PET-MR in Pediatric Oncology

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Disclosure

- No financial disclosure
Objectives

- PET-MRI Technique
- Potential advantages/applications?
- Questions unanswered
What is PET/MRI?

ACR/SNMMI Definition:

A complex hybrid medical imaging technology that incorporates PET and MRI into a single device. Such an imaging system allows either sequential acquisition (i.e., tandem back-to-back design) or simultaneous acquisition (i.e., a PET insert in an MRI gantry or an integrated PET/MRI design). In either hybrid system, the goal is to combine PET and MR image data for exact co-registration.

Types of PET-MR scanners

Sequential Scanner

Simultaneous Scanner
Simultaneous PET-MR Scanners

- MR-based attenuation correction of PET data
- Simultaneous acquisition of MR and PET data
Simultaneous PET-MR Scanners

**Siemens Biograph mMR**
- 3Tesla, 60 cm bore
- FOV ~60/25cm
- Dixon based attenuation correction

**GE SIGNA PET/MR**
- 3Tesla, 60 cm bore
- FOV ~62/25cm
- Dixon base attenuation correction
- TOF PET scanner
Clinical Experience at Washington Univ/SLCH

- Main clinical indications
  - Epilepsy
  - Oncology
    - Neuro-oncology
    - Hematology (lymphoma/PTLD)
    - Solid tumors
    - Neurofibromatosis-1
Who oversees the study?

- Physicians’ role:
  - Review the indication
  - Prescribe radiopharmaceutical
  - Specify the pulse sequences
  - Prescribe MRI contrast agent
  - Ensure patient safety and quality

Who oversees the study?

- Physicians’ role:
  - Evaluate images and generate report
  - The two physicians *must reach consensus* regarding the final interpretation of the combined PET/MRI findings in order to *issue a joint PET/MRI report* (with one billing physician of record) or *two separate correlative PET and MRI reports*.
  - Please refer to the separate report, Accession # [ ], for interpretation of the MRI components of this examination.
  - CPT codes for PET and MRI

Clinical Workflow with PET/MR at Washington University

- Clinical Indications:
  - PET-CT and Regional MRI
  - Pediatric patient needs a PET-CT

When the Physician’s office orders PET/MRI, PET/MR is approved and protocolled by NM and Pediatric MR service, and CPT codes are provided to ordering physician’s office for precertification of SOC PET and SOC MRI (if needed). MRI screening and instructions to the patient are done over the phone. PET/MRI study is performed and jointly interpreted by NM and MRI services, and Radiopharmaceutical is ordered. Billing is performed separately for SOC PET +/- SOC MR.
Simultaneous PET-MR Imaging

Basic Whole Body PET-MR Protocol

<table>
<thead>
<tr>
<th>PET</th>
<th>Dixon HASTE DWI</th>
<th>4-5min</th>
</tr>
</thead>
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Simultaneous PET-MR scanner

- NAC PET
- In phase
- Out of phase
- Water only
- Fat only
- μmap
- AC PET

Imaging modalities:
- HASTE
- DWI
- ADC
Simultaneous PET-MR scanner
## Simultaneous PET-MR scanner

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<th>NAC PET</th>
<th>In phase</th>
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<th>μmap</th>
<th>AC PET</th>
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</table>

![Image of PET-MR scanner with various modalities](image)

**Modalities:**
- HASTE
- DWI
- ADC
# Whole-body Protocol + Regional Imaging

| PET     | Dixon HASTE DWI | \[ \text{Regional T}_1 \] \text{Regional T}_2 \text{Pre contrast T}_{1FS} \text{Post contrast T}_{1FS} |
Whole-body Protocol + Regional Imaging

3 year old with Ewing Sarcoma
Whole-body Protocol + Regional Imaging

Whole Body PET/MR
- PET
- Dixon
- HASTE
- STIR/DWI

Regional Scan
- Liver
  - Coronal HASTE
  - Axial HASTE
  - Axial T2 FS
  - Axial IR
  - Axial in/out phase
  - Axial DWI
  - Axial pre contrast vibe
  - Axial post contrast vibe x 3
Whole-body Protocol + Regional Imaging

Whole Body PET/MR
- PET
- Dixon
- HASTE
- STIR/DWI

Modified Regional Scan
- Liver
  - Axial T2 FS
  - Axial pre contrast vibe
  - Axial post contrast vibe x 3

- Total Scan time <60 minutes
- Should not increase the need for sedation
MR-based Attenuation Correction

- Attenuation map: $\mu$-map
MR-based Attenuation Correction

- Challenges
  - Bone: 30% variability in SUV estimation in Dixon based attenuation correction

MR-based Attenuation Correction

SUV correlation between PET-MR & PET-CT

MR-based Attenuation Correction
SUV correlation between PET-MR & PET-CT

\[ R^2 = 0.88 \]

<table>
<thead>
<tr>
<th>Normal Organs</th>
<th>SUV_{\text{mean}}</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET/MR SUV_{\text{mean}}</td>
<td>PET/CT SUV_{\text{mean}}</td>
</tr>
</tbody>
</table>

Correlation Co-efficient

<table>
<thead>
<tr>
<th>Organ</th>
<th>Co-efficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone</td>
<td>0.90</td>
</tr>
<tr>
<td>Liver</td>
<td>0.86</td>
</tr>
<tr>
<td>Skeletal Muscle</td>
<td>0.78</td>
</tr>
<tr>
<td>Lung</td>
<td>0.65</td>
</tr>
<tr>
<td>Blood pool</td>
<td>0.61</td>
</tr>
</tbody>
</table>

MR-based Attenuation Correction

SUV correlation between PET-MR & PET-CT

- 16 pediatric patients

MR-based Attenuation Correction

SUV correlation between PET-MR & PET-CT

- 25 pediatric patients on sequential scanner

Sher, et al. AJR. 2016
MR-based Attenuation Correction

SUV correlation between PET-MR & PET-CT

- 25 pediatric patients on sequential scanner

PET-MR First

Sher, et al. AJR. 2016
Whole-body Protocol

- 15 year old with relapsed Hodgkin's Disease
Excitement for PET-MR

- PET and MRI performed in one setting
  - Single sedation
  - Better patient throughput ??
  - Co-registration
  - Better soft tissue contrast
  - Diffusion weighted imaging
  - Radiation Protection
Improved Evaluation of Soft Tissues Diffusion weighted Imaging

18 year old post BMT - PTLDc
Improved Evaluation of Soft Tissues Liver Imaging

18 year old post BMT - PTLD
## Impact on Diagnosis

<table>
<thead>
<tr>
<th>Author/Year</th>
<th>Tumor</th>
<th>N</th>
<th>Main Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catalano, et al. 2013</td>
<td>Variety</td>
<td>134</td>
<td>• 17.9% of cases additional findings on PET/MR</td>
</tr>
</tbody>
</table>
| Huellner, et al. 2014 | Variety            | 160 | • PET/MR with STIR $<$ PET/CT  
• PET/MR with LAVA and PROPELLER $=$ PET/CT |
| Schafer, et al. 2014  | Pediatric Solid tumors | 18  | • PET/MR equivalent to PET/CT in lesion detection                           |
| Ishii, et al. 2016   | Variety            | 123 | • Detected more brain metastasis but less lung and bone lesions              |
| Sher, et al. 2016    | Pediatric Lymphoma | 25  | • Comparable diagnostic accuracy to PET/CT                                  |
| Afaq, et al. 2017    | Lymphoma           | 66  | • Comparable accuracy  
• Good SUV correlation  
• No impact of DWI on management |
<table>
<thead>
<tr>
<th>Publication</th>
<th>Population</th>
<th>Average Radiation Dose Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shafer et al, 2014</td>
<td>Solid tumors &amp; lymphoma (18)</td>
<td>73%</td>
</tr>
<tr>
<td>Ponisio et al, 2016</td>
<td>Aggressive lymphoma (9)</td>
<td>39%</td>
</tr>
<tr>
<td>Sher et al, 2016</td>
<td>Lymphoma (25)</td>
<td>45%</td>
</tr>
<tr>
<td>Gatidis, 2016</td>
<td>Solid tumors (9)</td>
<td>48%</td>
</tr>
</tbody>
</table>
Radiation Reduction?
Reduce Imaging Studies

- Voss, et al. JCO 2012
  - CT surveillance in HD up to 5 years post therapy

  - Combine CECT with PET/CT using tube current modulation
  - Radiation dose savings ~25%
Challenges with PET-MR
Pulmonary Metastasis

- Radial vibe/Star vibe
- 32 adult patients
- 69 pulmonary nodules → 45 FDG avid
- Overall sensitivity of PET/MR
  - 70.3%
- Sensitivity of PET/MR >5mm
  - 88.6%
- Sensitivity of PET/MR for non-FDG avid nodules
  - 22.9%

PET-MR Challenges
Evaluation of Pulmonary Metastasis

- Free breathing ultrashort TE sequence (TE <80 microsec)
- 8 adult patients with known pulmonary metastasis
- 82 pulmonary nodules
- Mean size 6.2+/−2.7mm
- 82% detection rate ≥ 4mm
- 17% detection rate < 4mm

PET-MR Challenges
Evaluation of Pulmonary Metastasis

**PET-MR Challenges: Patient Comfort**

![Graph showing VAS ratings for PET/CT and PET/MR.](image)

**Future Techniques in PET/MR**

- Ferumoxytol
  - Whole body PET
  - Whole body SPGR
  - 33 children/young adults with lymphoma/sarcoma
  - Sens 99.3%, Spec 99.8 vs. 99.9%
  - Scan time reduced by 10 minutes

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Adapting Body MR to PET/MR: Challenges

- 3Tesla imaging
- SAR
- Artifacts
- Susceptibility effects

μ-map  Fused PET-MR

Metal artifacts  Truncation Artifacts  Respiratory motion
MR-based Attenuation Correction

- Challenges
  - Metal implants/Fe

HASTE  μ-map

NAC-PET  AC PET
Adapting Body MR to PET/MR: Challenges

- Multiplanar viewing

3 year old with diaphragmatic rhabdomyosarcoma; post Rx
Summary of PET/MR

- Equivalent to PET-MR
- SUV estimation correlates
- Added value?
  - Superior imaging vs. complexity/expense
  - Impact on patient outcome
Thank you!

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