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Review

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SPECT/CT in the Assessment of Postoperative Spine: A Comprehensive Literature Review

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ABSTRACT

Back pain is a widespread and debilitating condition that significantly impairs quality of life, often eroding patients' sense of autonomy and independence, and contributes to global disability rates. The initial management of back pain generally follows a conservative approach, encompassing physical therapy, pharmacological interventions, and lifestyle modifications aimed at alleviating symptoms and restoring functionality. Spine surgery, while frequently beneficial in addressing underlying structural issues, carries certain inherent risks. Among the most challenging outcomes of spine surgery is the persistence or recurrence of pain, a condition commonly referred to as failed back surgery syndrome (FBSS). The effective management of FBSS requires a comprehensive and meticulous approach. When conservative measures for FBSS fail to yield satisfactory results, revision surgery can be considered. The role of advanced imaging techniques is critical in these cases. Standard imaging modalities each involve unique advantages and limitations, and a multimodal approach is therefore important to achieve a comprehensive and accurate evaluation of the patient's condition. In recent years, single-photon emission computed tomography combined with computed tomography (SPECT/CT) has gained recognition as a valuable tool in the postoperative assessment of spine surgery patients. SPECT/CT has demonstrated superior efficacy in detecting specific complications, such as pseudoarthrosis, hardware failure, and screw loosening. By integrating metabolic activity data from the spine and surrounding bony structures with the three-dimensional reconstruction capabilities of CT, SPECT/CT enhances diagnostic accuracy and informs more precise treatment decisions. This review aims to synthesize the current body of literature on the application of SPECT/CT in the postoperative evaluation of spine surgery patients, while also providing a comparative overview of other imaging modalities within this context. Our objective is to underscore the pivotal role that advanced imaging techniques play in improving patient outcomes after spine surgery, reducing the incidence of FBSS, and shortening its duration.

KEYWORDS: Postoperative back pain, SPECT/CT, Pseudoarthrosis, Hypermetabolism, Hardware failure

ABBREVIATIONS: CT: Computerized tomography, **MRI:** Magnetic resonance imaging, **SPECT:** Single photon emission computed tomography, **CSF:** Cerebrospinal fluid, **PET:** Positron emission tomography, **ACR:** American college of radiology, **US:** Ultrasound, **18F-NaF:** 18F Sodium fluoride, **18F-FDG:** 18F-Fluorodeoxyglucose, **FBSS:** Failed back surgery syndrome

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INTRODUCTION

Back pain is a leading cause of disability and diminished quality of life in the global population, with up to 85% of individuals experiencing it at least once in their lifetime (2,7,40). The related economic burden includes both direct healthcare costs and societal impacts such as lost productivity and early retirement. Treatment strategies are individualized, and initial emphasis is placed on conservative approaches such as physical therapy and analgesic medications. When these fail or neurological symptoms arise, surgical intervention may be necessary. While spine surgery is effective, it carries risks, including major neurological deficits (<1%) and complications like instrumentation failure, infection, and persistent pain (5,9,13,17,18).

A particularly challenging condition related to poor postoperative outcomes is failed back surgery syndrome (FBSS). FBSS is characterized by persistent or recurrent back pain, with or without accompanying sciatica, following one or more spinal surgeries (4,30). Its etiology is multifactorial, complicating management. Radiological evaluation is critical in diagnosing FBSS, typically utilizing plain radiography, CT, and MRI. While effective, these methods are limited for evaluating metabolic processes. Nuclear medicine imaging modalities, such as SPECT/CT and PET/CT, integrate structural and metabolic assessment and enhance diagnostic accuracy.

This review examines the role of SPECT/CT in postoperative spinal evaluation, providing a comparison of various imaging modalities to improve diagnostic accuracy and patient outcomes.

MATERIAL and METHODS

Literature Search

This systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (1). Pubmed, ScienceDirect, and Scopus databases were searched from 27.03.2025, using Medical Subject Headings (MeSH) terms and keywords. The Boolean operators “OR and “AND” were used as follows: (“SPECT/CT” OR “single photon emission computed tomography”) AND (“postoperative spine” OR “spinal surgery” OR FBSS OR pseudoarthrosis OR “screw loosening”) AND (diagnosis OR “diagnostic accuracy” OR sensitivity OR specificity) AND (comparison OR MRI OR CT OR “PET/CT”). Search result references were uploaded into Rayyan (https://www.rayyan.ai) for duplicate removal and screening.

Study Selection

Articles were screened under the following inclusion/exclusion criteria. The inclusion criteria were 1) case reports or case series reporting non-pooled data on clinical radiographic evaluation by SPECT/CT imaging, treatment procedures, and follow-up results; and 2) studies written in English. Exclusion criteria were as follows: 1) literature reviews, meta-analyses, autopsy reports, editorials, and conference abstracts; 2) studies only reporting histopathologic or radiologic results without any clinical, demographic, and follow-up data; 3) non-English language articles and non-peer-reviewed sources.

Data Extraction

The following data was extracted from the included studies: first author, publication year, study design, sample size, the primary indication for SPECT/CT (persistent postoperative pain, infection, screw loosening, arthropathy), the type of radiotracer (99mTc-MDP, 99mTc-UBI 29-41), reported spinal level and location (lumbar vertebrae, facet joints, sacroiliac joint, thoracolumbar fusion levels), type of instrumentation (pedicle screws, interbody cages), postoperative infection status, sensitivity, specificity, and AUC values when compared with other modalities. One reviewer (M.D.Y.) extracted data from each study, and two more reviewers (A.S.A.) and (K.D.T.) independently verified the data.

Data Synthesis and Quality Assessment

Two independent authors (M.D.Y. and A.S.A.) evaluated the risk of bias using the Joanna Briggs Institute checklists for case reports and case series, and assessed the quality of evidence according to the 2011 Oxford Centre for Evidence-Based Medicine standards (2–4).

Statistical Analysis

The Jamovi (version 2.4.7) MAJOR module was used for all statistical analyses. Continuous variables were summarized as medians (ranges), and categorical variables were summarized as frequencies (percentages). The themes of the studies were categorized as Infection Diagnosis, Pseudoarthrosis/Nonunion, Screw Loosening/Hardware Complications, and Facetogenic/Mechanical Pain.

RESULTS

Our search strategy yielded 391 results (PubMed: 26, Science Direct: 351, Scopus: 14). Following duplicate removal and screening, 15 studies, including several case reports, were included in our review (Figure 1).

The studies included a total of 1022 patients. There were four prospective case reports, and eight retrospective case series with a weighted mean patient age of 55.1 years (43.4% Male). The most common tracer utilized was 99mTc-MDP, appearing in 14 studies. All studies included SPECT/CT in their assessments. However, the limited number of studies reporting demographic and clinical data, along with the heterogeneity of these data and low evidence levels (IV–V), prevented the calculation of hazard ratios and precluded a meta-analysis.

SPECT/CT vs Conventional Imaging Modalities for Spinal Pathologies

Several studies compared conventional imaging and SPECT/CT for postoperative patient assessment. These reports revealed the superiority of SPECT/CT for diagnosing pathology in cases where MRI results were ambiguous (1,3,8,20,24,27). Lehman et al. reported that the management strategy was altered in 79% of cases due to SPECT/CT results, for which MRI had been inconclusive (24). Furthermore, Hudayana et al. showed 100% sensitivity and 89.7% specificity in diagnosing screw loosening through SPECT/CT imaging (20). However, Paez et al. reported contradictory results for infection detection,

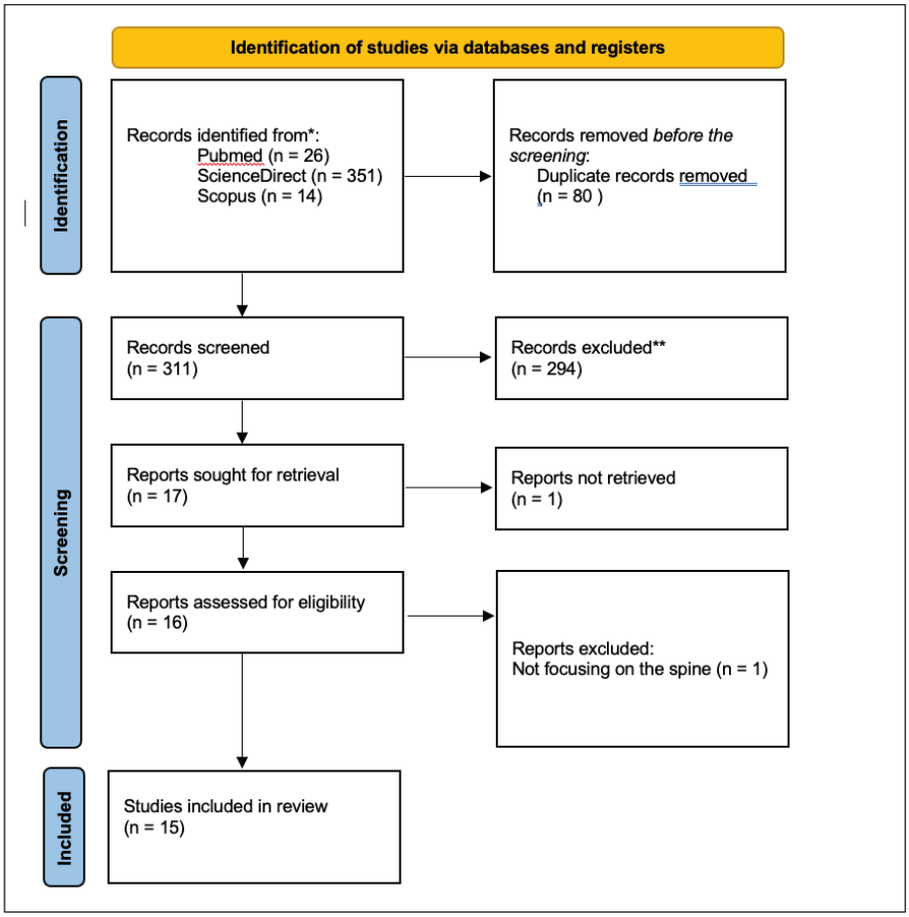

Figure 1: PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and registers only.
*Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/registers).
**If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools.
Source: Page MJ, et al. BMJ 2021;372:n71. doi: 10.1136/bmj.n71. This work is licensed under CC BY 4.0. To view a copy of this license, visit https://creativecommons.org/licenses/by/4.0/

with SPECT/CT producing suboptimal results compared to MRI (27). Finally, Carsten et al. presented a case in which CT results were normal, with pathology uncovered using SPECT/CT; this case highlights the discordance between structural integrity and metabolic activity (8).

Impact on Clinical Decision-Making

Several studies explored different clinical strategy options based on SPECT/CT findings (3,20–22,24,34). Kaiser et al. utilized SPECT/CT in degenerative disc disease patients and showed significant improvements in VAS and ODI scores in postoperative compared to preoperative assessments (21). In an attempt to prevent extensive fusion, Kato et al. utilized SPECT/CT to localize specific pain generators in elderly patients, using this information to manage these patients conservatively (22). Furthermore, in their cohort, Shapovalov et al. demonstrated that patients benefited more and had greater pain relief following SPECT/CT-guided revision surgeries (34). SPECT/CT was also used to diagnose and alter the management planning for patients with facet arthropathy and hardware loosening (20,24).

Biomechanical Correlation and Metabolic Activity

Correlations between tracer uptake and several factors—including mechanical stress, anatomical abnormalities, and degenerative disease progression—were investigated in several studies (8,12,32). Russo et al. found that Modic type I changes and Pfirrmann grade IV discs were associated with high tracer uptake, indicating a more metabolically active region, presumably connected to greater pain generation (32). Dharia et al. found increased tracer uptake in patients with elevated pelvic incidence and sacral slope, and sacroiliac joint pathologies (12). Finally, Carsten et al. demonstrated increased uptake associated with minimal degenerative changes; meanwhile, severely degenerated regions exhibited minimal uptake, indicating that metabolic activity represents early degenerative changes (8).

Detection of Hardware Failure, Pseudoarthrosis, and Other Complications

Detecting recent complications in the postoperative setting can be challenging. Several studies aimed to clarify these changes utilizing SPECT/CT. Rager et al. used SPECT/CT to differentiate true and pseudoarthrosis from other causes of pain, demonstrating greater sensitivity when compared to CT (29). In further studies, Rager et al. demonstrated that the absence of tracer uptake does not correlate with an absence of complications in patients with broken screws (28). Tamm and Abele reported that SPECT/CT is equivalent to spinal MRI in the capacity to detect spinal infection. This is especially useful when MRI is contraindicated (36).

DISCUSSION

Causes of Postsurgical Back Pain

Complication rates for spinal procedures range between 4% and 19%; these issues can be broadly categorized into acute and chronic causes of pain (10,35,37) (Table I). Chronic complications, such as hardware failure, may manifest months after surgery and include problems like the loosening or fracture of pedicle screws, cage migration, and rod breakage, all of which can lead to fusion failure. Fusion failure can result in spondylolisthesis and spinal instability, especially in the case of rod fractures. Early radiologic assessment is vital for detecting these complications, identifying sources of pain, and enabling timely surgical revision to prevent further deterioration.

Table I: Acute and Chroic Causes of Postoperative Back Pain

Acute	Chronic
Hemorrhage	Hardware Failure
Edema	Chronic infection
Postoperative Inflammation	Spondylolisthesis
Screw malpositioning	Infection
Infection	Dural tears
Nerve root injury	Pseudoarthrosis
	Facet joint degeneration
	Adjacent segment degeneration
	Sacroiliac Joint secondary to previous spinal surgery
	Cage subsidence

In addition to hardware-related issues, other complications such as infection, spinal or epidural hematoma, pseudomeningocele, and nerve root injury can contribute to persistent postoperative pain. Early identification and management of these complications are crucial, as they can quickly progress to permanent neurological deficits or even death. Postsurgical pseudomeningocele, though rare, often arises from inadvertent meningeal tears or inadequate closure during surgery, and can lead to symptoms such as wound swelling, headaches, and radicular pain. Another potential issue, known as "battered root syndrome," can cause persistent radicular pain following lumbar surgery. This is often due to prolonged and aggressive root retraction, excessive bleeding, or the presence of a conjoined nerve root. Surgery may also lead to arachnoiditis, a condition where persistent inflammation of the arachnoid mater causes irritation of the nerve roots, resulting in pain that can affect both the spine and lower limbs.

Postoperative Radiologic Assessment of the Spinal Column

Plain radiographs, CT, and MRI scans are the primary radiological tools used for postoperative evaluation. These modalities are crucial for monitoring spinal column alignment, hardware integrity, and the progression of bony fusion. Regular follow-up with thorough clinical and radiological assessments is essential to ensure optimal outcomes. However, each of these imaging techniques has limitations and should not be relied upon in isolation; they must be interpreted in the context of a patient's symptoms and medical history to provide accurate diagnoses (Table II). Plain radiography is cost-effective for evaluating bone structure and hardware integrity. Static radiographs can detect hardware failure, while dynamic mo-

Table II: Comparing the Imaging Modalities Utilized in The Studies

Modality	Strengths	Limitations	Clinical Application
SPECT/CT	High sensitivity for detecting metabolically active pain generators (e.g., pseudoarthrosis, facet degeneration, screw loosening); increased efficacy for postoperative assessment with metal hardware	Increased Radiation exposure; limited in early postoperative phase due to bone healing activity shows as increased tracer uptake; cannot effectively differentiate inflammation from infection	Postoperative back pain with ambigious CT/MRI scans; suspected hardware loosening, pseudoarthrosis, and facet degeneration
PET/CT (FDG)	Superior for infection detection (spondylodiscitis, osteomyelitis); less affected by metal artifact	High cost; limited availability; not routinely used in mechanical pain diagnosis; also increased radiation exposure	Suspected postoperative infection or systemic inflammation; early discitis/osteomyelitis with negative MRI
MRI	Gold Standard for soft tissue, nerve root, and scar tissue as well as spinal cord and disc assessment	Metal artifacts limits postoperative imaging; decreaced efficacy in visualizing fusion long scan time	Initial evaluation for soft tissue/ spinal pathology; radiculopathy or cord compression; disc herniation
CT	Superior bone detail and hardware visualization; 3D reconstruction; Effective in detecting nonunion and foraminal stenosis	No functional/metabolic information; increased radiation exposure	Excellent structural evaluation of bone, hardware, and nonunion in the early postoperative period

dalities assess spinal instability (6,26). Spondylolisthesis can be identified, but soft tissue and neural impingement cannot be assessed. Meanwhile, CT provides detailed 3D visualization of bone and hardware, excelling in detecting nonunion and foraminal stenosis in FBSS (11,38). MRI is the best tool for soft tissue evaluation, and can identify conditions like stenosis, disc disease, and infections (16). Research has shown that the extent of scar tissue is directly linked to the recurrence of radicular pain, with a 25% increase in scar tissue doubling the risk (23,31). Despite its strengths, MRI has certain limitations, particularly in evaluating the bony cortex or assessing fusion across operated levels. Metallic implants can also introduce artifacts that complicate imaging, although modern titanium hardware typically causes fewer problems. Moreover, advances in metallic artifact reduction sequences, when appropriately selected, can effectively address both in-plane and through-plane artifacts by using multi-acquisition variable resonance image combinations and slice-encoding techniques to enhance image quality (25). However, patients with chronic pain may struggle to remain still for the lengths of time required to obtain high-quality multiplanar images, and reactions to contrast agents can limit the widespread use of MRI in the postoperative population. These considerations highlight the importance of selecting appropriate imaging modalities and techniques to maximize diagnostic accuracy while minimizing patient discomfort.

SPECT/CT

SPECT utilizes the pharmacokinetic properties of specific radionuclide substances to detect areas of altered or hypermetabolic activity within the bone structure of the spinal column. This can identify anatomical or functional sources of postoperative pain. Common radiotracers include technetium-99m, which binds to hydroxyapatite—a key mineral in the bone cortex—^{18}F Sodium Fluoride (^{18}F-NaF), and ^{18}F-fluorodeoxyglucose (^{18}F-FDG). These tracers are incorporated into the bone matrix with hydroxyapatite and are also taken up by inflammatory cells, enabling the detection of metabolically active cells within the spine through SPECT and positron emission tomography (PET) imaging.

Recent advancements in imaging technology have given rise to hybrid techniques like SPECT/CT and PET/CT, which seamlessly integrate the metabolic insights of SPECT and PET with the detailed 3D anatomical reconstructions provided by CT scans (2). This powerful combination enables the precise evaluation of metabolically active sites, even in challenging areas such as around implanted hardware or regions affected by infection, where metabolic activity is often heightened. The studies included in our systematic review have consistently demonstrated the prognostic utility of SPECT/CT in revealing pathologies missed by CT or MRI scans. This is especially useful in the postoperative period, in which artifacts caused by instrumentation can impede image quality (Table III). Lehman

Table III: Summarization of Studies with Key Findings

Study	Study Aim	Key Results	Added Benefit of SPECT/CT	Evidence & Quality
Lehman et al. (24)	Postoperative back pain	Patient management strategy changed in 79% of cases	MRI scans cannot increased tracer uptake at facet joints	JBI: High OCEBM: IV
Hudyana et al. (20)	Screw loosening, Hardware Failure	SPECT/CT had 100% sensitivity, and 89.7% specifity	SPECT/CT outperformed CT	JBI: High OCEBM: IV
Rager et al. (29)	Pseudarthrosis vs facet pain	SPECT/CT has increased efficacy inpain generator localization	Detected facet joint tracer uptake not visible on CT	JBI: High OCEBM:IV
Kaiser et al. (21)	DDD in patients with positive SPECT/CT findings	Improved ODI and VAS scores after SPECT/CT imaging targeted fusions	Increased uptake by ı-increased metabolic activity has improved outcomes	JBI: High OCEBM: III
Kato et al. (22)	Exploring, Management and assessment of elderly patients presenting with back pain with SPECT/CT	SPECT/CT has guided and help avoid surgery in multilevel disease in elderly patients	Conservative management guided by SPECT	JBI: High OCEBM: IV
Awosika et al. (3)	Systematic review and case series on the utilization of SPECT/CT and PET scan on postoperative spine assessment	Confirmed superior detection of facet degeneration through SPECT/CT scan	They have concluded through systematic review that SPECT/CT is a valuable adjunsct were traditional imaging fails	JBI: High OCEBM: I

Table III: Cont.

Study	Study Aim	Key Results	Added Benefit of SPECT/CT	Evidence & Quality
Paez et al. (27)	Multicenter, prospective study in evaluating postoperative infection assessment through PET/CT and SPECT/CT	FDG PET/CT superior to SPECT with UBI in detecting postoperative infections	MRI + FDG has the AUC of 0.938	JBI: Moderate OCEBM: II
Dharia et al. (12)	Sacroiliac joint pain	Increased uptake correlated with increased pelvic tilt and other spinopelvic parameters	While SPECT/CT is superior in assessing postoperative osteoblastic activity, PET/CT showed incresed efficacy in assessing postoperative infectious assessment	JBI: Moderate OCEBM: IV
Shapovalov et al. (34)	Postoperative cervical spine fusion syndrome	SPECT-guided revision improved patient outcomes	Higher revision success in patients assessed with SPECT/CT vs non-SPECT	JBI: Moderate OCEBM: IV
Russo et al. (32)	Evaluation of chronic back pain with SPECT/CT	Increased Uptake associated with Modic I and Pfirrmann grade 5 disc degenerations	Metabolic confirmation of degenerative pain	JBI: Moderate OCEBM: IV
Rager et al. (28)	Differentiating pseudoarthrosis from other causes of postoperative back pain	Controversially SPECT/CT -failed to detect broken screw	underscoring the importance of metabolic activity in SPECT/CT	JBI: Moderate OCEBM: IV
Carstensen et al. (8)	Chronic facet joint pain assess by SPECT/CT	SPECT showed increased uptake in facet joints in patients with no appearent facet disease on CT scan	SPECT/CT showed metabolic activity in patients without any symptoms and structural degeneration	JBI: Moderate OCEBM: IV
Acosta et al. (1)	Postoperative lumbar spine fusion syndrome	Localized pain generator not seen on MRI revealed by SPECT/CT	Management strategy altered based on metabolic activity seen on SPECT/CT	JBI: Moderate OCEBM: IV
Tamm and Abele (36)	Assessment of suspected spondylodiscitis	SPECT/CT is equivalent to MRI in infection detection	Viable alternative in stiuations where MRI is contraindicated	JBI: Moderate OCEBM: IV

SPECT/CT: *Single photon emission computed tomography/computed tomography,* ***PET/CT:*** *Positron emission tomography/computed tomography,* ***FBSS:*** *Failed back surgery syndrome,* ***DDD:*** *Degenerative disc disease,* ***ODI:*** *Oswestry disability index,* ***VAS:*** *Visual analog scale,* ***MRI:*** *Magnetic resonance imaging,* ***CT:*** *Computed tomography,* ***FDG:*** *Fluorodeoxyglucose,* ***UBI:*** *Ubiquicidin,* ***JBI:*** *Joanna Briggs Institute,* ***OCEBM:*** *Oxford center for evidence-based medicine levels.*

et al. emphasized the clinical utility of SPECT/CT in treatment planning; SPECT/CT findings led to changes in the treatment plans of 79% of patients through the identification of facet joint abnormalities previously missed by MRI (24). Meanwhile, Rager et al. and Hudyana et al. reported that SPECT/CT effectively revealed metabolically active areas with increased tracer uptake in patients with postoperative back pain, which had been missed on CT scans (20,29). Finally, Carstensen et al. illustrated that ambiguous CT findings could be visualized as metabolically active sites by SPECT/CT (8). This shows the capacity of SPECT/CT to capture lesions before any radiographically significant changes occur. Notably, focal intensities detected by these hybrid methods can remain positive for up to a year following surgery, potentially signaling issues such as nonunion or pseudoarthrosis. In contrast, diffuse activity may indicate increased bone turnover in a normally fused spine, reflecting the body's ongoing healing process. Furthermore, the use of technetium-labeled white blood cells enhances the ability to detect infections in the operated area, providing a comprehensive toolset for assessing complex postoperative conditions (16). The updated American College of Radiology (ACR) Appropriateness Criteria endorse SPECT/CT as the standard for identifying radiographically hidden spondylosis as a pain generator in younger patients (Figure

2) (14). SPECT/CT is also recommended as an adjunctive imaging technique for detecting pseudoarthrosis and screw loosening in patients who have undergone prior lumbar surgery, with or without radiculopathy (14). Hudyana et al. reported that SPECT/CT significantly outperformed CT for the diagnosis of screw loosening, with sensitivity of 100% and specificity around 90 (20). However, in consecutive studies, Rager et al. underscored that metabolic activity may not always be present in the event of mechanical failure of a construct. While it can be deduced from these studies that the presence of a metabolically active site can confidently indicate pseudoarthrosis, a negative scan does not necessarily exclude the possibility (28,29). In a systematic review, Awosika et al. highlighted the superiority of SPECT/CT in diagnosing pseudoarthrosis and adjacent segment disease, and guiding further revision surgeries (3). One study explored the relationship between SPECT/CT findings and the outcomes of revision surgery in patients with FBSS, and determined the modality's use in identifying sources of pain in patients with suspected inflammatory back pathology, thereby guiding more effective treatment strategies (Figure 3). The utility of SPECT/CT for guiding patient management has been indicated by several studies. Kaiser et al. found that patients benefited more when treated at SPECT/CT positive levels compared to SPECT/CT negative or other non-targeted levels, reporting overall reduced postoperative pain and increased functional improvement (21). Kato et al. investigated the conservative treatment of active pain generators using SPECT/CT in older patients. Use of the technique allowed these patients to receive conservative management and avoid surgery (22). Furthermore, Shapovalov et al. demonstrated that SPECT/CT-guided revision surgeries had better outcomes than traditional image-guided revision surgeries (34). These findings underscore the wide utility of SPECT/CT, not only in diagnosis but also in improving patient outcomes. Together, these results suggest a paradigm shift for the assessment of radiologically ambiguous cases.

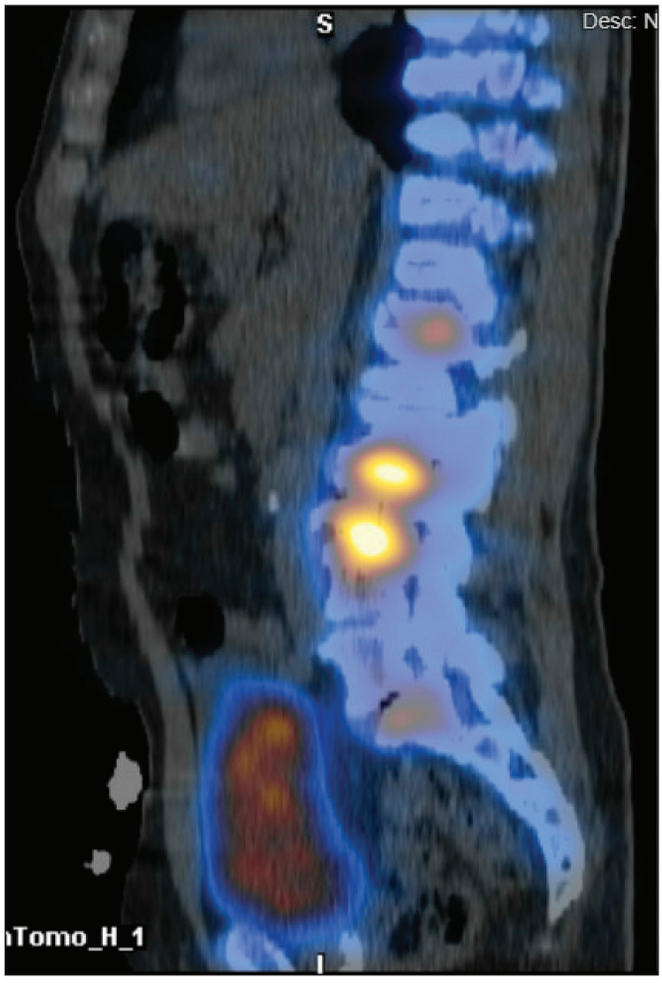

Figure 2: 71-year-old male who had a Lumbar MRI performed, which demonstrated multilevel degenerative disc disease as well as Multilevel neural foraminal stenosis at L2-L3, L3-L4, and L5-S1 bilaterally. SPECT CT demonstrated scintigraphic activity at multiple levels, including T12-L1, L2-L3, and L3-L4, though the greatest degree of tracer uptake was noted at L3-L4 end plates. He had an L2-4 prone Trans psoas lateral fusion and was followed up with 1 year later. He reported his pain level to be at a zero at his 1-year follow-up.

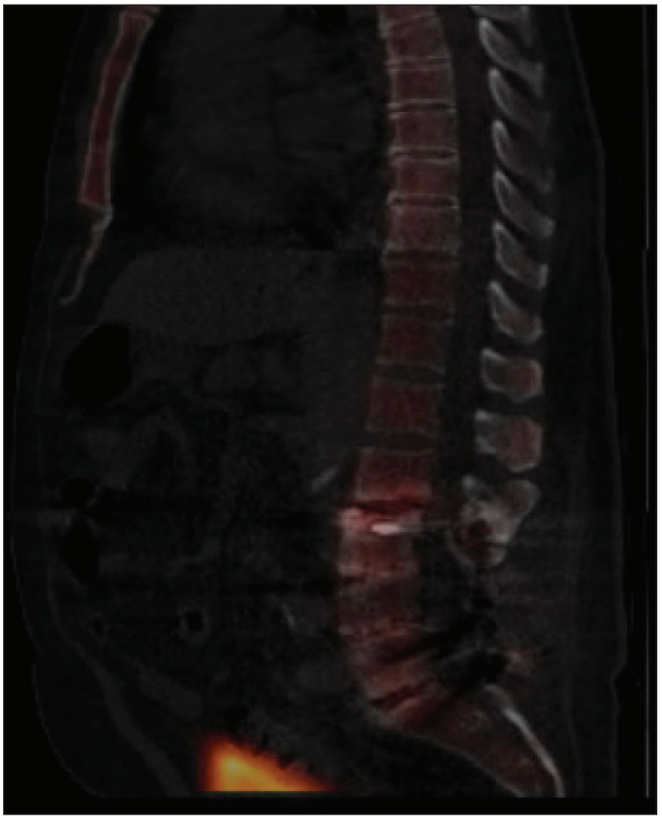

Figure 3: 70-year-old Male with a history of L3-L4, L4-L5, and L5-S1 TLIF. MRI demonstrated multiple-level degenerative disease. His SPECT CT demonstrated activity at the L2-L3 disc space. He subsequently had L2-L3 extension TLIF. Subsequently, pain improved from a 6 at his baseline consult visit to a 2 at 6 months follow.

Patients with positive SPECT/CT results—indicating conditions such as facet arthritis, disc inflammation, or pedicle screw loosening—responded better to re-operation than those with negative SPECT/CT findings (19). While research on the use of SPECT/CT as an adjunct to other imaging modalities is still emerging, there is already substantial evidence demonstrating its added value. Significantly, SPECT/CT can detect active metabolic sites not only at operated levels but also those adjacent and in other load-bearing structures, such as the sacroiliac joints. This capability is particularly useful in guiding targeted injections, which can provide significant relief for patients. However, it is crucial to distinguish asymmetrical increased uptake in the sacroiliac joints, often seen at bone grafting sites, from inflammatory processes.

SPECT/CT has increasingly been established as a valuable imaging modality for evaluating conditions such as pseudoarthrosis, hardware failure, metallic work fractures, screw loosening, and misalignment, especially in cases where other imaging techniques yield inconclusive results. A recent systematic review by Awosika et al. highlighted SPECT/CT's superiority in detecting facet degeneration compared to CT alone (3). Their findings suggest that SPECT/CT has higher diagnostic accuracy than conventional imaging methods and can provide additional information for identifying pain-generating sites, including pseudoarthrosis, hardware loosening, and facet joint degeneration. Furthermore, ^{18}F-FDG PET/CT was noted for its efficacy in detecting postoperative infections; increased FDG uptake was associated with increased inflammatory activity, aiding in the diagnosis of suspected infection. Additionally, Hudyana et al. demonstrated that SPECT/CT could detect screw loosening with remarkable accuracy, boasting a sensitivity of 100% and a specificity of 89.7% (20). Besides hardware assessments, SPECT/CT also showed efficacy in identifying other sources of recurrent back pain, including active fact degeneration and degenerative changes in the discs and sacroiliac joint.

SPECT/CT is particularly effective in identifying pain generators related to adjacent segment degeneration following spinal surgery, offering a clear differentiation between tracer uptake by facet joints and pedicle screws. This is crucial in cases of device subsidence, where CT scans might overestimate lucencies, potentially leading to false diagnoses. SPECT/CT helps to distinguish between physiological height loss and pathological processes, with the latter showing increased tracer uptake and CT evidence of subsidence (15). Huang et al. investigated the utility of SPECT/CT in FBSS, and found it to be effective in pinpointing sources of persistent pain and identifying facet joint inflammation and pedicle screw loosening (16). Moreover, patients exhibiting more positive findings in SPECT were reported to have more favorable outcomes following revision surgery compared to patients with high uptake and increased signal intensity on imaging.

Pedicle screw loosening, seen in 18% to 31% of patients, typically appears as a rim of lucency around the screw on CT scans. SPECT/CT provides valuable information by identifying increased metabolic activity associated with this process (33,39). However, caution is advised when using SPECT/CT in the early postoperative period, as the heightened metabolic activity of osteoblasts during tissue repair may lead to misdiagnosis or overdiagnosis. Russo et al. demonstrated increased tracer uptake with degenerative disc changes, further showing the correlation between increased uptake and inflammation (32). Further studies reported similar observations in the sacroiliac and facet joints (8,12).

Experts, including Al-Riyami and Gnanasegaran, have recommended the use of SPECT/CT in patients with persistent postoperative pain lasting 12 months or more, especially when other modalities produce inconclusive results (2,15). They also underscored the robustness of SPECT/CT for detecting pseudoarthrosis and hardware failure even in very close proximity to the instrumented level, yielding highly detailed information. Gnanasegaran et al. further validated the efficacy of SPECT/CT in detecting pseudoarthrosis, hardware failure, and adjacent segment disease (15).

Interestingly, SPECT/CT can also uncover significant findings in asymptomatic patients with clean radiographic images. For example, Rager et al. reported on six patients with normal CT scans, who were later found to have facet joint disease upon SPECT/CT evaluation (Figure 4) (29). Despite the normal CT images, SPECT/CT was able to capture the active sites of facet disease on the anatomical landmarks provided by the original scan.

If we compare PET/CT and SPECT/CT for postoperative spinal evaluation, both provide valuable information. While PET/CT shows increased utility in identifying postoperative infection, particularly with FDG tracers, SPECT/CT has demonstrated superiority for detecting mechanical complications, including pseudoarthrosis and hardware failure, due to its ability to assess osteoblastic activity. The choice of imaging modality should be based on the clinical scenario and initial evaluation.

SPECT/CT has certain limitations, particularly in the evaluation of disc herniations, cord and root compressions, and listhesis, where it may not provide sufficient detail. Furthermore, in the immediate preoperative period, SPECT/CT may not be as well adapted as it is in the later treatment periods. Inflammation caused by the trauma of surgery and early osteoblastic activity can be easily misinterpreted as infection or pseudoarthrosis. Unfortunately, there is no established evidence-based cutoff in follow-up duration for when best to utilize this modality. As a further limitation, SPECT/CT may not be able to differentiate infection from inflammation due to other causes, including pseudoarthrosis, facet joint degeneration, adjacent disease, and hardware failure; the patient's clinical and other biomarkers should be taken into account when making a diagnosis of postoperative infectious disease. Finally, in cases of concurrent multiple complications, SPECT/CT may fall short in differentiation, and may lead to the underdiagnosis of certain conditions. Moreover, this procedure requires ingestion of certain chemicals, which may not be feasible in patients with chronic kidney disease or allergies.

Future directions for SPECT/CT should focus on its implementation in preoperative planning, alongside improvements in accounting for anatomical variations and individual meta-

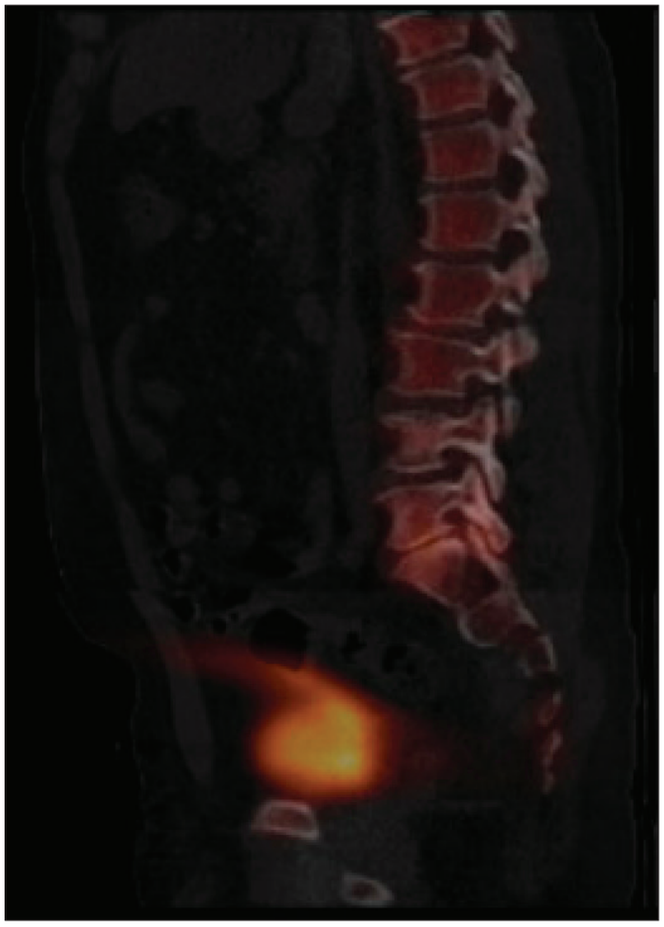

Figure 4: 51-years-old, Male with a history of T12-L1 Laminectomy. SPECT CT was performed and demonstrated L5-S1 disc & facet joint uptake. He ended up receiving an L5-S1 TLIF. Pain at baseline before most recent surgery was a 7, at 3 months it was a 0, and at 6 months it was a 4.

bolic profiles. Progress in these factors would allow for a more individualized approach for patients and enhance the clinical utility of SPECT/CT. Furthermore, research focused on radiotracers specific to spinal pathologies could enhance the diagnostic sensitivity of SPECT/CT. Integration with other imaging modalities, such as functional MRI, could also improve preoperative planning and patient outcomes. Naturally, these modalities are costly, so optimization and standardization of imaging protocols are necessary, especially in the postoperative term, for the differentiation of inflammation and bone healing from other common complications.

CONCLUSION

Postoperative pain that recurs or persists despite initial treatment necessitates a comprehensive approach, combining both clinical evaluation and advanced radiological investigations. SPECT/CT and PET/CT have become widely used for evaluating postoperative spinal conditions, and can effectively pinpoint sources of persistent pain. These hybrid imaging techniques merge metabolic and anatomical data to accurately detect issues like nonunion, pseudoarthrosis, and infection. Identifying active metabolic sites, both proximal and distal from surgical areas, enables targeted treatments such as guided injections, enhancing patient outcomes. As evidence of its efficacy grows, SPECT/CT is poised to become a mainstay in diagnosing complex spinal pathologies. Nevertheless, clinicians must interpret results carefully to differentiate between pathological findings and normal postoperative changes. Further large-scale patient studies are needed to better define the role of SPECT/CT in managing complex postoperative pain complications.

Declarations

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AUTHORSHIP CONTRIBUTION

Study conception and design: ASA, MDY, BGF, KDT, MAEB
Data collection: ASA, MDY, MP, KDT
Analysis and interpretation of results: ASA, MDY, MP, BGF, KDT
Draft manuscript preparation: ASA, MDY, MAEB
Critical revision of the article: ASA, MDY, KDT, MAEB
Other (study supervision, fundings, materials, etc...): ASA, MDY, MP, BGF, KDT, MAEB
All authors (ASA, MDY, MP, BGF, KDT, MAEB) reviewed the results and approved the final version of the manuscript.

REFERENCES

1. Acosta FL, Shapovalov VS, Lobo BM, Liker MA: Radiographic evaluation of low back pain after lumbar fusion using Technetium-99 single-photon emission computed tomography: Impact on clinical decision-making and outcome. Interdiscip Neurosurg 24:101089, 2021. https://doi.org/10.1016/j.inat.2021.101089
2. Al-Riyami K, Gnanasegaran G, Van den Wyngaert T, Bomanji J: Bone SPECT/CT in the postoperative spine: A focus on spinal fusion. Eur J Nucl Med Mol Imaging 44:2094-2104, 2017. https://doi.org/10.1007/s00259-017-3765-6
3. Awosika T, Davidar AD, Hersh AM, Menta A, Weber-Levine C, Alomari S, Khan MA, Theodore N: SPECT/CT and PET/CT for the evaluation of persistent or recurrent pain after spine surgery: A systematic review and case series. World Neurosurg 182:e344-e359, 2024. https://doi.org/10.1016/j.wneu.2023.11.108
4. Baber Z, Erdek MA: Failed back surgery syndrome: Current perspectives. J Pain Res 9:979-987, 2016. https://doi.org/10.2147/JPR.S92776
5. Barber SM, Fridley JS, Konakondla S, Nakhla J, Oyelese AA, Telfeian AE, Gokaslan ZL: Cerebrospinal fluid leaks after spine tumor resection: Avoidance, recognition and management. Ann Transl Med 7:217, 2019. https://doi.org/10.21037/atm.2019.01.04

6. Borkar SA, Sharma R, Mansoori N, Sinha S, Kale SS: Spinopelvic parameters in patients with lumbar degenerative disc disease, spondylolisthesis, and failed back syndrome: Comparison vis-à-vis normal asymptomatic population and treatment implications. J Craniovertebr Junction Spine 10:167-171, 2019. https://doi.org/10.4103/jcvjs.JCVJS_70_19
7. Buchbinder R, Blyth FM, March LM, Brooks P, Woolf AD, Hoy DG: Placing the global burden of low back pain in context. Best Pract Res Clin Rheumatol 27:575-589, 2013. https://doi.org/10.1016/j.berh.2013.10.007
8. Carstensen MH, Al-Harbi M, Urbain JL, Belhocine TZ: SPECT/CT imaging of the lumbar spine in chronic low back pain: A case report. Chiropr Man Therap 19:2, 2011. https://doi.org/10.1186/2045-709X-19-2
9. Cramer DE, Maher PC, Pettigrew DB, Kuntz C: Major neurologic deficit immediately after adult spinal surgery: Incidence and etiology over 10 years at a single training institution. J Spinal Disord Tech 22:565-570, 2009. https://doi.org/10.1097/BSD.0b013e318193452a
10. Dekutoski MB, Norvell DC, Dettori JR, Fehlings MG, Chapman JR: Surgeon perceptions and reported complications in spine surgery. Spine (Phila Pa 1976) 35:S9-S21, 2010. https://doi.org/10.1097/BRS.0b013e3181d830de
11. Dhagat PK, Jain M, Singh SN, Arora S, Leelakanth K: Failed back surgery syndrome: Evaluation with magnetic resonance imaging. J Clin Diagn Res 11:TC06-TC09, 2017. https://doi.org/10.7860/JCDR/2017/24930.9817
12. Dharia AA, Guillotte AR, De Stefano FA, Rouse AG, Ohiorhenuan IE: Biomechanical predictors of sacroiliac joint uptake on single-photon emission computed tomography/computed tomography. World Neurosurg 188:e606-e612, 2024. https://doi.org/10.1016/j.wneu.2024.05.176
13. Esses SI, Sachs BL, Dreyzin V: Complications associated with the technique of pedicle screw fixation. A selected survey of ABS members. Spine (Phila Pa 1976) 18:2231-2238; discussion 2238-2239, 1993. https://doi.org/10.1097/00007632-199311000-00015
14. Expert Panel on Neurological Imaging, Hutchins TA, Peckham M, Shah LM, Parsons MS, Agarwal V, Boulter DJ, Burns J, Cassidy RC, Davis MA, Holly LT, Hunt CH, Khan MA, Moritani T, Ortiz AO, O'Toole JE, Powers WJ, Promes SB, Reitman C, Shah VN, Singh S, Timpone VM, Corey AS: ACR appropriateness criteria® low back pain: 2021 update. J Am Coll Radiol 18:S361-S379, 2021. https://doi.org/10.1016/j.jacr.2021.08.002
15. Gnanasegaran G, Paycha F, Strobel K, van der Bruggen W, Kampen WU, Kuwert T, Van den Wyngaert T: Bone SPECT/CT in postoperative spine. Semin Nucl Med 48:410-424, 2018. https://doi.org/10.1053/j.semnuclmed.2018.06.003
16. Van Goethem JWM, Van den Hauwe L, Parizel PM: Spinal imaging: Diagnostic imaging of the spine and spinal cord. Am J Neuroradiol 29:e60-e61, 2008. https://doi.org/10.3174/ajnr.A0984
17. Guerin P, El Fegoun AB, Obeid I, Gille O, Lelong L, Luc S, Bourghli A, Cursolle JC, Pointillart V, Vital JM: Incidental durotomy during spine surgery: Incidence, management and complications. A retrospective review. Injury 43:397-401, 2012. https://doi.org/10.1016/j.injury.2010.12.014
18. Hamilton DK, Smith JS, Sansur CA, Glassman SD, Ames CP, Berven SH, Polly DW, Perra JH, Knapp DR, Boachie-Adjei O, McCarthy RE, Shaffrey CI, Scoliosis Research Society Morbidity and Mortality Committee: Rates of new neurological deficit associated with spine surgery based on 108,419 procedures: a report of the scoliosis research society morbidity and mortality committee. Spine (Phila Pa 1976) 36:1218-1228, 2011. https://doi.org/10.1097/BRS.0b013e3181ec5fd9
19. Huang BR, Peng BR, Pan LK, Chen CY: Potential usefulness of single photon emission computed tomography/computed tomography in management of patients with failed back surgery syndrome. J Med Imaging Health Inform 9:1386-1392, 2019. https://doi.org/10.1166/jmihi.2019.2782
20. Hudyana H, Maes A, Vandenberghe T, Fidlers L, Sathekge M, Nicolai D, Van de Wiele C: Accuracy of bone SPECT/CT for identifying hardware loosening in patients who underwent lumbar fusion with pedicle screws. Eur J Nucl Med Mol Imaging 43:349-354, 2016. https://doi.org/10.1007/s00259-015-3158-7
21. Kaiser R, Varga M, Lang O, Waldauf P, Vaněk P, Saur K, Beneš V, Netuka D: Spinal fusion for single-level SPECT/CT positive lumbar degenerative disc disease: The SPINUS I study. Acta Neurochir 165:2633-2640, 2023. https://doi.org/10.1007/s00701-023-05666-8
22. Kato S, Demura S, Matsubara H, Inaki A, Shinmura K, Yokogawa N, Murakami H, Kinuya S, Tsuchiya H: Utility of bone SPECT/CT to identify the primary cause of pain in elderly patients with degenerative lumbar spine disease. J Orthop Surg Res 14:185, 2019. https://doi.org/10.1186/s13018-019-1236-4
23. Lee YS, Choi ES, Song CJ: Symptomatic nerve root changes on contrast-enhanced MR imaging after surgery for lumbar disk herniation. AJNR Am J Neuroradiol 30:1062-1067, 2009. https://doi.org/10.3174/ajnr.A1497
24. Lehman VT, Murphy RC, Maus TP: 99mTc-MDP SPECT/CT of the spine and sacrum at a multispecialty institution: Clinical use, findings, and impact on patient management. Nucl Med Commun 34:1097-1106, 2013. https://doi.org/10.1097/MNM.0b013e328364bfa6
25. Lu W, Pauly KB, Gold GE, Pauly JM, Hargreaves BA: SEMAC: Slice encoding for metal artifact correction in MRI. Magn Reson Med 62:66-76, 2009. https://doi.org/10.1002/mrm.21967
26. Mehta VA, Amin A, Omeis I, Gokaslan ZL, Gottfried ON: Implications of spinopelvic alignment for the spine surgeon. Neurosurgery 76 Suppl 1:S42-56; discussion S56, 2015. https://doi.org/10.1227/01.neu.0000462077.50830.1a
27. Paez D, Sathekge MM, Douis H, Giammarile F, Fatima S, Dhal A, Puri SK, Erba PA, Lazzeri E, Ferrando R, Almeida Filho P, Peter Magboo V, Morozova O, Núñez R, Pellet O, Mariani G, Giammarile FGiammarile F: Comparison of MRI, [18 F]FDG PET/CT, and 99m Tc-UBI 29-41 scintigraphy for postoperative spondylodiscitis-a prospective multicenter study. Eur J Nucl Med Mol Imaging 48:1864-1875, 2021. https://doi.org/10.1007/s00259-020-05109-x/Published

28. Rager O, Amzalag G, Varoquaux A, Schaller K, Ratib O, Tessitore E: SPECT-CT assessment of pseudarthrosis after spinal fusion: diagnostic pitfall due to a broken screw. Case Rep Orthop 2013:1-3, 2013. https://doi.org/10.1155/2013/502517
29. Rager O, Schaller K, Payer M, Tchernin D, Ratib O, Tessitore E: SPECT/CT in differentiation of pseudarthrosis from other causes of back pain in lumbar spinal fusion: Report on 10 consecutive cases. Clin Nucl Med 37:339-343, 2012. https://doi.org/10.1097/RLU.0b013e318239248b
30. Reisener MJ, Pumberger M, Shue J, Girardi FP, Hughes AP: Trends in lumbar spinal fusion-a literature review. J Spine Surg 6:752-761, 2020. https://doi.org/10.21037/jss-20-492
31. Ross JS, Robertson JT, Frederickson RC, Petrie JL, Obuchowski N, Modic MT, deTribolet N: Association between peridural scar and recurrent radicular pain after lumbar discectomy: Magnetic resonance evaluation. ADCON-L European Study Group. Neurosurgery 38:855-861; discussion 861-3, 1996.
32. Russo VM, Dhawan RT, Dharmarajah N, Baudracco I, Lazzarino AI, Casey AT: Hybrid bone single photon emission computed tomography imaging in evaluation of chronic low back pain: Correlation with modic changes and degenerative disc disease. World Neurosurg 104:816-823, 2017. https://doi.org/10.1016/j.wneu.2017.03.107
33. Sandén B, Olerud C, Petrén-Mallmin M, Johansson C, Larsson S: The significance of radiolucent zones surrounding pedicle screws. Definition of screw loosening in spinal instrumentation. J Bone Joint Surg Br 86:457-461, 2004. https://doi.org/10.1302/0301-620x.86b3.14323
34. Shapovalov V, Lobo B, Liker M: SPECT/CT imaging for diagnosis and management of failed cervical spine surgery syndrome. Interdiscip Neurosurg 32: 101699, 2023. https://doi.org/10.1016/j.inat.2022.101699
35. Smith JS, Fu KMG, Polly DW, Sansur CA, Berven SH, Broadstone PA, Choma TJ, Goytan MJ, Noordeen HH, Knapp DR, Hart RA, Donaldson WF, Perra JH, Boachie-Adjei O, Shaffrey CI: Complication rates of three common spine procedures and rates of thromboembolism following spine surgery based on 108,419 procedures: A report from the Scoliosis Research Society Morbidity and Mortality Committee. Spine (Phila Pa 1976) 35:2140-2149, 2010. https://doi.org/10.1097/BRS.0b013e3181cbc8e7
36. Tamm AS, Abele JT: Bone and gallium single-photon emission computed tomography-computed tomography is equivalent to magnetic resonance imaging in the diagnosis of infectious spondylodiscitis: A retrospective study. Can Assoc Radiol J 68:41-46, 2017. https://doi.org/10.1016/j.carj.2016.02.003
37. Veeravagu A, Cole TS, Azad TD, Ratliff JK: Improved capture of adverse events after spinal surgery procedures with a longitudinal administrative database. J Neurosurg Spine 23:374-382, 2015. https://doi.org/10.3171/2014.12.SPINE14659
38. Waguespack A, Schofferman J, Slosar P, Reynolds J: Etiology of long-term failures of lumbar spine surgery. Pain Med 3:18-22, 2002. https://doi.org/10.1046/j.1526-4637.2002.02007.x
39. Winter RB: Complications after transpedicular stabilization of the spine. Spine (Phila Pa 1976) 20:1847-1848, 1995.
40. Wu A, March L, Zheng X, Huang J, Wang X, Zhao J, Blyth FM, Smith E, Buchbinder R, Hoy D: Global low back pain prevalence and years lived with disability from 1990 to 2017: Estimates from the Global Burden of Disease Study 2017. Ann Transl Med 8:299, 2020. https://doi.org/10.21037/atm.2020.02.175