Performance of SwiftScan planar and single photon emission computed tomography technology using low-energy high-resolution and sensitivity collimator

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Abstract

Background

A new low-energy high-resolution-sensitivity (LEHRS) collimator was developed by General Electric Healthcare. SwiftScan planar and SPECT system using LEHRS collimator were formulated to achieve the low-dose and/or short-term acquisition. We demonstrated the performance of SwiftScan planar and SPECT system with LEHRS collimator using phantoms.

Methods

Line source, cylindrical and flat plastic dish phantoms were used to evaluate the performance of planar and SPECT images for four patterns of Siemens LEHR, GE LEHR, GE LEHRS and SwiftScan using two SPECT-CT scanners. Each phantom was filled with ^{99m}Tc solution, and the spatial resolution, sensitivity and image uniformity were calculated from the planar and SPECT data.

Results

The full-width at half maximum (FWHM) values as system spatial resolution of Siemens LEHR, GE LEHR and GE LEHRS were 7.3, 7.5 and 7.3 mm, respectively. GE LEHRS showed the lower FWHM value by increasing the blend ratio in Clarity 2D processing. The system sensitivities of Siemens LEHR, GE LEHR and GE LEHRS were 88.4, 67.6 and 89.8 cps/MBq, respectively. The system sensitivity of GE LEHRS increased by approximately 30% compared with that of GE LEHR and was similar to that of Siemens LEHR. The FWHM values of SPECT with an FBP method were 10.3, 10.4, 10.4 and 10.3 mm ($p = \text{n.s.}$). The FWHM values of the OSEM method were better with an increase in iteration values. The differential uniformities of Siemens LEHR, GE LEHR, GE LEHRS and GE SwiftScan were 15.3%, 15.1%, 15.4% and 14.6%, respectively, using the FBP method. The differential uniformity of OSEM method was higher with an increase in iteration value.

Conclusion

The SwiftScan planar and SPECT have a high sensitivity while maintaining the spatial resolution compared with the conventional system.

Background

The image quality of nuclear medicine depends on the acquisition method, image reconstruction and image processing. In particular, a choice of the collimator to acquire planar and single photon emission computed tomography (SPECT) images is an important determinant of image quality [1-3]. The collimator is designed by a combination of different septal thickness, hole diameter and hole length, and

it determines the performance such as spatial resolution, sensitivity and septal penetration of X- and γ -rays [4].

Recently, a novel low-energy high-resolution-sensitivity (LEHRS) collimator was developed by General Electric Healthcare (GE Healthcare, Milwaukee, WI, USA). SwiftScan planar and SPECT system using LEHRS collimator were formulated to achieve the low-dose and/or short-term acquisition. Although initial results of clinical and phantom studies of bone scintigraphy using SwiftScan planar and SPECT system were reported [5], the performance of SwiftScan planar and SPECT system have not fully been evaluated. The aim of this study was to demonstrate the performance of SwiftScan planar and SPECT using the LEHRS collimator.

SwiftScan Planar and SPECT

SwiftScan planar image is created by processing Clarity 2D into conventional planar or whole-body images, and it can reduce the statistical noise maintaining spatial resolution and contrast. Clarity 2D procedure is composed of three processes of noise reduction, contrast enhancement and blending. First, the noise of original image reduced by bilateral filter using adaptive edge preservation [6,7]. Second, the contrast enhancement by the Lucy-Richardson algorithm with the empirical kernel is applied to the images after noise reduction [8, 9]. Finally, the original and the processed images after noise reduction and contrast enhancement were blended with a pixel by pixel manipulation according to the following formula:

$$\text{Pixel}_c = (1 - W_p) \times \text{Pixel}_o + W_p \times \text{Pixel}_p$$

where, pixel_c , pixel_o and pixel_p are pixel value of Clarity 2D image, the original image and the processed image after noise reduction and contrast enhancement, W_p is the weight (0-100%) of the processed image and considered as a Clarity 2D blending weight.

Conventional SPECT with a step-and-shoot mode cannot acquire data while the detector is moving, and the rotating time is not used as an effective acquisition. SwiftScan SPECT was intended to acquire data even during the detector movement. To achieve data acquisition during the detector movement, the data is divided into the front half and the back half of the detector movement. Then the front half data are added to the projection view before the detector movement, and the back half data are added after the detector movement.

Materials And Methods

Two SPECT-CT scanners used; Discovery NM/CT670 Q.suite Pro (GE Healthcare, Tokyo, Japan) with low-energy high resolution (LEHR) or LEHRS collimators, and Symbia Intevo 16 (Siemens, Tokyo, Japan) with a LEHR collimator. The collimator design is shown in Table 1. The flat plastic dish phantom (diameter 15cm), line source and cylindrical phantom in accordance with Japanese industrial standards (JIS) Z4922 phantom (KYOTO KAGAKU, Co., Ltd, Kyoto, Japan) were used to measure the basic performance

of SwiftScan planar and SPECT. Each acquisition parameter of system spatial resolution, system planar sensitivity, SPECT reconstructed spatial resolution, system volume sensitivity and image uniformity with SPECT image were determined with reference to National Electrical Manufacturers Association (NEMA) NU-1 2018 or Japanese Engineering Standards of Radiological Apparatus (JESRA) X-0051*C-2017 guidelines [10, 11]. All images were analyzed using Prominence Processor ver. 3.1 (Prominence conference, Japan) or Daemon research image processor (FUJIFILM Toyama Chemical Co., Ltd., Tokyo, Japan).

System spatial resolution

A line source (inner diameter: 1.5 mm, and length: 200 mm) filled with 784 MBq/mL of ^{99m}Tc solution was created and was set at 10 cm from the detector to measure the system spatial resolution. The photo-peak window of GE and Siemens was set to $140.5 \text{ keV} \pm 7.5\%$ and $140 \text{ keV} \pm 7.5\%$. The anterior view was acquired using 512×512 matrices for both GE LEHR and LEHRS, and Siemens LEHR, with a pixel size of 1.1 and 1.2 mm for GE and Siemens, respectively, and average counts of line source image were 10 k counts/pixel. The count profile drawn on the center of the line source image was used to analyze the full width at half maximum (FWHM). Five planar images with a blend ratio of 0%, 20%, 40%, 60% and 80% were created with GE LEHRS collimator using Clarity 2D processing.

System planar sensitivity

System planar sensitivity was measured by scanning the flat plastic dish phantom, 15 cm in diameter, filled with 187 MBq of ^{99m}Tc activity positioned at the center of each detector.

A planar image of each detector was acquired using 256×256 matrices for both GE and Siemens collimators, with a pixel size of 2.2 and 2.4 mm for GE and Siemens, respectively, and total acquisition counts was 4000 k counts. System planar sensitivity was calculated by dividing the total counts in the detector by the measured activity (1).

$$S_{\text{TOT}} = \frac{C_t \times \exp\left[\frac{(T_s - T_{\text{cal}})}{T_{\text{half}}} \ln 2\right] \times \left[\frac{\ln 2}{T_{\text{half}}}\right] \left[1 - \exp\left(-\frac{T_{\text{acq}}}{T_{\text{half}}} \ln 2\right)\right]^{-1}}{A_{\text{cal}}} \quad (1)$$

where S_{TOT} and C_t are decay-corrected count rate and summed counts on the region of interest (ROI) over the entire image, respectively, T_s , T_{cal} , T_{acq} and T_{half} are start time of the acquisition, time of the activity calibration, duration of the acquisition and half-life of radionuclide, respectively, and A_{cal} is the amount of radioactivity measured in the phantom at time T_{cal} after correcting for residual activity in the syringe.

SPECT reconstructed spatial resolution without scatter

The same phantom used in the measurement of system spatial resolution was located the center of rotation to measure the SPECT reconstructed spatial resolution without scatter. The photo-peak windows

with GE and Siemens cameras were set to $140.5 \text{ keV} \pm 10\%$ and $140 \text{ keV} \pm 7.5\%$. SPECT acquisition was performed using 256×256 matrices for both GE and Siemens cameras, with a pixel size of 2.2 and 2.4 mm for GE and Siemens, respectively. The step-and-shoot or SwiftScan modes of a 360° circular orbit (radius of rotation, 15 cm) and 60 projections of step angle 4° , and average pixel counts of line source image of approximately 110 k counts/pixel. Projection data were reconstructed by filtered back projection (FBP) and ordered subset expectation maximization (OSEM) incorporating Flash 3D [12, 13] or Evolution for Bone [14, 15] algorithms, and pre- or post-filters were not used. The number of iterations varied from 1 to 20 (subset number fixed 12) for Flash 3D and from 1 to 25 (subset number fixed 10) for Evolution for Bone, respectively. Neither scatter correction (SC) nor attenuation correction (AC) were performed. The count profiles of x- and y-axes were drawn on a transverse image of five slices across the center of line source were also used to analyze the average FWHM on x- and y- axes.

System volume sensitivity

A cylindrical phantom (inner diameter, 20 cm; and length, 20 cm) filled with $^{99\text{m}}\text{Tc}$ solution of 40 kBq/mL was used to evaluate system volume sensitivity. The photo-peak window of GE and Siemens cameras was set to $140.5 \text{ keV} \pm 10\%$ and $140 \text{ keV} \pm 10\%$, respectively. Other acquisition parameters were the same as the reconstruction conditions of the SPECT for spatial resolution without scatter. System volume sensitivity was calculated (2):

$$\text{System volume sensitivity} = \frac{A}{B} \quad (2)$$

where A is the average counts/sec for the SPECT acquisition divided by the total counts imaged by the total elapsed time, and B is the source activity concentration (MBq/cm^3) at halfway of total time through the 360° SPECT acquisition. A proper source decay correction factor for the radionuclide was applied.

Image uniformity with SPECT image

Image uniformity with SPECT image was analyzed by the same cylindrical phantom for the system volume sensitivity. Projection data were reconstructed by FBP and OSEM incorporating Flash 3D or Evolution for Bone as well as the parameter of the SPECT reconstructed spatial resolution without scatter. Differential uniformity was calculated using the maximum and minimum values in 75% circular areas drawn on five contiguous transverse images (3).

$$\text{Differential uniformity (\%)} = \frac{\text{Maximum counts} - \text{Minimum counts}}{\text{Maximum counts} + \text{Minimum counts}} \times 100 \quad (3)$$

Results

The FWHM values calculated in the conditions with Siemens LEHR, GE LEHR and GE LEHRS collimators were 7.3, 7.5 and 7.3 mm, respectively. GE LEHRS showed the lower FWHM value with the blend ratio

increased (Fig. 1). The system sensitivity of Siemens LEHR, GE LEHR and GE LEHRS collimators were 88.4, 67.6 and 89.8 cps/MBq, respectively. The system sensitivity of GE LEHRS increased by approximately 30% compared with that of GE LEHR, and was similar to that of Siemens LEHR collimator. (Fig. 2). The FWHM values of Siemens LEHR, GE LEHR, GE LEHRS and GE SwiftScan for SPECT reconstructed spatial resolution without scatter were 10.30, 10.35, 10.35 and 10.25 mm for FBP, and 3.2 – 6.9, 3.9–7.0, 4.4–7.5, 4.5–7.5 mm for OSEM, respectively (Figs. 3 and 4). When FBP reconstruction was used, FWHM values were similar among the collimators and SwiftScan system. The FWHM values of the OSEM method showed a lower value with an increase in iteration value. Moreover, Siemens LEHR collimator condition showed the lowest FWHM in all systems. The system volume sensitivities of Siemens LEHR, GE LEHR, GE LEHRS collimators, and GE SwiftScan were 494, 375, 483 and 550 kcounts/sec/MBq/cm³, respectively (Fig. 5).

The system volume sensitivity of GE LEHR collimator was lower than that of Siemens LEHR collimator. The system volume sensitivity of GE LEHRS increased by approximately 30% compared with that of GE LEHR collimator, which was almost the same as Siemens LEHR collimator. Moreover, the system volume sensitivity of GE LEHRS increased by approximately 14% by SwiftScan SPECT acquisition. The differential uniformities of Siemens LEHR, GE LEHR and GE LEHRS collimators and GE SwiftScan were 15.3%, 15.1%, 15.4% and 14.6% for FBP, and 8.0% – 24.9%, 8.2% – 27.4%, 7.6% – 27.0%, 7.5% – 25.2% for OSEM, respectively (Figs. 6 and 7). The differential uniformity of the FBP method was equivalent in all acquisition methods. The differential uniformities of the OSEM method were higher with an increase in iteration value. Moreover, the OSEM method of Siemens LEHR showed low differential uniformity compared with that of others.

Discussion

The differences of collimator design, acquisition method and image processing are important to understand its characteristics to affect the image quality. System sensitivity of the GE LEHR collimator was inferior to that of Siemens LEHR collimator due to difference in useful field of view (UFOV), so that GE LEHRS collimator was developed to improve low system sensitivity of GE LEHR collimator.

GE LEHRS has a characteristic of thin septum thickness and short hole length compared with GE LEHR as shown in Table 1. GE LEHRS collimator showed approximately 33% higher system sensitivity than GE LEHR collimator. However, spatial resolution was reduced and scatter radiation was increased caused by the septal penetration of photons. The spatial resolution of GE LEHRS was similar to other collimators, and the reason would be the effect of the smaller diameter the collimator holes. Furthermore, the SwiftScan planar image with Clarity2D reduced the noise in the images while maintaining at least an equivalent contrast recovery and spatial resolution. In addition, the effect of Clarity 2D processing, or improvement resolution, can be more clearly observed when the blend ratio of Clarity 2D and the original image was increased [5]. On the other hand, the septal penetration of GE LEHRS collimator increased scatter radiation by approximately 6.5 times due to thin septal thickness compared with GE LEHR collimator. However, Image uniformity of SPECT with GE LEHRS collimator was equivalent to that of GE

LEHR collimator owing to the improvement of system sensitivity. Therefore, image uniformity was not related to scatter from septal penetration for all these collimators examined. Since the impact of increased scatter radiation on absolute quantitation is not clear, we need to clarify the effects in a further study.

The OSEM with Siemens LEHR showed good the performance with respect to spatial resolution and image uniformity compared with GE SPECT-CT system by the effect of the Flash3D algorithm. The Flash3D algorithm has the characteristics of strong edge enhancement compared with Evolution for Bone algorithm [18, 19]. However, the FWHM value and differential uniformity of the FBP method were similar. Thus, the quality of SwiftScan SPECT image is comparable to that of conventional SPECT image from the viewpoints of spatial resolution and image uniformity.

We used the ^{99m}Tc solution to evaluate the performance of SwiftScan using LEHRS collimator in compliance with NEMA or JESRA guidelines [10, 11], since ^{99m}Tc labelled radiopharmaceuticals are most widely used in clinical practice. The effect of SwiftScan for radionuclides other than ^{99m}Tc , however, was not evaluated. In particular, image quality and contrast of ^{123}I -labelled tracers were significantly influenced by septal penetration from γ -ray of 529 keV [16, 17]. To extend the use of SwiftScan to various kinds of nuclear studies, we have to evaluate the utility of other radionuclides including medium or high energy tracers as further work.

Conclusion

We demonstrated the performance of SwiftScan planar and SPECT using LEHRS collimator using phantom studies. The SwiftScan planar and SPECT have a high sensitivity maintaining the spatial resolution compared with the conventional system.

Abbreviations

SPECT: single photon emission computed tomography; LEHRS: low-energy high-resolution-sensitivity; LEHR: low-energy high-resolution; JIS: Japanese industrial standards; NEMA: National Electrical Manufacturers Association; JESRA: Japanese Engineering Standards of Radiological Apparatus; FWHM: full width at half maximum; FBP: filtered back projection; OSEM: ordered subset expectation maximization; SC: scatter correction; AC: attenuation correction; UFOV: useful field of view

Declarations

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Authors' contributions

TS performed all acquisition and reconstructions, evaluated the data, and drafted the manuscript. MO assisted with research planning and data acquisition and revised the manuscript. HY and TK supported all acquisition, data analysis and evaluation. KN assisted with study design and revised the manuscript, and entered into collaborative research work. The authors read and approved the final manuscript.

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Availability of data and materials

All data and materials used within this study are available on reasonable request.

Ethics approval and consent to participate

This article does not contain any studies with human participants or animals performed by any of the authors.

Consent for publication

Not applicable.

Competing interests

K. Nakajima has a collaborative research work with GE healthcare Japan (Tokyo, Japan). Other authors report no potential conflicts of interest relevant to this study.

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Tables

Table 1 Collimator designs of Siemens LEHR, GE LEHR and LEHRS. LEHR, low-energy high resolution; LEHRS, low-energy high-resolution-sensitivity.

Collimator	Hole diameter (mm)	Septum thickness (mm)	Hole length (mm)	Hole number	Septal penetration (%)
SIEMNS LEHR	1.11	0.16	24.05	148000	1.5 (^{99m} Tc)
GE LEHR	1.5	0.2	35	86300	0.3 (^{99m} Tc)
GE LEHRS	1.43	0.13	32	Private	2.3 (^{99m} Tc)

Figures

Figure 1

The FWHM value of the planar image. The percentage of the x-axis is the bled ratio of Clarity2D processing for SwiftScan planar. FWHM, full width at half maximum; LEHR, low-energy high resolution; LEHRS, low-energy high-resolution-sensitivity.

Figure 2

System sensitivity of planar image. LEHR, low-energy high resolution; LEHRS, low-energy high-resolution-sensitivity.

Figure 3

The FWHM value with the FBP method for SPECT image without scatter. FWHM, full width at half maximum; FBP, filtered back projection; SPECT, single photon emission computed tomography; LEHR, low-energy high resolution; LEHRS, low-energy high-resolution-sensitivity.

Figure 4

The FWHM value with the OSEM method for SPECT image without scatter. The transverse images were reconstructed by three dimensional OSEM method incorporating resolution recovery of Flash3D or Evolution for Bone algorithm. FWHM, full width at half maximum; OSEM, ordered subset expectation maximization; SPECT, single photon emission computed tomography; LEHR, low-energy high resolution; LEHRS, low-energy high-resolution-sensitivity.

Figure 5

System volume sensitivity of SPECT image. SPECT, single photon emission computed tomography; LEHR, low-energy high resolution; LEHRS, low-energy high-resolution-sensitivity.

Figure 6

Differential uniformity with the FBP method for SPECT image. FBP, filtered back projection; SPECT, single photon emission computed tomography; LEHR, low-energy high resolution; LEHRS, low-energy high-resolution-sensitivity.

Figure 7

Differential uniformity with OSEM method for SPECT image. The transverse images were reconstructed by three dimensional OSEM method incorporating resolution recovery of Flash3D or Evolution for Bone algorithm. OSEM, ordered subset expectation maximization; SPECT, single photon emission computed tomography; LEHR, low-energy high resolution; LEHRS, low-energy high-resolution-sensitivity.