

MRI of Soft Tissue Tumors and Tumor Mimickers

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Magnetic resonance imaging (MRI) has become a vital part of the routine work up of a patient with a suspected soft-tissue tumor of the musculoskeletal system. Unlike for bone lesions, plain radiography and CT are of little help in evaluating noncalcified tumors in soft tissue. True multiplanar capability and unparalleled capacity for soft-tissue contrast make MRI superbly suited to this particular clinical indication. Not only can MRI frequently suggest a specific diagnosis, but it is unsurpassed in its ability to delineate the soft-tissue extent of the tumor for accurate staging. Moreover, constant innovations in coil design, gradient hardware and pulse sequences continue to advance the diagnostic capacity of MRI at a remarkable rate.

Nevertheless, plain radiography is still recommended for the initial evaluation of soft-tissue tumors, as small intralesional calcifications or gas bubbles may be overlooked with MRI, and yet can strongly influence differential diagnosis and ultimate patient management. An intact cortex adjacent to a soft-tissue neoplasm on plain radiography is usually reliable evidence that the bone is not involved. Bone metastases are actually uncommon among the majority of soft-tissue tumors; although bone scintigraphy offers a sensitive and convenient method for surveying the entire skeleton when this is a consideration. Chest CT is still the method of choice for screening lung metastases in patients with known malignant soft-tissue tumors.

TECHNICAL CONSIDERATIONS

Routine MRI of a patient suspected of having a soft-tissue tumor should include both T1-weighted and T2-weighted sequences in the axial plane and at least one longitudinal plane. It is preferable to use an appropriate surface coil or volume coil whenever possible; however, for large tumors or when comparison with the contralateral side is desired, the body coil must be used. T2-weighted spin-echo sequences are excessively lengthy, and have mostly been replaced by *fast* spin echo or partial flip-angle gradient-echo imaging. T2-weighted *fast* spin-echo sequences in particular can provide heavily T2-weighted images with sufficient signal-to-noise ratio (SNR) to support a high resolution matrix. High spatial resolution is necessary to evaluate local vascular and neural involvement by the

tumor for accurate staging. However, because *fast* spin-echo sequences tend to depict fat with a high signal intensity, lesions surrounded by adipose tissue may be less conspicuous than with conventional spin-echo imaging unless some form of fat suppression is used. STIR (Short T1 Inversion Recovery) is useful in this regard, as it depicts most lesions with extremely high signal intensity while suppressing adjacent fat. One considerable limitation of STIR, however, is its relatively poor spatial resolution.

Conventional T2*-weighted gradient-echo sequences offer relatively limited soft-tissue contrast. However, T1-weighted gradient-echo techniques are also now routinely available, and the high-resolution capabilities of thin-partitioned 3-dimensional imaging, which is restricted to gradient-echo sequences, can be helpful in determining whether local nerves or arteries are involved. Static GRASS images are particularly useful in delineating the local vasculature. Characteristic magnetic susceptibility effects seen with gradient-echo sequences can be problematic in postoperative cases in which surgical clips or micrometallic fragments from surgical instrumentation obscure the operative bed. These sequences can also be used, however, to increase the conspicuity of hemosiderin-containing lesions by capitalizing on the rapid T2* of this substance.

Intravenous administration of gadolinium-diethylenetriamine pentaacetic acid (Gd-DTPA) enhances most hypervascular lesions by leaking into the local interstitium and shortening T1 relaxation. This results in elevation of the signal intensity on T1-weighted images. Of course, if the lesion is surrounded by fat, a fat-suppression technique must be included. Only chemical-shift based methods, such as frequency-selective presaturation or phase contrast (e.g. Dixon) are applicable, however, since STIR nulls fat due to its short T1, and would tend also to suppress tissues in which T1 was shortened by Gd-DTPA (See "Advances in Musculoskeletal MRI" for a more detailed discussion of the limitations and potential pitfalls associated with fat suppression techniques). Gd-DTPA is helpful in differentiating hematomas from liposarcomas or other neoplasms, as the former will only rim-enhance, while neoplasms will enhance centrally as well. Simple cysts and abscesses also do not enhance centrally. However, it is important

to remember that fat suppression alone will tend to increase the relative signal intensity of water-containing structures due to rescaling of their signal intensities by the scanner, so that a pre-Gd-DTPA image with fat-suppression should also be obtained for comparison.

SURGICAL STAGING

MRI has replaced CT as the method of choice for preoperative staging of soft-tissue tumors. Based on a modification of the GTNM (Grade, Tumor, Node, Metastasis) system [1], current surgical staging describes lesions in terms of *grade* (G0-G2: based on combined histological and radiological appearance), *site* (T0: lesion confined to its capsule; T1: extracapsular but within the compartment of origin and bounded by natural barriers (e.g. bone, fascia, cartilage); T2: extracompartmental extension or lack of barriers to extension in the compartment of origin) and *metastasis* (M0-M1). In addition, it is important to note the relationship of the lesion to adjacent vessels, nerves and joints, as this impacts on the applicability of limb-sparing surgery. While the proximity of a lesion to local joints and vessels is usually well delineated by MRI, excluding tumoral involvement of even major nerves, such as the sciatic, can be extremely tenuous. In these cases, high-resolution imaging (e.g. T2-weighted *fast* spin echo with 3 mm slice thickness and 512x384 matrix, or 3D gradient-echo with 1-2 mm consecutive slices and high-resolution matrix) is imperative. Finally, it is important that MRI staging be done prior to tumor biopsy, as bleeding and edema within the tumor and adjacent soft tissues can result in overestimation of the surgical stage, as well as confusion about the histological identity of the tumor.

BENIGN VS MALIGNANT

There is some debate over whether MRI can reliably predict the benignity of soft-tissue lesions. In a recent study by Berquist, et al. [2] of 95 consecutive tumors, specificity and negative predictive value averaged 90% and 94% respectively among three reviewers. Signs of benignity included smooth margination, small size and signal homogeneity, particularly on T2-weighted sequences, while malignant lesions were generally large, irregular and heterogeneous. Despite the encouraging results of this study, a 10% false-positive rate

is still too high to obviate biopsy in deciding the management of a potentially malignant lesion, and other studies suggest that even this degree of specificity may even be optimistic [3,4]. However, all these studies sought to define general criteria of malignancy and benignity applicable to all soft-tissue tumors of the musculoskeletal system. Quite a different experimental design would be required to test the discriminative power of MRI for determining the malignant potential of individual histological types. A simple cyst, for example, can often be diagnosed by MRI with virtually 100% confidence, and in these instances, the patient can be assured of the benignity of the lesion. The same can be said for typically appearing muscular hemangiomas or classical soft-tissue lipomas. So that while in general, the larger and more heterogeneous a tumor appears, the greater should be the concern of malignancy, in many instances, both the histology and benignity of a particular soft-tissue tumor can be determined with confidence.

SPECIFIC MRI APPEARANCES

MRI of the majority of soft-tissue tumors and tumor-like conditions is dominated by increased amounts of mobile water protons and therefore slow T1 recovery and slow T2 decay. This produces a nonspecific low signal intensity on T1-weighted images and high signal intensity on T2-weighted and STIR sequences. But, while the MRI appearance of many soft-tissue tumors is admittedly nonspecific, there are nevertheless a number of characteristic appearances that can narrow the differential diagnosis considerably, and some that are virtually pathognomonic of a particular histology. Lesion morphology, and growth behavior on follow-up examination are occasionally helpful, but the presence of unusual signal properties, such as rapid T1 recovery or rapid T2 decay, can be particularly useful in identifying the underlying histological makeup of a specific tumor.

Short-T1 Lesions: Substances that exhibit rapid T1 recovery on MRI include fat, methemoglobin, some proteinaceous fluids, and substances enhanced by Gd-DTPA. The vast majority of lesions that exhibit high signal intensity on T1-weighted images, however, contain either fat or hemorrhage. The most notable of these is also the most common soft-tissue tumor: the **benign lipoma** [5]. Derived from primitive mesenchyme, these tumors are composed of mature adipose tissue, and usually present

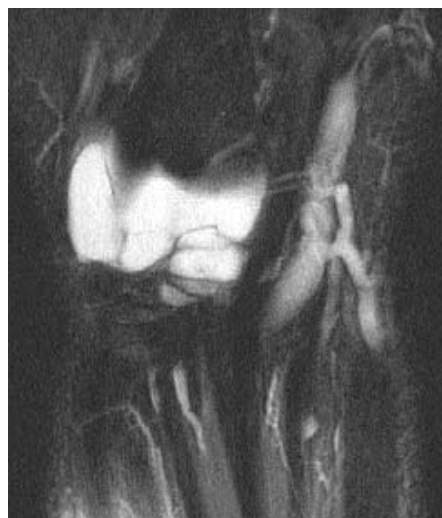
in the 5th and 6th decades. The majority are superficial and may be difficult to distinguish from adjacent normal subcutaneous adipose, particularly in obese patients. Most lipomas are solitary (95%), slightly lobulated and usually encapsulated. They are characteristically homogeneous on MRI; although, some contain other mesenchymal elements, usually fibrous connective tissue in the form of fine intralesional septations. Benign lipomas do not enhance with Gd-DTPA. Deep lipomas commonly arise in the retroperitoneum, and are more variable in shape. Lipomas that arise in skeletal muscle, tendon sheath and joint (discrete synovial lipoma, lipoma arborescens) or neural tissue (neural fibrolipoma) are occasionally referred to as heterotopic lipomas. Intramuscular lesions may have an infiltrative appearance, and may appear more aggressive.

Liposarcomas [5,6] also may contain mature adipose tissue, but are considerably more heterogeneous than their benign counterparts. Liposarcomas are among the most common soft-tissue sarcomas in adults, and typically present in the same age group as benign lipomas (5th and 6th decades). In general, the malignancy of liposarcomas varies inversely with the degree of differentiation (i.e. the amount of mature intralesional fat). The most common liposarcoma is the myxoid variant (50%), which demonstrates very little fat on MRI, and tends to appear intermediate in signal intensity and slightly heterogeneous, usually with a swirled pattern, on T1-weighted images. These tumors typically arise in the lower limbs, and enhance intensely with Gd-DTPA. They are extremely hyperintense on T2-weighted images, and may occasionally mimic cysts. Well-differentiated

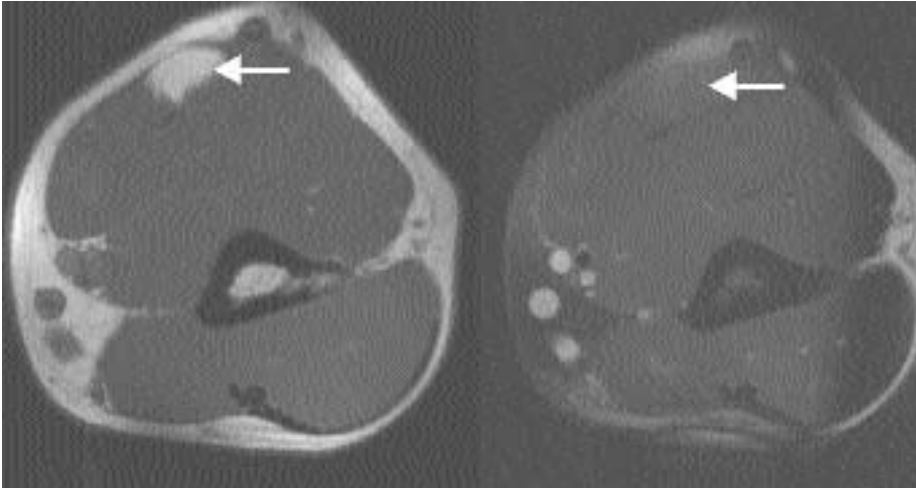
liposarcomas, on the other hand, contain predominantly fat, and can in rare cases mimic benign lipomas. These have been termed *atypical lipomas* in the extremities, and exhibit a propensity to recur locally, but do not metastasize. The same lesions in the retroperitoneum are simply called *well-differentiated liposarcomas*. Myxoid and well-differentiated liposarcomas carry significantly better prognoses than pleomorphic and dedifferentiated liposarcomas. The latter three most commonly arise in the retroperitoneum, while as stated above, myxoid liposarcoma is generally a tumor of the extremities. Since all groups of liposarcoma have a tendency toward local recurrence, follow-up MRI of the surgical bed is recommended 1 month postoperatively to serve as a baseline.

Hematomas can mimic liposarcomas since both methemoglobin and fat exhibit high signal intensity on T1-weighted sequences [7]. Most hematomas also display marked heterogeneity, with swirls of low signal intensity representing collections of deoxyhemoglobin or fresh blood from recurrent bleeding, interspersed among the high signal intensity methemoglobin. Poorly contained hematomas may in addition have an infiltrative appearance that can look highly aggressive. The presence or absence of a history of trauma is often unreliable as a criterion for distinguishing hematoma from liposarcoma. Hemorrhage within a friable neoplasm can result from only minor trauma, and may even obscure the neoplasm itself. While methemoglobin and fat both exhibit a short T1, T2-relaxation of extracellular methemoglobin is substantially longer than that of fat, so that the two can often be separated by comparing T1-weighted and T2-weighted images. Methemoglobin can also be differentiated from fat by chemical-shift based fat-suppression techniques, providing the fat suppression is adequately homogeneous (see *Advances in Musculoskeletal MRI*). STIR is not ideal for this purpose, as it may also suppress the methemoglobin, which has a short T1 similar to that of fat. Intravenous Gd-DTPA can also be helpful in differentiating hematomas from liposarcomas, since hematomas at a stage in which methemoglobin is still present will only show rim enhancement, while most of the nonfatty components of a liposarcoma enhance intensely.

Soft-tissue **hemangiomas** [5,8] can be cutaneous, subcutaneous, intramuscular or synovial. Superficial hemangiomas are often palpable or visible as a bluish discoloration of the skin, and as such, do not pose a significant diagnostic challenge. However, deep hemangiomas, such as those in



Fat Saturated T2 Coronal image of the wrist. Demonstrating a dorsal ganglion. This has the characteristics of a benign lesion.



T1 Weighted image demonstrating an intramuscular lipoma as an increased signal intensity mass (short T1).

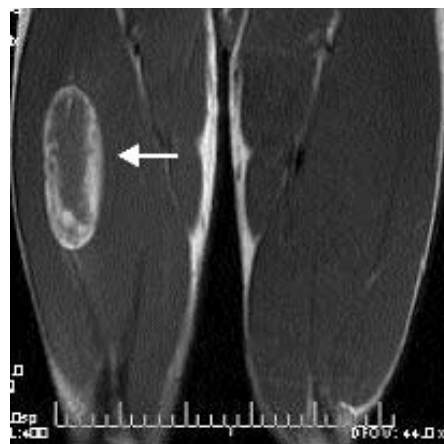
Fat saturated T2 weighted image showing that the lesion saturates proving its fat composition.

muscle, are difficult to diagnose clinically. Intramuscular hemangiomas are relatively rare (0.8% of all hemangiomas), and tend to arise in childhood or adolescence. Intramuscular hemangiomas also typically contain fat, sometimes so much so as to be virtually indistinguishable from lipomas. This is particularly true of cavernous (large vessels) hemangiomas, which tend to contain greater amounts of nonvascular elements than do capillary (small vessels) hemangiomas. While ambiguous forms of any soft-tissue tumor exist, the MRI appearance of intramuscular hemangiomas is frequently characteristic. Demonstration of a somewhat poorly marginated intramuscular mass composed of a dense collection of serpiginous, sometimes visibly branching, vascular channels lined by parallel arrays of fat is virtually pathognomonic for hemangioma. Vascular channels generally contain slow-flowing blood and thus exhibit high signal intensity on T2-weighted images and enhance following intravenous Gd-DTPA injection. Occasionally, the vascular channels are extremely large and sinusoidal, giving them a frond-like appearance. Phleboliths are frequently visible on plain radiography or CT.

Short-T2 Lesions: Substances that exhibit rapid T2 relaxation and therefore low signal intensity on T2-weighted sequences include collagen, deoxyhemoglobin and hemosiderin. Collagen shortens the T2 of local water protons by constraining them within its highly regular structure and thus promoting spin-spin interactions, while deoxyhemoglobin and hemosiderin shorten T2* via their paramagnetic effects. In most of these cases, T2 decay is sufficiently rapid

that even relatively short echo times employed in T1-weighted imaging come too late to capture any signal from these tissues. Collections of calcium and gas are also dark on T2-weighted (as well as T1-weighted) images, but this is because of their low proton density rather than a short T2. The presence of calcium or gas within a lesion can be excluded by CT. All other tumors exhibiting a low signal intensity on T2-weighted images must therefore be either fibrous, hemorrhagic or hemosiderin containing.

One tumor that contains a significant amount of collagen is the soft-tissue **desmoid**, or aggressive fibromatosis as it is sometimes called [9]. These lesions are benign with respect to their potential to metastasize, but have a high propensity for recurrence (25%-65%) [10] and local invasion. 10% of desmoid tumors are



Post gadolinium T1 weighted coronal image demonstrating a rim enhancing fluid intensity lesion in a patient with a history of direct trauma to the anterior thigh consistent with a hematoma.

multifocal at presentation [11]. Deaths have resulted from the unrelenting advance of this benign neoplasm. The MRI appearance of desmoid tumors reflects both their high collagen content and aggressive nature. Lesions typically exhibit marked heterogeneity, with large areas of low signal intensity fibrosis on T1- and T2-weighted images interspersed between more cellular regions that demonstrate a higher signal intensity on T2-weighted images. Lesion margins are characteristically irregular and invasive, and often encase neurovascular structures and bone. Because of this "malignant" appearance, desmoid tumors may be difficult to distinguish from **fibrosarcomas**; although the latter tend to exhibit greater cellularity. Fibrosarcomas arise in children, usually before the age of 2 years, as well as in adults, and have a tendency toward late recurrence, so that protracted follow up is recommended.

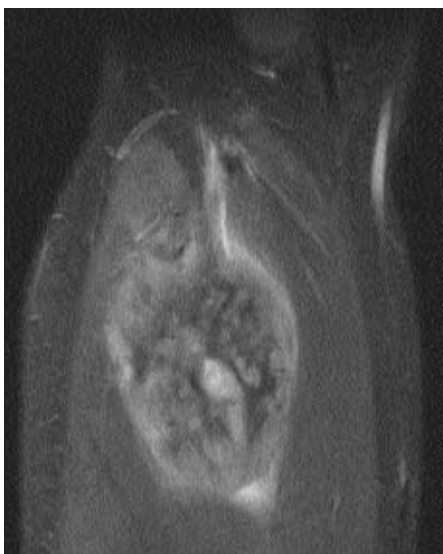
Malignant fibrous histiocytoma (MFH) is another tumor that can present with intralesional foci of low signal intensity fibrosis, but typically contains abundant cellular material that appears bright on T2-weighted images. Finally, **myositis ossificans (MO)**, which is not, of course, a neoplasm at all, can have a highly aggressive and heterogeneous appearance, with low signal intensity areas (on both T1-W and T2-W) representing calcification/ossification, fibrosis and hemosiderin, and a high signal intensity core of proliferating fibroblasts and myoblasts in a myxoid stroma [12]. The characteristic zonal appearance of MO, with peripheral ossification and central cellularity, can be virtually pathognomonic. Occasionally, fatty marrow forms in the peripheral areas of ossification, raising the signal intensity on T1-weighted MRI. Often, no specific traumatic incident is recalled.

Recurrent desmoid tumors tend to have less cellular material and can be extremely difficult to differentiate from postsurgical fibrosis [13,9]. The presence of significant mass effect is suggestive but not definitive [9]. For this reason, it is important to obtain postoperative baseline studies in patients with these neoplasms.

Other tumors that exhibit rapid T2-decay due to collagen include **peripheral nerve-sheath tumors (PNST)**, such as benign schwannomas (neurilemmoma, neurinoma) and neurofibromas, and the malignant PNST (malignant schwannoma, neurogenic sarcoma, nerve-sheath fibrosarcoma). Multiple tumors suggest neurofibromatosis, but solitary lesions can also be found in patients without neurofibromatosis. Most solitary neurofibromas arise in small cutaneous nerves, and are less than 5 cm [14]. In

neurofibromatosis, these tumors tend to be larger and involve deep visceral nerves in addition to cutaneous nerves. Large, irregular plexiform neurofibromas are virtually pathognomonic for neurofibromatosis. Malignant transformation of neurofibromas is also most common in patients with neurofibromatosis. Peripheral schwannomas and malignant PNST tend to involve major nerve trunks, such as the sciatic nerve or brachial or sacral plexuses. Both malignant and benign PNSTs are typically smoothly margined and ovoid. They are relatively homogeneous and intermediate in signal intensity on T1-weighted images, but often (>50%) heterogeneous on T2-weighted images due to the presence of central fibrosis, usually in a whorled or stellate configuration, surrounded by high signal intensity myxomatous material [15]. Rarely, fatty atrophy of the ipsilateral muscle suggests the diagnosis [16]. Since benign and malignant PNSTs cannot be distinguished by MRI, surgical excision or liberal biopsy is required.

Giant cell tumor of the tendon sheath (GCTTS) [17,18] also exhibits low signal intensity on T2-weighted images, but in addition to having a fibrous stroma, this tumor contains a benign proliferation of hemosiderin-laden histiocytes and giant cells. These tumors are closely related to pigmented villonodular synovitis, except that instead of involving the synovium of large joints, such as the knee, GCTTS arise from the synovial lining of tendon sheaths, most commonly the fingers and toes. Clinically, GCTTS presents as a slow growing noncalcified mass in the adult. On MRI, the lesions are well margined, homogeneous and low in signal intensity on both T1-weighted and T2-weighted images. An



T2 weighted fat saturated image of a desmoid tumor.

adjacent tendon is invariably seen. Pressure erosion of the adjacent bone often occurs. The appearance is distinctively nonaggressive in contrast to that of desmoid tumors.

Pigmented villonodular synovitis (PVNS) is generally a more diffuse, nodular process involving the synovium of a single joint. The MRI appearance is dominated by an abundance of hemosiderin in these neoplasms, and can be indistinguishable from hemophilic arthropathy due to recurrent hemarthrosis. The appearance must also be distinguished from **synovial osteochondromatosis**. Low signal intensity in this tumor, however, is due to synovial calcification and ossification rather than fibrosis. Occasionally, fatty marrow develops within the osteochondral lesions producing foci of high signal intensity on T1-weighted images.

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