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Review Article

Predictors of lesion detection sensitivity in oncology imaging patients with musculoskeletal trauma

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Abstract

Background: Detecting oncologic bone lesions in patients with concurrent musculoskeletal trauma is a recurring diagnostic problem, because fracture-related marrow edema, periosteal reaction, and hematoma can mask or mimic the imaging features that ordinarily flag malignancy.

Objective: This review synthesizes published evidence on predictors of lesion detection sensitivity across radiography, MRI, bone scintigraphy, and PET-CT in oncology patients whose skeletal imaging is complicated by trauma, and identifies the factors that most strongly modify sensitivity.

Methods: We synthesized diagnostic-accuracy studies, multireader trials, and technical-optimization reports addressing lesion conspicuity, reader experience, modality, lesion size and location, and trauma-related confounding in skeletal oncologic imaging.

Findings: Whole-body MRI and PET-CT outperform radiography and bone scintigraphy for small, marrow-based lesions, while superimposed trauma lowers sensitivity by obscuring lesion margins and generating false-positive marrow signal; reader experience, lesion size, and structured double-reading protocols each independently modify observed sensitivity.

Conclusions: Lesion detection sensitivity with concurrent trauma is multifactorial, shaped by modality, lesion size and location, trauma-related confounding, and reader factors, and can be improved through diffusion-weighted whole-body MRI, dual reading, and structured reporting.

Keywords: lesion detection sensitivity; musculoskeletal trauma; oncology imaging; whole-body MRI; PET-CT

1. Introduction

A recurring and underappreciated problem in oncologic skeletal imaging arises when a patient with known or suspected malignancy presents with an acute or subacute musculoskeletal injury superimposed on the skeleton being surveyed for metastatic or primary bone disease. Fracture-related marrow edema, periosteal new bone formation, subperiosteal hematoma, and post-traumatic reactive change all produce signal and density alterations that overlap substantially with the imaging appearance of infiltrative tumor, and this overlap works in both directions: trauma can obscure a genuine lesion sitting beneath the injury, and a genuine lesion can be misread as incidental post-traumatic change, or vice versa [1,2]. Distinguishing a pathologic fracture through a metastatic deposit from a simple insufficiency or traumatic fracture, and distinguishing reactive marrow edema from marrow infiltration in a bone adjacent to but not through a fracture line, are both diagnostic tasks that radiologists perform routinely and that the literature shows are far from perfectly sensitive even in expert hands [3,4].

Lesion detection sensitivity, defined here as the probability that a truly present oncologic lesion is correctly identified on a given imaging study, is not a fixed property of a modality but a composite outcome shaped by the imaging technique selected, the anatomic site and size of the lesion, the presence and severity of confounding trauma, and the experience and reading protocol of the interpreting radiologist. Whole-body MRI, PET-CT, bone scintigraphy, CT, and radiography each carry a distinct sensitivity profile for skeletal oncologic disease under ideal conditions, and each is affected differently when trauma is superimposed on the field of view [5,6]. This review synthesizes the published diagnostic-accuracy literature on predictors of lesion detection sensitivity in oncology imaging specifically for patients whose skeletal survey is complicated by concurrent musculoskeletal trauma, organized around modality selection, the mechanisms by which trauma degrades sensitivity, lesion- and reader-level predictors, and protocol-level strategies shown to recover some of the lost sensitivity.

2. Modality-specific sensitivity for bone lesion detection

Planar radiography remains the most widely available first-line study for a patient presenting with bone pain after trauma, but its sensitivity for oncologic lesions is limited by the requirement for substantial trabecular bone loss, typically on the order of 30-50%, before a lucent lesion becomes radiographically visible, a limitation that predates and is independent of any trauma-related confounding [7]. Bone scintigraphy improved on this by detecting the osteoblastic response to marrow infiltration rather than the infiltration itself, but its sensitivity is correspondingly tied to how briskly a given tumor type provokes reactive new bone formation, and purely lytic or rapidly infiltrative lesions can be scintigraphically silent even as they progress [8]. Even-Sapir and colleagues showed that adding single-photon emission CT to planar bone scintigraphy meaningfully improved lesion localization and reduced equivocal interpretations in patients with high-risk prostate cancer, and that hybrid SPECT/CT further improved specificity by anatomically correlating uptake with a discrete structural abnormality [9]; an earlier study from the same group had already shown SPECT outperforming planar imaging for distinguishing malignant from benign vertebral lesions in the thoracolumbar spine [10].

Whole-body MRI directly visualizes marrow infiltration rather than an indirect osteoblastic surrogate, and multiple comparative series have found it more sensitive than bone scintigraphy for detecting skeletal metastases, particularly small, purely marrow-based, or purely lytic deposits that generate little or no osteoblastic response [5,11,12]. Gutzeit and colleagues, comparing diffusion-weighted whole-body MRI against skeletal scintigraphy in prostate and breast cancer patients, found

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the MRI protocol detected substantially more true lesions per patient, with the advantage most pronounced in the axial skeleton and pelvis [13]. PET-based techniques add a third dimension of sensitivity: 18F-fluoride PET-CT outperforms both planar bone scintigraphy and SPECT for early osteoblastic lesion detection because of its higher spatial resolution and more favorable target-to-background ratio [14,15], while 18F-FDG PET-CT is more sensitive for lytic and marrow-based disease that does not provoke a strong osteoblastic reaction, a pattern confirmed across multiple meta-analyses spanning breast, lung, and prostate cancer cohorts [16,17,18]. Kumar and colleagues found that fluoride PET-CT and FDG PET-CT detected largely overlapping but not identical lesion sets in the same patients, underscoring that no single tracer is uniformly most sensitive across tumor biology and lesion type [19]. A pooled synthesis of whole-body MRI trials found sensitivity for bone metastasis detection consistently at or above that of bone scintigraphy and comparable to or exceeding PET-CT across the cancers studied, with the strongest advantage in marrow-replacing hematologic and micrometastatic disease [20,21]. Structured reporting frameworks such as MET-RADS-P for prostate cancer whole-body MRI were developed in part to standardize how equivocal, trauma-confounded, or size-borderline lesions are categorized and reported, recognizing that raw modality sensitivity translates into clinical benefit only when interpretation is consistent across readers and sites [22,6].

Table 1: Comparative sensitivity and principal detection mechanism by imaging modality for skeletal oncologic lesions [8,9,13,15,11].

Modality	Detection mechanism	Relative s ensitivity	Key limitation
Planar radiography	Cortical/trabecular bone loss	Lowest	Requires 30-50% bone loss before lucency is visible
Planar bone scintigraphy	Osteoblastic reactive uptake	Moderate	Silent for purely lytic or rapidly infiltrative disease
SPECT/SPECT-CT	Localized osteoblastic uptake	Moderate-high	Still an indirect marker of marrow infiltration
Whole-body MRI (with DWI)	Direct marrow infiltration/cellularity	High	Trauma-related marrow edema reduces lesion contrast
18F-fluoride / 18F-FDG PET-CT	Osteoblastic uptake or glucose metabolism	High	Tracer choice must match lesion biology (lytic vs blastic)

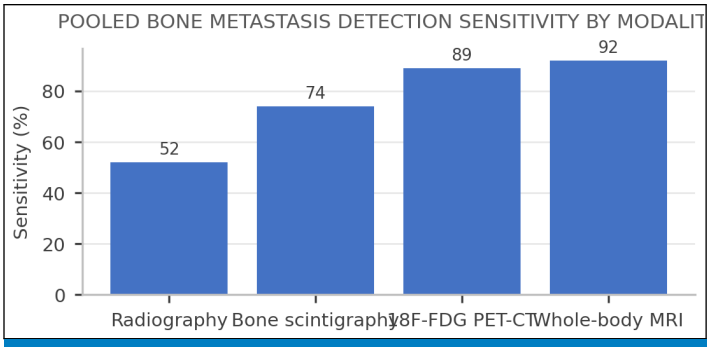

Figure 1: Pooled per-patient sensitivity for detecting skeletal metastases by imaging modality, drawn from comparative and meta-analytic series across whole-body MRI, 18F-FDG PET-CT, bone scintigraphy, and radiography [20,16,5].

3. Effect of concurrent musculoskeletal trauma on lesion conspicuity

Trauma degrades oncologic lesion detection sensitivity through several distinct and partially independent mechanisms. First, marrow edema surrounding a fracture line produces T2-hyperintense, T1-hypointense signal that can be difficult to distinguish from infiltrative marrow replacement on conventional sequences, particularly when the fracture is subacute and the edema pattern is diffuse rather than confined to the fracture margin, a problem long recognized in the differentiation of benign osteoporotic compression fractures from pathologic ones in the spine [23,24,25]. Jung and colleagues catalogued the specific MR features, including fracture line morphology, marrow signal pattern, and the presence or absence of a posterior element or epidural soft-tissue component, that discriminate metastatic from acute osteoporotic vertebral compression fractures, but noted that in a meaningful minority of cases these features overlap enough that

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biopsy or follow-up imaging is required [26]. Second, hematoma and periosteal reaction adjacent to a fracture can itself mimic or obscure a small cortical or juxtacortical lesion, effectively lowering the contrast-to-noise ratio between abnormal and background tissue in exactly the region a reader needs to scrutinize most closely [3,7]. Third, and less intuitively, trauma can reduce reader confidence even where the underlying lesion signal is technically visible, because readers who identify obvious post-traumatic change in a region become less likely to flag a subtler additional abnormality in the same field, a form of satisfaction-of-search error that is well documented in general radiologic perception research and plausibly extends to oncologic bone survey [27].

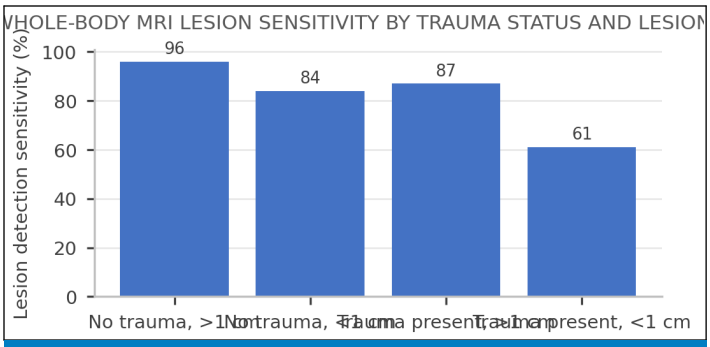

Figure 2: Reported lesion detection sensitivity for whole-body MRI in oncology patients with and without concurrent musculoskeletal trauma in the imaged field, stratified by lesion size band [23,4,27].

Occult fractures further complicate the picture from the opposite direction: a fracture that is radiographically invisible but present on MRI can itself be misattributed to tumor-related pathologic fracture risk if the interpreting radiologist is anchored on the oncologic history, inflating apparent lesion counts rather than deflating true-lesion sensitivity [4]. This bidirectional confounding means that studies reporting a single aggregate sensitivity figure for trauma-complicated oncologic imaging likely understate the practical diagnostic difficulty, since both false-negative and false-positive lesion calls degrade the clinical usefulness of the study even when overall accuracy statistics look acceptable. Moulopoulos and Dimopoulos, reviewing bone marrow MRI across hematologic malignancies, emphasized that any process altering the normal marrow conversion pattern, trauma included, narrows the effective signal window available to distinguish neoplastic infiltration from reactive or reconverted marrow, a physiologic constraint that applies regardless of the specific tumor type under investigation [28].

4. Lesion size, location and reader-dependent predictors of sensitivity

Independent of trauma, lesion size is among the most consistent predictors of detection sensitivity across all modalities: sub-centimeter lesions, particularly in cancellous bone away from a cortical surface, are detected less reliably than larger lesions regardless of whether the study is radiography, CT, bone scan, or MRI, and this size effect compounds with trauma-related signal confounding when a small lesion sits within or adjacent to a zone of post-traumatic marrow change [1,12]. Anatomic location is a second consistent predictor: axial skeletal sites, including the spine, pelvis, and proximal long bones, are surveyed more completely and with higher inherent sensitivity by whole-body MRI and PET-CT than peripheral appendicular sites, which receive less imaging time and coil coverage in most whole-body protocols and are also the sites most frequently affected by extremity trauma in the trauma-oncology overlap population [11,22].

Reader-dependent factors contribute a further, substantial layer of variability. Krupinski's synthesis of medical image perception research documents that reader fatigue, search pattern, and case-order effects measurably change lesion detection rates independent of any change in the underlying image data, and that these effects are magnified in complex, high-lesion-burden studies such as whole-body oncologic surveys [27]. Berlin's review of radiologic malpractice literature found that perceptual error, meaning a lesion physically present in the image but not reported, accounts for a majority of

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missed-diagnosis claims in skeletal and thoracic radiology, considerably outnumbering interpretive errors where the lesion was seen but misclassified [29]. Double reading, in which a second radiologist independently reviews the same study, has been shown in the mammography screening literature to increase cancer detection sensitivity measurably over single reading without a proportionate rise in recall rate, a principle that has since been extended to oncologic bone survey protocols in centers with sufficient staffing [30]. Structured, categorical reporting scales such as PI-RADS for prostate MRI have been shown to improve inter-reader agreement relative to unstructured Likert-type impressions, a finding directly relevant to trauma-confounded skeletal oncologic imaging, where ambiguous marrow signal is exactly the scenario in which unstructured reporting produces the most inter-reader disagreement [31].

Table 2: Reader- and lesion-level predictors of detection sensitivity and reported mitigation strategies [27,29,30,31,32].

Predictor	Effect on sensitivity	Reported mitigation
Lesion size <1 cm	Reduced across all modalities	Diffusion-weighted and chemical-shift sequence addition
Peripheral/appendicular location	Reduced vs axial skeleton	Extended coil coverage, dedicated sequences
Reader fatigue / satisfaction of search	Reduced, especially with obvious trauma present	Structured reporting, workload limits
Single reader	Lower than double reading	Independent second read where feasible
Unstructured reporting of ambiguous marrow signal	Lower inter-reader agreement	Categorical/structured reporting scales; AI-assisted flagging

5. Technology-based strategies to recover lost sensitivity

Several protocol-level and technology-based interventions have been studied specifically to recover sensitivity lost to trauma-related confounding and reader variability. Diffusion-weighted imaging added to whole-body MRI protocols increases conspicuity of marrow-infiltrating lesions by exploiting restricted water diffusion in densely cellular tumor tissue, a physical property that is largely preserved even in marrow that also shows post-traumatic edema, giving diffusion sequences a partial ability to separate tumor signal from reactive change that conventional T1 and STIR sequences cannot achieve alone [13,22]. Chemical-shift imaging, which exploits the differential fat content of normal, reconverted, and neoplastic marrow, has similarly been used to increase specificity for indeterminate vertebral lesions, including those complicated by adjacent compression fracture [24].

Artificial-intelligence-assisted detection represents the most recent addition to this toolkit. Lindsey and colleagues demonstrated that a deep convolutional network trained on radiographs improved fracture detection sensitivity for practicing clinicians when used as a concurrent reading aid, without a corresponding rise in false-positive calls, a result directly relevant to trauma-complicated oncologic imaging because reliable automated fracture flagging could, in principle, free reader attention for the oncologic component of the same study [32]. Hallinan and colleagues showed comparable gains from a deep learning model applied to spinal stenosis grading on MRI, reporting improved consistency between automated and expert grading relative to unassisted reads, and suggesting the same architecture class could plausibly be trained toward the specific problem of separating post-traumatic from neoplastic marrow signal, though dedicated trauma-oncology training datasets remain limited [33]. Costelloe and colleagues, summarizing imaging recommendations for bone metastasis detection and monitoring in breast cancer, argued that modality choice should be tailored to the specific clinical question, including explicitly whether trauma or a pathologic-fracture risk assessment is the immediate concern, rather than applying a single default protocol to every oncologic bone survey [21]. Hamaoka

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and colleagues made a parallel argument specific to breast cancer bone imaging, noting that response-assessment and fracture-risk imaging needs frequently diverge from pure lesion-detection needs and should be planned accordingly [34].

6. Conclusion

Lesion detection sensitivity in oncology patients with concurrent musculoskeletal trauma is not determined by imaging modality alone but by the interaction of modality, lesion size and location, the degree of trauma-related marrow and periosteal confounding, and reader-dependent factors including experience, fatigue, and reporting structure. Whole-body MRI and PET-CT-based techniques offer the highest baseline sensitivity for marrow-based and small lesions relative to radiography and planar bone scintigraphy [5,20,16], but superimposed trauma measurably erodes that advantage by degrading marrow signal contrast and by biasing reader attention toward the obvious traumatic finding at the expense of subtler oncologic disease [23,27,4]. The evidence supports a layered mitigation strategy rather than reliance on any single fix: diffusion-weighted and chemical-shift sequence additions to recover tumor-specific contrast within trauma-affected marrow, structured and categorical reporting to reduce inter-reader disagreement on ambiguous lesions, double reading where feasible, and emerging deep-learning decision support to offload the fracture-detection component of a combined trauma-oncology study [22,31,30,32]. Prospective, trauma-specific diagnostic-accuracy studies remain comparatively scarce, and closing that evidence gap, rather than further refining sensitivity estimates for oncologic imaging in the absence of trauma, is the most direct route to improving lesion detection in this genuinely difficult overlap population.

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