I. 11. Scatter Correction for 3D PET Based on Image Subtraction Method


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Introduction

Development of PET scanner is basically addressed toward improvement of spatial resolution and increase of sensitivity. 3D PET was originated from the request of the latter. Sensitivity of 3D PET is higher than that of 2D PET because septa, which restrict detection coincidence lines in 2D PET, are removed. In the case of the Shimadzu SET-2400W scanner in CYRIC, sensitivity in 3D mode is about 15 times than the one in 2D mode. Therefore, 3D PET is suitable for children and normal volunteer because 3D scan has lower radiation limits compared to 2D scan.

However, the increased sensitivity brings the problem that a larger amount of scattered photons in objects are detected compared to 2D mode. This phenomenon increases the background if the scattered photon is detected in coincidence line, in other words, LORs defined by coincidence events coming from scattered photons are not true coincidence lines. The scatter fraction in 2D PET is only about 10% of total events, so that it can be neglected. However, in 3D PET, total events include a scatter fraction of about 40%. Therefore, it should be corrected in order to get accurate quantitative images.

In this paper, we propose an image subtraction method by using scatter distribution model. Scatter distribution is modeled as a Gaussian distribution. Using this model, true events distribution is determined from the total measured distribution (true + scatter distribution) by an iterative method.

Method

When a point source is set at the coordinates (x’,y’,z’), the scatter distribution is
modeled as follows:

\[
g(x, y, z, x', y', z') = n(r) \cdot f(x - \alpha', y - \gamma', z - z')
\]

\[
f(x - \alpha', y - \gamma', z - z') = n_0 \exp \left\{ - \frac{(x - \alpha')^2 + (y - \gamma')^2}{a^2} - \frac{(z - z')^2}{b^2} \right\}
\]

\[
r = \sqrt{x^2 + y^2 + z^2}
\]

where \( g(x,y,z,x',y',z') \) is the scatter distribution, \( n(r) \) is a function that corrects the intensity of the distribution and \( \epsilon(<1) \) represents the scatter distribution center’s shifts toward the origin direction. In this case, measured distribution \((m(x,y,z))\) shows as follows by using true distribution \((t(x,y,z))\) and scatter distribution \((s(x,y,z))\):

\[
m(x, y, z) = t(x, y, z) + s(x, y, z)
\]

\[
= t(x, y, z) + \iiint n(r') t(x', y', z') f(x - \alpha', y - \gamma', z - z') dx'dy'dz'
\]

This equation can not be directly calculated in the reconstructed image because it includes scatter fraction. Therefore, iterative method is carried out by substituting measured distribution for true distribution.

\[
\begin{align*}
  s_i &= t_{i-1} \otimes g \\
  t_i &= m - s_i = m - t_{i-1} \otimes g \\
  t_0 &= m
\end{align*}
\]

Parameters are determined by experimental data which was measured with pool phantom (diameter 20cm, length 20cm) and a sodium point source (27µCi) set at the center of axial direction and 0, 2, 4, 6, 8 cm, respectively, of radial direction in the phantom filled with water. Scatter fraction is estimated on the projection and fitted with Gaussian function.

**Experiment**

All experiments were carried out with the Shimadzu SET-2400W scanner, which has the axial view of 20cm and 32 slices, in CYRIC. When scatter correction is applied, the numbers of iteration are 5 times in both experiments.

*<Uniform phantom>*

The radioisotope injected in the pool-phantom (20cm of the diameter, 28.5cm of height) was F-18 (640µCi) and scan time was 10 minutes.
<Non-uniform phantom>

Used phantom are showed in Fig. 1. The hot area is filled with F-18 solution (250µCi). Diameter of the three cold spots is 5cm and they are assumed to be water, air and Teflon. The center of cold spot is 6cm distance from the center of phantom Scan time was 5 hours both 2D and 3D mode.

Result and Discussion

<Uniform phantom>

Uncorrected (left) and corrected (right) images are shown in Fig. 2 and average of ROI’s at 0 (center), 2, 4, 6 and 8cm in Fig. 3. In the uncorrected image, central part is found concave because of scatter fraction, but that part is suppressed and flat by scatter correction.

<Non-uniform phantom>

Uncorrected (left) and corrected (right) images are shown in Fig. 4 and profiles across water, air and Teflon cold area in Fig. 5. This scatter correction method is very successful in water cold area but underestimated in Teflon area and overestimated in air area (Fig. 5). It is because the parameters were experimentally determined only for a phantom filled with water. If scatter medium is not water, rate of Compton scatter changes compare to the case of water. Therefore, we must review this point.

Conclusion

This method is effective when scatter medium is water, for example in brain studies. However, if scatter medium is not uniform, for example in whole body studies, this correction method can not be applied because this correction method leads to under or over estimation according to the attenuation coefficient. Therefore, scatter distribution in air, Teflon and so on must be evaluated. For this point, most researches are carried out with Monte Carlo simulation\textsuperscript{1,2). We are making the simulator of SET-2400W and estimating the scatter distribution in air, Teflon and so on. We will continue this research for this point and develop a scatter correction method for all cases.
References


Fig. 1. Non-uniform phantom.

Fig. 2. Uncorrected (left) and corrected (right) images.

Fig. 3. Average of ROI.
Fig. 4. Uncorrected (left) and corrected (right) images.

Fig. 5. Profiles including cold area (top:30-50 water, bottom:30-40 air and 70-85 Teflon).