Co-registration in Hybrid Imaging Devices

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CO-REGISTRATION IN PET-CT AND SPECT-CT

1. Introduction and rationale

Hybrid PET-CT and SPECT-CT systems are usually supplied with a special calibration procedure for the initial establishment of the co-registration of the PET or SPECT and CT fields of view. Routinely checking the accuracy of image registration in these multimodality devices is of importance for two reasons. Errors in registration will cause inaccuracies in attenuation correction procedures and improper correlations of anatomy and function. Especially for PET-CT systems, the accuracy of image registration becomes even more important when considering the scanner in conjunction with radiotherapy applications. Note that chapter "PET-CT in radiation treatment planning" is dedicated to quality controls for PET-CT when incorporating PET in radiation treatment planning.

Co-registration in SPECT-CT is considered to be more complicated than in PET-CT. In PET-CT both PET and CT are rings in fixed positions, which implies that (apart from extreme situations) the central axis of PET and CT stay in line. In SPECT, however, the centre of rotation (COR) can be adjusted and depends on the collimator that is used. Consequently, this can result in misalignment of the central axis of the gamma camera and CT. Hence, for SPECT-CT, not only the movement of the bed is affecting the alignment but also the calibration of the COR.

The objective of the quality checks set out in what follows, is to provide means of verifying the accuracy of co-registration in PET-CT and SPECT-CT devices.

2. Frequency

It is recommended that quality control of co-registration in PET-CT and SPECT-CT is performed at the time of (re)acceptance testing and whenever the system is serviced in a way that might have an impact on image registration accuracy, including, but not limited to, servicing of the table, separating the PET or SPECT and CT gantries for servicing, COR calibration (applicable for SPECT only) and software changes or upgrades (method 1). Depending on the use of PET-CT for radiotherapy purposes, frequency should be increased.

In case of (sudden) doubt about the alignment in clinical practice, a direct and quick test is recommended (method 2).

3. Method

Method 1

Image registration can be checked using a phantom with well-delineated point, line, or volume markers that are both SPECT- (or PET-) and CT-visible. The markers should

be placed centrally, and off center. Each marker, for example, should be fillable with a solution containing both a radionuclide such as ^{99m}Tc (for SPECT) or ^{18}F (for PET) and a radio-opaque contrast agent such as iodine. Alternatively, sealed reusable markers composed of long-lived ^{57}Co (for SPECT) or ^{68}Ge (for PET) uniformly dispersed in a radio-opaque resin or plastic may be used.

In addition, it may be important to perform the measurements with substantial weight (75 kg) on the table to mimic the clinical situation.

Method 2
A point source needs to be positioned adjacent to a patient on the table bed, where special care should be taken that the point source is not close to any pathology.

4. Requirements
Method 1
A phantom with well-delineated point, line or volume markers that is both SPECT- (or PET-) and CT-visible. The activity concentration should be between 1 and 10 MBq for point sources, and around 50 kBq/ml for volume markers, unless the manufacturer recommends another dose.

Lead bricks or other heavy materials, with a total weight of at least 75 kg, can be used to mimic the scanning of a patient.

Method 2
One point source (e.g. ^{57}Co or ^{99m}Tc for SPECT, and ^{68}Ge or ^{18}F for PET) of 1 to 10 MBq, with some radio-opaque contrast agent (if necessary).

5. Procedure
Method 1
For SPECT-CT, for all collimators and geometric collimator configurations that are used in clinical practice, the co-registration accuracy should be measured using a phantom type as described above. The desired collimator has to be mounted and the manufacturer's prescribed protocol (for acquisition and reconstruction) has to be used. It should be verified that this complies with acquisition and reconstruction protocols as being used in clinical practice, except for allowing for larger image matrices and smaller slice thickness (for both SPECT and CT). Preferably, the slice thickness should not exceed 5 mm.

For PET-CT the manufacturer's prescribed protocol should be used when imaging the phantom. This has to comply with a standard clinical protocol in which both the CT and PET acquisition matrices are set to 512x512, or, if those values are not available, to the largest values possible. Preferably, the slice thickness should not exceed 3 mm.

To mimic patient weight, the lead bricks (or equivalent heavy weights) have to be uniformly distributed over 1.5 m length of the patient bed. To analyse the impact of patient weight, the co-registration accuracy should be measured with and without the weights placed on the bed.

Method 2
A standard protocol from clinical practice should be used when scanning the point source together with the patient.

6. Analysis and interpretation
The reconstructed CT and PET or SPECT images should be displayed simultaneously (fused and/or side-by-side using a synchronized cursor). This may be done using the image fusion software provided by the manufacturer.

First, the images have to be examined visually, in all three directions, to inspect the adequacy of the alignment. Subsequently, this needs to be quantified. The misregistration can be quantified as the mean or maximum Euclidean distance (in mm), among all the markers, between the (central) positions of each marker in the 2 modalities. These measurements are then compared with the acceptable errors for the system.

7. Action thresholds and actions
On (re)acceptance and after servicing of the system, factory specifications must be met. Considering the accuracy of the alignment procedures from the different vendors, a misalignment of 5 mm should be considered as threshold. If the co-registration specifications are not met, the initial calibration procedure should be repeated. If values are persistently exceeded, repair needs to take place as soon as possible.

In case PET-CT is used for radiotherapy applications, a stricter limit may be adopted than specified by the manufacturer (see chapter "PET-CT in radiation treatment planning").

8. Pitfalls and marginal notes
When analysing SPECT-CT or PET-CT images of the phantom, make sure that only the initial co-registration matrix is applied. In the analysing software, other registration matrices may be applied in addition to the one derived with the calibration procedure for the initial alignment. This may seemingly affect the co-registration accuracy.

To study the co-registration accuracy, several phantoms can be suitable, amongst which there is the NEMA image quality phantom, which consists of a 'body compartment', six fillable spheres with diameters ranging from 10 to 3,7 mm and a cylindrical insert. By filling the spheres and background compartment with suitable radionuclide concentrations, where the sphere-to-background ratio is approximately 8, appropriate measurements can be performed. Moreover, the accuracy of the CT-based attenuation corrections can be assessed, which directly relates to the accuracy of the co-registration.

When PET-CT is used in conjunction with radiotherapy applications, the relevant protocols for radiotherapy must be used with the emphasis on the geometric precision (sagging of the bed, more frequent/more precise check of the co-registration of PET and CT, and co-registration with any mounted external lasers). For further details, see chapter "PET-CT in radiation treatment planning".

Finally, it should be realized that in clinical practice unavoidable misalignments will occur

due to patient movement, in particular due to the patient's breathing. SPECT and PET images are acquired during free breathing, as the acquisition time is relatively long). CT is usually acquired during a specific stage of the breathing cycle. Especially in the region around the diaphragm severe misinterpretations may occur.

9. Literature

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