Potential of PET/MRI in Lung Cancer

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Objectives

• Introduce the hardware design and technical issues in PET/MRI.
• Discuss the potential role of PET/MRI in lung cancer evaluation.
• Understand the advantages and disadvantages of PET/MRI in lung cancer evaluation in comparison with PET/CT.

PET/MRI vs PET/CT

• MR: superior soft tissue contrast
  – CT: small lung nodule, bone
• No additional radiation exposure
• Functional studies with various MR sequences and MRS

Technical Aspects

Technical Challenges

• PET detectors
  – Magnetic compatibility
• Attenuation correction
  – Essential for the quantification of PET data
  – MR signal intensity: no direct relationship to electron density

Scanner Design

• Sequential PET/MRI system
• Image coregistration in separate PET and MRI systems
• Integrated PET/MRI

### Comparison of Various Systems

<table>
<thead>
<tr>
<th></th>
<th>Integrated PET/MRI system</th>
<th>PET/MRI system</th>
<th>Image Registration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simultaneity in PET and MRI acquisition</td>
<td>High</td>
<td>Intermediate</td>
<td>Low</td>
</tr>
<tr>
<td>Accuracy of PET/MRI registration</td>
<td>High</td>
<td>Intermediate</td>
<td>Low</td>
</tr>
<tr>
<td>PET attenuation correction</td>
<td>MRI-based</td>
<td>MRI-based</td>
<td>CT-based</td>
</tr>
<tr>
<td>Time-of-flight PET</td>
<td>Not possible*</td>
<td>Possible</td>
<td>Possible</td>
</tr>
<tr>
<td>Flexibility of scheduling</td>
<td>Less flexible</td>
<td>Less flexible</td>
<td>More flexible</td>
</tr>
</tbody>
</table>

*Yoon SH, et al. J Thorac Imaging 2014;29:4-16*

### Scintillation Light Detection

- **PMTs (Photomultiplier tubes)**
  - Standard PET detector
  - Extremely sensitive to magnetic fields
- **APDs (Avalanche photodiode)**
  -Insensitive even to very high magnetic fields
  - Inferior to PMT: gain, temporal resolution
- **Silicon photodiode (Geiger-mode APD)**
  - Higher gain
  - Faster temporal resolution: enabling TOF PET

### Simultaneous Acquisition

- Reduced imaging time compared to sequential imaging
- Better registration accuracy
  - Patient, physiologic movement
- MR-based motion correction for PET

### Attenuation Correction

- Segmentation-based approach
- **Dixon technique**
  - In phase and opposed phase
  - Water and fat
  - Air, fat, soft tissue, lung
- **UTE (ultrashort echo-time)**
  - Bone segmentation
  - Head and neck region

### Attenuation Correction

- **Virtual air artifacts**
  - Cortical bone, heart, aorta (blood flow)
  - Morphological closing filter
- **Instrumentation**
  - Patient bed, fixed MRI coils
  - Automatically integrated into the attenuation maps
Errors of decreased uptake in bone: 13%-17% in SUV

Potential sources of difference
- PMT vs APD
- Time of flight
- PSF, 3D AW OSEM
- Scanning order

Potential new artifacts by MR-AC: truncation
- Transaxial FOV of the MR is smaller than the PET-FOV
- Parts of the arms, shoulders, hips and breast might be missing in the segmented AC-map

Clinical Applications
Potential Applications: Body

- Oncology
  - MR: superior in detection of brain, liver, and bone marrow mets
  - PET: LN and soft tissue mass
  - DDx of therapy-related scar tissue from recurrent tumor

Whole body MR vs PET/CT

- NSCLC staging (Yi CA et al. Radiology 2008)
  - Comparable
  - MR: brain, liver
  - PET/CT: LN, soft tissue mets
- MR > PET/CT
  - Liver, bone, brain
- Adding brain MR to PET/CT (Lee HY et al. JKMS 2009)
  - Brain mets were detected in additional 7% of patients

Cerebral Metastases

- FDG-PET: detected only 61% of the metastases detected with MRI (Rohren EM. Radiology 2003)
- Whole body MR is more accurate than FDG PET/CT (Schmidt GP Invest Radiol 2005)

Coregistered WB MRI-PET vs PET/CT+brain MR

<table>
<thead>
<tr>
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<th>WB MRI-PET</th>
<th>PET/CT + brain MR</th>
<th>P-value</th>
</tr>
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<tbody>
<tr>
<td>Correct staging</td>
<td>37/143</td>
<td>26/120 (21.7%)</td>
<td>0.426</td>
</tr>
<tr>
<td>Over staging</td>
<td>26/143</td>
<td>7/120 (5.8%)</td>
<td>0.003</td>
</tr>
<tr>
<td>Under staging</td>
<td>18/143</td>
<td>28/120 (23.3%)</td>
<td>0.022</td>
</tr>
</tbody>
</table>

PET/MR Protocol: SNUH

- 5 bed positions
  - Attenuation correction: Dixon VIBE
  - T1 TSE coronal
  - HASTE FS axial
  - VIBE axial
- DWI: 2 BP, b-value: 50, 400, 800
- Post contrast VIBE axial
PET/MR: Pulmonary lesion

- 10 patients: proven or suspected lung cancer
- PET/CT followed by PET/MRI
- Tumor-to-liver ratio
  - PET/MR > PET/CT
- TNM scores
  - Identical in 7 of 10 patients
  - Differences in staging due to measurement differences


PET/MR: Pulmonary nodules

- 32 patients
- PET/CT followed by PET/MRI
- PET/CT (reference)
  - 69 nodules including 45 FDG-avid nodules
- PET/MR (radial VIBE+PET) sensitivity
  - 70% for all nodules
  - 96% for FDG-avid nodules
  - 89% for nodules ≥ 0.5 cm


Assessment of biological properties by MR and PET

- MR
  - Morphology
  - Cell density
  - Perfusion
  - Metabolism
- PET
  - Glucose metabolism
  - Perfusion
  - Tissue hypoxia
  - Apoptosis

Multiparametric Imaging

Reduced Radiation Exposure

- PET/CT total effective dose to the patient
  - Total: ~ 10 mSv
  - Internal irradiation due to radiopharmaceuticals
    - 18F-FDG: ~ 6–7 mSv
  - CT scan
    - Low-dose CT scan: ~ 2–4 mSv

Leide-Sveghorn, Radiation Protection Dosimetry 2010;1-6

Potentials and Challenges
Challenges

- Detection of small lung nodules
- Interpretation of discordant lesions
  - Development of joint criteria and specific reading recommendations
- Examination time
  - Optimization of the protocols

### Metastatic LN: PET vs MR

- Inclusive vs Exclusive Interpretation


### Lung Cancer: PET/MRI vs PET/CT

<table>
<thead>
<tr>
<th>Task</th>
<th>Superior Modality</th>
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<tbody>
<tr>
<td>Lung nodule detection</td>
<td>PET/CT</td>
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<tr>
<td>T-staging</td>
<td>PET/MRI except for satellite nodules</td>
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<tr>
<td>N-staging</td>
<td>PET/MRI</td>
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<tr>
<td>M-staging</td>
<td>PET/MRI except for metastatic nodules</td>
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<tr>
<td>Radiation exposure</td>
<td>PET/MRI</td>
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<tr>
<td>Examination time</td>
<td>PET/CT</td>
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<td>Multiparametric imaging</td>
<td>PET/MRI</td>
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### Summary

- PET/MRI may serve as appealing tool over PET/CT for workup of patients with lung cancer in terms of contrast resolution, multiparametric imaging, and radiation dose.
- It can offer a potential “one-stop” imaging modality in the evaluation of the whole-body status of lung cancer.