Introduction to PET/MRI Combined Scanner and Potential Pediatric Applications

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Learning Objectives

• Illustration of PET/MRI combined scanner configuration
• Advantages and disadvantages, capabilities and limitations of combined scanner
• Presentation of some early results
• Potential pediatric applications of combined PET/MRI scanning
Siemens BrainPET prototype scanner installed inside the MAGNETOM Trio MR Scanner (left); BrainPET withdrawn from the MR scanner for stand alone MR operation (right)

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PET Detector Basics

- PMT: path of electrons deviated by magnetic field, therefore unsuitable for PET/MRI combined scanner.
Strategies for MR-compatible PET Detectors

- PET detector components – selected and designed for minimal interference with magnetic and radiofrequency fields of MRI system
  - Position PMT detectors remotely from magnetic connected by optical fibers
  - Semi-conductor-based detectors
    - Avalanche Photodiodes (APD)
    - Silicon photomultipliers (SiPM)
Avalanche Photodiode (APD) detector

- APD is insensitive to even high magnetic fields up to 9.4T

BrainPET Scanner Design

- Standard MR 3T tunnel (60 cm ID)
- BrainPET insert (35 cm ID)
- 32 Detector Cassettes
- 6 LSO Blocks/Cassette
  - crystal size $2.5 \times 2.5 \times 20 \text{ mm}^3$
  - 12 x 12 crystals/block
  - 3 x 3 array of Hamamatsu APDs
- 192 LSO Blocks total
- 1732 APDs total
- 19.25 cm axial / 30 cm transaxial
- Air/Water cooling
MR Coils

- Coils are positioned inside the PET-insert
  - Minimize field inhomogeneity due to conductivity of PET detectors

- Standard bird cage transmit-receive head coil with inner head coil
  - 8-channel head coil designed to minimize components within the PET field-of-view (19.5 cm)
Combined PET and MRI - Why?

Simultaneous acquisition of PET and MRI

- More precise co-registration and anatomic localization
- Potential for simultaneous quantitative dynamic PET and contrast-enhanced MRI
- MRI-based motion-correction techniques
- Compared to separately-acquired MRI and PET, shorter acquisition time → less sedation/GA
Combined PET and MRI - Why?

PET-MRI vs. PET-CT

– Advantages of MRI

• No ionizing radiation → dose reduction
• Better characterization of soft tissues, bone marrow, brain and spine
Combined PET and MRI – Why?

PET-MRI vs. PET-CT

– Disadvantages/limitations of MRI

• Poorer characterization of cortical bone, lungs/lung nodules
• MRI takes longer that CT → longer sedation/GA
• (NB – sedation often required for pediatric PET)
• Contraindicated or unhelpful in those with metallic implants, pacemakers, etc.
• Attenuation correction is challenging
  – Segmentation approaches
  – Atlas-based approaches
Combined PET and MRI – Why?

PET-MRI image fusion
- Precise anatomic localization of abnormal uptake
  - Distinguish physiologic uptake versus tumor
- Potential quantitation of physiologic function through dynamic analysis of contrast-enhancement and radiotracer accumulation
  - More accurate and precise ROIs based on MR anatomy
  - Tumor characterization
  - Normal tissue characterization, e.g.:
    - Renal GFR
    - Myocardial motion, perfusion, viability
Limitations of Current PET-MRI Combined Scanner

- Small bore size
  - I.D. of head coil = 22 cm
  - I.D. of transmit-receive coil = 26 cm
  - Some adult heads have been too large to fit

- Coil limitations
  - Head coil has closed-end
    - ? Hand or foot imaging possible
  - Transmit-receive coil has tubular configuration but sub-optimal SNR
    - Infant or small child could potentially fit
  - Only 8-channel
Limitations of Current PET-MRI Combined Scanner

- Location of scanner
  - Off-campus imaging research facility
  - No nursing, sedation, GA

- FDA
  - MRI scanner is FDA-approved, but PET insert is not

- IRB
  - Few clinical indications for PET in infants and small children
Early Results

Simultaneous MR-PET Data Acquisition

20 cm diameter phantom
Hole size range 2.5-6 mm
Center-to-center = 4 times hole diameter

PET
• 1.5 mCi F-18 water
• 20 min acquisition scan
• OSEM 3D reconstruction

MR
• FLASH (shown), TSE, MP-RAGE sequences run simultaneously
• CP coil

Catana/Rosen/Sorensen (MGH)
Simultaneous MR-PET Data Acquisition

54 year old with malignant glioma and cutaneous extension

PET

• 5.45 mCi FDG injected approx. 2.5 hours prior to data acquisition
• OSEM 3D reconstruction
• Attenuation correction performed based on the MR data

MR

• T1 MP-RAGE, T2 SPACE (shown), FLAIR, DTI, CSI, SVS sequences run simultaneously
• CP coil
Simultaneous MR-PET Data Acquisition

17-old male with epilepsy

**PET**
- ~5 mCi FDG injected ~2.5 hours prior to data acquisition
- OSEM 3D reconstruction
- Attenuation correction performed based on the MR data

**MR**
- T1 MP-RAGE, T2 SPACE, FLAIR, DTI, CSI, SVS sequences run simultaneously
- 8 channel coil

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Fused MR-PET

Catana/Benner/van der Kouwe/Grant/Madan/Rosen/Sorensen (MGH)

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Simultaneous MR-PET acquisition

Diffusion Tractography

Fused PET - MR

Surface Rendering

High Res Anatomy

MRA
Catana/Rosen/Sorensen (MGH)
Early Results - the complete version:

**Oncology Investigations**

Sunday, June 14  
4:15 PM - 5:45 PM  
Room 711

**Presentation Time:**  
5:27 PM - 5:39 PM

**Simultaneous MR-PET of Human Brain Tumors - Initial Experience**

Ciprian Catana; Thomas Benner; Elizabeth Gerstner; Dominique Jennings; Larry Byars; Michael Hamm; Christian Michel; Matthias Schmand; Bruce Rosen; Gregory Sorensen
Potential Pediatric Applications of PET-MRI

- In what clinical scenarios is MRI a more effective modality than CT?
  - Brain tumors
  - Seizure disorders
  - Head and neck tumors
  - Body tumor imaging, including but not limited to:
    - Lymphoma
    - Neuroblastoma
    - Liver tumors
    - Pelvic tumors
    - Musculoskeletal tumors
Potential Pediatric Applications of PET-MRI (cont’d)

• Screening of multiple hereditary neoplasms for malignant transformation
  – Neurofibromatosis
  – Multiple hereditary osteochondromas
  – Ollier / Maffucci syndromes

• Developing MR techniques:
  – Diffusion-weighted MRI - lymphoma
  – Functional MRI – ADHD, autism, developmental disorders
  – MR spectroscopy – tumor, metabolic disorders
  – Arterial Spin Labelling - perfusion
  – BOLD imaging - oxygenation
Potential Pediatric Applications of PET-MRI (cont’d)

• Non-18F-FDG radiotracers:
  – Bone scan - 18F-NaF
  – Amino acid analogs - e.g. 11C-MET, 18F-FET, 18F-FACBC
  – Other tumor proliferation - e.g. 18F-FLT
  – Myocardial perfusion – e.g. 15O-H₂O, 13N-NH₃
  – Hypoxia imaging – e.g. 18F-MISO, 64Cu-ASTM
  – Neurotransmitters and receptors – e.g. 18F-DOPA, 11C-raclopride
Potential Pediatric Applications of PET-MRI

Brain Tumor

Choroid Plexus Carcinoma

Where is the tumor?

18F-FDG PET

Fused PET/MRI
Potential Pediatric Applications of PET-MRI
Brain Tumor

Follow-up MRI
Residual tumor has grown
Potential Pediatric Applications of PET-MRI Brain Tumor

7 year-old female with bithalamic astrocytoma
Potential Pediatric Applications of PET-MRI
Brain Tumor

11C-Methionine PET and PET-MRI fusion
Potential Pediatric Applications of PET-MRI Seizure

Right mesial temporal sclerosis
Patient underwent right temporal lobectomy – now seizure-free

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Potential Pediatric Applications of PET-MRI Lymphoma

Axial Diffusion-Weighted MRI and 18F-FDG PET
Potential Pediatric Applications of PET-MRI Lymphoma

Axial T2 MRI for anatomic localization and 18F-FDG PET
Potential Pediatric Applications of PET-MRI Neuroblastoma

Whole-Body Coronal STIR MRI and 18F-FDG PET
Potential Pediatric Applications of PET-MRI
Musculoskeletal tumor

L5 metastasis from osteosarcoma of left femur

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Potential Pediatric Applications of PET-MRI Metastatic Staging

Ewing sarcoma of right pelvis
Coronal STIR MRI and 18F-FDG PET
Potential Pediatric Applications of PET-MRI Metastatic Staging

Ewing Sarcoma
Coronal STIR MRI and 18F-FDG PET
Potential Pediatric Applications of PET-MRI Neurofibromatosis

Whole-Body Coronal STIR MRI and 18F-FDG PET
Potential Pediatric Applications of PET-MRI Neurofibromatosis

Whole-Body Coronal STIR MRI and 18F-FDG PET
Potential Pediatric Applications of PET-MRI Hypoxia Imaging

Chordoma
18F-MISO PET and Sagittal T2 FS MRI

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Challenges in Development of PET-MRI Whole Body Imaging

• Integrated system and longitudinal field of view
  – Is it better to have side-by-side MR and PET systems since table will need to move anyway?

• Attenuation correction
  – Body tissues not as homogeneous as brain, and therefore automated segmentation is more challenging

• Need for fast whole-body MRI sequences
  – Minimize motion artifacts and bladder filling
Conclusions

- For pediatric conditions in which MRI is a more effective imaging modality than CT, combined PET/MRI holds great potential to reduce radiation dose and amount of sedation/anesthesia.

- Currently available PET/MR systems have a small bore that can accommodate adult brain imaging. Body imaging of infants and small children has not yet been attempted, but is theoretically possible.
Conclusions

• PET/MR imaging of infants and small children is now logistically difficult due to unavailability of off-campus sedation/anesthesia and the rarity of clinically-indicated PET scan in this age group

• Pediatric brain applications include tumor and seizure

• Pediatric body applications are also numerous and include: lymphoma, neuroblastoma, neurofibromatosis, multiple hereditary cartilage tumors
  – Whole-Body MRI and Whole-Body 18F-FDG PET (separately acquired) are already being used in some of these patients!
For more details...

Tuesday, June 16
12:30 PM - 2:00 PM
PET/MR
Session Type: SNM Continuing Education
Room 716AB