PET/MR: An Update

Weili Lin, Ph.D.

Director and Dixie Lee Soo Distinguished Professor of Neurological Medicine
Biomedical Research Imaging Center (BRIC)

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MR vs. PET

- Detailed anatomical information
- Exquisite soft tissue contrast
- No radiation
- Availability of many sequences
- Limited sensitivity to molecular events

- Limited anatomical definitions
- Poor soft tissue contrast
- Radiation
- High sensitivity to molecular events

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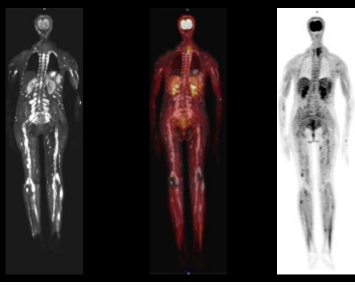
MR vs. PET



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Outlines

- Technical specs of Siemens and GE hybrid PET/MR scanner
- Attenuation correction approaches
- Motion correction of PET images
- Radiation dose reduction
- Clinical applications

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Technical Specs: PET

		Siemens		GE	
Detector		8 rings		45 rings	
			56 blocks		28 modules
			8x8 array of LSO		4x9 array of Lutetium-based Scintillator
			3x3 array of APD		1x3 array of SiPMs
Detector position		Between body and gradient coils		Between body and gradient coils	
Cooling for detectors		Chilled water		Chilled water	
Trans/Axial FOV		59.4/25.8 cm		60/25cm	
Energy Resolution		14.5%		11%	
Timing Resolution		2.93 ns		<400ps	
Spatial Resolution (FWHM)	Trans/axial @1cm	4.4mm		4.2mm	
TOF		No		Yes	

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Technical Specs: MR

	Siemens	GE
Field Strength	3T	3T
Bore-size	60cm	60cm
Gradient	45mT/m	44mT/m
Raise time	200T/m/s	200T/m/s

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Attenuation Correction

- Standalone PET
  - Using an external radionuclide source ($^{68}Ge/^{68}Ga$) emitting gamma photons at ~511 KeV
- PET/CT
  - 80-140 KeV
  - CT-based attenuation maps
- PET/MR
  - MR works under different physical principles from CT-based and external radionuclide based attenuation correction

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MR-Based Attenuation Correction Methods

- Atlas-based approaches
- Direct imaging methods
  - Two-point Dixon methods
  - Double-echo Ultra-short TE methods

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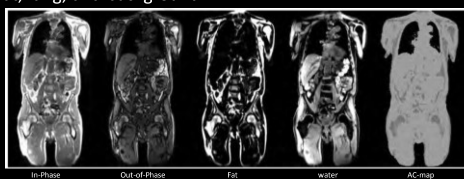
Two-Point Dixon Method

- Separate tissues into four tissue classes, including soft tissues, fat, lung, and background.



Copied from Catana, Magn Reson Imaging Clinics of NA, 2017; 25 (2): 231-243

Double-echo Ultra-short TE (DUTE)

- Since bone is MR “invisible”, bone is assigned as soft tissue, using two-point Dixon
- Double-echo Ultra-short TE approaches were proposed to provide accurate delineation of bone from air
  - Echo 1 (TE < 0.1ms)
    - bone tissues → somewhat MR visible
    - air → not MR visible
  - Echo 2 (TE ~ 2ms)
    - bone tissues → not MR visible
    - air → not MR visible

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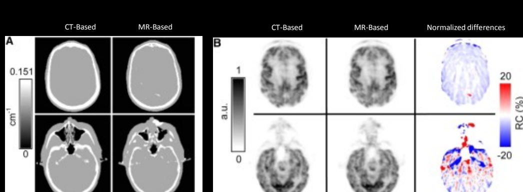
Double-echo Ultra-short TE



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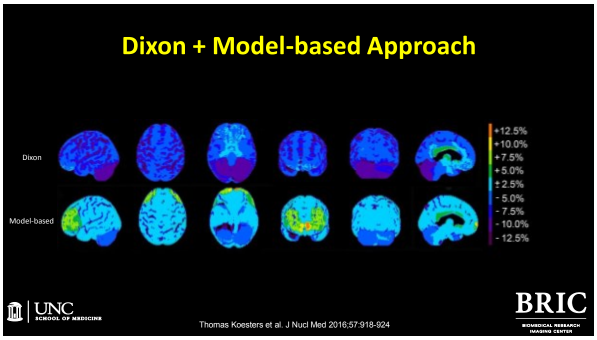
Dixon + Model-based Approach
Dixon
Model-based
+12.5%
+10.0%
+7.5%
+5.0%
±2.5%
- 5.0%
- 7.5%
- 10.0%
- 12.5%
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Thomas Koesters et al. J Nucl Med 2016;57:918-924
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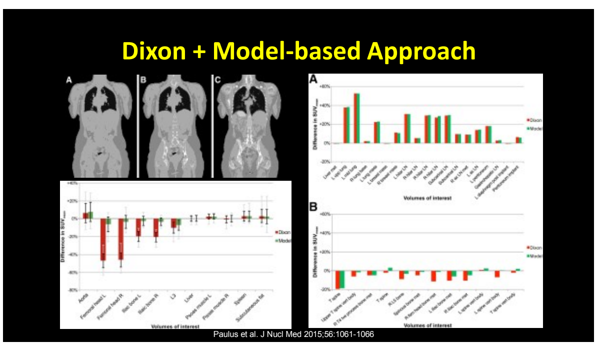
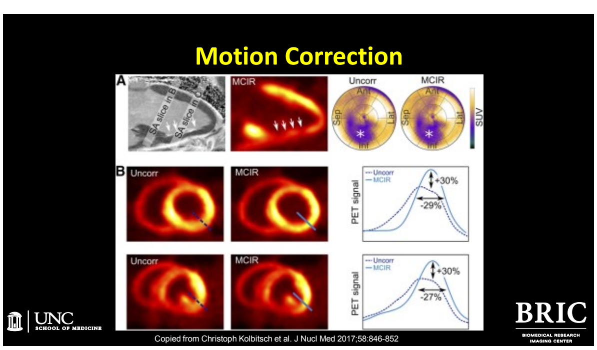

Dixon + Model-based Approach
A
B
C
A
B
Volumes of interest
Paulus et al. J Nucl Med 2015;56:1061-1066


Motion Correction
A
MCIR
Uncorr
MCIR
Sep
Lat
SUV
B
Uncorr
MCIR
PET signal
+30%
-29%
Uncorr
MCIR
+30%
-27%
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Copied from Christoph Kolbitsch et al. J Nucl Med 2017;58:846-852
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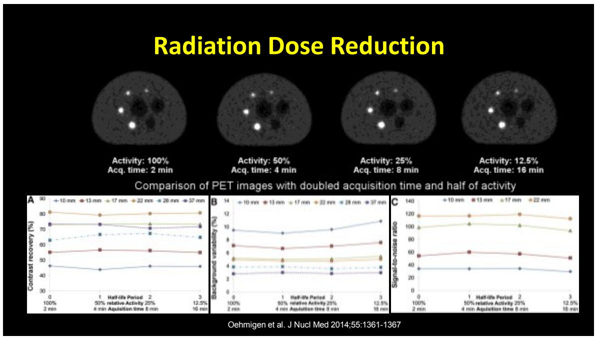
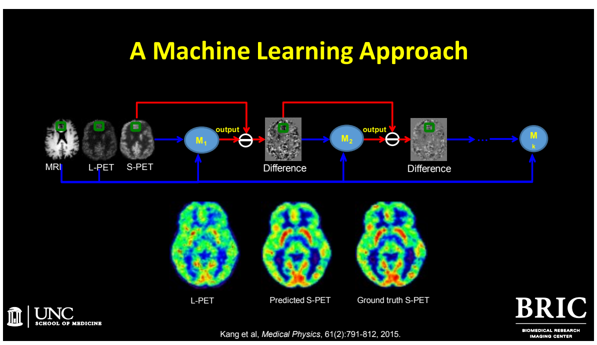

Radiation Dose Reduction
Activity: 100%
Acq. time: 2 min
Activity: 50%
Acq. time: 4 min
Activity: 25%
Acq. time: 8 min
Activity: 12.5%
Acq. time: 16 min
Comparison of PET images with doubled acquisition time and half of activity
A
Contrast recovery (%)
B
Background variability (%)
C
Signal-to-noise ratio
Half-life Period
relative Activity
Aquisition time
Oehmigen et al. J Nucl Med 2014;55:1361-1367


A Machine Learning Approach
MRI
L-PET
S-PET
output
Difference
Difference
L-PET
Predicted S-PET
Ground truth S-PET
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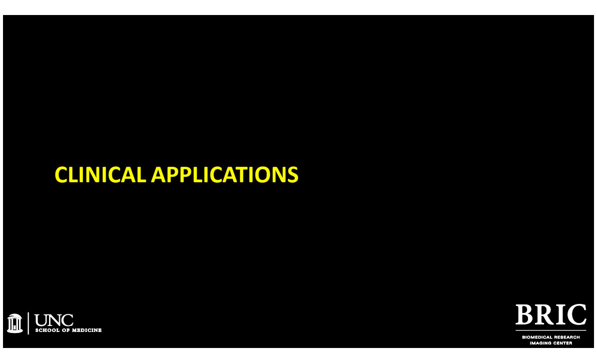
Kang et al, Medical Physics, 61(2):791-812, 2015.


CLINICAL APPLICATIONS
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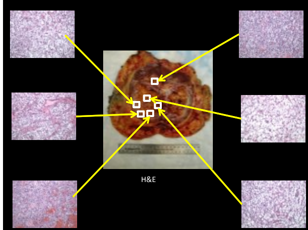
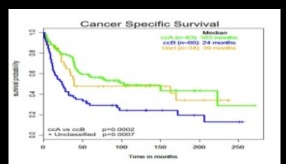
Heterogeneity of Renal Cell Carcinoma Tumors

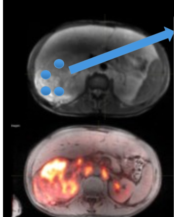


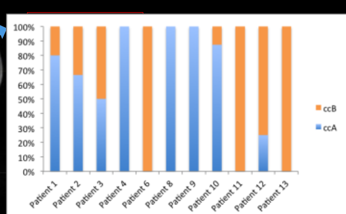


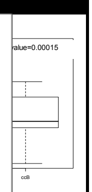
Brannon et al. *Genes and Cancer*. 2010;1(2):152-163.

Brooks et al, Cancer Research, 2016

PET/MR Evaluation of Tumoral Heterogeneity







Research, 2016

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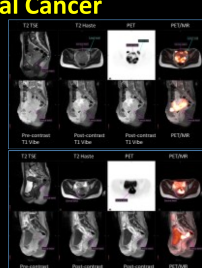
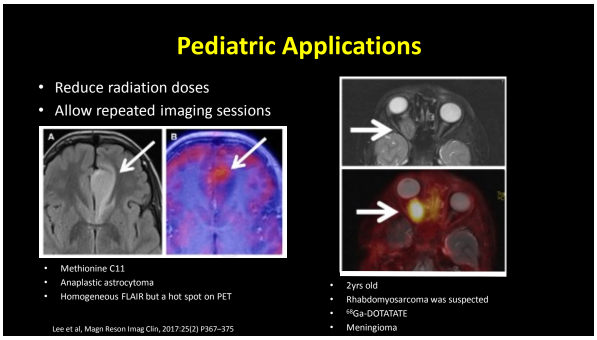
Cervical Cancer

- 26 yo, female
- Staging/path/size
  - IIIB (clinically) vs. metastatic IB2 (by imaging) with positive pelvic nodes by PET;
  - Adenosquamous carcinoma with both clear cell and glassy cell areas;
  - initially 10 cm decreased to 5 cm at time of removal
- PET/MR added values
  - Provided baseline anatomic and functional data including L external iliac lymph node
  - Mid-tx scan showed significant decrease in size by MR and residual active disease adjacent to the cervix by PET

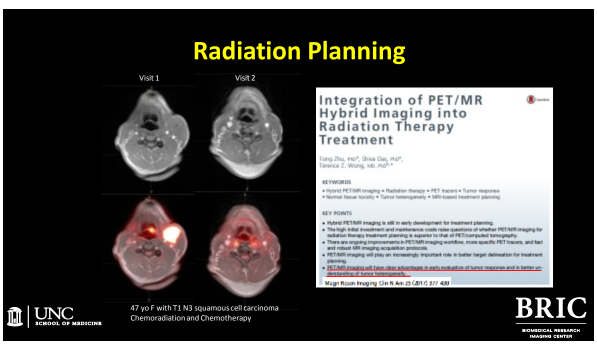


Pre-treatment

Mid-treatment



Pediatric Applications
Reduce radiation doses
Allow repeated imaging sessions
A
B
Methionine C11
Anaplastic astrocytoma
Homogeneous FLAIR but a hot spot on PET
Lee et al, Magn Reson Imag Clin, 2017:25(2) P367–375
2yrs old
Rhabdomyosarcoma was suspected
68Ga-DOTATATE
Meningioma



Radiation Planning
Visit 1
Visit 2
Integration of PET/MR Hybrid Imaging into Radiation Therapy Treatment
Tong Zhu, PhD, Shiva Das, PhD, Terence Z. Wong, MD, PhD
KEYWORDS
Hybrid PET/MR imaging • Radiation therapy • PET tracers • Tumor response • Normal tissue toxicity • Tumor heterogeneity • MRI-based treatment planning
KEY POINTS
Hybrid PET/MR imaging is still in early development for treatment planning.
The high initial investment and maintenance costs raise questions of whether PET/MR imaging for radiation therapy treatment planning is superior to that of PET/computed tomography.
There are ongoing improvements in PET/MR imaging workflow, more specific PET tracers, and fast and robust MR imaging acquisition protocols.
PET/MR imaging will play an increasingly important role in better target delineation for treatment planning.
PET/MR imaging will have clear advantages in early evaluation of tumor response and in better understanding of tumor heterogeneity.
Magn Reson Imaging Clin N Am 25 (2017) 377–430
47 yo F with T1 N3 squamous cell carcinoma
Chemoradiation and Chemotherapy
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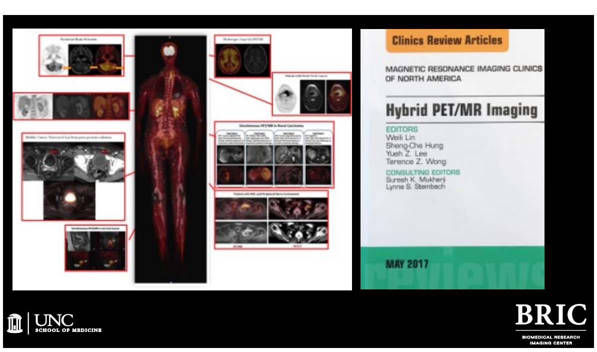

Clinics Review Articles
MAGNETIC RESONANCE IMAGING CLINICS OF NORTH AMERICA
Hybrid PET/MR Imaging
EDITORS
Weili Lin
Sheng-Che Hung
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Terence Z. Wong
CONSULTING EDITORS
Suresh K. Mukherji
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