Instrumentation

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Alex Dunlop

Content

Due to recent improvements in radiotherapy treatment planning and delivery, we are now able to generate and deliver highly conformal and homogenous dose distributions to designated targets whilst sparing organs at risks (OARs) [1]. However, the ability to accurately delineate the clinical target volume (CTV) remains one of the major challenges of radiotherapy treatment [2]. Currently, it is standard practice to delineate the CTV on a CT data-set, whilst other imaging modalities may be used to aid the localisation of the target. Functional PET images enable the metabolic activity and extent of the target to be assessed [3].

A single-scan PET/CT approach (Fig. 2.1a) enables the radiotherapy plan to be generated on the CT data-set acquired alongside the PET [4]. This can reduce both the hospital visits for the patient and the image registration uncertainty between the PET image and the radiotherapy planning CT [4]. Indeed, a maximum three-dimensional displacement error between the CT and PET of 0.5 mm has been reported for single-gantry PET/CT systems [5].

To ensure that tumour volumes can be targeted and OARs spared with acceptable accuracy, the position of the patient must remain consistent and reproducible on a daily basis throughout the entire treatment pathway. In order to be able to plan directly from PET/CT data, it is therefore necessary to adapt the PET/CT suite so that patients can be imaged in the treatment position.

Soft-mattress couches commonly used for PET scans (Fig. 2.1b) are not used for radiotherapy treatment; instead flat-top rigid couches are employed to improve

A. Dunlop
Department of Physics, The Royal Marsden NHS Foundation Trust, London, UK
e-mail: Alex.dunlop@rmh.nhs.uk

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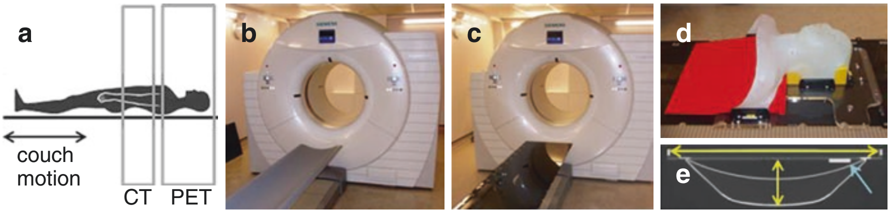

Fig. 2.1 *From left* (**a**) schematic of a single-gantry PET/CT system; (**b**) a Siemens Biograph PET/CT system with diagnostic imaging soft-mattress couch; (**c**) the same PET/CT suite but with a flat radiotherapy couch installed; (**d**) thermoplastic shell attached to the PET/CT flat-top couch using the same immobilisation devices used for radiotherapy treatment—see Chap. 3 for detailed information regarding patient set-up and immobilisation; and (**e**) an axial CT slice of the couch as used for QA—the *yellow arrows* indicate separations that could be measured at regular intervals to check the absolute distance of the CT scanner. Markers of known separation should also be present in the longitudinal direction. The *turquoise arrow* points to a feature of the couch that enables confirmation of left/right sides in the CT image

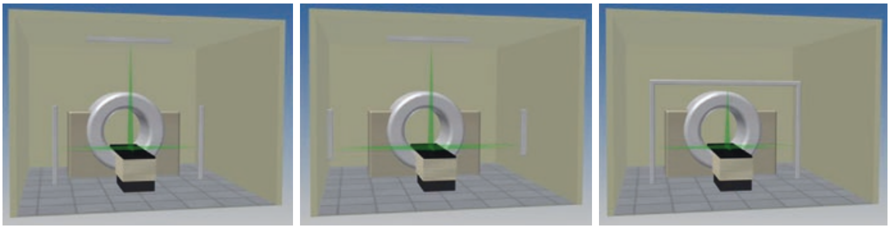

Fig. 2.2 Various commercially available radiotherapy laser systems that could be used within a PET/CT suite, *from left*; free-standing columns for lateral lasers; wall-mounted lateral and sagittal lasers; and a bridge laser arrangement

patient position reproducibility. Therefore, radiotherapy-ready PET/CT systems must be able to easily mount flat-top radiotherapy couches (Fig. 2.1c). The couch top must be consistent with those used for treatment and, in particular, must be compatible with additional immobilisation devices that will be used during treatment. Such devices vary depending on the site of treatment. For example, a patient-specific thermoplastic shell may be used for a head and neck cancer patient (Fig. 2.1d). The flat-top couch should ideally contain markers at known distances from each other (Fig. 2.1e) to allow absolute distance quality assurance (QA) checks to be made at regular intervals in both the longitudinal and lateral directions.

To be used for radiotherapy planning, the PET/CT suite must also incorporate a dedicated radiotherapy laser system. The intersection of the lateral and sagittal lasers determines localisation coordinates within the immobilised patient from which the isocentre for treatment can be defined. The laser system should be consistent with that used on the treatment unit. However, equipment within the PET/CT suite may determine the laser system options that are available (Fig. 2.2). Routine QA must be carried out on the laser system in order to maintain consistency with the lasers in the treatment room. A further consideration is the colour of the laser light. Usually red or green lasers are used; both have the same accuracy and are similar in

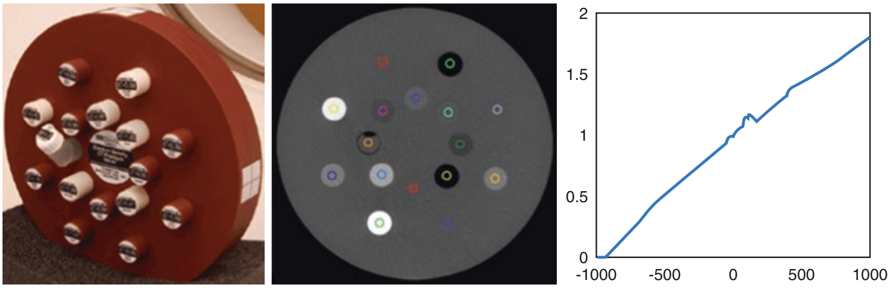

Fig. 2.3 (*Left*) Electron density CT phantom RMI 467 (Gammex, Middleton, WI) in bore of PET/CT scanner. The phantom consists of a solid-water disc the size of an average pelvis with 16 holes in which inserts of differing densities can be placed; (*Middle*) axial CT slice of the RMI phantom viewed within the Pinnacle[3] (Philips, Fitchburg, WI) radiotherapy treatment planning system (TPS). The different inserts have been contoured (various colours) in order to determine the average Hounsfield units (HUs) for each material within the phantom; (*Right*) the resulting scanner-specific plot of physical density (g/cm^3 on the y-axis) as a function of CT number (HU - 1000 on the x-axis)

cost [6]. However, green lasers are known to be more visible on darker skins [6], whereas red lasers are better when aligning patients immobilised within thermoplastic shells. Therefore, careful consideration is needed in the choice of laser colour, particularly in the context of PET/CT where efficiency of patient set-up is important to ensure staff doses are kept as low as reasonably practicable (ALARP).

In order to calculate dose, radiotherapy treatment planning systems (TPSs) require conversion of all voxels in the CT scan from CT numbers or Hounsfield units (HUs) to physical density (g/cm^3). To achieve this, a scanner-specific HU-density look-up table (LUT) is generated and stored within the TPS. The calibration of CT numbers to material density can be realised by performing a CT acquisition on the scanner to be calibrated, using the same scanning parameters to be used for patient scans, of a phantom with various inserts of differing, and known, physical densities. An example of a commercially available phantom capable of defining the calibration is shown in Fig. 2.3. Regular QA should be performed on the CT images to ensure constancy of CT numbers within the image. This can practically be achieved by regularly scanning a phantom of known density and interrogating the resulting image to ensure the CT numbers are as expected.

Key Points

- The ability to accurately delineate the clinical target volume (CTV) remains one of the major challenges of radiotherapy treatment, the use of PET images can aid this process.
- A single-scan PET/CT approach for radiotherapy treatment planning enables the radiotherapy plan to be generated on the CT data-set acquired alongside the PET, thereby reducing the image registration uncertainty between the two image sets.

- If a single-scan PET/CT acquisition is to be used directly for radiotherapy treatment planning it is vital that the necessary instrumentation is in place to ensure that the patient can be scanned in the treatment position and that localisation can be performed in the same way as on the treatment unit.
- It is vital that a flat-top couch can be easily mounted and that the couch is able to accommodate patient immobilisation systems.
- Radiotherapy-quality laser systems should be installed and tested regularly. Additionally, measurements need to be taken to generate a look-up-table between CT numbers and physical density.

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