Multi-Modality Imaging: Technologies and Applications

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Princess Margaret Hospital

Multi-Modality Imaging

- Becoming the standard of clinical care
  - Diagnosis and staging
  - Treatment planning
  - Response assessment
- Also at the heart of the rapidly evolving field of molecular imaging (genetic expression etc.)
- Primary modalities
  - Structural / morphological imaging
    - CT
    - MR
  - Functional / molecular imaging
    - PET
    - SPECT
    - Optical
    - fMRI

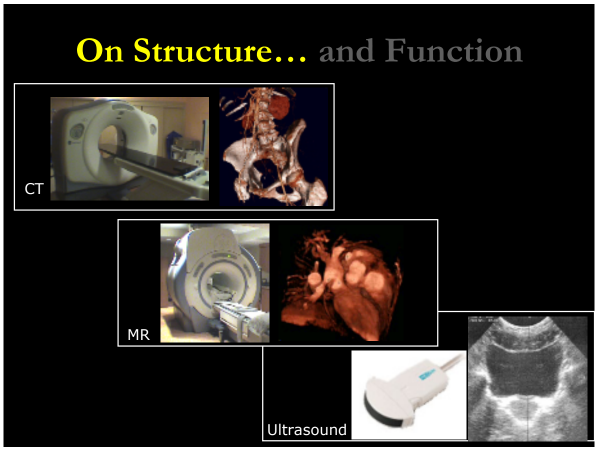
Multi-Modality Imaging

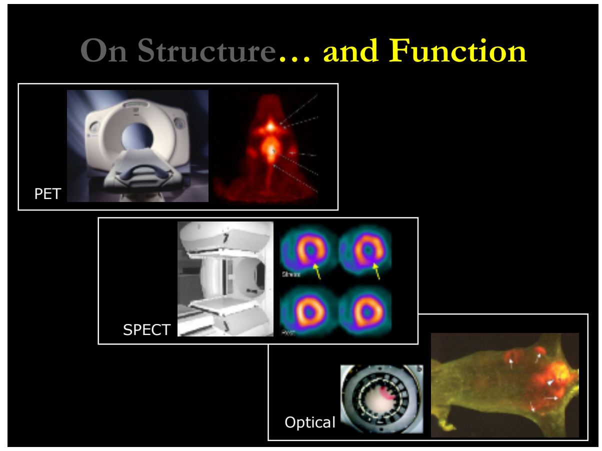
- A highly inter-disciplinary field of research:
  - Clinical oncology, neurology, cardiology,…
  - Engineering, physics
  - Biochemistry, pharmacology, nanotechnology
  - Cell and molecular biology
- Applications throughout clinical and preclinical medicine
  - Cancer screening, staging, response monitoring
  - Integrated stroke imaging
  - Neurological assessment
  - Drug development
  - Small animal imaging
    μPET, μSPECT, μMRI, optical (fluorescence, bioluminescence)
  - Fundamental understanding of disease origin, progression, response

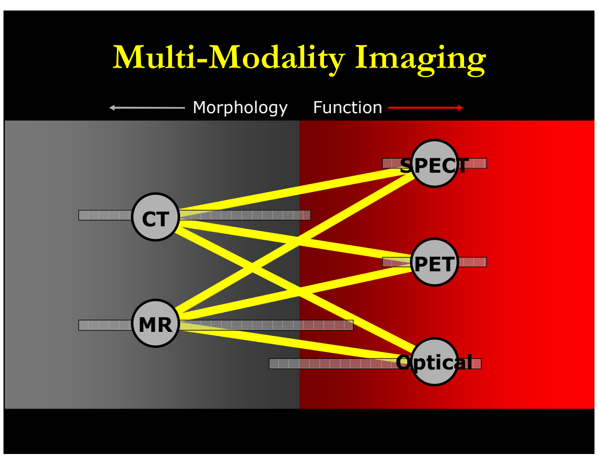
Multi-Modality Imaging

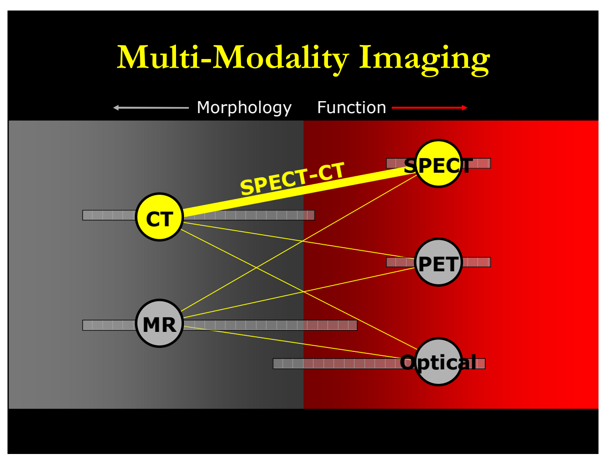
- MMI is typified by the integration of 2 or more modalities within a single examination
  - Incorporation of multiple modalities within a single / hybrid scanner
    - PET-CT
    - SPECT-CT
    - Optical-CT
    - PET-MR
    - MR-Optical
  - Double- or triple-labeled reporter agents
    - E.g., optical or nuclear agents
- Basic goal:

  Provide spatial localization [and quantitation] of function (e.g., metabolic activity, flow, etc.)


On Structure… and Function
CT
MR
Ultrasound

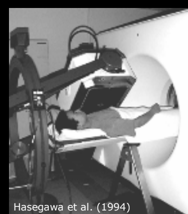

On Structure… and Function
PET
SPECT
Optical

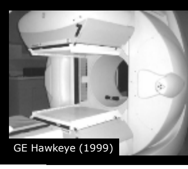

Multi-Modality Imaging
Morphology
Function
SPECT
CT
PET
MR
Optical


Multi-Modality Imaging
Morphology
Function
SPECT-CT
SPECT
CT
PET
MR
Optical

SPECT-CT

- Primary advantages
  - Attenuation correction
  - Structural / anatomical referencing
- Early development
  - First truly integrated hybrid
    - UCSF (Hasegawa et al.)
    - Single-head SPECT + Single-slice CT
    - Demonstrated potential of SPECT-CT
  - First commercially available system
    - GE Hawkeye (1999)
    - Dual-head SPECT
    - Single-slice CT
      - 13 s (180°+Fan) rotation
      - Low-mA (low-dose); low image quality
      - Exquisite attenuation map (compared to line-source radionuclide)


Hasegawa et al. (1994)


GE Hawkeye (1999)

SPECT-CT

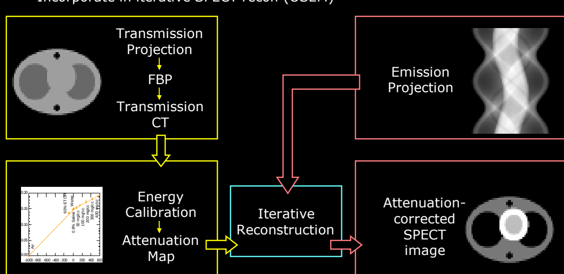

GE Infinia Hawkeye


Philips Precedence


Siemens Symbia

SPECT-CT: Attenuation Map

- Basic principle
  - Estimate heterogeneous attenuation map, μ
  - Incorporate in iterative SPECT recon (OSEM)



Images courtesy of B. Hasegawa, UCSF

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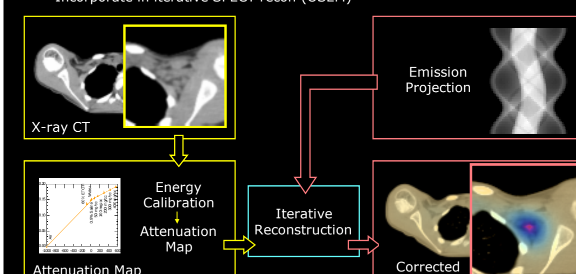
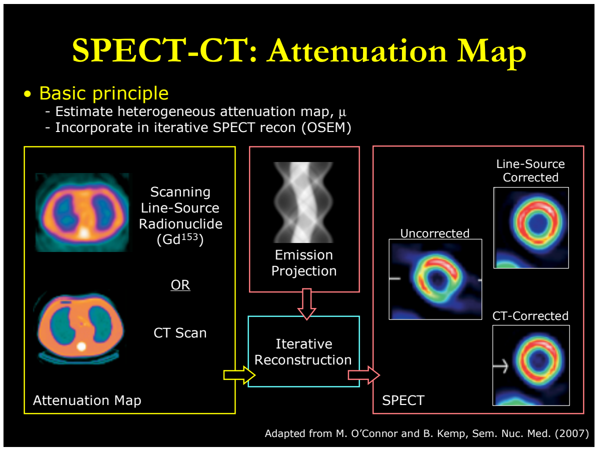
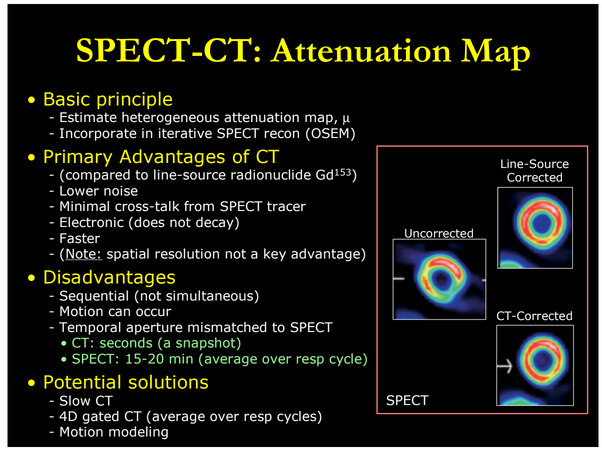
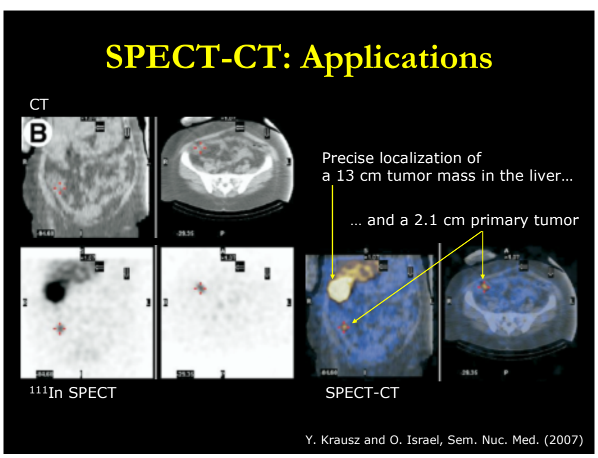
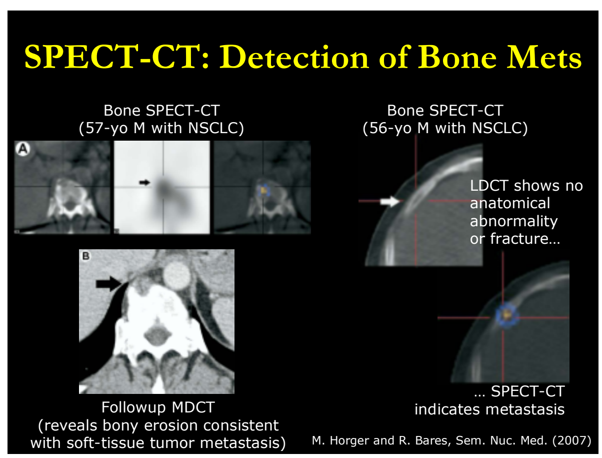


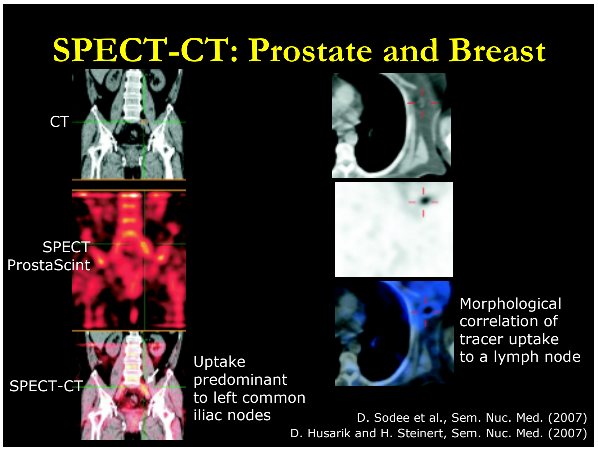
Images courtesy of B. Hasegawa, UCSF

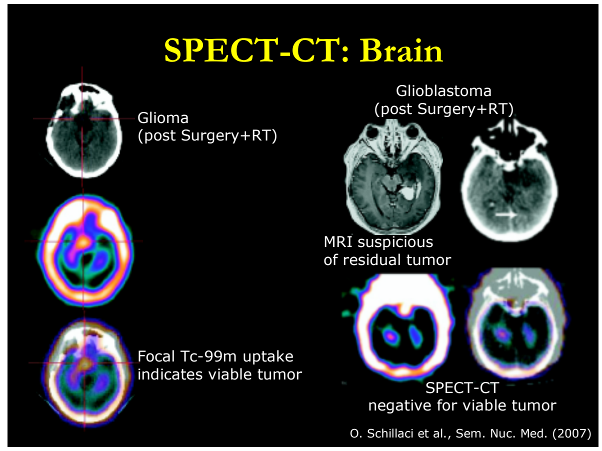

SPECT-CT: Attenuation Map
• Basic principle
- Estimate heterogeneous attenuation map, μ
- Incorporate in iterative SPECT recon (OSEM)
Scanning Line-Source Radionuclide (Gd153)
OR
CT Scan
Attenuation Map
Emission Projection
Iterative Reconstruction
Uncorrected
Line-Source Corrected
CT-Corrected
SPECT
Adapted from M. O'Connor and B. Kemp, Sem. Nuc. Med. (2007)


SPECT-CT: Attenuation Map
• Basic principle
- Estimate heterogeneous attenuation map, μ
- Incorporate in iterative SPECT recon (OSEM)
• Primary Advantages of CT
- (compared to line-source radionuclide Gd153)
- Lower noise
- Minimal cross-talk from SPECT tracer
- Electronic (does not decay)
- Faster
- (Note: spatial resolution not a key advantage)
• Disadvantages
- Sequential (not simultaneous)
- Motion can occur
- Temporal aperture mismatched to SPECT
• CT: seconds (a snapshot)
• SPECT: 15-20 min (average over resp cycle)
• Potential solutions
- Slow CT
- 4D gated CT (average over resp cycles)
- Motion modeling
Uncorrected
Line-Source Corrected
CT-Corrected
SPECT


SPECT-CT: Applications
CT
B
Precise localization of a 13 cm tumor mass in the liver…
… and a 2.1 cm primary tumor
111In SPECT
SPECT-CT
Y. Krausz and O. Israel, Sem. Nuc. Med. (2007)


SPECT-CT: Detection of Bone Mets
Bone SPECT-CT
(57-yo M with NSCLC)
A
B
Followup MDCT
(reveals bony erosion consistent with soft-tissue tumor metastasis)
Bone SPECT-CT
(56-yo M with NSCLC)
LDCT shows no anatomical abnormality or fracture…
… SPECT-CT indicates metastasis
M. Horger and R. Bares, Sem. Nuc. Med. (2007)





SPECT-CT

Current and Future Technical Applications

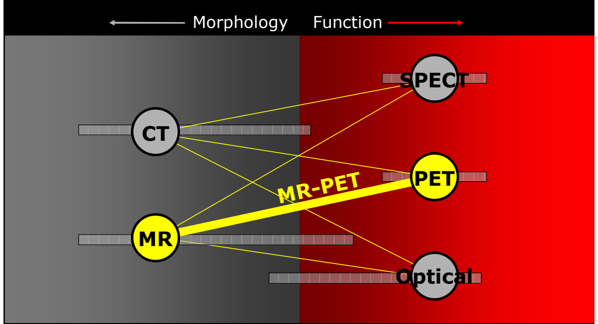
- SPECT dosimetry
  - Use CT for more accurate estimation of organ volume
  - More accurate quantitation of tumor uptake, dose
- One-stop cardiology
  - Quantify coronary Ca
  - Evaluate patency of coronary arteries
  - Assess myocardial perfusion
  - Will require fast (64-slice) CT capable of imaging coronary arteries
- Detector development
  - Single detector systems for both SPECT and CT
  - Simultaneous x-ray and gamma operation (not count-rate limited)
  - Semiconductor detectors (CdZnTe)
    - “Current mode” (x-rays)
    - “Event mode” (gamma)
- Image registration techniques
  - Patient motion – still an issue (e.g., chest / abdomen)
  - MR is sometimes the other modality of choice (e.g., brain)
    - MR-SPECT still under development

SPECT-CT

Seminars in Nuclear Medicine (Vol. 36, 2007)

- M. O’Connor and B. Kemp (Mayo Clinic)
  SPECT-CT: Basic instrumentation and innovations
- Y. Krausz and O. Israel (Hadassah)
  SPECT-CT: Endocrinology
- O. Shillaci (University Tor Vergata, Rome)
  SPECT-CT: Lung Cancer and Malignant Melanoma
- M Horger and R. Bares (Tubingen)
  SPECT-CT: Benign and Malignant Bone Disease
- T. Bunyavorich et al. (Boston University)
  SPECT-CT: Evaluation of Infection and Inflammation
- D. Sodee et al. (Case Western)
  SPECT-CT: Prostate Cancer
- D. Husarik and H. Steinert (Zurich)
  SPECT-CT: Sentinel Node Mapping in Breast Cancer
- O. Shillaci et al. (University Tor Vergata, Rome)
  SPECT-CT: Brain Tumors
- O. Shillaci et al. (University Tor Vergata, Rome)
  SPECT-CT: Abdominal Diseases

Multi-Modality Imaging



MR-PET

- Original motivation
  - To improve PET spatial resolution by reducing the range of positron travel within a magnetic field (University of Minnesota)
    B. E. Hammer et al., "Use of a magnetic field to increase the spatial resolution of positron emission tomography," Med. Phys. 21 (1994).
- Motivation has shifted to simultaneous image acquistion
  - Similar acquisition times for MR and PET (~minutes)
  - Real-time MR (e.g., navigator-based planar imaging) can be used to rebin the PET data (4D PET)
- Early work addressed the challenge of MR-compatible PET detectors
  - A single ring LSO detector within the magnetic field
  - Coupled to position-sensitive PMTs placed outside the field
  - Long (3-4 m) fiber optic coupling (Simon Cherry, UCLA)
    K. Farahani et al., "Contemporaneous positron emission tomography and MR imaging at 1.5 T," J. Magn. Reson. Imaging 9 (1999).

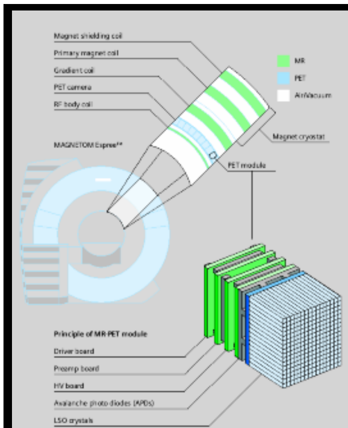
MR-PET

Photograph of a photomultiplier tube as it is used in PET scanners and an APD array suitable for operation in the magnetic field.

- Avalanche photodiodes (APDs) provide an improved MR-compatible PET detector
- Can operate in high magnetic fields
- Still required incorporation of APD control / readout electronics within the magnetic field.

Image adapted from M. Schwaiger et al.
Technical University Munich
S.Ziegler@lrz.tum.de

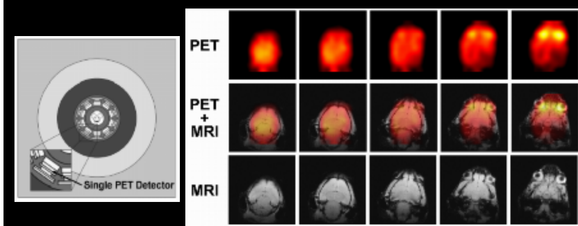
MR-PET



- PET is acquired with a ring positioned inside the MR magnet
- Permits simultaneous acquisition of MR and PET images within an identical reference frame

Adapted from M. Schwaiger et al.
Technical University Munich
S.Ziegler@lrz.tum.de

MR-PET: Early Success



Simultaneously acquired PET and MR of a mouse head

PET: [^{18}F]FDG (filtered backprojection)

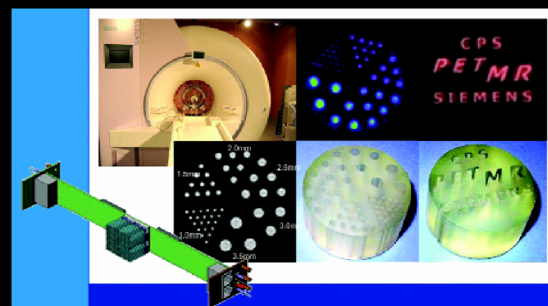
MR: fast low angle shot, no contrast medium

Increased uptake in PET localizes to the harderian glands

M. Judenhofer,[1] C. Catana,[2] B. Swann,[3] S. Siegel,[3] W. Jung,[4] R. Nutt,[3] S. Cherry,[2] C. Claussen,[1] and B. Pichler[1]

[1]University of Tubingen, Germany
[2]University of California, Davis CA
[3]Siemens Preclinical Solution, Knoxville TN
[4]Bruker BioSpin MRI, Ettlingen Germany

MR-PET: From Feasibility to Reality

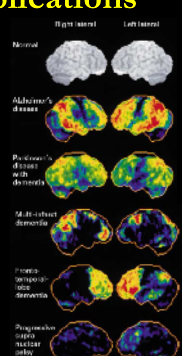


B. Pichler et al., ISMRM 2007
University of Tubingen, Germany
in collaboration with Siemens Medical Solutions

MR-PET: Applications

Neurology

- Neurosurgery: Delineation of eloquent brain pre and post Surgery + RT
- Epilepsy: More accurate localization of epileptic foci.
- Stroke: MR perfusion + PET
- Alzheimer's: O-15 PET + MR + MR(BOLD)



FDG-PET mapped to MR

C. P. Schultz, PhD
Global Business Development
Siemens Medical Solutions

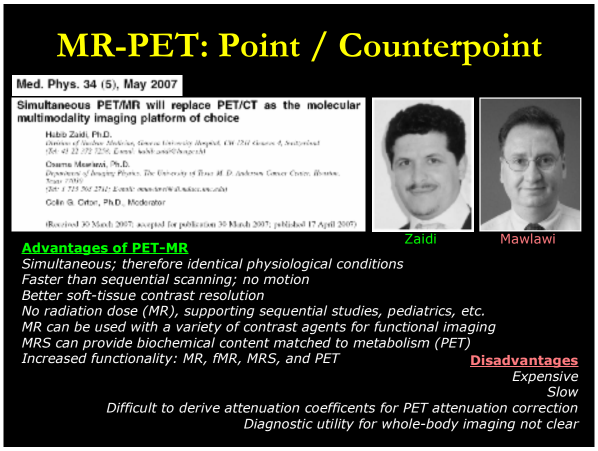
MR-PET: Applications

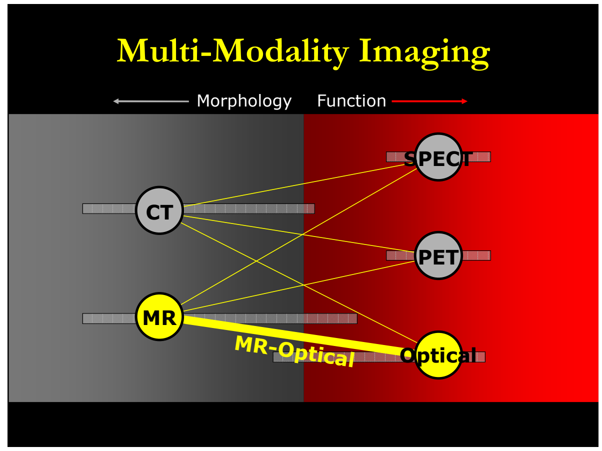
Oncology

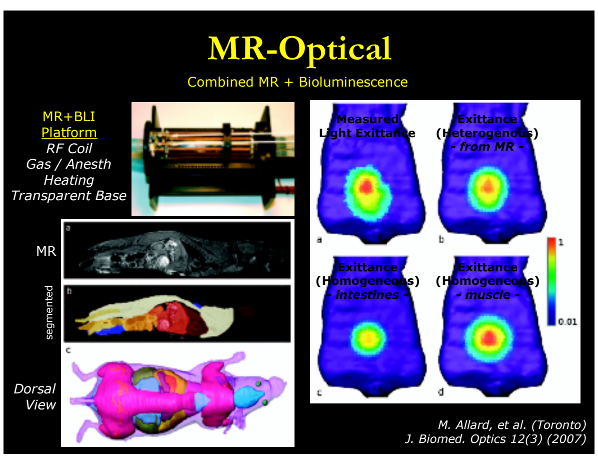
- Treatment planning and therapy assessment
- Improved visualization of soft-tissue targets and surrounding normal tissues
- Accurate registration of intra-tumoral morphology and function
- Structural / biochemical / functional assessment
  MR + MRS + PET

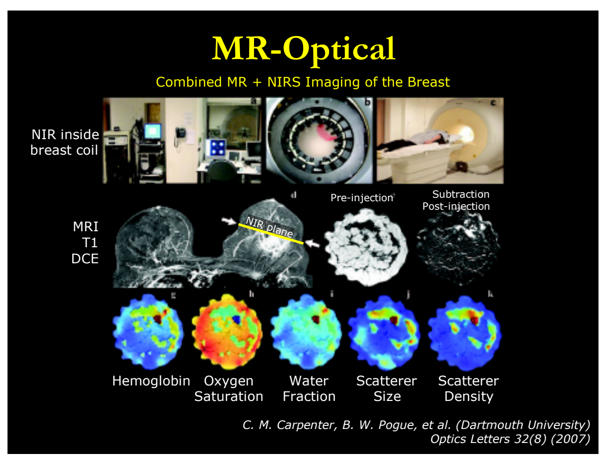
Cardiac

- Assessment of myocardial blood flow (MBF) improved
  - N-13 or O-15 PET flow tracers
- Delineation of infarcted tissue
  - MR (high resolution) + PET (high specificity)


MR-PET: Point / Counterpoint
Med. Phys. 34 (5), May 2007
Simultaneous PET/MR will replace PET/CT as the molecular multimodality imaging platform of choice
Habib Zaidi, Ph.D.
Osama Mawlawi, Ph.D.
Colin G. Orton, Ph.D., Moderator
Zaidi
Mawlawi
Advantages of PET-MR
Simultaneous; therefore identical physiological conditions
Faster than sequential scanning; no motion
Better soft-tissue contrast resolution
No radiation dose (MR), supporting sequential studies, pediatrics, etc.
MR can be used with a variety of contrast agents for functional imaging
MRS can provide biochemical content matched to metabolism (PET)
Increased functionality: MR, fMR, MRS, and PET
Disadvantages
Expensive
Slow
Difficult to derive attenuation coefficents for PET attenuation correction
Diagnostic utility for whole-body imaging not clear


Multi-Modality Imaging
Morphology
Function
SPECT
CT
PET
MR
MR-Optical
Optical

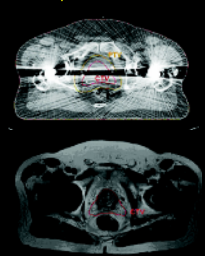

MR-Optical
Combined MR + Bioluminescence
MR+BLI
Platform
RF Coil
Gas / Anesth
Heating
Transparent Base
MR
segmented
Dorsal
View
Measured
Light Exittance
Exittance
(Heterogeneous)
- from MR -
Exittance
(Homogeneous)
- intestines -
Exittance
(Homogeneous)
- muscle -
1
0.01
M. Allard, et al. (Toronto)
J. Biomed. Optics 12(3) (2007)


MR-Optical
Combined MR + NIRS Imaging of the Breast
NIR inside
breast coil
MRI
T1
DCE
NIR plane
Pre-injection
Subtraction
Post-injection
Hemoglobin
Oxygen
Saturation
Water
Fraction
Scatterer
Size
Scatterer
Density
C. M. Carpenter, B. W. Pogue, et al. (Dartmouth University)
Optics Letters 32(8) (2007)

What about CT-MR?

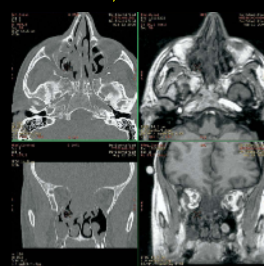
Yes… but acquired separately
and fused according to (rigid or deformable) image registration…

Hip Prostheses



N. Charnley
Brit. Journ. Radiol. 78 (2005)

ENT / Skull Base



J. Leong
J. Otolaryngol – Head and Neck Surg. 134 (2006)

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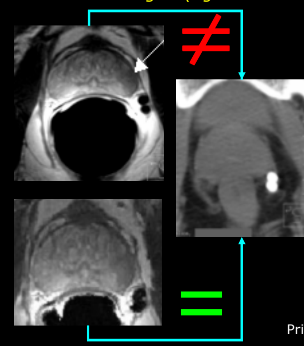


Deformable Modeling

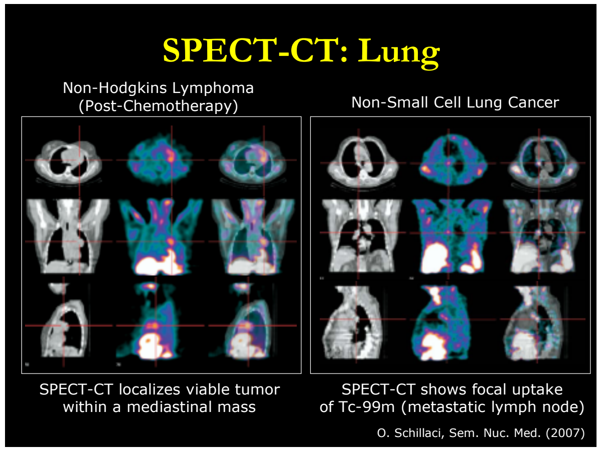
- Integrating multi-modality and multi-instance images
- Resolving geometric discrepancies between images
- Tracking tissue throughout Tx

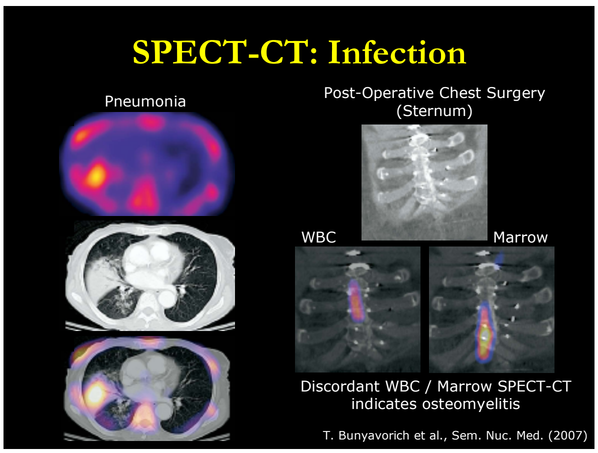
Images courtesy of K. K. Brock
Princess Margaret Hospital, Toronto ON

Discussion

- Multi-modality imaging a central component of current and future clinical and preclinical medicine
  - Preclinical: Fundamental nature and response of disease
  - Clinical: Screening, Dx, staging, Tx planning, response assessment
- Burgeoning technological / clinical investigation of integrated structural / functional imaging modalities within a single scanner
  - PET-CT
  - SPECT-CT
  - Optical-CT
  - PET-MR
  - MR-Optical
- Clinical applications
  - Oncology, Neurology, Cardiac, …

Thank you.


SPECT-CT: Lung
Non-Hodgkins Lymphoma
(Post-Chemotherapy)
Non-Small Cell Lung Cancer
SPECT-CT localizes viable tumor
within a mediastinal mass
SPECT-CT shows focal uptake
of Tc-99m (metastatic lymph node)
O. Schillaci, Sem. Nuc. Med. (2007)


SPECT-CT: Infection
Pneumonia
Post-Operative Chest Surgery
(Sternum)
WBC
Marrow
Discordant WBC / Marrow SPECT-CT
indicates osteomyelitis
T. Bunyavorich et al., Sem. Nuc. Med. (2007)