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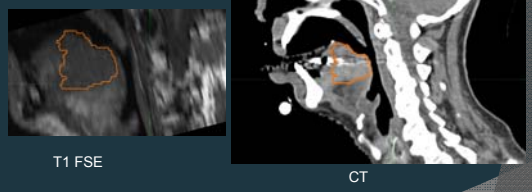
# MR SIMULATION FOR RADIOTHERAPY

## The need for MRI in radiotherapy



T1 FSE



CT

Tumor and normal tissues in brain, breast, head and neck, liver, prostate, cervix, rectum, etc. are markedly better visualized in MRI than in CT

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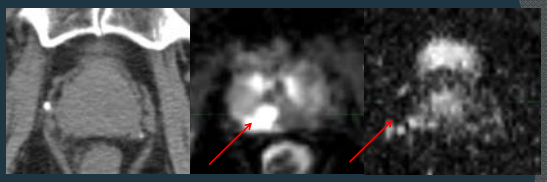
## Multiparametric MRI reflects a more complete picture of the tumor biology



CT DCE MRI ADC MRI

MRI is commonly used to detect Intraprostatic lesions

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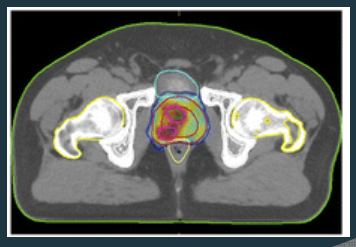
## Simultaneous integrated boost to the intraprostatic lesions



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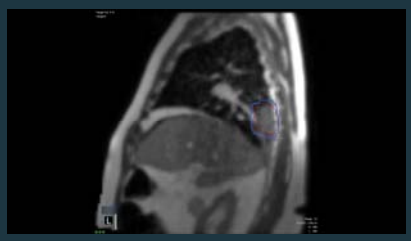
Onal et al. Br J Radiol. 2014 87(1034):20130617.

## MR-guided radiation therapy



Dynamic MRI images recorded during ViewRay treatment provides high quality real time internal anatomy images.

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## MRI simulation for RT

- Geometric distortion
- MR-CT registration
- MR-only simulation

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## MR geometric distortions

Different than CT, MR images have an intricate geometric distortion problem that is caused by:

- B0 inhomogeneity
  - Largely mitigated by shimming
- Susceptibility (tissue air/bone interface)
- Gradient nonlinearity
  - Contribute most to observed distortion
- Chemical shift
  - Relatively small

The distortion if uncorrected may result in registration, segmentation and dose calculation errors in radiotherapy particularly relying on geometric integrity.

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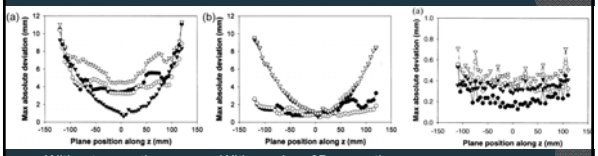
## Distortion correction

Siemens Sonata 1.5 T



Without correction | With vendors 2D correction | W/ piecewise interpolation

Distortion increases with increasing distance to the isocenter
Vendors' correction is typically effective with limitations
xy correction does little to correct the distortion along the z direction

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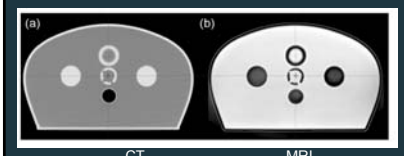
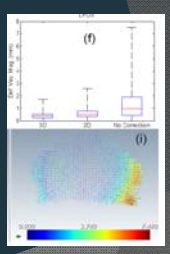
Wang et al. Magnetic Resonance Imaging 22(9), 2004, PP 1211–1232

## MR image distortions using a pelvic phantom and deformable registration



CT | MRI



For Siemens Skyra 3T scanner, vendor's 2D and 3D distortion correction methods reduce the error from 7.5 mm to 2.6 and 1.7 mm respectively

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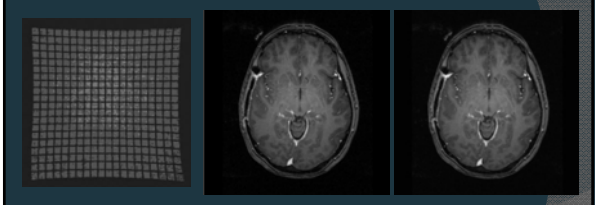
Sun et al. Phys. Med. Biol. **60** (2015) 3097–3109

## Distortion can be hard to notice in patients



uncorrected uncorrected corrected

Patient geometric distortion can be hard to notice
Machine and process QA needs to be in place to prevent error

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Sun et al. Phys. Med. Biol. **60** (2015) 3097–3109

## Question 1: MRI geometric distortion is caused by?

20% (a). B0 field inhomogeneity
20% (b). Susceptibility artifacts
20% (c). Chemical shift
20% (d). Gradient nonlinearity
20% (e). All the above

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## Answer to question 1

(e). All the above

Reference: Wang et al. Magnetic Resonance Imaging 22(9), 2004, PP 1211–1232

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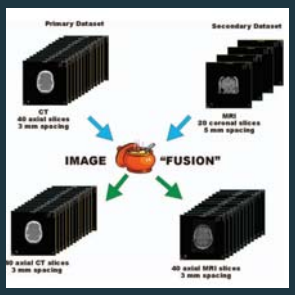
## MRI simulation for RTP: fusion




Typical workflow involving MRI in RT

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Devic S. Medical Physics 39, 6701 (2012);

## MR-CT registration

Rigid/manual registration
- Example: Brain, head and neck

Affine registration
- Example: Head and neck

Deformable registration
- Example: Abdominal and pelvis

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## Cranial rigid registration

45 institutions and 11 software registered a set of CT and MR with known ground truth based on BRW (Brown-Roberts-Wells) stereotactic head frame

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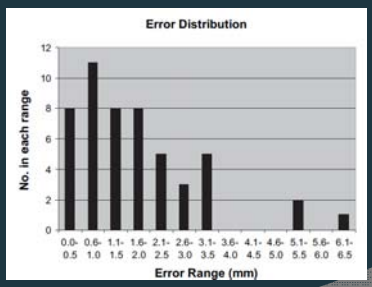
Ulin K et al Int J Radiat Oncol Biol Phys. 2010 Aug 1;77(5):1584-9

## Cranial rigid registration

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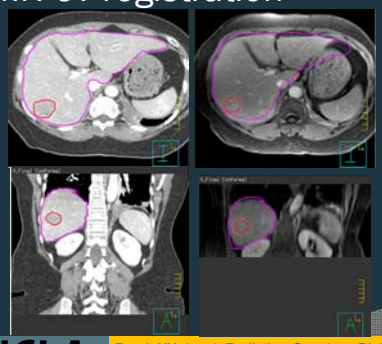
Ulin K et al Int J Radiat Oncol Biol Phys. 2010;77(5):1584-9

## MR-CT registration



The mean absolute error for the liver MR-CT registration ranged from 1.1 to 5.0 mm,

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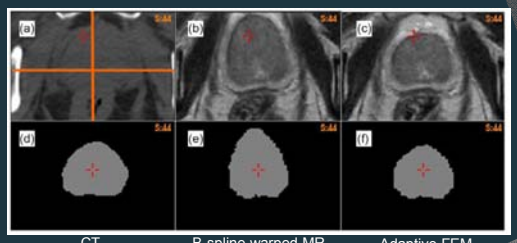
Brock KK. Int. J. Radiation Oncology Biol. Phys., 76(2), pp. 583–596

## MR CT registration of the prostate



CT B-spline warped MR Adaptive FEM

Average prostate centroid distance 3.7 mm using commercial B-spline registration

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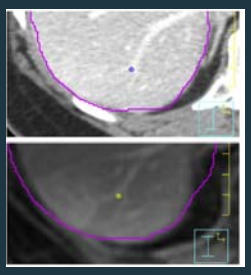
Zhong et al. Phys. Med. Biol. 60 (2015) 2837–2851

## Use of commercial registration software for MR-CT registration



- Caution needs to be excised.
- Use rigid registration when possible because rigid registration errors are more explicit
- Manual check of deformable registration needs to be performed using common landmarks

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Brock KK. Int. J. Radiation Oncology Biol. Phys., 76(2), pp. 583–596

## MRI only simulation

- Avoid the uncertainties from MR-CT registration
- Reduce patient exposure to imaging doses
- For MR guided radiotherapy, the MR simulation provides more native imaging format for IGRT registration

Challenges

- Need electron density for dose calculation and CT IGRT
- Not straightforward to generate DRR
- Compromise between limited FOV and high resolution
- Low throughput

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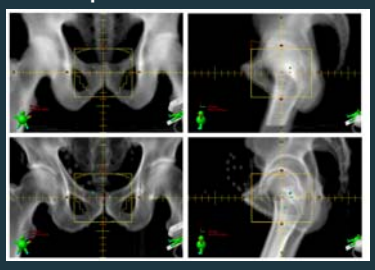
## DRR from pseudo MRI



Manual, semi-automated and automated bone segmentation was used to create pelvic bony anatomies from MR and then DRR

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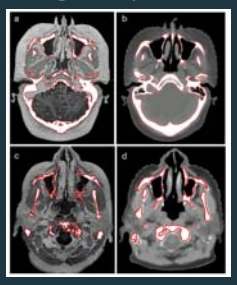
Chen L et al. IJROBP 68(3), 2007, pp 903–911
Dowling JA et al . IJROBP 83 (1), 2012 pp e5–e11

## Creating bony anatomy for MRI



Creating bony anatomies for the head and neck region is more difficult due to abutting airways.

Manual contouring of all airways was used to create air mask and then subtract from the automated MR bone segmentation

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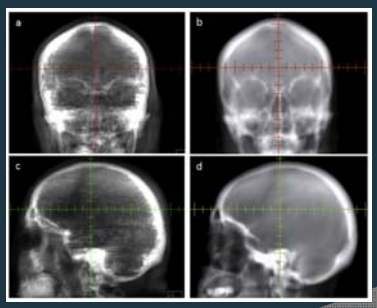
Yu H et al. IJROBP 89(3), 2014, Pages 649–657

## DRR from MRI



DDR from automated bone segmentation-manual airway segmentation

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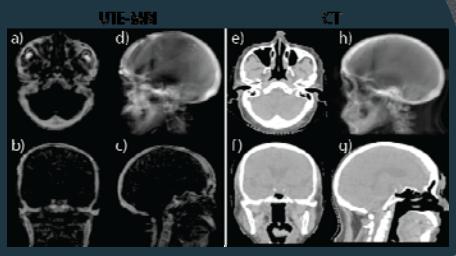
Yu H et al. IJROBP 89(3), 2014, Pages 649–657

## Ultra-short TE MRI




T2 relaxation time of cortical bones~1 ms vs 250 ms in tissue
Ultra-short TE MR has been used to image the bones directly

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Yang Y et al. Under review

## Electron density estimation for MRI

- Direct segmentation
  - Bulk density assignment
- Atlas based method
  - Generate average MR/CT data set with individual organ labeling
- Classification-based method
  - Based on image texture analysis and learning

Require *a priori* CT-MR registration

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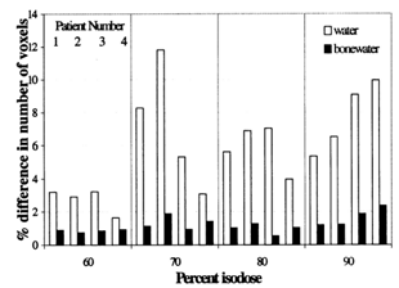
## Impact of electron density estimation for prostate IMRT

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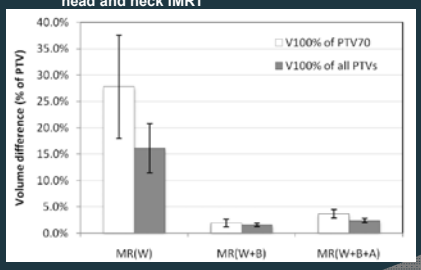
Lee YK, Radioth. Oncol. 66(2), pp 203–216
Residual error<2%

## Impact of electron density estimation for head and neck IMRT




Bones accounts for the majority of density heterogeneity effects
Residual error ~2%

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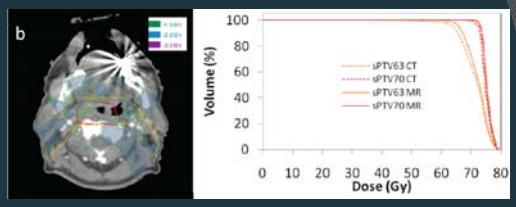
Chin AL et al. JACMP Vol 15, No 5 (2014)

## Other heterogeneous density objects




Assigning cortical bone density to the implant results in 4% dose calculation error.
Correction of such errors may require laborious manual segmentation of the implant.

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Chin AL et al. JACMP Vol 15, No 5 (2014)

## Question 2: Compared to CT, what is the expected dosimetric difference using MR for planning after density correction?

20% (a). 0.5%
20% (b). 2%
20% (c). 8%
20% (d). 12%
20% (e). 18%

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## Answer to question 2

(b). 2%

- Lee YK, Radioth. Oncol. 66(2), pp 203–216
- Chin AL et al. JACMP Vol 15, No 5 (2014)

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## Summary

- MRI is becoming increasingly important in radiotherapy but requires special attentions to geometric distortion, MR-CT registration and electron density assignment.
- MRI geometric distortion can be manageable using the vendors' tool but it needs to be rigorously QA'd for both the specific machine and the process.
- MRI-CT registration is challenging and error prone.
- Multiple methods are available to assign electron density to MRI for dose calculation and generation of DRR but varying levels of manual intervention are often needed.
- Bone (teeth) density contributes to the majority of density heterogeneity effects.

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## Acknowledgement and disclosure

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NIH R21CA144063

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