Positron Emission Tomography for Oncologic Imaging and Treatment

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Outline

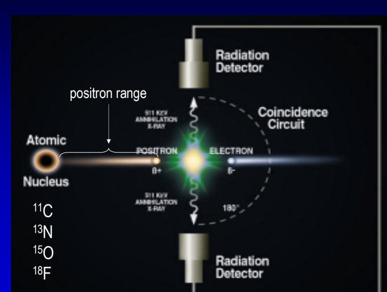
- Physics of PET and PET-CT
- Oncology Imaging with FDG PET
- PET and Radiation Treatment Planning
- Non-FDG PET Oncology Imaging
  - Bioanatomic Imaging and Treatment
- Summary

Work supported in part by research grants from North Carolina Baptist Hospital, Varian Medical Systems, and GE Healthcare

Physics of PET and PET-CT

- Coincidence detection of two 0.511 MeV photons
- Annihilation radiation from positron-electron pair
- Photon directions at 180° at annihilation point - different from decay point → range of positron
- Positron emitters with biological compatibility
- Low Z (typically), proton rich, short half-lives
- "Local" production with a cyclotron

Positron Annihilation



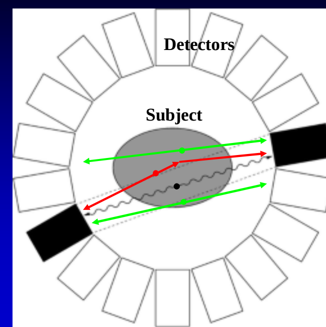
PET Radionuclides

biologically compatible, short half-life

Radionuclide	Half-Life
Fluorine 18 (^{18}F)	110 min
Carbon 11 (^{11}C)	20 min
Nitrogen 13 (^{13}N)	10 min
Oxygen 15 (^{15}O)	122 sec
Rubidium 82 (^{82}Ru) (cardiac)	75 sec

Coincidences: Detected Events

- True
- Scattered
- Random



Adapted from Rohren, Turkington, Coleman, Radiology 2004; 231:305-332

PET Device Parameters

- Resolving time – detector material
- Spatial resolution – nominally, detector size
  - 4 to 6 mm (voxel side)
- Temporal resolution – acquisition time, gating (?)
- Number of detectors – SNR, spatial resolution
- Aperture size – 70 cm max – large bore?
- 2D or 3D acquisition modes – both are volumes
- Several others, inter-related

Characteristics of Detector Crystals

Crystal Common name	Formula	Density (g/cm^3)	Effective Atomic Number	Photoelectric Effect Probability (%)	Energy Resolution (%)	Decay Time (ns)
NaI	NaI(Tl)	3.7	51	17	***8***	230
BGO	$Bi_4Ge_3O_{12}$	7.1	***75***	***40***	15	300
LSO	$Lu_2SiO_5(Ce)$	***7.4***	66	32	12	***40***
GSO	$Gd_2SiO_5(Ce)$	6.7	59	25	***8***	60

Desirable: Low decay time

Impacts: Detector dead time (affects scan time); allows shorter coincidence window for better rejection of random events

Effect of Positron Range

inherent loss of spatial resolution

Isotope	$T_{1/2}$	$E_{\beta}+$ (MeV)	Resolution * (mm)
^{11}C	20 min	0.96	0.92
^{13}N	10 min	1.2	1.35
^{15}O	122 sec	1.7	2.4
^{18}F	110 min	0.64	0.54
^{68}Ga	68 min	1.9	2.8
^{82}Rb	76 sec	3.4	6.1

* 2.35 × rms of distribution - related to the positron range

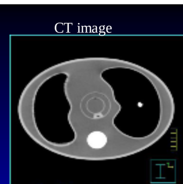
Attenuation Correction Using Transmission Images

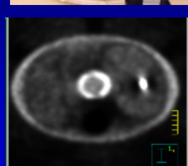
- Emission photon intensity must be corrected for attenuation that occurred along the path length from an origin
- A rotating source of photons is used to obtain a CT-like image that yields voxel electron densities
  - Original method: rotating radioisotope, near 511 keV energy
  - Recent method: CT scan, eg, with a hybrid scanner

γ ray (radioactive material)		or	x ray (CT)	
^{68}Ge (β^+)	511 keV		CT	100 kVp
^{137}Cs (β^-)	662 keV			

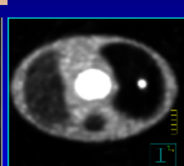
Phantom with 'normal' uptake except left lung that has air and one spherical 'hot tumor'

CT image

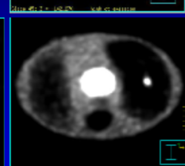




non-corrected PET



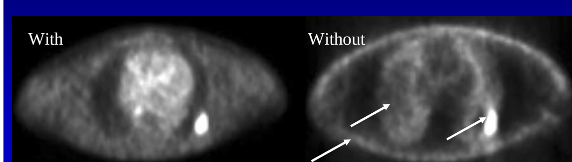
CT-attenuated corrected



Cs-attenuated corrected

With-Without Attenuation Correction

- Intensities under-estimated at depth
- Intensities over-estimated on surface
- Intensities over-estimated for low-density objects (lung)

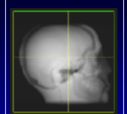


From Rohren, Turkington, Coleman: Radiology 2004; 231:305-332

Why PET Oncology Imaging?

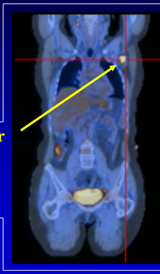
- Distribution of activity is imaged
  - Physiology, function, biology
- Complementary to (~anatomic) CT and MR
- Increased sensitivity compared to CT alone
- Indications approved for reimbursement
  - Most approved indications are for oncology
- Devices available
- Image handling toolsets maturing, still new

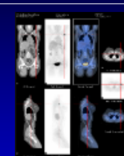
Why PET? A Picture of the Patient



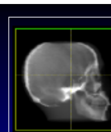
MR "Radiograph"

PET-avid tumor registered with CT obtained at the same time





CT-PET Hybrid Imaging for Tumor Diagnosis and Treatment Planning: (Courtesy General Electric Healthcare)



MR "Radiograph" with bone added - the MR is changed into a CT-like radiograph

Oncology Imaging with FDG PET

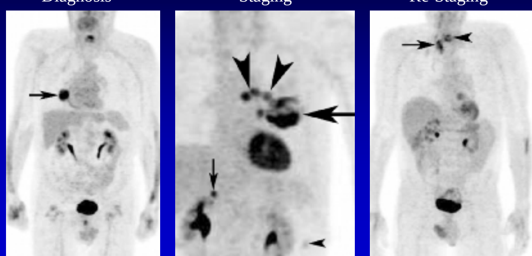
- Diagnosis – less common
- **Staging - yes**
- Target Definition
  - Radiation treatment
  - Other "targeted" therapy
- Re-staging – yes
- Treatment Evaluation

2-[^{18}F]-fluoro-2-deoxy-D-glucose (FDG)

- The most important positron-emitting radiotracer for oncology today is 2-^{18}F-fluoro-2-deoxy-D-glucose (FDG)
- Glucose analogue tagged with ^{18}Fluorine
- Many malignant tissues are associated with increased glycolysis and thus demonstrate increased uptake of FDG
- FDG-PET images are maps of glucose metabolism

Example: Non-Small Cell Lung Cancer

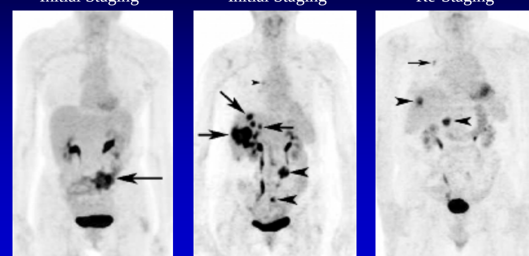
Diagnosis | Staging | Re-Staging



From Rohren, Turkington, Coleman: Radiology 2004; 231:305-332

Example: Colon Cancer

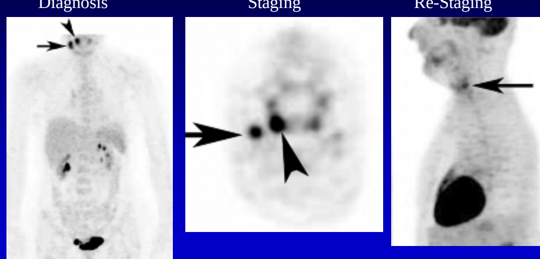
Initial Staging | Initial Staging | Re-Staging



From Rohren, Turkington, Coleman: Radiology 2004; 231:305-332

Example: Head & Neck Cancer

Diagnosis | Staging | Re-Staging



From Rohren, Turkington, Coleman: Radiology 2004; 231:305-332

Approved Indications: Oncology FDG PET

Cancer	Diagnosis	Staging	Re-Staging	Monitoring (Clin Trial)
Lung	X	X	X	X
Solitary Node	X (Char)			
Colorectal	X	X	X	X
Lymphoma	X	X	X	
Esophageal	X	X	X	X
Head/Neck	X	X	X	X
Breast + mets, recur	X	X	X	X
Thyroid	X	X	X	X
Cervical, + mets?	X	X	X	X
Brain				X
Ovarian				X

Caveat: A summary: Restrictions and latest information on:
http://cms.hhs.gov/manuals/103_cov_determ/ncd103c1_Part4.pdf

Clinical Imaging (FDG) with PET

- ^{18}F-Fluorodeoxyglucose (FDG) only
- Imaging of tumor glucose metabolism: glycolysis
- Non-specific imaging agent – metabolically active sites
- Staging, re-staging of lung, breast, colon, cervical, head/neck, melanoma, lymphoma. Some diagnosis.
- Difficulties with small tumors (< 3 – 10 mm diameter)
- Use increasing – 200 PET-CT scanners in 2 years*
- PET-CT hybrid scanners: registration solved

*From Bradley, Thorstad, Mutic, et al., IJROBP 59(1):78-86, 2004.

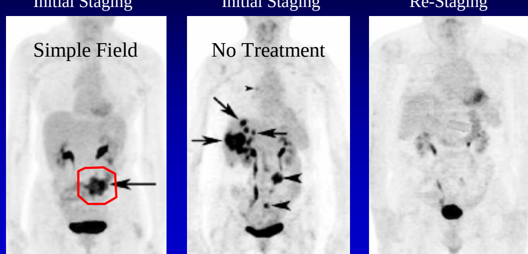
PET and Radiation Treatment Planning

- Main contribution – Staging: Target Localization
  - Very important: stage determines treatment approach
  - Binary results: presence/absence of disease, metastasis
- Dramatic differences possible
  - Treatment mode: reamo, chemo, beamo (EG Shaw)
    - none, one, all three? 10-30% NSCLC patients stage changes
  - Radiation treatment fields: ie, inclusion of nodes
    - Estimation – better coverage of target with PET in 30 – 60% of patients receiving definitive radiation treatment*

*From Bradley, Thorstad, Mutic, et al., IJROBP 59(1):78-86, 2004.

Colon Cancer: Possible Treatment Fields

Initial Staging | Initial Staging | Re-Staging



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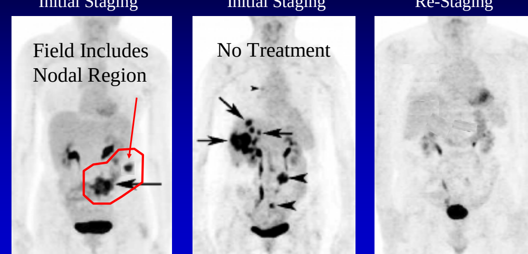
Colon Cancer: Possible Treatment Fields

Initial Staging | Initial Staging | Re-Staging



Adapted from Rohren, Turkington, Coleman: Radiology 2004; 231:305-332

FDG PET and Staging, Localization

Change in stage before and after PET-CT

Table 4. American Joint Committee on Cancer stage before and after PET-CT.

		No. patients by post–PET-CT stage							
Pre–PET-CT stage	No. patients	I	II	III	IVA	IVB	IVC	Upstage ratio	Downstage ratio
I	1	1	—	—	—	—	—	0/1	0/1
II	2	—	1	—	—	—	1	1/2	0/2
III	10	—	1	8	1	—	—	1/10	1/10
IVA	21	—	—	—	20	—	1	1/21	0/21
IVB	2	—	—	—	—	1	1	1/2	0/2
IVC	0	—	—	—	—	—	—	0/0	0/0
Total	36	1	2	8	21	1	3	4/36	1/36

Abbreviation: PET, positron emission tomography.

From Koshy, Paulino, Howell et al., Head & Neck, 27:6 494-502, 2005.

Increased Dose: Boost High Uptake Regions

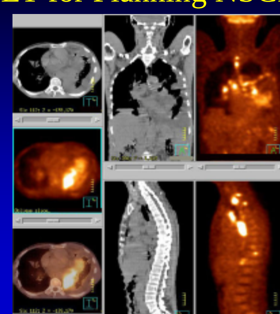
- Das et al. Med Phys. 2004 looked at feasibility of delivering radiation dose in proportion to FDG distribution in 2 patients
- Rationale: FDG-uptake is correlated to tumor cell proliferation rate
- PET for targeting; SPECT (normal lung perfusion) for avoidance
- Compared uniform dose distribution with non-uniform dose based on FDG distribution & IMRT
- While feasible, word of caution, was that non-uniform dose distributions attempting to increase dose to high uptake regions, may result in unacceptable dose-volume levels for normal structures.

PET and Radiation Treatment Planning

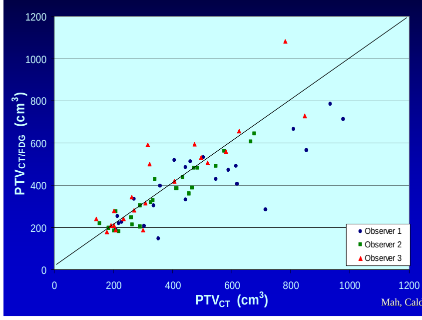
- Secondary contribution – Target Definition
  - Image-based target extent, shape – quantitative
  - Important topic
  - Subject of investigation: concepts, methods, tools
- Secondary contribution – Treatment Monitoring
  - Image-based response and evaluation of treatment
  - Important topic
  - Subject of investigation: concepts, methods, tools

“Secondary” to become “Primary” ?

PET for Planning NSCLC



Impact on size of PTV: CT vs PET/CT



- Relative changes ranged from 0.40 to 1.86
- In 5 of 23 cases, new FDG nodes detected that increased PTV

Mah, Caldwell, Ung et al. IJROBP 52, 2002

FDG PET and Radiation Treatment

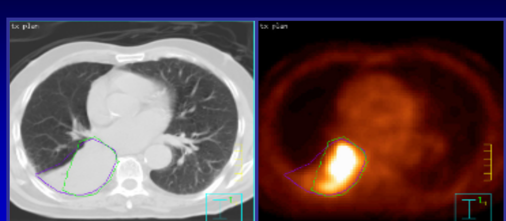
Change in PTV and prescribed dose

Table 5. Summary of changes in management with PET-CT.

Patient no. and disease site	Pre–PET-CT TNM (AJCC stage)	Post–PET-CT TNM (AJCC stage)	Management changes
1 Maxillary sinus	T3N0M0 (III)	T4aN0M0 (IVA)	Increase in PTV to encompass tumor identified on PET
2 Unknown primary (base of tongue)	T0N2bM0 (IVA)	T1N2bM0 (IVA)	Decrease in initial PTV as primary site was found (nasopharynx not included); primary tumor in oropharynx received higher RT dose
3 Unknown primary (vallecula)	T0N1M0 (III)	T1N1M0 (III)	Decrease in initial PTV as primary site was found (nasopharynx not included); primary tumor in oropharynx received higher RT dose
4 Tonsil	T2N2bM0 (IVA)	T2N2cM0 (IVA)	Increase in PTV to include PET identified tumor extension to deep muscles of tongue and contralateral (right) neck disease; increase in RT dose to right neck
5 Larynx	T2N0M0 (II)	T2N2cM1 (IVC)	Diffuse metastatic disease and bilateral neck metastasis seen only on PET; RT intent changed from curative to palliative; RT volume decreased to include only esophageal mass causing dysphagia; and RT dose decreased to palliative 30 Gy.
6 Tonsil	T2N1M0 (III)	T2N0M0 (II)	No change in RT dose or volume; based on the finding of N0 status with PET, a decision to not give chemotherapy and treat with RT alone

From Koshy, Paulino, Howell et al., Head & Neck, 27:6 494-502, 2005.

Ex: *FDG-PET decreased the target volume*

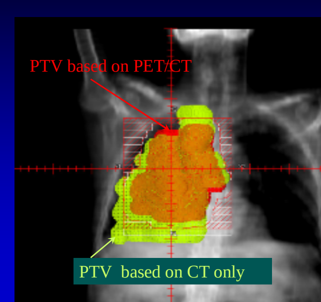


Purple Outline: CT only Green Outline: PET/CT

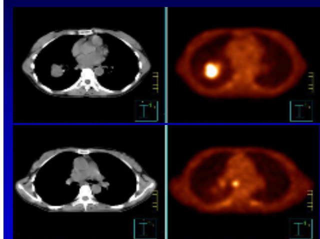
PET can minimize volume of normal tissue irradiated

Reduction of radiation volume due to better distinction between tumor and atelectasis

Sparing of normal tissue such as lung will result in less morbidity and possibly, allow higher dose to tumor



Ex: *FDG-PET* *<u>increased</u>* *the target volume*



Pre-PET : RLL lesion with right paratracheal node

Post-PET: RLL lesion with right paratracheal; subcarinal; and hilar lymphadenopathy (some < 1 cm on CT)

GTV increased to encompass these nodal regions.

Impact of PET-CT on RT Volume Delineation Using Combined PET-CT Scanner: Wash U Group

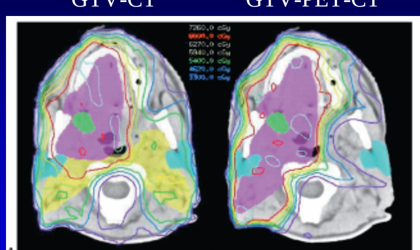
- Prospective study : 26 NSCLC patients
  - 8/26 (31%) PET changed staging
  - Of 24 still planned radically
    - In 3, PET/CT reduced volume compared to CT alone due to atelectasis
    - In 10, PET/CT increased volume as unsuspected nodal disease was detected
    - In 1, new separate tumour focus was found in same lung
  - Overall PET/CT resulted in alterations in radiation planning in over 50% of patients by comparison to CT alone.

Bradley, J et al. IJROBP 59, 2004

GTV: CT v PET-CT

Use of PET-CT may **reduce** GTV/CTV

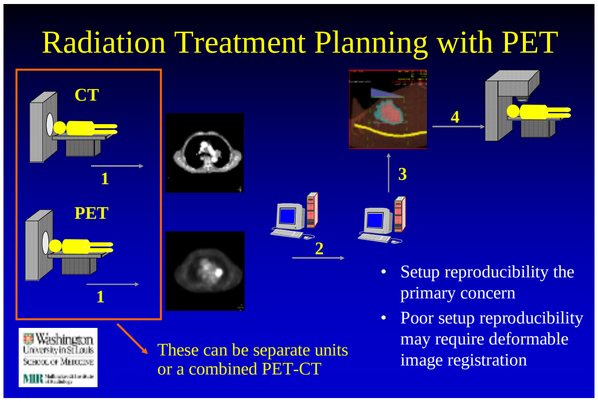
GTV-CT GTV-PET-CT



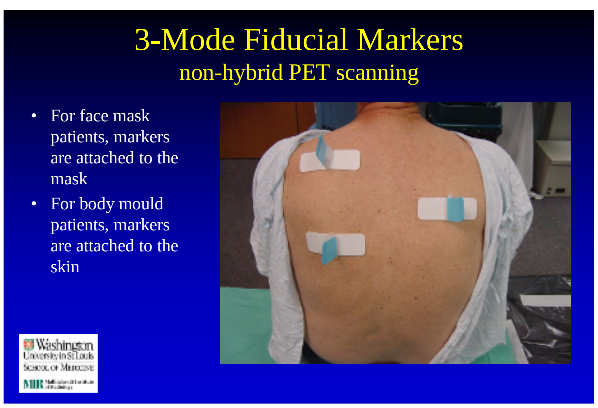
From Schwartz, Ford, Rajendran, et al., Head & Neck 27(6): 478-487, 2005.

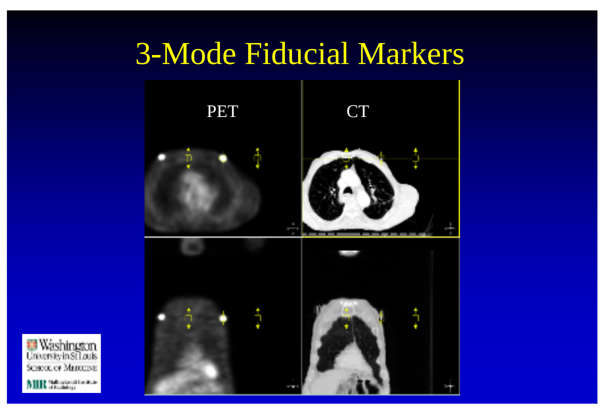
Process: PET in Radiation Treatment

- Cancer diagnosis → biopsy, imaging
- Treatment position, immobilization
- PET imaging in treatment position
- Expert image review
- Image transfer – DICOM, other?
- Image registration (if needed)
- Target localization and definition
- Treatment planning

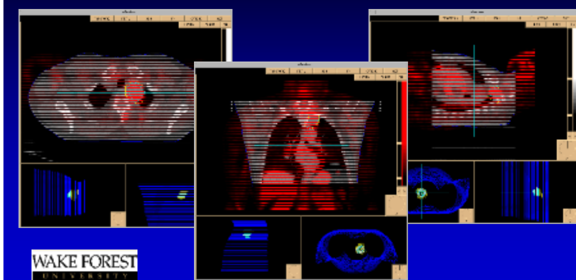

Radiation Treatment Planning with PET
CT
1
PET
1
2
3
4
Setup reproducibility the primary concern
Poor setup reproducibility may require deformable image registration
These can be separate units or a combined PET-CT


Patient Positioning And Immobilization
Flat Tabletop
Immobilization Device


3-Mode Fiducial Markers
non-hybrid PET scanning
For face mask patients, markers are attached to the mask
For body mould patients, markers are attached to the skin


3-Mode Fiducial Markers
PET
CT

PET-CT Image Registration

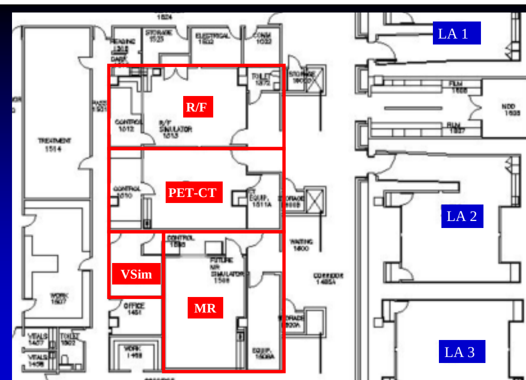


Hybrid PET-CT Scanner

- Combined helical, multislice CT scanner mated to a PET scanner
- Possibly three scans acquired during procedure
  - Attenuation correction CT
  - PET: 2D or 3D acquisition
  - Treatment planning CT +C

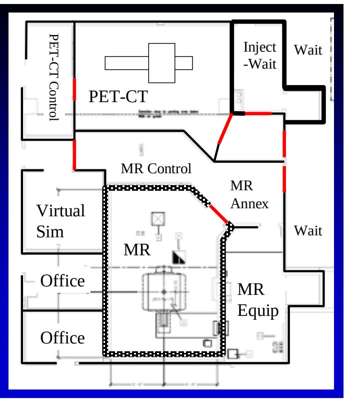
PET-CT Logistics

- On-site cyclotron for FDG production
- Delivery to secure isotope room
- Calibration check and syringe preparation
- Injection in Injection Room, and waiting there
- Usually: Coarse CT, PET, hi-quality CT
  - Protocols match Radiology protocols
  - Research protocols – H/N chemo-radiation trial
- Dose monitoring to environs show no difficulties
- Approximately five PET-CT patients per week
- Cross-trained technologists and Radiology faculty input
- All scans to institutional PACS for interpretation, archive
- Performing CT +C scans per Radiology protocol



PET-CT

- Adjacent control, scanner, inject-wait, lab, and toilet
- 1/8 in Pb; control, scanner
  - adjacent waiting, scanner bkg
- 1/2 in Pb; inject-wait, toilet
- Isotope prep near on-site
- CT, PET-CT operation is quality – future additional QA testing
- Shared Virtual Simulation
- Laser marking system
- Automated PACS archive, selective push to TPS
- Normal access security



View from Operator Entry

Patient Access, Injection Room

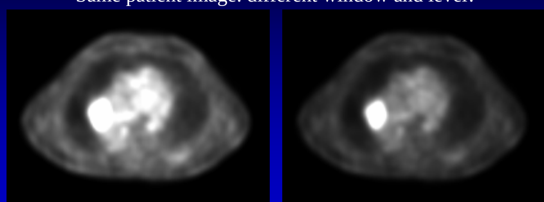
Target Definition

- Qualitative: Expert clinical review
  - Visual, inclusion of clinical history and data
  - Above background
- Quantitative: Voxel intensity values
  - 40-50% of peak intensity (above background?)
  - Standardized Uptake Value (SUV) of ROI
    - ie, SUV > 2.5 indicates positive for cancer
  - Region determined by PET, extent by CT

Radiation Treatment Planning with PET

Target Definition

Same patient image: different window and level!



Depending on image window and level setting, target volume can change by 50%. Also:
a) SUV not a part of DICOM data
b) SUV utility unclear

Radiation Treatment Planning with PET

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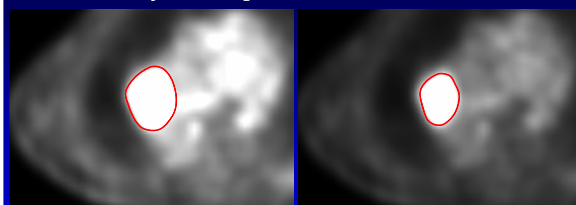
Same patient image: different window and level!

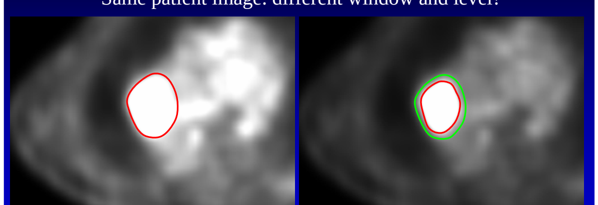


In this example, Lt target is larger than Rt target by factor of 1.2 (Lt v Rt), and shape is slightly different

Radiation Treatment Planning with PET

Target Definition

Same patient image: different window and level!



In this example, Lt target is larger than Rt target by factor of 1.2 (Lt v Rt), and shape is slightly different

Standardized Uptake Value (SUV)

- Semi-quantitative measure of glucose metabolism
- Essentially: Average voxel value within an ROI
  - normalized by activity and body weight
- Relative to an individual patient
  - Malignancy v benign
  - Tumor grade
  - Treatment response
  - Prognosis (?) – biological models

In part from Rohren, Turkington, Coleman: Radiology 2004; 231:305-332

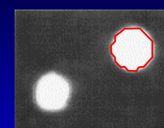
SUV Limitations

- Semi-quantitative measure of glucose metabolism
- Definition of the ROI (CT? self-referencing), and its location over time (ie, scan to scan)
- Tumor heterogeneity: necrosis, variable grade
- Tumor volume changes with time
- Small tumors difficult to image (size → resolution)
- Glucose load?

Consensus? Quantification of FDG uptake?

In part from Greven: Sem Rad Onc 14:2, 2004.

SUV Phantom Investigation



- Threshold SUV-function can be determined via measurement to enable definition of an FDG PET-GTV
- Depends on mean target SUV
- May be better than constant-valued SUV (ie, "2.5" or 50% FWHM)
- Difficult for low SUVs (SUV < 2.0)
- Tested in patient population

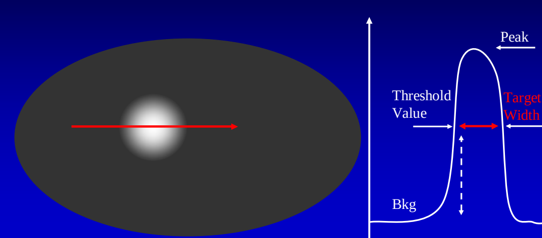
From Black, Grills, Kestin, et al., IJROBP 60(4):1272-1282, 2004

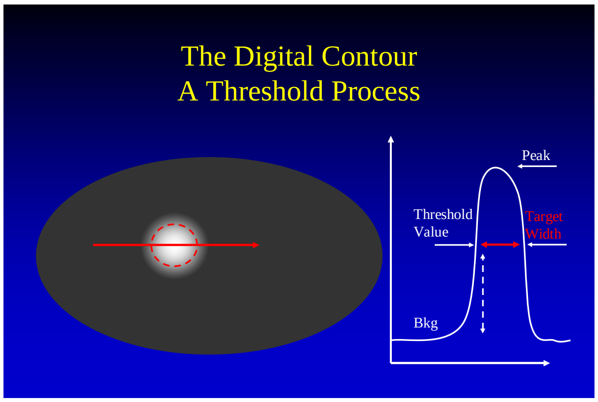
Approaches to PET-Target Definition

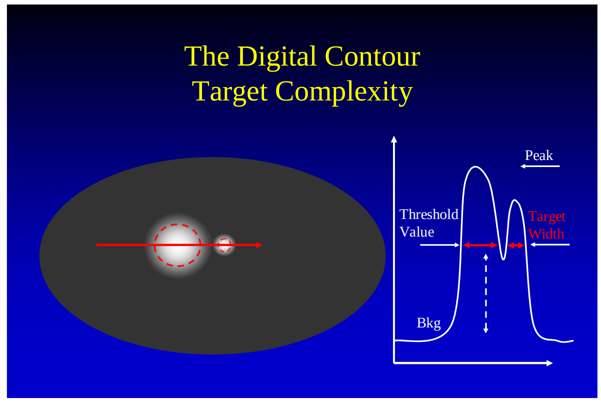
- 40-50% of peak intensity (above background?)
- Standardized Uptake Value (SUV) of ROI
  - ie, SUV > 2.5 indicates positive for cancer
- Region determined by PET, extent by CT
- Calibrated method for scanner?

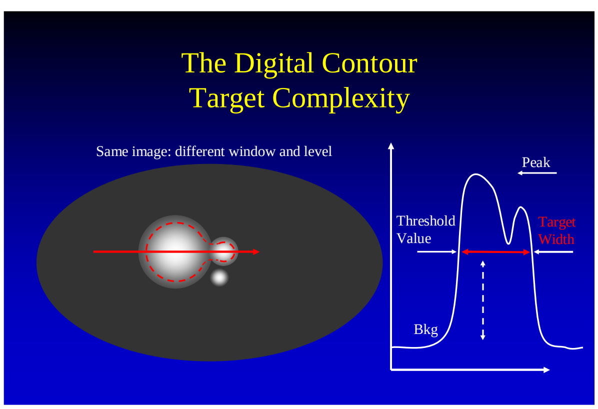
In common – digital image with voxel intensities

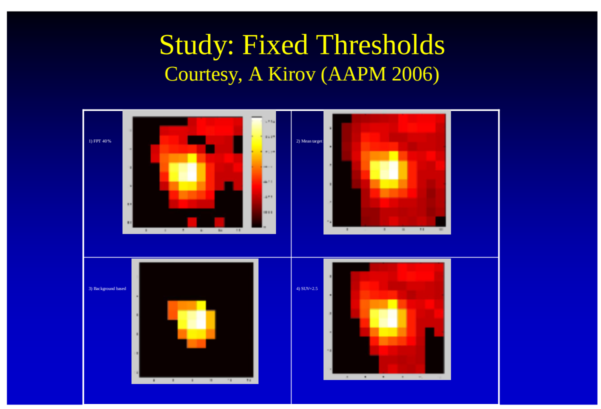
The Digital Contour
A Threshold Process




The Digital Contour
A Threshold Process
Peak
Threshold
Value
Target
Width
Bkg


The Digital Contour
Target Complexity
Peak
Threshold
Value
Target
Width
Bkg


The Digital Contour
Target Complexity
Same image: different window and level
Peak
Threshold
Value
Target
Width
Bkg


Study: Fixed Thresholds
Courtesy, A Kirov (AAPM 2006)

Conceptual Framework: Image-Based

Imaging Pre, During, and Post Therapy: Ideal Timepoints

Pre-T → Mid-Point T → End T → 1 mo post T → 3+ mo post T

Hypotheses for use of midpoint-RT imaging:

- Imaging will provide data for identifying early response and/or modifying therapy
- Imaging will provide data useful for therapy modification for no response

PET-CT Dose Assessment

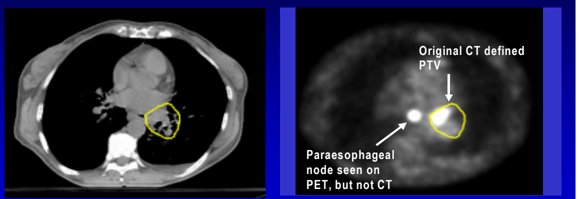
- Whole-body PET-CT scanning (top of head to mid-thigh) is proposed for the evaluation of squamous head/neck cancer to be treated by combined modality chemo-radiation. The PET-CT simulations are a) PET-CT, followed by b) CT + contrast.
- Dose assessment is summarized as follows:

Scan Type	Dose Equivalent (rem; (mSv)) [per scan]		
1.	CT attenuation scan	1.3 rem	(13.4 mSv)
2.	PET scan (FDG, per 10 mCi)	0.7 rem	(7 mSv)
3.	CT + contrast, high quality CT	2.1 rem	(20.8 mSv)
Total dose-equivalent per set of scans:		4.1 rem	(41.2 mSv)
(Whole-body)			

- Assumptions
- CT attenuation scan: 3.75 mm thickness, 130 mA, CTDI ~ 9.1 mGy
- PET scan: 18F-FDG, per 10 mCi
- CT +C, high quality scan: 2.5 mm thickness, 200 mA, CTDI ~ 14.2 mGy
- Note: CT scans obtained with auto-mA; actual mA varies with body thickness
- Formulism is as follows1:
- D = G x CTDI, where D[T] is dose and G[T] ("Gamma") is the organ-specific dose coefficient. Then, G[E] is used to compute Effective Dose where G[E] = S(G[T]i x w[T]i) (classic weight factors per organ). So, D[E] = G[E] x CTDI
- The total conversion coefficient, G [E], weighted over all organs, is 1.47 mSv/mGy 1
- References

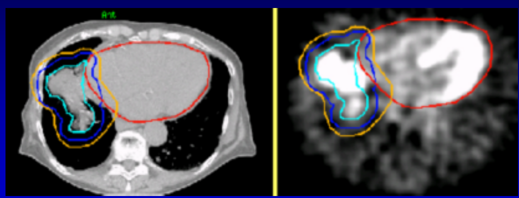
1. Brix, Lechel, et al, JNM 46:608-613, 2005.

FDG PET and CT Image Registration



Courtesy of A Kirov, MSKCC

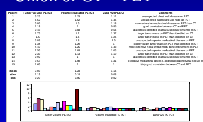
FDG PET and CT Image Registration

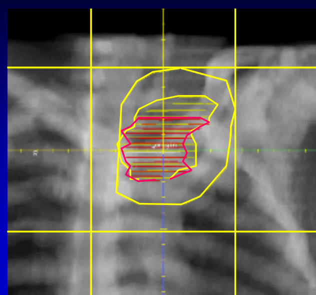


Courtesy of A Kirov, MSKCC

Target Volume Differences

- New target area not previously covered
- Change in target volume
- Union of CT + PET

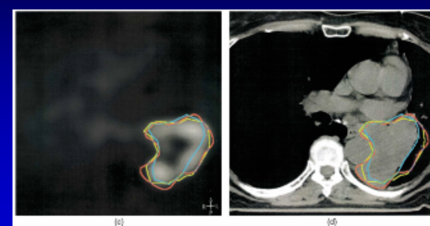




Tomlinson, Russo, Bourland: ASTRO 2000

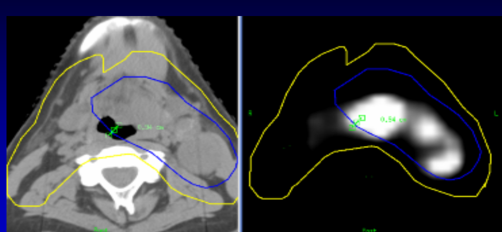
GTV-CT and GTV-PET
Other Issue: Inter-observer Variation

PET CT



From Caldwell, Mah, Ung, et al., IJROBP 51(4):923-931, 2001

Other Issue: PET Artifact Near a Cavity

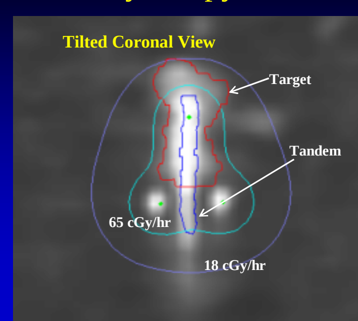


RT planning contours displayed on registered CT (left) and PET (right) images from a PET/CT scan, showing PET signal appearing to originate from a ~1 cm wide air cavity inside the trachea.

Courtesy of A Kirov, MSKCC

PET in Brachytherapy

- Applicators, critical structures and tumor contoured
- Software places sources at predefined positions with respect to applicator tips
- Source strengths and treatments times optimized
- Alternatively, deliver conventional dose distributions



Non-FDG PET Oncology Imaging

Biological and Molecular Imaging

- Hypoxia: F-misonidazole (U Wash)
- Hypoxia: Cu-ATSM (Wash U)
- Proliferation: C-Thymidine (U Wash)
- Blood flow: Water
- Others: permeability, DNA synthesis, tumor receptors, chemotherapy drugs

Radiopharmaceutical development important

Does It Matter?

Indicators of Cancer Diagnosis, Treatment, and Evaluation can be Molecularly Imaged

- Hypoxia and indicators/results of hypoxia
- Cell proliferation and cell cycle sensitivity
- Apopotosis
- Growth factors, stroma and vascular environments
- Radiosensitivity and radioresistance

Molecular Signature

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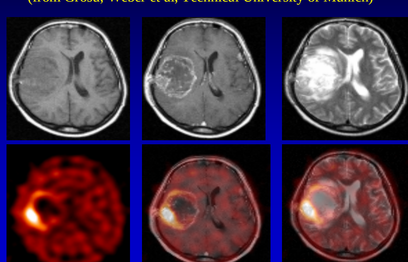
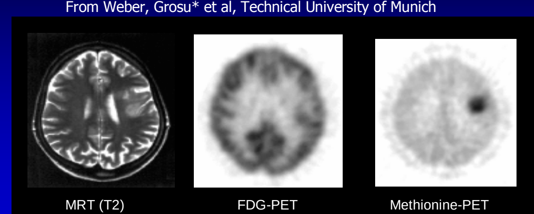
IMT (Thymidine)-SPECT/MRI: GBM Proliferation

(from Grosu, Weber et al, Technical University of Munich)



Methionine PET: Anaplastic Astro

From Weber, Grosu* et al, Technical University of Munich



* Grosu et al, ASTRO 2002: MET PET delivered additional information in 79% patients with resected gliomas

Bioanatomic Imaging and Treatment BAIT – Wake Forest University

- Can tumor biology be imaged?
  - MR, MRs, PET, SPECT, fMR
- Can image-based tumor biology direct "biologically correct" cancer therapy
- RTP has been/is anatomically based
- What will molecular images contribute?

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Paradigm Shift for Radiation Oncology

a shift to

- Biological and Molecular Target Volumes
- Bio-physical Modeling
- Custom Dose Coverage of Target Volumes

made possible by

- *Quantitative* Use of Bio-molecular Images
- Hi-Tech Radiation Treatment, called:

Intensity Modulated Radiation Treatment

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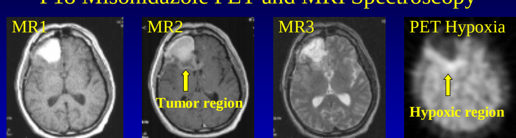
Patient 3: Bioanatomic Imaging

F18 Misonidazole PET and MRI Spectroscopy



Applications
- 3D RTP (IMRT)
- "Biologically targeted" therapy
- Response assessment

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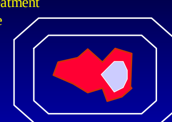
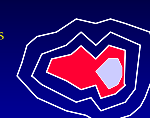
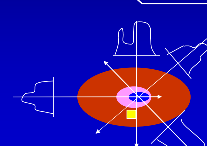
Conformal Radiation Treatment

conventional treatment (rectangular dose distribution)

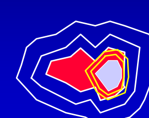


conformal (dose matches target shape)



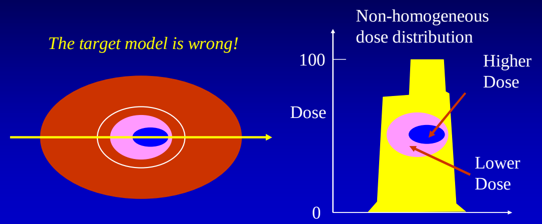


bioanatomic IMRT (dose matches target shape <u>and</u> biology)



The Ideal Dose Distribution?
A “New” Model

The target model is wrong!

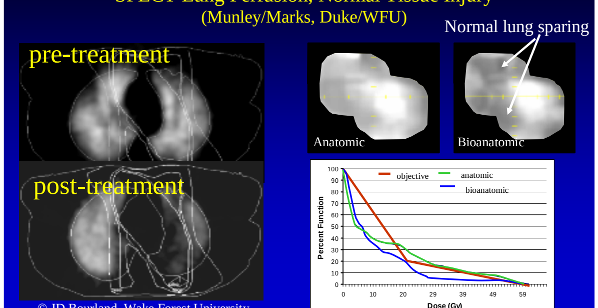


Is the target model wrong?

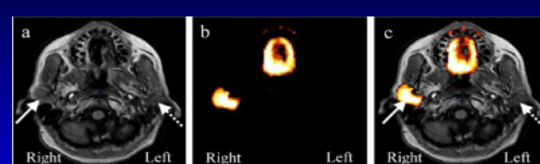
PET Imaging and Biological Models

- Mathematical Representations of Effect
- Model Generation
  - Theoretical models: bio-physio-molecular principles
  - Micro models: fit of bio-molecular observations
  - Macro models: fit of clinical observations
- Model Application
  - Predictive models: guidance of therapeutic decisions
  - Predictive models: estimation of prognosis
- Image-Based: what does voxel intensity mean?

Biological Modeling: Dose Function Histogram
SPECT Lung Perfusion, Normal Tissue Injury
(Munley/Marks, Duke/WFU)



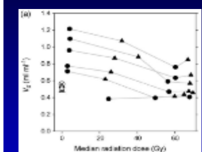
11C-Methionine PET
Regional Salivary Gland Function

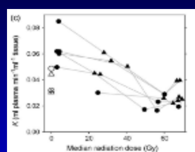


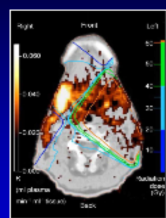
Right side: mean dose 30Gy   Left side: mean dose 57 Gy

Buus *et al*, Radiotherapy and Oncology 73:289-296, (2004).

11C-Methionine PET
Regional Salivary Gland Function







a) Volume of distribution of 11C-methionine
b) K, the net metabolic clearance of 11C-methionine

Washington University in St. Louis School of Medicine
MIR

Buus *et al*, Radiotherapy and Oncology 73:289-296, (2004).

The Digital Imaging Process

- Acquisition Mode/Device
  - MR (MR MRs, pMR, fMR); PET (FDG, hypoxia, perfusion, proliferation); SPECT; Optical (in vivo microscopy, tomography)
- Post Acquisition Processing
  - Reconstruction, Transfer
- Manipulation/Application
  - Classification, Localization, Registration, Segmentation, Measurement [spatial, intensity], Physical and Biological Models
- Secondary Image Generation
  - DRRs, Composite Images
- Display
  - Observation, Evaluation

Digital Imaging and RTP
Image Content and Pixel Meaning

Images provide 3D and 4D information. The challenge is to extract the morphologic, pathologic, biologic, physiologic, or metabolic “meaning” of the image numbers.

CT: electron density (attenuation, dose)
MR: proton density, magnetic moment (?)
PET: radionuclide distribution (physiology?)
SPECT: radionuclide distribution (physiology ?)
Other: What does a pixel mean?

Imaging Science Tasks
Classification/Estimation
Hypothesis of data, (tumor, kidney)
Sample object
→ image: SNR, contrast, …

Imaging Science Tasks
Four outcomes
- True positive (TP); Sensitivity (TPF)
- False positive (FP); Specificity (1 - FPF)
- True negative (TN)
- False negative (FN)

Limitations and Opportunities
PET Oncology Imaging And Treatment

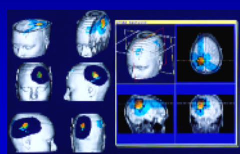
- Image resolution, SNR, specificity, sensitivity
- Scan speed, effects of motion, gating
- FDG and radiopharmaceutical development
- Image registration/image processing tools
- Kinetic modeling
- SUVs, equivalent reference values
- Patient positioning
- RTP target delineation
- RTP dose compartments and resolution

Why Image Patients?
A Picture of the Patient

- The patient is his own best representation
- An image set is only an approximation
- Do we know what the numbers mean?

"A picture tells …"

A collage showing where tumor has regressed, stayed the same, or grown.



Summary

- Physics of PET and PET-CT
- PET oncology imaging: impact is staging and thus treatment pathway or approach
- PET and Radiation Treatment Planning
  - Localization of regions to be treated
  - Targeting, contour delineation, with limits
  - Clinical trials important: H/N, Lung, GI
- Non-FDG PET Oncology Imaging
- Limitations and opportunities with PET
- Paradigm shift for Radiation Oncology
- Growth of PET, PET-CT in the RadOnc clinic

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