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.
Streamlined workflow for therapy planning with CT and MR

MR Simulator

Liver

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.

Pancreas

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

Pancreas

CT and MR images of pancreatic cancer
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

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**Lung: Cine MRI**

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

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**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>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Method</th>
<th>Anatomical site</th>
<th>Accuracy (cm)</th>
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<td>1990</td>
<td>Matching scanning method</td>
<td>Brain</td>
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<td>Dedet al. (Ref. 1)</td>
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<td>Minimum gradient technique</td>
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<td>Contour-matching</td>
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<td>Karp et al. (Ref. 1)</td>
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<td>3D anatomical handshakes</td>
<td>Private</td>
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<td>Kamogawa et al. (Ref. 1)</td>
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<td>Bacon et al. (Ref. 1)</td>
<td>2010</td>
<td>Various deterministic</td>
<td>Various</td>
<td>0.4 (L/F)</td>
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</tbody>
</table>

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 immobilization devices, breathing status
- Use of fiducial markers/applicators

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

MRI Artifacts

- Susceptibility
- FOV Aliasing
- GRE Aliasing
- Chemical Shift
- Ghost
- Respiration
MRI Geometric Distortion

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

Prostate
- Fiducial makers (SBRT), immobilization
- 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**

Workflow:
- Input: Multiple MR Images
  - Image Pre-processing
  - Multi-source MR Fusion
- Output: Fused MR Images

Adaptation:
- Input-driven
- Output-driven
- Knowledge-driven
XCAT Digital Phantom

Adaptive & customizable contrasts

Liver Cancer Patient

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

Liver Cancer Patient

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

Input

Output

T1w
T2w
T2/T1w
DWI

Input

Output

T1w
T2w
T2/T1w
DWI

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

Liver Cancer Patient

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

Liver Cancer Patient
4D-MRI For Liver SBRT TX Planning

Plan based on 4D-CT

Plan based on 4D-MRI

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.
Sequential T2-w MRI

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

Slice Stacking MIP and ITV

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).

ITV stabilizes after ~5 repeats in SS method, while 4D-MRI usually requires 10-15 repeats.

Super Quality Lung MRI

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

• The use of MRI in RT treatment planning for extracranial 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
Liz Hua, PhD
Brian Czito, MD
Marilisa Falta, MD
Chris Kelsey, MD
Rachel Blitzblau, MD

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

MDACC
Jhong 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