Hybrid Imaging Systems

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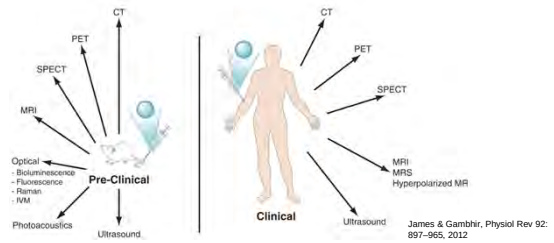
What is Hybrid Imaging?



James & Gambhir, Physiol Rev 92: 897–965, 2012

Hybrid (or multimodality) imaging is the integration of two or more modalities: PET, SPECT, CT, MRI, fMRI, optical, ultrasound, etc with the images being registered in space and time.

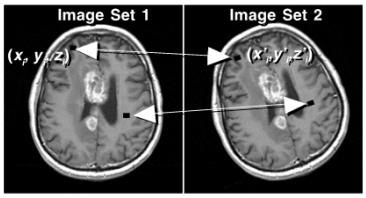
Hybrid Imaging Approaches

Serial Hybrid Imaging

- Images acquired separately and fused together by rigid or nonrigid image registration.
- Useful, but prone to registration error due to body deformation, respiratory motion, disease progression.

Rigid Transformation

$$T = f(x, y, z, rot_x, rot_y, rot_z)$$



$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = T \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

Hybrid Imaging Approaches

Integrated Hybrid Imaging

- Simultaneous or near simultaneous acquisition,
  - Examples: PET/CT, SPECT/CT, PET/MR, ..
  - Better co-registration.

PET/CT

Hybrid Imaging Advantages

Combining Strengths

- Hybrid imaging should provide some kind of added value.
- To be useful a hybrid imaging system should enable the modalities to do things that they could not do alone.
  - To answer clinical questions that could not be answered using the scanners separately.
  - To improve the quantitative accuracy of functional/molecular imaging studies.
  - To enable clinical or preclinical studies to be done in less time.
  - To reduce costs.

PET/CT

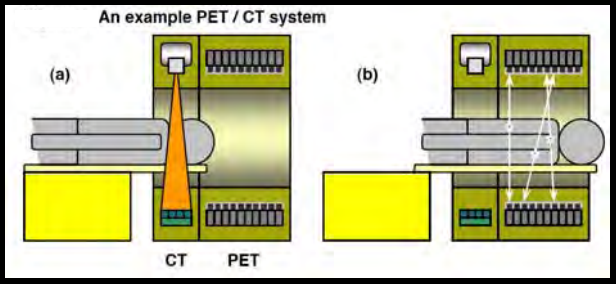
Commercial PET-CT Scanners

Siemens Biograph
LSO, 2/6/16/64 slice CT

GE Discovery ST
BGO, 4/8/16 slice CT

Philips Gemini
GSO, 6/10/16 slice CT

PET/CT

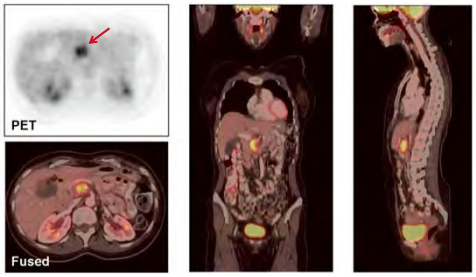


D. Platten, ImPACT Technology update no. 4, 2004.
http://www.impactscan.org/download/petct.pdf

PET/CT Advantages

Localization

› Provides accurately aligned structural and functional information.



PET/CT ^{18}FDG scan of 50 y.o. female with pancreatic cancer.

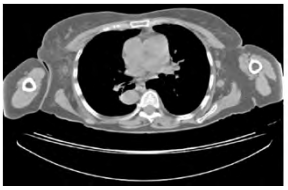
D. Townsend, Phys. Med. Biol. 53 (2008) R1–R39.

PET/CT Advantages

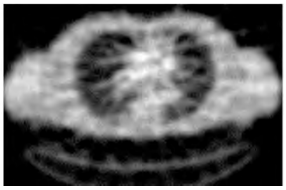
Low noise attenuation correction factors, fast

› CT provides low noise attenuation information in a short time for attenuation correction of the PET emission data.

CT (~80 keV – 120 keV)
Low noise, fast.
Needs to be scaled to 511 keV.



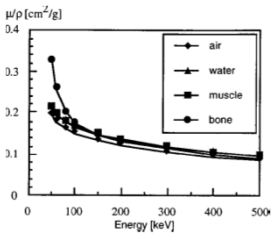
PET Transmission (511 keV)
Noisy, slow, quantitatively accurate for 511-keV.



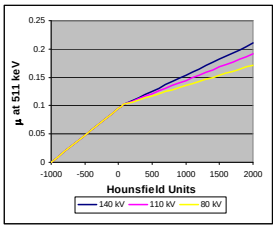
PET/CT Attenuation correction

CT-based Attenuation Correction

› A two segment linear scale is used
- Different scaling for soft tissues and bone
- Break point at about 0 - 70 HU unit
- Bone scale depends on CT kV

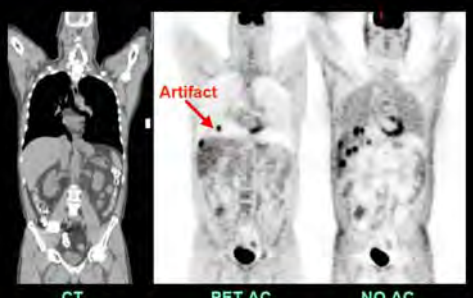


Kinahan et al Med Phys 25(10), pp2046-2053, 1998



Rappoport V et al IEEE NSS Conference Record 2004

Breathing Artifacts: Misregistration Of Lesions



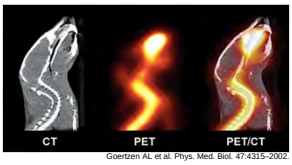
58-y-old man diagnosed with colon cancer. A lesion at the dome of the liver appears erroneously in the lower right lung base on the PET AC image. On the non-AC image all the liver lesions are confined to the liver.

Courtesy P. Kinahan, University of Washington

Preclinical PET/CT

Bioscan NanoPET/CT

Siemens Inveon PET/CT



Goertzen AL et al. Phys. Med. Biol. 47:4315–2002.

PET and CT images showing distribution of 18F-fluoride ion in a mouse.

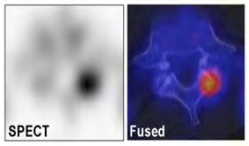
SPECT/CT

Commercial SPECT-CT Scanners

GE Hawkeye

Siemens Symbia

Philips Precedence



Imaging bone disease on a Symbia T2 SPECT/CT with 99mTc-MDP. D. Townsend, Phys. Med. Biol. 53 (2008) R1–R39

Infected screw after knee replacement on a 99mTc bone SPECT/CT scan. Courtesy D. Bailey, The Radiographer 59 (2012) 98-103.

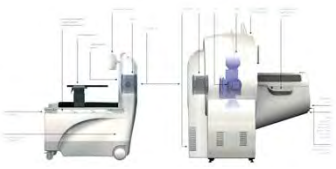
PET/CT and SPECT/CT

- Use of CT for attenuation correction introduces some potential sources of artifacts.
- Non-simultaneous acquisition creates a propensity for motion between scans.
- CT can deliver significant radiation doses dependent on chosen scan parameters.

Trimodality PET/SPECT/CT

TRIMODALITY – Preclinical PET / SPECT / CT

Gamma Medica Triumph II Trimodality System



Siemens Inveon

TRIMODALITY SYSTEMS

Clinical

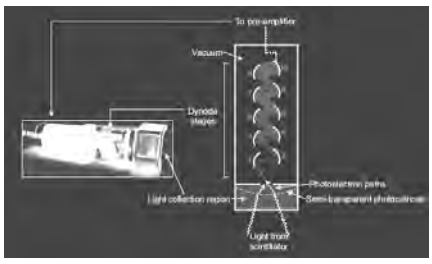
Mediso Anyscan - Human PET, SPECT and CT.
http://www.mediso.com

Preclinical

Carestream Albira - uPET, uSPECT and uCT.
http://carestream.com

PET/MR

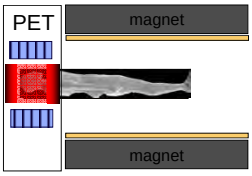
PMTs and magnetic fields do not mix



- Solution 1: *transport the light from the scintillation crystal to the PMTs a distance away (outside the* B *field)*
- Solution 2: *replace the PMTs with solid state devices (APDs)*

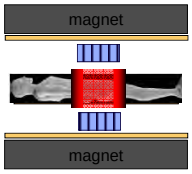
Approaches to PET/MRI

"tandem" PET/MRI



+ interference easier to avoid
+ largely use existing hardware
+ least expensive

"integrated" PET/MRI

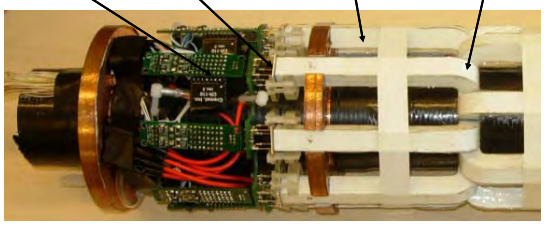


+ simultaneous PET/MRI possible
+ higher throughput
+ best image registration

UCDAVIS UNIVERSITY OF CALIFORNIA cmg

PET Insert

preamplifiers PSAPDs optical fibers scintillator ring



Catana C , et al. (2006) J Nucl Med 47:1968–1976

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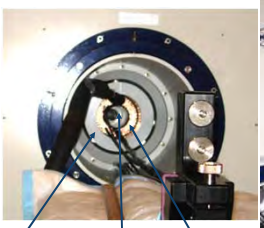
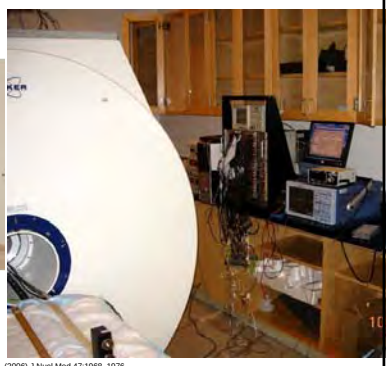
PET-MRI Set Up



Gradient set RF coil PET insert



Catana C , et al. (2006) J Nucl Med 47:1968–1976

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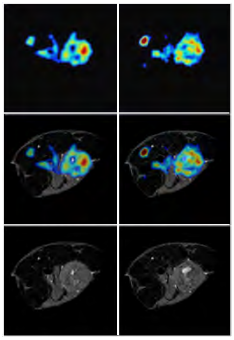
Simultaneous in vivo PET and MR imaging



Mouse
FDG Tumor Imaging

PET
- ~200 µCi ^{18}F-FDG
- Voxel size: 0.35 x 0.35 x 1.5 mm^3

MRI
- RARE sequence
- Whole body imaging RF coil
- FOV=4x4 cm^2
- Matrix size 256x256

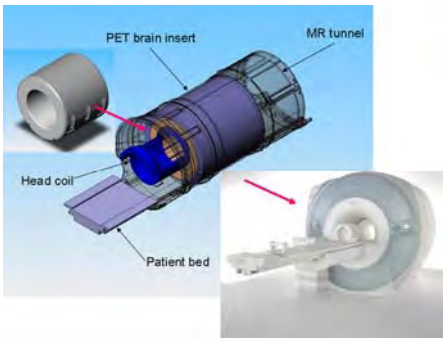
Catana C et al. PNAS 2008;105:3705-3710

PNAS

PET/MR SYSTEM TYPES

INTEGRATED

- Siemens BrainPET
- PET insert - LSO crystal ring, APDs
- 3T MR
- Simultaneous PET/MR

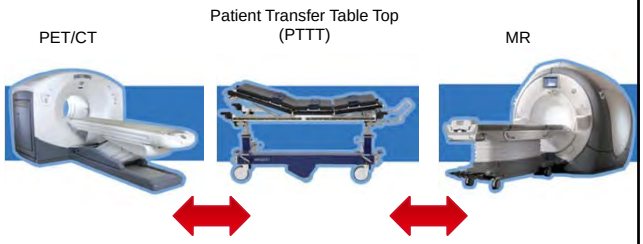


Schlemmer H W et al. Radiology 2008;248:1028-1035

PET/MR SYSTEM TYPES

SEQUENTIAL – TWO ROOMS

- GE TRI-MODALITY- PET/CT + MR



PET/MR SYSTEM TYPES

SEQUENTIAL ('Tandem') – SAME ROOM

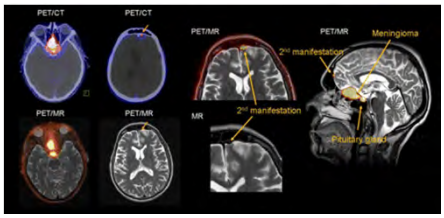
- Philips Ingenuity TF
- PET/CT and MRI share same bed

WHOLE BODY PET/MR

Integrated whole body PET/MR

PET/MRI

PET/MRI vs PET/CT

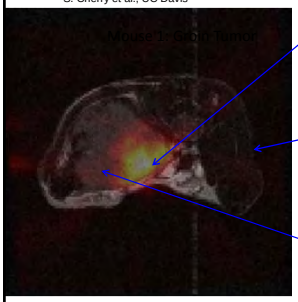


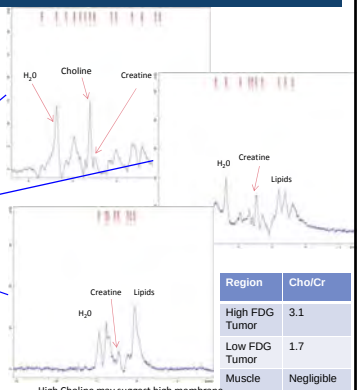
Frontobasal meningioma - ^{68}Ga-DOTA-TOC

Pichler et al. J. Nucl. Med. (2010) 51(3) 333-336.

FDG-PET guided MRS

S. Cherry et al., UC Davis





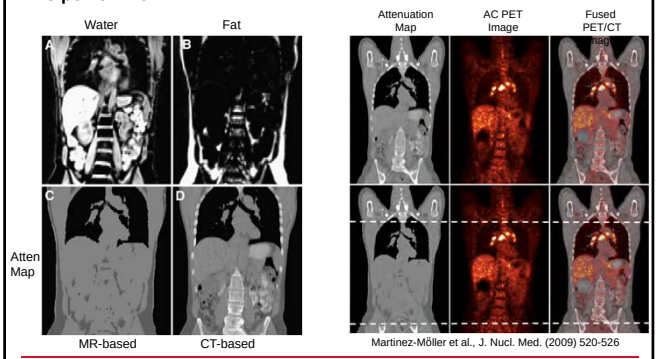
Region	Cho/Cr
High FDG Tumor	3.1
Low FDG Tumor	1.7
Muscle	Negligible

PRESS: TR/TE: 1685/10ms; 3mm^3 voxel; VAPOR H_2O suppression

High Choline may suggest high membrane turnover rate = cell proliferation

Attenuation Correction in PET/MR

Two point Dixon MRI



Martinez-Möller et al., J. Nucl. Med. (2009) 520-526

Why PET/MR?

› Potential Strengths
- Excellent registration of structural and molecular imaging data with better soft tissue contrast than CT
- Anatomic priors for PET reconstruction, partial volume correction and data modeling
- PET can be combined with advanced MRI techniques such as fMRI, DWI, MR spectroscopy, and MR molecular imaging agents.
- No additional radiation dose.
- Potential to obtain motion information from MRI for motion correction of PET data.

› Weaknesses
- More expensive than PET/CT
- Attenuation information not directly measured as in CT
- Uncertainty regarding throughput, cost effectiveness and ultimate clinical role.

OTHER HYBRID IMAGING MODALITIES

OTHER HYBRID IMAGING MODALITIES

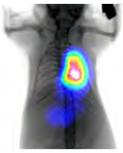
A partial list:

› PET/MR, PET/CT,..
› SPECT/CT, SPECT/MR,..
› MR/PET, MR/Ultrasound, MR-EIT,..
› Optical/PET, Optical/SPECT, Optical/CT, Optical/MR
› Photoacoustic/Thermoacoustic
› Trimodality – Optical/x-ray/radioisotopic, Magneto-photo-acoustic
› Omnitomography

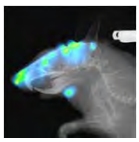
HYBRID OPTICAL MODALITIES

Optical / Planar x-ray [/ Radioisotope]

Use of co-registered x-ray image for source localization.



Injected tumour cells labelled with near infra-red fluorophores (fluorescent chemical compounds that can re-emit light upon light excitation).



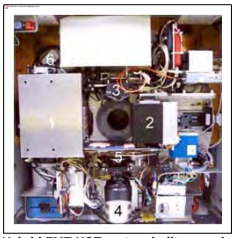
Intracranially injected NIR fluorophores.

- Optical (Luminescence/Fluorescence)
- Radioisotopic
- X-ray

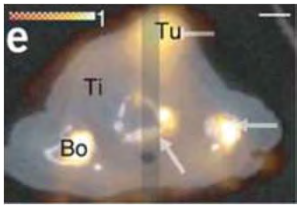
http://www.carestream.com/invivo-imaging-image-gallery.html

Hybrid FMT-XCT

Hybrid fluorescence molecular tomography (FMT) / X-ray CT (XCT)



- **Hybrid FMT-XCT system built around a GE eXplore Locus MicroCT.** (1) X-ray source. (2) X-ray detector. (3) XY stage for two lasers, 680nm and 750nm. (4) CCD camera. (5) Filter wheel. (6) Rotating gantry.



Nude mouse with subcutaneous tumor. FMT image superimposed on microCT image.

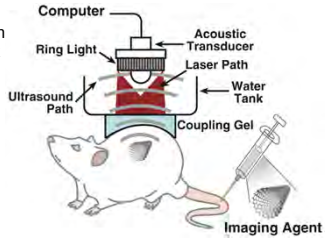
A. Ale et al., Nature Methods 9, 615–620 (2012)

PHOTOACOUSTIC IMAGING

Photoacoustic Imaging

Principle

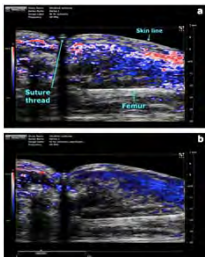
- Illuminate biological tissue with pulsed laser light (when radio frequency pulses are used, the technology is referred to as thermoacoustic imaging).
- Molecules (endogeneous or imaging agents with specific optical absorption properties) in tissue heat up and emit sound which can be detected with an ultrasound transducer.
- Optical absorption is closely associated with physiological properties, such as hemoglobin concentration and oxygen saturation.
- **Advantage:** Inherent co-registration of photoacoustic signal to 2D/3D anatomical target in real-time.



James & Gambhir, Physiol Rev 92: 897–965, 2012

Photoacoustic Imaging

Vevo LAZR Photoacoustic Imaging System
http://www.visualsonics.com/photoacoustic-technology



Hindlimb of a mouse under non-ischemic (a) and ischemic conditions (b).

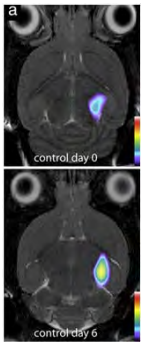
MR/OPTICAL

FMT-MR

Tumour protease activity

Co-registration of 3D FMT and MRI images.

FMT-MR imaging of mouse with implanted glioma.



- Mouse injected i.v. with 2 nmol of ProSense680.
- Fluorescence neuroimaging conducted in a VisEn Medical FMT Fluorescence Molecular Tomography system.
- MR imaging performed immediately after FMT imaging on a 7 T Bruker Pharmascan MR scanner.
- Co-registration of 3D FMT and the MR images.

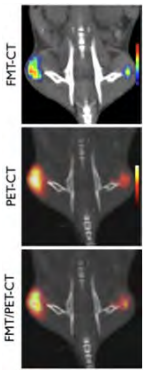
McCann et al., NeuroImage 45 (2009) 360–369

PET/OPTICAL

PET-FMT-CT

Correlation of FMT and PET signal

- Biocompatible nanoparticles (containing a ^{18}F isotope and a far red fluorochrome).
- Mouse with bilateral flank tumours.
- PET/CT performed on Siemens Inveon
- FMT performed on VisEn Medical FMT system
- Images co-registered using fiducial markers
- Correlation in amplitude and location.



Nahrendorf et al, PNAS (2010) 107: 7910-7915

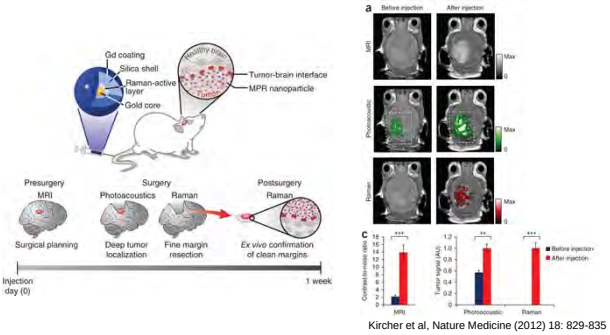
THE FUTURE

Multi-modality Contrast Agents

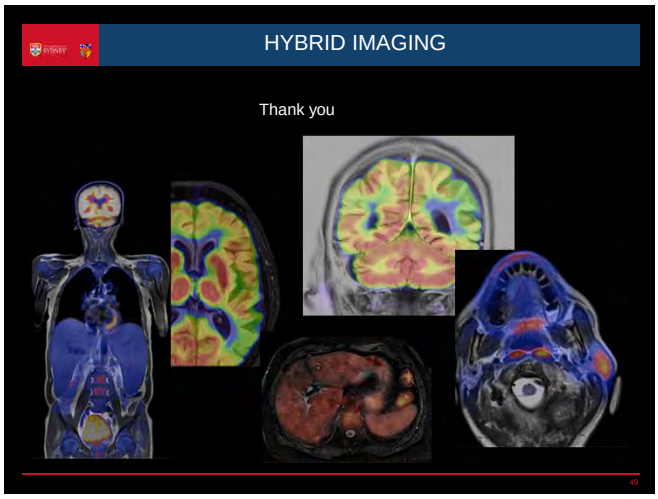
- Further refinement of existing hybrid Imaging technologies.
- Emergence of new hybrid imaging technologies.
- Development of multi-modality contrast agents.

Multimodality Probes

Triple-modality MRI-photoacoustic-Raman (MPR) nanoparticle



Kircher et al, Nature Medicine (2012) 18: 829-835


HYBRID IMAGING
Thank you
49