PET/CT IN RADIATION THERAPY TREATMENT PLANNING

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OBJECTIVES

• REVIEW BASIC CONCEPTS OF RADIATION THERAPY
• ROLE OF IMAGING IN RADIOTHERAPY
• IMPLEMENTATION OF PET, PET/CT IN RT PLANNING
• FUTURE DIRECTIONS
BASIC CONCEPTS:

#1

- Radiation induced lethal events – random
- Higher the dose – better results
- Higher dose = more collateral damage
- Dose to tumor – *limited* by dose to normal tissues
BASIC CONCEPTS:
#2.

• LOCOREGIONAL RECURRENCE IS THE LEADING CAUSE OF DEATH AFTER PRIMARY RADIATION
• LINKED TO INADEQUATE ERADICATION OF CLONOGENIC CELLS
BASIC CONCEPTS:

#3.

• TUMOR STAGE IS ONE OF THE MOST IMPORTANT PREDICTORS OF OUTCOME
CURRENT RADIATION DELIVERY SYSTEMS

• HIGHEST UNIFORM TO TARGET
• MINIMAL EXPOSURE TO ORGANS AT RISK
TARGET VOLUME DEFINITIONS

- GTV: GROSS TUMOR VOLUME – VISIBLE EXTENT & LOCATION

- CTV: CLINICAL TARGET VOLUME – CORRECT FOR MICROSCOPIC SPREAD

- PTV: PLANNING TARGET VOLUME – CORRECT FOR MOTION & OTHER INACCURACIES
INTENSITY MODULATED RADIATION THERAPY: IMRT

CTV

IRRADIATED VOL

PTV

GTV
EVOLUTION OF IMAGING IN RADIOTHERAPY

• 1890’s: VISUAL INSPECTION
• 1918: EASTMAN INTRODUCES FILM
• 1950’s: IMAGE INTENSIFIER
• 1972: HOUNSFIELD INVENTS CT
• 1980’s: CLINICAL USE MRI
• 1990’s: PET
• 2000 & ON: PET/CT, 4D CT, 4D PET, NEW PHARMACEUTICALS(?)
IMAGING CHALLENGES

• ACCURATE LOCALIZATION
  • TUMOR vs ATELECTASIS/POST-OP & POST-RT FIBROSI S

• ACCURATE STAGING
  • EXTENT OF PRIMARY, NODAL & DISTANT METASTASES

• IMAGE IN TREATMENT POSITION
RECURRENT NSCLC: POST CHEMO RX
CT- DEFINED PTV

PET/CT DEFINED PTV
### IMPACT OF FDG-PET ON RT VOLUMES IN NSCLC

<table>
<thead>
<tr>
<th>STUDY</th>
<th>YEAR</th>
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Impact of FDG-PET on radiation therapy volume delineation in non-small-cell lung cancer.


- STAGE ALTERED: 31%
- GTV CHANGED: 58%
Image fusion between $^{18}$FDG-PET and MRI/CT for radiotherapy planning of oropharyngeal and nasopharyngeal carcinomas.


- 21 pts
- GTV increased by 49% in one pt & decreased by 45% in one pt
- Allowed parotid sparing in 71%
Reduction of observer variation using matched CT-PET for lung cancer delineation: A three-dimensional analysis


• DISAGREEMENT:
  • CT 45%
  • CT-PET 18%

• CONTOURING TIME:
  • CT 16 min
  • CT-PET 12 min

• CORRECTIONS:
  • CT 39
  • CT-PET 25
PET/CT DIRECTED RT PLANNING BENEFITS

- MORE ACCURATE STAGING: IMPROVED TREATMENT CHOICE
- DISTINGUISH TUMOR FROM POST-OP, POST-RT CHANGES, ATELECTATIC LUNG
- 3-D VIRTUAL PATIENT MODEL
  - CT DENSITY MAPS – DOSE CALCULATION
- ACCURATELY EXCLUDE NON-TUMOR BEARING ORGANS/TISSUES
PET/CT DIRECTED RT PLANNING BENEFITS

• PROGNOSTIC INFORMATION BASED ON PET SUV MEASUREMENTS
• MONITOR/QUANTIFY THERAPY EFFECTS
  • Changes in SUV/tumor size
• IMPROVED TARGET DELINNIATION RESULTS IN LESS VARIABLITY IN CONTOUR DEFINITION.
NSCLC: NODAL EXTENT
79 Y0 MALE: NSCLC   10 MONTH INTERVAL: COMPLETE
METABOLIC RESPONSE?
20 MONTHS FOLLOW-UP POST CHEMO-RT
44 yo CA cervix –staging/RT planning
Usefulness of (18) F-Fluorodeoxyglucose positron emission tomography to detect para-aortic lymph nodal metastasis in advanced cervical cancer with negative computed tomography findings.

Lin, et al. Gynecol Oncol 2003;89(1):73-76

50 patients; prospective study; NEG CT
Correlated with surgical pathology results

PET:
Sensitivity: 85.7%
Specificity: 94.4%
Accuracy: 92%
OCCULT SECOND PRIMARY:
76 YO MALE H&N CA
MONITORING RESPONSE

PRE-RT: 2001

POST RT: 2005
PET/CT RT SIMULATION CANDIDATES

- Head & Neck
- NSCLC
- Cervical
- Rectal
- Lymphoma
- Esophageal

- Gastric
- Pancreatic
- Endometrial
- Hepatocellular
- Thymic
- Cardiac
CT and PET images exported to RT workstation

Contouring typically performed on axial images

PET intensity set to optimize target
LESION SIZE AND CONSPICUITY IS EFFECTED BY DISPLAY INTENSITY
WHERE’S THE EDGE?

Too Light!                   Too Dark!                   Just Right!
40% Max                     80% Max                    60% Max

courtesy of A Caggiano
Segmentation of lung lesion volume by adaptive positron emission tomography image thresholding.


- Phantom analysis showed convergence of activity with CT edge at 36% - 44% threshold value for volumes larger than 4ml.
Comparison of different methods for delineation of 18-F-FDG PET-positive tissue for target volume definition in radiotherapy of patients with non-small cell lung cancer

- "GTV (40) does not appear to be suitable in patients with inhomogeneous tumors. More complex methods, such as system-specific contrast-oriented algorithms for contour definition, should be further evaluated…"
RECURRENT COLORECTAL CA
Colorectal CA– Para-aortic nodes
PET/CT SIM: HNH PROTOCOL

• FDG Injection – 30 min uptake (total 60 min)

• Part 1 SIM – Fluoroscopic/Radiographic isocenter placement and immobilization creation – 30 min

• RT team positions patient on Exact Couch with proper immobilization: 5 – 20 min

• Whole-body PET/CT: 30 – 36 min

Limited PET/CT 30 – 40 min
ORCHESTRATION

• Scheduling
  • Coordinate with RT department
• Patient condition
  • One day vs day protocol
  • Whole body before or after PET/CT SIM
• Radiation exposure
• Speak to your patient!!!!
OTHER OPTIONS

- BENEFIT WITH SIMPLE VISUAL CORRELATION OF FDG-PET WITH CT SIM
- 3rd PART SOFTWARE - COMPUTER FUSION OF PET WITH CT SIM
Changes in RT Management

• Improved staging
• Border changes due to nodal coverage
  • Modified target volume in 58% (HNH)
• Decrease target volume >> increase tumor boost dose
• Increase in Re-Treats
THE FIRST STEP
WHAT NEXT?

• DEFINE BIOLOGICALLY ACTIVE TUMOR
• NEW PET AGENTS
  • Cell proliferation (FLT)
  • Hypoxia (MISO)
  • Membrane synthesis (Choline)
• TUMOR MOTION: RESPIRATORY-GATED RT
RESPIRATORY-GATED DELIVERY OF RADIATION - PLANNING WITH 4DPET/4DCT
EQUIPMENT

• RESPIRATORY GATING:
  • 2 REAL TIME POSITION MANAGEMENT SYSTEM (RPM) – LINAC AND PET/CT
    • PASSIVE INFRARED MARKER, VIDEO CAMERA INTERFACED TO PC, AUDIO PROMPT
  • SCANNER – GATING THROUGH CARDIAC GATE
RESPIRATORY CYCLE

Increase Treatment Time by \( \times 4.2 \) (24% Duty Cycle)

- Inspiration: 2.8 Sec.
- Expiration: 3.3 Sec.
- Breathing Period: 6.1 Sec.

INHALE

Gated Motion 9.2 mm

EXHALE
Beam Enable

Beam Hold

Seconds

0 \hspace{1cm} 5
PATENT 1

- 80YO FEMALE, 5 CM RT HILAR NSCLC, 2 SATELLITE LESIONS
- HX SMOKING, CHRONIC COPD
- RX CHOICE: PALLIATION
- RESPIRATORY GATED RT: TO SPARE ALREADY COMPROMISED LUNG
PATIENT 1: 7 MONTHS POST-GATED RT
78 YEAR OLD MALE: NSCLC
02/17/2005 – 15 month follow-up

SUV 2.8
70 YO FEMALE NSCLC
77 YO FEMALE: UNRESECTABLE SARCOMA OF LEFT ATRIUM
4D CT AND 4D PET
CORONAL 4DPET / FUSED 4DPET/CT

Coronal scan
Sc: 11000
Sec: 13.7
DFOV 30.0 cm

4.2 mm of 2.2 g
1:4:30 AM
m=0.3 ml/7.5 g/kh
12:38
RESPIRATORY-GATED RT COMPLETED AUGUST 17 2004
RESTAGING PET/CT: DECEMBER 2004
57 yo male NSCLC 6/2004
RESPIRATORY GATED RT + CHEMO
COMPLETED 08/17/04
# PRIMARY TARGET DATA: NSCLC

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RESPIRATORY GATED RT

• WHICH PATIENTS BENEFIT?
• DECREASE IN TOXICITY
• DOSE ESCALATION
• IS THERE BETTER LOCAL CONTROL?
• IS OUTCOME IMPROVED?
• CUSTOMIZED RADIATION THERAPY
SUMMARY

• PET and PET/CT provide significant improvement in radiation therapy planning by providing:
  • More accurate staging & therefore better treatment stratification
  • Improved tumor target delineation
  • Decreased possibility of geographic miss
  • Potentially improved local tumor control resulting from increased target radiation dose