The Effects of Scan Duration and Injection Dose on the Image Quality of a LSO-PET: A Phantom Study

Çekim Süresi ve Enjeksiyon Dozunun Bir LSO-PET'in Görüntü Kalitesi Üzerine Etkileri: Bir Fantom Çalışması

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ABSTRACT Objective: The aim of the study is to evaluate the effect of scan duration and injection dose on image quality of a LSO-PET using a whole body phantom. **Material and Methods:** A whole body phantom with four lung lesions in the shape of cylinders (6, 10, 16 and 24 mm diameters) was designed considering a human body of 100 kg. Seventy-two lung PET images were separately acquired with combinations of 3, 4, 5, 6, 7, 8 MBq/kg injection doses and 2, 3, 4, 5 min scan durations in activity ratio of A_{lesion}/A_{lung}= 4, 8, and 16 using a LSO-PET. **Results:** For the lesion with 6 mm diameter at A_{lesion}/A_{lung}=16:1; contrast is 1.2 at 3 MBq/kg and 2 min, contrast is rapidly increased to 3.2 at 3 MBq/kg and 5 min. On the other hand, while the contrast value is 3.2 at 3 MBq/kg injection doses and 5 bed/min scan duration, the contrast value is 3.4 at 8 MBq/kg and 3 min. According to these results, nearly the same image contrast values were seen at the scan conditions of 8 MBq/kg and 3 min and at the scan conditions of 3 MBq/kg and 5 min. **Conclusion:** Because the effect of scan duration on the image quality is more dominant than the effect of injection dose (not to mention the radiation safety of the patients and staff), this study suggests that the longer scan duration against lower injection dose must be applied to maintain good image quality for overweight patients.

Key Words: Positron-emission tomography, image enhancement, fluorodeoxyglucose F18

ÖZET Amaç: Bu çalışmada bir LSO-PET'in görüntü kalitesi üzerinde enjeksiyon dozu ve çekim süresinin etkisinin bir tüm vücut fantom ile incelenmesi amaçlandı. **Gereç ve Yöntemler:** Fantom, 100 kg ağırlıklı bir hastayı taklit edecek şekilde ve 6, 10, 16 ve 24 mm çaplı 4 adet silindirik akciğer lezyonu içermektedir. Fantom çekimlerinde 3, 4, 5, 6, 7, 8 MBq/kg enjeksiyon dozları, 2, 3, 4, 5 dakika/yatak çekim süreleri ve $A_{lezyon}/A_{akciğer}$= 4, 8, 16 aktivite konsantrasyon oranlarında 72 adet akciğer PET görüntüsü elde edildi. **Bulgular:** 6 mm çaplı lezyon için $A_{lezyon}/A_{akciğer}$= 16:1 oranında; 3 MBq/kg ve 2 dakikada kontrast 1.2 iken, 3 MBq/kg ve 5 dakika çekim süresinde kontrast hızla 3.2 ye çıkmaktadır. Öte yandan, 3 MBq/kg enjeksiyon dozu ve 5 dakika çekim süresinde kontrast 3.2 iken, 8 MBq/kg ve 3 dakikada kontrast 3.4 dür. Bu sonuçlara göre, 8 MBq/kg ve 3 dakika çekim şartları ile 3 MBq/kg ve 5 dakika çekim şartlarının yaklaşık aynı imaj kontrast değeri verdiği görülmüştür. **Sonuç:** Görüntü kalitesi üzerinde çekim süresinin enjeksiyon dozundan daha etkili olması (ayrıca, hasta ve personelin radyasyon güvenliği açısından), ağır kilolu hastaların PET görüntü kalitelerini arttırılması için düşük enjeksiyon dozlarına karşın daha uzun çekim sürelerinin tercih edilmesi önerilmektedir.

Anahtar Kelimeler: Pozitron emisyon tomografi, imaj güçlendirme, fluorodeoksiglukoz F18

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Positron Emission Tomography (PET) is a radioisotope imaging method to study organs and metabolism within human body. In the last decade, PET image quality is increased by new detector technologies such as lutetium oxyorthosilicate (LSO) that significantly reduces imaging-time. LSO has a higher light output and a shorter scintillation decay time than conventional bismuth germanate (BGO) detectors, resulting in markedly improved counting-rate capabilities. These features permit whole-body PET images to be acquired in the 3-dimensional (3D) mode, thereby greatly enhancing sensitivity of the PET scanner.[1] However, because of the higher photon attenuation and scattering resulting in increased image noise, PET image quality for overweight patients is limited in comparison to patients with normal weight regardless of PET detector type.[2] Because of these limitations, producing a PET image with high quality is not easy, especially to detect small tumours in overweight patients. Therefore, proper selection of scan protocol parameters for a certain PET studies (e.g., amount of injected activity, duration of scan) are important to avoid artefacts those might directly affect the image quality.

Although there are some clinical studies reporting the effects of injection doses and scan duration on the image quality, these studies have some limitations with respect to retrospective nature of the studies.[3-5] However, in a phantom, it is possible to make a systematic study investigating the lesion detection performance of a PET depending on injection doses, scan durations and lesion dimension.[6-9] In the present study, we experimentally evaluated the lesion detection performance of a LSO-PET depending on injection doses and scan durations using a whole body phantom.

MATERIAL AND METHODS

SIEMENS HIRES PET/CT

The LSO-based whole-body PET/CT B-HIRES scanner combines a 6-slice helical CT scanner (Somatom Sensation, Siemens Medical Solution) with a high-resolution PET scanner (HI-RES) coupled to new, high improved detection electronics. The PET component of tomography has no septa, thus allowing 3-dimensional (3D)-only acquisitions. The detector ring is made of 144 detection units (block) containing 169 single crystals (4 X 4 X 20 mm^3 each) arranged in a 13 X 13 array and coupled to 4 photomultiplier tubes. In this configuration 24.336 crystals cover to 162-mm axial FOV with 39 rings generating 81 image planes with 2 mm thick for each acquired bed position. The low and high-energy thresholds are set to 425 and 650 keV, respectively. The coincidence time window is set to 4.5 ns.

THE WHOLE BODY PHANTOM

To create a real scatter condition of an overweight patient in the PET ring, a whole body phantom is designed considering a standard adult human body of average weight of 100 kg. The phantom is about the same size as the chest of a relatively large patient (~42 cm wide, ~28 cm deep). The phantom has three separate parts as: i) the head-shoulder, ii) thorax-abdomen iii) pelvis-lower extremities. The head is also divided into a different brain part (brain weight 1.5 L). The thorax-abdomen part of the phantom has two lungs with 1.5 L volume and a separate component below the lungs enables simulation of the liver (2.5 L) uptake. Styrofoam mixed with water is used for the lung to mimic tissue attenuation. The ratio of styrofoam to water is 1:3. Thus, a density of 0.35 gr/cm^3 for lungs was obtained. Four lung lesions in the shape of cylinders were manufactured. Each of them was 2 cm long and has diameters 6, 10, 16 and 24 mm, respectively. An axial CT slice from thorax part shows lesions in the lungs given in the text (Figure 1).

ACTIVITY CONCENTRATION USED IN THE PHANTOM

This study was performed for 3, 4, 5, 6, 7, 8 MBq/kg injection doses. In our clinic, patient imaging is started at about 50 min after the injection of ^{18}F-FDG. Therefore, the activity concentrations of the

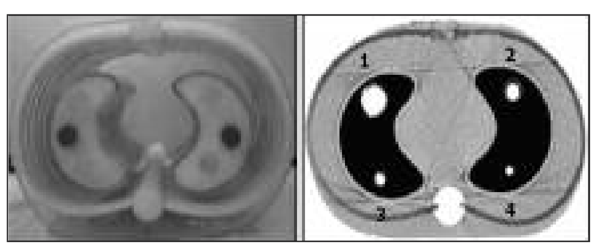

FIGURE 1: The axial lung CT image of phantom and the position of the lesion in the lungs. Lesions 1, 2, 3, 4 have 24 mm, 16 mm, 10 mm, and 6 mm diameters respectively.

organs and lesions simulated in the phantom were separately calculated and phantom imaging was performed using the situation of a patient at 50 min after the injection. For example; to simulate the ^{18}F-FDG distribution in the normal human body at 50 min after a total injection dose of 21.6 mCi ^{18}F-FDG (8 MBq/kg and total 800 MBq injection dose for a patient weighted 100 kg), the hollow organs of phantom were filled with ^{18}F-FDG mixed with water as follows; brain, 31.6 kBq/ml (activity ratio of brain to adipose background= 7:1); liver, 9.04 kBq/ml (activity ratio of liver to adipose background= 2:1); heart, 22.65 kBq/ml (activity ratio of heart to adipose background= 5:1); lungs, 2.26 kBq/ml (activity ratio of lung to adipose background= 1:2), bladder, 54.24 kBq/ml (activity ratio of bladder to adipose background= 11:1); adipose tissue, 4.52 kBq/ml. Besides, the lung-lesions were filled with different activity-concentration ratios as 2, 4 and 8 times more than that of adipose tissue background (4, 8 and 16 times more than lung tissue background). Activity-concentrations of lesions are 18.1, 36.1 and 72.3 kBq/ml.

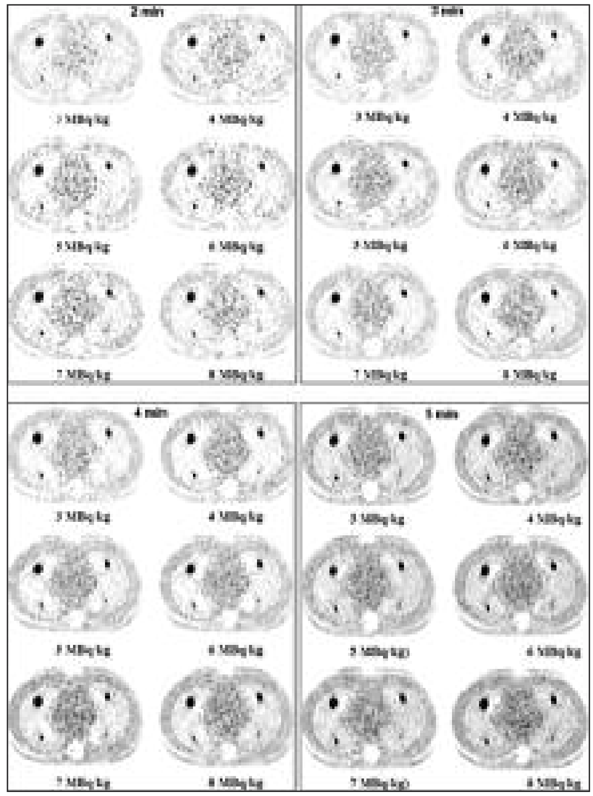

FIGURE 2: The lung PET images of phantom for different injection doses and different scan durations at A_{lesion}/A_{lung}= 16:1 activity ratio.

IMAGE ACQUISITION AND EVALUATION

Seventy-two transaxial lung PET images were acquired with combinations of 3, 4, 5, 6, 7, 8 MBq/kg injection doses and 2, 3, 4, 5 min/bed scan durations in the lesion to lung background activity ratio (LLA) of 4:1, 8:1, and 16:1 using whole body phantom. A set of these images are given in Figure 2 as examples (Figure 2).

The effects of scan duration and injection dose on the lesion image quality of LSO-PET were evaluated by two different methods, i) visual and ii) quantitative. Firstly, the lung PET images of phantom were evaluated visually regarding the image quality by seven nuclear medicine experts using a scoring system as follows: i) poor quality ii) good quality and iii) very good quality. To create a PET image at good quality, the threshold values of injection dose in MBq/kg versus scan duration in minutes are given in the table (Table 1).

Secondly, apart from visual evaluation of the images, the effects of scan duration and injection dose on the lesion image quality of LSO-PET were quantitatively evaluated by lesions contrast values. The image contrasts of lesions were calculated with the help of the below formula.

$$C= (A-B)/B$$

Where; C is lesion contrast,

A, amount of the counts obtained from a ROI, which is equal to the lesion size

B, amount of the counts obtained from a ROI on the lung tissue, which is equal to the lesion size.

Counts for each hotspot were calculated individually on images by drawing identical circular region of interests (ROIs). And then, the calculated contrasts were tabulated depending on the injected activity and scan duration (Table 2).

RESULTS AND DISCUSSION

PET is now an effective and useful imaging modality for diagnosis and follow up of cancer patients. But, imaging of overweight patients with PET is ge-

TABLE 1: To create a good quality PET image, the threshold values of injection doses as MBq/kg versus scan duration as minutes. The lesions are accepted as good or very good quality from the injection dose in the table. (-) is negative scan condition and in negative scan condition, lesions are not visible in all injection doses for all scan duration and therefore they are accepted as poor quality.

		Lesion			
Activity Ratio (A_{lesion}/A_{lung})	**Scan Duration (bed/min)**	**6 mm**	**10 mm**	**16 mm**	**24 mm**
4:1	2	-	-	6 MBq/kg ≤	3 MBq/kg ≤
	3	-	-	4 MBq/kg ≤	3 MBq/kg ≤
	4	-	-	3 MBq/kg ≤	3 MBq/kg ≤
	5	-	-	3 MBq/kg ≤	3 MBq/kg ≤
8:1	2	-	6 MBq/kg ≤	3 MBq/kg ≤	3 MBq/kg ≤
	3	-	4 MBq/kg ≤	3 MBq/kg ≤	3 MBq/kg ≤
	4	-	3 MBq/kg ≤	3 MBq/kg ≤	3 MBq/kg ≤
	5	-	3 MBq/kg ≤	3 MBq/kg ≤	3 MBq/kg ≤
16:1	2	-	3 MBq/kg ≤	3 MBq/kg ≤	3 MBq/kg ≤
	3	-	3 MBq/kg ≤	3 MBq/kg ≤	3 MBq/kg ≤
	4	3 MBq/kg ≤	3 MBq/kg ≤	3 MBq/kg ≤	3 MBq/kg ≤
	5	3 MBq/kg ≤	3 MBq/kg ≤	3 MBq/kg ≤	3 MBq/kg ≤

TABLE 2: Measured contrast values of different lesion sizes depending on injection activity and scan duration. The contrasts are calculated using the formula of C= (A-B)/B Where; C is lesion contrast, A is the amount of the counts obtained from a ROI, which is equal to the lesion size and B is the amount of the counts obtained from a ROI on the lung tissue, which is equal to the lesion size.

	6 mm lesion				10 mm lesion				16 mm lesion				24 mm lesion			
	Scan Duration (bed/min)															
Injection dose (MBq/kg)	2	3	4	5	2	3	4	5	2	3	4	5	2	3	4	5
	Activity Ratio (A_{lesion}/A_{lung})= 16:1 and Expected Contrast= 15															
3	1.2	2.4	2.5	3.2	5.2	5.2	5.3	5.5	10.8	11.1	11.3	11.4	14.9	15.1	15.4	15.3
4	1.6	2.9	2.9	3.2	5.6	5.5	5.8	5.8	11.6	11.7	11.7	11.5	15.3	15.3	15.4	15.4
5	2.0	3.0	3.2	3.4	5.7	5.6	5.4	5.9	11.8	11.7	11.7	11.6	15.4	15.5	15.5	15.4
6	2.1	3.2	3.4	3.5	5.9	6.0	5.7	5.8	11.5	11.9	12.0	12.1	15.4	15.5	15.5	15.4
7	2.7	3.3	3.5	3.6	6.3	6.2	5.8	5.9	11.6	11.7	12.0	12.0	15.6	15.6	15.6	15.8
8	2.8	3.4	3.8	3.6	6.2	6.3	6.3	6.8	11.6	11.8	12.0	12.0	15.7	15.7	15.8	15.8

nerally a problematic issue because of higher photon attenuation and scattering than the average patients.[10] Besides, detectability capacity of small tumours by PET is decreased by resolution effects. This phenomenon, known as the partial volume effect (PVE), reduces the apparent target to background ratio in the reconstructed images and thus, small lesions may go undetected.[11] On the other hand, organ movements such as lung motion, cardiac motion and abdominal organ motion can significantly affect the image quality.[12] Because of above unfavorable influences on the image quality, scan protocol parameters used in the clinics (e.g., amount of injected activity, duration of scan) should be optimized to create a good image quality.

In the present study, the effects of scan duration and injection dose on the lesion image quality of LSO-PET were evaluated using a whole body phantom. In the images in Figure 2, impact of administered activity and scan duration on the PET images were clearly seen. In general, there were good agreements among the visual evaluations of experts except five images. Two (accepted as poor quality) of these five images were obtained at 7 MBq/kg and 8 MBq/kg injection doses for LLA= 16:1 (LLA; Lesion to Lung Activity) at 2 min scan duration for 6 mm lesion. Other three lesions accepted as good or very good image quality were created at 3 MBq/kg injection doses for LLA= 8:1 at 3 min scan duration for 10 mm lesion (one of three lesions) and at 4 MBq/kg injection doses (two of three lesions) for LLA= 8:1 at 3 min and 4 min scan duration for 10 mm lesion. Evaluation of these five images were accepted on decisions of four experts and the others were accepted with full consensus of seven experts. To create a good quality PET image, the threshold values of the injection doses determined by seven experts as MBq/kg versus scan duration were given in Table 1. From Table 1, it can be seen that the smallest lesion (6 mm diameter) is not detected for LLA= (4:1) and for (8:1) by the LSO-PET, even with the 8 MBq/Kg injection doses. Furthermore, 10 mm lesion is not detected at LLA= (4:1) at 8 MBq/kg for all scan duration. On the other hand, 16 and 24 mm lesions are evaluated as good or very good quality at almost all scan durations and all injection doses.

Although there is no any phantom study investigating the effects of these scan parameters on the image quality using a LSO-PET scanner in the literature, some clinical studies investigating these effects on the patient images have been made using a LSO-PET scanner. One of them is the study of Everaert et al.[3] They visually studied on the clinical PET images created in standard 3 min/bed scan duration to determine the impact of the injection dose on the PET image quality. Activities ranging from 185 to 843 MBq (average 585 MBq) in their study were administered to a group of patients (average 69.7 ± 14.5 kg). They concluded that administration of activities of ^{18}F-FDG ≥8 MBq/kg resulted in PET images of high quality in the significant part of patients. At lower activities a rapid decline in image quality and increasing noise are observed. Therefore, they recommended that alternative protocols with longer scan duration should be adopted in order to compensate for the loss in image quality when activities < 8 MBq/kg are used.[3]

In another study, Halpern et al.[4] investigated the impact of the scan duration (1 min. to 7 min.) on lesion visibilities (range, 0.8 cm-7.9 cm) using a standard 7.77 MBq/kg injection doses for overweight patients (average 113 ± 23 kg) in LSO-PET, while they did not change the scan duration (3 min) for the patients under the 91 kg, they modified the scan protocol for the patient weight ≥91 kg and they increased the scan duration. The replaced their prior scan duration of 4 min/bed to scan duration of 5 min/position for all patients weighing≥ 91 kg.

These clinical studies were performed as retrospective and by changing only one scan parameter (scan duration or injection dose). On the other hand, in the study of Masuda et al.,[13] one of the latest clinical studies performed on this issue, the effect of scan duration and injection dose on the image quality were simultaneously evaluated. According to their results, the effect of scan duration on the image quality is more dominant than the injected activity and they suggest that the only way to maintain image quality for overweight patients is to scan longer. Doses as much as 2.5-fold higher than 3.7 MBq per kilogram of body weight did not improve image quality even in a LSO PET/CT scanner with high-performance detector electronics. Their results suggest that longer scan duration is more suitable than higher injection dose.

Results of visually and numerically evaluation of our phantom images are similar with the results of Masuda et al.[13] According to our results, at the scan conditions of 8 MBq/kg and 3 min and at the scan conditions of 3 MBq/kg and 5 min, nearly same image contrast values were seen.

In conclusion of this phantom study, it is determined that a special care should be given for the detection of small lung tumours in case of overweight patients because the small lesions (<10 mm) are not clearly detected by a LSO-PET, especially at the low lesion activity ratio compared to background activity. On the other hand, because the effect of scan duration on the image quality is more dominant than the effect of injected activity, this study suggests that the longer scan duration must be applied to maintain good image quality for overweight patients. Besides, longer scan duration with small injection activity should be preferred for the radiation safety of patients and staff.

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