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ROLE OF RADIOLOGY IN DIAGNOSTIC METASTATIC DISEASE: A COMPREHENSIVE SYSTEMATIC REVIEW

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ABSTRACT

Background: *Radiology plays a pivotal role in detecting, characterization, and managing metastatic disease. Advanced imaging modalities like ultrasound (USG), computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), and hybrid techniques have become indispensable tools. AI and deep learning applications enhance diagnostic accuracy. Challenges remain in balancing sensitivity, specificity, and patient safety, but ongoing research refines techniques for early detection and precise characterization.*

Methods: *This systematic review adhered to PRISMA 2020 principles and focused exclusively on full-text papers published in English between 2015 and 2025. Editorials and review articles without a DOI were omitted to preserve the integrity of high-quality sources. A literature review was conducted utilizing esteemed databases like ScienceDirect, PubMed, and SagePub to discover relevant studies.*

Result: *The preliminary database search yielded over 400 relevant publications on the topic. Following a comprehensive three-stage screening process, eight papers met the specified inclusion criteria and were selected for in-depth analysis. Each study underwent a comprehensive critical assessment, enabling a thorough understanding of the role of radiology in diagnosing metastatic disease. This methodical method guaranteed that the analysis relied on high-quality evidence, corresponded with the study's aims, and was capable of producing substantial insights into this intricate relationship.*

Conclusion: *Imaging techniques like USG, MRI, and CT are essential for detecting metastatic disease. A multimodal approach, combining strengths of these techniques, is often necessary for accurate assessment. Future advancements in imaging technology, including artificial intelligence and hybrid techniques, may further refine diagnostic precision, improving metastatic disease detection and patient outcomes.*

Keyword: *USG, CT Scan, MRI, imaging, metastati.*

INTRODUCTION

Radiology plays a pivotal role in the detection, characterization, and management of metastatic disease, which is crucial for determining appropriate treatment strategies and improving patient outcomes.[1] Advanced imaging modalities such as computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), and hybrid techniques like PET/CT have become indispensable tools in oncological practice. These modalities enable clinicians to accurately assess the extent of metastatic spread, monitor therapeutic responses, and detect disease recurrence.[2,3] For instance, whole-body MRI has emerged as a highly sensitive and radiation-free alternative for detecting multifocal metastatic disease, offering superior soft tissue contrast compared to traditional imaging techniques.[4]

Integrating artificial intelligence (AI) into radiological practices has further enhanced diagnostic accuracy and efficiency in identifying metastatic lesions.[5] Systematic reviews have demonstrated that AI algorithms can effectively analyze medical imaging data to detect tumor metastases across various primary tumors and metastatic sites, thereby augmenting the capabilities of radiologists and potentially reducing diagnostic errors.[6] Additionally, deep learning applications in CT imaging have shown promise in the diagnostic evaluation of metastatic disease,[7] highlighting the potential of AI to revolutionize cancer diagnostics and patient management.

Despite these advancements, challenges remain in the radiological assessment of metastatic disease. The choice of imaging modality often depends on the primary tumor type, suspected metastatic locations, and the need to balance sensitivity, specificity, and patient safety.[1] For example, while bone scintigraphy has been traditionally used for detecting bone metastases, it has limitations in sensitivity compared to newer modalities like whole-body MRI and PET/CT.[8] Furthermore, the interpretation of imaging findings requires a high level of expertise to differentiate between benign and malignant lesions accurately.[9] Ongoing research and technological innovations continue to refine imaging techniques, aiming to improve the early detection and precise characterization of metastatic disease, which is essential for optimizing therapeutic interventions and prognostic assessments.

METHODS

PROTOCOL

This study was meticulously conducted in strict accordance with the PRISMA 2020 guidelines, ensuring methodological precision and a high standard of research integrity. By adhering to these rigorous protocols, the review maintains transparency, enhances reproducibility, and upholds scientific rigor. Each phase of the process—including comprehensive literature searches, meticulous data extraction, and systematic synthesis of findings—was carefully executed to minimize bias and ensure analytical robustness. This methodologically sound approach not only enhances the study's credibility but also significantly contributes to the advancement of evidence-based research.

CRITERIA FOR ELIGIBILITY

This systematic review aims to comprehensively evaluate the role of radiology in diagnosing metastatic disease by analyzing and synthesizing data from a diverse range of research studies. By identifying key patterns, emerging trends, and gaps within the existing literature, this review seeks to generate meaningful insights that can inform the development of more effective imaging strategies. The ultimate objective is to enhance the understanding of radiological approaches in detecting metastatic disease, providing a robust evidence base to support improved patient care and clinical decision-making.

To ensure methodological rigor, the study adhered to strict inclusion and exclusion criteria. Only peer-reviewed articles published in English between 2015 and 2025 were included, with each study's validity confirmed through DOI verification. To maintain a focused and high-quality dataset, non-research materials such as reviews, editorials, and duplicate entries were excluded. This meticulous selection process enhances the reliability of the analysis, ensuring that findings are derived from credible and relevant sources. By implementing these stringent criteria, the study strengthens its contribution to evidence-based practice and enhances the overall validity of its conclusions.

By adopting a systematic and comprehensive approach, this study ensures that its conclusions are grounded in robust empirical evidence. The anticipated findings aim to refine current imaging protocols, optimize diagnostic accuracy, and improve patient outcomes by facilitating earlier and more precise detection of metastatic disease. Ultimately, this research aspires to advance radiological diagnostic methodologies, contribute to the evolution of clinical practice, and enhance the quality of life for individuals affected by metastatic conditions.

SEARCH STRATEGY

A comprehensive and systematic search strategy was employed to identify relevant studies for this review, utilizing key terms such as "role," "radiology," "diagnostic," and "metastatic disease." To ensure a thorough and balanced exploration of the topic, searches were conducted across three major academic databases—PubMed, SagePub, and ScienceDirect—providing access to a wide range of high-quality, peer-reviewed literature. This rigorous methodology facilitated the inclusion of diverse and credible sources, strengthening the evidence base and ensuring a well-rounded analysis. By emphasizing methodological precision and scholarly rigor, this approach enhances the reliability and validity of the

review's findings, ultimately contributing to a more comprehensive understanding of radiology's role in diagnosing metastatic disease.

Table 1. Search Strategy

Database	Search Strategy	*Hits*
Pubmed	*("role" AND "radiology " AND "diagnostic" AND "metastatic disease")*	323
Science Direct	*("role of radiology " AND "diagnostic" AND "metastatic disease")*	124
Sagepub	*("role of radiology " AND "diagnostic" AND "metastatic disease")*	5

DATA RETRIEVAL

The authors conducted a meticulous preliminary screening of each article, systematically evaluating titles and abstracts to determine their relevance before proceeding with an in-depth analysis. Only studies that aligned with the research objectives and met the predefined inclusion criteria were selected for further review. This structured and methodical approach facilitated the identification of key themes and significant patterns within the literature, ensuring that the analysis remained focused on studies directly relevant to the research question. By maintaining a clear and consistent selection process, the review effectively synthesized high-quality evidence to support its conclusions.

To ensure consistency and enhance comparability, only full-text articles published in English were included in the final dataset. A rigorous screening process was implemented to verify that all selected studies adhered to the established inclusion criteria and directly addressed the study's objectives. Articles failing to meet these standards were excluded, thereby maintaining a dataset that was both precise and aligned with the scope of the research. This careful selection process strengthened the reliability of the review and minimized potential biases, ensuring that findings were derived from credible and methodologically sound sources.

The evaluation process encompassed a thorough examination of multiple factors, including study titles, authorship, publication dates, research locations, and methodologies. By systematically assessing these elements, the authors ensured that only the most relevant and scientifically rigorous studies were included in the analysis. This comprehensive and methodologically robust selection strategy enhanced the credibility of the findings, providing a solid foundation for drawing reliable and actionable conclusions that contribute meaningfully to the field of radiology in diagnosing metastatic disease.

QUALITY ASSESSMENT AND DATA SYNTHESIS

The authors employed a meticulous initial screening process, systematically evaluating article titles and abstracts to identify studies that met predefined relevance and quality criteria. Only those that closely aligned with the research objectives and demonstrated methodological rigor were selected for comprehensive, in-depth analysis. This structured approach ensured the inclusion of high-quality studies that provided meaningful contributions to the review. By refining the selection process, the authors curated a dataset composed of scientifically robust and contextually significant studies. This rigorous methodology not only enhanced the precision and focus of the analysis but also strengthened the overall validity, reliability, and scholarly integrity of the systematic review.

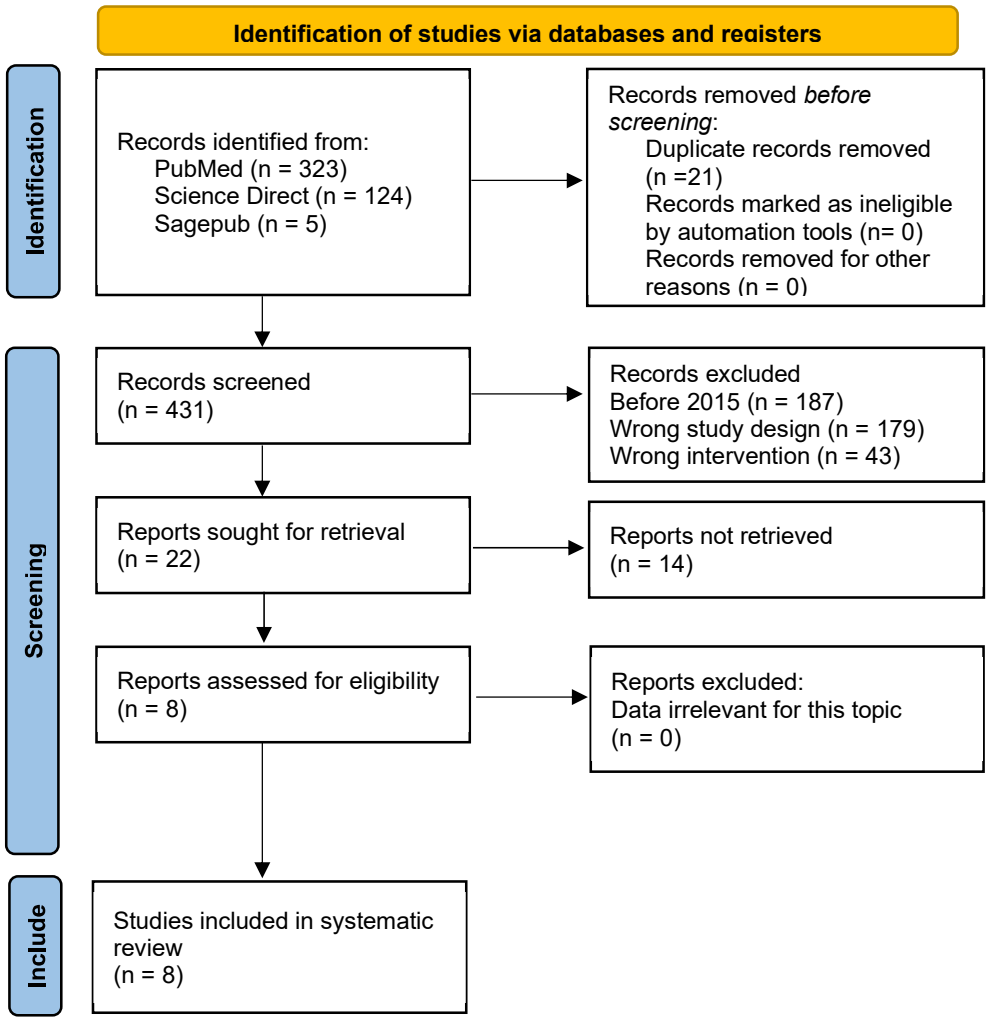

Figure 1. Article search flow chart

Table 2. Critical appraisal of Study

Parameters	(O'Sullivan et al., 2015)	(Rani et al., 2016)	(Pesapane et al., 2020)	(Rhee et al., 2020)	(Derks et al., 2021)	(Hafizar et al., 2022)	(Armando et al., 2023)	(Airlangga et al., 2023)
1. Bias related to temporal precedence Is it clear in the study what is the "cause" and what is the "effect" (ie, there is no confusion about which variable comes first)?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2. Bias related to selection and allocation Was there a control group?	No	No	Yes	Yes	No	No	No	Yes
3. Bias related to confounding factors Were participants included in any comparisons similar?	No	Yes	Yes	Yes	Yes	Yes	No	Yes
4. Bias related to administration of intervention/exposure Were the participants included in any comparisons receiving similar treatment/care, other than the	No.	Yes.	Yes.	Yes.	Yes.	Yes.	No.	Yes.

exposure or intervention of interest?								
5. Bias related to assessment, detection, and measurement of the outcome								
Were there multiple measurements of the outcome, both pre and post the intervention/exposure?	No	No	No	No	No	No	No	No
Were the outcomes of participants included in any comparisons measured in the same way?	No	No	Yes	Yes	No	No	No	Yes
Were outcomes measured in a reliable way?	No	Yes	Yes	Yes	Yes	Yes	No	Yes
6. Bias related to participant retention								
Was follow-up complete and, if not, were differences between groups in terms of their follow-up adequately described and analyzed?	No	No	Yes	Yes	No	No	No	Yes
7. Statistical conclusion validity								
Was appropriate statistical analysis used?	No	Yes	Yes	Yes	Yes	Yes	No	Yes

RESULT

The investigation began with a systematic search across reputable academic databases, including ScienceDirect, PubMed, and SagePub, to identify studies relevant to the review. A rigorous three-stage screening process was employed to meticulously filter and select the most pertinent studies, ultimately refining the selection to eight papers that met the predefined inclusion criteria. These studies then underwent a comprehensive analysis, with key themes and findings carefully extracted and examined in depth. To ensure clarity and a structured presentation of the results, the synthesized data is concisely summarized in Table 3, offering a well-organized overview of the analyzed information for easy interpretation and comparison.

Table 3. The literature included in this study

Author	Origin	Method	Sample	Result
O'Sullivan et al.[10] (2015)	Ireland	Review	-	Imaging techniques play a crucial role in early detection of skeletal metastasis, enabling accurate staging and optimal treatment. Hybrid techniques, combining morphological and functional data, are the most sensitive and specific, while PET/computed tomography and PET/magnetic resonance imaging are increasingly important.
Rani et al.[11] (2016)	India	Review	-	Imaging plays a crucial role in detecting hidden metastases in head and neck cancers, particularly in oral cavity areas. Advancements in

				radiography, computerized tomography, magnetic resonance imaging, positron emission tomography, ultrasonography, nuclear medicine, and sentinel node lymphoscintigraphy enhance diagnostic accuracy.
Pesapane et al.[12] (2020)	Italy	Review	-	Imaging modalities like bone scintigraphy, multiplanar-CT, PET, MRI, and hybrid scans are commonly used for staging advanced breast cancer metastases, with no specific recommendations for preferential use.
Rhee et al.[13] (2020)	Korea	Review	-	Imaging plays an essential role in pancreatic cancer surveillance, diagnosis, resectability evaluation, and treatment response evaluation. Endoscopic ultrasound (EUS) and magnetic resonance imaging (MRI) are used for high-risk surveillance, with computed tomography (CT) being the preferred modality. Imaging also aids in treatment response evaluation and prognosis prediction.
Derks et al.[14] (2021)	Netherlands	Review	-	Imaging plays a crucial role in the diagnosis and treatment of brain metastases (BMs). It helps select the right patients for screening, differentiate between intracranial aetiologies, and aid in surgical resection. Techniques like T1W MRI sequence are the gold standard, but additional information can differentiate BMs. Imaging also aids in treatment planning, surveillance, and distinguishing true tumor progression from pseudoprogression. Future perspectives include radiomics, biomarkers, and theranostics.
Hafizar et al.[15] (2022)	Indonesia	Systematic Review	26 studies	Prostate cancer staging using MRI has shown moderate sensitivity and high specificity, particularly in detecting lymph nodes. It is a crucial modality for bone metastatic prostate cancer detection, with a sensitivity of 47% and a specificity of 93% in nodal involvement staging and 94% and 99% in M-staging, respectively.

Armando et al.[16] (2023)	Indonesia	Retrospective Study	51 participants	The study identified 51 patients with metastatic breast, thyroid, and lungs cancer, with adenocarcinoma being the most common histology. Most metastases are found in vertebrae, with most lesion being multiple and osteolytic. Pathological fractures were present in 55.37% of cases, highlighting the need for further research.
Khan et al.[17] (2023)	India	Review	-	The role of imaging techniques in detecting bone metastases is crucial for effective management and treatment planning. Radiology, including X-ray, CT, MRI, and nuclear medicine techniques, plays a pivotal role in detecting these cancers. The emerging role of advanced imaging techniques and artificial intelligence enhances the accuracy and efficiency of this process.

DISCUSSION

Accurate detection of metastatic disease is paramount in guiding treatment decisions and improving patient prognosis. Various imaging modalities, including ultrasound (USG), magnetic resonance imaging (MRI), and computed tomography (CT) scans, are widely utilized to identify metastatic lesions. Each modality has unique advantages and limitations, making it essential to evaluate their diagnostic performance and accuracy systematically. A thorough assessment of these imaging techniques is crucial for determining the most effective approach to detecting metastases and ensuring optimal patient management.[18,19]

USG is frequently employed due to its widespread availability, cost-effectiveness, and non-invasive nature. It is particularly effective in assessing superficial structures and serves as an essential tool for guiding biopsy procedures. Additionally, USG allows for real-time imaging, making it useful for dynamic evaluations of metastatic involvement in certain anatomical regions.[20] However, its utility in detecting deeper, smaller, or less defined metastatic lesions is limited by operator dependency and lower tissue penetration capabilities. Studies have highlighted that while USG exhibits high specificity in identifying cervical lymph node metastases, particularly in patients with papillary thyroid cancer, its sensitivity remains comparatively lower, leading to a higher risk of false negatives.[21,22] This limitation necessitates the use of complementary imaging modalities for a more definitive assessment.

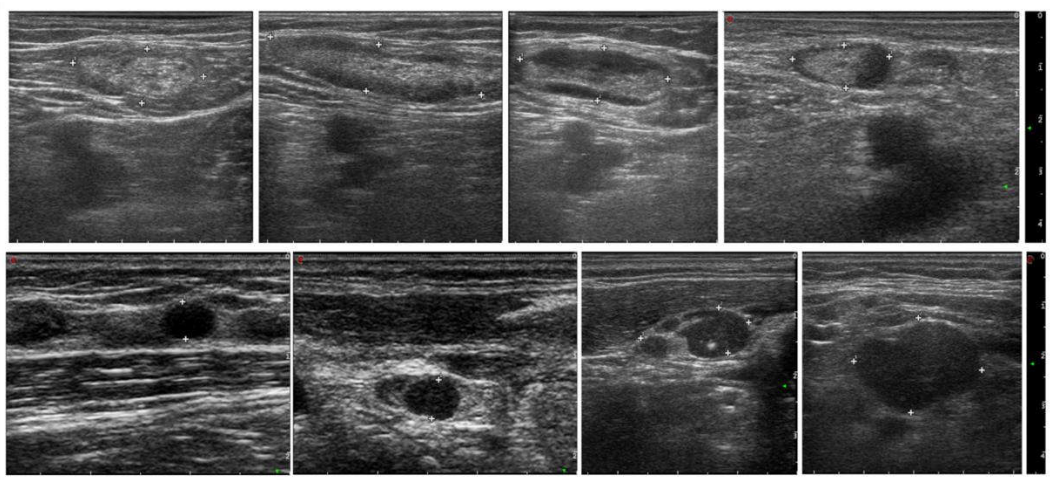

Figure 1. USG pictures of lymph nodes, depicting benign instances (upper row) and malignant cases (lower row).[20]

CT has revolutionized oncological imaging by offering high-resolution, cross-sectional visualization of metastatic disease. CT scanning is particularly effective in detecting metastases in the thoracic, abdominal, and pelvic regions due to its superior spatial resolution and contrast enhancement capabilities. It is widely used for staging and treatment planning, providing critical insights into disease progression.[1,12] However, CT imaging involves exposure to ionizing radiation, which may pose risks for repeated use, particularly in younger patients or those requiring long-term follow-up. Additionally, while CT provides excellent anatomical details, it may have limitations in differentiating between benign and malignant lesions, necessitating further evaluation with more advanced imaging techniques.[23]

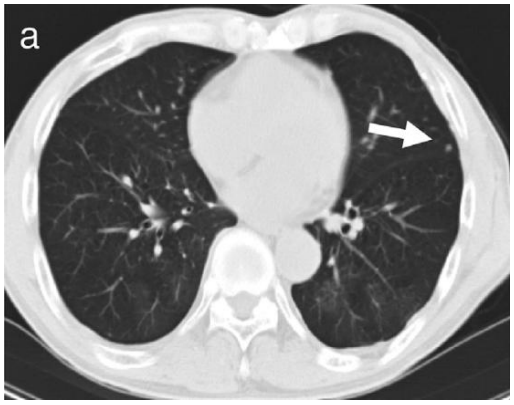

Figure 2. Metastatic lung neoplasm on computed tomography. Temporal progression of pulmonary metastases in individuals diagnosed with osteosarcoma. CT can detect lung metastases above 3 mm in diameter.[23]

MRI is recognized for its exceptional soft-tissue contrast, making it highly valuable for detecting metastatic involvement in the central nervous system, liver, and musculoskeletal system.[24] MRI, particularly when enhanced with gadolinium-based contrast agents, has demonstrated superior sensitivity compared to contrast-enhanced CT in diagnosing central nervous system metastases, improving early detection and treatment planning.[25,26] Despite its diagnostic superiority in specific contexts, MRI's high cost, longer acquisition times, and contraindications in patients with certain implants or renal impairment present challenges for its widespread application.[27] Furthermore, motion artifacts in uncooperative patients or those with respiratory issues may affect image quality, necessitating additional considerations when selecting imaging modalities.

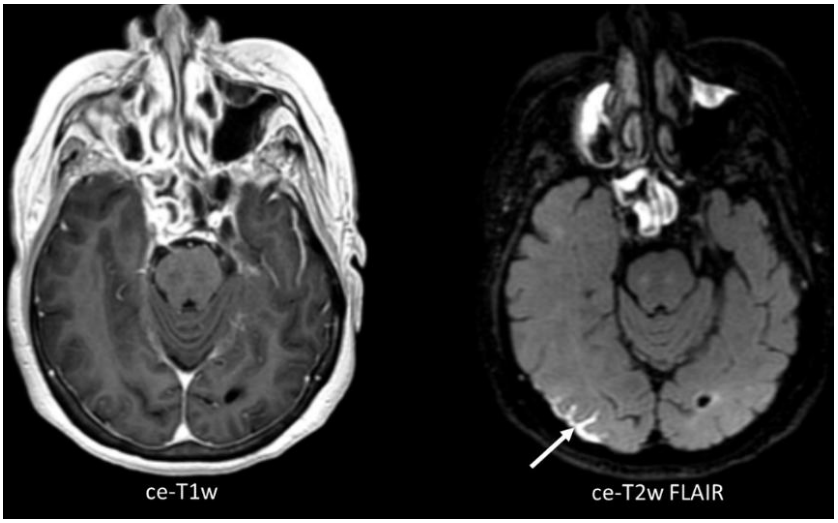

Figure 3. Axial view, three-dimensional (3D) contrast-enhanced T1W image (ce-T1W) on the left and T2W Fluid Attenuated Inversion Recovery image (ce-T2W FLAIR) on the right from a leptomeningeal disease patient.[14]

Comparative studies of these imaging techniques underscore the importance of selecting the appropriate modality based on clinical indications. For instance, MRI is more sensitive than CT in detecting spinal metastases, while positron emission tomography (PET)/CT has demonstrated superior specificity in differentiating metastatic lesions from inflammatory or benign processes.[27,28] Whole-body MRI has also emerged as a promising modality for comprehensive metastatic screening, outperforming conventional imaging pathways in terms of sensitivity; however, variations in specificity necessitate careful interpretation of findings.[29,30] These comparative insights highlight the need for a tailored imaging strategy that optimally balances sensitivity, specificity, accessibility, and cost.

CONCLUSION

In conclusion, no single imaging modality can be universally recommended for detecting metastatic disease across all scenarios. Instead, the choice of imaging technique should be individualized based on factors such as the primary tumor type, suspected metastatic sites, patient-specific characteristics, and clinical urgency. A multimodal imaging approach,

integrating the strengths of USG, CT, and MRI, is often necessary to achieve the most accurate and comprehensive assessment. Future advancements in imaging technology, including the integration of artificial intelligence and hybrid imaging techniques, may further refine diagnostic precision, ultimately improving metastatic disease detection and patient outcomes.

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