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Optimizing diagnostic yield in computed tomography-guided musculoskeletal bone biopsy: a narrative review

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ABSTRACT

Computed tomography (CT) -guided percutaneous bone biopsy is a cornerstone technique in the diagnostic evaluation of musculoskeletal lesions, offering high diagnostic accuracy with lower morbidity and cost compared with open surgical biopsy. Despite its widespread use, diagnostic yield varies considerably across studies, influenced by lesion biology, anatomical location and modifiable technical factors. Non-diagnostic sampling remains a clinically relevant problem, particularly in sclerotic, occult and necrotic or cystic intraosseous lesions, often leading to repeat procedures and delayed definitive management. This narrative review synthesizes current evidence on the diagnostic performance of CT-guided musculoskeletal bone biopsy and organizes predictors of biopsy success into lesion-related, site-related and technique-related domains. Particular emphasis is placed on technical strategies aimed at optimizing diagnostic yield and specimen adequacy, including meticulous pre-procedural planning, appropriate needle selection, multi-core sampling, use of on-site cytologic or histologic assessment and advanced imaging guidance for challenging lesions. Emerging low-cost innovations such as the "sandwich technique" are discussed as potential solutions for traditionally low-yield scenarios, especially in resource-constrained settings. The review also highlights important gaps in the existing literature, which is dominated by retrospective single-centre studies from high-income environments and underscores the need for prospective, protocol-driven, multicentre research using standardized outcome definitions and inclusive of low- and middle-income settings. Continued refinement and validation of pragmatic biopsy strategies are essential to reduce non-diagnostic rates, minimize repeat procedures and improve the efficiency and equity of musculoskeletal biopsy care worldwide.

Keywords: CT-guided bone biopsy, Musculoskeletal lesions, Diagnostic yield, Percutaneous core needle biopsy, Sandwich technique, Resource-limited settings

INTRODUCTION

Computed tomography (CT) -guided percutaneous bone biopsy has emerged as a cornerstone in the diagnostic evaluation of musculoskeletal lesions, offering reliable tissue diagnosis with significantly lower morbidity and cost compared with open surgical biopsy across both high- and low-resource settings.[1,2] Despite its widespread use, reported diagnostic yield varies substantially among published series, reflecting heterogeneity in lesion biology, anatomical location, operator expertise and biopsy technique.[1,3]

Non-diagnostic or indeterminate biopsy results frequently necessitate repeat procedures or conversion to open surgical sampling, leading to delays in definitive management and increased economic and logistical burden

concerns that are particularly pronounced in low- and middle-income countries, where access to advanced imaging modalities and interventional expertise may be limited.[2,3] In this context, recent research has increasingly focused on identifying modifiable technical factors to enhance diagnostic yield and specimen adequacy, including optimized trajectory planning, appropriate needle selection, real-time cytologic assessment and innovative sampling approaches such as the recently described "sandwich technique" for necrotic or cystic intraosseous lesions.[1-3]

This narrative review synthesizes the current evidence on the diagnostic performance of CT-guided musculoskeletal bone biopsy and categorizes established predictors of biopsy success into lesion-, anatomical site- and technique-related domains. Particular emphasis is placed on technical approaches aimed at optimizing diagnostic yield and specimen adequacy, including recent innovations such as the "sandwich technique," with discussion of their relevance and evaluation priorities in both resource-constrained and high-income healthcare settings.

MATERIALS AND METHODS

This article is structured as a narrative review examining diagnostic yield and technique-related factors in CT-guided musculoskeletal bone biopsy. Priority was given to clinical series and review articles reporting diagnostic yield, accuracy and predictors of success for image-guided bone biopsy, with particular emphasis on studies describing technical modifications or procedural strategies aimed at improving specimen adequacy.

Relevant literature was identified through targeted searches of major medical databases using combinations of terms including "CT-guided bone biopsy," "musculoskeletal," "diagnostic yield" and "percutaneous core needle biopsy," supplemented by manual screening of reference lists from key publications to identify additional relevant studies. Preference was accorded to larger cohorts, more recent publications and studies with clearly defined methodologies, while highly overlapping reports or those lacking sufficient technical detail were de-emphasized. Given the narrative nature of this review, formal risk-of-bias assessment and quantitative meta-analysis were not performed.

BASELINE DIAGNOSTIC PERFORMANCE OF CT-GUIDED MUSCULOSKELETAL BONE BIOPSY

Across multiple published series, CT-guided percutaneous bone biopsy has demonstrated consistently high, though heterogeneous-diagnostic performance. Reported diagnostic yields typically range from approximately two-thirds to the mid-90% range, reflecting variability in patient selection, lesion composition, anatomical location and procedural technique.[1,2,4] Large cohort studies have shown that CT-guided biopsy enables reliable histological characterization of the majority of musculoskeletal lesions, with overall diagnostic yields most commonly reported between 70% and 90% and with high accuracy for the detection of malignancy when histopathological findings are interpreted in conjunction with imaging features and clinical context.[1,2]

More recent investigations examining factors influencing biopsy success have reported overall yields in the 80% to 90% range, while providing greater granularity regarding scenarios associated with reduced diagnostic performance.[2,4,5] Non-diagnostic or indeterminate results are consistently more frequent in specific lesion subsets, including occult lesions, densely sclerotic lesions and purely intraosseous processes without extraosseous extension. These observations underscore the inherent technical challenges of sampling such lesions and reinforce the rationale for ongoing refinement of biopsy techniques and sampling strategies to improve diagnostic yield in these demanding clinical settings (Table 1).

FACTORS INFLUENCING DIAGNOSTIC YIELD

Diagnostic yield in CT-guided musculoskeletal bone biopsy is governed by an interplay of lesion-specific, anatomical and technical factors rather than any single determinant. Lesion morphology and underlying biology play a central role; multiple series have demonstrated higher diagnostic success in lytic or mixed lesions containing viable solid components compared with sclerotic, occult or purely intraosseous lesions. In particular, small-volume lesions, hematologic malignancies and metabolically inactive or necrotic lesions have been consistently associated with higher rates of non-diagnostic sampling.[5,6]

Anatomical location further influences biopsy performance. Contemporary multicentre data suggest that axial skeletal sites, including the spine and pelvis as well as deep-seated lesions or those involving small bones, present greater challenges in terms of safe trajectory planning, needle access and the ability to obtain repeat or multiple cores. These anatomical constraints contribute to site-specific variability in reported diagnostic yields when compared with more accessible diaphyseal lesions of the long bones.[2,6,7] In parallel, technical factors have been shown to substantially affect diagnostic performance. Parameters such as imaging protocol optimization, appropriate needle gauge and design, the number and distribution of core samples obtained and the availability of on-site cytologic or histologic assessment have all been associated with improved specimen adequacy and diagnostic yield in several series. Operator experience and multidisciplinary planning between radiologists, pathologists and referring clinicians further enhance biopsy success by ensuring accurate target selection and technically sound approaches that maximize the likelihood of obtaining representative tissue.[5-7]

Table 1: Overview of representative clinical series evaluating diagnostic yield of CT-guided musculoskeletal bone biopsy, with emphasis on study environment, lesion spectrum, anatomical site, biopsy technique and reported factors affecting diagnostic performance in both resource-rich and resource-limited settings.

Study	Country /setting	Number of biopsies (N)	Lesion spectrum	Main skeletal sites	Guidance/needle details	Diagnostic yield (DY)	Key observations relevant to yield
Omura et al[1] (2011)	U.S.A, Tertiary Sarcoma Centre	>200	Primary bone tumors, metastasis, infections	Axial and appendicular skeleton	CT-guided core biopsy (11 to 13G)	~80% to 90% overall	Identified contributors to biopsy success; higher yield with larger lesions, extraosseous component, and careful planning; haematologic lesions more often non-diagnostic.
Spinnato et al[2] (2023)	Italy, Multi-Specialty-Centre	>300	Primary bone tumors, metastasis, infections	Axial and appendicular skeleton	CT-guided core biopsy (mixed Gauges)	~85% to 90% overall	Demonstrated high feasibility and yield across all skeletal regions; noted site-specific differences, with some small/complex locations more challenging.
Shah et al[3] (2025)	U.K, Tertiary Ortho-Oncology Centre	61	Necrotic or cystic intraosseous musculoskel-etal lesions	Appendicular Skeleton (mainly distal femur)	CT-guided 8G bone biopsy needle; sandwich technique	~97%	"Sandwich technique" (normal–lesion–normal core) markedly reduced non-diagnostic sampling in necrotic/cystic lesions; no direct non-ST control arm.
Rimondi et al[4] (2011)	Italy, Multi-Centre Musculoskeletal units	2027	Primary bone tumors, metastasis, infections	Axial and appendicular skeleton	CT-guided core biopsy (mixed Gauges)	~89%	One of the largest series; high accuracy for malignancy; showed good performance across sites but lower yield in some sclerotic/occult lesions.
Gataa et al[5] (2024)	Scandinavia, Tertiary Musculoskeletal Centre	~250	Primary bone tumors, metastasis, infections	Axial and appendicular skeleton	CT-guided core biopsy (13G)	~80% to 90% overall	Analysed factors affecting success with 13G needle; lesion size, location, and radiologic appearance significantly associated with diagnostic outcome.
Li et al[6] (2014)	China, Tertiary Referral Centre	~150	Primary bone tumors, metastasis	Appendicular skeleton and pelvis	CT-guided core biopsy (mixed Gauges)	~80% to 85%	Showed that lytic/mixed lesions and presence of soft-tissue mass predicted higher yield; sclerotic lesions and small volumes linked to non-diagnostic sampling.
Hwang et al[7] (2011)	USA, Cancer Centre	~200	Lesions with initial indeterminate biopsy findings	Axial and appendicular skeleton	CT-guided core biopsy (mixed Gauges)	~ 80% to 85% for malignancy on repeat	Evaluated lesions with prior indeterminate results; described CT features associated with eventual diagnostic versus indeterminate outcomes on repeat biopsy.
Dominic et al[12] (2017)	India, Tertiary Orthopaedic Centre (LMIC)	~80 to 100	Primary bone tumors	Appendicular skeleton	CT-guided core biopsy (11G)	~75% to 85%	One of the few LMIC series; highlighted need for repeat biopsies and practical constraints (needle choice, CT access) in high-volume trauma/oncology practice.

Continued.

Study	Country /setting	Number of biopsies (N)	Lesion spectrum	Main skeletal sites	Guidance/needle details	Diagnostic yield (DY)	Key observations relevant to yield
Maqsood et al[13] (2025)	Pakistan, Tertiary Centre (LMIC)	~100	Primary bone tumors, metastasis, infections	Axial and appendicular skeleton	CT-guided core biopsy (mixed Gauges)	~80% to 90%	Reported overall diagnostic yield comparable to high-income series; emphasised feasibility of core biopsy in an LMIC setting and importance of careful planning to minimise non-diagnostic samples.

TECHNICAL STRATEGIES TO OPTIMIZE DIAGNOSTIC YIELD

A wide range of technical strategies has been explored to enhance the diagnostic performance of CT-guided musculoskeletal bone biopsy beyond careful lesion selection alone. Multiple clinical series and expert reviews emphasize meticulous pre-procedural planning as a foundational element of biopsy success. This includes detailed assessment of cross-sectional imaging to identify solid, metabolically active or contrast-enhancing components; deliberate avoidance of predominantly necrotic or cystic regions where feasible; and selection of a biopsy trajectory that balances procedural safety with direct access to the most diagnostically informative portion of the lesion.[1-3,6-8] Several studies further suggest that appropriate selection of core needle gauge, acquisition of multiple tissue cores and preferential sampling of extraosseous or soft-tissue components when present can meaningfully improve diagnostic yield, particularly in primary bone tumours and metastatic disease. The availability of on-site cytologic or histologic assessment also permits immediate additional sampling when initial cores are scant or non-representative, thereby reducing the likelihood of non-diagnostic outcomes.[2,3,6,9-11]

Beyond these general measures, targeted technical refinements have been proposed for specific challenging clinical scenarios. In sclerotic or radiologically indeterminate lesions, protocol adaptations such as high-resolution CT acquisition, oblique multiplanar reconstructions and in selected centres, PET/CT or MRI fusion guidance have been used to direct the biopsy needle toward small foci of viable tumour within otherwise dense bone, with several reports documenting acceptable diagnostic yields even in this traditionally low-yield subgroup.[2,3,8,9,11] Adjuncts such as needle stabilisation devices and patient positioning aids have been described as low-cost methods to maintain trajectory accuracy and minimise motion or loss of sterility during long or angulated approaches, while real-time CT fluoroscopy can facilitate incremental needle adjustments without the need for repeated full-volume scans.[2,3,6,7,10] Most recently, Shah et al. introduced the “sandwich technique” for necrotic or cystic intraosseous lesions, in which the biopsy needle is intentionally advanced beyond the abnormal zone so that the core specimen contains normal bone–lesion–normal bone.[3] In their series of 61 lesions, this approach achieved a diagnostic success rate of 97%, substantially exceeding yields typically reported for comparable lesions using conventional centring techniques. However, direct prospective comparisons and external validation across diverse practice settings remain limited.[3,5,9-11]

CONSIDERATIONS IN LOW- AND MIDDLE-INCOME SETTINGS

The majority of high-quality evidence on CT-guided musculoskeletal bone biopsy originates from high-income centres with ready access to advanced imaging infrastructure, subspecialty-trained musculoskeletal radiologists and on-site pathology services.[1-3] In contrast, data from low- and middle-income countries (LMICs) remain relatively limited, despite substantial patient volumes and a disproportionate burden of neoplastic and infectious bone disease. As a result, key metrics such as local diagnostic yield, complication rates and the frequency of repeat biopsy are often extrapolated from high-resource settings rather than directly quantified in LMIC practice environments.[1,12,13]

Resource-related constraints in LMIC settings including restricted access to CT scanner time, a smaller interventional radiology workforce, limited availability of smaller-gauge or specialised biopsy systems and the absence of immediate cytologic or histologic assessment may influence procedural decision-making. These limitations can result in greater reliance on larger-gauge needles, fewer tissue cores and more conservative biopsy trajectories, with potential implications for both diagnostic yield and procedural safety when compared with high-resource environments.[10,12,13]

In this context, technical refinements that are simple, reproducible and independent of additional hardware or advanced imaging platforms are particularly attractive. Strategies such as the “sandwich” technique, which modify needle trajectory and sampling approach rather than equipment, offer a pragmatic means of improving retention of friable lesional tissue and reducing non-diagnostic sampling in necrotic or cystic intraosseous lesions without substantial incremental cost.[3,10,13] However, the available evidence supporting such approaches is largely derived from single-centre

experiences in high-income settings. There is therefore a clear need for prospective, multicentre studies that deliberately include LMIC cohorts to assess diagnostic yield, repeat-biopsy rates and complication profiles under real-world resource constraints.[10,12,13]

FUTURE DIRECTIONS

Future research should progress beyond single-centre retrospective analyses toward prospective, protocol-driven studies designed to directly evaluate specific technical refinements against conventional CT-guided bone biopsy in well-defined, high-risk clinical scenarios.[1-3,5,6] Priority areas for investigation include comparisons between standard lesion centring and targeted subregion sampling in heterogeneous lesions, routine multi-core acquisition versus limited-core strategies and the integration of on-site cytologic or histologic assessment versus deferred evaluation. Such studies should employ standardized definitions of diagnostic yield, diagnostic success and complication rates to enable meaningful comparison across cohorts and institutions.[2,3,5,6,10]

In parallel, specialised sampling approaches such as the "sandwich technique" for necrotic or cystic intraosseous lesions, require validation in larger, multicentre populations. Ideally, these studies should incorporate stratification by lesion type and anatomical location to determine whether the high diagnostic success reported in early single-centre series can be consistently reproduced across diverse practice settings and patient populations.[5,6,10]

Limitations

This review has several important limitations that merit consideration. First, as a narrative rather than a systematic review, the literature search was targeted rather than exhaustive and no formal risk-of-bias assessment or quantitative meta-analysis was undertaken. Consequently, the possibility of selection bias and selective reporting cannot be excluded. Secondly, the synthesis reflects the inherent heterogeneity of the existing literature, which is dominated by single-centre retrospective studies. These reports vary widely in their definitions of diagnostic yield, provide inconsistent descriptions of technical parameters and often lack detailed subgroup analyses based on lesion characteristics or anatomical location. Thirdly, the evidence from low- and middle-income settings remains limited. Perspectives on practice in these environments are therefore informed by a relatively small number of published cohorts and institutional audit experience rather than large, prospective datasets, which may constrain the generalisability of certain conclusions to other resource-constrained healthcare systems.

CONCLUSION

CT-guided percutaneous bone biopsy remains a highly effective and minimally invasive diagnostic tool for musculoskeletal lesions, but meaningful variability in diagnostic yield persists due to lesion biology, anatomical location and modifiable technical factors. Non-diagnostic sampling remains a clinically relevant challenge, particularly in sclerotic, occult and necrotic or cystic intraosseous lesions. The existing literature indicates that meticulous pre-procedural planning, appropriate needle selection, multi-core sampling and on-site cytologic or histologic assessment can significantly enhance specimen adequacy and diagnostic success, while emerging low-cost strategies such as the "sandwich technique" show promise in improving yield in traditionally low-performing lesions without additional equipment requirements. However, current evidence is largely derived from retrospective, single-centre studies in high-income settings, highlighting the need for prospective, protocol-driven, multicentre research using standardized outcome definitions and inclusive of resource-constrained environments. Such efforts are essential to validate pragmatic technical refinements, reduce non-diagnostic rates and repeat procedures and improve the efficiency and equity of musculoskeletal biopsy care globally.

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