Strengths and Limitations of Anatomical and Spectroscopic MRI in Radiation Oncology Treatment Planning

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Disclosure

• Research funding support from Siemens Medical Solutions
Learning Objectives

- Widespread applications of MRI in radiation oncology treatment planning
- Assessment of geometric distortion when MRI is utilized as one of several imaging modalities: reproducibility of patient setup and image distortion
- Application of MRI to quantify and validate motion management models
- Review obstacles to clinical utilization of magnetic resonance spectroscopic imaging (MRSI)
Difficulty in Delineation of Clinical Target Volume

Planning ⇒ highly conformal dose distributions

Treatment ⇒ high precision delivery

Contour CTV ⇒ significant subjectivity

Neuroimaging with MR for RT

- 56 yr female
- GBM
Neuroimaging with MR for RT
Neuroimaging with MR for SRS
Image Registration Review – H&N
Image Registration Review – H&N
Image Registration Review – H&N
Patient Alignment Between CT and MR Image

Mean RMS Error = 0.1 cm

Registration Error (cm)
Vector Difference

Anatomical Region

Right eye, Left eye, Pituitary, Tentorium, RIAC, LIAC, C2 canal, C2 R artery, C2 L artery, C3 canal, C3 R artery, C3 L artery, C4 canal, C4 R artery, C4 L artery, C5 canal, C5 R artery, C5 L artery, C6 canal, C6 R artery, C6 L artery

Patient A, Patient B, Patient C, Patient D, Patient E, Patient F
Morphological Imaging - Breast
Morphological Imaging - Breast
Morphological Imaging - Breast

CT

T1

T2
Morphological Imaging - Prostate
Morphological Imaging - Prostate
Morphological Imaging - Prostate
Morphological Changes During RT
T1 MRI of Pancreas – Free Breathing
T1 MRI of Pancreas – Breath Hold
Magnetic Resonance Spectroscopic Imaging

- N-acetyl-aspartate, NAA,
- neuronal integrity
- choline - cell membrane
- creatine /
- phosphocreatinine
Iso-metabolite Map - GBM
MRSI of Recurrent Glioblastoma

Case #1

Disease extend beyond the region of $T_1$ contrast enhancement
MRSI of Glioblastoma

Case #2

61 yr old Female with disease progression ~2 yr post RT

Moderate CNI

Possible post- XRT necrosis!

Lipids
Comparison of conventional CT and MR based GTV, CTV with MRSI derived Choline-to-NAA maps. MRSI fused with CT (left), T1-contrast enhanced MRI (middle), and T2-MRI of rim enhancing GBM lesion. Contours: Cho:NAA = 2.0 → purple, GTV → red, and CTV → Green. Note significant portion of metabolically active tumor fall outside both GTV and CTV.
Metabolically active tumor volume covered well within GTV & CTV. MRSI Choline-to-NAA maps fused with CT (left), T1-contrast enhanced MRI (middle), and T2-MRI of rim enhancing GBM lesion. Contours: Cho:NAA= 2.0 → purple, GTV → red, and CTV → Green.
Contouring the Tumor: Morphology vs. Biology

Metabolic Tumor Volume Vs GTV, CTV

- **GTV**
- **CTV**
- **Cho:NAA = 2**

Volume (cc)

Pt #1, Pt #2, Pt #3, Pt #4, Pt #5, Pt #6, Pt #7, Pt #8, Pt #9
Contouring the Tumor: Morphology vs. Biology

Meltabolic Tumor Volume Outside GTV, CTV

% Cho:NAA = 2 Volume

- Outside GTV
- Outside CTV

Pt #1  Pt #2  Pt #3  Pt #4  Pt #5  Pt #6  Pt #7  Pt #8  Pt #9
MRSI – Effects of Susceptibility Mismatch

More pronounced @ High Magnetic Field!
So now the MD’s want to begin using MRSI data in treatment planning...

- Issues to be addressed when using MRSI clinically:
  - Shimming to achieve uniform magnetic field
  - Finding the peak for each resonance frequency
  - Phase adjustment
  - Spatial distortion
  - Integration into RT planning
  - Fighting with Radiology
  - Buying your own MRI scanner
  - Finding an MRI physicist to work in Radiation Oncology

Data acquisition

Post-processing

Integration into treatment planning
MRSI Integration into Planning

Generation of Metabolic Maps

- Normalize Each Image to Common Metabolic Scale
- Determine 6DOF Transformation
- Re-sample, Fuse, and Register with Planning CT

Contour Voxels Based On Metabolic Scale
Imaging of Moving Anatomy

3 reasons for MRI
#1 Breath Hold - EXHALE
#1 Breath Hold - INHALE
#2b Cardiac Gated MRI
#3 MRI provides better geometry?
#3

MRI provides better geometry!
MR-PET-CT

- Is there a role for all three imaging modalities in the simulation of Radiation Therapy treatment planning?
Conclusions

- MRI has widespread applications RT
- Geometric distortion – minimize & quantify
- MRI useful to quantify and validate motion management models
- MRSI shows promise – much work remains before routine clinical use
Acknowledgements

• Manickam Murugandanham, PhD
• RTT’s/MR Techs
• RN’s
• MD’s
Siemens 3.0 Tesla Magnetom Trio MR in Radiation Therapy

- Convenient for patients and staff
- Our needs in RT are not necessarily the same as DI’s needs
  - High contrast to noise
  - High spatial resolution (thin slices)
  - Full anatomy
  - Minimal spatial distortion
  - Functional imaging
  - Approximating treatment conditions
  - Length of scan time is not critical
So why 3.0 Tesla?
MRSI metabolite ratio (choline-to-NAA) superimposed on...

Contours shown represent:
- GTV-T1 (red)
- PTV-conventional (yellow)
- CNI4.0 (green)
- CNI3.0 (blue)
- CNI2.5 (purple)

Table 1. Region of Interest Changes

<table>
<thead>
<tr>
<th>ROI</th>
<th>Volume (cc)</th>
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<tbody>
<tr>
<td>GTV - T1</td>
<td>3.37</td>
</tr>
<tr>
<td>GTV - CNI 4.0</td>
<td>1.35</td>
</tr>
<tr>
<td>GTV - CNI 3.0</td>
<td>7.57</td>
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<tr>
<td>GTV - CNI 2.5</td>
<td>14</td>
</tr>
<tr>
<td>PTV - conventional</td>
<td>71.9</td>
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<tr>
<td>PTV - MRSI</td>
<td>29.7</td>
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