PET/CT and Planning of Radiation Therapy

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

Vincent Gregoire, Arturo Chiti

In medicine, clinical practice cannot resist fashion: in the year 2000, 5 publications dealt with the “use of PET in radiotherapy planning”; by the end of 2005, 197 articles have been published on this subject, and by the end of June 2018, PubMed indicated 500 times using the same keywords!
Expert consensus statement

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

_Begoña Caballero Perea_ª, _Antonio Cabrera Villegas_ª, _José Miguel Delgado Rodríguez_ª, _María José García Veloso_ª, _Ana María García Vicente_ª, _Carlos Huerta Cabrero_ª, _Rosa Morera López_ª, _Luis Alberto Pérez Romasanta_ª, _Moisés Sáez Beltrán_ª, _The Cooperative Group for PET-CT in Radiotherapy Treatment Planning_ª

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

1. The Radiotherapy Process
2. Required equipment
3. Interdepartmental 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

![Diagram of the radiotherapy process]

**Fig. 1** - Schematic diagram of the radiotherapy process. Reproduced from [JCO] Journal of Clinical Oncology: Prescribing, Delivering, and Reporting Photon Beam Intensity-Modulated Radiation Therapy (IMRT). Volume 18, Issue 1, April 2000 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)](image)
78 cm gantry opening

3. Interdepartmental organization

**Coordination, colaboration:**

- **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

Torax
4. Image acquisition: Immobilization

**Abdomen, Pelvis**

<table>
<thead>
<tr>
<th>Prone position</th>
<th>Rectal Carcinoma</th>
</tr>
</thead>
</table>

4. Image acquisition

**CT Simulation**

![CT Simulation Image]

![Prone position Image]
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.

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
- Threshold methods (Semi-quantitative)
  - Cut-off value (SUV \text{max} 2.5)
  - A percentage of the SUV \text{max} (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

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**PET may reduce the CT-based tumoral volume**

CT: Purple  
PET/CT: Green  
PTV based on CT only  
PTV based on PET/CT  

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

- PET may increase the CT-based tumoral volume

Sunnybrook, U. Toronto

<table>
<thead>
<tr>
<th>Axial</th>
<th>CT-based</th>
<th>PET-based</th>
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</thead>
<tbody>
<tr>
<td>MC</td>
<td>[Image]</td>
<td>[Image]</td>
</tr>
<tr>
<td>CT</td>
<td>[Image]</td>
<td>[Image]</td>
</tr>
<tr>
<td>FDG-PET</td>
<td>[Image]</td>
<td>[Image]</td>
</tr>
</tbody>
</table>

Daisne JF. Radiology 2004

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

Rajendran et al., EJNMMI, 2006
7. Physics and radioprotection: Verification

<table>
<thead>
<tr>
<th>Department of Medical Physics</th>
<th>Patient</th>
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</thead>
<tbody>
<tr>
<td>Quality controls</td>
<td>Verify patient positioning</td>
</tr>
<tr>
<td>Isodose distribution</td>
<td></td>
</tr>
</tbody>
</table>

7. Physics and radioprotection: Treatment

![RTC and IMRT images](fisica.unav.es/publicaciones/Tesinas/Azcona.pdf)
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

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