TECHNICAL NOTE

Imaging technology for myocardial perfusion single-photon emission computed tomography 2018 in Japan

Takayuki Shibutani[1] · Koichi Okuda[2] · Hajime Ichikawa[3] · Toyohiro Kato[3] · Kenta Miwa[4] · Hiroyuki Tsushima[5] · Masahisa Onoguchi[1] · Akio Nagaki[6]

Abstract

Aim Recently, nuclear cardiology has dramatically advanced by a new technology development such as the device, short-term acquisition system, image reconstruction algorithm and image analysis. Although these innovations have been gradually employed in routine examinations, we did not investigate the current use of image acquisition, image reconstruction, and image analysis with myocardial perfusion single-photon emission computed tomography (MPS). We investigated the current status of MPS imaging technology in Japan.

Methods We carried out a survey using a Web-based questionnaire system, the opening of which was announced via e-mail, and it was available on a website for 3 months. We collected data on the current use of MPS with ^{201}Tl and/or ^{99m}Tc agents with respect to routine protocols, image acquisition, image reconstruction, and image analysis.

Results We received responses to the Web-based questionnaire from 178 and 174 people for ^{99m}Tc and ^{201}Tl MPS, respectively. The routine protocols of MPS of stress-rest and rest-stress MPS on 1-day protocols with ^{99m}Tc were 41.2% and 14.5%, respectively, and the rest-only scan response rate was 23.7%, whereas that of ^{201}Tl MPS was 65.9% with stress-rest MPS, 19.0% with rest-only MPS, and 10.9% with stress-rest MPS adding a rest scan 24 h after injection. The filtered back projection (FBP) method is most commonly used image reconstruction method, yielding 70.5% for ^{99m}Tc MPS and 76.8% for ^{201}Tl MPS, including combined FBP and ordered subset expectation maximization method. The results for no-correction (NC) images were 49.2% with ^{99m}Tc MPS and 55.2% with ^{201}Tl MPS including the response of NC and combined attenuation correction (AC) and scatter correction (SC) (i.e., ACSC) images. The AC or ACSC images of ^{99m}Tc and ^{201}Tl were provided by 30–40% of the institutions surveyed.

Conclusions We investigated the current status of MPS imaging technology in Japan, and found that although the use of various technical developments has been reported, some of these technologies have not been utilized effectively. Hence, we expect that nuclear medicine technology will be used more effectively to improve diagnosis.

Keywords Myocardial perfusion SPECT · Japan · Survey · Questionnaire · Nuclear cardiology technology

Introduction

Nuclear cardiologists have performed disease severity assessment, decisions regarding treatment strategies, evaluation of treatment effects, and prognosis of cardiac diseases (e.g., ischemic heart disease and myocardial infarction) using qualitative images and quantitative indexes created from myocardial perfusion single-photon emission computed tomography (MPS). Recommendations on the use of image acquisition, image reconstruction, and image analysis have been published by expert nuclear cardiologists in several academic conferences [1–6]. Dramatic advances have been made in the field of nuclear cardiology thanks to recent technological developments, such as the use of short-term image acquisition, image reconstruction algorithms, and image analysis [7–12]. Although these innovations have been gradually employed in routine examinations, the current use of image acquisition, image reconstruction and image analysis with MPS has not been investigated so far.

The device of MPS is becoming more multifaceted; dedicated cardiac cadmium zinc telluride camera and single-photon emission computed tomography (SPECT)–computed

✉ Takayuki Shibutani
  iwsb03100621@staff.kanazawa-u.ac.jp

Extended author information available on the last page of the article

tomography (CT) scanner is gradually beginning to spread across Japan. Therefore, it is now much easier to provide an attenuation correction (AC) with CT or an absolute quantitative index of myocardial blood flow and myocardial flow reserve [13]. In addition, the ordered subset expectation maximization (OSEM) method incorporating scatter correction (SC), AC and resolution correction (RC) can be rapidly processed because of the improvements made in the processing power of personal computers, which contributes to improvements in the diagnostic accuracy [14–16]. Hence, these technologies can now be used more easily than before. Unlike other countries, the acquisition and image reconstruction parameters of MPS in Japan are mainly determined by nuclear medicine technologists who are also licensed radiological technologists, not by nuclear cardiologists or medical physicists. Therefore, a nationwide survey on MPS is also important in raising awareness regarding the role of nuclear medicine technologists, which will lead to an improvement in the diagnostic accuracy. The aim of this study was to investigate the current status of MPS imaging technology in Japan.

Materials and methods

Study design

A research survey was performed using a Web-based questionnaire system of the Japanese Society of Radiological Technology (JSRT). The opening of the questionnaire survey was announced to the members of the JSRT (approximately 9000 people) via e-mail, and it was conducted online for 3 months (from October to December 2017). The survey was approved by the Human Research Ethics Committee of the hospital to which the research leader and coauthor belong.

Questionnaire contents

We collected data on the management style of the participating institutions, the levels of experience of their nuclear medicine technologists and the presence of professional licensees of the Japan Board of Nuclear Medicine Technology (JBNMT) to figure out the profiles of the questionnaire respondents. We also collected the current status of MPS with ^{201}Tl and/or ^{99m}Tc agents with respect to routine protocols, image acquisition, image reconstruction, and image analysis methods, as shown in Table 1. The options of the routine protocol with ^{99m}Tc were set as follows: stress-rest (1 day), rest-stress (1 day), stress-rest (2 days), rest-stress (2 days), stress only, and others. Stress-rest (1 day) means the stress-first MPS protocol, whereas rest-stress (1 day) is the rest-first MPS protocol. Stress-rest (2 days) and rest-stress (2 days) mean performing stress and rest MPS, respectively, on different days. We allowed multiple responses for the routine pattern of image acquisition, reconstruction, correction, and analysis to respond to various examination situations.

Results

We received responses to the Web-based questionnaire from 226 people. Questionnaires related to ^{99m}Tc and ^{201}Tl MPS were answered by 178 and 174 people, respectively (response ratio: 2% for both ^{99m}Tc and ^{201}Tl), including 126 people who answered both questionnaires for ^{99m}Tc and ^{201}Tl MPS. Among all institutions, respondents from a public hospital were the most: 66 (37.1%) people for ^{99m}Tc and 62 (35.6%) people for ^{201}Tl. Furthermore, many of the respondents were nuclear medicine technologists who had more than 10 years of experience, whereas respondents of

Table 1 Questionnaire contents

Question	Option
Routine protocol	Stress-rest (1 day), rest-stress (2 day), stress-rest (2 days), rest-stress (2 days), stress only, rest only and others
Routine acquisition pattern	Planar, SPECT and SPECT–CT (check all that apply)
Routine image reconstruction methods	FBP and iterative recon with and/or without RC (check all that apply)
Routine correction method	NC, AC and SC (check all that apply)
	Gating process, scoring, phase analysis,, absolute quantitative analysis, three cross-sectional image excluding cardiac axis, CCTA fusion, CAD, fusion image of SPECT and plane-CT scan, washout rate, and lung to heart ratio
Addition or omission pattern	Yes or no, and example case

Stress-rest (1 day) means the stress-first MPS protocol, while rest-stress (1 day) is the rest-first MPS protocol. Stress-rest (2 days) and rest-stress (2 days) mean to perform stress and rest scans on different days

SPECT single-photon emission computed tomography, *CT* computed tomography, *FBP* filtered back projection, *RC* resolution correction, *NC* no correction, *AC* attenuation correction, *SC* scatter correction, *CCTA* coronary computed tomography angiography, *CAD* computer-aided diagnosis, *MPS* myocardial perfusion SPECT

a professional license for JBNMT were less than 50% each for both ^{99m}Tc and ^{201}Tl MPS (Table 2).

The routine protocols for ^{99m}Tc and ^{201}Tl MPS are shown in Fig. 1. The response rate of routine protocol for ^{99m}Tc MPS was 41.2% and 14.5% with stress-rest and rest-stress MPS on 1-day protocols, and the rest-only scan was 23.7%, respectively. Stress-only MPS or stress-rest MPS on 2 days' protocol was categorized as "Others" in Fig. 1. The response rate of ^{201}Tl MPS was 65.9 for stress-rest MPS, 19.0% for rest-only MPS, and 10.9% for stress-rest MPS adding rest scan with 24 h after injection. Stress-rest with reinjection MPS and stress-only MPS are categorized as "Others" in Fig. 1. The response rate of routine image acquisition pattern

Table 2 Basic information of respondents

	^{99m}Tc-MIBI ^{99m}Tc-tetrofosmin ($n=178$)	^{201}TICI ($n=174$)
Institution		
University hospitals	30.3% (54)	27.6% (48)
Public hospitals	37.1% (66)	35.6% (62)
Private hospitals	30.9% (55)	34.5% (60)
Others	1.7% (3)	2.3% (4)
Experience as nuclear medicine technologists		
<5 years	27.5% (49)	31.0% (54)
5 < years < 10	30.3% (54)	27.0% (47)
11 < years	42.1% (75)	42.0% (73)
Professional license for JBNMT		
Yes	46.1% (82)	45.4% (79)
No	53.9% (96)	54.6% (95)

JBNMT Japan Board of Nuclear Medicine Technology

for SPECT only and SPECT–CT only was approximately 40% and 15% for both ^{99m}Tc and ^{201}Tl MPS, respectively. Furthermore, planar scans of ^{99m}Tc and ^{201}Tl were performed 41% and 43.8%, respectively (Fig. 2). The response rate of supine MPS with ^{99m}Tc and ^{201}Tl was approximately 90%, and prone or upright positions were acquired as the routine examination in the part of the hospital (5.6% and 2.0% with ^{99m}Tc and ^{201}Tl MPS).

The filtered back projection (FBP) method was the most commonly used image reconstruction method, with results of 70.5% with ^{99m}Tc MPS and 76.8% with ^{201}Tl MPS, including the combined FBP and OSEM methods (Fig. 3). The OSEM with RC was 66.7% for ^{99m}Tc and 63.6% for ^{201}Tl in all OSEM methods. The no-correction (NC) images were 49.2% with ^{99m}Tc MPS and 55.2% with ^{201}Tl MPS including the response of NC and combined AC and SC (ACSC) images (Fig. 4). The AC or ACSC images of ^{99m}Tc and ^{201}Tl were provided by 30–40% of the institutions, and many hospitals (approximately 75% using both ^{99m}Tc and ^{201}Tl) with a SPECT–CT scanner created those images using CT-based AC (CTAC).

More than 50% of the respondents reported that their preferred image analysis method was processed by an electrocardiogram (ECG) gating process, scoring both ^{99m}Tc and ^{201}Tl MPS, and washout rate of ^{201}Tl MPS (Table 3). In particular, the gating process of ^{99m}Tc MPS was performed in most of the respondent hospitals. Various validation techniques were adopted, such as phase analysis, computer-aided diagnosis, fusion image combined coronary CT angiography (CCTA) and MPS image, and absolute quantitative analysis.
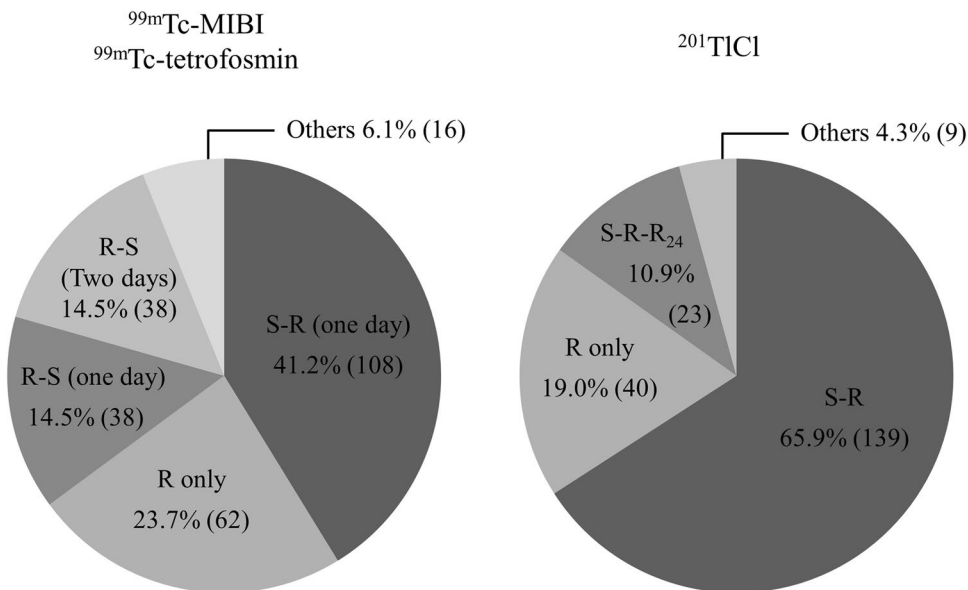
In most of the institutions, decisions to use additional images or to omit routine images were performed by nuclear cardiologists. The hospitals that acted upon the

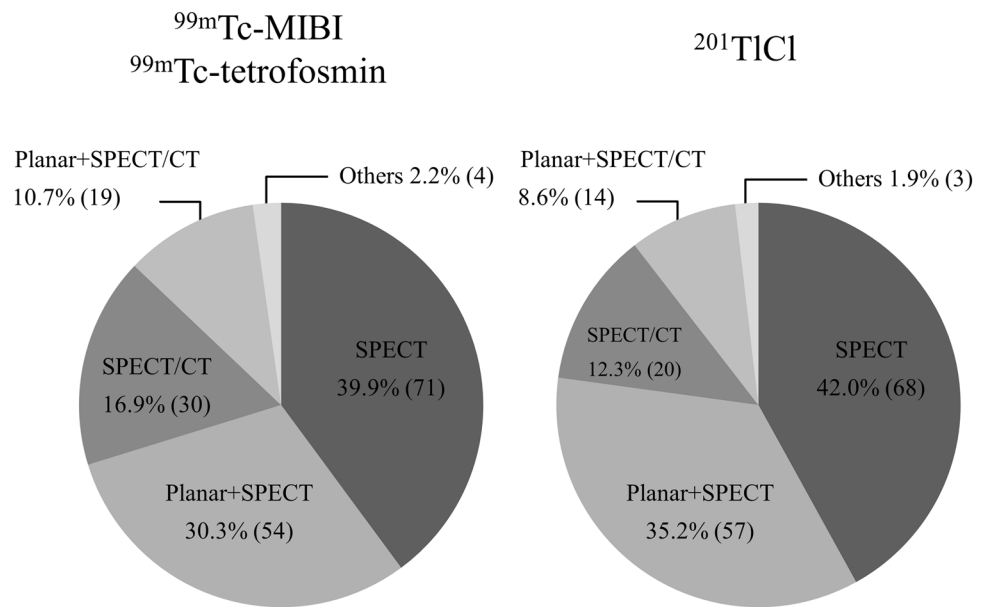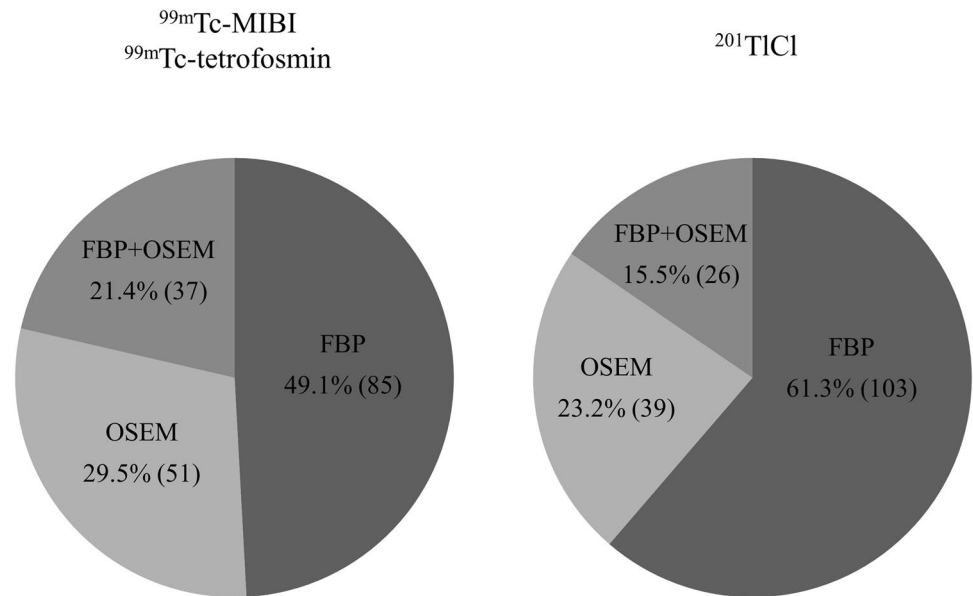**Fig. 1** Examination protocol with ^{99m}Tc and ^{201}Tl myocardial perfusion SPECT. *S* stress scan, *R* rest scan, R_{24} 24-h rest scan after injection

Fig. 2 Acquisition pattern of ^{99m}Tc and ^{201}Tl myocardial perfusion SPECT. *SPECT* single-photon emission computed tomography, *CT* computed tomography

^{99m}Tc-MIBI
^{99m}Tc-tetrofosmin

^{201}TlCl

Planar+SPECT/CT 10.7% (19)
Others 2.2% (4)
SPECT/CT 16.9% (30)
SPECT 39.9% (71)
Planar+SPECT 30.3% (54)

Planar+SPECT/CT 8.6% (14)
Others 1.9% (3)
SPECT/CT 12.3% (20)
SPECT 42.0% (68)
Planar+SPECT 35.2% (57)

Fig. 3 Image reconstruction method with ^{99m}Tc and ^{201}Tl myocardial perfusion SPECT. *FBP* filtered back projection, *OSEM* ordered subset expectation maximization, *SPECT* single-photon emission computed tomography
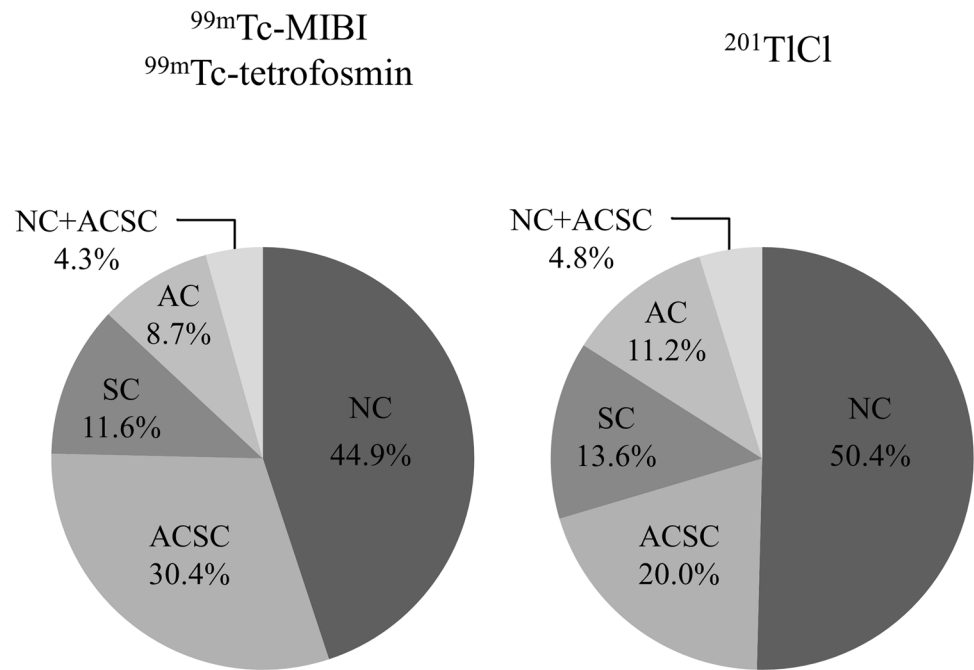
^{99m}Tc-MIBI
^{99m}Tc-tetrofosmin

^{201}TlCl

FBP+OSEM 21.4% (37)
FBP 49.1% (85)
OSEM 29.5% (51)

FBP+OSEM 15.5% (26)
OSEM 23.2% (39)
FBP 61.3% (103)

judgment of nuclear medicine technologists achieved results of 18.0% with ^{99m}Tc and 13.8% with ^{201}Tl. For example, when some of the respondents generated artifacts by a high accumulation of liver, gallbladder or bowels, there were underestimation of the LV volume for small hearts and detection of an abnormal physiological uptake pattern. Therefore, they provided nuclear cardiologists with additional images. Furthermore, if we performed the MPS with an arrhythmia, implantation of a pacemaker or small heart patients, some respondents omitted the gating process.

Discussion

Even though MPS with ^{201}Tl produces more radiation exposure compared to that with ^{99m}Tc, it is still widely used in Japan [17]. MPS with ^{201}Tl in Japan has a greater level of diagnostic evidence than that with ^{99m}Tc, having been in use for a longer time [4]. Furthermore, ^{201}Tl MPS has several advantages: obtaining stress and rest images by a single injection of the radiopharmaceutical and calculating the washout rate. The washout rate is an additional index which is useful for risk stratification

Fig. 4 Correction method with ^{99m}Tc and ^{201}Tl myocardial perfusion SPECT. *NC* no correction, *AC* attenuation correction, *SC* scatter correction, *ACSC* AC and SC

^{99m}Tc-MIBI
^{99m}Tc-tetrofosmin

^{201}TlCl

Table 3 Image analysis of routine examination with ^{99m}Tc and ^{201}Tl myocardial perfusion SPECT

	^{99m}Tc-MIBI ^{99m}Tc-tetrofosmin ($n=178$)	^{201}TICI ($n=174$)
ECG gating process (e.g., EDY, ESV, and LVEF)	95.5% (170)	71.3% (124)
Scoring (e.g., SSS, SRS, and SDS)	58.4% (104)	56.3% (98)
Phase analysis	45.5% (81)	28.7% (50)
CAD (e.g., ANN score)	33.7% (60)	28.7% (50)
CCTA fusion	15.2% (27)	8.0% (14)
Three cross-sectional images excluding cardiac axis (e.g., transverse axial, coronal, or sagittal image)	8.4% (15)	11.5% (20)
Absolute quantitative analysis (ex. MBF and MFR)	6.7% (12)	4.6% (8)
Fusion of SPECT and plane CT images	6.2% (11)	4.6% (8)
Washout rate	–	56.3% (98)
Lung to heart ratio	–	9.2% (16)

ECG electrocardiogram, *EDV* end-diastolic volume, *ESV* end-systolic volume, *LVEF* left ventricular ejection fraction, *SSS* summed stress score, *SRS* summed rest score, *SDS* summed difference score, *CAD* computer-aided diagnosis, *ANN* artificial neural network, *CCTA* coronary computed tomography angiography, *MBF* myocardial blood flow, *MFR* myocardial flow reserve, *SPECT* single-photon emission computed tomography, *CT* computed tomography

of ischemia [18]. In particular, diffuse slow washout of ^{201}Tl is important as an indicator of multi-vessel coronary artery disease [19]. Therefore, many respondents performing the stress-rest ^{201}Tl MPS provided the washout rate as the routine protocol. However, if re-distribution image from 3 to 4 h after injection is insufficient, the detection of a viable myocardium is underestimated. Twenty-four-hour delayed scan or fill-in scan after reinjection has been reported to improve the underestimation for detection of a viable myocardium [20, 21]. Only a small number of

respondent institutions undertook those scans routinely. ^{99m}Tc MPS has various advantages, such as a high quantitative accuracy and image quality, as well as improved inferior attenuation compared with ^{201}Tl MPS [22–24]. Therefore, the ratio of ^{99m}Tc to ^{201}Tl in MPS has been gradually increasing in Japan [17].

Recently, stress-only MPS with ^{99m}Tc has been attracting attention related to radiation exposure and patient burden [25], but it has not been commonly performed. Many hospitals suffer from a shortage of nuclear cardiologists and so

do not consistently have the facilities to interpret images of stress MPS. Nuclear cardiologists cannot, therefore, judge immediately after an examination using stress MPS whether rest MPS is necessary. To expand the use of stress-only MPS in the future, it will be necessary to determine criteria for quantitative indices and image interpretation that can judge stress MPS images in the absence of nuclear cardiologists.

A planar image is often acquired in addition to MPS. Planar image with ^{201}Tl can help analyze the lung-to-heart ratio as a quantitative index, which is useful in the detection of multi-vessel disease [26, 27], wall thickening, evaluation of the left ventricular chamber, and detection of diseases like tumors other than cardiac disease [28, 29]. Multi-vessel diseases are particularly difficult to diagnose from nuclear medicine images, due to display of relative value normalized by the maximum value. Therefore, the lung-to-heart ratio will offer good diagnostic support. Similarly, a planar image with ^{99m}Tc is useful for the detection of incidental tumors and in assisting with the long-term prognosis of multi-vessel disease [30, 31]. Therefore, a planar image should be acquired regardless of whether ^{99m}Tc or ^{201}Tl is used.

CTAC reduces the likelihood for a false positive of the inferior wall [12]. However, 25% of hospitals with SPECT–CT scanners do not perform a CTAC. Furthermore, an additional scan in a prone or an upright positions is also very useful in improving the attenuation artifacts of the inferior wall [32–35]. However, the MPS images of these positions were less than 5% of the routine examination. There are disadvantages associated with myocardial imaging with CTAC, such as the insufficient maintenance of the normal database (NDB) and the increase in radiation exposure. In particular, the NDBs created by the Japanese Society of Nuclear Medicine (JSNM) consist only of myocardial images without AC [36, 37]. Thus, NDBs data that provide the quantitative index of myocardial image with AC are insufficient. It is also noted that the criteria to perform additional scans of prone or upright positions have not been clarified. If there is no nuclear cardiologist at an institution, the use of an additional scan must be determined by a nuclear medicine technologist. Consequently, it is very important to set the criteria for additional scans and to expand NDBs to include images with AC.

The MPS images reconstructed using OSEM with AC, SC, and RC have been reported to be useful for improving the diagnostic accuracy [14, 15, 38]. Furthermore, OSEM can improve streak-artifact caused by the strong accumulation of liver, gallbladder and/or bowels. However, MPS images were reconstructed by FBP without AC, SC, and RC in many hospitals. One of several reasons may be that the maintenance of NDBs is inadequate, and so a JSNM working group created the Japanese NDB from the MPS image reconstructed by FBP [36, 37]. The NDB for scanner-specific

systems has also gradually been added in recent years [8, 39, 40], but the NDBs of OSEM with and without SC, AC, and RC have not been reported yet. Differences in image reconstruction and correction patterns affect the normal values of %uptake. In particular, the RC algorithm is different for each vendor [41–43] and it is difficult to create the NDB of OSEM with RC. Efforts to add to the NDB will be very important in the future expansion of OSEM incorporating AC, SC, and RC. OSEM with RC is useful for patients with small hearts to improve the partial volume effect [16], and this effect depends on the RC algorithm. However, OSEM with RC has been reported to overestimate the quantitative index owing to the presence of a Gibbs artifact [44]. Some venders always include the RC when SPECT data are reconstructed with the OSEM method. Therefore, OSEM with RC images must be checked for Gibbs artifacts. To improve the problem of NDBs and artifacts, images from some hospitals were reconstructed using both the FBP and the OSEM methods. Therefore, it is important that nuclear cardiologists understand the image interpretation arising from different image reconstructions.

Each quantitative index of gated MPS improves the diagnostic accuracy by the adding of a non-gated MPS image [45, 46], and there are important considerations arising from these indexes. The end-diastolic volume and end-systolic volume (ESV) by partial volume effect in Japanese women and pediatric patients have been underestimated, and this has been particularly remarkable with the ESV, with some improvements reported [16, 47]. As these methods can be easily used, they should be positively encouraged. Another point is that in arrhythmic patients, it is possible that a false impression of wall thickening would reduce the benefits of incorporating visual assessments of thickening and motion into perfusion observations and inhibit the recognition of artifacts [48]. Some of the respondents omitted acquiring a gated MPS of arrhythmic patients, only having acquired a non-gate MPS. If a gated MPS is performed on arrhythmic patients, attention should be paid to the interpretation of quantitative indexes.

The number of CCTAs dramatically increases every year in Japan. However, the fusion imaging of MPS and CCTA was less than 16%. This may be because the software needed for creating fusion images of MPS and CCTA is not part of standard packages, but must be purchased separately from venders. Additionally, if workstations are set up outside nuclear medicine rooms, the workflow of nuclear medicine technologists becomes more complicated. We have also found that the number of fusion images of CCTA and MPS increases with the increase in CCTA, but CCTAs cannot be performed routinely because of the lack of manpower. Fusion images improve the sensitivity and specificity in the diagnosis of coronary artery disease [49]. Moreover, it helps distinguish whether the affected coronary artery is RCA or

LCX if there is an ischemic finding in the inferolateral wall in MPS [50]. We, therefore, strongly recommend creating fusion images where a CCTA is carried out before or after MPS.

MPS is rarely carried out beyond acquisition protocols, image reconstruction, and image processing other than in routine examinations, and the guidelines for its use are based on a considerable body of evidence [1–6]. Certain guidelines for the image acquisition and image processing protocols needed for performing routine examinations are determined by each hospital, and we found minor differences between hospitals. Thus, MPS diagnosis should be possible with only image acquisition protocols and image processing for routine examinations in most cases.

The questionnaire could not obtain a high response rate, because it contained the members of JSRT who had not worked in nuclear medicine, and there are approximately 450 JSRT members working in nuclear medicine. Therefore, we assumed a response rate of approximately 40% (174 or 178 out of 450 people). Every respondent to our questionnaire was the only member of JSRT in his/her hospital department of nuclear medicine. Thus, we believe that our results reflect the current state of nuclear medicine technology in Japan, but there is little other survey on the state of nuclear medicine [51, 52]. Therefore, the results of our research will provide important data for the improvement of MPS technology.

Conclusion

We have investigated the current status of MPS imaging technology in Japan, and found that, despite the use of various technological developments that have been reported, some of these technologies have not been effectively utilized. Hence, we expect that nuclear medicine technology will be used more effectively to improve diagnosis.

Compliance with ethical standards

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Affiliations

Takayuki Shibutani[1] · Koichi Okuda[2] · Hajime Ichikawa[3] · Toyohiro Kato[3] · Kenta Miwa[4] · Hiroyuki Tsushima[5] · Masahisa Onoguchi[1] · Akio Nagaki[6]

Koichi Okuda
okuda@kanazawa-med.ac.jp

Hajime Ichikawa
ballocks10@yahoo.co.jp

Toyohiro Kato
chapmani_zebra@yahoo.co.jp

Kenta Miwa
kenta5710@gmail.com

Hiroyuki Tsushima
tsushima-ocu@umin.ac.jp

Masahisa Onoguchi
onoguchi@staff.kanazawa-u.ac.jp

Akio Nagaki
nagaki@kchnet.or.jp

[1] Department of Quantum Medical Technology, Institute of Medical, Pharmaceutical and Health Sciences, Kanazawa University, 5-11-80, Kodatsuno, Kanazawa, Ishikawa, Japan

[2] Department of Physics, Kanazawa Medical University, Kahoku, Japan

[3] Department of Radiology, Toyohashi Municipal Hospital, Toyohashi, Japan

[4] Department of Radiological Sciences, School of Health Sciences, International University of Health and Welfare, Ohtawara, Japan

[5] Department of Radiological Sciences, Ibaraki Prefectural University of Health Sciences, Ibaraki, Japan

[6] Department of Radiological Technology, Kurashiki Central Hospital, Kurashiki, Japan