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Integrating Conventional and Functional MRI in ST-RADS: A Structured Approach to Characterization of Extremity Soft Tissue Tumors

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ABSTRACT

***Background*:** Extremity soft tissue tumors represent a heterogeneous group of lesions with a wide spectrum of biological behavior, ranging from benign masses to aggressive sarcomas. Accurate characterization is essential for guiding clinical management; however, conventional magnetic resonance imaging (MRI), despite its superior soft tissue contrast and multiplanar capability, remains limited by significant overlap in imaging features between benign and malignant lesions . This diagnostic challenge has led to the development of structured reporting systems such as the Soft Tissue Tumor Reporting and Data System (ST-RADS), which aims to standardize MRI interpretation and improve diagnostic consistency.

The integration of functional MRI techniques, particularly diffusion-weighted imaging (DWI) and dynamic contrast-enhanced MRI (DCE-MRI), into conventional MRI protocols has further enhanced the ability to assess tumor biology. These advanced techniques provide quantitative and physiological information related to tissue cellularity, vascularity, and perfusion, which are critical in differentiating benign from malignant lesions. Within the ST-RADS framework, combining morphological and functional imaging features offers a more comprehensive and structured approach to lesion characterization.

This review aims to evaluate the role of integrating conventional and functional MRI within the ST-RADS system for the characterization of extremity soft tissue tumors. Emphasis is placed on the diagnostic contribution of signal characteristics, lesion morphology, enhancement patterns, and functional imaging parameters such as apparent diffusion coefficient (ADC) values and enhancement kinetics. The review also explores how this integrated approach improves lesion stratification and supports clinical decision-making.

Emerging evidence suggests that combining DWI and DCE-MRI with conventional MRI enhances diagnostic performance compared to individual techniques alone. Functional imaging contributes to improved assessment of tumor cellularity and vascularity, which are key indicators of malignancy. However, limitations remain, including overlap in imaging findings and variability in acquisition and interpretation of advanced MRI techniques.

In conclusion, the integration of conventional and functional MRI within the ST-RADS framework represents a significant advancement in the imaging evaluation of extremity soft tissue tumors. This structured approach enhances lesion characterization, improves diagnostic confidence, and supports more accurate and reproducible radiological assessment. Continued validation and refinement of this integrated model are necessary to optimize its clinical utility.

Keywords: Conventional , Functional MRI, ST-RADS, Extremity Soft Tissue Tumors

INTRODUCTION

Extremity soft tissue tumors comprise a heterogeneous group of lesions with diverse histological subtypes and biological behavior, ranging from benign entities to highly aggressive sarcomas. Accurate preoperative characterization is essential for appropriate management, including biopsy planning, surgical decision-making, and prognostic assessment. Magnetic resonance imaging (MRI) has emerged as the primary imaging modality for evaluating these tumors due to its superior soft tissue contrast resolution and ability to delineate lesion extent and anatomical relationships. However, despite its advantages, conventional MRI remains limited by significant overlap in imaging features between benign and malignant lesions, which can reduce diagnostic specificity [1-3].

Traditional MRI assessment relies predominantly on morphological and signal intensity characteristics, including lesion size, depth, margins, and internal heterogeneity. While certain features may suggest malignancy, such as large size, deep location, and heterogeneous enhancement, these findings are not sufficiently specific to allow definitive characterization. Consequently, reliance on conventional MRI alone often necessitates further diagnostic procedures, including biopsy, to establish a definitive diagnosis [3].

In recent years, functional MRI techniques have gained increasing importance in the evaluation of soft tissue tumors. Diffusion-weighted imaging (DWI) provides quantitative information regarding tissue cellularity through apparent diffusion coefficient (ADC) values, while dynamic contrast-enhanced MRI (DCE-MRI) evaluates tumor vascularity and perfusion characteristics. These techniques offer insight into tumor biology beyond structural imaging and have demonstrated potential in improving differentiation between benign and malignant lesions [3].

The growing complexity of MRI data, particularly with the addition of functional imaging parameters, has highlighted the need for structured and standardized reporting systems. The Soft Tissue Tumor Reporting and Data System (ST-RADS) has been proposed as a comprehensive framework that integrates conventional MRI findings with advanced imaging features into a unified classification system. This approach aims to enhance lesion characterization, reduce variability in interpretation, and improve diagnostic confidence in musculoskeletal imaging [4].

Despite the potential advantages of combining conventional and functional MRI within a structured system, the practical integration of these techniques into routine clinical workflows remains underexplored. In particular, there is a need to better understand how functional imaging parameters contribute to lesion stratification within the ST-RADS framework and whether this integration significantly improves diagnostic performance.

Therefore, this review aims to evaluate the role of integrating conventional and functional MRI techniques within the ST-RADS system for the characterization of extremity soft tissue tumors, with emphasis on improving diagnostic accuracy, enhancing lesion stratification, and supporting clinical decision-making.

Conventional MRI Features in Characterization of Extremity Soft Tissue Tumors

Conventional MRI remains the cornerstone for initial characterization of extremity soft tissue tumors, providing detailed anatomical and morphological information that forms the basis for diagnostic evaluation. Its superior soft tissue contrast resolution allows accurate assessment of lesion location, size, extent, and relationship to surrounding structures, including muscles, fascia, bone, and neurovascular bundles. These features are critical for determining tumor compartmentalization and planning subsequent management, including biopsy and surgical intervention [5].

A standard MRI protocol typically includes T1-weighted and fluid-sensitive sequences such as T2-weighted or short tau inversion recovery (STIR) images obtained in multiple orthogonal planes. T1-weighted images provide excellent anatomical detail and are particularly useful for identifying fat within lesions, which may suggest specific benign entities such as lipomas. In contrast, T2-weighted sequences highlight areas of increased water content, enabling detection of edema, cystic changes, necrosis, or myxoid components within tumors. These signal characteristics contribute significantly to lesion characterization, although they are often nonspecific [5].

Signal intensity patterns play an important role in narrowing the differential diagnosis. Lesions demonstrating high signal intensity on T1-weighted images may contain fat, hemorrhage, or proteinaceous material, whereas low signal intensity on T2-

weighted images is typically associated with fibrous tissue, hemosiderin, or calcification. However, many soft tissue tumors exhibit heterogeneous signal characteristics due to varying internal composition, limiting the specificity of these findings in distinguishing benign from malignant lesions [5].

Morphological features provide additional diagnostic clues. Important parameters include lesion size, margin definition, internal heterogeneity, and depth relative to the deep fascia. Features suggestive of malignancy include large lesion size, deep location, irregular or infiltrative margins, and heterogeneous signal intensity reflecting necrosis or hemorrhage. Involvement or encasement of adjacent neurovascular structures and bone invasion further increase suspicion for malignancy. Nevertheless, overlap exists, as some benign lesions may also demonstrate similar characteristics, particularly when large or complicated by secondary changes [5].

Contrast-enhanced MRI is an essential component of conventional imaging, as it allows evaluation of lesion vascularity and internal architecture. Gadolinium-enhanced sequences help differentiate viable tumor tissue from necrotic or cystic components and can guide biopsy by identifying the most active tumor regions. Malignant tumors often exhibit heterogeneous or peripheral enhancement patterns, while benign lesions tend to show more homogeneous enhancement, although exceptions are common [5].

Despite its comprehensive capabilities, conventional MRI alone is insufficient for definitive differentiation between benign and malignant soft tissue tumors due to considerable overlap in imaging findings. This limitation underscores the need for integrating additional functional imaging techniques and structured reporting systems such as ST-RADS to improve diagnostic accuracy and consistency.

Functional MRI Techniques: Diffusion-Weighted Imaging and Dynamic Contrast-Enhanced MRI

Functional MRI techniques have significantly expanded the diagnostic capabilities of conventional imaging by providing insight into the biological behavior of soft tissue tumors. Unlike standard morphological sequences, functional imaging evaluates physiological and microstructural properties such as tissue cellularity, vascularity, and perfusion. Among these techniques, diffusion-weighted imaging (DWI) and dynamic contrast-enhanced MRI (DCE-MRI) play a central role in improving lesion characterization and are increasingly incorporated into structured systems such as ST-RADS [6].

Diffusion-weighted imaging assesses the random motion of water molecules within tissues, which is influenced by cellular density and membrane integrity. In highly cellular tumors, such as malignant soft tissue sarcomas, diffusion is restricted due to limited extracellular space, resulting in high signal intensity on DWI and low apparent diffusion coefficient (ADC) values. In contrast, benign lesions typically demonstrate less restricted diffusion and higher ADC values, reflecting lower cellularity and greater extracellular matrix components. This quantitative capability makes DWI a valuable adjunct to conventional MRI in differentiating benign from malignant lesions [6].

Despite its advantages, the diagnostic performance of DWI is not absolute. Several studies have demonstrated overlap in ADC values between benign and malignant soft tissue tumors, particularly in lesions with myxoid components or necrotic areas. Additionally, factors such as hemorrhage, fibrosis, and cystic degeneration may influence diffusion characteristics, potentially leading to misinterpretation. Therefore, DWI findings should always be interpreted in conjunction with conventional MRI features rather than in isolation [6].

Dynamic contrast-enhanced MRI provides complementary information by evaluating tumor vascularity, perfusion, and capillary permeability. Following intravenous administration of gadolinium-based contrast agents, serial imaging captures the temporal pattern of enhancement within the lesion. Malignant tumors typically demonstrate early, rapid, and heterogeneous enhancement due to increased angiogenesis and abnormal vascular architecture, often with a steep initial slope followed by washout or plateau phases. In contrast, benign lesions more commonly exhibit gradual and progressive enhancement patterns [6].

DCE-MRI also allows assessment of internal tumor heterogeneity by distinguishing viable tumor tissue from necrotic or cystic components. This is particularly useful in guiding biopsy to the most metabolically active regions and in evaluating treatment response. Furthermore, parameters derived from DCE-MRI, such as enhancement kinetics and perfusion characteristics, provide additional markers of tumor aggressiveness, although overlap between lesion types can still occur [6].

The combined use of DWI and DCE-MRI enhances the overall diagnostic performance of MRI by integrating information on both cellularity and vascularity. When interpreted alongside conventional morphological features, these functional techniques

contribute to a more comprehensive assessment of soft tissue tumors. This integrated approach forms the basis for advanced structured reporting systems such as ST-RADS, where multiple imaging parameters are collectively used to stratify lesions according to malignancy risk.

Integration of Conventional and Functional MRI into the ST-RADS Framework

The integration of conventional and functional MRI findings within the Soft Tissue Tumor Reporting and Data System (ST-RADS) represents a significant advancement in the structured evaluation of extremity soft tissue tumors. While conventional MRI provides detailed morphological assessment, the addition of functional imaging parameters such as diffusion-weighted imaging (DWI) and dynamic contrast-enhanced MRI (DCE-MRI) enables a more comprehensive evaluation of tumor biology. This combined approach allows ST-RADS to move beyond descriptive imaging toward a more objective and reproducible risk stratification model [7].

Within the ST-RADS framework, conventional MRI features form the foundation of lesion assessment. Parameters such as lesion size, depth relative to fascia, margin characteristics, internal heterogeneity, and anatomical relationships are systematically evaluated. These features are well-established indicators of malignancy risk, with larger size, deep location, infiltrative margins, and heterogeneous internal architecture favoring malignant pathology. However, when used alone, these criteria are limited by overlap between benign and malignant lesions, highlighting the need for additional functional data [7].

Functional MRI techniques provide critical complementary information that enhances the discriminatory power of ST-RADS. Diffusion-weighted imaging contributes quantitative assessment of tissue cellularity through apparent diffusion coefficient (ADC) values, with lower ADC values generally associated with malignant tumors due to increased cellular density. Similarly, DCE-MRI evaluates vascularity and perfusion characteristics, where early, rapid, and heterogeneous enhancement patterns are more suggestive of malignancy. Incorporating these parameters into ST-RADS allows for a more nuanced and biologically relevant classification of lesions [7].

The strength of ST-RADS lies in its ability to synthesize multiple imaging features into a structured scoring system that reflects the probability of malignancy. By combining morphological and functional findings, lesions can be categorized along a spectrum ranging from likely benign to highly suspicious for malignancy. This integrated approach reduces subjectivity in interpretation and improves consistency across radiologists, facilitating standardized reporting and clearer clinical communication [7].

In practical application, the integration of functional MRI into ST-RADS enhances diagnostic confidence, particularly in indeterminate cases where conventional imaging alone is inconclusive. For example, lesions with borderline morphological features may be more accurately classified when functional data reveal restricted diffusion or aggressive enhancement kinetics. Conversely, lesions with suspicious morphology but benign functional characteristics may be downgraded, potentially reducing unnecessary invasive procedures.

Despite these advantages, certain limitations persist. Overlap in ADC values between benign and malignant lesions and variability in enhancement patterns may affect interpretation. Additionally, differences in MRI acquisition protocols and lack of standardized thresholds for functional parameters can introduce variability. Therefore, while the integration of functional imaging significantly strengthens the ST-RADS framework, it should be applied in conjunction with clinical correlation and, when necessary, histopathological confirmation [7].

Overall, the incorporation of conventional and functional MRI into ST-RADS represents a comprehensive and structured approach to soft tissue tumor evaluation. This integration not only improves lesion characterization but also supports more accurate risk stratification and informed clinical decision-making.

Clinical Impact and Applications of Integrated ST-RADS in Extremity Soft Tissue Tumors

The integration of conventional and functional MRI within the ST-RADS framework has important clinical implications, particularly in improving decision-making across the diagnostic and therapeutic pathway of extremity soft tissue tumors. Accurate imaging-based characterization is essential for determining the need for biopsy, planning surgical intervention, and guiding follow-up strategies. By providing a structured and reproducible assessment, ST-RADS facilitates a more standardized approach to patient management and reduces variability in clinical practice [8,9].

One of the most significant clinical applications of ST-RADS is in **guiding biopsy planning**. Imaging plays a crucial role in

identifying the most representative and viable regions of a tumor for tissue sampling. Conventional MRI can delineate tumor extent and internal heterogeneity, while functional imaging techniques such as DWI and DCE-MRI help identify areas of high cellularity and vascularity, which are more likely to yield diagnostic tissue. Targeting these regions reduces the risk of non-diagnostic or misleading biopsy results, particularly in heterogeneous tumors with necrotic components [10,11].

In addition to biopsy guidance, ST-RADS contributes to **preoperative planning and surgical decision-making**. Accurate delineation of tumor margins, compartmental involvement, and relationship to critical neurovascular structures is essential for achieving complete surgical resection while preserving function. Functional MRI further refines this assessment by highlighting biologically active tumor regions, which may influence surgical margins and resection strategy. This integrated imaging approach supports more precise and individualized surgical planning [9,12].

ST-RADS also plays a role in **risk stratification and treatment selection**, particularly in distinguishing lesions that require immediate intervention from those that may be managed conservatively or followed with imaging surveillance. Lesions categorized as low-risk based on combined morphological and functional features may avoid unnecessary invasive procedures, while high-risk lesions can be prioritized for prompt biopsy and treatment. This stratification improves resource utilization and reduces patient morbidity associated with overtreatment [8,13].

Another important application is in the **multidisciplinary management of soft tissue tumors**. Radiological findings are central to discussions within tumor boards, where imaging, clinical, and pathological data are integrated to determine optimal management strategies. The structured nature of ST-RADS enhances communication between radiologists, surgeons, oncologists, and pathologists by providing a clear and standardized description of lesion characteristics and malignancy risk. This consistency improves collaborative decision-making and patient outcomes [9,11].

Furthermore, the integration of functional MRI into ST-RADS has implications for **treatment response assessment and follow-up**. Changes in ADC values and enhancement patterns can reflect alterations in tumor cellularity and vascularity following therapy, often preceding morphological changes. This allows earlier evaluation of treatment efficacy and detection of recurrence. Functional imaging therefore adds a dynamic component to ST-RADS, extending its utility beyond initial diagnosis to longitudinal patient monitoring [12,14].

Despite these advantages, certain challenges remain in clinical implementation. Variability in MRI acquisition protocols, lack of standardized thresholds for functional parameters, and overlapping imaging features between lesion types may affect reproducibility. Additionally, interpretation of advanced imaging requires expertise and may not be universally available. Therefore, while ST-RADS enhances clinical workflow, it should be integrated with clinical judgment and histopathological confirmation when necessary [10,15].

Overall, the integration of conventional and functional MRI within the ST-RADS framework significantly strengthens its clinical utility. By improving lesion characterization, guiding biopsy and treatment decisions, and enhancing multidisciplinary communication, this approach contributes to more precise and effective management of extremity soft tissue tumors.

The integration of conventional and functional MRI within the ST-RADS framework represents a significant evolution in the radiological evaluation of extremity soft tissue tumors. While conventional MRI provides essential anatomical and morphological information, its limitations in differentiating benign from malignant lesions are well recognized due to considerable overlap in imaging features. The addition of functional imaging techniques, particularly diffusion-weighted imaging (DWI) and dynamic contrast-enhanced MRI (DCE-MRI), addresses these limitations by providing insight into tumor cellularity and vascularity, thereby enhancing diagnostic specificity [16,17].

A major strength of this integrated approach lies in its ability to combine structural and physiological data into a unified, standardized system. ST-RADS facilitates this integration by incorporating multiple imaging parameters into a structured classification that reflects malignancy risk. This reduces subjectivity in interpretation and improves reproducibility across radiologists, which is critical in musculoskeletal oncology where imaging plays a central role in guiding clinical decisions [11,16].

The contribution of functional MRI is particularly valuable in indeterminate cases. DWI allows quantitative assessment through ADC values, which correlate with tumor cellularity, while DCE-MRI evaluates enhancement kinetics related to tumor perfusion

and angiogenesis. When combined with conventional MRI features such as lesion size, depth, and heterogeneity, these parameters significantly improve lesion characterization. However, it is important to recognize that overlap in ADC values and enhancement patterns may still occur, especially in lesions with complex histological composition, which remains a diagnostic challenge [13,15].

From a clinical perspective, the integration of functional MRI into ST-RADS enhances multiple aspects of patient management. It improves biopsy targeting by identifying the most viable tumor regions, supports surgical planning through better delineation of tumor extent and activity, and contributes to treatment monitoring by detecting early physiological changes. Furthermore, the structured reporting format improves communication within multidisciplinary teams, facilitating more consistent and evidence-based decision-making [12,18].

Despite these advantages, several limitations must be acknowledged. Variability in MRI acquisition protocols, lack of universally accepted thresholds for functional parameters, and dependence on radiologist expertise may affect the consistency of interpretation. Additionally, access to advanced MRI techniques may be limited in some clinical settings, which could impact the widespread adoption of this integrated approach. Therefore, while ST-RADS enhanced by functional MRI represents a powerful diagnostic tool, it should be applied in conjunction with clinical assessment and histopathological confirmation when required [15].

Future developments are likely to focus on further standardization of functional imaging parameters and integration with emerging technologies such as artificial intelligence and radiomics. These advancements may enable automated lesion characterization, improve risk prediction, and further enhance the diagnostic performance of MRI in soft tissue tumors.

Conclusion

The integration of conventional and functional MRI within the ST-RADS framework provides a comprehensive and structured approach to the characterization of extremity soft tissue tumors. By combining morphological assessment with quantitative evaluation of tumor cellularity and vascularity, this approach significantly enhances diagnostic accuracy, improves reproducibility, and supports more informed clinical decision-making. Despite existing limitations, including overlap in imaging features and variability in advanced imaging techniques, the incorporation of functional MRI represents a meaningful advancement in musculoskeletal imaging. Continued refinement, standardization, and validation of this integrated model are essential to optimize its clinical application and maximize its impact on patient care.

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REFERENCES

1. Choi JH, Ro JY. The 2020 WHO classification of tumors of soft tissue: selected changes and new entities. *Adv Anat Pathol.* 2021;28(1):44–58.
2. Fletcher CDM, Bridge JA, Hogendoorn PCW, Mertens F, eds. *WHO Classification of Tumours of Soft Tissue and Bone.* 4th ed. Lyon, France: International Agency for Research on Cancer (IARC); 2013.
3. Diana Afonso P, Mascarenhas VV. Imaging techniques for the diagnosis of soft tissue tumors. *Rep Med Imaging.* 2015;8:63–70.
4. Chhabra A, Ashikyan O, Ratakonda R, et al. Soft-Tissue Tumor Reporting and Data System (ST-RADS): MRI reporting guideline with multi-institutional validation study of extremity soft tissue tumors. *J Tumor Res.* 2022;8:179.

5. Aga P, Singhi R, Parihar A, et al. Imaging spectrum in soft tissue sarcomas. *Indian J Surg Oncol.* 2011;2(4):271–279.
6. Knapp EL, Kransdorf MJ, Letson GD. Diagnostic imaging update: soft tissue sarcomas. *Cancer Control.* 2005;12(1):22–26.
7. Bermejo A, De Bustamante TD, Martinez A, Carrera R, Zabia E, Manjón P. MR imaging in the evaluation of cystic-appearing soft-tissue masses of the extremities. *Radiographics.* 2013;33(3):833–855.
8. Grimer R, Judson I, Peake D, Seddon B. Guidelines for the management of soft tissue sarcomas. *Sarcoma.* 2010;2010:506182.
9. Datir A, James SLJ, Ali K, Saifuddin A. MRI of soft-tissue masses: the relationship between lesion size, depth, and diagnosis. *Clin Radiol.* 2008;63(4):373–378.
10. Bancroft LW, Pettis C, Wasyliw C. Imaging of benign soft tissue tumors. *Semin Musculoskelet Radiol.* 2013;17(2):156–167.
11. Chhabra A, Ashikyan O, Slepicka C, et al. Conventional MR and diffusion-weighted imaging of musculoskeletal soft tissue malignancy: correlation with histologic grading. *Eur Radiol.* 2019;29(8):4485–4494.
12. Fayad LM, Jacobs MA, Wang X, et al. Musculoskeletal tumors: how to use anatomic, functional, and metabolic MR techniques. *Radiology.* 2012;265(2):340–356.
13. Boruah DK, Gogoi B, Patni RS, et al. Added value of diffusion-weighted magnetic resonance imaging in differentiating musculoskeletal tumors using sensitivity and specificity: a retrospective study and review of literature. *Cureus.* 2021;13(1):e12422.
14. Van der Woude HJ, Bloem JL, Hogendoorn PCW. Preoperative evaluation and monitoring chemotherapy in patients with high-grade osteogenic and soft-tissue sarcomas: review of current imaging modalities. *Skeletal Radiol.* 1998;27(2):57–71.
15. Einarsdóttir H, Karlsson M, Wejde J, Bauer HC. Diffusion-weighted MRI of soft tissue tumors. *Eur Radiol.* 2004;14(6):959–963.
16. Moulton JS, Blebea JS, Dunco DM, Braley SE, Bisset GS, Emery KH. MR imaging of soft-tissue masses: diagnostic efficacy and value of distinguishing between benign and malignant lesions. *AJR Am J Roentgenol.* 1995;164(5):1191–1199.
17. Crombé A, Marcellin PJ, Buy X, et al. Soft-tissue sarcomas: assessment of MRI features correlating with histologic grade and patient outcome. *Radiology.* 2019;291(3):710–721.
18. Fayad LM, Jacobs MA, Wang X, et al. Functional MRI of musculoskeletal tumors: emerging techniques and clinical applications. *Radiology.* 2012;265(2):340–356.