Introduction

Intramuscular tumor- and tumorlike lesions can represent a diagnostic challenge to the general radiologist. There is a myriad of soft tissue lesions with variable biological behaviour ranging from benign to malignant that may involve skeletal muscles [1]. Magnetic Resonance Imaging (MRI) is the imaging modality of choice for defining the precise extent of a soft tissue lesion within skeletal muscles [2] and for characterization. Benign intramuscular tumor- or tumorlike lesions often have specific imaging features that aid confident diagnosis [1]. MR characteristics of malignant soft tissue tumors arising within the skeletal muscles are nonspecific. Biopsy is therefore required for definitive histological diagnosis and assessment of prognosis. Indeterminate intramuscular lesions on imaging should also be referred for biopsy [2]. This pictorial-essay will focus on the role of MRI in intramuscular tumors that show histologically skeletal muscle differentiation, including benign, malignant and some tumor mimics.

Imaging features of intramuscular tumors

The following MR imaging features may suggest malignancy in soft tissue tumors, regardless of their histological origin [1,3]: Large volume (any lesion exceeding 3 cm), ill-defined margins, lesion inhomogeneity on all pulse sequences, intralesional haemorrhage and necrosis, extensive and peripheral enhancement pattern (with papillary projections) on static contrast examination, rapid enhancement with a steep slope on dynamic contrast examination, extracompartmental extension, and invasion into adjacent bones and neurovascular bundles. Histological confirmation remains mandatory when there is any suspicion of malignancy [1-3]. Imaging should always precede the biopsy, as changes caused by the biopsy like blood, edema and granulation tissue can be difficult to differentiate from the tumor or the peritumoral reactive zone [2,3].

Tumors with skeletal muscle differentiation

Tumors with skeletal muscle differentiation can be benign or malignant lesions [4]. Malignant tumors with histologically myogenic differentiation are more frequent than their benign counterpart [3,5,6].

Rhabdomyosarcomas (▶**Fig. 1**) are the most common malignant soft tissue sarcomas in children and adolescents [4], encountered in five subtypes i.e. embryonal rhabdomyosarcoma, alveolar rhabdomyosarcoma, pleomorphic rhabdomyosarcoma, spindle cell / sclerosing

rhabdomyosarcoma and ectomesenchymoma [4]. MR imaging features of rhabdomyosarcomata are nonspecific (Table 1) [1,3] warranting clinical correlation and a low threshold for biopsy.

Rhabdomyoma is the benign counterpart of rhabdomyosarcoma [4]. Extra-cardiac rhabdomyoma are divided in three subtypes i.e. fetal rhabdomyoma, adult rhabdomyoma and genital rhabdomyoma [4]. Adult rhabdomyoma is the most common subtype, occurs most frequently in the head and neck and only rarely involves the extremities. It most often occurs in middle-aged men [4]. The least frequent fetal subtype has a predilection for the postauricular area, with a mean age of 2 years [4]. The genital subtype arises in the genitalia, most commonly in the vagina in middle-aged women [4]. MRI features are summarized in Table 1 [1,3].

Other benign soft tissue tumors with intramuscular location

Intramuscular lipoma (▶**Fig. 2**) is a benign neoplasm composed of mature adipocytes [4]. Intramuscular lipomas are most frequently located in the thigh [4], the shoulder, trunk and upper arm [3]. MR imaging features are summarized in table 1 [1,3]. The most useful diagnostic criteria on MRI to differentiate between a simple lipoma from a liposarcoma are based on location, size, shape, contents and the enhancement pattern [1,3]. A simple lipoma is typically located in the subcutaneous fat, measures less than 5cm, has a round, oval or fusiform shape, consists of a homogeneous fat-like content with or without thin internal (fibromuscular) septa of less than 2mm, and does not enhance [1,3]. Atypical lipomatous tumour or liposarcoma typically are deeper than the subcutaneous adipose layer (i.e. intramuscular, intermuscular with invasion of fascia or retroperitoneal), measure more than 5cm, have a multilobulated shape, consist of an inhomogeneous content with intralesional non-fat containing soft tissue components or septa thicker than 2mm, and contain intralesional foci of enhancement, calcification, invasion of surrounding structures and perilesional oedema [1,3]. Other criteria include rapid change in size, the presence of necrotic foci, change in the clinical examination with more rubbery consistency, tethering to surrounding structures or new onset pain [1,3]. According to the histological composition of the non-lipomatous components within the lesion, malignant adipocytic tumors can be subdivided in myxoid, pleomorphic and dedifferentiated liposarcoma [3]. Myxoid components are of high signal on T2-weighted images [3]. Often malignant adipocytic tumors cannot be differentiated from other intramuscular sarcomas owing to the small amount of fat on imaging [3].

It should be emphasized that intermingled muscle fibers are common in intramuscular lipomas. They should not be misinterpreted with malignant foci. Intermuscular lipoma are located between the bellies of adjacent muscles which may be displaced. They do not contain intermingled muscle fibers.

Intramuscular myxoma (►**Fig. 3**) is histologically characterized by the presence of an abundant, hypovascular myxoid stroma [4]. Intramuscular myxomas are most frequently located in the large muscles of the thigh, shoulder, buttock and upper arm of middle-aged individuals [4]. MR imaging features are summarized in table 1 [1,3,4].

Extra-abdominal desmoid fibromatosis (►**Fig. 4**) is a locally aggressive, deep-seated myofibroblastic neoplasm with infiltrative but non-metastasizing propensity for local recurrence [4]. The term "desmoid" refers to a band-like or tendon-like lesion [1,3]. Extra-abdominal desmoid fibromatosis is most frequently located in the deep compartments of the extremities [4]. MR imaging features are summarized in table 1 [1,3,4].

Intramuscular vascular anomaly (►**Fig. 5**) comprises a heterogeneous spectrum of vascular lesions encompassing either low-flow (venous, lymphatic, capillary or a combination) or high flow malformations (arteriovenous malformations) [1,3,4,7]. MR imaging features are summarized in table 1 [1,3,4].

Tumor mimics arising in skeletal muscle

Myositis ossificans (MO) (►**Fig. 6-8**) is benign heterotopic bone formation typically occurring within skeletal muscle [1,3,8]. A history of trauma is only present in about 60% of cases [1,3,8]. MO shows a typical evolution over time and imaging findings are time dependent [1,3,8,9]. In the early, *active stage* (less than 2 to 4 weeks), the patient presents with pain, tenderness and soft tissue swelling [1,3]. Subtle peripheral calcifications may appear after 7 to 10 days [1,3]. CT shows a nonspecific soft tissue swelling without calcifications (►**Fig. 6**). In the *subacute, intermediate stage* (4 weeks to 6 months) a well-defined peripheral calcification and coarser central calcification appear [1,3]. Peripheral calcifications are seen on CT in this stage (►**Fig. 7**). In the *chronic, mature stage* (more than 6 months) the calcification-ossification front further develops following a 'zoning' pattern, with

lamellar bone at the periphery proceeding towards the center, and the lesion becomes densely calcified or ossified on plain films and CT (▶**Fig. 8**) [1,3].
MR imaging features of MO are summarized in table 1 [1,3].

Focal myositis is a rare, usually self-limiting, focal inflammatory pseudotumor [1,3,10]. Focal myositis typically presents as a painful intramuscular mass usually limited to one muscle predominantly in a lower limb, which can grow rapidly in a few weeks. It can also affect muscle groups [1,3,10]. MR imaging features are summarized in table 1 [1,3,9].

Calcifying myonecrosis is a rare posttraumatic condition characterized by latent formation of a dystrophic calcified mass with central liquefaction and peripheral calcifications [1,3,8]. Calcifying myonecrosis typically presents as a slowly enlarging, usually painful soft tissue mass involving one or more compartments of the lower leg, most frequently the anterior compartment, many years (i.e. 10 to 64 years) after the initial injury [1,3,8]. MR imaging features are summarized in table 1 [1,3,8]. The mass may enlarge slowly because of repeated intralesional hemorrhage over time [1,3,8]. On plain radiographs or CT, the diagnosis is much more straightforward than on MRI by demonstration of characteristic plaque-like calcifications in the long axis of the muscles (▶**Fig. 10**).

Intramuscular abscess(es) is an unusual presentation, albeit seen fulminant infection, in immunocompromised patients, in muscles adjacent to foci of intraosseous osteomyelitis or in adults following intramuscular injection of medications (steroids for recreational sports being the most common presentation). MR imaging features are summarized in table 1 [1,3] An additional tool to differentiate an intramuscular abscess from an intramuscular malignant tumor with central necrosis is diffusion weighted imaging. Diffusion restriction is typically seen in thick pus collections, whereas diffusion restriction is not a characteristic feature of tumor necrosis [1,3]. Similar to MRI, CT shows peripheral enhancement and may show the presence of intralesional air bubbles (▶**Fig. 11**).

Discussion

In this pictorial-essay we discussed MRI features of intramuscular tumors and tumorlike conditions. It is important to correlate the MRI findings with all available information including demographic characteristics (particularly age), clinical history, and prior imaging

including all other imaging modalities when available. Conventional radiography or CT, although not very sensitive, may demonstrate intralesional calcifications or gas bubbles which could be missed on MRI. Other helpful characteristics to narrow down the differential diagnosis include patient's age, preferential locations, multiplicity, imaging characteristics on standard MR sequences, enhancement patterns, and morphological signs like 'bunch of grapes', fat rim, fluid-fluid levels, and signal voids (i.e. high flow, calcification, ossification, gas bubbles). In the early stages of myositis ossificans, one should abstain from performing a biopsy as this may result in an erroneous diagnosis of soft tissue sarcoma [8]. In case of suspicion of malignancy or indeterminate lesions, image-guided biopsies should be performed, in a tertiary specialist tumor center to confirm the diagnosis and assess prognosis thereby enabling personalised medical care to each patient to ensure a favourable outcome. The biopsy should be performed by a trained radiologist in musculoskeletal tumors or by a surgeon involved in a multidisciplinary tumor group after multidisciplinary discussion [2].

Conclusion

MRI is the preferred imaging technique to define the precise extent of a soft tissue tumor located in a skeletal muscle, and to further characterize the lesion. Benign intramuscular soft tissue lesions have often signal characteristics or typical morphological characteristics that guide the radiologists towards making a confident and accurate diagnosis. Nonetheless, malignant intramuscular tumors with myogenic differentiation cannot be reliably distinguished from other histological groups of soft tissue tumors based solely on the MRI findings. Whilst MR is the imaging modality of choice, there is an ancillary role for plain radiographs and / or CT. Discussion of imaging and correlation with the clinical presentation in a specialised multidisciplinary tumor board improves patients outcomes.

References

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Table 1

Summary of MR features

Diagnosis	MR features
Rhabdomyosarcoma	Isointense compared to muscle on T1-weighted images (WI) and heterogeneous hyperintense on T2-WI, often with necrotic foci. Marked enhancement is the rule.
Rhabdomyoma	Well-delineated mass isointense or hyperintense compared to muscle on T1-WIand T2-WI. Intralesional haemorrhage and central necrosis are rarely seen. Marked enhancement either homogeneous or heterogeneous.
Intramuscular lipoma	Similar signal characteristics as subcutaneous fat on all pulse sequences. Fat-suppression techniques show homogeneous suppression. Minor internal septa less than 2mm and a low signal intensity capsule may be seen. In addition, intermingled muscle fibers that are isointense with normal muscle on all pulse sequences should not be misinterpreted as sign of malignancy. Except for the peripheral fibrous capsule or the subtle internal septa, there is no contrast enhancement.

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Intramuscular myxoma	Typically very low signal intensity compared to muscle (but could be isointense as well) on T1-WI and a bright signal intensity on T2-WI(i.e. higher than the signal intensity of fat). A small rim with fat signal may be seen corresponding to focal atrophy of surrounding muscle. Perilesional strands of hyperintense signal on T2-WI may correspond either to leakage of myxoid tissue or edema. There may be moderate, central enhancement giving it a 'smoke'-like appearance. Other patterns of enhancement are peripheral enhancement, peripheral and patchy internal enhancement, and peripheral and linear internal enhancement.
Extra-abdominal desmoid fibromatosis	Well-demarcated or ill-defined with variable signal intensity reflecting the degree of cellularity and the degree of fibrous stroma. Hypocellular and collagen-rich areas are hypointense on T2-WI and T1- WI and more cellular areas with large extracellular spaces or myxoid areas are hyperintense on T2-WI. There is typically heterogeneous moderate to marked enhancement. Hypocellular, collagenized bands do not enhance and are therefore accentuated at postcontrast MR images.
Intramuscular vascular anomaly	Hyperintense signal intensity on T2-WI and isointense signal intensity compared to muscle on T1-WI. Frequently multilobular resembling a "bunch of grapes". A peripheral fat rim phenomenon is a typical feature. Fluid-fluid levels may be seen. High-flow lesions may show signal voids on all pulse sequences and show serpiginous, marked enhancement. Low-flow venous lesions are associated with late enhancement. Intralesional phleboliths present as round to oval signal voids on MRI and when verified on plain radiographs or CT confirm the diagnosis of a vascular anomaly.
Myositis ossificans; early, active stage	Focal mass with an isointense to slightly hyperintense signal intensity compared to muscle on T1-WI and a hyperintense signal intensity on T2-WI. Enhancement varies from peripheral rim to a more diffuse pattern. Surrounding muscle fibers are usually markedly edematous.
Myositis ossificans; subacute, intermediate stage	Peripheral rim of low signal intensity on all pulse sequences, corresponding to calcifications. The signal intensity of the center of the lesion varies according to the degree of calcification. Perilesional edema gradually decreases after four weeks.

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Myositis ossificans; chronic, mature stage	Low signal intensity on all pulse sequences. However, areas isointense to normal bone marrow may be seen due to intralesional bone marrow formation. Perilesional edema is absent.
Focal myositis	Focal enlargement of a muscle with typical sparing of the internal muscle fibers and a heterogeneous increased signal intensity on T2-WI. Imaging after administration of intravenous gadolinium contrast is of limited value because the enhancement is variable.
Calcifying myonecrosis	Peripherally located plaque-like calcifications have a low signal intensity on both T1-WI and T2-WI. On T2-WI, the mass often has a heterogeneous signal intensity, with areas of hyperintense signal intensity consistent with central liquefaction, while other areas demonstrate an isointense signal intensity compared to muscle. On T1-WI, the central fluid region has a homogeneous low signal intensity. Peripheral enhancement may be seen due to anastomosing small blood vessels around the mass.
Intramuscular abscess	Low to isointense signal intensity compared to muscle on T1-WI and hyperintense signal intensity on T2-WI. There typically is peripheral rim enhancement. Intralesional foci with a low signal representing intralesional gas bubbles may be seen, which can be confirmed on CT.

Captions to figures
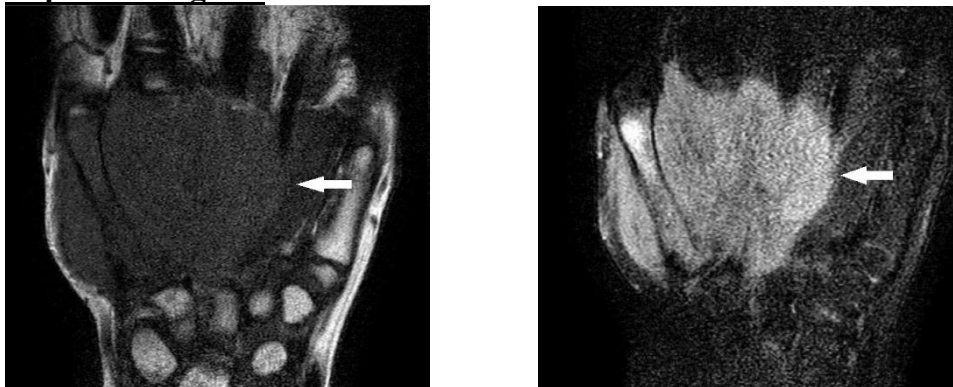
►Fig. 1. Rhabdomyosarcoma of the left hand in a 2-old-year man.
Coronal images show an expansile, well-defined mass centered on metacarpal 2 to 5 (arrow), isointense to muscle on T1-weighted image (a) and heterogeneously hyperintense on T2-weighted images with fat suppression (b).
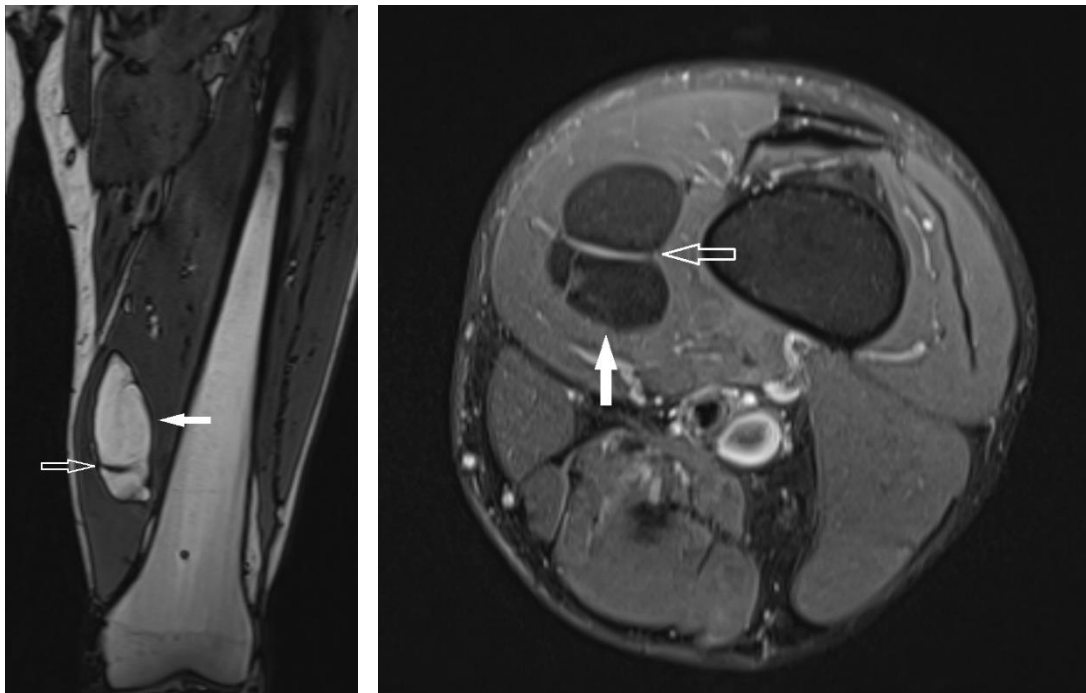
►Fig. 2.

Intramuscular lipoma in the left vastus medialis muscle in a 79-old-year man.
Coronal T1-weighted image (a) and axial T2-weighted image with fat suppression (b) show a well-delineated mass (full arrow), isointense to subcutaneous fat on both sequences. A horizontal intralesional strand is present (void arrow), isointense to muscle tissue, in accordance with a focus of residual muscle tissue.
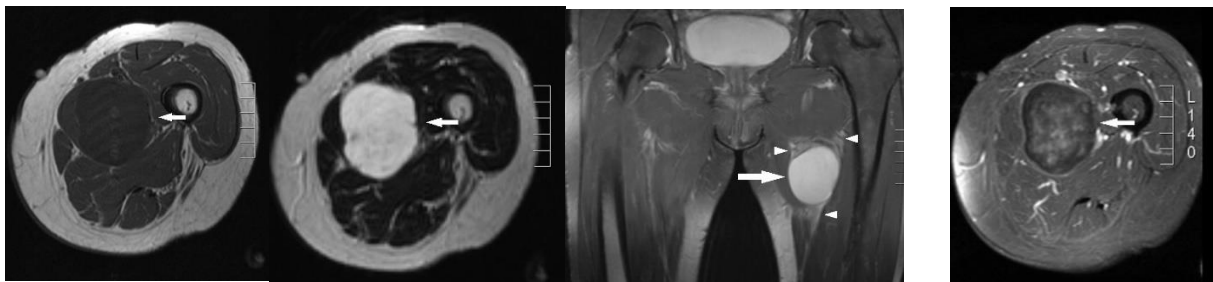

►Fig. 3. Intramuscular myxoma in the left thigh in a 76-year-old woman.
Axial T1-weighted image (a) shows an expansile, well-defined lesion (arrow) in the adductor magnus muscle, hypointense to muscle and hyperintense to muscle on the axial T2-weighted images (b).
Coronal T2-weighted image (c) shows perilesional strands of hyperintense signal on T2-weighted images, seen at the superior and inferior pole of the lesion, in keeping with edema or due to leakage of myxoid tissue through an incomplete capsule (arrowheads).
Axial image after gadolinium contrast administration (d) shows moderate, central enhancement giving it a 'smoke'-like appearance.
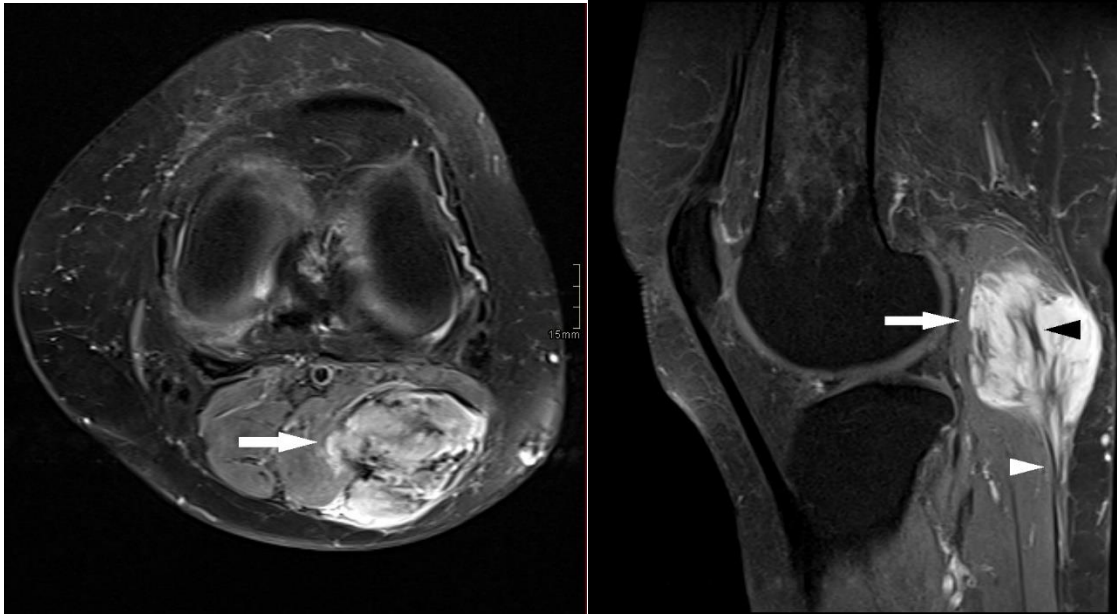
►Fig. 4. Desmoid type fibromatosis of the left knee in a 57-year-old woman.
Axial T2-weighted image (a) shows a well-defined lesion, heterogeneous T2 hyperintense
mass centered on the intramuscular aponeurosis of the lateral gastrocnemius muscle.
Sagittal Fatsuppressed T1-weighted image after gadolinium contrast administration (b) shows
a heterogeneous moderate to marked enhancement with some intralesional strands that do not
enhance (black arrowhead): hypocellular, collagenized bands. Note the tail-like extension of
the lesion at the lower pole (white arrowhead).
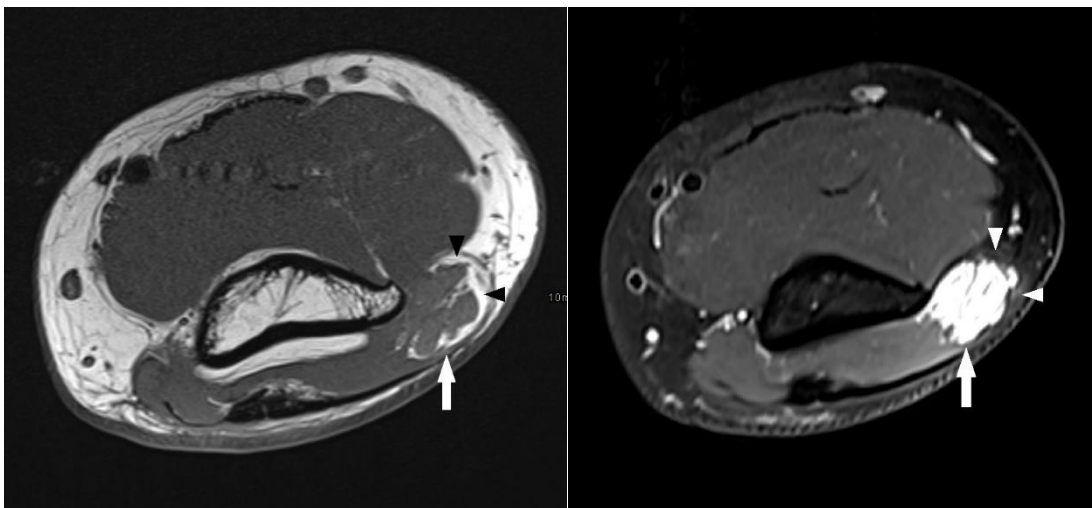
►Fig 5. Intramuscular vascular anomaly of the left elbow in an 38-year-old man.
Axial T1-weighted image (a) shows a lesion at the radial aspect of the triceps brachii muscle,
predominantly isointense to muscle (arrow), with a surrounded by a peripheral rim of fatty
tissue (arrowheads).
Axial T2-weighted image with fat suppression shows that most of the lesion is hyperintense,
except for the fatty peripheral rim which is suppressed similar to subcutaneous fat
(arrowheads).
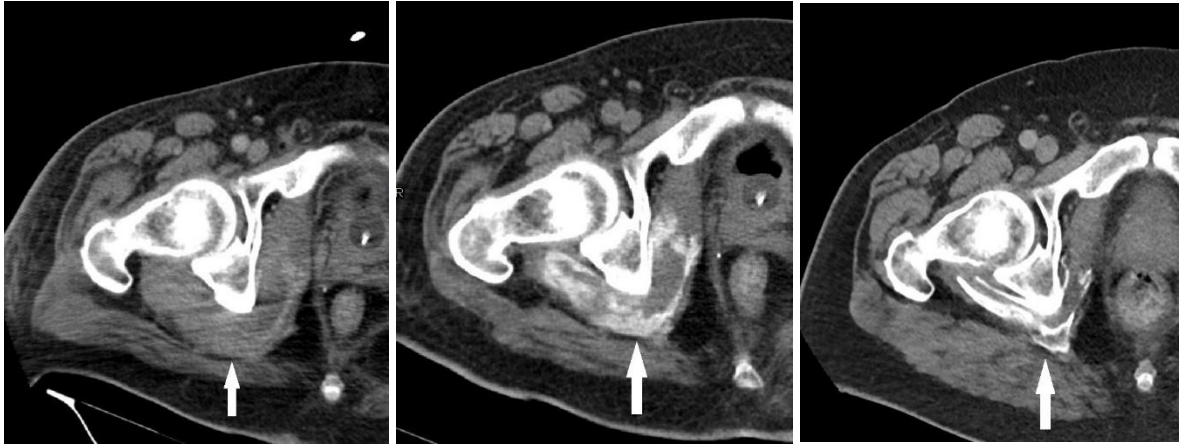
►Fig. 6. Myositis ossificans of the right obturator internus muscle in a 53-year-old man.
Axial CT image (a) shows a nonspecific soft tissue swelling of the right obturator internus muscle (arrow): early, active stage.
Axial CT image (b) shows peripheral calcifications in the lesion (arrow): subacute stage (follow-up CT 8 days later).
Axial CT image (c) shows mature ossification of the right obturator internus muscle (arrow): chronic, mature stage (follow-up CT 3 years later).

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►Fig. 7. Focal myositis of the left foot in a 44-year-old woman.
Sagittal T2-weighted image with fat suppression shows focal enlargement and hyperintensity of the dorsal interosseous muscle of the second webspace with typical sparing of the internal muscle fibers.

►Fig. 8. Calcifying myonecrosis of the left forearm in a 20-year-old male.
Oblique lateral radiograph shows plaque-like calcifications at the extensor side of the forearm
(a) which are confirmed on the coronal CT image (b).

►Fig. 9. Bilateral intramuscular abscesses of the thigh in a 55-year-old man with sepsis.
Axial contrast-enhanced CT image shows bilateral lesions within the quadriceps muscles.
There are intralesional air bubbles (arrowhead) on the right side and rim enhancement of the
left side (void arrows).