Comparison of myocardial blood flow SPECT imaging with ^{201}Tl with guidelines

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Abstract

Objective: In this study, we compared myocardial blood flow single photon emission computed tomography (SPECT) using technetium-99m (^{99m}Tc) and thalium-201 (^{201}Tl) preparations. **Materials and Methods:** An the EMIT phantom was used to confirm that the ^{99m}Tc formulation met the criteria of the "myocardial blood flow SPECT standardization guidelines," and ^{201}Tl formulation was imaging performed under the same conditions. **Results:** In the physical evaluation, no significant differences were found in differential homogeneity and % counts. However, in the evaluation using the RH-2 phantom, increasing the ^{201}Tl concentration from 2% to 4% decreased the difference from the ^{99m}Tc preparation in the bull's eye display. **Conclusion:** The lack of differences in physical and visual evaluations despite different collection energies and doses may be because the number of gates and matrix size remained constant. These results suggest that imaging conditions that meet the criteria for ^{99m}Tc formulations can be applied to ^{201}Tl formulations.

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Introduction

Myocardial blood flow scintigraphy is useful for imaging myocardial blood flow in ischaemic heart disease and has played an important role in the diagnosis of cardiovascular diseases since the introduction of thallium-201 (^{201}Tl) in the 1990s, along with the introduction of technetium-99m (^{99m}Tc), which can be administered in larger doses than ^{201}Tl, and synchronized electrocardiography, which enables simultaneous analysis of blood flow and function. Advances in single-photon emission computed tomography (SPECT) equipment have led to the optimisation of acquisition and processing conditions and improvements in image quality [1-3]. In recent years, the use of the ^{99m}Tc preparation for myocardial SPECT in myocardial perfusion scintigraphy has been increasing in Japan. However, the number of tests using the ^{201}Tl preparation is still high for reasons such as per-sonnel allocation and simplicity of the procedure. In 2020, the guidelines for standardization of myocardial blood flow SPECT [3] were published, but the guidelines only apply to ^{99m}Tc agents, and there are no standards yet for ^{201}Tl agents. Therefore, we investigated the optimization of myocardial perfusion SPECT images using the EMIT phantom and ^{201}Tl preparation. In addition, we examined the difference in trends by nuclide using an RH-2 type phantom and optimum image creation criteria.

Materials and Methods

We investigated the optimization of myocardial blood flow SPECT images using the ^{201}Tl formulation at our hospital. We also examined the effect of differences in drug use between the ^{99m}Tc and ^{201}Tl formulations on image analysis using an RH-2 phantom.

Equipment used and imaging conditions (Table 1)

The imaging system used was Bright View X with XCT (Philips); the analysis software used was Prominence Proceser Version 3.1 (provided by the Nuclear Medicine Division of the Radiological Technology Society of Japan), medi+FALCON (Nippon Medi-Physics Co., Ltd.), and Windows 11 (PC), (Kyoto Scientific Corporation).Technetium-99m and

^{201}Tl preparations were used. The collimator was a cardiac high resolution collimator, with an energy window of 141 Kev ±20% for the ^{99m}Tc formulation, 72Kev ±20% and 164Kev ±20% for the ^{201}Tl formulation, matrix size of 64×64, collection range of 180°, collection time of 32min, and collection direction of 32°. The acquisition range was 180°, acquisition direction was 32°, acquisition time (s/step) was 40s, sampling angle was 5.6, and pixel size was 6.2. A non-circular orbit and step-and-shoot non-cardiac synchronous imaging was used. The image reconstruction conditions were as follows: ordered subset expectation maximization method, Butterworth processing filter, cut-off frequency: 0.5 (cycles/cm), order: 8, iteration: 8, subset: 4, attenuation correction, and scatter correction. Attenuation, scatter, and resolution corrections were not applied.

Experimental flow

1. We confirmed that the imaging conditions at our facility met the guidelines for standardization of SPECT imaging of myocardial blood flow (Guideline 1.03) using a ^{99m}Tc formulation (concentration adjusted).
2. After confirming that the bottom line was cleared using the ^{99m}Tc preparation, imaging was performed using the ^{201}Tl preparation (concentration adjusted) using the same equipment and acquisition conditions.
3. The reconstructed images of both preparations were compared by physical and visual evaluation of specific slices using the EMIT phantom.

The ^{201}Tl formulation was imaged at various concentrations. The reconstructed images were evaluated using a bull's eye view.

Phantom creation

1) Preparation of the EMIT phantom [4].
According to the guidelines for standardization of myocardial blood flow SPECT imaging1.0 [3], the dose of ^{99m}Tc-labe-

Table 1. *Equipment used and imaging conditions.*

	Preparation used	^{99m}Tc	^{201}Tl
Collection condition	Number of detectors	2	
	Collimator	CHR	
	Collection range	180	
	Collection matrix	64×64	
	Number of collection directions	32	
	Collection time (sec/step)	40	
	Sampling angle	5.6	
	Pixel size	6.2	
Reconfiguration condition	Reconfiguration Method	OSEM	
	Reconstruction filter	—	
	Processing filter	Butterworth	
	Cut-off frequency (cycles/cm)	0.5	
	Order	8	
	FWHM (mm)	—	
	Iteration	8	
	Subset	4	
	Attenuation compensation	—	
	Scattered ray correction	—	
	Resolution Correction	—	
Radiation concentration	EMIT phantom (kBq/mL)	50	25
	RH-2type phantom (kBq/mL)	50	25・19・12.5

led myocardial blood flow product [5] is 555-1,110MBq, of which the accumulation rate in the myocardium is reported to be less than 2% [6]. The volume of the EMIT phantom in the myocardial section was 375mL. Therefore, the radioactivity concentration (^{99m}Tc formulation) in the myocardium was set at 50kBq/mL.

The phantom dose for the ^{201}Tl formulation, which is the subject of comparison, was calculated. It has been reported that approximately 4% of the ^{201}Tl formulation is taken up by myocardial tissue [7]. When 111MBq is injected intravenously, 111MBq×0.04=4.44MBq accumulates in the myocardium. Therefore, the radiation concentration (^{201}Tl formulation) in the myocardial portion of the EMIT phantom was set at 25KBq/mL.

The inner container (volume approximately 375mL) was filled with water using a funnel provided with the phantom. Distilled water (400mL) was prepared, and an appropriate amount of radioactivity was added to reach 18 to 22MBq/mL at the start of the collection, and the water was thoroughly stirred.

2) Preparation of the RH-2 phantom.

The dose in the RH-2 phantom was prepared according to the same criteria as in (1).The myocardial volume in the RH-2 phantom was 95.4mL. The radioactivity concentration (^{99m}Tc formulation) and radiation concentration (^{201}Tl formulation) in the myocardium were adjusted to 50 and 25kBq/mL, respectively.

In this experiment, three concentrations of the ^{201}Tl solution were prepared: 2% (12.5kBq/mL), 3% (19kBq/mL), and 4% (25kBq/mL), and a simulated defect (20mm front wall and 10mm lower wall) was placed inside the phantom (Figure 1).

However, in both phantom experiments, both preparations were adjusted to the appropriate dose at the time of imaging, in consideration of attenuation.

Items to be examined

1) Calculation of the profile curve in the EMIT phantom

The analysis software Prominence Proceser Version 3.1 was used to reconstruct images of the collected data. The profile curves were calculated using coronal and transverse images in the depth (long-axis image) and width (short-axis image) directions, respectively, of the EMIT phantom. Both profile curves had negative values, indicating defects.

i) Calculation of the contrast ratio of the defects in the EMIT phantom [8].

Image reconstruction of the collected data was performed, and a region of interest (ROI) was established using Image J (National Institutes of Health) at the centre of the myocardial thickness and centred on the defect in the slice section, where the defect was centred in the short-axis image in the depth direction of the EMIT phantom. The contrast ratio was calculated using the following equation, where the minimum value is the lowest pixel value of the defect and the maximum value is the maximum pixel value of the normal area in the centre of the surrounding myocardial thickness.

Contrast ratio of the defect = (max - min)/(max + min) (1)

min: pixel value of the missing area, max: pixel value at the center of myocardial thickness

2)*Calculation of the full width at half maximum (FWHM) of the defect in the EMIT phantom (defined as "negative FWHM")*

The FWHM of the defect in the EMIT phantom was calculated as the width of the defect between the pixel value of the defect in the profile curve calculated from (1) and the median myocardial thickness. The half width of each defect was compared. The FWHM of each missing area was compared [8]. The FWHM of each defect was calculated and compared with that of other defects.

3) Visual evaluation of defects in the EMIT phantom

In accordance with the guidelines, one medical specialist and seven radiology technologists evaluated the uniformity of the normal area and a defect of 10mm in width at five levels, and the average value was calculated by eight technologists. Uniformity was rated as 1 (overall non-uniformity and a high degree of image distortion), 2 (uniformity was noticeable and moderate image distortion was observed), 3 (slight density difference in the normal area and irregularity in the myocardial limbus), 4 (slight density difference in the normal area), or 5 (uniformity was sufficiently ensured). The following results were obtained for a 10-mm width of the inferior wall: 1 (no hypodensity),), 2 (undecided), 3 (mild hy-

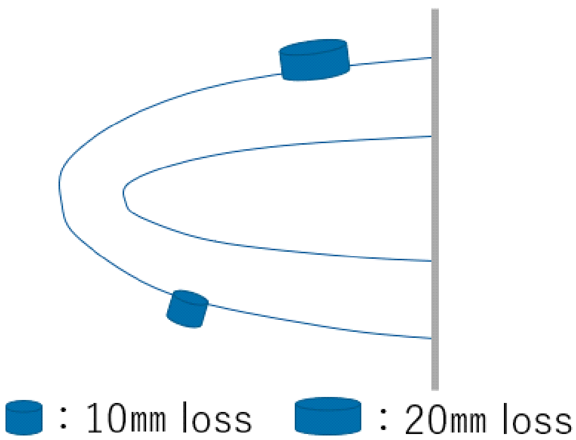

Figure 1. Ten mm defect is placed on the lower wall and 20mm defect on the front wall. The volume of the defect was adjusted appropriately at the time of imaging in both phantom experiments.

podensity), 4 (moderate hypodensity), and 5 (severe hypodensity).

4) Calculation of % counts in the EMIT phantom

The percentage counts in the EMIT phantom were calculated using equation (2) as the percentage of the minimum count value of the 10-mm wide defect on the lower wall of the EMIT phantom divided by the maximum count value in the same slice.

Percentage count = min (ROI2) / max (ROI1) (2)

min: minimum count of the missing area, max: maximum count of the slice section

5) Evaluation of bull's eye view in the RH-2 type phantom

Results

EMIT phantom analysis

1) Calculation of the profile curve in the EMIT phantom

A pixel volume comparison of the defects in the ^{99m}Tc and ^{201}Tl formulations revealed a slight difference in the depth of the defects. Regarding the defect width, the ^{201}Tl formulation was superior at a defect width of 5mm, whereas the ^{99m}Tc formulation was superior at a defect width of 20mm. Regarding the defect depth, there was no significant difference between the maximum and minimum pixel volumes of the two formulations. Regarding the defect width, there was a slight difference in the pixel volume between the 5 and 20mm defects, but the difference was not significant.

2) Calculation of percentage counts in the EMIT phantom

The percentage counts of the ^{99m}Tc and ^{201}Tl products were 56.5 and 59.4, respectively, for a 10-mm defect in the broad direction, showing little difference between the two nuclides. A bottom line of 70.34, as defined in the EMIT phantom guideline1), was also met. The analysed images are shown in Figure 2.

Value

3) Calculation of the FWHM in the EMIT phantom

The FWHM of 5, 10, 15, and 20mm for each defect in the broad direction of both preparations was 21.6, 18.8, 22.4, and 34.6 for the ^{99m}Tc preparation and 21.8, 16.4, 24.5, and 34.2 for the ^{201}Tl preparation, respectively. No significant differences were found between the defects in the two nuclei.

4) Visual evaluation

Visual evaluation was performed using the reading terminals at each facility. The terminal most clearly displayed the slice with the 10-mm defect in the lower wall. The results were as follows: ^{99m}Tc: 4.25 and ^{201}Tl: 3.62 for uniformity and ^{99m}Tc: 3.37 and ^{201}Tl: 3.25 for defect delineation. The ^{99m}Tc formulation was slightly superior to the ^{201}Tl formulation in terms of both uniformity and defect delineation. However, both nuclides met the criterion of bottom line: 3.0.

EMIT phantom visual evaluation

5) Calculation of contrast ratio in the EMIT phantom

The contrast ratios at 2.5, 5.0, 7.5, and 10.0mm for each defect in the depth direction of both preparations were 7.2, 20.9, 46, and 83.9 for the ^{99m}Tc preparation and 4, 19.9, 42.5, and 75.6 for the ^{201}Tl preparation, respectively. There were no significant differences in the defects between the two formulations. The analytical graph is shown in Figure 3.

RH-2 phantom analysis

6) Bull's eye display in the RH-2 phantom

Image reconstructions of the ^{99m}Tc and ^{201}Tl formulations at concentrations of 2%, 3%, and 4% were taken in a RH-2 phantom with a 20-mm defect on the anterior wall and a 10-mm defect on the inferior wall. The reconstructed images were analysed using the medi+FALCON (Nihon Medi-Physics Co., Ltd.) application Heart Risk. When the concentrations of ^{99m}Tc and ^{201}Tl were changed from 2% to 4%, the evaluation of the 20mm defect was 60.6 for the ^{99m}Tc formulation and 51.2, 53.9, and 61.7 for the ^{201}Tl formulation (Figure 4). The 10mm defect was difficult to assess in both formulations. However, visual evaluation of sagittal images showed that the ^{201}Tl formulation was slightly easier to see, with an analysis value of 85.5 for the ^{99m}Tc formulation and 84.1 for the ^{201}Tl formulation (Figure 5).

Discussion

The results of this study suggest that the imaging conditions

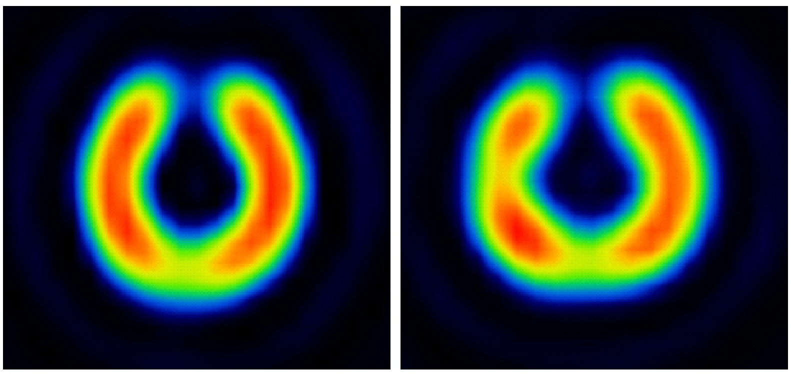

Figure 2. Calculation of % counts in EMIT phantoms. The bottom line as defined by the guidelines1) in the EMIT phantom: 70.34 was met. a) Short axis image of ^{201}Tl formulation, b) Short axis image of ^{99m}Tc formulation.

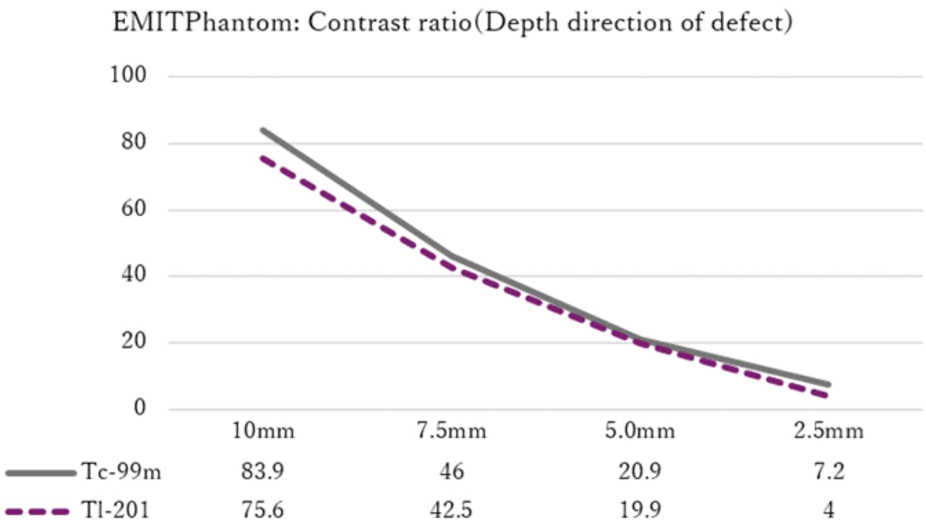

Figure 3. Calculation of contrast ratio in EMIT phantom. The contrast ratio for each size of defect for each formulation is included in the graph. (Solid line is the depth contrast ratio of the defect in the ^{99m}Tc formulation. The dotted line shows the contrast ratio in the depth direction of the defect in the ^{201}Tl formulation.

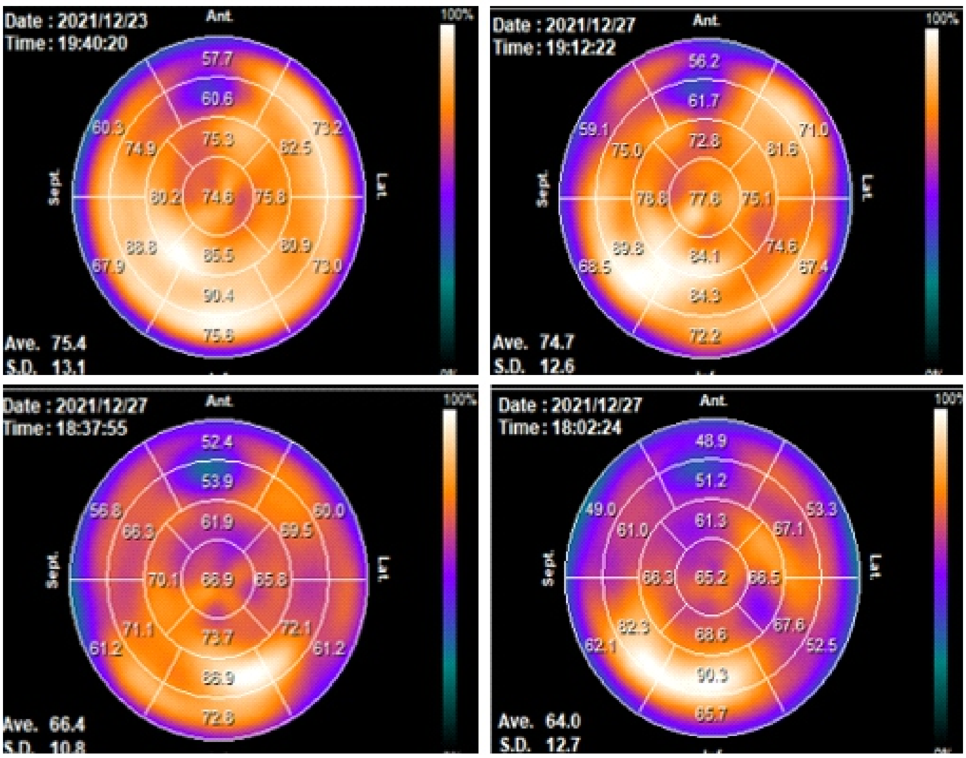

Figure 4. Bull's-eye display in RH-2 type phantom. Image reconstruction data of the RH-2 type phantom with ^{99m}Tc formulation and ^{201}Tl formulation with varying concentrations of 2%, 3%, and 4% were analyzed in medi+FALCON (Nippon Medi-Physics Corporation) using the application Heart Risk View-S (hereinafter HRV-S) for bull's eye display. A 20mm defect on the anterior wall and a 10mm defect on the inferior wall of the RH-2 type phantom were placed. a) Display in ^{99m}Tc formulation, b) 4% concentration display in ^{201}Tl formulation, c) 3% concentration display in ^{201}Tl formulation, d) 2% concentration display in ^{201}Tl formulation.

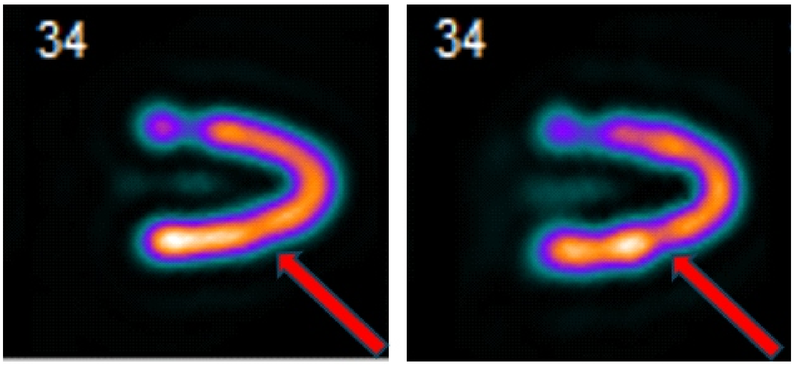

Figure 5. Visual evaluation by sagittal plane image. The target site analysis values were 85.5 for a) the ^{99m}Tc formulation and 84.1 for b) the ^{201}Tl formulation (4%).

that met the guidelines [3] for the ^{99m}Tc formulation may also meet the guideline criteria (bottom line) for the ^{201}Tl formulation in the EMIT phantom experiments.

The ^{201}Tl formulation has the disadvantage of lower γ-ray energy (71Kev) than the ^{99m}Tc formulation, as well as a longer half-life, and cannot be administered in large doses from the viewpoint of radiation exposure. Image degradation is determined by the type of collimator and the distance between the specimen and collimator [9]. This was considered necessary in this study.

The contrast ratio was slightly higher for the ^{99m}Tc formulation in the depth direction of each defect. However, the difference was not significant. Both formulations were within the bottom line of the guideline standard. The difference between the ^{201}Tl and ^{99m}Tc preparations was small, and the ^{201}Tl preparation showed a slightly higher percentage count than the ^{99m}Tc preparation. The ^{201}Tl preparation has lower γ-ray energy of 71Kev, resulting in larger energy attenuation. The method used to calculate the percentage counts is based on the maximum counts of normal myocardium, resulting in an uneven sensitivity of the images affected by noise, which is thought to be the reason for the similar values. Another factor is that the difference in dosage between the ^{99m}Tc and ^{201}Tl preparations was more pronounced than when they were administered to the human body. The influence of the difference in the number of counts per collection angle was also considered a factor in the small difference in % counts and contrast ratio. Furthermore, the shape of the EMIT phantom itself may have affected the results, as the shape of the EMIT phantom was cylindrical and the actual heart is conical, which may have prevented an accurate assessment of defects.

In fact, the RH-2 phantom evaluation showed that the coronal section was difficult to detect for both preparations, whereas the sagittal section was slightly easier to detect for the ^{201}Tl preparation.

Visual evaluation of the EMIT phantom met the guideline values for both nuclides, with the ^{99m}Tc formulation showing slightly higher values; however, the difference was not significant. The difference in visual evaluation may increase if the sampling theorem and other settings are adjusted to the imaging conditions of the ^{99m}Tc formulation. However, as there were no significant differences in the contrast ratio or percentage counts, there were no differences in visual evaluation either. It was also suggested that the images could be expressed regardless of the nuclide, as long as the imaging collection conditions were appropriate.

The authors decare that they have no conflicts of interest.

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