PET/CT and Planning of Radiation Therapy

Maria José García Velloso
Servicio de Medicina Nuclear
Clinica Universidad de Navarra
mjgarciave@unav.es

PET in radiotherapy planning: Particularly exquisite test or pending and experimental tool?

Vincent Gregoire, Arturo Chiti
Radiation Oncology Department, Université catholique de Louvain, Belgium; Nuclear Medicine Department, Humanitas, Milan, Italy

In medicine, clinical practice cannot resist fashions: in the year 2000, 9 publications dealt with the “use of PET in radiotherapy planning”; by the end of 2005, 115 articles have been published on this subject, and by the end of June 2010, PubMed indicated 500 items using the same keywords!
Expert consensus statement

Recommendations of the Spanish Societies of Radiation Oncology (SEOR), Nuclear Medicine & Molecular Imaging (SEMNiM), and Medical Physics (SEFM) on $^{18}$F-FDG PET-CT for radiotherapy treatment planning

Begoña Caballero Perea, Antonio Cabrera Villegas, José Miguel Delgado Rodríguez, María José García Vellido, Ana María García Vicente, Carlos Huerga Cabrerizo, Rosa Morera López, Luis Alberto Pérez Romasanta, Moisés Sáez Beltrán, The Cooperative Group for PET-CT in Radiotherapy Treatment Planning

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**PET/CT and Planning of Radiation Therapy**

1. The Radiotherapy Process
2. Required equipment
3. Interdepartamental organization
   - Patient preparation: the role of radiation oncology
   - Patient preparation: the role of the nuclear medicine department
4. Image acquisition
5. Interpretation criteria for metabolic images
6. Segmentation methods for metabolic images
7. Physics and radioprotection
8. Psychological impact and patient safety
1. The Radiotherapy Process

**Image Description:**
- Imaging for planning
  - Treatment planning
  - Patient set-up for treatment
  - Imaging for verification
  - Treatment
  - Imaging response

**Figure 1:** Schematic diagram of the radiotherapy process. Reproduced from *Cancer* Issue 60: Prescribing, Delivering, and Reporting Photon Beam Intensity Modulated Radiation Therapy (IMRT), Volume 16, Issue 1, April 2009 by permission of Oxford University Press.
2. Required equipment

The PET/CT scanner must be converted into a PET-CT simulator:

- A specially adapted table (a firm flat tabletop)
  - With indentations in the edges for indexing the immobilization devices
- An alignment-marking system that uses external lasers
- A larger gantry aperture

PET/CT-64 (mCT)
78 cm gantry opening

3. Interdepartmental organization

**Coordination, collaboration:**

- **Patient preparation** (Dept. of Radiation Oncology)
  - Patient positioning
  - Patient alignment
  - Immobilization devices and masks

- **Patient preparation** (Dept. of Nuclear Medicine)
  - Before the appointment: Recommendations
  - FDG administration
  - Intravenous contrast & Diagnostic CT (Radiology Dept.)
4. Image acquisition

**Image acquisition protocol**

- **CT Protocol**
  - Acquisition of the topogram
  - CT acquisition
    - Contrast media
    - Respiratory control (Gated, 4D CT)
- **PET Protocol**
  - PET emission scan
    - Respiratory control (4D Gated PET, HD Chest)
- **Dosimetry**

*Sattler B et al. Radiotherapy and Oncology 2012;96:288-297*
4. Image acquisition

• Position of patient according to tumour location:

<table>
<thead>
<tr>
<th>Tumour location</th>
<th>Trunk</th>
<th>Neck</th>
<th>Extremities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head and neck</td>
<td>Supine</td>
<td>Extension</td>
<td>Arms along the length of the body; caudal retraction of the shoulders</td>
</tr>
<tr>
<td>Lung</td>
<td>Supine</td>
<td>Neutral</td>
<td>Arms flexed above the head</td>
</tr>
<tr>
<td>Upper abdomen</td>
<td>Supine</td>
<td>Neutral</td>
<td>Arms flexed above the head</td>
</tr>
<tr>
<td>Pelvis-rectum</td>
<td>Prone/supine</td>
<td>Flexion</td>
<td>Arms in front of the head</td>
</tr>
<tr>
<td>Pelvis-crevit</td>
<td>Supine</td>
<td>Neutral</td>
<td>Arms crossed over the chest</td>
</tr>
</tbody>
</table>

• Patient alignment:
  – Laser beams
  – Patient's reference marks

4. Image acquisition: Immobilization

Head and Neck

Wang D, IJROBP 2006
### 4. Image acquisition: Immobilization

#### Brain, Head and Neck

![Images of MRI scanner setup and patient in a head coil](image1)

#### Torax

![Images of MRI scanner setup and patient in a chest coil](image2)
4. Image acquisition: Immobilization

Abdomen, Pelvis

Prone position → Rectal Carcinoma

4. Image acquisition

CT Simulation
4. Image acquisition

PET/CT Simulation

Respiratory Gating for PET/CT

Sattler B et al. Radiotherapy and Oncology 2012;96:288-297

Bettinardi V et al./ Radiotherapy and Oncology 96 (2010) 311-216
Respiratory Gated PET

- Technique:
  - Acquisition synchronized with the respiratory cycle.

Respiratory motion

Gating 4D:
- Based on the phase of the movement
- Divided into equal intervals

HD Chest:
- Based on the amplitude
- Includes data in \( W = U - L \)
- 35% PET data
Mediastinal lymph node metastases visualized by non-gated whole-body PET, HD•Chest, and 4D gated PET. Whole-body PET defines the node well with SUV of 7.3. However with HD•Chest, the lesion contrast is higher with a significant 38 percent increase in SUVmax. The 4D gated PET end expiratory frame also shows a higher SUV, but with more image noise.

HD•Chest images are visually comparable to the non-gated PET, with clearly improved lesion contrast and higher SUV, though motional blurring in mediastinal lymph nodes is likely to be less than in lung tumors.

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5. Interpretation criteria for metabolic images

- The first step is to visually assess the image.
- A semiquantitative study can be performed to determine the SUV indices for each observed lesion.
- Region of interest (ROI) or Volume of interest (VOI).
- The reported SUV threshold separating benign from malignant lesions is 2.5–3
- FDG uptake reflects the pathophysiology:
  - Proliferation
  - Inflammation
  - Neoangiogenesis
  - Hypoxia

Caballero P. Rep Pract Oncol Radiother 2012
6. Segmentation methods for metabolic images

- Contouring of the target volume
  ICRU Nomenclature

  GTV: Gross Tumor Volume
  CTV: Clinical Target Volume
  PTV: Planning Target Volume
  • ICRU 62
  ITV: IM+SM+CTV
  • IM: Internal Margin
  • SM: Setup Margin

Three methods can be used to evaluate PET images:

- Qualitative (visual interpretation)
- Semi-quantitative segmentation (Threshold methods based on SUV)
- Kinetic-quantitative (variation in uptake time)

6. Segmentation methods for metabolic images

FDG PET/CT

- Visual (Qualitative) or manual
- Treshold methods (Semi-quantitative)
  - Cut-off value (SUVmax 2.5)
  - A percentage of the SUVmax (40-50%)
  - Relative threshold level
  - Variational approaches (gradient method)
### 6. Segmentation methods for metabolic images

**FDG PET/CT**
- Visual (Qualitative) or manual
- Threshold methods (Semiquantitative)
  - SUVmax cut-off value (2.5)
  - Percentage of the SUVmax (40-50%)
  - Relative threshold level
  - Variational approaches (gradient method)

**But also…**
- Learning curve
- Knowledge of tumors:
  - Anatomy
  - Histology
  - Tumor cell dissemination (lymphatic, hematogenous)

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**Recurrent nasopharyngeal carcinoma**
6. Segmentation methods for metabolic images

FDG PET/CT
- Extra information provided by metabolic data (30-60%)
- Precise contouring of the target volume.
- Dosimetric calculations: functional information
- New information about GTV subvolumes
- PET-CT-based images
  - GTV FDG PET-CT

6. Segmentation methods for metabolic images

- PET may reduce the CT-based tumoral volume

Sunnybrook, U. Toronto
6. Segmentation methods for metabolic images

- PET may increase the CT-based tumoral volume

Sunnybrook, U. Toronto

Daisne JF. Radiology 2004

IMRT: Schwartz DL, Head Neck 2005
7. Physics and radioprotection
7. Physics and radioprotection: Verification

- Department of Medical Physics
  - Quality controls
  - Isodose distribution
- Patient
  - Verify patient positioning

7. Physics and radioprotection: Treatment

[Images showing RTC and IMRT]
7. Physics and radioprotection: Treatment

PET/CT and Planning of Radiation Therapy

68-year-old male.
Squamous Carcinoma in left nasal cavity
PET/CT and Planning of Radiation Therapy

68-year-old male.
Squamous Carcinoma in left nasal cavity

**Chemotherapy**

**IMRT**
Cetuximab

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8. Psychological impact and patient safety

- Quality control
  - Acquisition equipment
  - Registration/fusion/segmentation software
  - Treatment planning system
  - Routine and periodic testing of the PET and CT

- Radiological protection for patients and workers

**ALARA**