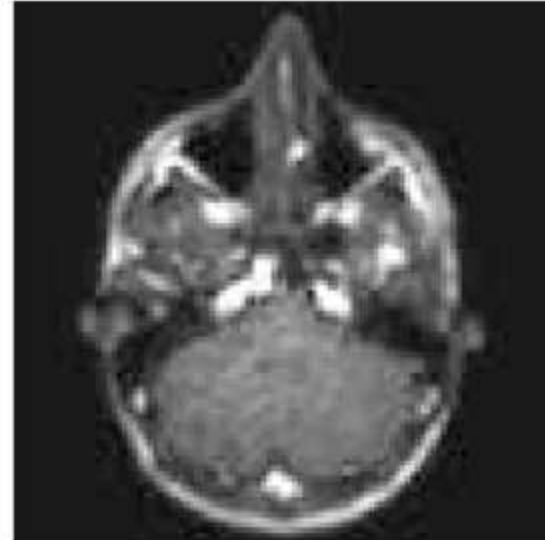
(b) SPI

Water/Fat Chemical Shift

Patient Scans



(a) SE



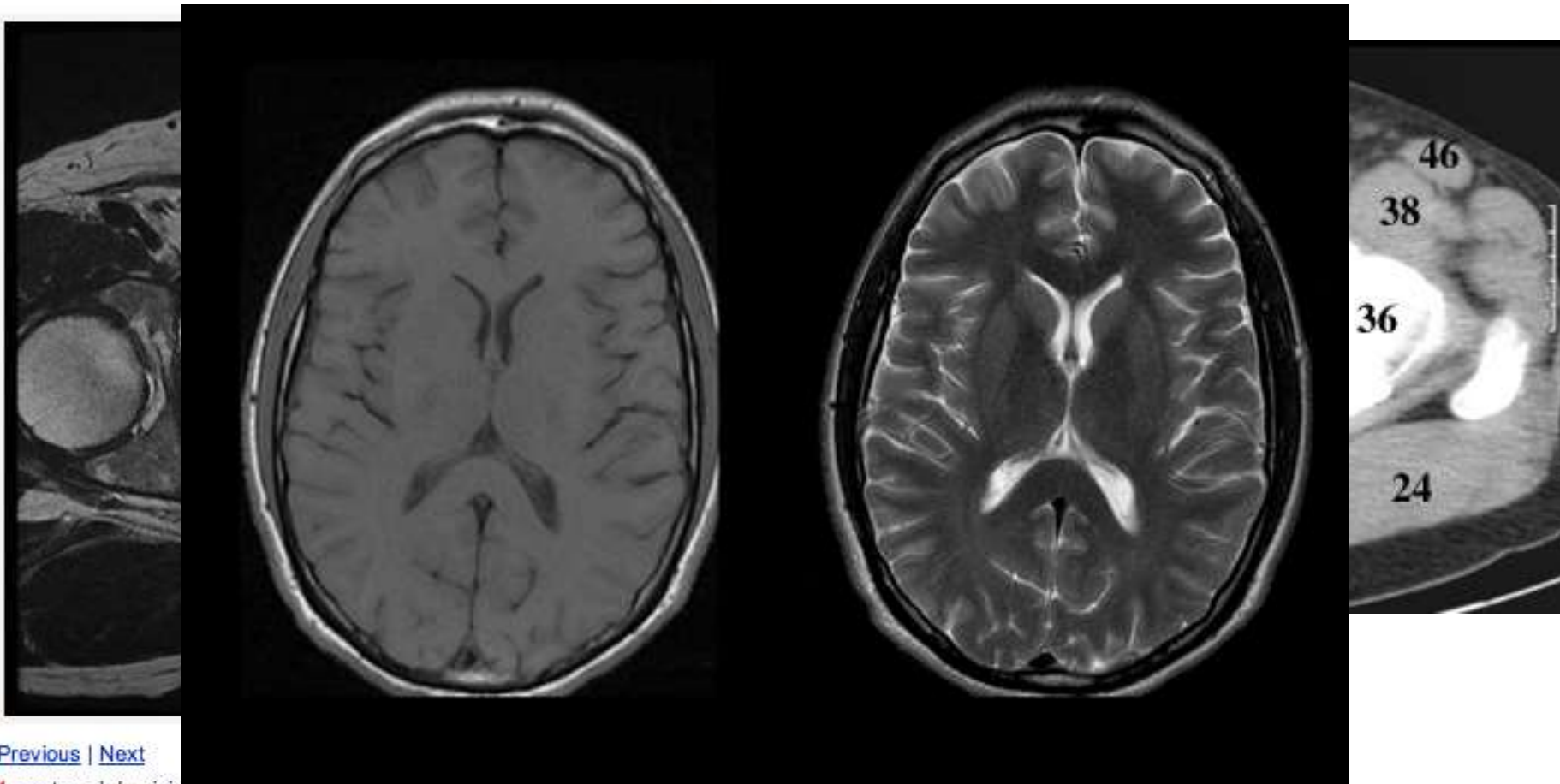
(b) SPI

Water/Fat Shifts

Limitations

- 2D acquisition (still need slice selection)
- Improve spatial accuracy in 3rd dimension with strong slice selection gradients
- Inefficient sequences lead to noisy or coarse resolution images

Training

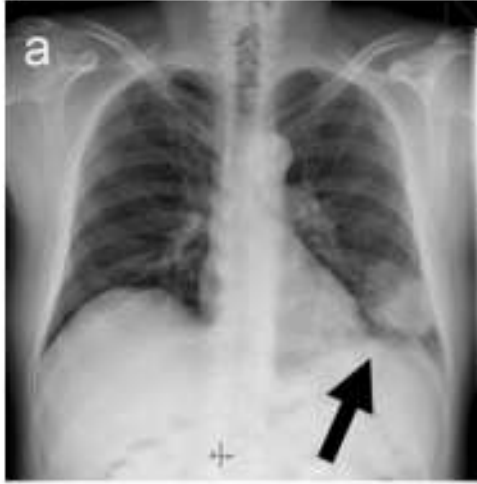


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1, rectus abdominis m. 2, bladder 3, seminal vesicle 4, rectum 5, coccyx
6, coccygeus m. 7, obturator internus m. 8, ischium 9, femoral head

Lung Cancer?

Planar x ray



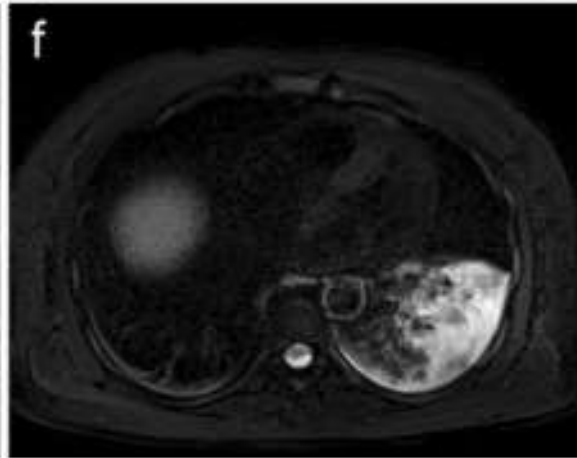
No Contrast CT

T1 3D GRE



SSFP

Fat-Sat T2 FSE



T2

Conclusions

- Many steps to get from CT to MR simulation
- My opinion: Biggest unknown challenge is reference image generation
- Unproven potential for improving treatment planning
- Potential for routine functional imaging