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Nuclear medicine

Week 3; Lecture 6; Section 4: Corrections in PET

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Section 4

Corrections

Corrections; normalisation

Want response to be proportional to activity in a given pixel

PET systems have many (10,000–20,000) PMTs. Various factors determine the signal recorded for a given number of incident photons, including:

- Precise dimensions of crystal in neighbourhood of PMT;
- Coupling of crystal to PMT;
- γ's angle of incidence and crystal uniformity;
- PMT gain and gain in electronics;
- Response of CFD;

So, require to "normalise" signal

Corrections; normalisation

Exploit rod source; take data while performing 360° rotation of rod

Normalisation factor, $\mathcal{N}_{ij}$ for pair of PMTs i, j is given by:

$$\mathcal{N}_{ij} = \frac{N_{ij}}{\bar{N}}$$

where N_{ij} is the number of coincidences recorded between PMTs i and j and $\bar{N}$ is the mean number of coincidences for all PMT pairs

Normalised number of coincidences, $\mathcal{C}_{ij}$ for PMT pair i, j is given by:

$$\mathcal{C}_{ij} = \frac{C_{ij}}{\mathcal{N}_{ij}}$$

where C_{ij} is the number of coincidences recorded between PMTs i, j recorded in a patient scan

Corrections; random coincidences; delayed window method

Coincidence time window Δt usually set to 2τ, where τ is the width associated with the PMT timing signal

Take $t_{\rm delay} >> \Delta t$, then the number of coincidences between:

- Hit in PMT i at t_i and
- Hit in PMT j at $t_j = t_i + t_{\rm delay} \pm \Delta t$

will give an estimate of the random coincidence rate

The delayed-window estimate of the random coincidence rate between PMTs i and j can be subtracted from the measured coincidence rate

Subtraction of the random coincidence rate leads to an increase in the statistical (counting) uncertainty:

$$\sigma\left(N_{\rm true} + N_{\rm scat}\right) = \sqrt{N_{\rm true} + N_{\rm scat} + 2N_{\rm random}}$$

Corrections; random coincidences; singles method

Random coincidence rate between PMTs i and j determined above:

$$\mathcal{R}_{\rm random}(i,j) = \Delta t \mathcal{R}_{si} \mathcal{R}_{sj}$$

$\mathcal{R}_{\rm random}(i,j)$ can now be subtracted PMT pair by PMT pair

Singles rate is large, so, correction for random coincidences based on singles has much greater statistical weight than delayed-window method

For the singles method the increase in the statistical (counting) uncertainty is:

$$\sigma\left(N_{\rm true} + N_{\rm scat}\right) = \sqrt{N_{\rm true} + N_{\rm scat} + N_{\rm random}}$$

To use this method requires that the singles rate is monitored continuously

Corrections; scatter coincidences

Energy resolution of BGO/LGO used in PET is inferior to that of NaI making the "dual window" approach used in SPECT is inappropriate for PET

Common approaches to the calculation of the scatter correction:

1. Use the "unscatter-corrected image" and transmission image as input to estimate the rate of scatters
   $\rightarrow$ the image is then re-derived from the scatter-corrected image
2. Use a CT image taken in parallel with the PET image to derive the scatter correction
   $\rightarrow$ the image is then re-derived from the scatter-corrected image
3. Use events reconstructed outside the object. Such events can only arise due to scatter
   $\rightarrow$ the image is then re-derived from the scatter-corrected image

Corrections; attenuation

Attenuation correction derived for two colinear photons derived for SPECT . . . applies here too, so:

$$\mathcal{P}_{\mathrm{coinc}} \propto \exp(-\mu D) \tag{1}$$

where $\mathcal{P}$ is the probability a coincidence will be formed, μ is the attenuation coefficient, and D is the total thickness of the subject

Equation 1 does not depend on the position of the source between the two PMTs

Attenuation correction can be obtained by taking a "blank" transmission scan with the rod source and a transmission scan with the patient in position. The correction factor for PMTs i and j, A_{ij} is given by:

$$A_{ij} = \frac{\mathrm{Blnk}_{ij}}{\mathrm{Trns}_{ij}}$$

where Blnk_{ij} is the result of the blank scan and Trns_{ij} is the result of the patient scan

Corrections; dead time

When the scanner is recording a valid coincidence event it is not able to record a second one

This leads to a period during which the scanner is “dead” and is referred to as “dead time”

Dead time is measured empirically using sources of varying activity to determine the fall-off in efficiency as a function of the activity of the source, the size of the object, and the detection threshold

The dead-time correction is then calculated using a computer model based on the measured dead time

Summary of section 4

Corrections are applied for:

- Normalisation;
- Random coincidences;
- Scatter coincidences;
- Attenuation;
- Dead time