Improvement of Accidental Coincidence Estimation for Scanditronix PC2048/4096 PET Scanners

Chi-Hsien Chen Chin-Lung Yu[1] Liang-Chih Wu[2] Ren-Shyan Liu[*,2]

Graduate Institute of Medical Informatics, Taipei Medical University, Taipei, Taiwan, 110 R.O.C.
[1]*Department of Molecular and Medical Pharmacology, School of Medicine UCLA, USA*
[2]*Department of Nuclear Medicine, Taipei Veterans General Hospital, Taipei, Taiwan,112 R.O.C.*

Received 4 Aug 2004; Accepted 10 Sep 2004

Abstract

Accidental coincidence (randoms) is one of the factors that degrade the accuracy of positron emission tomography (PET). In contrast to widely-held beliefs, we have previously shown that randoms can significantly affect quantitative PET even after current hardware/software randoms correction is applied. In order to have better estimation of randoms for our Scanditronix scanner, we investigated the limitation of the vendor-provided randoms estimation and proposed a simple modification. *Methods:* Multiple short-frame data of a homogeneous circular cylinder were collected over 12 hours. Summed data were generated by summing up selected frames. Randoms of the summed data estimated by the vendor-provided method and our modified method were compared. *Results:* The vendor-provided randoms estimation did not work as well as the modified method when frame duration is much larger than the half-life of the radioactive agent used. *Conclusion:* Our minimal modification of the vendor-provided method significantly improves randoms estimation.

***Keywords*:** Positron emission tomography, Scintillation counting, Algorithms

Introduction

In regard to system modeling for a PET scanner, it is common practice to assume that counting errors such as accidental coincidence (randoms) and deadtime loss are well compensated for by the built-in hardware/software correction schemes. However, after these counting error corrections were applied, the first author has shown that an activity-dependent point spread function was necessary to correct partial volume effect [1]. Randoms ratio is one of the adjusting factors that represent the activity dependency of the model [1]. Recently, we discovered that an activity-independent point spread function [2], while it accurately predicted activity concentrations of hot spheres in warm backgrounds, was unable to correctly predict those of cold spheres (data not shown). Because different scanner types and correction schemes were used in the aforementioned studies, the results suggest that activity dependency of system models could be universal and an activity-dependent system model is required in many situations such as studies that simultaneously involve both hot and cold small objects in warm backgrounds.

*Corresponding author: Ren-Shyan Liu
Tel: +886-2-28715849; Fax: +886-2-28715849
E-mail: rsliu@vghtpe.gov.tw

Methods

Theory

In Scanditronix PC2048/4096 scanners, randoms rate, R, is estimated by

$$R = \omega S_{ci} S_{cj} \ , \tag{1}$$

where ω is the coincidence time window, S_c stands for deadtime-corrected singles rate, i and j are for detectors i and j. The corrected singles rate is calculated by unified deadtime correction method [*3*], which is based on the measured singles rate and some pre-calculated/measured scanner parameters. However, only total singles are stored in the raw data file, average singles rate is therefore used in the estimation of deadtime and randoms. For relatively long scan duration, which is quite common in research, usage of the average singles rate is inappropriate. In order to apply or develop an activity-dependent point spread function for Scanditronix scanners, one needs more accurate estimation of randoms.

Following the argument of the unified deadtime correction [*3*], the total singles, S_{tot}, collected in a frame is

$$S_{tot} = \int_0^{F_d} S(t)dt \tag{2}$$

where $S(t) = S_c(t)e^{-S_c(t)t_d}$, $S_c(t) = S_0 e^{-\tau t}$, F_d is the scan duration, S is the measured singles rate, S_c is the the deadtime-corrected singles rate, t_d is the deadtime constant [3], τ is the decay constant, and S_0 is the initial true singles rate. The time singles rate curve, $S(t)$, could be obtained after S_0 is numerically solved. Theoretically, randoms could be more accurately estimated using the time singles rate than the average singles rate. For a centered circular cylinder with homogeneous activity, the theoretical ratio, RR, between total randoms estimated by the two methods could be derived from equations (1) and (2):

$$RR = TR_{S_{avg}} / TR_{S(t)}$$
$$= \frac{S_{tot_i}(t) S_{tot_j}(t) / F_d}{\int_0^{F_d} S_i(t) S_j(t) dt} \quad ,(3)$$
$$= \frac{4\left(1 - e^{-\tau F_d}\right)^2 S_0^2 t_d^2}{\tau F_d \left(2 S_0 t_d \left(e^{-\tau F_d - 2e^{-\tau F_d} S_0 t_d} - e^{-2 S_0 t_d} \right) + e^{-2e^{-\tau F_d} S_0 t_d} - e^{-2 S_0 t_d} \right)}$$

where TR is the estimated total randoms, S_{avg} is the average singles rate, and other symbols are defined as in equation (2). Since a significant p value in statistics is usually set at 0.05 and TR_{Savg} is always no more than $TR_{S(t)}$, RR could be arbitrarily chosen as 0.95 (1 – 0.05) to represent a non-significant difference. It could then be found from equation (3) that τF_d is approximately ln2 for a wide range of S_0.

Data collection and analysis

Using a water-filled circular cylinder (23.8 cm inner diameter), two experiments were performed to validate our modified randoms estimation method. The initial activity concentrations of the two experiments were 4.1 and 8.9 kBq/ml (F-18). Forty-eight frames with 15 min frame duration were collected for each experiment. Frames 1 to 24 in each experiment were summed together and the result, which has both summed singles and counts, was designated as a long high count summed frame. On the other hand, a long low count summed frame resulted from summation of frames 25 to 48. For short summed frames, 8 instead of 24 frames were used. Frames 1 to 8 and 25 to 32 were summed together to generate the short high and low count summed frames, respectively.

For each summed frame, a time singles rate curve, $S(t)$, was estimated by the method described above. The method was then validated by comparing the estimated $S(t)$ and the average singles rates in the fifteen minute frames. The underlying assumption was that the decay of F-18 could be ignored for the 15 min frames.

Results

The average ratio between the estimated and measured time singles rates is 1.005±0.033 (mean±standard deviation). Since the ratio is almost one, the estimation of randoms by our modified method in *all* cases is as accurate as that by the vendor-provided method in the cases of *short* frame duration. The ratios between randoms estimated by our modified method (time singles rate method) and the vendor-provided method (average singles rate method) are shown in Table 1. Note that the average singles rate method underestimates the randoms almost 40% when scan duration is approximately 3 times the half-life of the radioactive agent used.

Table 1. Ratios Between Randoms Estimated by the Modified and the Vender-Provided Methods in Different Scan Conditions

	Short Scan		***Long Scan***	
Singles Rate	***high***	***low***	***high***	***low***
Experiment 1	1.04	1.05	1.37	1.39
Experiment 2	1.04	1.05	1.34	1.39

*The frame durations for the short and long scans are 2 and 6 hours, respectively.

* For experiment 1, high and low initial singles rates are pproximately 740 and 80 cps, respectively; Those are 1820 and 200 cps for experiment 2.

Conclusion

In this simple study, we have shown that time singles rate curve could be accurately estimated from total singles with appropriate models and scanner parameters. The above results also show that the estimation of randoms by average singles rate is less than 5% different from that by the time singles rate method as long as the scan duration is not much longer than the half-life of the radioactive agent used in the scan. Therefore, the vendor-provided method is quite robust in many clinical situations. However, for short half-life agents or relatively long scan duration, the modified method significantly improves the accuracy of randoms estimation

Acknowledgment

We would like to thank K.L. Chou and B.H. Yang for their assistance in performing PET phantom studies, J.K. Wang for programming advices, and C.W. Chang, H.M. Lin, and C.H. Tsai for preparing radiopharmaceuticals. This work was partly supported by Taipei Veterans General Hospital Research Project 353C.

References

[1] Chen C.-H., Muzic R. F. Jr, Nelson A. D. & Adler L. P.: Simultaneous Recovery of Size and Radioactivity Concentration of Small Spheroids with PET Data. *J Nucl Med*., 40:118, 1999.

[2] Chen C.-H., Muzic R. F. Jr, Nelson A. D. & Adler L. P.: A Non-Linear Spatially-Variant Object-Dependent System Model for Prediction of Partial Volume Effects and Scatter in PET. *IEEE T Med Imaging*., 17 (1998), 214.

[3] Daube-Witherspoon M. E. & Carson R. E.: Unified Deadtime Correction Model for PET," *IEEE T Med Imaging*., 10:267, 1991.