Modified Dead Time Correction For Prompt Gamma Radiation Emitting PET Isotopes

Mark Lubberink, Harald Schneider, and Hans Lundqvist

***Abstract*-- Several long-lived positron emitters, such as ^{76}Br ($t_{1/2}$ = 16.2 h, 55% β^+) and ^{124}I ($t_{1/2}$ = 4.2 d, 23% β^+), emit photons simultaneously with positrons. Coincidence detection of these photons with each other or with annihilation photons leads to essentially true coincidences that can not be distinguished from coincidences involving two annihilation photons. These photons also lead to higher singles count rates and thus to a higher dead time. Furthermore, photons that are rejected by the energy discriminator, the number of which is considerably increased for prompt gamma emitting nuclides, are not counted as singles but do contribute to dead time and lead to inaccuracy of the standard dead time correction. The aim of the present study was to assess the effect of additional gamma radiation on dead time correction accuracy and to improve the existing dead time correction for prompt gamma emitting nuclides. Singles life time as a function of singles rate is lower for ^{76}Br than for ^{18}F, whereas coincidence life times are similar. Total dead time for ^{76}Br is considerably increased compared to ^{11}C for similar singles count rates. Multiplication of the measured ^{76}Br singles rate with a fixed factor of 1.3 leads to a similar dead time as a function of singles rate as for ^{11}C and in an accurate prediction of the total dead time by the standard dead time correction. Multiplication factors for different energy windows correlate well with the relative number of rejected photons.**

I. Introduction

There is an increasing interest in the use of long-lived positron emitters, such as ^{124}I or ^{76}Br, in PET because of new applications in for example radionuclide therapy dosimetry and the possibility of centralised production and transport over longer distances. ^{76}Br ($t_{1/2}$ = 16.2 h, 55 % β^+) emits a number of photons simultaneously with positrons in its decay. Coincidence detection of these photons with each other or with annihilation photons leads to essentially true coincidences that can not be distinguished from coincidences involving two annihilation photons. Since there is no angular correlation between the two photons in these prompt gamma coincidences, they lead to a sinogram background and a bias and reduced contrast in PET images, and several correction methods for this effect have been published [e.g. 1-3].

However, the emitted photons also lead to higher singles count rates and thus to a higher dead time. Furthermore, photons that are rejected by the energy discriminator because there energy is outside the scanner's energy window, the number of which is considerably increased for prompt gamma emitting nuclides, are not counted as singles but do contribute to dead time.

The aim of the present study was to assess the effect of additional gamma radiation on dead time correction accuracy and to improve the existing dead time correction for prompt gamma emitting nuclides.

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II. Materials and Methods

A. Tomograph

Measurements were made with an ECAT Exact HR+ scanner (CTI/Siemens, Knoxville, Tennessee) in 2D or 3D acquisition mode at Uppsala University PET Centre (now Uppsala Imanet) and the Department of Nuclear Medicine and PET Research of the VU University Medical Centre, using the standard settings for acquisition and reconstruction of the scanner. The dead time correction of the scanner is based on a quadratic fit to the singles count rate. Photons outside the energy window of the scanner are not registered as singles counts.

B. Phantom measurements

A 20 cm diameter, 20 long water-filled cylindrical phantom was filled with approximately 130 MBq of either ^{76}Br or ^{11}C or 90 MBq of ^{124}I. A series of emission scans was made during at least 10 half-lifes of each of the nuclides. Apart from the standard energy window of 350-650 keV, the ^{124}I scans were made in 2D and 3D modes using 150-850 keV, 425-650 keV and 460-562 keV energy windows. Scans were reconstructed using FBP without attenuation correction.

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C. Analysis

The mean number of counts in a 15 cm diameter, 15.5 cm long VOI in the centre of the phantom image was plotted versus the known phantom radioactivity concentration to assess the accuracy of the dead time correction, as described previously [1].

The count rate behaviour of a PET system can be described in terms of the measured singles and prompts rates [e.g. 4]:

$$T_m = \lambda_S^2 \cdot \lambda_C \cdot T_{ex} \qquad (1)$$

T_m denotes the measured gross trues count rate, $\lambda_S(S)$ is the singles life time as function of the singles count rate, $\lambda_C(P)$ is the coincidence life time as function of the prompts count rate, and T_{ex} is the 'ideal' trues count rate as extrapolated from the measured count rates at low radioactivity concentrations. Multiple coincidences are registered as separate coincidences in all involved lines of response and are neglected in this model. The data from the dynamic count rate measurement was used to determine $\lambda_S(S)$:

$$\lambda_S = \frac{S_m}{S_{ex}} \qquad (2)$$

Where S_{ex} is determined by linear extrapolation of the measured singles rates S_m at low radioactivity concentrations. The coincidence life time can then be calculated as follows:

$$\lambda_C = \frac{T_m}{\lambda_S^2 T_{ex}} \qquad (3)$$

To account for the contribution of rejected singles, the assumption was made that the contribution of rejected singles to detector dead time is proportional to the contribution of accepted singles. Equation 2 should then read:

$$\lambda_S' = \frac{S_m(1+\delta)}{S_{ex}'} \qquad (4)$$

where S'_{ex} is the extrapolated singles rate of $S_m(1+\delta)$. The additional factor $1+\delta$ accounts for rejected singles, with $\delta=0$ for ^{11}C and δ to be determined for ^{76}Br and ^{124}I. The dead time corrected trues count rate T_c is then calculated by:

$$T_c = \frac{T_m}{\lambda_S'^2 \lambda_C} \qquad (5)$$

D. Rejected photons

Using the ^{124}I measurements with different energy windows, the ratio of the registered singles in all energy windows to the singles in the most wide window, 150-850 keV, was calculated. These ratios were plotted against the factors $(1+\delta)$ calculated to adjust the ^{124}I singles rates to ^{11}C singles rates. A proportionality between the two would indicate that the rejected singles rate is indeed responsible for the increased dead time.

III. Results

Figure 2 shows the mean count rate in a 15 cm diameter VOI in the cylindrical phantom versus the radioactivity concentration in the phantom for ^{76}Br and ^{11}C. Clearly, the dead time correction of the HR+ scanner is not accurate for the prompt gamma emitting nuclide ^{76}Br. Similar results were found for ^{124}I, although others have reported accurate dead time correction for this isotope [5]. Singles, prompts and total life times as a function of the count rates are given in figure 3. Figure 3A shows the increased ^{76}Br dead time for a given singles rate compared to ^{11}C.

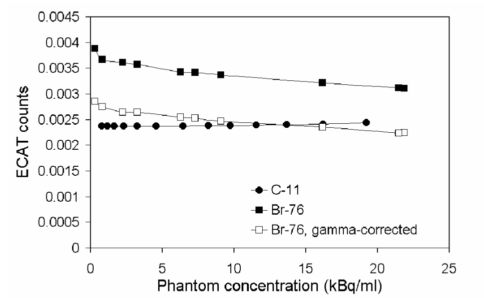
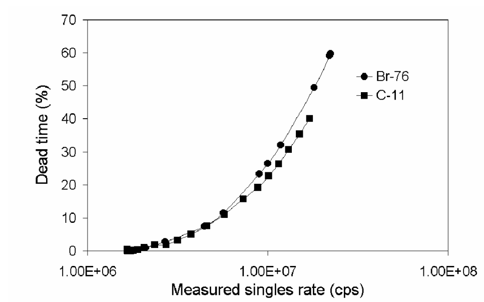
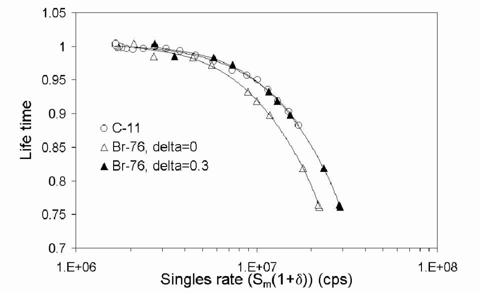


Figure 2 – HR+ 3D counts per second per voxel after decay, dead time and positron abundance correction. From [1].

(A)



(B)



(C)

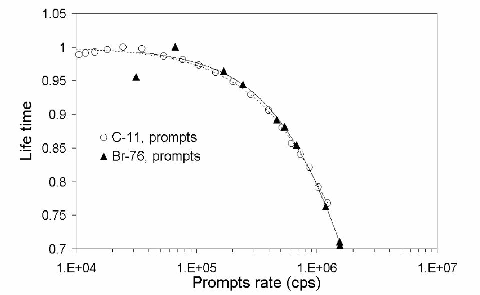


Figure 3 – Total dead time (A) and singles (B) and prompts (C) life times for ^{11}C and ^{76}Br, the singles life time with and without multiplication with a factor $1+\delta$ to account for rejected photons.

Multiplication of the measured ^{76}Br singles count rate with a factor 1+δ, with δ=0.3, as suggested in equation (4), results in a similar singles life time as a function of S(1+δ) as for ^{11}C and in an accurate prediction of the total dead time.

Figure 4 shows the total life time versus the singles rates of ^{124}I for various energy windows. Figure 4b shows that multiplication of the singles rates in each of the energy windows with the factors 1+δ as given in Table 1 leads to similar life times as for ^{11}C independent of the energy window. Table 1 further shows the ratios of the ^{124}I singles in the 350-650 keV, 425-650 keV and 460-562 keV energy windows relative to the singles rate in the 150-850 keV window. Figure 5 shows that there is a clear correlation between these ratios and the factors 1+δ needed to obtain an accurate dead time correction.

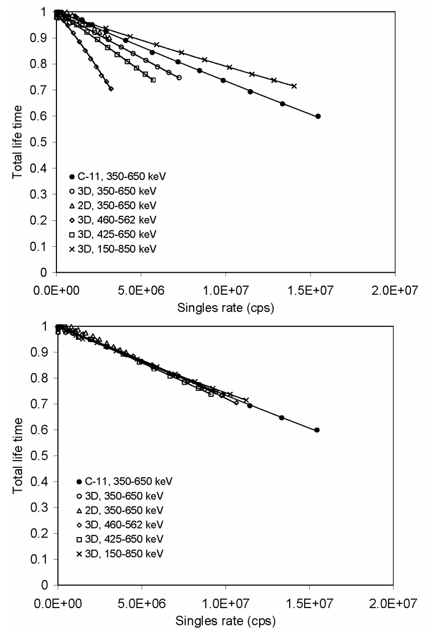


Figure 4 – Total life times versus singles rates of ^{124}I for a number of different energy windows without (top) and with (bottom) consideration of rejected singles by multiplication of the singles rate with a factor $1+\delta$.

Table 1 – Ratios of ^{124}I singles rates for different energy windows compared to 1+δ.

Energy window (keV)	2D $S_{150\text{-}850}/S$	3D $S_{150\text{-}850}/S$	1+δ
150-850	1	1	0.8
350-650	1.6	1.9	1.3
425-650	2.0	2.4	1.7
460-562	3.6	4.3	3.3

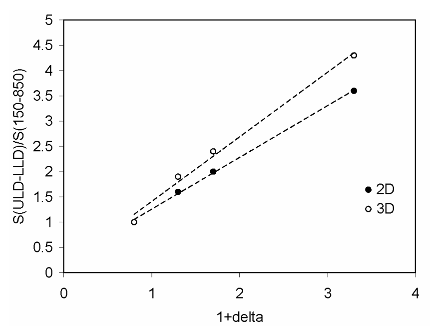


Figure 5 – Ratio of ^{124}I singles rate in each energy window to that in the 150-850 keV window, compared to singles correction factor $1+\delta$.

IV. DISCUSSION AND CONCLUSION

Photons with energy outside the energy window of the PET scanner are not accounted for in the ECAT dead time correction. This is not a problem for standard PET nuclides, but it poses a challenge for PET nuclides that emit many photons with energy outside this window. Therefore, a method was developed to correct the registered ^{76}Br or ^{124}I singles rate for rejected photons, and use the corrected rate as input for the standard ECAT dead time correction. In this first attempt using a global dead time correction, this led to an accurate ^{76}Br dead time correction.

Total ^{124}I dead time as a function of $S(1+\delta)$ is equal for different energy window settings, and the rate of rejected singles relative to a wide 150-850 keV window is proportional to this correction factor $(1+\delta)$. A similar result as in figure 4b can be seen if singles life times are plotted instead of total life times. The dead time at a certain singles rate is highest for the most narrow energy window, whereas the prompts rate at this singles rate is lowest for the most narrow energy window. The rejected singles must indeed be taken into account for accurate dead time correction.

Determination of dead time by extrapolation of counts at low activity is not entirely uncomplicated because of the contamination of other isotopes of iodine or bromine in the batches used for these measurements and the contribution of transmission sources, the effects of which on the presented results should be investigated. Further measurements will also be made to study if the multiplication factors determined here are independent of the radioactivity distribution. Instead of separate dead time corrections for each isotope, a single dead time correction with varying correction factors for different isotopes could then be implemented.

V. REFERENCES

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