

REVIEW

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SPECT/CT in the diagnosis of degenerative spine diseases: aspects of clinical application

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Abstract

Background Chronic low-back pain (LBP) is an extremely common symptom, especially in the older population. It is difficult to diagnose using conventional imaging because the underlying mechanisms of chronic LBP are complex and often multifactorial. With the development of single-photon emission computed tomography/computed tomography (SPECT/CT), a more precise method has become available for identifying the source of chronic LBP by localizing radiotracer uptake and detecting subtle anatomical and physiological signs of instability or inflammation. Its ability to highlight pain-generating structures has substantially improved diagnostic confidence in degenerative spine disease, contributing to its widespread clinical adoption.

Objective This review evaluates the diagnostic performance, clinical utility, and technical considerations of SPECT/CT in degenerative spine diseases, with particular emphasis on its contribution to clinical decision-making. We provide an overview of its use in patients with persistent chronic low back pain, discuss how precise localization of pain-generating structures may inform both invasive and non-invasive management strategies, and examine its value in preoperative planning. In addition, the advantages and limitations of SPECT/CT relative to conventional imaging modalities are summarized.

Methods A narrative review was performed using focused searches of major medical databases. Studies were included according to their relevance to clinical use, interpretation, and management implications of SPECT/CT.

Results Across the literature, SPECT/CT demonstrated high diagnostic performance in detecting clinically significant pain generators, particularly facet joint arthropathy, active pars lesions, adjacent segment disease, pseudarthrosis, and symptomatic vertebral compression fractures. Multiple studies report that SPECT/CT frequently influences management decisions, enhances preoperative planning, guides targeted spinal injections or ablations, and distinguishes between symptomatic and incidental degenerative changes. Furthermore, SPECT/CT has demonstrated value in postoperative patients where other modalities are limited by the presence of metallic implants, and in confirming metabolically active lesions that require intervention.

Conclusions SPECT/CT has demonstrated itself to be an effective imaging modality for localizing pain generators and facilitating spine surgeons in formulating appropriate treatment strategies for degenerative spine diseases and failed fusion. When conventional imaging is inconclusive, SPECT/CT serves as an additional imaging modality with

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high sensitivity to detect subtle lesions along the spinal axis. Overall, current evidence highlights the growing role of SPECT/CT in targeted diagnosis and individualized treatment planning.

Keywords SPECT/CT, Degenerative, Spine, Diagnosis, Treatment, Chronic low back pain

Introduction

Chronic low back pain (LBP) is widely recognized as the primary cause underlying years lived with disability [1]. Its high frequency in adults and the elderly makes it a major cause of disability, repeated healthcare use, and loss of productivity, underscoring the need for precise diagnostic and therapeutic strategies [2, 3]. According to practice guidelines in the management of chronic LBP from the American Society of Interventional Pain Physicians, the prevalence of LBP is between 54% and 80% and is a global social and medical problem [4]. Chronic LBP and neck pain can persist for one year or longer in 25% to 60% of the adult and elderly population [5, 6]. The pain is multi-factorial in nature with the involvement of various anatomical structures, which complicates the diagnosis of the primary pain generator and often leads to unsatisfactory treatment results [2, 3].

Patients with axial back pain of unknown origin often experience a debilitating constellation of symptoms that significantly reduces quality of life. Conventional radiological modalities, including Magnetic Resonance Imaging (MRI) and Computed Tomography (CT), are commonly used to evaluate the source of pain [7, 8, 9]. Chronic lower back and neck pain could persist for years due to their multi-factorial genesis, impeding successful surgical or conservative treatment and ultimately leading many patients to lifelong use of pain medications, which are known to carry serious side-effects and an increased risk of addiction [5, 6, 10, 11]. However, with introduction of single-photon emission computed tomography/computed tomography (SPECT/CT) in practical medicine, its use has revealed prospects of precise evaluation of spinal skeletal lesions with a higher rate of anatomical fidelity.

The first clinical hybrid systems were developed about two decades ago, integrating a SPECT camera with a CT scanner for bone scintigraphy [12]. Enhancement of SPECT/CT as a diagnostic modality tool presents opportunities to define locations of active bone metabolism by using certain radiotracers, commonly technetium-99 m (Tc-99 m) labelled polyphosphonates, which accumulate in the foci of increased bone remodeling as a biomarker of osteoblastic activity [13].

SPECT/CT is increasingly used across various fields of medicine, including the diagnosis of degenerative changes in the spine [14–16]. This imaging technique provides not only detailed anatomical information about spinal structures but also functional insight by identifying pain-generating “hot” foci within elements such as

the intervertebral discs, facet joints (FJs), and vertebral bodies [13].

The purpose of this narrative review is to evaluate the role of SPECT/CT in visualizing pain-generating structures of the spine in patients with chronic LBP and to assess its diagnostic value in both preoperative evaluation and postoperative follow-up to guide appropriate subsequent therapy. This review aims to advance the current literature by providing a comprehensive assessment of SPECT/CT for identifying spinal pain generators, including FJ pathology, pars interarticularis defects, postoperative sources of pain such as adjacent segment disease and pseudoarthrosis, and painful vertebral compression fractures relevant to vertebroplasty planning. It further outlines key technical considerations in SPECT/CT acquisition and interpretation and discusses procedure-related complications and potential hazards.

SPECT/CT for identifying pain generators in chronic LBP

SPECT/CT makes it possible to identify tumors and other pain generators in degenerative spinal conditions such as endplate disorders, FJ changes, osteophytes, and compression fractures, and to differentiate symptomatic foci after spine surgery [15–18]. From a diagnostic point of view, SPECT/CT allows distinction between clinically relevant lesions and incidental morphological abnormalities, including degenerative findings that may not produce symptoms [18–20]. The introduction of SPECT/CT into clinical practice has therefore provided an opportunity for more precise evaluation of spinal skeletal lesions with improved anatomical fidelity [12, 14].

Axial pain in the neck and lower back is among the most common reasons for hospital visits in the aging patient population [2, 4]. One of the potential sources of persistent chronic back pain, present in 15–45% of patients in the lower back and in 39% of patients in the neck, is FJs [21, 22]. FJs can cause axial and/or radiating pain along the dermatomal distribution in the arms and legs [23]. Conventional radiological methods are not always reliable [15, 16]. Provocation tests followed by local anesthetic injections have become an alternative diagnostic method [24]. To improve diagnostic accuracy, SPECT/CT can be particularly useful, as it allows precise assessment of active bone remodeling in the FJs, helps identify pain generators, and supports the development of appropriate conservative or surgical treatment strategies [16, 25, 26].

One of the largest studies, which included 486 patients, was conducted by Makki D. et al. [25]. The

authors reported that in 91.1% of patients who underwent SPECT/CT, at least one anomaly was detected, and in 42.8% of patients, the areas of active absorption were located in FJs. Similarly high rates of FJ-related pain were reported in another study, which identified pain-generating foci in 42% of cervical levels and 48% of lumbar levels [15]. The effectiveness of the method was demonstrated in a retrospective study analyzing data from 190 patients with axial pain who underwent SPECT/CT evaluation [16]. In 85 (48%) patients, a total of 202 hyper-metabolic FJs were detected (average number per patient 2.38 ± 1.91), of which 69% (of which 32% L4-L5) were lumbar, 24% (of which 22% C1-2 and C2-3) cervical, and 6% were thoracic.

In another study conducted at the Nuclear Medicine Department at the Royal Free Hospital National Health Service (NHS) Trust, London, the diagnostic effectiveness of SPECT/CT was also demonstrated. Among 49 patients with LBP, 34 (69.4%) lumbar FJs were determined as possible pain generators based on active remodeling, and among 25 patients with cervical spine pain, 13 (52%) cervical FJs were similarly identified [26]. Clinicians initially identified localized facet arthropathy in 21 of 49 (42.9%) patients with LBP; however, SPECT/CT confirmed this diagnosis in only 8 of the 21 cases (38%). Additionally, among patients with neck pain, SPECT/CT findings were consistent with the clinical diagnosis in only 8 of 25 patients (32%). Based on SPECT/CT findings, patients diagnosed with FJ arthropathy received appropriate targeted treatment. The authors concluded that SPECT/CT was valuable in guiding further clinical decision-making and overall patient management.

In another study by Kim et al., 76 of 177 evaluated patients (42.9%) demonstrated scintigraphically active FJ arthritis, involving 175 joints in total [27]. Most often, the lesion was traced at L4-5 (60 FJs). In other areas, L3-4, L2-3, L5-S1, L1-2, FJ arthritis rates were lower (46, 26, 16, and 10 FJs, respectively). The rates were lower for upper-level (T10-11, T11-12, and T12-L1) FJs. Differences between right and left FJs were not established. Based on SPECT/CT findings, 38 of 76 patients (50%) received percutaneous local anesthetic injection. Overall, the study identified additional etiological factors in approximately 60% of patients with LBP, including recent compression fractures, spondylolysis, unusual active degenerative changes in patients under 40, intervertebral foraminal narrowing, active sacroiliitis, spinal canal stenosis, lumbar ligament calcification, non-union of prior pelvic fractures, sacral insufficiency fractures, and active arthritis in lumbosacral transitional vertebrae or in cases of kissing spine [27].

In a retrospective study, treatment of LBP was guided by the identified changes on SPECT/CT. Of the patients included in the study, the majority (96% of 113 patients)

had increased absorption of the radioactive indicator in the bony structures of the vertebral segment [28]. 59 (75.6%) patients with increased absorption in lumbar FJs were identified, and intra-articular facet injections or medial branch blocks were performed. Patients' average VAS (visual analogue scale) scores decreased from 4.9 to 1.5. Of these, twenty-nine (49.2%) patients underwent further treatment with radiofrequency ablation, of which 22 (75.9%) experienced a 50% decrease in pain during the observed period (1 month). In total, among the 113 patients included in this study, SPECT/CT enabled adequate treatment decision-making for 100 patients (88.5%), resulting in improved clinical outcomes for 70 patients (61.9%).

The importance of using the SPECT/CT was also established in a randomized, double-blinded, controlled trial [29]. Eighty patients (aged 20–80 years) with clinically and radiologically suspected sacroiliitis or L4–L5/L5–S1 FJ pathology were randomized into two groups. In the SPECT/CT group, the clinical diagnosis was changed in 23 out of 40 patients, and the intervention was performed accordingly based on the new diagnosis. In this group, 28 patients reported a 70–100% decrease in pain, while only 10 in the control group did.

Another study primarily aimed to assess pain severity using the Visual Analogue Scale (VAS) score in 48 patients who underwent cervical or lumbar fusion surgery based on SPECT/CT-identified pain generators. Overall, self-reported axial pain decreased from an average of 9.04 ± 1.4 to 4.34 ± 2.3 ($p = 0.026$) [30]. Thus, SPECT/CT data show that FJ lesions are detected at a high frequency among other spinal structures, and identifying these pain-generating foci enables more targeted and effective therapy.

SPECT/CT may be a sensitive diagnostic modality for evaluating candidates for cervical spine surgery by identifying pain generators and regions of increased metabolic activity. In one study, preoperative SPECT/CT findings were confirmed intraoperatively, with focal radiotracer uptake corresponding to hypertrophic and degenerated FJs [19]. The average values of Neck Disability Index (NDI) and VAS decreased by an average of 20% after surgery, which allowed the authors to conclude about the effectiveness of preoperative diagnostics using SPECT/CT.

SPECT/CT for assessing pars interarticularis defects and their progression to spondylolysis or spondylolisthesis

Pars interarticularis defects and spondylosis are important causes of chronic LBP in adolescents and young adults engaging in athletic activities requiring repetitive lumbar extension and rotation [31–33]. In this context, SPECT/CT may help clinicians differentiate between active stress reactions, characterized by increased tracer

uptake in the pars, and chronic non-union defects, which may present with minimal metabolic activity but persistent mechanical instability [33, 34]. Central to this argument, studies indicate that SPECT/CT can diagnose early pars lesions when CT and MRI are negative, thereby aiding in making a decision between conservative treatment (rest, bracing, physiotherapy) and timely surgical intervention [34–36]. Aligning with this, meta-analytical data support these observations, as an analysis encompassing 9 studies found that SPECT showed 85% sensitivity and 92% specificity in diagnosing pars interarticularis defects, and was noted for its superiority to conventional imaging in early detection [32].

Furthermore, the ability of SPECT/CT to localize metabolically active pars lesions helps distinguish them from nonspecific mechanical back pain that may result from disc degeneration, facet arthropathy, or muscular strain [33, 37]. Specifically in young athletes, when persistent symptoms and non-specific imaging findings are present, functional data obtained by SPECT/CT may support person-tailored treatment, prevent unnecessary surgeries, and decrease the risk of progression to spondylolisthesis [36–38].

SPECT/CT in the evaluation of patients after spinal surgery

The literature on the use of SPECT/CT in evaluating patients with chronic LBP and planning surgical treatment demonstrates its clear advantage in identifying pain generators compared with traditional imaging methods. However, only a limited number of studies have addressed its role in the postoperative assessment of patients with chronic or recurrent pain following spinal fusion.

The outcomes of surgical interventions, such as cervical or lumbar fusion, in patients evaluated with SPECT/CT for spondylosis have been investigated. A retrospective review of the medical records of 23 patients (60.0 ± 11.0 years) who underwent preoperative SPECT/CT followed by surgical treatment at the SPECT/CT-identified spinal levels was conducted [15]. Three months after surgery, 18 patients (78.3%) reported clinical improvement, after 6 months, 11 patients (47.8%) reported a decrease in pain, and after 1 year, 19 patients (82.6%) reported significant pain relief. The study concluded that SPECT/CT is a useful addition to existing diagnostic modalities (MRI, CT) for improving clinical outcomes and surgical planning.

The presence of spinal implants can compromise MRI diagnostic accuracy due to artifacts. One study demonstrated that SPECT/CT successfully identified pain generators in patients with metal interbody fusion implants, thereby facilitating appropriate treatment planning [17]. Thirty-five patients were diagnosed using SPECT/CT and subsequently received appropriate treatment.

The authors concluded that, in cases where MRI artifacts limit diagnostic accuracy, SPECT/CT is a reliable alternative.

When conducting SPECT/CT studies in the early postoperative period, it is essential to consider that osteoblastic activity associated with regeneration can lead to high tracer uptake in the bone-implant interface and may be falsely interpreted as a pain generator. Overall, evaluating additional regions with SPECT/CT in postoperative patients, where various structures may serve as pain generators, allows for more accurate planning of subsequent therapy.

A retrospective study compared three-phase planar bone scintigraphy (planar/SPECT) with SPECT/CT in patients who had undergone lumbar fusion surgery (LFS) [18]. Based on the evaluation of metal implants (including loosening and compromised stability) and the condition of adjacent segments, the authors concluded that SPECT/CT provides greater accuracy in identifying pathological lesions and should be considered the diagnostic modality of choice for patients with LBP following LFS.

Several studies have demonstrated that SPECT/CT can help differentiate symptomatic age-related degenerative changes from adjacent segment disease developing after lumbar or cervical fusion [18, 39, 40]. Al-Riyami et al. investigated persistent/recurrent lumbar pain following LFS with negative conventional imaging and found that adjacent segments showed higher radiopharmaceutical uptake (40.6% vs. 15.0%; $p=0.001$). Their results indicate that SPECT/CT may be preferable for diagnosis when adjacent segment disease is not localized on conventional imaging [39]. Another case series by Kato et al. examined five elderly patients initially scheduled for multilevel fusion based on conventional imaging, but SPECT/CT localized the true pain generator to a single metabolically active level in three cases, allowing short-segment fusion instead of extensive surgery, and identified alternative lesions (L4 endplate insufficiency fracture, L3 transverse process fracture) in two patients who were successfully treated conservatively, collectively their results reported a mean numerical rating scale improvement from 8.4 to 2.2 with the aforementioned strategy [40]. Altogether, these findings indicate that SPECT/CT may not only enhance diagnostic accuracy in postoperative patients with suspected adjacent segment disease but also help avoid overtreatment by distinguishing truly symptomatic levels from incidental degenerative changes that are not contributing to the patient's pain.

Use of SPECT/CT before percutaneous vertebroplasty of compression fractures

Osteoporosis, which develops in elderly patients, leads to an increased risk of osteoporotic vertebral fractures,

accompanied by kyphosis, pain, impaired quality of life, and increased mortality [41]. In the treatment of compression fractures, an effective method is minimally invasive surgery, percutaneous vertebroplasty, or kyphoplasty. For vertebroplasty, preoperative diagnosis of osteoporotic fractures and identification of active lesions are essential.

In a study, SPECT/CT was compared with MRI for the diagnosis of compression fractures. After examining 46 patients with 79 abnormal segments detected on MRI, SPECT/CT showed 83 affected segments and 77 affected vertebral bodies that met the diagnostic criteria for acute compression fractures [42]. The authors concluded that SPECT/CT is the preferred diagnostic method for compression fractures.

SPECT/CT has also been successfully used in the preoperative evaluation to guide treatment planning and to predict the therapeutic response to percutaneous vertebroplasty [43]. A preoperative study demonstrated that SPECT/CT predicted clinical improvement in 91% of patients (21 of 23). The scans revealed new fractures, areas of bone remodeling in previously cemented vertebrae, facet pathology, and degenerative disc changes. By enabling more accurate localization of pain generators, SPECT/CT enabled the authors to reassess alternative pain causes, refine vertebroplasty planning, and, in some cases, revise the indication. The authors concluded that SPECT/CT may serve as a reliable predictor of postoperative success. This value has been supported by another study, which similarly reported radiotracer accumulation around vertebral compression fractures, corresponding to painful sites and aiding preoperative decision-making [17].

Additionally, to minimize the impact of bone cement-related artifacts on image contrast, several SPECT/CT-based protocol modifications have been proposed [44]. The use of attenuation correction and combined attenuation–scatter correction on SPECT/CT has been shown to improve image counts and generate higher-density, more diagnostically useful lesion images.

The combined use of SPECT/CT with complementary diagnostic modalities

The intervertebral disc is a complex structure that includes the annulus fibrosus, the nucleus pulposus, and the end plate. Degeneration of the intervertebral disc is associated with chronic pain [45, 46]. Intervertebral disc disorders are typically evaluated using MRI, with degeneration graded according to the five-level Pfirrmann classification system [46], while the condition of the vertebral body is assessed based on the three types of Modic changes [47].

In one study, SPECT/CT was used to evaluate the metabolic activity of vertebral endplates from L2–3 through

L5–S1, incorporating both the Pfirrmann grading system for disc degeneration and Modic changes to characterize associated vertebral body alterations [48]. Among the 99 patients examined, vertebral endplates showed increased metabolic activity on SPECT/CT in 96.1% of Modic type 1 changes, 56% of Modic type 2 changes, and 77.8% of Modic type 3 changes. The authors concluded that Modic type 1 changes and Pfirrmann grade 5 disc degeneration were the strongest predictors of positive bone SPECT/CT uptake.

In another study, foci of active radionuclide uptake in the end plates, as detected by SPECT/CT, were also correlated with Modic 1 changes [49]. However, unlike the previous study, Modic type 3 demonstrated only a weak correlation with radiotracer uptake, and Modic type 2 showed no association with increased activity on SPECT/CT. This study suggested that SPECT/CT findings, combined with Modic changes on MRI, can reflect various stages of degenerative and regenerative processes; however, further studies are needed to determine the role of the combined SPECT/CT and MRI in localizing pain sources.

Another study investigated the possible correlation between the degree of structural FJ degeneration and osteoblastic activity, assessed using SPECT/CT and the Pathria grading system on CT, in patients with LBP and degenerative spinal changes [48]. This prospective study included 99 patients with LBP, and a total of 792 FJs (L2–3 to L5–S1) were analyzed. In over 40% of FJs, SPECT/CT provided more precise localization of active regions than CT alone. Similar findings were also reported in a study that conducted a comparative analysis of FJs in 150 patients [23]. The authors concluded that SPECT/CT enhances diagnostic accuracy and informs appropriate treatment planning for patients with LBP.

Diagnosis of potential pain generators in degenerative spine diseases is typically made using conventional radiography; however, the results are inconclusive in approximately 20% of patients. Therefore, SPECT/CT is potentially helpful. In a study, patients requiring revision surgery for spinal deformity were evaluated. SPECT/CT was conducted as an adjunct to conventional radiological modalities. The results showed that SPECT/CT successfully identified areas of increased radiotracer uptake corresponding to pseudoarthrosis-related pain and enabled assessment of spinal fusion in patients who required surgical correction of first-, second-, or third-plane sagittal deformities. Mean Oswestry Disability Index (ODI) score improved from 53.88 to 12.0 and VAS from 7.25 to 2.0 [50].

A comparison between SPECT/CT and standalone CT findings was performed in patients with pseudoarthrosis who had previously undergone anterior and/or posterior LFS [51]. CT suggested screw loosening in five patients;

however, three of these showed no abnormal uptake on SPECT/CT. Further evaluation confirmed that these were cases of non-union rather than true screw loosening. Additionally, SPECT/CT identified six cases of FJ mobility that were not detected on CT alone.

In a study by Ucros et al., a comparative analysis of 113 patients with 446 abnormal lumbar facet joints (mostly L4-L5 and L5-S1) was performed using MRI and SPECT/CT. Of these 446 lumbar FJs, 311 (69%) were abnormal only on MRI, 100 (22%) were abnormal on both MRI and SPECT/CT, and 35 (7.8%) were abnormal only on SPECT/CT [20]. The vast majority of joints classified as abnormal in MRI did not find confirmation when tested by SPECT/CT, indicating a high specificity of the method.

In another study, MRI in 30 patients revealed intervertebral disc abnormalities and FJ arthropathy; subsequent SPECT/CT identified areas of active remodeling in 80% of these patients [52]. The most common anomaly detected on SPECT/CT (45%) was increased tracer uptake in the anterior vertebral body, reflecting degenerative intervertebral disc changes accompanied by osteophytes or sclerosis, which was identified as the primary source of LBP. Tracer uptake in the FJs was observed in 22% of patients, most commonly at the L3-L4 and L4-L5 levels. The authors concluded that morphological abnormalities identified on MRI were corroborated by SPECT/CT, supporting the specificity of this modality; however, they emphasized that the two techniques should be viewed as complementary.

Technical considerations in SPECT/CT for degenerative spine imaging

In the imaging of degenerative spine diseases, several technical nuances in SPECT/CT acquisition and reconstruction significantly influence lesion visibility and the accurate interpretation of tracer uptake. CT-based attenuation correction is essential in this context, as cervical, thoracic, and lumbar vertebrae are surrounded by tissues with markedly non-uniform attenuation, including the mandible, shoulders, and paraspinal musculature [53, 54]. Addressing this issue, creating an attenuation map with CT data improves contrast and quantitative accuracy in heavily attenuated regions [53]. Scatter correction further enhances image quality, as scattered photons can obscure small foci of increased uptake, such as in FJs, pars interarticularis, or endplates; modern systems commonly apply dual- or triple-energy window techniques or CT-derived scatter models to improve lesion contrast [55].

Precise fusion of SPECT and CT is crucial for assigning focal uptakes to specific anatomical structures, such as individual FJs, fusion levels, and adjacent segments. Misregistration between SPECT and CT, most often

occurring due to difference in patient motion between acquisitions, might cause attenuation-correction errors and mislocalization of hot spots, representing a known pitfall in quantitative bone SPECT/CT [56, 57]. Metal instrumentations from the previous surgeries pose another challenge in technical aspects by generating streak artifacts that may distort Hounsfield Units, leading to pseudo-defects or spurious uptake patterns. Optimized CT protocols, metal-artifact reduction algorithms, and comparison of attenuation-corrected with non-corrected SPECT images are recommended to mitigate this problem [58]. Overall, in terms of the technical nuances of SPECT/CT, precise handling of attenuation and scatter correction, accurate SPECT/CT fusion, appropriate handling of metal-related artifacts, and minimization of patient motion are critical to effective interpretation of radiopharmaceutical uptake in SPECT/CT imaging.

Complications and hazards of SPECT/CT

Although SPECT/CT effectively combines anatomical and metabolic data for diagnostic purposes, it involves exposure to ionizing radiation. A typical bone SPECT/CT performed with Tc-99 m phosphonates delivers approximately 8.3–10.1 mSv of effective dose [59–61]. Brix et al. reported that the effective dose for SPECT alone typically ranges from 2 to 10 mSv. They estimated the lifetime attributable cancer risk associated with SPECT/CT to be 0.27% in males and 0.37% in females aged 16 or older, noting that this risk decreases with advancing age [62]. Building on this, radiation exposure especially gains more importance in young patients, athletes requiring repetitive follow-up imaging, and multi-level affected post-operative patients, which underscores the importance of patient selection. Therefore, although the associated risk is presumed to be low, the advantages of SPECT/CT should be considered on an individual basis, and patient selection must be carefully performed, with attention to potential trade-offs, to optimize diagnostic yield.

Additionally, bone scintigraphies with Tc-99 m phosphonates are generally well tolerated; however, mild radiopharmaceutical-related adverse effects, such as transient nausea, headache, flushing, dysgeusia, or minor injection-site discomfort, have occasionally been reported [63]. Serious reactions such as urticaria and anaphylaxis are extremely rare, but reported in the literature [63, 64]. Altogether, these findings show that clinically significant adverse effects are present, though exceedingly rare.

Future directions

Future efforts are expected to focus on quantitative SPECT/CT to establish objective thresholds for clinically relevant lesions [65]. Artificial intelligence and radiomic

analyses may allow automated pipelines for the detection of pain generators and the prediction of treatment response [66–68]. Combined multi-parametric imaging protocols may further enhance the accuracy of diagnosing symptomatic degeneration [48, 49]. Additionally, new tracers may further improve sensitivity for early osseous changes [69]. However, the clinical expansion of these techniques will depend not only on diagnostic validity but also on practical considerations, as SPECT/CT remains a relatively expensive modality and is not available in every center, underscoring the importance of developing cost-effective protocols and improving accessibility in routine clinical practice [70].

Limitations

The present study has several limitations. Firstly, it is a narrative review; therefore, the selection of studies was not based on a systematic search protocol, which may introduce selection bias and limit the ability to generate quantitative conclusions. Secondly, the included studies are heterogeneous in terms of design, patient populations, imaging protocols, and reference standards, making direct comparisons challenging. Third, current evidence on SPECT/CT in degenerative spine disease is retrospective and based on single-center experiences, limiting the generalizability of the findings summarized here. Finally, emerging topics such as standardized reporting metrics, cost-effectiveness analyses, and long-term postoperative follow-up are underrepresented in the current literature; therefore, a comprehensive evaluation could not be conducted.

Conclusions

Elucidating pain generators in the spinal axis using conventional radiological modalities is challenging. SPECT/CT provides unique diagnostic information by demonstrating areas of increased radiotracer uptake associated with bone remodeling, helping clinicians select appropriate surgical or conservative treatment strategies. Pain related to FJ pathology remains a major focus; although MRI and CT may show degenerative changes, they often fail to distinguish symptomatic lesions. Evidence supports the usefulness of SPECT/CT for precisely localizing painful FJs and guiding targeted interventions or surgery. SPECT/CT has also demonstrated value in predicting pain relief following percutaneous vertebroplasty. The current literature suggests that SPECT/CT should be considered during preoperative planning for cervical and lumbar fusion procedures, as it can help identify segmental instability and inform stabilization strategies. Studies further show its value in localizing pseudoarthrosis and other postoperative pain generators, leading to more effective treatment decisions. These patients often suffer severe, disabling pain, while conventional imaging

frequently reveals only nonspecific degenerative findings. Additional research is needed to determine how SPECT/CT can contribute to focused diagnostic and therapeutic strategies in failed back surgery syndrome.

Abbreviations

MRI	Magnetic resonance imaging
CT	Computed tomography
VAS	Visual analogue scale
NHS	National health service
LBP	lower back pain
SPECT/CT	Single-photon emission computed tomography / computed tomography
Tc-99m	Technetium-99m
FJ	Facet joint
LFS	Lumbar fusion surgery
NDI	Neck disability index
ODI	Oswestry disability index

Author contributions

IB, HAO: Conceptualization, methodology, software, writing original draft. EG: Writing original draft, Writing review and editing, Investigation, Formal Analysis. KY: Writing original draft, Writing review and editing, Investigation, Formal Analysis. VSS, NB: Investigation, data curation. BC: Formal analysis, investigation, review and editing, supervision.

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Data availability

All data related to this study can be requested from the corresponding author via e-mail.

Declarations

Ethics approval and consent to participate

The study was carried out according to the latest revision of the Helsinki Declaration regarding medical research involving human subjects.

Consent for publication

No patients actively in the study.

Competing interests

The authors have no competing interests related to this study.

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