

Improving ^{99m}Tc -tetrofosmin Myocardial Perfusion Images by Time Subtraction Technique

Yasuyuki Takahashi, Hayato Ishimura, Masao Miyagawa, Teruhito Mochizuki

Abstract—Quantitative measurement of myocardium perfusion is possible with single photon emission computed tomography (SPECT) using a semiconductor detector. However, accumulation of ^{99m}Tc -tetrofosmin in the liver may make it difficult to assess that accurately in the inferior myocardium. Our idea is to reduce the high accumulation in the liver by using dynamic SPECT imaging and a technique called time subtraction. We evaluated the performance of a new SPECT system with a cadmium-zinc-telluride solid-state semiconductor detector (Discovery NM 530c; GE Healthcare). Our system acquired list-mode raw data over 10 minutes for a typical patient. From the data, ten SPECT images were reconstructed, one for every minute of acquired data. Reconstruction with the semiconductor detector was based on an implementation of a 3-D iterative Bayesian reconstruction algorithm. We studied 20 patients with coronary artery disease (mean age 75.4 ± 12.1 years; range 42-86; 16 males and 4 females). In each subject, 259 MBq of ^{99m}Tc -tetrofosmin was injected intravenously. We performed both a phantom and a clinical study using dynamic SPECT. An approximation to a liver-only image is obtained by reconstructing an image from the early projections during which time the liver accumulation dominates (0.5~2.5 minutes SPECT image-5~10 minutes SPECT image). The extracted liver-only image is then subtracted from a later SPECT image that shows both the liver and the myocardial uptake (5~10 minutes SPECT image-liver-only image). The time subtraction of liver was possible in both a phantom and the clinical study. The visualization of the inferior myocardium was improved. In past reports, higher accumulation in the myocardium due to the overlap of the liver is un-diagnosable. Using our time subtraction method, the image quality of the ^{99m}Tc -tetrofosmin myocardial SPECT image is considerably improved.

Keywords— ^{99m}Tc -tetrofosmin, dynamic SPECT, time subtraction, semiconductor detector.

I. INTRODUCTION

QUANTITATIVE measurement of the myocardium perfusion is possible with the semiconductor detector. However, accumulation of ^{99m}Tc -tetrofosmin in the liver is high during myocardial SPECT. About inferior myocardium, if liver is near, the accumulation decreases, on the other hand, a diagnosis is difficult when liver is overlap [1], [2]. Dynamic SPECT is tried as acquisition method for quantitative measurement of the myocardial perfusion using a semiconductor detector recently. This detector [3], [4] is L-shaped and does not rotate during the scan. Therefore, the

accumulation process over time can be observed by dynamic SPECT. The uptake of the tracer in the liver is observed to be earlier than the stable accumulation in the myocardium. A shape of the liver extracts using this process. An early liver-only image was subtracted from the SPECT image reconstructed from the data acquired 5~10 minutes after the injection. We then checked the result for its ability to evaluate all portions of the myocardium correctly.

II. MATERIALS AND METHODS

A. SPECT System and Acquisition Parameters

We evaluated the performance of the new SPECT with a cadmium-zinc-telluride (CdZnTe) solid-state semiconductor detector (Discovery NM 530c; DNM530c GE Healthcare, Milwaukee, WI, USA). The DNM530c, equipped with 19 pinhole collimators. The matrix size was 70×70 , and the image reconstruction voxel size was $4.0 \times 4.0 \times 4.0$ mm. The data processor was the Xeleris (GE Healthcare, Milwaukee, WI, USA). In this study, image reconstruction was based on an implementation of a 3-D iterative Bayesian reconstruction algorithm [5]. For all reconstructions, a Butterworth filter (order 7, cut-off frequency = 0.37 cycles/cm) [6] was used as a post-filter.

Our system acquired list-mode raw data over 10 minutes for a typical patient. From the data, ten SPECT images were reconstructed, one for every minute of acquired data. The sequence of reconstructed images reveals the accumulation process for the tracer. As shown in Fig. 1, the myocardial perfusion uptake is stable three minutes after the injection of the tracer (plus or minus a few seconds). And this uptake includes considerable heart pool activity during the first two minutes. The liver perfusion image is accumulated starting one minute later, and the count is higher than heart with an early stage (a). The myocardium has decreased accumulation, and it is stable, but the high liver accumulation continues (b).

An approximation to a liver-only image is obtained using the characteristics discussed above. That is;

$$\begin{aligned} \text{Liver-only image} &= 0.5\sim 2.5 \text{ minutes} \\ \text{SPECT image (a)} &= 5\sim 10 \text{ minutes SPECT image (b)} \end{aligned} \quad (1)$$

Then, a corrected myocardial perfusion image is obtained by Subtraction:

$$\text{corrected myocardial image} = 5\sim 10 \text{ minutes SPECT image liver-only image} \quad (2)$$

Y. Takahashi is with the Nuclear Medicine Technology Department, Gunma Prefectural College of Health Sciences, Maebashi 3710052 Japan (phone: +81-27-235-1211; e-mail: takahashi-yasuyuki2@gchs.ac.jp).

H. Ishimura is with the Radiological Technology Department, Ehime University Hospital, Toon 7910295 Japan (phone: +81-89-964-5111).

M. Miyagawa and T. Mochizuki are with the Radiology Department, Ehime University Graduate School of Medicine, Toon 7910295 Japan (phone: +81-89-964-5111).

B. Phantom and Human Studies

We inspected the subtractive effect by the next expression using a phantom study. Then a clinical study was carried out after the phantom study.

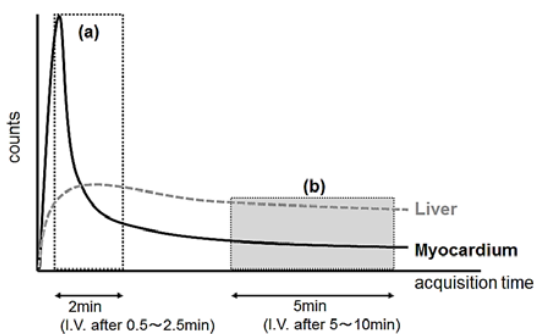


Fig. 1 Time-activity curve of cardiac and liver by Dynamic SPECT

Myocardial phantom only image □ Subtracted myocardial phantom image = (Myocardial phantom image + liver phantom image) – liver phantom image (3)

In the phantom study, only myocardial accumulation image compared with the myocardial image which subtracted only liver accumulation from accumulation of liver accumulation + myocardial accumulation. The myocardial phantom study was carried out using an anthropomorphic phantom (HL-D PH-25; Kyoto-Kagaku, Kyoto, Japan). Radioactive medium at a

concentration of 88.5 kBq/ml was injected into the part representing the myocardium. This phantom was set under two conditions; (1) without activity in the liver or gall bladder; (2) radioactivity was established in the myocardium, liver, and gallbladder in a ratio of 1:1:2. Resultant images were compared using the contrast ratio of whole image and Bull's eye map.

On the other hand, in the clinical study, influence of the high accumulation of the liver decreases depending on a case 90 minutes after injection. In this case, we compared it with 90 minutes later as standard image without the influence of the liver.

III. RESULTS

A. Phantom Study

Fig. 2 is the projection data and Fig. 3 is the reconstructed image. Fig. 2 (a) is myocardium phantom + liver phantom (original image), (b) is liver only phantom, (c) is subtracted image □ (a) – (b), (d) is myocardium only phantom. The subtracted image resembled only myocardium image.

B. Human Study

We studied 20 patients with coronary artery disease (mean age 75.4 ± 12.1 years; range 51-86; 16 males and 4 females).

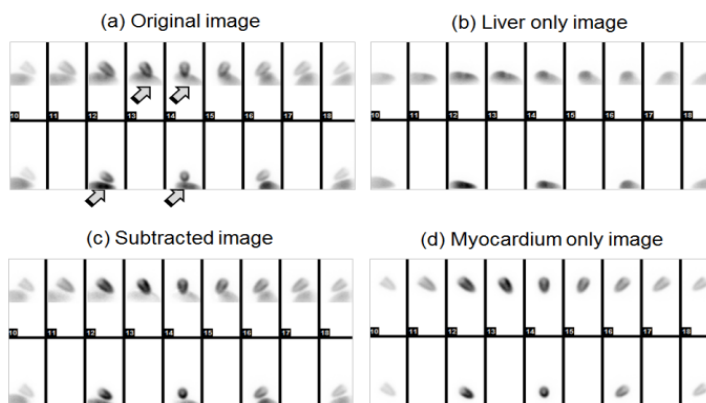


Fig. 2 Projection data of the phantom study: (a) myocardium + liver uptake [original image], (b) liver uptake only, (c) myocardium uptake after subtracted liver uptake and (d) myocardium uptake only

In each subject, 259 MBq of ^{99m}Tc-tetrofosmin was injected intravenously. Here, we show the case that SPECT image improved most. Fig. 4 is projection data and Fig. 5 is a reconstruction image. Fig. 4 (a) is before subtraction (original image), (b) is after subtraction, (c) is injected 90 minutes later image, and (d) is extracted liver image. Subtracted image was the influence of the liver decreased. The influence of the liver reduced the subtracted image.

This system has four characteristics in comparison with conventional Anger system. First, the sensitivity improves more than four times, so make possible to reduce SPECT scan time. Second, spatial resolution improves more than two times, and diagnostic accuracy is improved. Third, energy resolution is improved, so ^{99m}Tc and ¹²³I dual isotope simultaneous scan becomes possible. Fourth, the Lister function improves time resolution; it is important function to calculate myocardium perfusion quantitation.

IV. DISCUSSION

The semiconductor SPECT scanner attracted attention in nuclear cardiology most. The detector does not rotate during

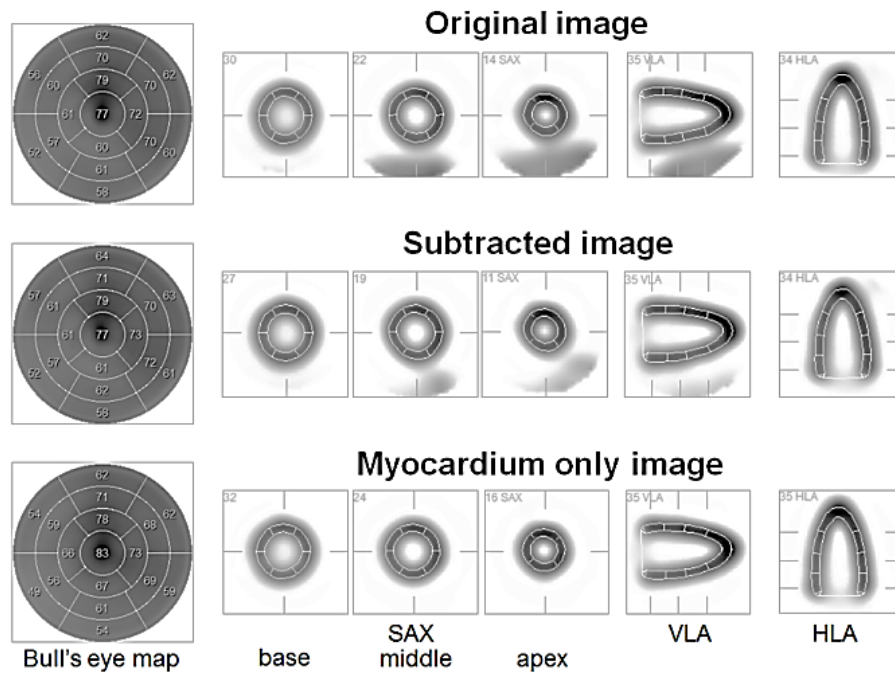


Fig. 3 Reconstructed image of the phantom study: (upper) before subtracted myocardium image [original image], (middle) after subtracted myocardium image and (lower) myocardium only image

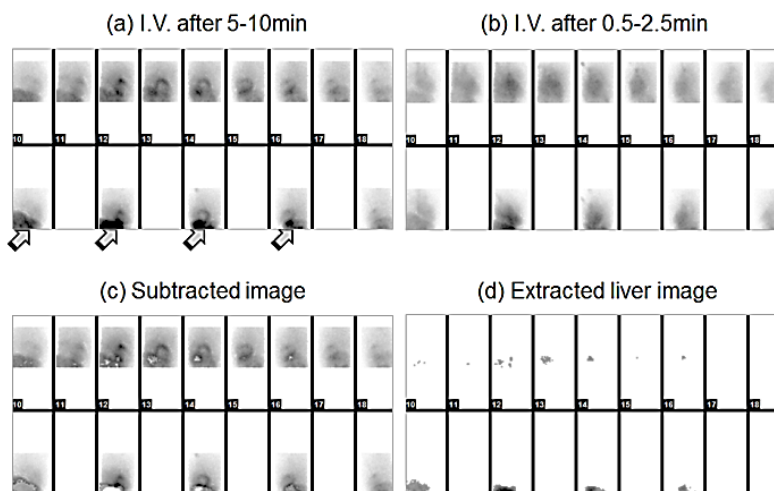


Fig. 4 Projection data of the human study: (a) I.V. after 5-10min [original image], (b) I.V. after 0.5-2.5min [pool image], (c) myocardium uptake after subtracted liver uptake and (d) extraction liver image

Before the appearance of the DNM530c we used in this study, a different type of semiconductor (CZT) detector SPECT scanner was released as D-SPECT [5]. D-SPECT was superior to a conventional SPECT scanner with a NaI(Tl) scintillation crystal in terms of sensitivity and energy resolution. Although both SPECT scanners were equipped with a semiconductor detector, there are several differences: the solid state detector of D-SPECT rotates but DNM530c does not rotate; D-SPECT consists of 9 arrays of CZT detectors, and D530c consists of 19 pinhole collimators. As well as the high sensitivity and better energy resolution, high spatial resolution can be expected from the use of pinhole collimators and a 3-D iterative Bayesian

reconstruction algorithm [7]. Therefore, we investigated the performance of the newly released semiconductor DNM530c SPECT scanner, mainly with phantom studies, in comparison with a conventional Angar type (Infinia) dual-head SPECT scanner. In the clinical study, EF values obtained by Quantitative Gated SPECT (QGS) [8] stabilized in 5 minutes in the D530c study. Although the image quality of the QGS at 5 min was not evaluated in detail, it is good enough at 1 minute as compared with the Infinia. And we felt that accuracy of the EF at 5 minutes, or even at 3 minutes, was good enough for the assessment of myocardial perfusion.

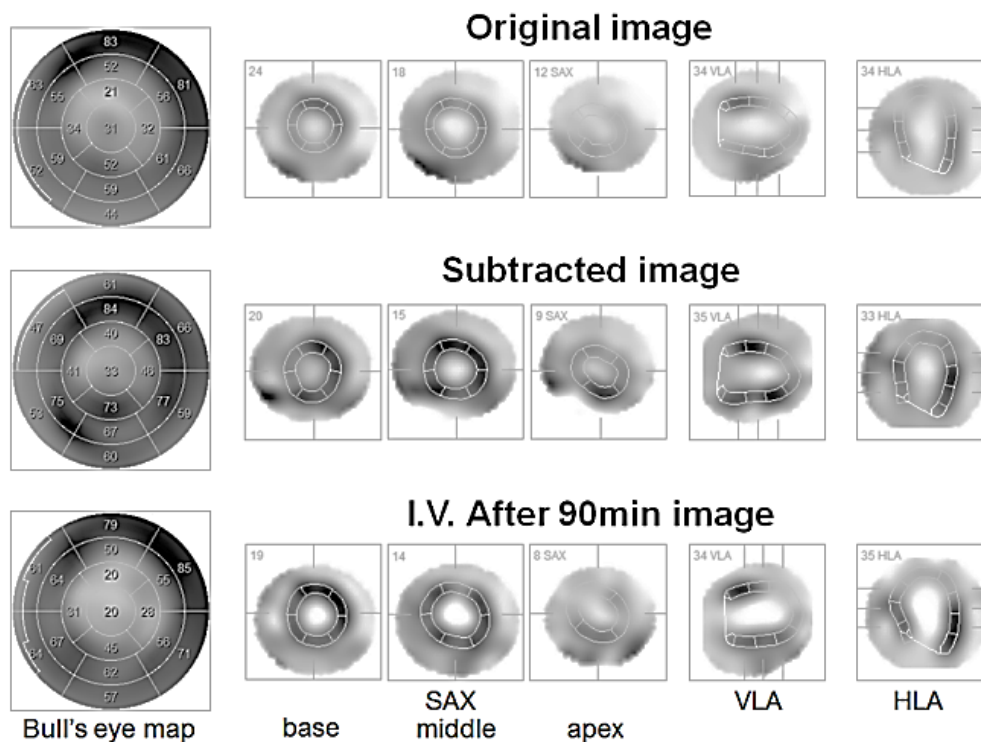


Fig. 5 Reconstructed image of the human study: (upper) before subtracted myocardium image [original image], (middle) after subtracted myocardium image, and (lower) injection after 90 minutes' image

In a conventional SPECT scanner, dual radionuclide simultaneous acquisition of ^{99m}Tc and ^{123}I was the technique of separating an energy window as much as possible. And, energy window width must set the high-energy-window and low-energy-window symmetrical on photopeak, and when energy window width is 15% or 20%, energy window

width overlaps. Therefore, acquisition energy peak which ^{99m}Tc moves to low energy side, and ^{123}I move to high energy side, respectively. However, an acquisition count decreases remarkably, and quality of image declined. And, energy resolution was bad, perfect separation was difficult. As for the energy window width of DNM530c system, it can change symmetrically and freely. It is not necessary to shift a photopeak and an energy window can be separated. Therefore, it is possible to acquire as many photons as possible in an efficient manner. And, since sensitivity is better with a semiconductor detector than with an Anger camera, one can acquire sufficient counts even if an energy window is narrow. We calculated in consideration of energy resolution and the rate of crosstalk according to the phantom study about suitable window width. ^{99m}Tc energy window were photopeak 140.5keV, high-energy-window width 3%, low-energy-window width 7%, and ^{123}I energy window were photopeak 159.0keV, high-energy-window width 6% and low-energy-window width 4%. The change of energy window width [9] does not largely influence in the single nuclide image.

Many problems were solved in a semiconductor SPECT scanner in this way. With ^{99m}Tc -radionuclide, the influence of high accumulation in the liver must be reduced. Historically, at

first, myocardium of projection data was standardized by the maximum count when displaying images [10]. However, this method did not improve reconstructed image quality. If the frequency of projection was higher for the liver than for the myocardium when restructuring images using projection data, the counts for the liver and myocardium were regarded to be similar [11]. There was some improvement, because liver is not deleted, higher accumulation by the overlap of the myocardium is undiagnosable, or a defect image when liver is near.

We devised a method to extract an approximation to a liver-only image, and using that image in a subtraction process considerably improved a final myocardium image. Scatter correction, attenuation correction, and spatial resolution correction are required for myocardium SPECT in order to improve the quantitatively. These correction methods can incorporate in an iterative algorithm. In addition, it has recently been argued that a correction for the partial volume effect is also necessary. We want to confirm our initial encouraging results and add quantitatively with future studies.

V. CONCLUSIONS

With this subtraction method, the image quality of the ^{99m}Tc -tetrofosmin myocardium SPECT image was considerably improved.

REFERENCES

- [1] G. Germano, T. Chua, H. Kiat, J. S. Areeda, D. S. Berman, "A quantitative phantom analysis of artifacts due to hepatic activity in

- technetium-99m myocardial SPECT studies," *J Nucl Med*, vol. 35, no. 2, pp. 356–359, Feb. 1994.
- [2] Y. Takahashi, Y. Yuyama, S. Yagi, M. Kitagawa, Y. Kimura, M. Abe, et al, "Influence of hepatic accumulation of ^{123}I -MIBG on myocardial imaging," *Ehime JM*, vol. 30, no. 1, pp. 13–18, Apr. 1994 (in Japanese).
- [3] B. A. Herzog, R. R. Buechel, R. Kats, M. Brueckner, L. Husmann, I. A. Burger, et al, "Nuclear myocardial perfusion imaging with a cadmium-zinc-telluride detector technique: optimized protocol for scan time reduction," *J Nucl Med*, vol. 51, no. 1, pp. 46–51, Jan. 2010.
- [4] Y. Takahashi, M. Miyagawa, Y. Nishiyama, H. Ishimura, T. Mochizuki, "Performance of a semiconductor SPECT system: comparison with conventional Anger-type SPECT," *Ann Nucl Med*, vol. 27, no. 1, pp. 11–16, Jan. 2013.
- [5] K. Erlandsson, K. Kacperski, D. van Gramberg, B. F. Hutton. "Performance evaluation of D-SPECT: a novel SPECT system for nuclear cardiology," *Phys. Med. Biol*, vol. 9, no. 54, pp. 2635–2649, Sep. 2009.
- [6] R. R. Buechel, B. A. Herzog, L. Husmann, I. A. Burger, A. P. Pazhenkottil, V. Treyer, et al. "Ultrafast nuclear myocardial perfusion imaging on a new gamma camera with semiconductor detector technique: first clinical validation," *Eur J Nucl Med Mol Imaging*, vol. 4, no. 37, pp. 773–778, Apr. 2010.
- [7] T. Hebert, R. Leath. "A generalized EM algorithm for 3D Bayesian reconstruction from Poisson data using Gibbs priors," *IEEE Trans Med Imaging*, vol. 2, no. 8, pp. 194–202, Jun. 1989.
- [8] G. Germano, H. Kiat, P. Kavanagh, M. Moriel, M. Mazzanti, H. Su, et al. "Automatic quantification of ejection fraction from gated myocardial perfusion SPECT," *J Nucl Med*, vol. 11, no. 36, pp. 2138–2124, Nov. 1995.
- [9] NEMA Standards publication NU 1-2001, "Performance measurements of scintillation cameras," 2001.
- [10] A. Takaki, K. Okada, J. Urata, H. Matsuda, Y. Takao, "Reduction of the influence of the liver uptake to the myocardial uptake on technetium-99m myocardial SPECT : Usefulness and problems of a mask processing method," *Jpn J Nucl Med*, vol. 36, no. 5, pp. 459–465, Jul. 1999 (in Japanese).
- [11] M. Funahashi, T. Shimonagata, K. Mihara, K. Kashiyama, R. Shimizu, S. Machida, et al, "Application of pixel truncation to reduce intensity artifacts in myocardial SPECT imaging with Tc-99m tetrofosmin," *J Nucl Cardiol*, vol. 9, no. 6, pp. 622–631, Nov. 2002 (in Japanese).