MR image processing, registration & planning for extra-cranial radiotherapy

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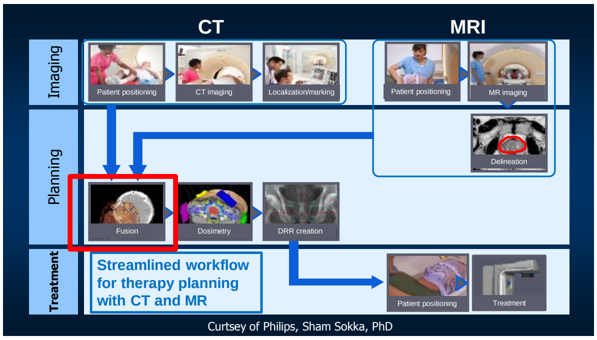
2017 AAPM 59th Annual Meeting, Denver, CO

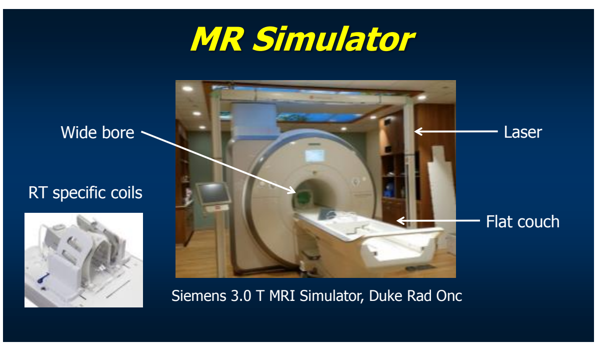
Disclosure

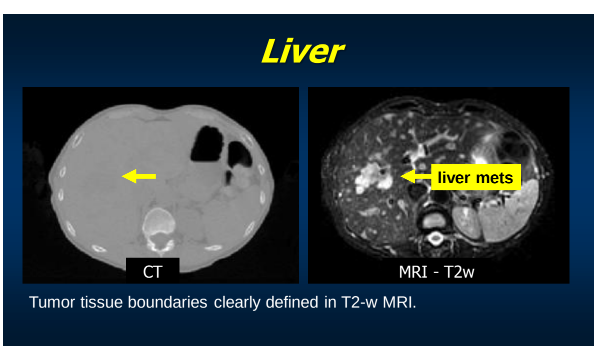
I have received research funding from NIH and Varian Medical System.

Learning Objectives

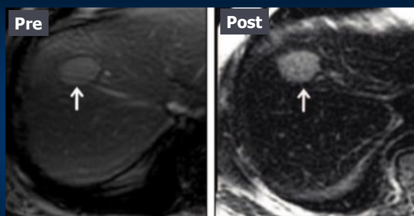
- Outline the common clinical practice of MR applications in extra-cranial radiotherapy.
- Discuss key challenges in the implementation of MRI in extra-cranial radiotherapy.
- Provide overviews of efforts to address these challenges.


CT
MRI
Imaging
Planning
Treatment
Patient positioning
CT imaging
Localization/marking
Patient positioning
MR imaging
Delineation
Fusion
Dosimetry
DRR creation
Streamlined workflow for therapy planning with CT and MR
Patient positioning
Treatment
Curtsey of Philips, Sham Sokka, PhD


MR Simulator
Wide bore
Laser
RT specific coils
Flat couch
Siemens 3.0 T MRI Simulator, Duke Rad Onc


Liver
liver mets
CT
MRI - T2w
Tumor tissue boundaries clearly defined in T2-w MRI.

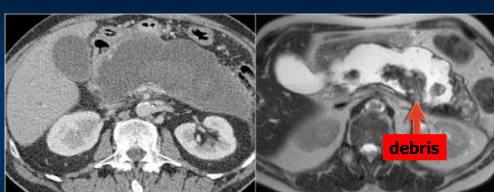
Liver - Perfusion MRI



Pre- and post administration of Feridex contrast on T2*w-MRI of HCC.

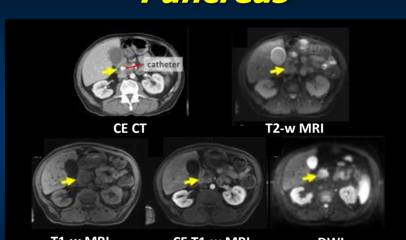
Cher T, et al, Appl Radiol. 2010;39(11):26-41.

Pancreas



MRI shows the cystic nature of a pancreatic lesion and it's internal structure. The MRI shows a large cyst with dependent internal debris.

Pancreas



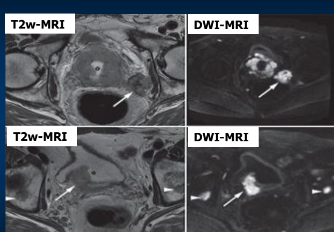
CT and MR images of pancreatic cancer

Prostate

Definition of the prostate gland boundaries and the adjacent structures is better visualized on MRI than with CT.

V S Koon, BJR September 1, 2006 vol. 79 n. Special Issue 1S2-S1

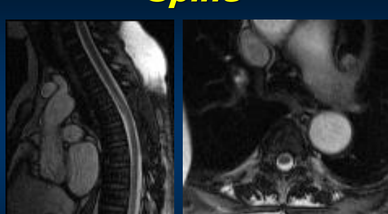
Prostate: DWI



- Metastatic small cell prostate cancer after resection of the prostate.
- Prostate replaced by tumor with extension outside the prostate.
- Tumor invades the bladder and nearby bone.

Lawrence E, *Nature Reviews Urology* **9**, 94-101 (February 2012)

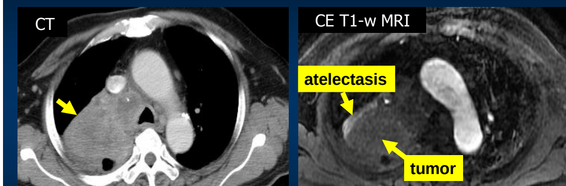
Spine



Spinal canal and cord motion generally < 0.5 mm

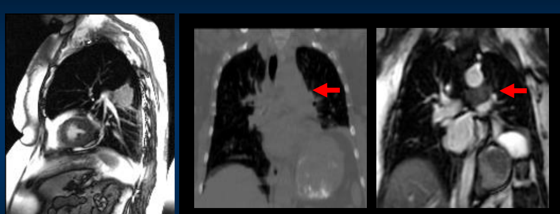
Cai, *et al*, Radiotherapy and Oncology, 2007

Lung



Contrast enhanced MRI differentiates atelectasis from tumor

Lung: Cine MRI



Cine MRI (~5 frames/sec) for tumor motion measurement and monitoring

MR/CT Registration

Manual Rigid Registration

- Based on interactive visual inspection
- Anatomy-based, fiducial-based, coordinate-based
- Large intra- and inter-observer variability

Automatic Rigid Registration

- Based on mutual information
- Affected by anatomy changes between scans
- Need visual verification and adjustment

Deformable Registration

- Need comprehensive evaluation

MR/CT Registration Accuracy

Various MR/CT Registration Methods

TABLE I. Reported MRI to CT coregistration errors for various used coregistration methods.

Author	Year	Method	Anatomical site	Reported coregistration error (mm)
Alpert *et al.* (Ref. 13)	1990	Matching moments method	Brain	1.0
Turkington *et al.* (Ref. 14)	1993	Maximum gradient technique	Brain	2
Van Herk and Kooy (Ref. 15)	1994	Contours chamfer matching	Brain	1.0
Kagawa *et al.* (Ref. 8)	1997	3 anatomical landmarks	Prostate	0.9 (±0.6)
Sannazzari *et al.* (Ref. 16)	2002	9–15 anatomical landmarks	Prostate	1.5
Krempien *et al.* (Ref. 10)	2003	Mutual information	H&N, GYN	1.8 (±0.9)
Brock *et al.* (Ref. 12)	2010	Various deformable	Various	0.4–6.2

Devic S, et al, Medical Physics, 39 (11), 2012

MR/CT Registration Challenges

Image Related

- MR artifacts (ghost, chemical shift, etc.)
- Spatial accuracy (distortion), spatial resolution
- Various image contrasts

Radiation Therapy Related

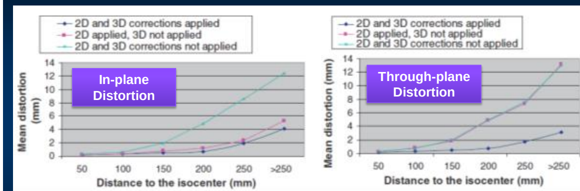
- Patient's anatomy change between scans
- Differences in immortalization devices, breathing status
- Use of fiducial markers/applicators

Human Related

- Inter- and intra-subject variations
- Lack of knowledge or training

MRI Artifacts

MRI Geometric Distortion



Distance to the isocenter (mm)	100	150	200	250
Corr Mean Distortion (mm)	0.33	0.35	0.51	1.95

Distance to the isocenter (mm)	100	150	200	250
Corr Mean Distortion (mm)	0.35	0.51	0.72	1.77

Torfeh T et al. Magnetic Resonance Imaging 34 (2016) 645–653

Liver SBRT

- CT with immobilization, MRI without
- Different breath-hold status (RPM for CT, belt for MRI)

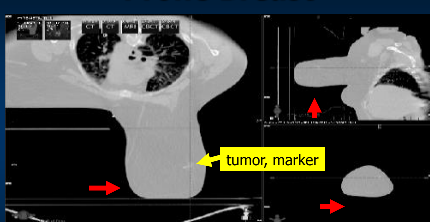
Prostate

- Fiducial makers (SBRT), immobalization
- Full/empty rectum/bladder

Spine SBRT

- PTV to cord distance only 1-2 mm
- Immobilization, patient movement , metal implants

Prone Breast

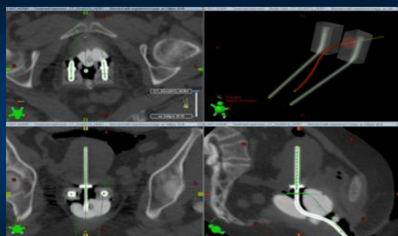


- Large patient anatomy variation (different immobilization)
- Marker-based registration for target alignment

GYN EBRT

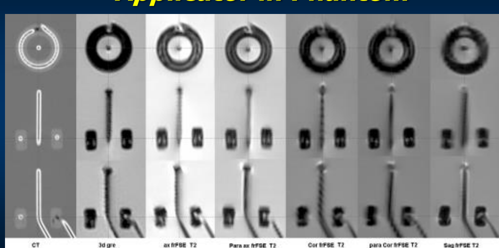
- Full/empty rectum/bladder
- Minimal respiratory issue

GYN HDR Brachytherapy

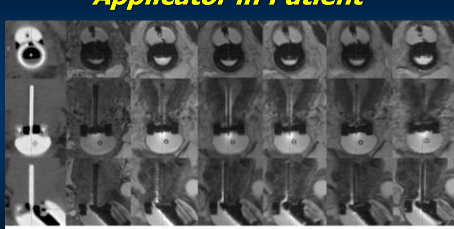


- Applicator induced susceptibility artifacts
- Registration based on applicator, not anatomy

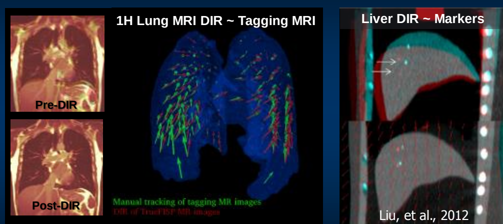
MR Images of Tandem and Ring (T&R) Applicator in Phantom



MR Images of Tandem and Ring (T&R) Applicator in Patient



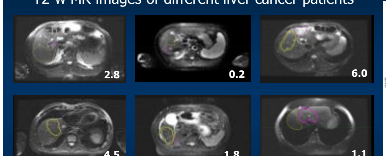
Limitations of DIR Methods



Focuses on *morphological* similarity, rather than *physiological* plausibility.

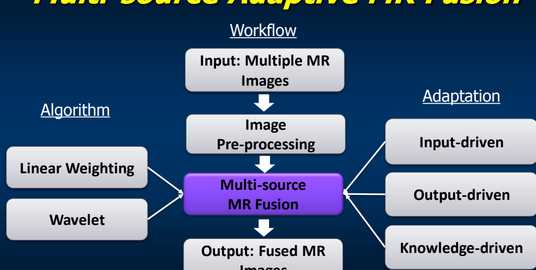
Tumor Contrast Variation

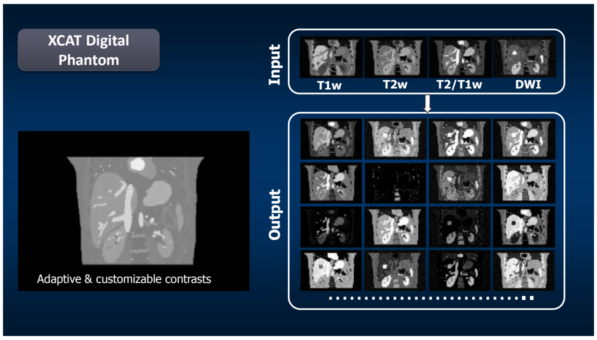
T2-w MR images of different liver cancer patients

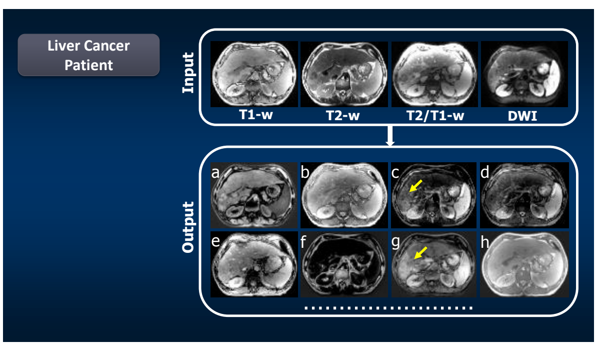


- Challenge: large inter-patient tumor contrast variation
- Strategy: fuse different contrast MR images to enhance tumor contrast

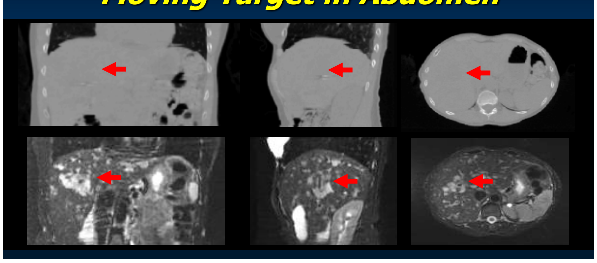
Multi-source Adaptive MR Fusion



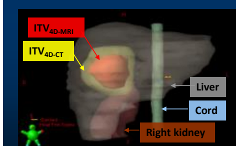


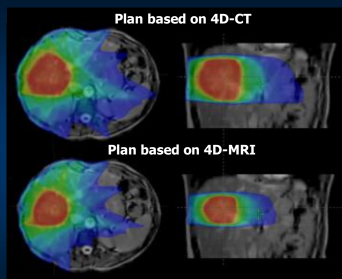


4D-MRI: Volume Delineation of Moving Target in Abdomen



4D-MRI For Liver SBRT TX Planning

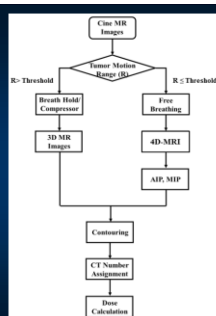


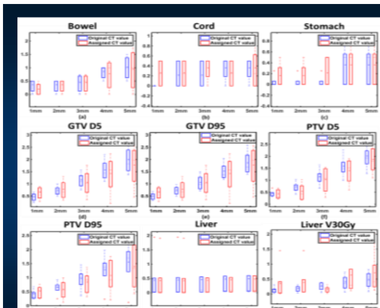


4D-MRI only based treatment planning and motion management for mobile abdominal cancers

Two major challenges:

- MRI-based dose calculation
- Target volume determination

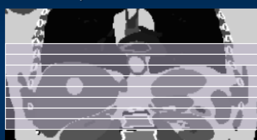




- Dose error increases as distortion increase.
- When distortion < 2 mm, dose error < 1.0 Gy or 1% in all studied metrics.

Fast ITV Determination

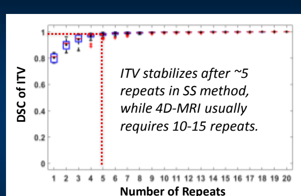
Sequential T2-w MRI



Slice Stacking MIP and ITV

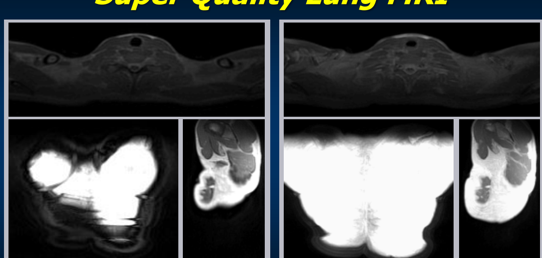
- Repeated acquisition of T2-w MR images using HASTE sequence
- Generate MIP using all acquired images after each volume acquisition

Fast ITV Determination



Slice-stacking of sequentially acquired T2-w MR images can be used for faster (~2 min) determination of ITV as compared to 4D-MRI (~6 min)

Super Quality Lung MRI



Curtsey of Dr. G. Wilson Miller, University of Virginia

Summary

- The use of MRI in RT treatment planning for excranial tumors is rapidly increasing at nearly all body sites.
- Unique advantages of MRI (versatile contrast, fast imaging, flexible plane, functional imaging, etc.) provides complimentary information for CT-based treatment planning.
- MR/CT coregistration, MR geometric uncertainties, imaging speed, and contrast variations still remain challenging for RT applications.
- A number of new MRI techniques have been developed or under development to overcome current limitations.

Acknowledgements

Duke Radiation Oncology

Fang-Fang Yin, PhD
Mark Oldham, PhD
Jim Chang, PhD
Lei Ren, PhD
Brian Czito, MD
Manisha Palta, MD
Chris Kelsey, MD
Rachel Blitzblau, MD

Duke Radiology

Nan-kuei Chen, PhD
Paul Segars, PhD
Mustafa Bashir, MD
Michael Zalutsky, PhD

MDACC

Jihong Wang, PhD

UCLA

Yingli Yang, PhD

Siemens

Xiaodong Zhong, PhD
Brian Dale, PhD

UNC-CH Radiology

Dinggang Shen, PhD
Guorong Wu, PhD

Duke Department of Radiation Oncology