—Japanese Society of Nuclear Medicine Technology Working Group Report.—

Key Point of Acquisition, Processing and Display for Standardized Images with Clinical Usefulness (Myocardial SPECT)

Working Group for Investigation and Research on Nuclear Medicine Image Quantification and Standardization, Japanese Society of Nuclear Medicine Technology

Yasuhiko MASUDA
Department of Radiological Technology, Asahikawa Red Cross Hospital

Akio NAGAKI
Department of Radiology, Kurashiki Central Hospital

Yasuhisa KAWABUCHI
Department of Radiology, Kanazawa Municipal Hospital

Nobuyoshi OHYA
Division of Radiology, Department of Medical Technology, Kyushu University Hospital

Tetsuro KATAFUCHI
Department of Radiological Technology, School of Health Science, Gifu University of Medical Science

Satomi TERAOKA
FUJIFILM RI Pharma Co., Ltd.

Masamichi YANAGISAWA
Nihon Medi-Physics Co., Ltd.

Hideharu NIIDA
Nihon Medi-Physics Co., Ltd.

Chairman of Scientific Committee, Japanese Society of Nuclear Medicine Technology
Masuo HAYASHI
Department of Radiology, Osaka Medical College Hospital

Chairman of strategic planning Committee, Japanese Society of Nuclear Medicine Technology
Hiroyuki TSUSHIMA
Department of Radiological sciences, Ibaraki Prefectural University of Health Sciences

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• Introduction

Nuclear medicine images today are not as standardized as images, provided by computed tomography (CT) and magnetic resonance imaging (MRI). Rather, an infinite variety of images may be provided by different institutions, depending on the facilities in each institution. The Working Group for Investigation and Research on Nuclear Medicine Image Quantification and Standardization started work in 2002 with the aims of improving the reliability and objectivity of nuclear medicine images to create evidence-based nuclear medicine technology (EBNMT) on a national basis. The Working Group has distributed questionnaires to members of the Japanese Society of Nuclear Medicine Technology (JSNMT), device manufacturers, and printer manufacturers, the results of which have been published in the JSNMT journal *Nuclear Medicine Technology*, and on the JSNMT website (in Japanese).

In the survey of JSNMT members, 87% responded that there is a need for guidelines on standardized acquisition, processing, and display, indicating that great hope is being placed on the Working Group's

activities and results.

The survey of device manufacturers showed that although there is a shared recognition of the need for standardization, some manufacturers also expressed the desire for users to understand their devices.

This report summarizes the standard images and some of the pitfalls of myocardial perfusion single-photon emission computerized tomography (SPECT) from the final report of the Working Group. A checklist has also been included at the end. We hope that readers will refer to these standard images and checklist during image acquisition, processing, display, and evaluation in their own institutions. Speaking on behalf of the JSNMT it is our hope that this report will provide a valuable reference for the appropriate performance of nuclear medicine testing in order to establish EBNMT.

• Myocardial SPECT

Evidence-based medicine (EBM) relating to the application of stress myocardial perfusion SPECT in coronary artery disease has been established in areas such as the diagnosis of ischemic heart disease, the determination of treatment to evaluate the severity of stenosis of coronary artery lesions to determine appropriate treatment, response to treatment, and risk assesment.[1] Appropriate testing methods and high-quality technologies are required to implement such EBM, and acquisition conditions such as acquisition time and pixel size, preprocessing filters, processing conditions such as scatter/attenuation correction, and display conditions such as gradation, display scales, and color scales are all important in myocardial SPECT.

In this section, we describe the techniques and knowledge required for myocardial SPECT image acquisition, processing, and display and we provide standard images for myocardial SPECT.

1. Devices used for myocardial SPECT

Myocardial SPECT image acquisition using a single-detector gamma camera was performed in most institutions over a 180° scan range from RAO45° to LPO45° to shorten acquisition time in supine position. The development of dual-detector and triple-detector gamma cameras has enabled 180° or 360° scan using L-shaped detectors with 90° or 76° angles between them. Lesser institutions are now using single-

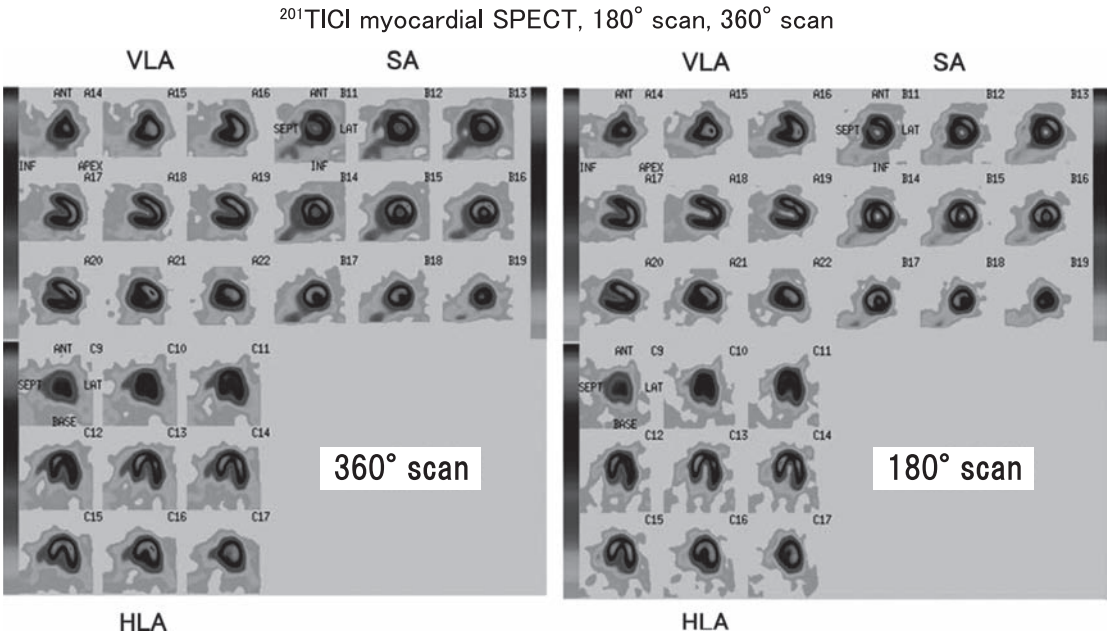

Figure 1 SPECT images of a normal volunteer acquired by 180° and 360° scan

detector gamma cameras, as they have been replaced by dual-detector gamma cameras. These cameras are capable of 180° scan by means of detectors joined at 90° angle or 360° scan by opposing detectors at 180° angles, depending on the choice of institutions. For triple-detector devices, 360° scan is generally used. The main difference between images acquired by 180° and 360° scan is that 180° scan provides high contrast and high spatial resolution, whereas with 360° scan the images are stable, with little distortion in the inferior

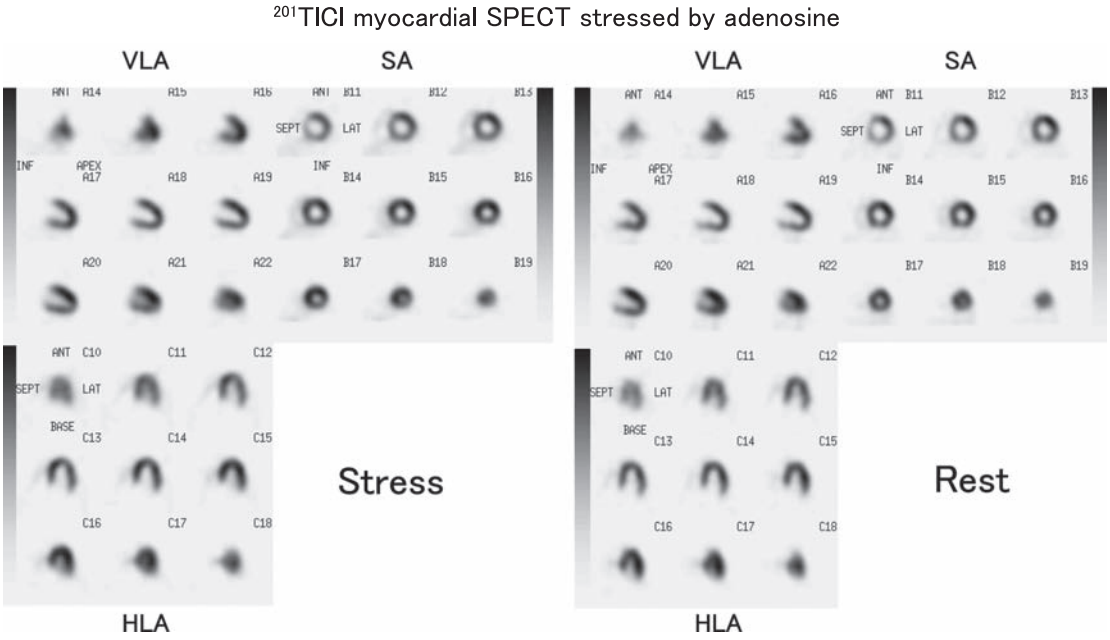

Figure 2 Standardized images acquired on triple-detector by 360° scan

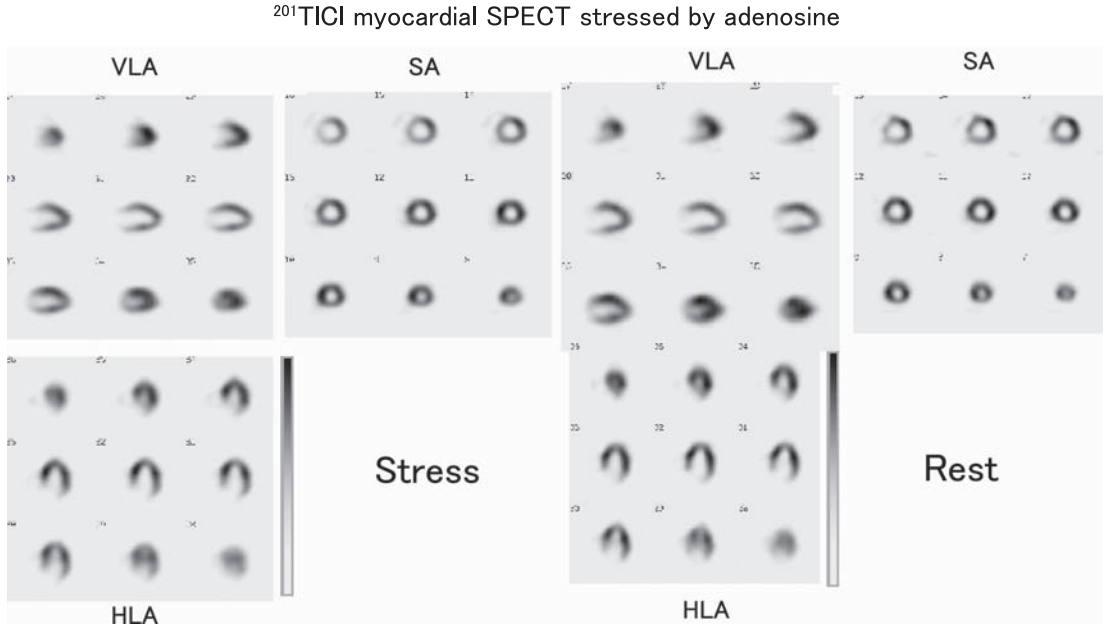

Figure 3 Standardized images acquired on L-shaped detectors by 180° scan

Table 1 Acquisition and processing conditions of standardized images of ^{201}TlCl myocardial SPECT

Scanner	GCA9300A/PI (Toshiba)	E.CAM (SIEMENS)
Scan conditions		
Detector formation	triangle shape by a triple detector	L-shape by a dual detector
Scan angle	360°	180°
Collimator	LEHR	LEHR
Energy Window	71 keV ± 10%	70 keV ± 10% and 166 keV ± 7%
Sampling angle	6°	5.6°
Scan time	30 sec/step	40 sec/step
Matrix	64 × 64	64 × 64
Pixel size	6.4 mm	6.1 mm
Reconstruction parameters		
Preprocess filter	Butterworth [order= 8, cutoff= 0.41 cycles/cm]	Butterworth [order= 5, cutoff= 0.42 cycles/cm]
Reconstruction filter	Ramp	Ramp
Attenuation correction	(−)	(−)
Scatter correction	(−)	(−)
Display parameters (gray)		
Concentration curve	square	square
Display scale	10−100%	10−100%

and posterior walls (shown in **figure 1**).[2] In this report, we provide the standardized images for triple-detector 360° scan (shown in **figure 2**), standardized images for 180° scan with a dual-detector gamma camera using L-shaped detectors with 90° angle (shown in **figure 3**), and acquisition conditions (**Table 1**).

In general, a low-energy high-resolution (LEHR) or low-energy general-purpose (LEGP) collimator is used for both ^{201}Tl and ^{99m}Tc, although an LEGP collimator is often used for ^{201}Tl in particular as the count rate is insufficient for short acquisition times or electrocardiogram (ECG) -synchronized acquisition (gated SPECT). ^{123}I has a 529 keV peak in addition to the main peak at 159 keV, and the effect of down scatter must therefore be taken into account, meaning that the use of low–medium energy general-purpose (LMEGP) collimators is preferable. Collimators should be chosen with reference not only to their 5% penetration energy, but also to the balance between sensitivity and resolution.

2. Acquisition conditions for myocardial SPECT

Myocardial SPECT involves administering a radiopharmaceutical agent and performing imaging, either under stress or at rest. The stress test may comprise exercise stress on a treadmill or ergometer, or pharmacological stress with an agent such as adenosine, dipyridamole, or dobutamine.

In terms of the radiopharmaceuticals and doses used for myocardial SPECT, when ^{201}TlCl is used as a myocardial perfusion agent the dose is normally 111 MBq, and for ^{99m}Tc-MIBI and ^{99m}Tc-tetrofosmin it is generally 296−740 MBq. ^{123}I-BMIPP is used to assess myocardial fatty acid metabolism and ^{123}I-MIBG to assess myocardial sympathetic nerve function, with a dose of 111 MBq generally used in each case. The imaging start time and pretreatment for these agents vary according to their pharmacodynamics, and the following points should be noted.

At rest, ^{201}TlCl is slightly affected by washout and early images may be obtained in 15−30 min after administration, with late images also obtained 3−4 h later in some cases. Under stress, early images are obtained in 5−10 min after administration to take into account of the effect of upward creep,[3] and late images are acquired 3−4 h later to evaluate redistribution. To avoid the uptake of ^{201}TlCl in the gastrointestinal tract, patients should fast for 3−4 h before imaging as pretreatment and during imaging,

with only water intake permitted.

High levels of ^{99m}Tc-MIBI and ^{99m}Tc-tetrofosmin accumulation in the hepatobiliary system precedes the myocardial uptake during the early stage after the administration, causing artifacts, and imaging is therefore generally performed 30–60 m after administration. The disposition of these two agents is not exactly the same.[4] The acquisition for ^{99m}Tc-tetrofosmin can be performed slightly earlier, since it has a comparatively high cardiac-hepatic uptake rate compared to ^{99m}Tc-MIBI. The consumption of fatty foods such as milk or chocolate after the administration of ^{99m}Tc myocardial perfusion agent is effective in promoting excretion from the hepatobiliary system. Food consumption prior to administration may conversely promote excretion from the liver and gall bladder. When imaging is performed twice with a ^{99m}Tc agent, either on the base of stress-rest or rest-stress protocols, an interval of 3–4 h should be left between the first and second administrations, and the second dose should be 2–3 times higher than the first dose.[5]

When using ^{123}I-BMIPP, early images are obtained in 15–20 min after administration, and late images may be obtained 3–4 h later. Fasting before administration is required as pretreatment. For ^{123}I-MIBG, early images are acquired in 15–20 min after administration and late images 3–4 h later. The use of reserpine, tricyclic antidepressants, and labetalol hydrochloride may inhibit the myocardial uptake of ^{123}I-MIBG.

The standard settings for data acquisition are matrix size 64×64, pixel size 5–7 mm, step angle 5°–6°, and acquisition time within 20–40 s in each direction, but if possible an acquisition time of around 40 s is preferred.[6] Recently, many institutions have started to perform gated SPECT at the same time,[7] and the acquisition count setting is important in order to obtain a highly accurate evaluation of left ventricular function. When using a polar map (bullseye) display to calculate the washout rate, it is necessary to confirm whether or not correction is being performed for acquisition time and nuclide decay. The number of R-R divisions in gated SPECT is normally set at eight for ^{201}Tl and 16 for ^{99m}Tc.

Table 2 Scanner type and acquisition parameters of myocardial SPECT

Scanner	Single (7%) > dual (63%) [L-shape > opposing] > triple
Scan angle	180°>180°
Gated SPECT	55%
Collimator	LEHR or LEGP
Matrix	64×64
Pixel size	5–7 mm
Matrix	64×64
Sampling angle	5–6°
Scan time	21–40 sec/frame
Allowance of heart rate	±20%
Interval of R-R	8 (60%)>16 (25%)
Analysis software	QGS, pFAST
Attenuation correction	(–)
Scatter correction	(–)

Energy window settings are generally 71 keV ± 10%–15% for ^{201}Tl. Acquisition with an added 167 keV ± 10% increases the acquisition count by around 10%. The setting for ^{99m}Tc is generally 140 keV ± 10% and that for ^{123}I is generally 159 keV ± 10%. In 2008, when this report was published, the majority of institutions did not perform scatter or attenuation correction (**Table 2**).[8] Currently, more institutions are using SPECT-CT scanners in performing myocardial perfusion imaging with the same position as needed for SPECT acquisition. CT scanning results in additional radiation exposure, and care is required when setting acquisition conditions.

3. Points to note for myocardial SPECT acquisition

Although the myocardial SPECT acquisition count or acquisition time per projection is dependent on the dose of the nuclide used and the patient's constitution, the conditions should be set so that a sufficient myocardial count can be obtained even in late imaging with ^{201}TlCl, which is affected by washout from the myocardium. To investigate the acquisition count, the region of interest (ROI) is set in the myocardial region on the LAO45° planner image from SPECT projection data, and the myocardial projection count is

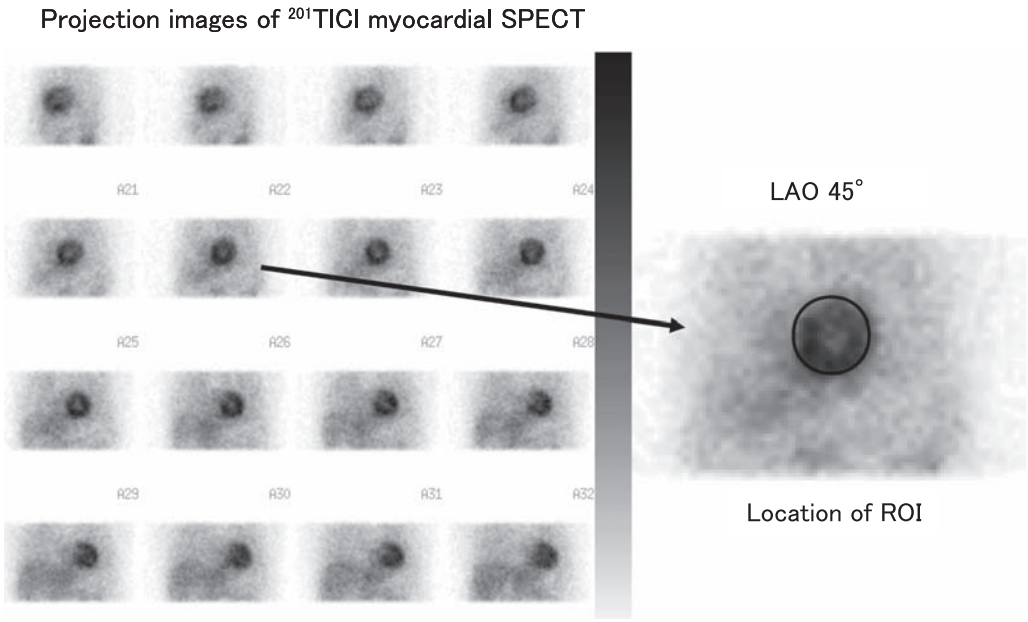

Figure 4 Investigation of acquisition count

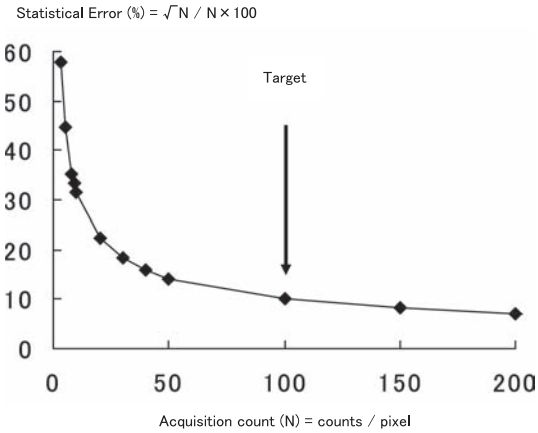

Figure 5 Relationship between statistical error and acquisition count

measured (**Figure 4**). The acquisition count should ideally be over 100 counts per pixel to reduce for statistical error influence (**Figure 5**), but acquisition time should be set at 15–20 min as scanning in a posture with both arms raised for a prolonged period of time may result in the generation of artifacts due to body movements. With large patients, however, the settings must be adjusted to ensure a constant acquisition count by prolongation of the acquisition time if ^{201}TlCl is used, or increasing the dose if ^{99m}Tc is used as the myocardial agent. This definition of ≥ 100 counts is also derived from the concept that the statistical noise included in the acquisition count can be kept within 10%, and as the scatter component also varies depending on collimator performance, it does not represent a uniform determination. When gated SPECT is used, the acquisition count must be investigated for non-gated SPECT with all the R-R divisions added together.

During actual acquisition, the patient is securely immobilized with a belt to restrict body movements, and measures such as aids to maintain the body position with both arms raised are also required. Scanning is also performed at close range with a diameter of rotation of 200–250 mm to improve its resolution.

4. Myocardial SPECT processing conditions

Myocardial SPECT image reconstruction is often carried out by filtered back projection (FBP), but when ^{99m}Tc is used as the myocardial agent it may cause streak artifacts due to hotspots in areas such as the liver, gall bladder, and small intestine, and an

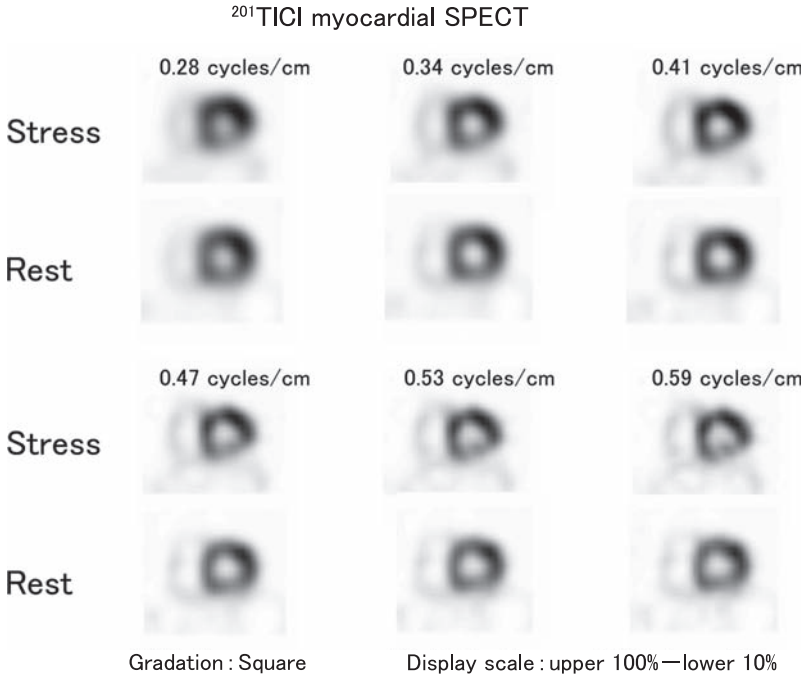

Figure 6 Effect of Butterworth filter by means of cutoff frequency change

increasing number of institutions are therefore using ordered subset expectation maximization (OSEM). It has recently become possible to use algorithms that incorporate spatial resolution correction for OSEM, enabling shorter acquisition times and reduced doses.

The filters used in myocardial SPECT image reconstruction generally comprise Butterworth filtering for preprocessing and ramp filtering for image reconstruction. With Butterworth filtering, a high cutoff frequency yields better resolution but more noise, whereas a low cutoff frequency yields poorer resolution but smoother images (**Figure 6**), and the settings must therefore take into account the device resolution, acquisition count, and noise elimination.

Scatter and attenuation correction are also performed in myocardial SPECT, but the anatomical complexity of the thoracic region means that their use requires caution. The triple energy window (TEW)[12] method used in scatter correction improves the contrast between the cardiac cavity and the myocardium, but the inferior wall is corrected to lower values. It is also necessary to be aware that the count is reduced by 30%−40%. Next, attenuation correction using a method such as Chang's method that assumes a homogenous absorber is problematic, as the thoracic region contains many organs that are heterogeneous absorbers, including the lungs, spine, heart, and mammary glands. Recent developments include the production of an attenuation map by X-ray CT or another method for the use of the CT-based attenuation correction (CTAC) incorporated in OSEM, and segmentation with scatter and photopeak window data for attenuation correction (SSPAC).[13] It is crucial to perform appropriate scatter correction at the same time as attenuation correction.

5. Points to note for myocardial SPECT processing

The projection data obtained from myocardial SPECT are checked for body movement in cine mode prior to image reconstruction. Body movements are mainly seen as defects in SPECT images (**Figure 7**). Therefore, correction to remove body movement artifacts must be performed if the device has with a

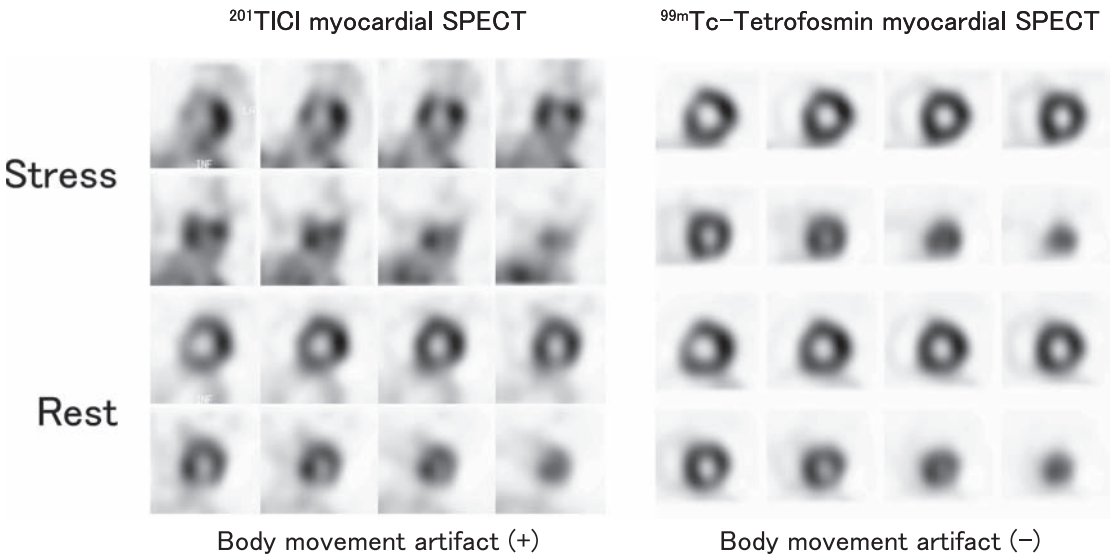

Figure 7 Case of false positive because of body movement TlCl : defect on inferior wall caused by patient movement as he felt nausea provoked by drug stress Tc-TF (re-test on another day) : normal

body movement correction program. However, it is impossible to correct for changes in posture or repeated severe coughs or deep breaths of the patient during acquisition. At best, correction can only deal with misalignments in the X and Y directions for each set of projection data.

The Butterworth filter is a smoothing filter that uses the combination of a cutoff frequency and order to eliminate or reduce the high-frequency component, creating smoother images. When determining the cutoff frequency, a simple method is to start by calculating the SPECT full width at half minimum (FWHM) and regard components above a frequency of 0.5/FWHM (cycles/cm) as noise, but visual evaluation of the clinical data before making a final judgment should not be forgotten.

It is still possible to correct for count reduction by attenuating the lower wall of the myocardium on images after scatter/attenuation correction, but this may result in false positives by reducing the counts of the anterior wall or the apex. Many institutions now use a combination of conventional uncorrected images and CTAC images. CTAC is a procedure whereby attenuation maps produced by X-ray CT are compared with SPECT images to confirm the absence of any misalignment. It is particularly important to pay attention to inconsistencies at the diaphragmatic level or apex as a result of the heartbeat or respiration.

6. Myocardial SPECT image display

Myocardial SPECT images are often displayed both in gray and in color. It is also important to set the appropriate gradient scale to express the relationship between count and concentration, whether linear or square.

Filmless operation has recently become standard, and for the gray display of myocardial SPECT images, it is now normal to make the concentration curve for the exponential or quadratic function (square) between count and concentration with the upper level of the display scale at around 100%−110% and the lower level at around 10%−20% (**Figure 8**).[9] The cutoff for the lower level is adjusted by the power of the number.

For the color display of myocardial SPECT images, a linear gradient is used with the upper level of the display scale at 100% and the lower level at 0% as standard. Areas of healthy myocardial perfusion, mild, moderate, or severe ischemia, and occlusion can be distinguished by variations in the color of color

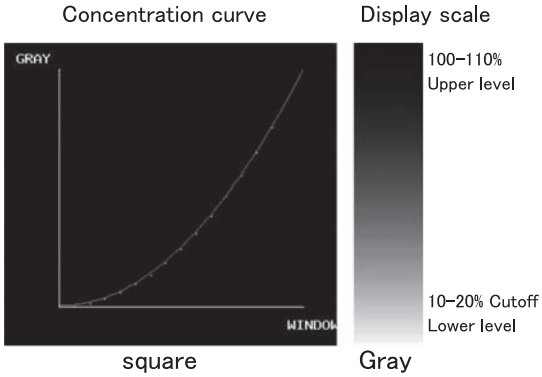

Figure 8 Concentration curve and display scale of myocardial SPECT

codes, and the determination may change as the result of major variations in the upper and lower levels. Particular care is required as the mistaken use of a non-linear gradient may result in misdiagnosis.

In myocardial SPECT image display, it is important that the evaluation of ischemia and viability be performed accurately, and that the right ventricle and the background are also visualized to provide information on cardiac function. When a linear gradient is used, the background concentration is high and the depiction of ischemic areas is difficult (**Figure 9**). Increasing the lower level to 40% removes data about the right ventricle together with the background (**Figure 10**). The use of inappropriate gradient and display scales may affect the visual evaluation of the contrast and size of lesions.

7. Points to note for myocardial SPECT display

Myocardial SPECT images are displayed in a total of 9–16 divisions of 5–7 mm per slice, with the vertical long axis (VLA) from the septum to the lateral wall, the short axis (SA) from the base of the heart to the apex, and the horizontal long axis (HLA) from the inferior wall to the anterior wall (**Figure 11**). As myocardial SPECT compares early and late images, diagnosis is easier if the SPECT slice cross sections for these early and late images are in the same position. A standard layout for myocardial SPECT displays has been proposed in the Nuclear Medicine Image (NMI) with Cardiac Option of the NMI Profile as part of the Integrating the Healthcare Enterprise initiative, and this should be used as reference. VLA, SA, and HLA myocardial SPECT images are displayed so that their maximum myocardial counts are consistent. If a ^{99m}Tc myocardial agent is used, the concentration display may not be the same in patients with high uptake outside the myocardium, and care is required to ensure that the maximum counts in each of the displayed images are the same. Effective measures for dealing with this involve excluding extramyocardial hotspots from the obtained SPECT images during reconstruction, masking hotspots on images after reconstruction,[10] and truncation processing for counts exceeding the maximum myocardial count.[11]

If the secondary capture SPECT images are transmitted to a picture archiving and communication system (PACS) and viewed on a diagnostic display after appropriate processing on the display of a nuclear medicine image processing device, it is vital that the brightness and gradient properties of both the processing device display and the diagnostic display are consistent to ensure that the images are displayed uniformly. The task of establishing uniformity of display is one that should be solved by technicians themselves in order to provide high-quality images with good reproducibility. Personal preferences on the part of the interpreting physician or requesting physician may have a major effect on the final decision. However, we hope that technicians will offer technical explanations and be willing to strive to achieve consensus, with the aim of promoting the standardization of displays based on the advice contained in these guidelines. The Japan Industries Association of Radiological Systems Standards has published a method for using the JIRA TG8-QC pattern for the visual evaluation of displays. Please refer to the Quality Assurance (QA) Guidelines for Medical Imaging Display Systems.[15]

8. Color display optimization

Color display optimization should start with the careful choice of which color scale to use. In

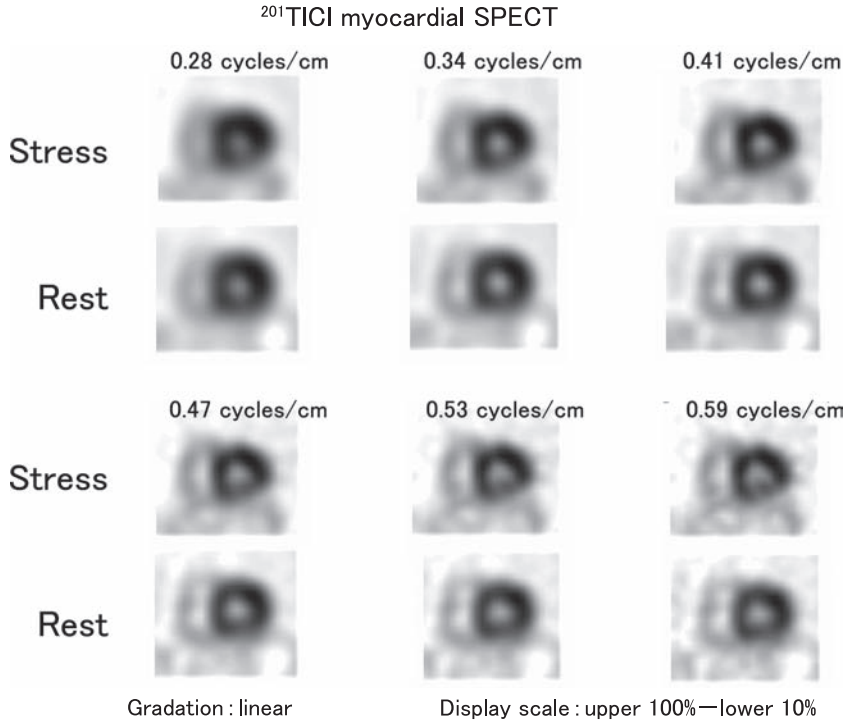

Figure 9 Relationship between SPECT images representation and Butterworth filter use at linear gradient (Difficulty of detection because of high B.G. concentration)

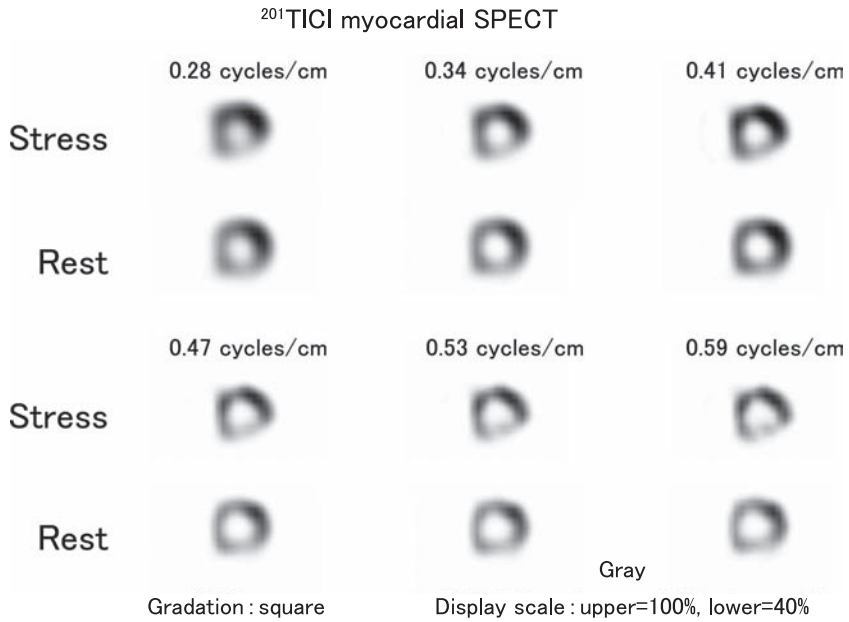

Figure 10 Relationship between SPECT images and display scale at square gradient (Depleted color scale of the right ventricle and the background)

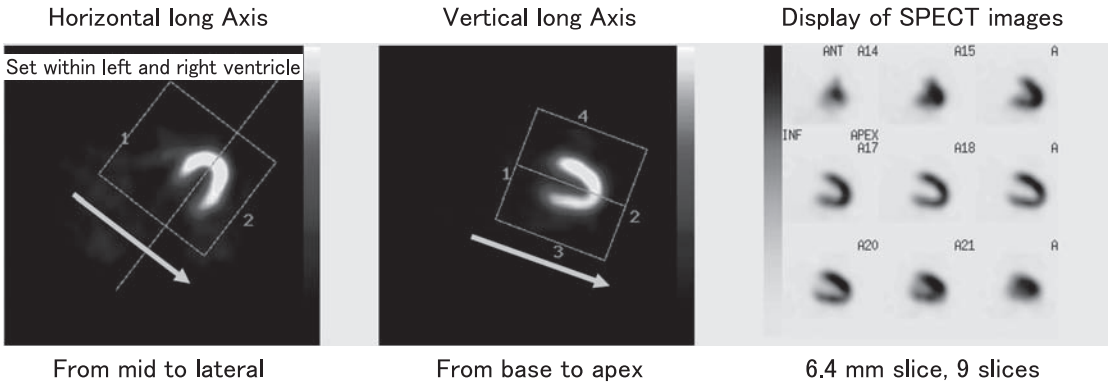

Figure 11 How to reformat and display myocardial SPECT

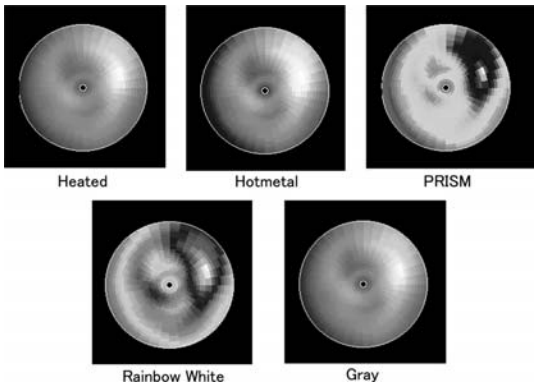

Figure 14 Comparison of myocardial polar map with regard to the color scale

myocardial perfusion SPECT, priority should usually be given to whether or not the visualization of defects corresponds to the diagnostic criteria used by the interpreting physician or requesting physician. For example, simply changing the color scale on a myocardial polar map (bullseye) display may have a major effect on the diagnosis (see **Figure 14** in color). The color codes displayed are input as counts, with their output expressed as 8-bit (256-gradient) values corresponding to red (R), green (G), or blue (B). It is possible to create numerous different color scales by allocating different count–gradient properties to R, G, and B, (see **Figure 1** in color). They can also be converted to black-and-white grayscale by allocating the same count-gradient properties (see **Figure 2** in color). Variation of the RGB color codes changes the shades of low-count regions into borderline ones and normal regions into high-count ones, which may make a major difference to the impression given by the color scale for diagnosis (see **Figure 3** in color).

The first step involved in appropriate color display is to talk to the doctor who will perform the diagnosis before selecting the display color codes. Most nuclear medicine images are displayed in rainbow colors from black to red at 0%–100% for the relative values of the counts, but if the 100% level is not present in the myocardial region (because of extramyocardial hotspots), it may appear that myocardial uptake has decreased. The use of a code other than red, such as white or pink (rainbow white, rainbow pink) for 100% regions makes it possible to confirm the presence of the 100% level in the myocardial region. The use of a color gradient other than a linear gradient (such as a square gradient) for the color display results in major changes in color tone distribution, and care is required as this may affect diagnosis. As shown in **Figure 4** (see in color), in general, when rainbow colors (the figure shows PRISM colors) are used, regions where the count has dropped to 50% are depicted in green (red triangular arrow). The doctor who performs the diagnosis should be aware of the level of the decrease in count expressed by the rainbow shades. In a linear display, there is no major breakdown of the rainbow shades even if the lower level is cut at around 10%, but if a square gradient is used, the shades break down and regions with a decreased count may be overestimated.

With the exception of color codes close to monotone, such as GE color and Hotmetal, a linear gradient is recommended for rainbow colors.

9. Conclusions

Myocardial count is the most important factor in myocardial SPECT acquisition, and the acquisition time and dose should be adjusted to obtain around 100 counts per pixel. As the preprocessing filter settings for myocardial SPECT processing take into account the SPECT device acquisition count and resolution, good images cannot be produced unless a sufficient myocardial count can be obtained. Immobilizing the patient and reducing the SPECT diameter of rotation are effective for reducing image artifacts and improving resolution. The quality of myocardial SPECT is determined by the projection data, and it therefore goes without saying that if the acquired data are poor, this will result in degraded reconstructed images.

The heart is surrounded by heterogeneous absorbers, and given the addition of the heart's own beat and respiratory movements, highly accurate scatter and attenuation correction are currently difficult in myocardial SPECT. Even if scatter correction is carried out, an additional CT scan for the purpose of attenuation correction should be performed, and this should be compared with the conventional uncorrected images.

The clinical evaluation of myocardial SPECT images following the more widespread introduction of SPECT-CT devices and new image reconstruction algorithms will be important for improving the diagnostic performance of myocardial SPECT, and at the very least gradation and display scale settings and display evaluation are essential for the adequate assessment of ischemia and viability.

10. Final thoughts

Imaging protocols for nuclear medicine devices have yet to be fully standardized not only in Japan, but also in European countries and North America. The emergence of combination CT and MRI and nuclear medicine devices is resulting in the clinical use of more and more image reconstruction methods and correction techniques, raising the importance of pressing ahead with the standardization of imaging protocols designed for these new devices.

In addition, amid a global trend to try to reduce the doses of radiopharmaceuticals, it is now time to reconsider imaging protocols for low-dose scanning, particularly of children.

The JSNMT will both continue to consider the standardization of imaging protocols and publish reports. It is our hope that this report will contribute to the standardization of nuclear medicine scanning techniques, not only in Japan but in other Asian countries and worldwide.

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