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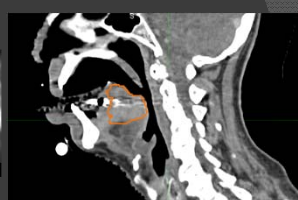
MR SIMULATION FOR RADIOTHERAPY

The need for MRI in radiotherapy

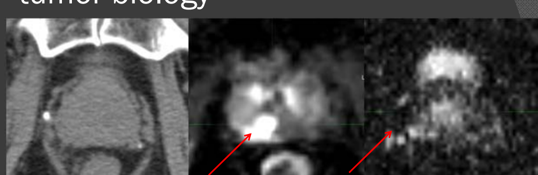
T1 FSE



CT

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

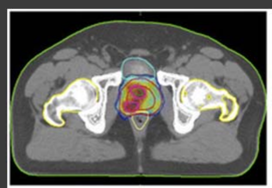
Multiparametric MRI reflects a more complete picture of the tumor biology



CT DCE MRI ADC MRI

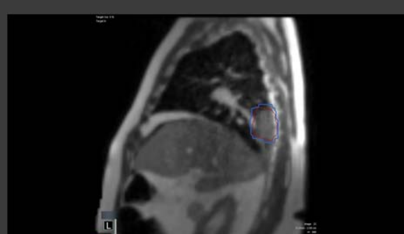
MRI is typically used to detect Intraprostatic lesions

Simultaneous integrated boost of the intraprostatic lesions



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

MR guided radiation therapy



Dynamic MRI images recorded during ViewRay treatment.
MRI guided radiotherapy provides high quality internal anatomy images during the treatment

MR geometrical distortions

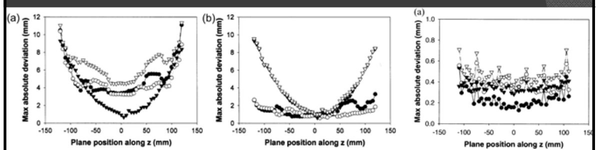
Compared to CT, MR images have an intricate geometric distortion problem that is caused by:

- B0 inhomogeneity
- Susceptibility (tissue air/bone interface)
- Gradient nonlinearity
- Chemical shift

The distortion if uncorrected may be cause segmentation and dose calculation errors in radiotherapy relying on MR simulation.

Understanding the distortion correction

Siemens Sonata 1.5 T

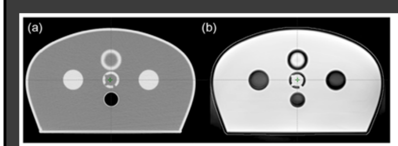


Without correction | With vendors 2D correction | W/ piecewise interpolation

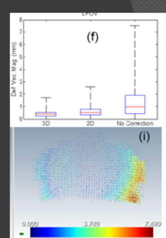
Wang et al. Magnetic Resonance Imaging 22(9), 2004, PP 1211–1232

Distortion increase 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

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

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

Question 1: MRI geometrical distortion is caused by?

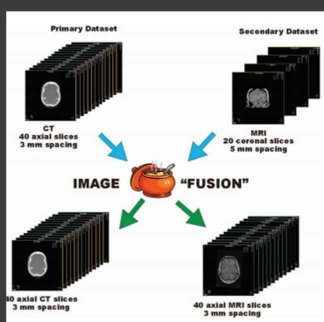
20%	(a). B0 field inhomogeneity
20%	(b). Susceptibility artifacts
20%	(c). Chemical shift
20%	(d). Gradient nonlinearity
20%	(e). All the above

Answer to question 1

(e). All the above

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

MRI simulation for RTP: fusion

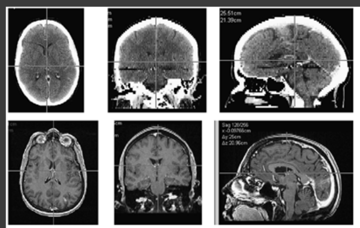


Devic S. Medical Physics 39, 6701 (2012);

MR-CT registration

- Rigid/manual registration
  - Example: Brain, head and neck
- Affine registration
  - Example: Head and neck
- Deformable registration
  - Example: Abdominal and pelvis

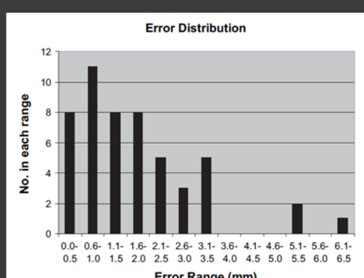
Cranial rigid registration



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

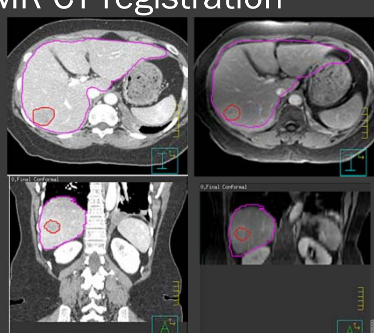
Ulin K et al Int J Radiat Oncol Biol Phys. 2010 Aug 1;77(5):1584-9

Cranial rigid registration



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

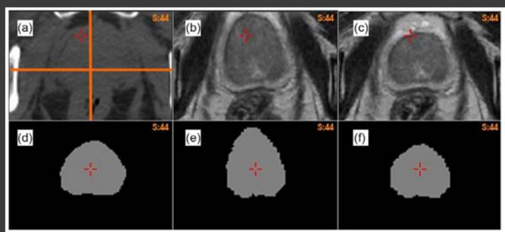
MR-CT registration



The mean absolute error for the liver ranged from 1.1 to 5.0 mm,

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

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

Question 2: Your planning system or PACS-RT can perform CT-MR deformable registration, how do you use the function?

20%	(a). Trust the registration results
20%	(b). Use it as often as applicable
20%	(c). Use it for intracranial registration
20%	(d). Only use it if the registration can be visually validated
20%	(e). Always use it over rigid registration

Answer to question 2

(d). Only use it if the registration can be visually validated

Reference: Brock KK. Int. J. Radiation Oncology Biol. Phys., Vol. 76, No. 2, pp. 583–59
Zhong et al. Phys. Med. Biol. 60 (2015) 2837–2851

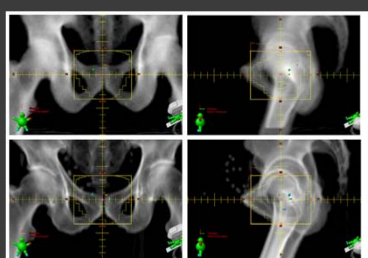
MRI only simulation

- 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 registration (avoid CT-MR registration during IMRT)

Challenges

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

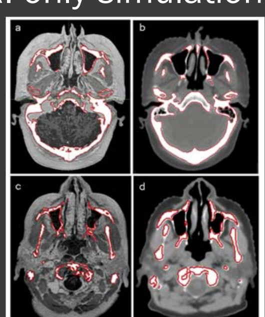
DRR from pseudo MRI



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

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

MRI only simulation

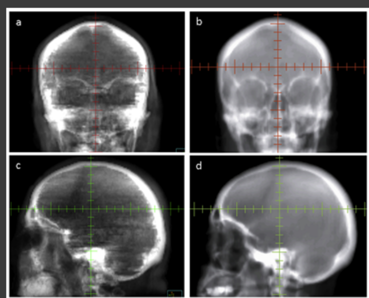


Creating bony anatomies for the head and neck region is more difficult due to abutting airways.

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

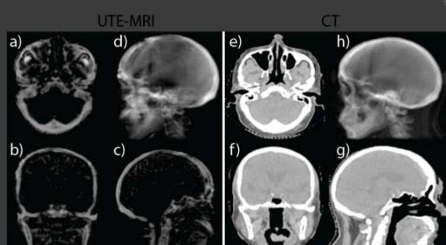
Yu H et al. IJROBP 89(3), 2014, Pages 649–657

DRR from MRI



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

Ultra-short TE MRI



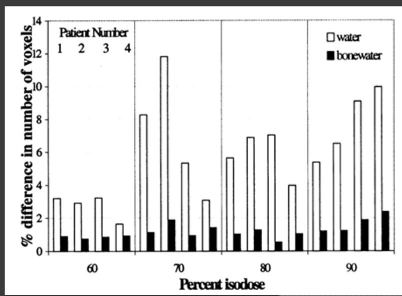
T2 relaxation time of cortical bones~1 ms vs 250 ms in tissue
Ultra-short TE MR has been used to image the bones directly
Yang Y et al. Under review

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

(Atlas based method and Classification-based method:) Require a priori CT-MR registration

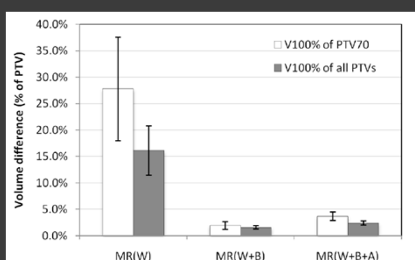
Impact of electron density estimation for prostate IMRT



Lee YK, Radioth. Oncol. 66(2), pp 203–216

Impact of electron density estimation for head and neck IMRT

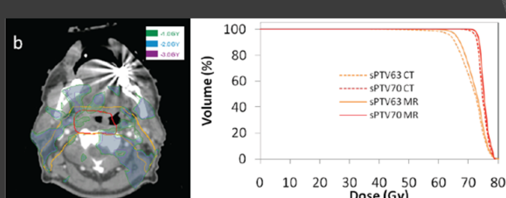
head and neck IMRT



Bones accounts for the majority of density heterogeneity effects

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.

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

Question 3: 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%

Answer to question 3

(b). 2%

- References: Brock KK. Int. J. Radiation Oncology Biol. Phys., 76(2), pp. 583–596
- Zhong et al. Phys. Med. Biol. 60 (2015) 2837–2851

Summary

- MRI is becoming increasingly important in radiotherapy
- MRI geometrical 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, particularly deformable registration.
- Multiple methods are available to assign electron density to MRI for dose calculation and generation of DRR.
- The process to assign electron density can involve manual segmentation that is labor intensive.
- Bone (teeth) density contributes to the majority of density heterogeneity effects.