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

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

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

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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 (Working Group) started work in 2002 with the aim 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 bone scintigraphy 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.

• Bone Scintigraphy

Bone scintigraphy is mainly used for the detection of disorders such as bone metastases of malignant tumors, primary bone tumors, stress fractures, metabolic bone disorders, osteomyelitis, and osteonecrosis and it is the most common nuclear medicine procedure in Japan. Almost 100% of institutions in Japan are now capable of performing whole-body scans.[1] In most cases, however, imaging conditions are determined heuristically, and there are no clear criteria concerning the advantages and disadvantages of SPECT and static imaging as supplementary tests. It means that testing is not being performed on the basis of evidence based medicine (EBM). We are now setting the massive task of standardizing the enormous number of bone scintigraphy tests. Though, imaging and processing are comparatively simple in bone scintigraphy, unfortunately no clear guidelines have been set.

In this section, we provide standard images for general bone scintigraphy and describe the acquisition, processing, and display conditions required for this method of imaging, together with points to note. We hope that these guidelines will serve as a foundation for the future standardization of bone scintigraphy.

1. Devices used for basic image scanning and imaging conditions

Around 70% of the gamma cameras currently mounted in Japan are of the dual-detector type,[1]

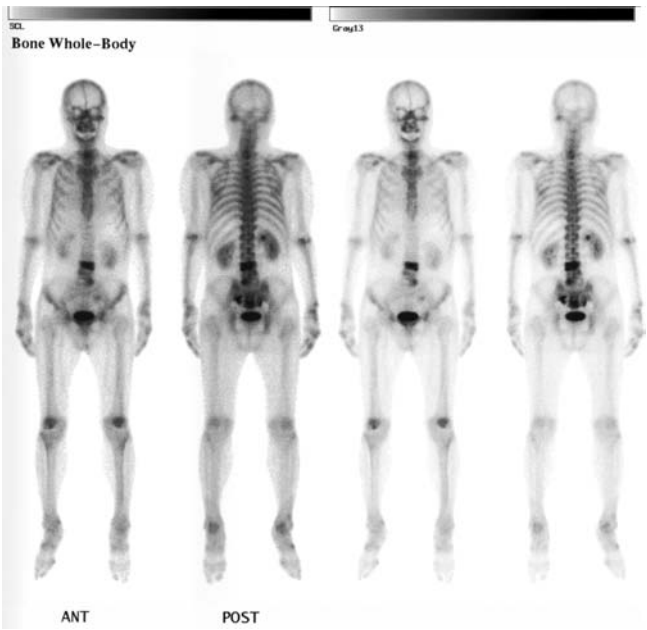


Figure 1 Whole body images (Abnormal accumulation in the third lumbar vertebra and the sacrum.)

which are also widely used for bone scintigraphy. Our description in this section therefore assumes the use of an opposing dual-detector gamma camera device.

Most gamma cameras are fitted with a low-energy high-resolution (LEHR) collimator as standard,[1] and these are generally used for bone scintigraphy. Bone scintigraphy is a test that uses a comparatively large dose of the tracer to obtain a high count rate, and as it also demands high resolution, in this section we assume the use of an LEHR collimator suitable for 140 keV gamma rays. For institutions that do not possess an LEHR-equivalent collimator, a low-energy general-

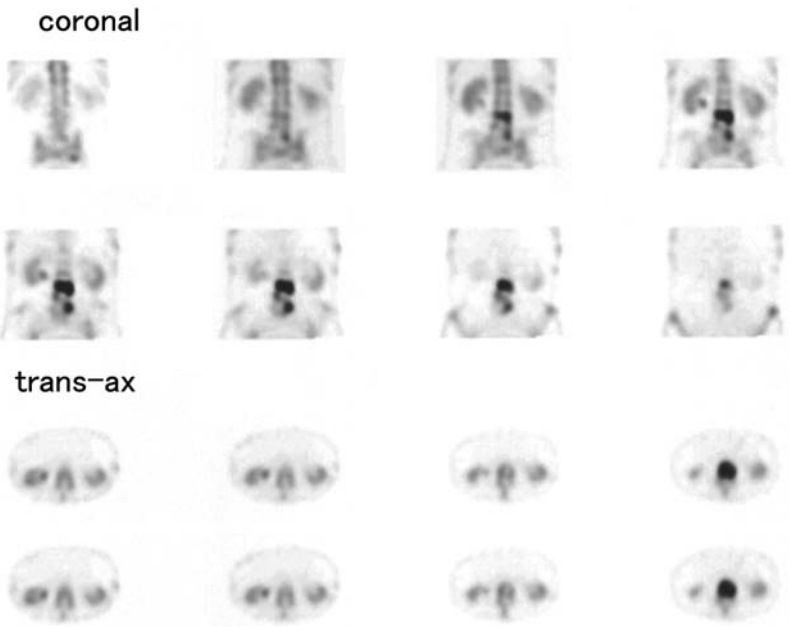


Figure 2 SPECT images (Same case as Fig.1)

Table 1 The imaging conditions of standard images

Scan mode	Whole-body	SPECT
Radiopharmaceutical	^{99m}Tc-HMDP	
Camera type	Opposing dual-detector gamma camera devise	
Dose	740 MBq	
Scan start time	3 hours after the administration	
collimator	LEHR	
Energy window	140 keV ± 10%	
Scan mode	–	continuous
Imaging time	15 min	10 sec/step
Scan speed	15 cm/min	–
Scan angle	–	6°
Projection number	–	60 views (30 steps)
Matrix size	256 × 1024	128 × 128
Zoom	–	–
Pixel size (mm)	2.18	4.67
Pre-processing filter	–	Butterworth
(order・cutoff frequency)	–	8.0, 0.86 cycles/cm
再構成法	–	OSEM
Subset・iteration	–	6・5
Attenuation correction and μ value	–	No study
Scatter correction	–	No study

purpose (LEGP) collimator may also be used.

As standard images, **Figure 1** shows a whole-body image and **Figure 2** shows SPECT coronal and transaxial images. The imaging conditions for these are listed in **Table 1**. The standard energy window has a photopeak of 140 keV ± 10%. This can be varied depending on conditions such as the performance of the gamma camera, choice of collimator, and throughput in individual institutions. However since several bone scintigraphy scans are usually performed on the same day and ^{99m}Tc has a short half-life of 6 hours, study duration time of around 30 min is generally allowed for each patient. A whole-body scan takes around 15 min of this 30-min timeframe, and the planning how to use the remaining 15 min is very important. It should be kept firmly in mind, that depending on which modality, static imaging or SPECT has chosen the capacity to detect lesions can be affected. The remainder of this section will describe the procedure in detail.

2. Pretreatment, radiopharmaceuticals, and administration

The two main bone scintigraphy agents currently used ^{99m}Tc-MDP and ^{99m}Tc-HMDP, do not differ significantly in their effectiveness. However, they somewhat vary in terms of blood clearance; the bone–background ratio may vary according to the time between administration and the start of imaging. According to its package insert, if HMDP is used, imaging can begin from 2 hours after administration, but hemodialysis patients or elderly individuals with reduced renal function have a lower excretion rate that may result in images with a higher background, making it preferable to wait at least 3 h before imaging. It is important to pay attention to test protocols, such as establishing consistency of timing between administration and imaging in a given institution.

The standard images provided here were obtained using a dose of 740 MBq. According to the questionnaire results,[1] 740 MBq is the most commonly used dose, but a significant number of institutions also use a dose of 555 MBq. The dose should be determined with reference to the patient's body weight while taking into account factors such as the test time, sensitivity and resolution of the device used, but no strict standards have been set out. If a bone scintigraphy agent is administered, before or after an organic iodine contrast agent, it has been reported that in rare cases this may hamper its uptake in bone,[2] so it is vital to avoid giving an organic iodine contrast agent for at least an hour after bone scintigraphy agent administration.

Pretreatment consists in instructing patients to ingest fluids after administration to increase urinary excretion and blood clearance immediately before the scan. It is important to be aware that performing imaging with an incompletely emptied bladder may directly cause pelvic findings to be overlooked. Another potential pitfall is the generation of false-positive images due to clothing contamination and similar causes, and this must be carefully explained to the patient. In addition to false-positives, metal items such as buttons, belt buckles, and accessories may also result in false-negative images.

3. Whole-body scanning

(a) Points to note for acquisition

The basic position for whole-body scanning is bilaterally symmetrical. The main point is to ensure the symmetry of parts such as the head, fingers, and toes, and to avoid rotation of the trunk. If possible, the fingers should be extended with the palms opening downward, as current gamma cameras are capable of resolving the fingers in this position. Bone metastasis characteristically exhibits an asymmetrical uptake pattern, and the primary objective is not to overlook this. Efforts to use the same position consistently help ensure reproducibility during follow-up. Care should also be taken to prevent body movements during prolonged scans by measures such as e placing a sponge over the head and immobilizing the trunk and toes with belts.

Count and resolution are the two most important factors determining image quality, and these are dependent on the performance of the device and collimator used. However, the count can be increased

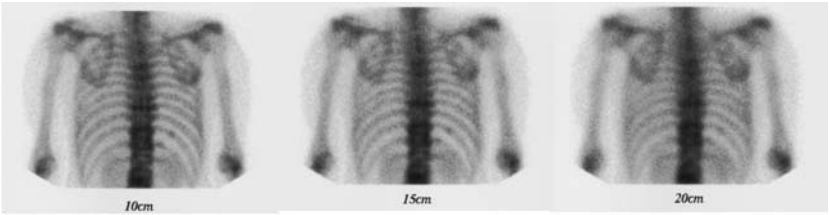


Figure 3 Deference of image quality when the distance between the patient and the collimator is 10 cm, 15 cm and 20 cm.

by varying the dose (depending on body type and age), changing the time at which imaging is started (the degree of attenuation), and adjusting the scanning speed. It is possible to prevent the spatial resolution from deteriorating by means of approximate acquisition.

It should be reiterated that all these factors interacting in a complex manner affect image quality during scanning. **Figure 3** shows thoracic images when the distance between the patient and the collimator is varied. Today's gamma cameras use automatic infrared proximity controls and prescanning to enable approximate acquisition. In terms of scanning speed, the published guidelines recommend a speed of 10−15 cm/min, based on the concept of visual equivalence with static images,[3] and the settings for bone scintigraphy whole-body scans should also follow this speed recommendations. A 256 × 1024 matrix is generally used.

Image processing techniques reducing noise while maintaining spatial resolution have been developed in recent years, and these are now coming into use in planar images. The algorithms used by different device manufacturers vary, but they are considered to reduce acquisition time greatly by improving noise attributes.

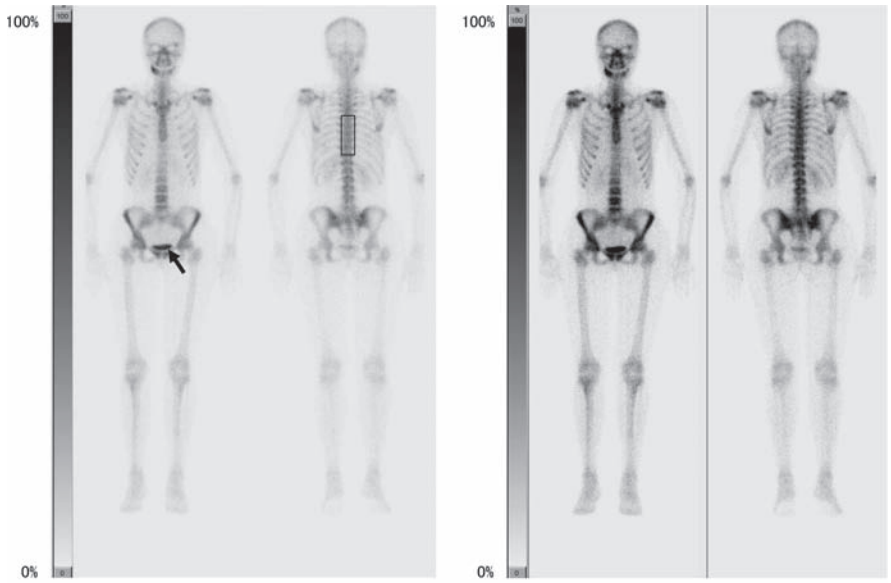
(b) Points to note for processing

Nuclear medicine images are relative displays, in which the pixel value for the maximum count in that image is displayed as 100% of the 256 gradients. In whole-body scans, the bladder is a particularly high-count region that is treated as 100%, and this frequently reduces the concentration in bones being the actual objective of visualization. Urine remaining in the bladder has a major effect on the concentration of the tracer in bones, and adjusting for this by visually lowering the upper level is a cause of interoperator error. The recommended method is to set a rectangular ROI in an area of normal uptake in bone (generally the posterior view of a thoracic vertebra, which has high bone density and is not susceptible to the effect of attenuation) and make the maximum count there the 100% display, with overcounts that exceed that of bone being truncated. **Figure 4** shows the use of this method in a whole-body scan. If there is a large amount of remaining urine, however, the patients should first be instructed to urinate, also it should be noted that this method may not work well if the ROI is set in an area with multiple bone metastases or in cases of super bone scan.

(c) Points to note for display

Bone scintigraphy deals with images that encompass a wide range of count regions from high-count to low-count, and two types of image display are therefore used, one matched to axial skeleton bones such as the spine or pelvis (high-count areas) and the other matched to peripheral bones or soft tissue (low-count areas) for ease of viewing. It is important to establish the regularity of these two types of image display to ensure that gradients and concentrations always remain consistent irrespective of the operator.

After the truncation processing described in (b) above, two images with obvious variety are displayed : such as one standard image with a 0%−100% linear gradient and the upper level lowered to, for example, 70% for higher concentration (**Figure 5**), and another standard image with a 0%−100% linear gradient with, for example, an upward convex logarithmic gradient (**Figure 6**). Images with a 0%−100% linear gradient



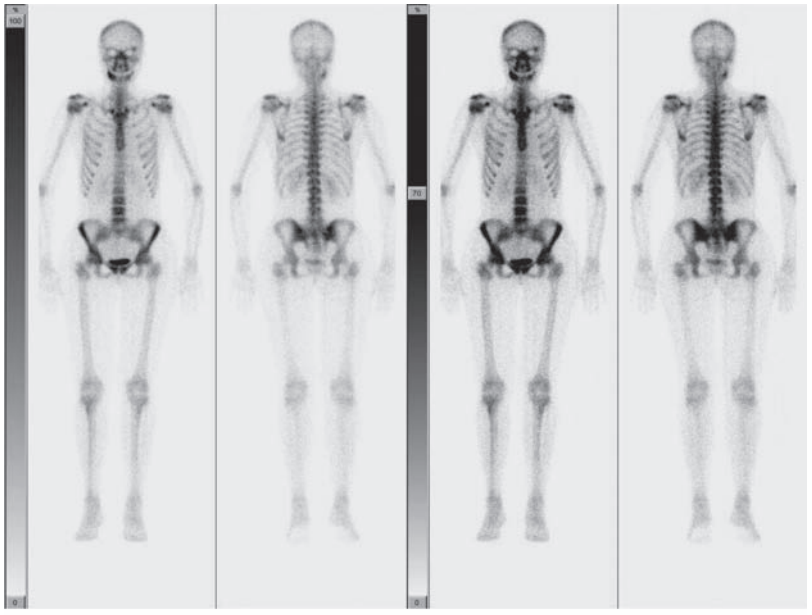
Unprocessed images

(The high count of the bladder is treated as 100%. The concentration of bone is low.)

Truncation images

(The count of thoracic vertebra is treated as 100%. The concentration of bone is good.)

Figure 4 The general truncation process of whole-body images.



After the truncation process
0–100% linear gradient

After the truncation process
0–70% linear gradient

Figure 5 2 images display

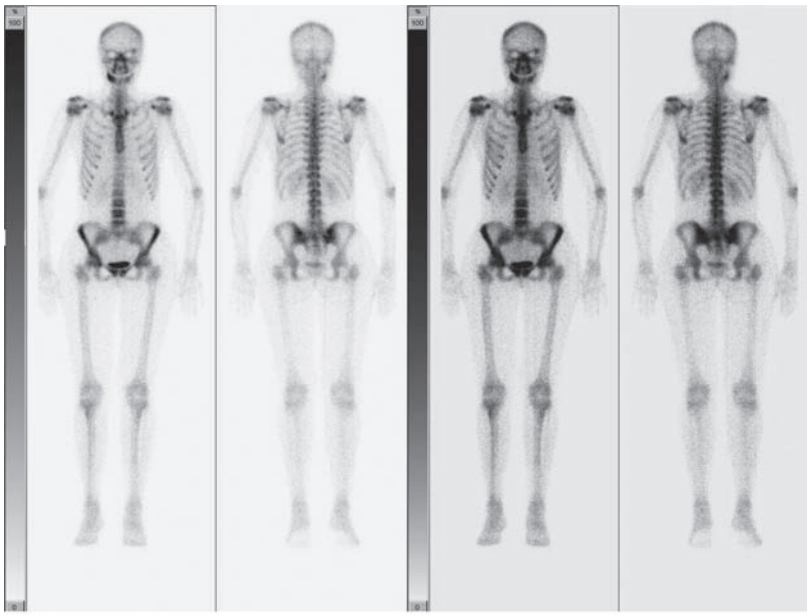


Figure 6 2 images display (linear gradient and upward convex logarithmic gradient)

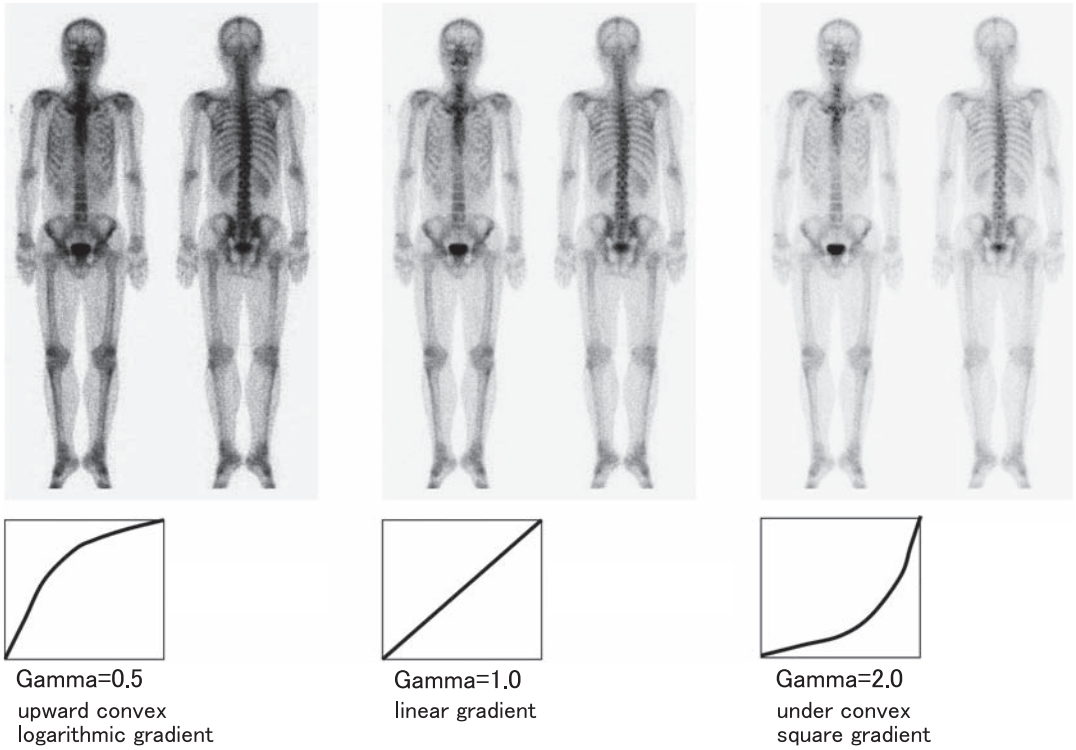


Figure 7 The effect of change in gradient on the whole-body images.

are always used as the standard because the diagnostic criteria for bone scintigraphy can be expressed without modification in terms of the display of high and low uptake as shades of concentration. Displaying the lower level as 0% is significance because uptake in soft tissue may also provide useful diagnostic information. Therefore, the concentration scale and upper and lower percentage values must always be shown on the display, and it is important to provide the interpreting physician with correct information about the gradients and concentrations on the images displayed. For reference, **Figure 7** shows the effect of changes in gradients on an image.

4. Static imaging

(a) Points to note for acquisition

Whole-body scans can only provide information from the anterior and posterior views. The head (cranium, skull base, and nasal cavity), chest (sternum, ribs, thoracic spine), and pelvis (pubic bone, sacrum) have a three-dimensional structure, and data from the deep layers are important. When visualizing bones that are difficult to view only from the anterior and posterior perspectives, additional data must be obtained from different directions. This can be effectively provided for the head by lateral views from both sides, and for the chest and pelvis from bilateral oblique views. For the limbs, magnified static acquisition is effective.

Imaging conditions vary between studies, but in view of those given in several different types of documentation,[1] the guideline values are as follows acquisition magnification 1.0–1.5 × (with further magnification for the limbs), 500 kcounts with a 256 × 256 matrix, and 1000 kcounts with a 512 × 512 matrix, controlled by a timer. For a dose of 740 MBq, imaging takes around 2–5 min. Approximate acquisition is also important to prevent the resolution from deteriorating. Image processing techniques can also be used to reduce noise while maintaining spatial resolution, in the same way as for whole-body scans.

(b) Points to note for processing

Additional acquisitions must be processed in such a way that lesions can be clearly diagnosed. If the field of view contains intense hotspots that do not represent abnormalities, such as the bladder or injection leakage, truncation processing must be used in the same way as for whole-body scans to ensure that the maximum count is that of bone.

(c) Points to note for display

Images should be displayed so that lesions are shown at appropriate concentrations in order to properly reflect information from directions that could not be observed in whole-body scans. A 512 matrix size is used to enable fine structures to be shown in detail. Display on monitor screens follows the description given in the previous section.

5. SPECT

(a) Points to note for acquisition

As described above for static acquisition, the head (cranium, skull base, nasal cavity), chest (sternum, ribs, thoracic spine), and pelvis (pubic bone, sacrum) have a three-dimensional structure, and as data from the deep layers are important, these can be replaced by SPECT. SPECT is also effective for identifying bone metastases in vertebral bodies.[4] It has the advantages of better contrast resolution than static scanning, It also enables the creation of multidirectional planar images viewed from the projection direction while maintaining contrast resolution through the use of maximum-intensity projection (MIP). But SPECT also has the disadvantage of inferior resolution, as compared to static imaging.

Imaging conditions for single SPECT are a 128 × 128 matrix, magnification 1.0 ×, and 360° acquisition by continuous rotation. Taking into account the resolution obtainable under these conditions, the number of projections should be about 60 and the pixel size around 5 mm. Unlike other types of SPECT, the dose of the tracer required for bone scintigraphy is comparatively large, with around 50% of the amount accumulating in bone, meaning that satisfactory images can be obtained with an acquisition time of 10 s/step (approximately 5 min).[5] Approximate acquisition and immobilization with belts or such as with the use of

belts are important to prevent further worsening of resolution. Sites that require additional imaging are identified on whole-body scans, and SPECT is performed if it is judged to be more valuable than static scanning. The role of bone SPECT is to identify the location and extent of pathological uptake, and to confirm the distinction between benign and malignant lesions. The protocol should be set up so that SPECT acquisition time is equivalent to that spent on static acquisition in two directions.[5] The necessary issue to consider is how much extra information can be obtained in a total test time of 30 min by adding SPECT to a whole-body scan.

There is little evidence that whole-body SPECT (two or more continuous SPECT scans) for bones provides data because of patient's stress in the test. However, this is not the ground for rejection of the whole-body SPECT entirely. MIP-processed images have dramatically improved image contrast. In the case of bone scintigraphy, however, it is risky to try to reach a definitive diagnosis based on whole-body SPECT MIP images alone, and they should be regarded as supplementary to whole-body scans.

Scatter and attenuation correction are generally not used. It is unclear whether the use of collimator broad correction simultaneously with iterative reconstruction is of any value in bone SPECT or not, and we here limit ourselves to saying that this may be feasible on some devices.

(b) Points to note for processing

Almost all bone SPECT images contain hotspots, which can cause streak artifacts in FBP reconstruction. OSEM should be used for reconstruction if possible. There is no problem with using a Butterworth filter for preprocessing, but great care is required when setting the cutoff frequency. OSEM does not involve a particular set number of subsets or iterations, but we recommend 10 projections per subset, and that at least five iterations are used. The number of data updates is determined by the number of subsets multiplied by the number of iterations, but to build up the number of updates it is preferable to increase the number of iterations rather than using a large number of subsets that contain the least possible amount of projection data. For projections from 60 directions, for example, six subsets and 5–6 iterations would generally be used. See the images in **Figure 8**, which compare SPECT reconstructions of pelvic bone processed by FBP and OSEM.

OSEM reconstruction is particularly useful when problems occur, such as poor urine elimination from the bladder and injection leakage in the arm. Institutions that are currently unable to perform OSEM processing, however, can obtain images almost comparable to those provided by OSEM by using FBP processing after truncating the counts for non-bone hotspots that exceed the maximum count for bone from the projection data, although this method has little effect on the signal-to-noise ratio in low-count areas.

(c) Points to note for display

Like the other types of SPECT, a downward convex curve gradient (square) may also be used in bone SPECT, but soft tissue other than bone should also be visualized to some extent to make site identification easier. Either a linear gradient with the lower level cut at 5%–10%, or a gently sloping downward convex gradient (square) may appropriately be used. Additional MIP images may be produced to enable the extent of uptake to be diagnosed from multiple directions, but these should always be displayed alongside SPECT images to provide accurate positional data on the site of uptake. SPECT displays consist of transaxial and coronal images, although sagittal images of the spine may also be added. MIP displays generally include eight directions. **Figure 9** shows coronal and transaxial images of a patient with abnormal uptake in the lumbar spine. The difference in the display gradient for the transaxial image only is also shown. Display on monitor screens follows the description given in the previous section.

6. Conclusions

At present, the objectives of bone scintigraphy can almost be gained by whole-body scans. Static scans, SPECT, and MIP may appropriately be regarded as

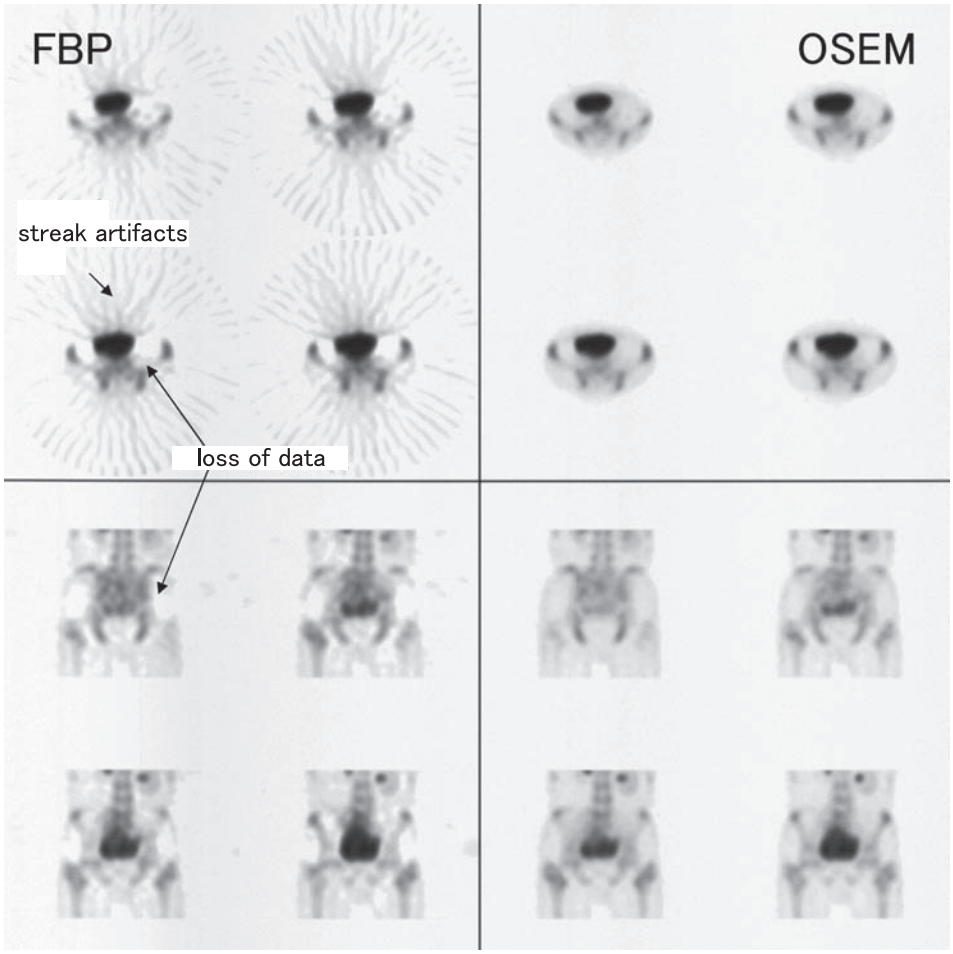


Figure 8 Comparison of FBP and OSEM in the pelvic bone SPECT. (OSEM processing conditions : 60views, 6 subsets and 5 iteration)

supplementary procedures for improving diagnostic accuracy. Conversely, diagnosing solely based on MIP images produced from whole-body SPECT entails disadvantages, including the lack of positional information, and cannot be recommended at all. Nevertheless, it doesn't mean that we should reject SPECT completely, and if there is uptake in areas such as the spine, SPECT should be proactively performed. Transaxial images can be used to differentiate between benign and malignant uptake in the spine.[4] If the results of a whole-body scan are reported to a requesting doctor simply with the comment that there is abnormal uptake in the spine, additional plain X-rays or MRI scanning will be requested, negating the meaning of the bone scintigraphy. The use of appropriate oblique static imaging or SPECT increases the benefit of bone scintigraphy, and leads to the formulation of evidence.

The most important factors for the image quality of whole-body scans are scanning speed and approximate acquisition. With respect to scanning speed, guidelines have been issued recommending a speed of 10–15 cm/min, equivalent to static images,[3] but at present there are no particular specifications for other elements. When performing a large number of tests in actual clinical settings, however, it became obvious that not all patients are capable of undergoing long-drawn-out scanning without any body movement. It

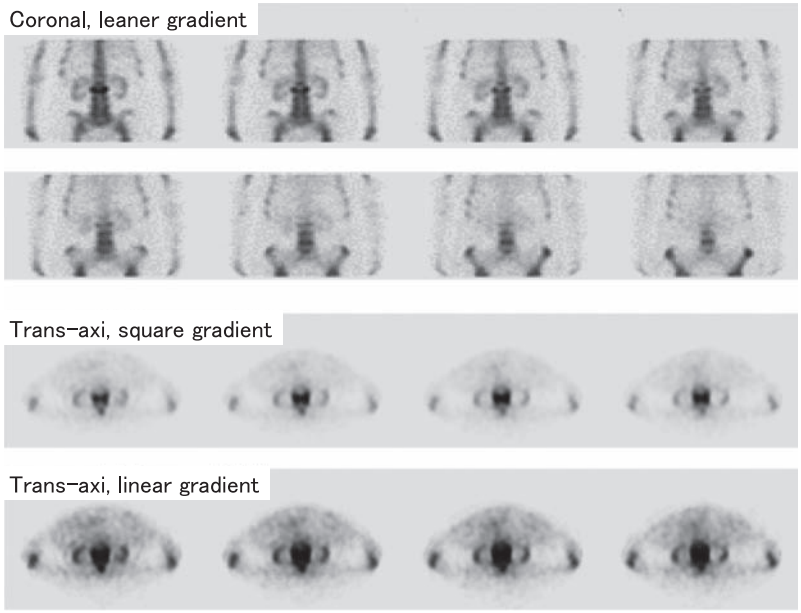


Figure 9 SPECT of lumbar spine (Visualization of high accumulation region and the soft tissue region is different due to the change gradient.)

may be necessary to use static split images, or to increase the scanning speed for a whole-body scan. It is important to implement the basics of nuclear medicine scanning properly while considering factors including the dose, scan speed (acquisition count), approximate acquisition (resolution), and the appropriate collimator to use (resolution and sensitivity) for each patient.

If the time allowed for the entire test is 30 min, a practical protocol might consist of a 15-min whole-body scan with the addition of either static images other than anterior and posterior views, or one SPECT scan (or two scans if possible). Some institutions prioritize static imaging and use the fastest scanning speed in order to scan anterior and posterior views as well, but this can only be described as putting the cart before the horse. Of course, in institutions where more than 30 min can be allowed for the test, then a whole-body scan together with multiple static and multiple SPECT scans could be performed. However, it should also be considered whether this really improves the diagnostic performance or if it just imposes discomfort on the patient. The guideline on bone scintigraphy lies, at a minimum, in following the descriptions given in this section, without being swayed by the preferences or biased opinions of the diagnosing doctor.

7. 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.

8. Reference

1) Niida H, Ohya N, Katafuchi T, et al : Questionnaire Report for Practical Conditions of Nuclear Medicine Ezamination and Standardization of Image Acquision. Processing, Display and Output. Japanese Society of Nuclear Medicine Technology, **24** : 95−118, 2004.
2) Subcommittee of Radiopahrmaceuticals, Medical and Pharmaceutical Committee, Japan Radioisotope Association : Effect of Drugs on Biodistribution of Radiopharmaceuticals. Radioisotopes, **56**(1) : 35−48, 2007.
3) Subcommittee for Radionuclide Imaging and Nuclear Medicine Technology Medical and pharmaceutical Committee Japan Radioisotope Association : Guideline for Optimum Scanning Speed on Whole-Body Imaging. Radioisotopes, **51**(7) : 272−284, 2002.
4) Kosuda S, Arai S, Yokoyama H, et al : Differential Diagnosis between Osseous Metastasis and Degenerative Joint Disease of the Vertebrae by Bone SPECT : Analysis by Accumulation Pattern. Kaku Igaku, **31**(6) : 613−618, 1994.
5) Subcommittee of Nuclear Medicine Japanese Society of Radiological Technology : Fundamentals of SPECT imaging. 94-97, 2002.
6) Japan Industries Association of Radiological Systems Standards (JAPANESE ENGINEERING STANDARDS OF RADIOLOGICAL APPARATUS X-0093 * A-2010) : Quality Assurance (QA) Guidelines for Medical Imaging Display Systems.