Hybrid PET-MR Imaging of Prostate Cancer: Potential Clinical Applications

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OBJECTIVES

• To provide an overview of PET-MR
• To illustrate potential clinical applications for prostate cancer imaging

PET/MR of the prostate showing 18F fluorocholine uptake in the left posterior peripheral gland
INTRODUCTION

• PET-MR is a relatively new imaging modality
  • First performed in small animals in the 1990s and in humans in 2006
  • Approved by the FDA in 2011
  • More than 50 PET/MR systems have been sold in Europe, North America, Asia, and Australia as of December 2013
INTRODUCTION

- Clinical applications:
  - **Oncologic imaging**: initial staging and follow-up; biopsy and radiation therapy (XRT) planning
    - Especially head and neck, breast, liver, rectal, gynecologic, prostate, and pediatric cancers
  - **Neuroradiology**: cortical dysplasia, neurodegenerative diseases
  - **Cardiac imaging**: myocardial viability

PET-MR shows an enhancing left breast mass with corresponding FDG uptake in this case of biopsy-proven invasive ductal carcinoma (arrows)
ONCOLOGIC IMAGING

• Many patients undergo both PET/CT and MR imaging to obtain complementary diagnostic information

PET/CT:
  • Anatomic and metabolic information
  • Whole body imaging
  • Quantitative

FDG-avid lung nodule on PET/CT

MR imaging:
  • Anatomic and functional information
  • Organ-specific imaging
  • Superior soft tissue contrast compared to CT
  • Wide range of functional information via multiparametric imaging
  • Non-ionizing radiation, especially important for younger patients
ONCOLOGIC IMAGING

• Combine the two most commonly used oncologic imaging modalities to provide both organ-specific and whole body imaging with T, N, and M staging in one examination

  • PET + MR = anatomic + functional + molecular imaging

  • Additional benefits for pediatrics: one sedation and imaging session, reduced radiation dose compared to PET/CT

PET/MR in pediatric oncologic imaging
IMPLEMENTATIONAL CHALLENGES

• Technology
  • PET detectors and MR magnetic fields interfere with each other
  • MR-based attenuation correction

• Cost
  • $5-7 million for PET/MR compared to $1.5-2 million for PET/CT, with same reimbursement as PET/CT
    • Unproven added value of PET/MR to justify expense

• Time
  • Personnel training of technologists and interpreting physicians
    • Requires collaboration between radiology and nuclear medicine departments
NEW PET DETECTORS

• Optical fiber design:
  • Optical fibers connect scintillation crystals to photomultiplier tubes (PMTs) located outside the magnetic field

• Semiconductor design:
  • Solid state scintillation detectors avalanche photodiodes (APDs) replace PMTs
    • APDs are located within the MR system (arrow)
MR-BASED ATTENUATION CORRECTION

- Necessary for image quality and quantitative analysis
- Whole body Dixon sequences provide basis for tissue segmentation into lung, soft tissue, fat, and background classes
- Attenuation values are assigned to tissue classes using standard reference values
LIMITATIONS

• **Truncation artifact**: does not account for anatomy outside the imaging field of view

• **Cortical bone**: produces little MR signal and standardized uptake values may be underestimated

• **Metal**: creates signal void and apparent photopenia

MR signal void from dental braces creates apparent photopenia on attenuation map (arrow, A). Similarly, MR signal void from orthopedic hardware (arrows, B) creates apparent photopenia on attenuation correction map (arrows, C)
PET/MR PROTOTYPES (General Electric)

- Separate PET and MR image acquisition
  - A moving table transports patients between scanners located in different rooms
- Software-based image fusion

Image courtesy mriandmedicalimaging.blogspot.com/2013/11/mrpet-current-status-in-clinical.html
PET/MR PROTOTYPES (Philips)

• Sequential image acquisition with time of flight PET and 3T MR scanners
  • Scanners stand 4.2 meters apart at each end of a sliding bed that rotates 180 degrees from one scanner to the other
• Software-based image fusion
PET/MR PROTOTYPES (Siemens)

- Integrated image acquisition
  - A full ring of APD PET detectors is located within the gantry of a 3T MR scanner

Images courtesy Siemens
PROSTATE PROTOCOL

• Patient empties bladder prior to imaging

• Nuclear medicine technologist injects 300 MBq of 18F fluorocholine (FCH) intravenously and immediately obtains PET images of the pelvis (duration 10 minutes), followed by PET images of the whole body from the head to the mid-thigh (seven to eight bed positions, four minutes per position)

  • PET images are acquired first to avoid artifacts related to radiotracer accumulation in bladder (scatter obscuring other pelvic structures and complicating image fusion)

• MR technologist obtains MR images of the whole body for attenuation correction, followed by dedicated MR sequences of the prostate and abdomen
## PROSTATE PROTOCOL

Dedicated MR sequences of the prostate and abdomen:

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Plane</th>
<th>Field of View</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2 FSE</td>
<td>Axial and sagittal</td>
<td>Pelvis</td>
</tr>
<tr>
<td>• Use endorectal and cardiac coils</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T2 FSE</td>
<td>Axial, sagittal, and coronal</td>
<td>Pelvis</td>
</tr>
<tr>
<td>• Use cardiac coil for all remaining sequences</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DWI</td>
<td>Axial</td>
<td>Pelvis</td>
</tr>
<tr>
<td>• b = 0, 500, 1000, 1500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1 FS FFE</td>
<td>Axial, sagittal, and coronal</td>
<td>Pelvis</td>
</tr>
<tr>
<td>Dynamic T1 FFE</td>
<td>Axial, sagittal, and coronal</td>
<td>Pelvis</td>
</tr>
<tr>
<td>• Inject 0.1 mmol/kg Dotarem intravenous gadolinium contrast</td>
<td></td>
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</tr>
<tr>
<td>Dynamic T1 FFE</td>
<td>Axial, sagittal, and coronal</td>
<td>Abdomen</td>
</tr>
</tbody>
</table>

**Abbreviations**: DWI, diffusion weighting imaging; FFE, fast field echo; FS, fat saturated; FSE, fast spin echo
PROSTATE PET/MR

• FCH is used for prostate cancer imaging in Europe
  • Choline is incorporated into the membranes of growing/dividing cells and is preferentially taken up by rapidly proliferating prostate cancer cells
• Multiparametric MR provides superior anatomic and functional information compared to CT
• PET/MR has the potential to delineate extracapsular extension, seminal vesicle invasion, metastatic lymphadenoapathy, and other metastatic disease

FCH PET/CT shows uptake in the posterior right prostate; further anatomic characterization by zonal anatomy is not possible
PROSTATE PET/MR

• Indications:
  • Positive biopsy for prostate cancer
  • Initial staging
    • Imaging evidence of extraprostatic extension, seminal vesicle invasion, lymphadenopathy, and other metastatic disease helps determine treatment
  • XRT planning
  • Suspected tumor in the setting of elevated prostate specific antigen (PSA) level with negative biopsy
  • Suspected tumor recurrence in the setting of elevated PSA after prostatectomy or XRT
FCH PET/MR in a 61 year-old man with an elevated PSA of 14 ng/mL and a positive biopsy with Gleason 3 + 3 disease. T2 hypointensity (A) and corresponding FCH uptake (B) in the right anterior peripheral gland suggested organ-confined disease (arrows). Pathologic staging after prostatectomy confirmed organ-confined disease (pT2a).
FCH PET/MR in a 64 year-old man with an elevated PSA of 23 ng/mL and a positive biopsy with Gleason 3 + 3 disease. T2 hypointensity (A) and corresponding FCH uptake (B) in the right greater than left central gland (arrows). Pathologic staging after prostatectomy confirmed organ-confined disease (pT2c). Incidental note is made of a prostatic cyst.
FCH PET/MR in a 71 year-old man with a PSA of 4 ng/mL and a positive biopsy with Gleason 4 + 4 disease. Clinical stage was T1c, with a 10% risk of seminal vesicle invasion (SVI) by Partin nomogram. T2 hypointensity (A, B) and corresponding FCH uptake (C) in the seminal vesicles suggested SVI (arrows). Pathologic staging after radical prostatectomy confirmed SVI (pT3b).
FCH PET/MR in a 64 year-old man with an elevated PSA of 6.8 ng/mL and a positive biopsy with Gleason 4 + 3 disease. Clinical stage was T2a with a 9% risk of SVI based on Partin nomogram. T2 hypointensity (A) with corresponding FCH uptake (B, C) in the left seminal vesicle suggested SVI (arrows). Pathologic staging after radical prostatectomy confirmed SVI (pT3b). Gross pathology specimen showed a relatively pale area in the left posterior prostate corresponding to known tumor (arrows).
FCH PET/MR in a 63 year-old man with an elevated PSA of 8.3 ng/mL and a positive biopsy with Gleason 3 + 4 disease. Clinical stage was T1c with a 6% risk of SVI based on Partin nomogram. T2 hypointensity (A) with corresponding FCH uptake (B) in the right greater than left seminal vesicles suggested SVI (arrows). Pathologic staging following radical prostatectomy confirmed SVI (pT3b).
FCH PET/MR in a 67 year-old man with an elevated PSA of 16 ng/mL and positive biopsy with Gleason 4 + 4 disease. FCH uptake in a left common iliac lymph node suggested regional lymph node metastasis and was confirmed on pathology after lymph node dissection at the time of prostatectomy.
FCH PET/MR in a 59 year-old man with an elevated PSA of 12 ng/mL and a positive biopsy with Gleason 4 + 5 disease. T2 hypointensity (A) with corresponding FCH uptake (B) in a right internal iliac lymph node suggested regional lymph node metastasis and was confirmed on pathology after lymph node dissection at the time of prostatectomy.
FCH PET/MR in a 68 year-old man with an elevated PSA of 14 ng/mL and a positive biopsy with Gleason 4 + 3 disease. Enlarged, rounded right external iliac lymph node (A) with corresponding FCH uptake (B) suggested regional lymph node metastasis and was confirmed on pathology after lymph node dissection at the time of prostatectomy.
FCH PET/MR in a 75 year old man with an elevated PSA of 11 ng/mL and a positive biopsy with Gleason 4 + 3 disease. Focal T2 hypointensity and FCH uptake in the right pubic bone (SUV max 7.3), left iliac bone (SUV max 3.7), and left ischial tuberosity (SUV max 5.5), consistent with metastases. Bone scan confirmed osteoblastic activity in these areas.
FCH PET/MR in a 70 year old man who had undergone prostatectomy for Gleason 4 + 4 disease with elevated an PSA of 12 ng/mL. T2 hypointense focus (A) with corresponding FCH uptake (B) in the prostate bed suggested disease recurrence, and the patient was referred to radiation oncology for treatment.
CONCLUSION

• PET-MR is a relatively new imaging modality with many promising, feasible clinical applications for prostate cancer imaging, including detection of:
  • Organ-confined disease
  • Extracapsular extension including seminal vesicle invasion
  • Regional lymphadenopathy
  • Osseous and other distant metastases
  • Disease recurrence
REFERENCES