



Computed Tomography (CT) Protocols Associated with Cardiac and Bone Single-Photon Emission Computed Tomography/CT (SPECT/CT) in Korea

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Abstract

Purpose Single-photon emission computed tomography/computed tomography (SPECT/CT) is an advanced hybrid nuclear medicine technology that generates both functional and anatomical images in a single study. As utilization of SPECT/CT in Korea has been increasing, the purpose of this study was to survey its application of cardiac and skeletal SPECT/CT imaging for protocol optimization.

Methods We surveyed CT protocols established for cardiac and skeletal SPECT/CT. We searched the guidelines for the CT protocols for SPECT/CT and reviewed the literature recently published.

Results Among 36 hybrid SPECT scanners equipped with four or more multi-channel detector CTs (MDCTs), 18 scanners were used to perform cardiac studies at both very low current CT (30–80 mA; 11.1%) and ultra-low current CT (13–30 mA; 88.9%). Among the 33 scanners, very low current (≤ 80 mA) CT or low current CT (80–130 mA) was used in 23.5%, and 41.8% for spine disorders, and in 36.4% or 30.3% for foot/ankle disorders, respectively. In the CT reconstructions, slice thickness of 5 mm for cardiac studies was most commonly used (94.4%); thinner slices (0.6–1.0 mm) for spine and foot/ankle studies were used in 24.2% and 45.5%, respectively. We also reviewed the international guidelines.

Conclusions The results and current recommendations will be helpful for optimizing CT protocols for SPECT/CT. Optimization of SPECT/CT protocols will be required for generating the proper strategy for the specific lesions and clinical purpose.

Keywords SPECT/CT · CT protocols · Optimization

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Introduction

Single-photon emission computed tomography/computed tomography (SPECT/CT) provides information on the distribution of radiotracer, displaying as functional tomographic image and anatomical tomographic image in a single format. SPECT/CT can be performed on any region of the body, following acquisition of two-dimensional planar images. Utilization of SPECT/CT is increasing in hospitals throughout Korea; however, there currently exists no specific standards, methods, or protocols for obtaining images. Korean hospitals have just recently acquired SPECT/CT capability as the first SPECT/CT device was installed in 2004, though not fully adopted due to the functional limitations on CT performance compared to the dedicated diagnostic CT scanners already in use and the lack of medical reimbursement. There are a few obese patients and some cancer patients who have benefited from them for attenuation correction and localization of the metastatic lesions. As improved CT technology applied for SPECT/CT, the use of this modality continues to increase in general. Hybrid SPECT scanner with multi-slice CT scanner that requires extensive knowledge for operating it appropriately, nuclear medicine physicians should be capable of carrying out such a task.

We undertook this investigation to explore how various Korean healthcare facilities created optimal SPECT/CT protocols, as well as to understand the current status and utilization of SPECT/CT in facilities overall. A literature search was performed that focused on the application of SPECT/CT for skeletal imaging, followed by a discussion on established international guidelines and protocols that are currently in common use.

Materials and Methods

Survey of Current Status of SPECT/CT in Korea

From February to March 2020, the Quality Control Committee from Korea Society for Nuclear Medicine (KSNM) contacted 31 nuclear medicine institutes and 2 equipment companies, gathering information on equipment, slice thickness, and CT acquisition protocols pertaining to cardiac and skeletal SPECT/CT.

Search Strategy and Study Selection

We performed our search using synonymous terms. We searched PubMed (Medline), EMBASE, and OVID Medline, Cochrane Library, KoreaMed, MedRIC, and KSI KISS to identify studies published in English between Jan 1, 2017 and Mar 13, 2020. We excluded studies of cancer, metastases, malignancies, and physics. We also excluded

reviews, case reports, and investigations not written in English. The search terms used were Bone SPECT/CT-related index words (“Spine SPECT/CT” OR “Hip SPECT/CT” OR “Pelvis SPECT/CT” OR “Knee SPECT/CT” OR “Foot SPECT/CT” OR “Ankle SPECT/CT” OR “Shoulder SPECT/CT” OR “Wrist SPECT/CT” OR “Bone SPECT/CT”).

Results

Survey Results of CT Settings Used for SPECT/CT

Of the 31 institutions in Korea housed with 39 hybrid SPECT scanners equipped with CT scanners, 29 institutions maintaining 36 SPECT scanners with four or more CT channels were included in this study. A total of 36 and 35 hybrid SPECT/CT scanners provided information on whether they were used for cardiac or skeletal studies, respectively. For the remaining three scanners at three institutions, two institutions did not conduct any skeletal studies and one provided information on cardiac SPECT/CT protocols only. In the end, a total of 18 and 33 CT protocols of hybrid SPECT scanners were examined for cardiac and skeletal studies, respectively (Table 1).

We found that 18 of the 36 SPECT/CT scanners were used to perform cardiac studies (50.0%); CT protocols for cardiac SPECT/CT were applied to correct attenuation and localization. These scanners featured both very low current CT (30–80 mA; 11.1%) and ultra-low current CT (13–30 mA; 88.9%).

SPECT/CT for skeletal imaging was a more common procedure and performed by 91.7% of the 33 scanners identified. In this cohort, the same protocols for SPECT/CT were used for both spine and foot/ankle studies (23/33; 69.7%). Among the applications of SPECT/CT for diagnosing spinal disorders, very low current (≤ 80 mA) CT was used in 21.2% (7/33) of the scans and low current CT (80–130 mA) in 45.5% (15/33) of the scans. For SPECT/CT utilized in foot/ankle imaging, low current (80–130 mA) or very low current (≤ 80 mA) CT was used in 36.4% (12/33) and 24.2% (8/34) of the cases, respectively. Of the total cohort, 18 SPECT/CT devices were equipped to perform iterative reconstructions. Rotation times of 0.5–0.8 s were used in all 77.8%, 78.8%, and 78.8% of the cardiac, spine, and foot/ankle reconstructions, respectively. Likewise, a pitch of 0.94:1–0.95:1 was used in 50.0%, 60.6%, and 60.6% of the cardiac, spine, and foot/ankle reconstructions, respectively.

In CT scans for reconstructions of cardiac SPECT/CT analyses, a slice thickness of 5 mm was used in 94.4% of the institutions; thinner slices (0.6–1.0 mm) were used in 24.2% (8/33) and 45.5% (15/33) of these institutions for spine and foot/ankle reconstructions, respectively. A 512×512 matrix size for CT was used throughout.

Table 1 Survey results of CT settings for SPECT/CT in a total of 31 institutions in Korea

Regions	Cardiac		Spine		Foot/ankle	
Scanners (<i>n</i> , %)	18	50.0%	33	91.7%	33	91.7%
Acquisition						
Voltage (kVp, <i>n</i>)	80/100	2	100/110	8	100/110	10
	110/120	12	120	19	120	17
	130	3	130	4	130	4
	140	1	140	2	140	2
Current (mA, <i>n</i>)			30–80	7	30–80	8
	13–30	16	80–130/100–130	15	80–130/100–130	12
	30–80	2	30–200/200–230	7	30–200/200–230	9
Rotation time (s, <i>n</i>)			80–300/300–350	4	80–300/300–350	4
	0.5–0.8	14	0.5–0.8	26	0.5–0.8	26
	1.0	2	0.9–1.0	6	0.9–1.0	6
	1.5	2	1.5	1	1.5	1
Pitch (<i>n</i>)	0.85:1	1	0.85:1	2	0.85:1	1
	0.94–0.95:1	9	0.94–0.95:1	20	0.94–0.95:1	20
	1–1.2:1	4	1–1.2:1	8	1–1.2:1	8
	1.25–1.5:1	3	1.25–1.375:1	3	1.25–1.375:1	4
Reconstruction						
Slice thickness (mm, <i>n</i>)			0.6–1.0	8	0.6–1.0	15
	2.0	1	1.25–1.5	8	1.25–1.5	7
	5.0	17	2.0–2.5	10	2.0–2.5	8
			3.0–5.0	5	3.0–5.0	3

Literature Search and Suggestions for the CT Protocols Used in SPECT/CT

Guidelines of SPECT/CT

The Society of Nuclear Medicine and Molecular Imaging (SNMMI) [1], the International Atomic Energy Agency (IAEA) [2], and the European Association of Nuclear Medicine (EANM) [3] all commonly use attenuation correction for CT imaging in SPECT/CT. Table 2 summarizes the CT protocols of SPECT/CT proposed by each of these agencies. The SNMMI guideline recommended that attenuation correction or localization CT should be performed at a “low mA setting” and that diagnostic CT would follow at a “standard CT mA setting,” but no specific protocols were given. More specific guidelines has been provided by IAEA and EANM. The attenuation correction or localization protocols (i.e., those ≤ 40 mA) [1–3]. The EANM guideline for SPECT/CT recommended that different slice thicknesses should be used to evaluate distinct regions between extremities and the spine (Table 2). A slice or section ranging from 0.5 to 0.8 mm thick is required to achieve spatial resolution in all three dimensions [4]. Multi-slice CT images in the axial plane with thinner slice generate higher-quality coronal and sagittal images; this is the reasoning behind the application of axial images for reconstructions using multi-planar reformation

(MPR) and three-dimensional (3D)-CT. In Figs. 1 and 2, post-processing MPRs using coronal and sagittal images (panel a) that were obtained with thinner slice along the axial plane shows the anatomy of the lesions much more clearly than the coronal and sagittal images (panels b) from thicker slices of along the same plane using the acquisition settings that include 120 kVp, 50–120 mA, and a rotation time of 0.95:1.

The Korean Society of Radiology (KSR) has published two guidelines for the use of dedicated CT scanners: guidelines for the CT scan and retests [5] and guidelines for the justification and optimization of CT studies [6].

However, no organization has provided any clearly defined parameter for CT acquisition such as collimation, table increment, pitch, scan field, reconstruction field of view, and window settings. It is also desirable to obtain the optimal CT image quality while reducing radiation dose to a minimum [1–5].

Literature Search of Bone SPECT/CT Used Over the Past 3 Years

We reviewed 13 original articles that focused on SPECT/CT for spinal imaging [7–19], eight that focused on SPECT/CT of the foot and/or ankle imaging [19–26], ten that focused on SPECT/CT at the knee imaging [19–21, 27–34], six that focused on SPECT/CT for hip imaging [19, 35–39], and four

Table 2 International guidelines for CT protocols for SPECT/CT

	Attenuation Correction/Localization	Diagnostic
SNMMI	140 kVp	140 kVp
	1–2.5 mA	80 mA (skeletal CT: lower mA)
IAEA	140 kV	140 kV
	1–2.5 mA	1–2.5 mA
	256 × 256 matrix	512 × 512 matrix
EANM	5 mm slice thickness	5 mm slice thickness
	80–130 kVp	80–130 kVp
	2.5–40 mA	40–335 mA
	512 × 512 matrix	512 × 512 matrix
	1–5 mm slice thickness	0.33–2.0 mm slice thickness (extremities), or 0.33–5.0 mm slice thickness (spines)

that focused on SPECT/CT for wrist imaging [19, 40–42]. Two of the publications on spinal imaging included no information on device settings or on slice thickness, and one publication each pertaining to foot/ankle and knee imaging harbored no information on optimizing slice thickness. All studies featured SPECT/CT scanners of various makes and models, including those manufactured by Philips, General Electric (GE), and Siemens. Parameters such as tube voltage, tube current, slice thickness, and pitch differed across the board, though the matrix size was consistent at 512 × 512. Various protocols for CT were used by each institution or research facility. Diagnostic CT protocols utilizing 40–400 mA accounted for 46.1% of the reports of spine SPECT/CT and 50.0% of those focused on the wrist and shoulder. A low-dose CT protocol (≤ 100 mA) was applied in 87.5%, 81.8, and 66.7% of cases of SPECT/CT used for diagnosis of foot/ankle, knee, and hip disorders, respectively. A slice thickness of 0.33–2 mm was commonly used. These CT protocols are summarized in Table 3.

Discussion

In this study, we investigated and identified the current status of SPECT/CT for clinical use throughout Korea, primarily focusing on the use of SPECT/CT for evaluating cardiac and bone disorders. Importantly among our results, we found there was little use of cardiac SPECT with attenuation correction of CT, and this may be because there are few patients in Korea who are severely obese and typically evaluated with this modality. One guideline for SPECT/CT only commented a reconstruction parameter of CT, axial slice thickness [2], and we also investigated axial slice thickness as a post-

processing parameter in this study. We are to familiarize the CT techniques for post-processing as well as acquisition of CT in considering post-processing reconstruction parameters affect the CT image quality. Herein, we briefly informed the readers of the post-processing as well as acquisition of CT to help optimization of SPECT/CT protocols in clinical purpose.

Obtaining the optimal CT image while keeping the dose of radiation to a minimum can be conducted by decreasing tube voltage, tube current, and rotation time as well as increasing pitch. For implementing and evaluating optimization protocols, the report on dose information report can provide useful information for reducing radiation exposure [6]. If you reduce the tube current or tube voltage in an attempt to reduce the radiation dose excessively, you will see decrease in contrast resolution and increase in electrical noise and thus poor image quality. On the other hand, it is also critical to remember that the diagnostic performance of images that result from a higher radiation dose may be comparable to an image produced using low-dose CT, so it is necessary to design a CT protocol that takes into account all of the critical factors and identify parameters that will maintain the diagnostic value of an image at the minimum dose of radiation [6]. The automatic exposure control (AEC) used in a multiple detector CT device has different dose control methods depending on the source of the equipment; its purpose is to control the radiation dose according to the degree of attenuation. The overall patient dose can be reduced [6, 43]; however, AEC is not necessarily useful in this regard. For low-dose protocols, fixed low tube current is the best method for dose control [6].

Regardless of increasing CT dose, several change to the reconstruction parameters are necessary for improving the image quality. In reconstruction of CT, the factors that influence the quality of a CT image are slice thickness (Z-axis resolution), reconstruction algorithm, field of view, and detector efficiency [6, 43]. Multi-slice CT scanners have isotropic spatial resolution with a 0.5 mm slice thickness [4, 44]. Isotropic spatial resolution means that the spatial resolution in the transaxial plane (X-Y plane) and the longitudinal direction (Z-axis) are equivalent [44]. The isotropic resolution of a given CT image is determined by the axial slice thickness. Thus, thin-sectioned axial image reconstruction can provide high resolution of coronal and sagittal images without additional CT radiation dose. The combination of the axial image with MPR coronal and sagittal images will result in a clear display of the relevant bone structures and provide outlines of complex lesions. Post-processing of CT images create MPRs and 3D reconstructions that provide more detailed images, which are especially critical for diagnosing of traumatic injuries. The image quality of 3D reconstructions and MPR can be improved by using overlapping image reconstruction up to 50% [45].

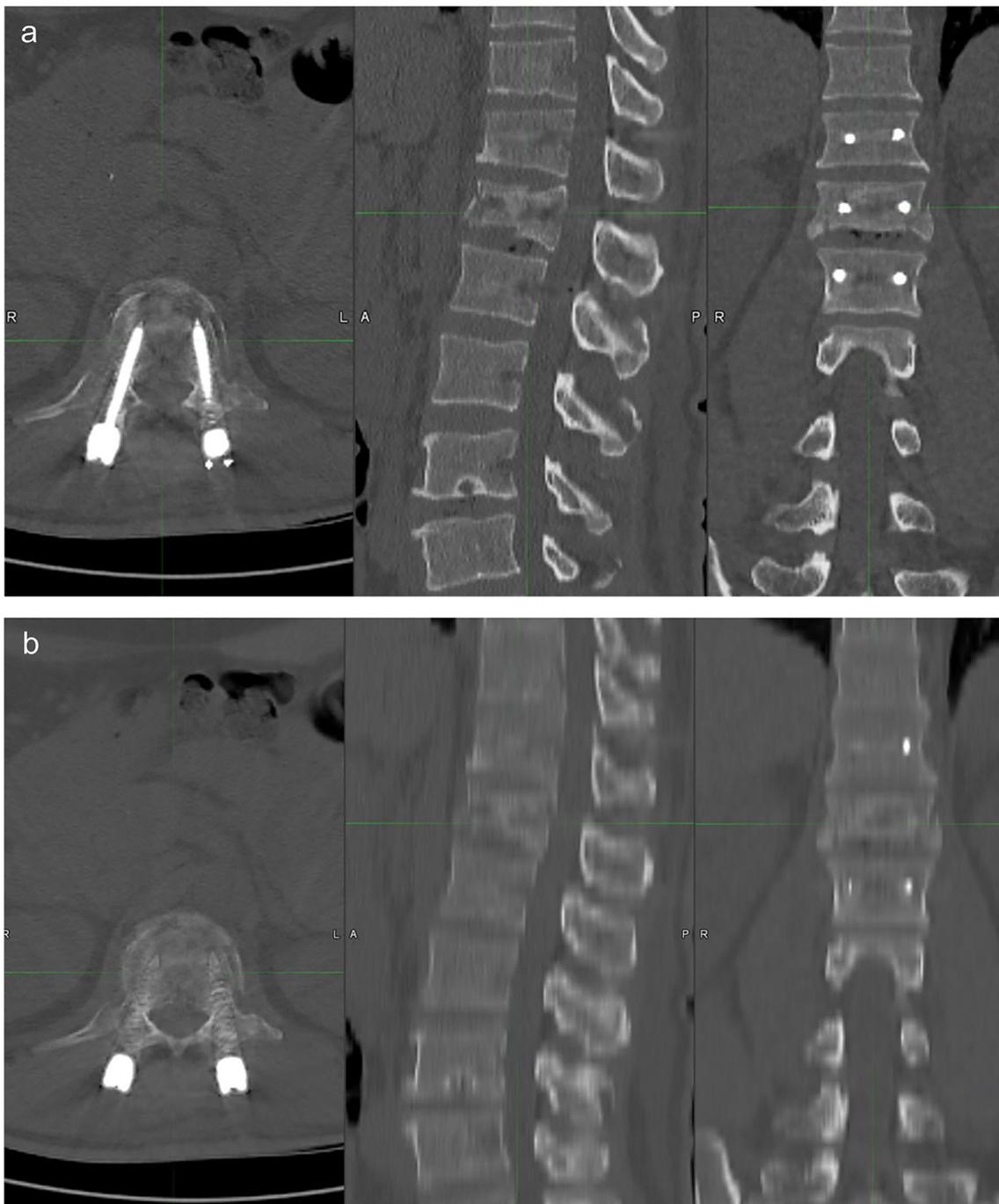


Fig. 1 Coronal and sagittal multi-planar reconstructed (MPR) CT images (left, axial; middle, sagittal; and right, coronal) obtained from axial images of the spine in the post-processing reconstruction. Coronal and sagittal images by axial CT images using 1.25 mm slice thickness (**a**) show a

clearer anatomy of the lesions than axial images using 5 mm slice thickness (**b**) in the post-processing CT reconstruction after the acquisition settings with 120 kVp, 50–120 mA, and rotation time 0.95:1

In the musculoskeletal system, high contrast between bone and soft tissues facilitates detection of lesions using ordinary two-dimensional evaluation modalities. All manufactures provide noise-reducing technologies, such as iterative reconstruction and specific filter algorithms in post-processing of reconstruction in multi-slice CT scanners (e.g., I70f very sharp kernel for Siemens and bone plus for GE). These algorithms can

improve the spatial resolution of CT images in skeletal studies. A smaller field of view with thinner slices can produce better sensitivity and diagnostic accuracy of small lesions in the foot, wrist, and orbital cavities [46–48]. A balance between the change in slice thickness and image noise should be considered when devising optimized protocols for these applications [49].

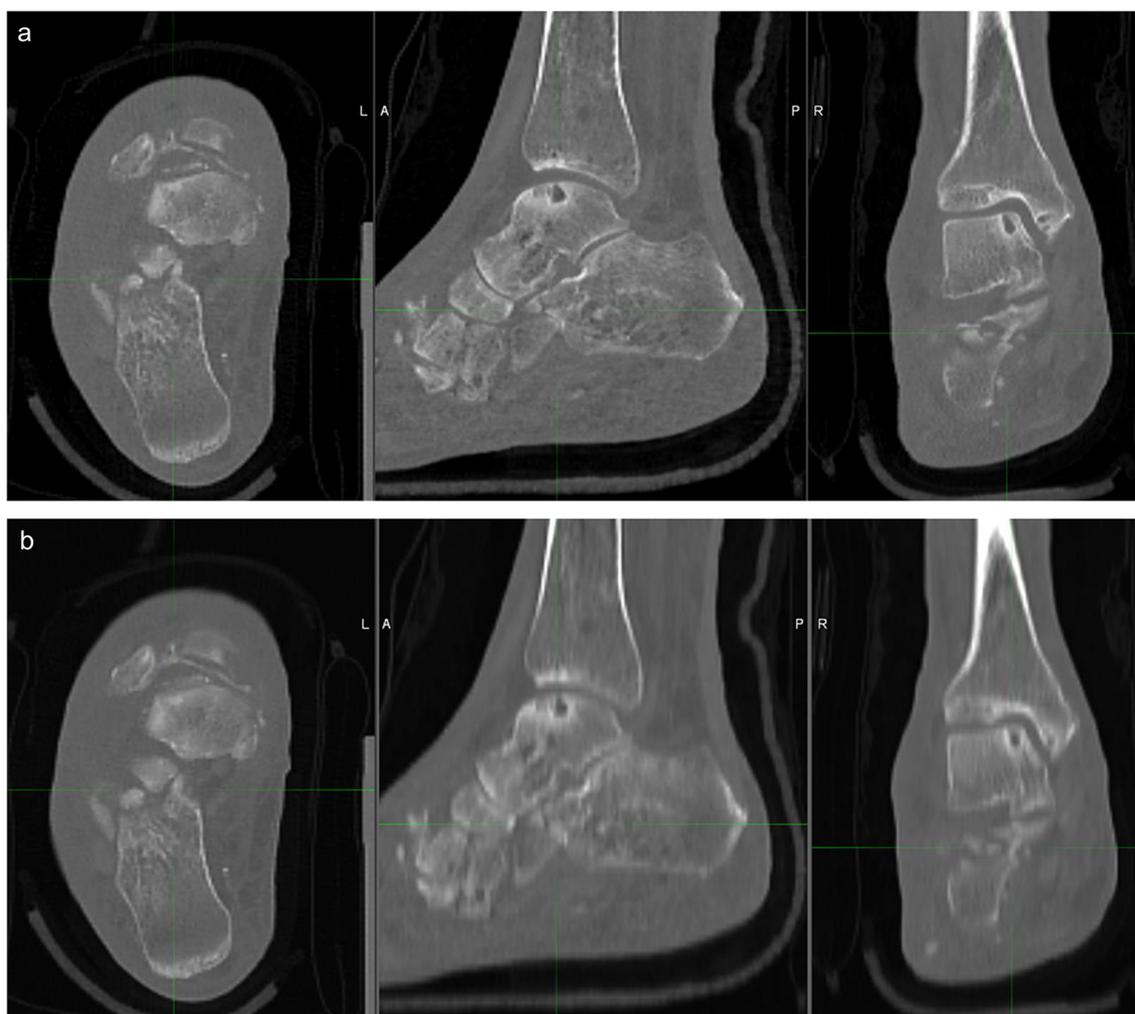


Fig. 2 Coronal and sagittal multi-planar reconstructed (MPR) CT images (left, axial; middle, sagittal; and right, coronal) obtained from axial images of the ankle in the post-processing reconstruction. Coronal and sagittal images by axial CT images using 0.65 mm slice thickness (a) show a

clearer the anatomy of the lesions than axial images using 2 mm slice thickness (b) in the post-processing CT reconstruction after the acquisition settings with 120 kVp, 50–100 mA, and rotation time 0.95:1

Table 3 CT protocols identified by literature survey for SPECT/CT (2017–2020)

Regions	Spine	Foot, Ankle	Knee	Hip	Wrist, Shoulder
N, References	13 [7–19]	8 [19–26]	11 [19–21, 27–34]	6 [19, 35–39]	4 [19, 40–42]
Voltage (kVp, <i>n</i>)	110	2	110	1	110
	120	8	120	4	120
	80–130	2	80–130	1	80–130
	140	1	140	2	130
Current (mA, <i>n</i>)	no	2			
	30–70	5	2.5–40	7	30–100
	90–200	3	60–200	1	135
	40–400	3			40–300
Slice thickness (mm, <i>n</i>)	no	1	no	1	
	0.33–2	7	0.625/1	4	0.33–2.0
	2.5	1	1.25–2.5	2	2.5
	5	4	5	1	

Conclusion

This study identified the current status of SPECT/CT of clinical use throughout Korea to provide information for optimization of the CT protocol. Per our findings, CT parameters need to be optimized for the specific regions examined and based on the diagnosis. All practitioners should recognize and understand how each of the variables impacts the radiation dose and image quality so the CT protocol of SPECT/CT can yield optimal results.

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Authors' Contribution All the authors contributed to the study design, data collection, and discussion of the result. Data analysis and the first draft were performed by Eun Jung Lee, Ji Young Kim, and Jung Mi Park. Jung Mi Park, Joon-Kee Yoon, and Seong Min Kim commented on revision of the manuscript. All the authors read and approved the first and final manuscript.

Compliance with Ethical Standards

Conflict of Interest Eun Jeong Lee, Ji Young Kim, Jung Mi Park, Bong-Il Song, Hongyoon Choi, Hye-kyeong Shim, Hye Lim Park, Ho-Young Lee, Kyung Jae Lee, Joon-Kee Yoon, Seongho Seo, Seong Min Kim, Soo Bin Park, Young Seok Cho, Seong Hoon Kim declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent is not applicable.

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