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Diagnostic value of SPECT/CT examinations with particular emphasis on the skeletal system*

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ABSTRACT
Hybrid devices are increasingly used in nuclear medicine diagnostics. They enable molecular imaging (single photon emission computerized tomography – SPECT) of pathological changes in the body. It is necessary to refine the parameters of image acquisition and reconstruction, as well as to formulate clinical recommendations for hybrid SPECT/computed tomography (CT) examinations. Therefore, this study aimed to investigate the diagnostic usefulness of SPECT/CT examinations using a hybrid gamma camera, with particular emphasis on skeletal scintigraphy. This work attempts to address this question.
Keywords: single photon emission computerized tomography/computerized tomography (SPECT/CT); scintigraphy; diagnostics; skeletal system.

INTRODUCTION

Nuclear medicine is a rapidly developing field of science. Diagnostic imaging using radioisotopes emerged as an experimental technology in the 1950s. At that time, the term "nuclear medicine" was introduced, previously also known as nuclear medicine. It defined the developing fields of medical sciences related to the use of radioactive isotopes in the form of compounds and preparations for research, therapeutic, and diagnostic purposes.

One of the most significant advancements in imaging has been the combination of functional and morphological imaging techniques within a single device. A hybrid single photon emission computerized tomography/computed tomography (SPECT/CT) device was developed by integrating SPECT and CT techniques [1, 2].

This camera allows the recording of functional and anatomical images during a single session with the patient in the same position. The patient's position remains unchanged, and the tests are performed sequentially. The SPECT gamma camera and the X-ray tube can be placed on a single ring [3]. The combination of images obtained through a SPECT/CT examination is made possible by image fusion, i.e., the common visual presentation of combined data. Until recently, image fusion was performed using images from 2 separate devices, which resulted in lower accuracy and a higher probability of errors in reconstructing the patient's position [4, 5, 6].

Image fusion can be achieved in 2 ways. The first is the manual method, which utilizes characteristic image points – markers (4 pairs of points visible in both images) placed on the patient's body or mask, or anatomical points designated as reference markers. The second method is automatic, in which the matching of SPECT and CT images is based on "mutual information" [7]. The concept of "mutual information" was pioneered by Viola and Wells and later applied by Collignon [8].

Image overlay, i.e., aligning both data sets to a common coordinate system, involves arithmetic operations in digital image processing. This includes combining individual layers of the reconstructed image through addition, subtraction, multiplication, or division. A commonly used operation between 2 images is masking, which allows a specific fragment of the image to be highlighted and processed separately [9].

Image reconstruction is based on advanced computer programs. The integration of SPECT, a functional imaging technique that provides information on cellular-level processes, with CT, an anatomical imaging modality, enhances the precise localization of pathological processes detected during scintigraphy and enables the creation of an absorption correction map [10, 11, 12, 13, 14, 15]. The combination of SPECT/CT images, by precisely determining radioisotope uptake areas in the body, improves diagnostic sensitivity and specificity while reducing the number of false-positive SPECT results [16, 17, 18, 19, 20, 21]. This leads to an overall increase in the diagnostic value of radioisotope imaging.

However, the integration of devices and image synthesis is not yet perfect. Due to the sequential nature of data recording, discrepancies in image alignment, such as mutual displacement, can occur [7, 22, 23, 24, 25]. Additionally, accidental patient movements, including those caused by breathing, cannot be entirely eliminated [22, 26, 27, 28, 29, 30, 31].

Given the specificity of SPECT/CT examinations, the decision to perform the procedure is made by the physician, taking into account appropriate radiological protection for the patient.

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In both SPECT and SPECT/CT techniques, gamma camera and X-ray tube settings can be adjusted according to the type of planned examination. Nuclear medicine departments often modify factory acquisition protocols based on their specific needs and the nature of the tests performed [32, 33, 34].

In this study, the diagnostic usefulness of SPECT/CT examinations using a hybrid gamma camera was investigated, with particular emphasis on skeletal scintigraphy.

MATERIALS AND METHODS

The research was carried out at the Department of Nuclear Medicine of the Pomeranian Medical University in Szczecin (PMU) between 2007–2011. Image acquisition was performed using a dual-head SPECT/CT gamma camera – Infinia Hawkeye 4 from General Electric Company (GE).

The analysis included 1,670 scintigraphy examinations performed in 1,403 patients referred to the Department of Nuclear Medicine at PMU between July and December 2009. Of this group, 614 patients underwent SPECT/CT examinations, including: cerebral perfusion scintigraphy, pulmonary perfusion scintigraphy, parathyroid scintigraphy, sentinel lymph node scintigraphy, liver scintigraphy with labeled erythrocytes, liver scintigraphy with colloid, receptor scintigraphy, whole-body (WB) scintigraphy, and skeletal scintigraphy. In the analysis of clinical trials, cardiac perfusion scintigraphy was not considered.

The diagnostic usefulness of SPECT/CT acquisition was analyzed in detail in 60 patients referred for skeletal scintigraphy. In these patients, a WB planar examination was performed following the administration of 700–800 MBq of ^{99m}Tc-methylenediphosphonic acid (^{99m}Tc-MDP), supplemented by SPECT/CT of a selected skeletal section. The decision to perform SPECT/CT was based on the results of the WB examination.

Each analyzed clinical SPECT/CT examination included both an emission and a transmission component. The parameters of the acquisition protocols for the SPECT technique varied depending on the type of examination performed. Differences included variations in the recording time per projection, changes in the detector angles, and the total number of projections. In most examinations, CT acquisition was performed at a voltage of 140 kV and a current of 2.5 mA. In the case of pediatric patients, the X-ray tube intensity was reduced. A common feature of all analyzed studies was the parallel alignment of gamma camera detectors and recording in the full angular range. A spiral technique was used for recording tomographic cross-sections.

All images were reconstructed on a GE Xeleris workstation using the Volumetrix for Hawkeye clinical program. Reconstruction was performed using an iterative algorithm with 2 iterations. An analysis was conducted to determine which areas of the skeleton were most frequently imaged using SPECT/CT technology.

Scintigraphy images of the entire skeleton and SPECT/CT images of selected skeletal sections were independently presented to 2 nuclear medicine specialists. The doctors were informed about the indications for skeletal scintigraphy and were asked to assess the usefulness of SPECT/CT according to the following proposed criteria.

Criteria for assessing the diagnostic usefulness of SPECT/CT examination:

1. diagnostically insignificant examination – the SPECT/CT examination does not contribute anything to the final scintigraphy assessment;
2. diagnostically significant test – the SPECT/CT examination dispelled the doubts of the doctor describing the examination; accurately visualized anatomical location or additional foci that were not visible in a planar examination of the skeleton.

RESULTS

The following types of scintigraphy examinations were performed: 1,118 skeletal scintigraphy, 414 parathyroid scans, 247 sentinel lymph node scans, 55 brain perfusion scans, 49 receptor scans, 33 whole body scans – labeled leukocytes (20) + metaiodobenzylguanidine (MIBG) ^{131}I(13) 26 hepatic scans with labeled erythrocytes, 17 pulmonary perfusion scans, 11 liver scans with colloid. A total of 1,670 scans examinations were performed in 1,403 patients. The analyzed group included 950 (68%) women and 453 (32%) men, whose average age was 49 years (Fig. 1).

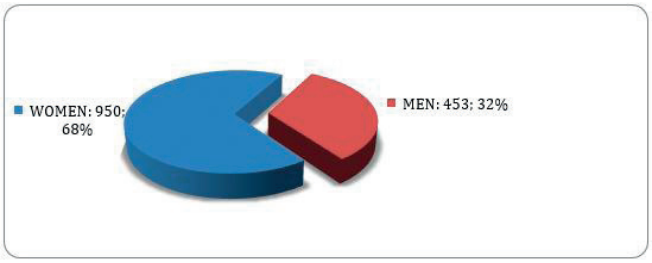

FIGURE 1. Division of the analyzed group by gender

From a group of 1,403 patients, 535 patients were singled out, in whom 614 (27%) SPECT/CT examinations were performed (Fig. 2).

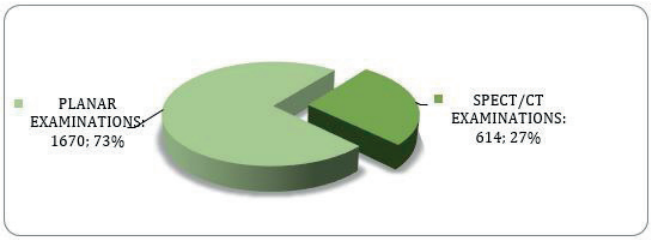

FIGURE 2. Percentage of single photon emission computerized tomography/computed tomography (SPECT/CT) and planar examinations in the analyzed patient group

Among the people who underwent SPECT/CT examination, there were 404 (76%) women and 131 (24%) men. The average age was 50 years.

Single photon emission computerized tomography/computed tomography was performed in the following types of

scintigraphy: 202 (33%) sentinel lymph node scans, 183 (30%) skeletal scans, 114 (18%) parathyroid scans, 48 (8%) receptor scans, 26 (4%) erythrocyte-labeled liver scans, 16 (3%) pulmonary perfusion scans, 11 (2%) colloid liver scans, 11 (2%) studies in WB scans (leukocytes + MIBG ^{131}I), 3 (0.5%) studies in brain perfusion scans (Fig. 3).

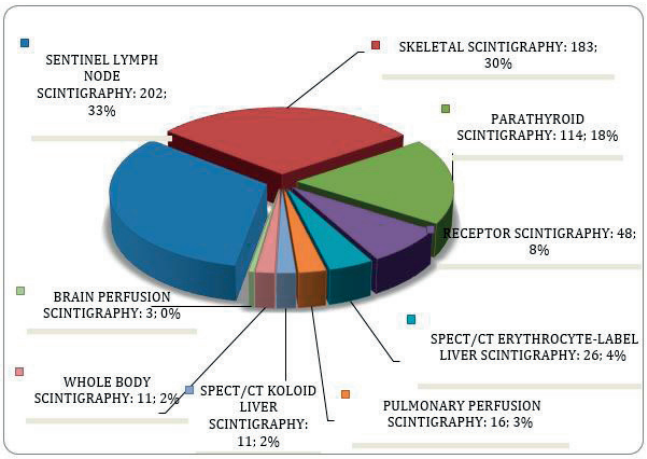

FIGURE 3. Single photon emission computerized tomography/computed tomography (SPECT/CT) examinations divided into individual types of scintigraphy

Skeletal scintigraphy was the second most frequently performed examination after sentinel lymph node scintigraphy in which SPECT/CT acquisition was utilized. Due to the diversity of skeletal imaging areas, a more detailed analysis of these studies was conducted. Single photon emission computerized tomography/computed tomography acquisition was most commonly ordered to assess a single section of the skeletal system: 48 (26%) pelvic examinations, 31 (17%) thoracolumbar spine examinations, 29 (16%) lumbar spine examinations, and 28 (15%) thoracic spine examinations were performed. The remaining 46 (26%) examinations included: 16 (9%) lower limb, lower leg, and foot examinations, 11 (6%) thigh-knee examinations, 11 (6%) head and cervical spine examinations, 4 (2%) cervicothoracic spine examinations, 3 (2%) hand examinations, and 1 (1%) WB examination (Fig. 4).

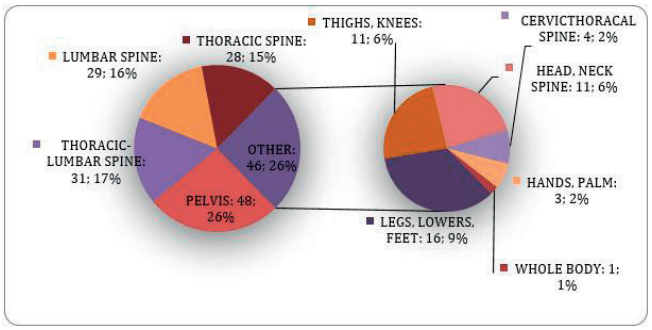

FIGURE 4. Division of single photon emission computerized tomography/computed tomography (SPECT/CT) examinations according to the examined section of the skeletal system

The most common indication for skeletal examination was: in 79 (44%) patients, assessment for bone metastasis; in 56 (31%) patients, evaluation of the skeletal system due to complaints; in 31 (18%) patients, assessment of the extent of the lesion; and in 13 (7%) patients, assessment of the presence of inflammation (Fig. 5).

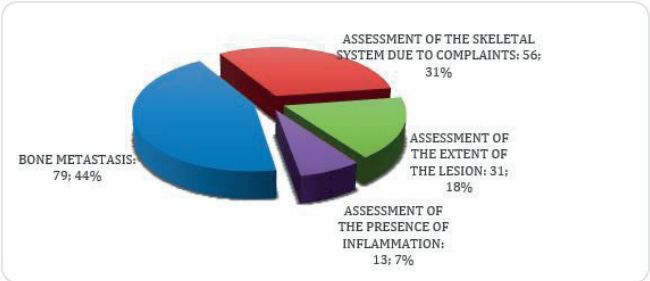

FIGURE 5. Classification of skeletal examinations according to clinical indications

A detailed analysis was carried out on 60 skeletal system examinations performed using the WB technique, followed by the subsequently ordered SPECT/CT procedure. The study included 37 women and 23 men, with an average age of 55 years.

In this group, 21 (35%) pelvic examinations, 10 (17%) thoracic spine examinations, and 8 (13%) thoracolumbar spine examinations were performed. The remaining 21 examinations (35%) included: 6 (10%) lumbar spine examinations, 5 (8%) cervicothoracic spine examinations, 5 (8%) thigh-knee examinations, 4 (7%) lower leg and foot examinations, and 1 (2%) hand examination.

The most common indications for SPECT/CT examination in this group were: bone metastases in 27 (45%) patients, assessment of the extent of the lesion in 17 (28%) patients, evaluation of the skeletal system due to complaints in 15 (25%) patients, and assessment for surgery in 1 (2%) patient.

Two nuclear medicine specialists assessed the diagnostic usefulness of SPECT/CT acquisition in 60 patients referred for skeletal scintigraphy according to the adopted criteria presented in the material and methodology. Figure 6 presents the results of the evaluation of the SPECT/CT scan performed by 2 observers.

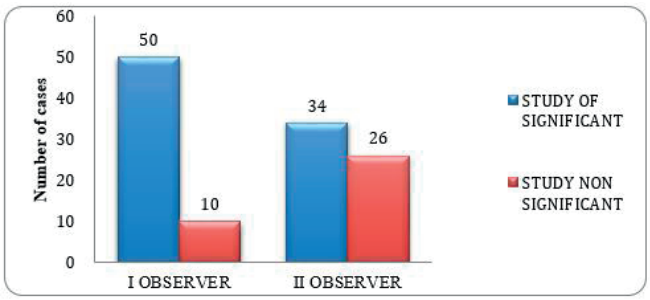

FIGURE 6. Assessment of the usefulness of single photon emission computerized tomography/computed tomography (SPECT/CT) by 2 observers

The first observer considered 50 (82%) SPECT/CT examinations to be significant and 10 (18%) SPECT/CT examinations to be non-significant. The second observer considered 34 (57%) SPECT/CT examinations to be significant and 26 (43%) SPECT/CT examinations to be non-significant. There was a discrepancy in the assessment of the usefulness of the SPECT/CT examination between the observers (Fig. 6).

Both observers assessed 19 (32%) of the analyzed studies in the same way. In the remaining 41 (68%) studies, the observers' ratings differed. Figure 7 presents a total assessment of 60 SPECT/CT examinations by both observers.

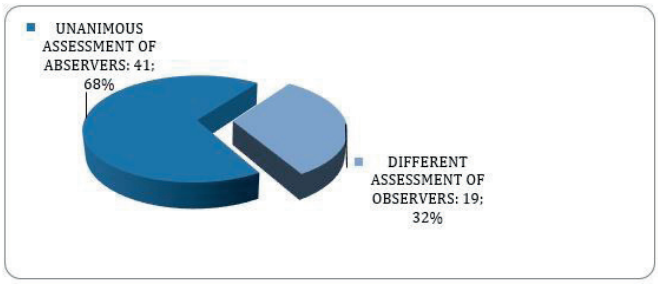

FIGURE 7. Summary assessment of single photon emission computerized tomography/computed tomography (SPECT/CT) examinations by 2 observers

After examining the agreement of the observers' assessments using nonparametric tests, the following results were obtained: Spearman's correlation score was 0.2; for Mann–Whitney's U-test, the result was U = 858 and p ~ 0. The results of both tests indicate a weak correlation between the assessments of the 2 observers.

Among the 19 (100%) unanimously assessed cases, 14 (74%) were classified as relevant studies, while 5 (26%) were considered non-relevant tests. Figure 8 presents the assessment of both observers regarding the usefulness of SPECT/CT in the group of 19 unanimously evaluated tests.

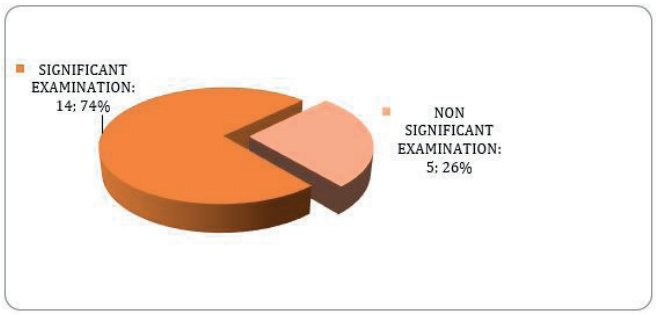

FIGURE 8. Usefulness of single photon emission computerized tomography/computed tomography (SPECT/CT) for the final assessment of skeletal scintigraphy

For the group of SPECT/CT results evaluated in the same way (Fig. 8), 74% were considered significant.

The analysis of clinical trials showed that over 25% of the tests performed within 6 months at the Department of Nuclear Medicine of the PMU were hybrid SPECT/CT examinations. It was found that the SPECT/CT technique was most frequently used for the examination of the sentinel lymph node, skeleton, and parathyroid glands. Among the skeletal SPECT/CT examinations performed, 48% involved the spine, 26% the pelvis, and 15% the lower limbs. The most common indications for SPECT/CT of the skeletal system were skeletal metastases and assessment of the extent of lesions. Additionally, it was shown that 74% of the ordered SPECT/CT examinations of the skeleton were considered important for the diagnostic result.

DISCUSSION

Over 25% of the tests performed within 6 months at the Department of Nuclear Medicine of the PMU were hybrid SPECT/CT examinations. This result demonstrates that the fusion of images obtained by different techniques – emission tomography (SPECT) and transmission tomography (CT) – can significantly increase the efficiency of nuclear diagnostics.

The SPECT/CT technique was used for various types of scintigraphy examinations, mainly of the sentinel lymph node, skeleton, and parathyroid glands. The usefulness of the SPECT/CT technique for the examination of sentinel lymph nodes has been described by Mar et al. [15], Giżewska-Krasowska et al. [35], and Zorga et al. [36]. Moreover, Wong et al. [37] and Kizu et al. [14] confirmed the accurate location of sentinel lymph nodes in more than 87% of studies.

Based on the literature [11, 21], bone scintigraphy is known to be one of the most commonly performed tests in nuclear medicine. The results obtained in this study confirm the high clinical usefulness of the hybrid technique for nuclear diagnostics of various skeletal system diseases. Similar results are presented in the works of Horger et al. [15, 38, 39, 40], Stembrowicz-Nowakowska et al. [41], Ben-Haim and Israel [42], and Górska-Chrzastek et al. [43, 44], which evaluated the diagnostic value of SPECT and SPECT/CT examinations for single focal lesions in the spine detected through WB scintigraphy.

Differentiating malignant from benign lesions can sometimes be challenging due to varying levels of radiopharmaceutical uptake. Additionally, the limited functional resolving power does not allow for the precise determination of lesion location [21]. Often, additional structural imaging tests are required to establish a definitive diagnosis. Therefore, SPECT/CT imaging has proven useful in accurately assessing and locating lesions, as well as providing valuable information for benign lesions, injuries, infections, and degenerative and rheumatic diseases [11, 21].

Even-Sapir describes methods for detecting malignant lesions in the skeleton, emphasizing the benefits of SPECT/CT imaging in various bone diseases. He reports that the sensitivity of skeletal scintigraphy for detecting malignant bone lesions ranges between 62–100%, while specificity is between 78–100% [10]. Buck et al. confirm the growing role of integrated SPECT/CT, particularly in oncology [1].

At the Department of Nuclear Medicine of the PMU, the standard skeletal scintigraphy examination is performed using the WB technique. The decision to perform a SPECT or SPECT/CT scan of a specific skeletal region is made by a nuclear medicine specialist after an initial analysis of the WB image. The purpose, scope, and frequency of hybrid skeletal examinations were analyzed in detail in this study due to the lack of global standards in this field.

As many as 48% of SPECT/CT referrals concerned spinal examinations, 26% the pelvis, and 15% the lower limbs. The most common indications for SPECT/CT were skeletal metastases and the assessment of lesion extent in the skeletal system. These findings serve as important guidance for physicians referring patients for scintigraphy, as well as for those interpreting the examinations.

Defining the specific skeletal region to be imaged at the referral stage could indirectly shorten examination time. Therefore, careful analysis of the purpose of referral for skeletal scintigraphy and accurate interpretation of the WB examination, which often precedes targeted SPECT/CT imaging, is essential in most nuclear medicine facilities.

D'Amico et al. identified the most common indications for image fusion, which included the evaluation of radioisotope therapy outcomes, the need for metabolic characterization of neoplastic lesions detected on CT, and the necessity for anatomical localization of uptake foci [33]. Obuchowski et al. obtained similar results [45].

Gnanasegaran et al. present potential indications for multislice SPECT/CT imaging in benign and malignant skeletal lesions, including: bone cancer, cancer patients with unspecified or ambiguous skeletal damage, benign bone diseases, post-orthopedic ankle surgery patients, injuries, wrist pain, lower back pain, infections, problematic knee pain, and biopsy indications [11].

Papathanassiou et al. describe bone metastases and osteoarticular infections as the primary indications for skeletal SPECT/CT. However, they state that SPECT/CT is not recommended for diagnosing degenerative disease [21]. The available data are still insufficient to determine the role of SPECT/CT in diagnosing conditions such as osteonecrosis or arthroplasty-related pain.

The assessment of the diagnostic usefulness of SPECT/CT revealed significant discrepancies in evaluating the impact of SPECT/CT images on skeletal scan interpretation between individual physicians. In only about $^1/_3$ of the 60 analyzed cases did the 2 observers agree on the diagnostic usefulness of SPECT/CT acquisition. Further analysis of the "unanimously assessed cases" showed that 74% of SPECT/CT examinations were considered significant for diagnostic results.

Groves et al. attempted to explain the reasons for observer discrepancies in scintigraphic image assessment. According to the authors, these discrepancies are largely due to the absence of clinical standards for hybrid SPECT/CT, positron emission tomography/computed tomography (PET/CT), and positron emission tomography/magnetic resonance imaging (PET/MRI) techniques in nuclear medicine [46]. Henriksen et al. also addressed this issue, encountering similar interobserver differences. As a solution, they proposed the inclusion of a third observer in the assessment process [47].

Although the body of evidence supporting the important role of SPECT/CT is rapidly growing, it remains relatively limited. Studies to date suggest that SPECT/CT image fusion enhances confidence and specificity in diagnosing bone and organ pathologies. The superiority of SPECT/CT over SPECT alone has been demonstrated in imaging benign and malignant skeletal diseases, thyroid cancer, neuroendocrine tumors, parathyroid adenomas, and sentinel lymph node mapping in the head, neck, and pelvic region. The use of SPECT/CT in cardiac and neurological imaging, which may become clinically significant in the future, is also being explored [1].

However, the available data remain insufficient to assess its usefulness for all potential indications or to define its precise role as a diagnostic tool in rheumatology. Single photon emission computerized tomography/computed tomography is becoming an increasingly accessible tool, offering the potential for a promising future [11, 21, 30, 48].

Further research is necessary to develop optimal procedures and acquisition protocols for hybrid imaging in specific disease entities. The combination of functional and anatomical imaging has the potential to drive the development of advanced image processing algorithms. Despite technological advances in medical imaging, bone scintigraphy continues to play a crucial role in diagnosing a broad spectrum of bone pathologies. Single photon emission computerized tomography/computed tomography is conceptually attractive, not only because it allows for 2 examinations in a single visit but also because it can often serve as the final imaging step, eliminating the need for further diagnostic procedures. Nevertheless, the exact role of SPECT/CT in comparison to MRI and CT in assessing bone metastases remains an area of ongoing investigation.

CONCLUSIONS

In the clinical practice of the nuclear medicine department, SPECT/CT examinations are most commonly performed in sentinel lymph node scintigraphy, skeletal scintigraphy, and parathyroid scintigraphy. Single photon emission computerized tomography/computed tomography acquisition provided additional diagnostic value in 74% of the skeletal scintigraphy cases analyzed. The pelvis, thoracic spine, and thoracolumbar spine were the most frequently imaged regions. Single photon emission computerized tomography/computed tomography is a valuable diagnostic tool for the skeletal system.

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