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MULTIMODAL APPROACH TO THE DIAGNOSIS OF BONE METASTASES USING COMPUTED TOMOGRAPHY, POSITRON EMISSION TOMOGRAPHY WITH COMPUTED TOMOGRAPHY AND OSTEOSCINTIGRAPHY

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The purpose of the study was to conduct a comparative analysis of the results of computed tomography, positron emission tomography combined with computed tomography, and osteoscintigraphy in the diagnosis of bone metastases. The diagnostic value and consistency levels of these methods in oncology patients were investigated. The results showed that positron emission tomography combined with computed tomography demonstrates higher diagnostic accuracy in detecting bone metastases and has the ability to provide additional complementary information in cases of discrepancy. Although computed tomography is useful in morphological assessment, in some cases its sensitivity in detecting metastases may be lower. Osteoscintigraphy, while suitable for widespread screening, may result in non-specific findings. Based on the obtained results, practical recommendations for diagnostic conclusions were proposed.
Key words: bone metastasis, positron emission tomography combined with computed tomography, computed tomography, osteoscintigraphy, diagnostic concordance, radiological examination, SUV max.

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МУЛЬТИМОДАЛЬНИЙ ПІДХІД ДО ДІАГНОСТИКИ КІСТКОВИХ МЕТАСТАЗІВ З ВИКОРИСТАННЯМ КОМП'ЮТЕРНОЇ ТОМОГРАФІЇ, ПОЗИТРОННО-ЕМІСІЙНОЇ ТОМОГРАФІЇ З КОМП'ЮТЕРНОЮ ТОМОГРАФІЄЮ ТА ОСТЕОСЦИНТИГРАФІЇ

Метою даного дослідження був порівняльний аналіз результатів комп'ютерної томографії, позитронно-емісійної томографії в поєднанні з комп'ютерною томографією та остеосцинтиграфії в діагностиці метастазів у кістках. Вивчено діагностичну цінність та достовірність цих методів у онкологічних хворих. Результати показали, що позитронно-емісійна томографія в поєднанні з комп'ютерною томографією демонструє вищу діагностичну точність у виявленні метастазів у кістках і дозволяє отримати додаткову інформацію у разі розбіжності результатів. Хоча комп'ютерна томографія корисна для морфологічної оцінки, у деяких випадках її чутливість у виявленні метастазів може бути нижчою. Остеоцинтиграфія, хоча й підходить для широкого скринінгу, може давати неспецифічні результати. На підставі отриманих результатів було запропоновано практичні рекомендації щодо діагностичних висновків.
Ключові слова: метастази в кістках, позитронно-емісійна томографія у поєднанні з комп'ютерною томографією, комп'ютерна томографія, остеоцинтиграфія, діагностична конкордантність, рентгенологічне дослідження, SUV max.

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Bone metastases are very frequently encountered in oncology patients and lead to serious clinical complications (pain, pathological fractures, etc.) as well as a decrease in the patient's quality of life. The likelihood of bone metastasis is particularly high in breast, prostate, lung, and kidney cancers, and in such cases early diagnosis has a significant impact on surgical, radiotherapy, or systemic treatment planning [6, 12].

Several modern imaging methods are available for the diagnosis of bone metastases. While computed tomography (CT) is highly useful for evaluating structural changes, it does not fully reflect functional alterations. Osteoscintigraphy allows for systemic evaluation of metabolic activity in bone tissue, but its specificity is relatively low [5, 11]. Positron emission tomography combined with computed tomography (PET-CT), especially with radiopharmaceuticals such as 18F-NaF, PSMA, or 18F-FDG, combines both morphological and functional assessment, thereby achieving higher diagnostic accuracy [10, 15].

The purpose of the study was to conduct a comparative evaluation of CT, PET-CT, and osteoscintigraphy results in patients with breast, prostate, lung, and kidney cancers, to assess the diagnostic effectiveness of these methods, to statistically analyze their levels of concordance, and to provide practical recommendations.

Materials and methods. This retrospective diagnostic accuracy study was conducted at the Oncology Clinic of Azerbaijan Medical University and included oncology patients examined for suspected bone involvement between 2013 and 2023. The study was designed in accordance with the principles of diagnostic test evaluation and reported with consideration of STARD recommendations.

A total of 170 patients were included in the analysis, comprising 57 men and 113 women aged 19 to 87 years. The study population consisted of patients with histologically or clinically established primary malignant tumors, including breast, prostate, lung, bladder, nasopharyngeal, and kidney cancers, who underwent imaging assessment for possible bone metastases in routine clinical practice.

Inclusion criteria: age 18 years or older; confirmed primary oncological disease based on available clinical and histopathological records; clinical and/or radiological suspicion of bone metastasis requiring further imaging evaluation; availability of at least one of the following imaging methods performed within the diagnostic work-up period: CT, PET/CT or osteoscintigraphy; sufficient clinical documentation and follow-up data allowing final verification of bone lesion status. Exclusion criteria: incomplete imaging or medical records precluding reliable retrospective assessment; uncertain final diagnostic classification of bone lesions; severe technical limitations of image quality preventing interpretation; insufficient follow-up data for confirmation or exclusion of metastatic bone disease. Patients with concomitant metabolic bone diseases (Paget's disease, severe osteoporosis) and diabetes mellitus (for the PET group) were excluded from the study.

Because of the retrospective design and real-world clinical setting, patients were not excluded solely on the basis of prior anticancer treatment. However, the potential influence of systemic therapy, radiotherapy, or bone-targeted treatment on imaging appearance was taken into account during final clinical interpretation and is acknowledged as a study limitation. Likewise, patients with concomitant bone conditions were not excluded if diagnostic verification remained feasible using the full reference standard.

Among the non-metastatic lesions, traumatic, benign dysplastic bone changes were encountered. For all patients, the following characteristics were recorded, where applicable: type of bone lesion (osteolytic, osteoblastic, mixed, non-metastatic lesion, no lesion), number of lesions (single, 2–5 lesions, more than 5 lesions), and anatomical distribution (skull, thoracic bones, spine, pelvis, and extremity bones).

The imaging methods evaluated in the study were CT, PET/CT, and osteoscintigraphy. CT examinations were performed using a multidetector computed tomography scanner (64-slice class) (Siemens SOMATOM Perspective 64 Siemens Healthineers, Germany), without intravenous contrast enhancement, and were used primarily for the assessment of structural bone changes and lesion morphology. PET/CT examinations were performed using an integrated hybrid PET/CT system (Siemens Biograph, Siemens Healthineers, Germany). Radiopharmaceuticals were selected according to clinical indication, including 18F-FDG, 18F-NaF, and in selected cases 68Ga-PSMA. PET/CT was used for combined metabolic and anatomical assessment. For metabolically active lesions, the maximum standardized uptake value (SUVmax) was recorded when available. Osteoscintigraphy was performed using a dual-head gamma camera system (Siemens Symbia, Siemens Healthineers, Germany) with 99mTc-MDP. Not all patients underwent all three imaging modalities. Each method was analyzed on the basis of the number of patients in whom that specific examination had been performed and for whom sufficient reference standard data were available.

The final diagnosis used as the reference standard was based on a comprehensive multidisciplinary assessment, including imaging findings, clinical data, disease course, and follow-up information. When available, histopathological verification was also considered. In cases where a biopsy was not clinically indicated or technically feasible, lesion status was verified by dynamic clinical and imaging follow-up. The follow-up period was no less than 6 months and, where available, extended up to 12 months, allowing differentiation between metastatic progression, stable non-metastatic lesions, and absence of bone involvement. Thus, the reference standard was not based on a single test result, but on the integrated final clinical diagnosis derived from all available data. Because of the retrospective nature of the study, image interpretations were based on archived clinical imaging reports and documented radiological conclusions generated during routine patient care. The study, therefore, assessed the agreement of each imaging modality with the final reference diagnosis rather than interobserver agreement between independent blinded readers. The primary outcome measure was the diagnostic performance of CT, PET/CT, and osteoscintigraphy in the detection of bone metastases. Secondary outcome measures included the imaging methods' ability to characterize lesion morphology and their diagnostic agreement with the final reference diagnosis across anatomical regions.

Statistical analysis was performed using standard biomedical methods. Categorical data were summarized as absolute numbers and percentages. Statistical analysis was focused primarily on diagnostic accuracy measures, including sensitivity, specificity, positive predictive value, negative predictive value, and overall accuracy. Cohen's kappa coefficient was additionally applied to estimate agreement between imaging-based categorical classification and the final reference diagnosis. This analysis was intended to reflect diagnostic concordance rather than interobserver reproducibility. The Pearson chi-square test was used to assess associations between imaging findings and metastasis-related variables. Mann–Whitney U test and Spearman correlation analysis were used as supplementary statistical tools for group comparisons and assessment of monotonic relationships, where appropriate. A p-value of less than 0.05 was considered statistically significant.

The study was retrospective and based on analysis of existing clinical and imaging records obtained during routine diagnostic care. No additional interventions or changes in patient management were performed for research purposes. All data were processed in an anonymized form, and confidentiality of patient information was maintained throughout the study. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki (2013) and the principles of Good Clinical Practice applicable to retrospective observational research. Because this was a retrospective non-interventional study based on previously acquired routine clinical data, individual written informed consent for participation in the analysis was not additionally obtained. No separate cognitive screening protocol was incorporated into the study design, which should be considered when interpreting data from the oldest age subgroup, and is acknowledged as a limitation.

Results of the study and their discussion. A total of 170 patients were included in the study. Among them, 85 (50 %) underwent osteoscintigraphy, 157 (92.4 %) underwent computed tomography, and 69 (40.6 %) underwent PET-CT (positron emission tomography). According to the type of metastasis, non-metastatic lesions were found in 32 (18.8 %) patients, while among 138 (81.2 %) patients, 44 (25.9 %) had osteoblastic, 45 (26.5 %) had osteolytic, and 49 (28.8 %) had mixed-type lesions. Regarding the number of metastases, 23 (16.7 %) patients had 1 lesion, 50 (36.2 %) had 2–5 metastatic lesions, and 65 (47.1 %) had more than 5 metastatic sites. In approximately half of the patients, more than 5 metastatic lesions were recorded. During the study, metastatic lesions were detected in the skull bones in 18 (10.6 %) patients, in the thoracic bones in 92 (54.1 %) patients, in the spine in 80 (47.1 %) patients, in the pelvis in 74 (43.5 %) patients, and in the extremities in 25 (14.7 %) patients.

CT examination results: CT examination of the skull region was performed in only 2 patients. Metastatic lesions were detected in the images (100 %). However, due to the very small sample size (n=2), the kappa statistics could not be calculated. CT examination for the evaluation of metastatic changes in the thoracic bones was performed in 111 patients. During CT examination, a correct metastatic diagnosis was made in 82 out of 85 patients with metastases (96.5 %). In all 14 patients with non-metastatic lesions (100 %), this result was confirmed, while among 12 patients without pathological changes, the same result was obtained in only 7 (58.3 %). In 3 patients (25 %), CT showed non-metastatic changes, and in 2 patients (16.7 %), metastatic changes were observed. The kappa value was calculated as 0.816±0.060 ($p<0.001$). CT examination of the spinal column was performed in 90 patients, and based on the final results, metastases were observed in 61 (93.8 %) of 65 patients with metastases, non-metastatic changes were identified in all 14 (100 %) patients with non-metastatic lesions, and in 4 (36.4 %) of 11 patients without lesions no lesions were observed. The concordance of visual analyses was evaluated with kappa statistics, and kappa=0.729±0.070, $p<0.001$ was determined. This is considered statistically significant. In CT examination of the pelvic bones performed in 70 patients, metastases were observed in 52 (91.2 %) of 57 patients with metastases, in 5 (8.8 %) no pathology was present, and in all 7 (100 %) patients with non-metastatic lesions, non-metastatic lesions were detected. Among 6 patients without pathological lesions, 3 (50 %) had the same result, while in 3 (50%) metastases were found. For the diagnosis of bone metastases in the extremities, CT was performed in 12 patients. Based on the results, metastases were observed in 11 patients (91.7 %), and in 1 patient (100 %) non-metastatic changes were observed. According to the final results, metastases and non-metastatic changes were identified correctly (metastases in 11 of 11 patients with metastases, and non-metastatic lesions in 1 of 1 patient with non-metastatic lesion). As a result, complete concordance was recorded (kappa=1.000, p=0.001).

With CT examination, the type of metastatic lesion in the bone was also determined. Among 43 patients with osteoblastic metastases, 37 (86 %) were correctly diagnosed as osteoblastic and 6 (15 %) as mixed; among 40 patients with osteolytic type, 37 (92.5 %) were osteolytic, 1 (2.5 %) mixed, and 2 (5 %) osteoblastic; among 45 patients with mixed type, 34 (75.6 %) were mixed, 3 (6.7 %) lytic, and 8 (17.8 %) osteoblastic. For NML (non-metastatic lesion), in 28 patients with non-metastatic lesions, all 28 (100 %) were correctly diagnosed.

Evaluation was carried out, and the concordance between results was assessed using kappa statistics. Based on the obtained result, the kappa coefficient was 0.827±0.036 ($p<0.001$), which is statistically highly significant.

Osteoscintigraphy examination results: In the evaluation of skull bones with osteoscintigraphy, metastases were detected in 5 (83.3 %) of 6 patients with metastases, while in 1 (16.7 %) no lesion was found. Among 2 patients with non-metastatic lesions, 1 (50 %) showed non-metastatic changes, and 1 (50 %) showed metastasis. Among 32 patients without lesions, 30 (92.8 %) had no lesion, while in 2 (6.3 %) metastasis was reported. The concordance was kappa=0.713±0.127 ($p<0.001$). This is considered statistically reliable and significant. Out of 45 patients with thoracic bone metastases, 41

(91.1 %) had metastatic lesions, 4 (8.9 %) had no lesions. Among 8 patients with non-metastatic lesions, 7 (87.5 %) showed non-metastatic changes, 1 (12.5 %) showed metastasis. Of 18 patients without pathology, 15 (83.3 %) had no pathological changes, 2 (11.1 %) had non-metastatic lesions, and 1 (5.6 %) had metastasis. For this region, kappa=0.789±0.069 (p<0.001). According to osteoscintigraphy results in the pelvic bones, among 36 patients with metastases, 30 (83.3 %) showed metastatic lesions, 6 (16.7 %) had no lesions; in all 5 (100 %) patients with non-metastatic lesions, non-metastatic changes were observed. Among 15 patients without lesions, 1 (6.7 %) had metastasis, while 14 (93.3 %) had no lesions recorded. The result of this evaluation was kappa=0.769±0.082, p<0.001, and considered reliable. For the spinal column, among 66 patients, 42 had metastases, of which 38 (90.5 %) showed metastases, 4 (9.5 %) had no lesions. Among 8 patients with non-metastatic lesions, all 8 (100 %) showed non-metastatic changes. Among 16 patients without lesions, 12 (75 %) had no lesions, 2 (12.5 %) had non-metastatic areas, and 2 (12.5 %) had metastases. The concordance of various morphological appearances was evaluated as kappa=0.774 ±0.074, p<0.001, and this indicator was considered statistically significant. In osteoscintigraphy of extremity bones, out of 11 patients with metastases, 10 (90.9 %) showed metastases, 1 (9.1 %) had no lesions. The 1 patient with a non-metastatic lesion showed non-metastatic lesion (100 %). Among 26 patients without lesions, 3 (11.5 %) had metastases, while 23 (88.5 %) showed no lesions. The evaluative concordance among the results was kappa=0.708±0.118, p<0.001. The evaluation of osteoscintigraphy for detecting metastases was conducted in 83 patients, and the results were assessed with kappa statistics. Based on the results, kappa=0.501±0.067, p<0.001.

Out of 22 patients with osteoblastic metastases, 21 (95.5 %) were correctly identified with osteoscintigraphy, while 1 (4.5 %) was incorrectly assessed as osteolytic metastasis. Among 24 patients with mixed metastases, 19 (79.2 %) were correctly identified with osteoscintigraphy, 2 (8.3%) were assessed as osteolytic, and 3 (12.5 %) as mixed. Out of 19 patients with osteolytic metastases, only 10 (52.6 %) were correctly identified by osteoscintigraphy, while 8 (42.1 %) were assessed as mixed, and 1 (5.3 %) as osteoblastic. In patients with non-metastatic lesions, 18 (100 %) showed correct results.

PET-CT examination results: In the evaluation of the skull bones with PET-CT, kappa=0.947±0.53 was obtained. This indicator reflects very high evaluative concordance. During the examination, 14 out of 15 patients with metastatic changes were correctly identified in the same category. Among 27 patients without lesions, 1 (3.7 %) showed metastasis, while 26 (96.3 %) had no lesions. In the thoracic bones, all 47 patients with metastases were identified as having metastases. Among 15 patients without lesions, 1 (6.7 %) showed metastasis, while 14 (93.3 %) had no lesions. Kappa=0.958±0.042.

In the pelvic region, PET-CT evaluation of 53 patients resulted in kappa=0.956±0.043. Among 38 patients with metastases, 37 (97.4 %) were recorded with full concordance, while 1 patient (2.6 %) had no lesion. The same result was obtained in 13 patients without lesions and 2 patients with non-metastatic lesions. The highest evaluative concordance for PET-CT was recorded in the spinal column – kappa=0.962±0.038. Among 37 patients with spinal metastases, 36 (97.3 %) had the same result. In 20 patients without lesions, the same result – no lesion – was obtained. In the evaluation of extremity bones with PET-CT, the result was kappa=0.912±0.061 in 46 patients. Among 15 patients with metastases, 14 (93.3 %) were detected with metastases, while among 29 patients without lesions, 28 (96.6 %) showed no lesions. In 2 patients with non-metastatic lesions, the same result – no lesion – was obtained. Sensitivity was 93.3 % and specificity was 96.8 %. The evaluation results demonstrated that PET-CT is superior to other methods in detecting metastases with high metabolic activity even in extremities. The effectiveness of PET-CT not only in detecting metastatic lesions but also in determining their morphological character – i.e., the type of metastasis – was analyzed. In our study, PET-CT images of 68 patients and their concordance with the actual metastasis type were evaluated and analyzed using kappa statistics. According to the results, kappa=0.913±0.042, p<0.001. As a result, all 19 patients (100 %) with osteolytic metastases were correctly identified as osteolytic; among 17 patients with osteoblastic metastases, 15 (88.2 %) were osteoblastic, 2 (11.8 %) mixed; among 27 patients with mixed metastatic type, 25 (93.1 %) were mixed, 2 (6.9 %) osteoblastic; and all 3 patients (100%) with non-metastatic lesions were correctly diagnosed. The sensitivity of PET-CT was 88.2 % for detecting osteoblastic metastases, 100 % for osteolytic, and 93.1 % for mixed. The highest accuracy was observed in osteolytic and non-metastatic lesion categories (100 %). This is based on the ability of PET-CT to detect even early-stage osteolytic lesions due to their high metabolic activity. Mixed and osteoblastic metastases were also differentiated with very high accuracy, further confirming the effectiveness of PET-CT as a hybrid method combining structural and functional components in clinical practice. To evaluate the statistical differences in the results of different imaging methods in patients with and without metastases, the Mann-Whitney U test was applied. The analysis showed that PET-CT examinations demonstrated a statistically highly significant difference between groups with and without metastases (Z=–3.979, p<0.001). This indicated that PET-CT has a very high ability to differentiate metastatic changes in bones, and as a method combining structural and functional imaging, it stands out with high diagnostic value.

On the other hand, with CT and osteoscintigraphy methods, no statistically significant difference was observed between patients with and without metastases (p>0.001) (Table 1).

Table 1

Mann-Whitney U test results for different imaging methods

Method	Mann-Whitney U	Wilcoxon W	Z	p
Osteoscintigraphy	2038	11629	–0.783	0.433916
CT	2076	2604	–1.143	0.252968
PET-CT	1359	1887	–3.979	0.000069

Note: Z-value is a standardized measure of statistical difference. Wilcoxon W is an additional statistic related to the Mann-Whitney test.

As a continuation of these analyses, the ability of imaging methods to differentiate bone metastases and their statistical association with metastasis were evaluated using the Pearson Chi-square test.

According to the results, a statistically highly significant association was identified only between PET-CT examination and metastasis status (χ^2=15.927, df=1, p<0.001). For the other examinations (osteoscintigraphy, CT), the Chi-square values were not statistically significant (p>0.01) (Table 2).

Table 2

Sensitivity, specificity, and predictive values of imaging methods used for bone metastasis detection

Statistical indicies	PET-CT	CT	Osteoscintigraphy
True Positive (n)	121.0	133.0	93.0
False Positive (n)	4.0	69.0	16.0
True Negative (n)	125.0	73.0	92.0
False Negative (n)	5.0	8.0	13.0
Sensitivity (%)	96.0	94.3	87.7
Specificity (%)	96.9	51.4	85.2
Positive Predictive Value (%)	96.8	65.8	85.3
Negative Predictive Value (%)	96.2	90.1	87.6
Overall Accuracy (%)	96.5	72.8	86.4

The results of computed tomography showed that the detection of metastatic lesions in the thoracic and spinal regions with 93–96 % sensitivity confirms the effectiveness of CT in terms of structural visualization. The fact that non-metastatic lesions were also correctly identified with CT in 100 % of cases demonstrates the high specificity of this method. However, in some cases, particularly in patients without pathological changes, false-positive results were observed, which can be explained by the limited ability of CT to determine metabolic activity [2]. The ability of CT to differentiate the morphological type of metastasis (lytic, osteoblastic, mixed) was also high, with correct diagnostic results obtained in 92.5 % of osteolytic lesions and 86 % of osteoblastic lesions. The fact that all non-metastatic lesions (100 %) were correctly identified once again emphasizes the discriminative power of this method. Our results show that CT is an effective and reliable method for the initial detection and morphological analysis of bone metastases, but it is unreliable in evaluating metabolic activity. Similar results have been obtained in other studies [1].

According to the results of the study, osteoscintigraphy demonstrated high sensitivity in detecting bone metastases in certain anatomical regions; however, in terms of overall specificity and morphological differentiation, it produced weaker results compared to PET-CT and CT. In particular, the fact that only 52.6 % of osteolytic metastases were correctly identified shows the limitations of this method in detecting lytic lesions. In contrast, the correct identification of 95.5 % of osteoblastic changes and 79.2 % of mixed-type metastases indicates that this method is effective mainly in areas with high metabolic activity.

Regional analysis showed that osteoscintigraphy was able to detect metastases in the skull, thoracic, and pelvic bones with an accuracy of 83–91 %. The kappa coefficients for the spine and extremity bones were 0.774 and 0.708, respectively, which indicates statistical reliability. However, when evaluating overall concordance, the obtained kappa=0.501 (p<0.001) confirmed that the diagnostic stability of osteoscintigraphy is lower than that of PET-CT and CT.

In particular, the correct identification of 100 % of non-metastatic lesions demonstrates the ability of this method to differentiate changes present in bone that are not evaluated as metastatic processes.

Nevertheless, the likelihood of misdiagnosis was higher in differentiating morphologically mixed and lytic lesions. Overall, studies have also shown that osteoscintigraphy can be recommended as a useful and rapid method for large-scale metastatic screening [9, 14], but for morphological accuracy and functional assessment, it is advisable to complement it with PET-CT.

PET-CT examination demonstrated superiority in detecting bone metastases with high diagnostic accuracy in terms of both morphological type and anatomical localization. In evaluations of the skull, thoracic cage, pelvis, spine, and extremity bones, kappa values ranged between 0.912 and 0.962, indicating a very high level of concordance. Similar results have been reported in previous studies [13].

The fact that PET-CT identified lytic lesions with 100 % sensitivity highlights its superiority in detecting metabolic activity [7]. Sensitivity values of 88.2 % and 93.1 % were also achieved for osteoblastic and mixed metastases, respectively.

The highest concordance was observed in the spinal region (kappa=0.962), while the greatest specificity was noted in lytic and non-metastatic lesions (with 100 % accuracy). According to the results of the Mann-Whitney U-test, a statistically significant difference was found only between PET-CT and the groups with and without metastases (Z=–3.979, p<0.001). In the Chi-square test as well, a statistically significant association was identified only between PET-CT and metastasis status (χ^2=15.927, p<0.001). The results showed that PET-CT is the most superior imaging method for early detection of bone metastases, determination of their morphological type, and minimization of false results. In experiments conducted by Fan Z, et al (2023), Madsen C, et al (2024) it was also concluded that the sensitivity and specificity of 18F-NaF PET-CT were higher than those of 99mTc-MDP SPECT-CT [3, 8].

For a more complete assessment of the diagnostic value of the methods, the use of ROC analysis and AUC calculation is promising, which is reflected as an area for further research.

Limitations. The study is limited by the retrospective design and the heterogeneity of the control group, including patients with non-metastatic malignant bone lesions, which may have influenced specificity estimates. In addition, the absence of uniform histological verification in all cases and reliance on follow-up data may affect the robustness of the reference standard. Finally, the absence of a separate cognitive screening protocol for the oldest age subgroup, the potential influence of systemic therapy, radiotherapy, or bone-targeted treatment on imaging appearance, is also acknowledged as a study limitation.

Conclusions

1. PET-CT imaging has the highest diagnostic sensitivity (96.0 %), specificity (96.9 %) and accuracy (96.5 %), and concordance levels in the diagnosis of bone metastases. PET-CT, particularly in detecting lytic and mixed morphological types of metastases and in excluding non-metastatic cases, demonstrated more precise and reliable results compared to other methods.

2. While CT is useful in showing structural details, its ability to assess metabolic activity is limited.

3. Osteoscintigraphy, on the other hand, has limited diagnostic value, especially in osteolytic metastases.

It is recommended that for early and accurate detection of bone metastases, structural imaging be used in the first stage, while PET-CT should be applied in a multimodal approach for the assessment of metabolic activity and morphological differentiation. This will not only increase diagnostic accuracy but also allow treatment strategies to be planned more effectively.

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