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MR imaging of skeletal muscle signal alterations: Systematic approach to evaluation

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ABSTRACT

Muscle edema or edema-like signal alterations are commonly encountered findings in musculoskeletal magnetic resonance (MR) imaging. Although such signal alterations are very sensitive for detection of the underlying muscle pathology, these are often non-specific findings. Encompassing knowledge of their typical clinical presentations, characteristic appearances and patterns of muscle signal alterations and following a systematic approach towards their assessment, a reader can effectively narrow down the differential diagnosis. This article outlines the role of conventional imaging and advanced anatomic and functional musculoskeletal MR imaging techniques in the evaluation of various muscle disorders and presents a systematic approach towards their diagnosis and management.

1. Introduction

Edema or edema-like signal alterations of the skeletal muscle are very sensitive but non-specific findings in musculoskeletal magnetic resonance (MR) imaging [1]. Various causes include trauma, infection, ischemia, myonecrosis, denervation, myopathy, and treatment-related response, all of which can produce similar appearances on fluid sensitive imaging and increased WBC and serum CPK levels. Knowledge of the presenting clinical features, characteristic imaging appearances and patterns of muscle signal alterations and following a systematic approach towards their assessment can help narrow down the differential diagnosis. In this article, we will review the MR imaging appearances of various conditions that result in muscle edema or edema-like signal alterations on conventional MR imaging techniques (Table 1). A systematic approach towards differentiation of various entities will be illustrated. We will also discuss role of recently introduced advanced imaging sequences, such as chemical shift imaging, diffusion-weighted imaging, perfusion imaging and MR neurography with review of the relevant literature.

2. MR imaging-technical considerations

MR imaging for suspected muscle disorder is commonly performed using conventional T1W and T2W sequences and fat suppressed fluid sensitive imaging (i.e. STIR, short tau inversion recovery or fat suppressed T2W technique). Intravenous gadolinium is added to the protocol based on institutional preference, especially if there is suspicion of mass lesion, infarction or infection [2]. The recently applied advanced imaging includes chemical shift imaging (CSI), diffusion weighted imaging/diffusion tensor imaging (DWI/DTI), perfusion imaging, and MR neurography. CSI is a gradient echo based fast sequence that allows in- and out-of phase maps based on fat-water frequency shifts. It is useful in finding hemorrhage and microscopic fat [3]. Recently, Dixon based T2W imaging sequence has become available, which produces 4 maps- water, fat, in- and out-phase maps. Dixon quantitative imaging also allows automated computation of muscle fat fraction [4]. The relative utility and role of different MR pulse sequences is highlighted in Table 2. DWI is a noninvasive method used to measure the Brownian motion of water molecules in the adjacent microscopic environment. Apparent diffusion coefficient (ADC) maps, obtained by repeating the sequence with different b values, quantify the

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Table 1
Differential considerations of muscle edema or edema-like signal alterations on conventional MR imaging techniques.

Trauma	Infection and tumor	Ischemia and myonecrosis	Denervation	Disuse atrophy	Myopathy	Iatrogenic causes
Peripheral muscle strain – Grade I – Grade II – Grade III	Pyogenic	Diabetes	Nerve injury	Patchy	Polymyositis	Radiation therapy
Myotendinous strain – Grade I – Grade II – Grade III	Viral	Thromoembolic	Inflammatory neuritis e.g., parsonage turner syndrome poliomyelitis	Diffuse	Dermato-myositis	Chemotherapy
Muscle Laceration/contusion	Fungal	Rhabdomyolysis	Compressive neuropathy		Inclusion-body myositis	Surgery
Compartment syndrome	Parasitic	Drugs	Charcot-Marie-Tooth disease		Systemic connective tissue disorders	
Delayed onset Muscle soreness	Chronic granulomatous disease – TB – Sarcoidosis	Sickle cell crisis	Chronic inflammatory demyelinating polyneuropathy		Paraneoplastic	
Superimposed rhabdomyolysis	Tumor – Primary – Secondary	Compartment syndrome	Multifocal motor neuropathy			

Table 2
MR pulse sequences used for detection of muscle edema.

MR sequence	Primary purpose
T1W	Anatomy, fatty infiltration, muscle atrophy, hemorrhage
T2W	Anatomy and muscle edema or edema-like signal, fascial edema
STIR/fat suppressed T2W	Muscle edema or edema-like signal, fascial edema
Fat Sat T1W	Muscle hemorrhage
Post contrast T1W	Rim enhancement in infection, hematoma or myonecrosis, solid or central enhancement of tumor, strandy enhancement in muscle strain and post-treatment changes
Chemical shift imaging	Fatty infiltration or hemorrhage
Dixon based T2W	Fat map—anatomy, fatty infiltration, muscle atrophy Water map—muscle edema or edema-like signal, fascial edema In- and out-of phase maps- Fatty infiltration or hemorrhage
DWI	Muscle edema or edema-like signal, myonecrosis, tumors, infection, neuropathy
Diffusion tensor imaging	Fractional anisotropy (FA) and tractography of the muscle fibers and nerves
Perfusion imaging	Compartment syndrome, ischemia, myonecrosis and tumors
MR neurography	Neuropathy, differentiation of neuropathy from myopathy

observed signal loss related to particle motion. DWI is sensitive to muscle signal alterations and enhances conspicuity of the lesions. It also provides quantitative maps of average ADC, mono- or bi-exponential ADC, 10th percentile ADC and kurtosis factor, and there is ongoing research to find which of these methods is most valuable in muscle pathologies [5,6]. DTI in addition, provides fractional anisotropy (FA) and tractography of the muscle fibers [7]. Perfusion imaging can be performed with and without intravenous contrast, i.e. with arterial spin labeling. It provides various quantitative parameters, such as area under the curve, k-trans, permeability, time to peak and total blood volume [8,9]. It has potential usefulness in tumor imaging, assessing active inflammation and muscle ischemia [10]. Finally, MR neurography (MRN) allows 3 dimensional nerve evaluation in the same setting as muscle evaluation by application of nerve selective and non-nerve selective imaging sequences and diffusion tensor imaging [11–14]. It is therefore helpful in differentiating myopathy from neuropathy conditions as further discussed in the relevant section.

3. Normal muscle and nerve MR imaging appearances

Normal skeletal muscles appear symmetrical in size and show intermediate signal intensity. These demonstrate smooth convex borders with minimal interspersed fat, which is best seen on T1W images, in a linear or feathery distribution (Fig. 1) [15]. There is similar, minimal loss of normal muscle signal on CSI or Dixon out of phase images [16]. In authors' experience, the loss of signal is more pronounced in asymptomatic adult subjects in the soleus, gastrocnemius, gluteus maximus, pronator quadratus and semimembranosus muscles (Fig. 2) [17]. The muscles show uniform dark appearance on DWI trace images with ADC of $1.4–1.6 \times 10^{-3}$ mm^2/s and symmetrical perfusion on intravenous contrast images [18,19] (Fig. 1). Normal peripheral nerves on T2-weighted images appear as isointense to mildly hyperintense in signal, compared with the signal intensity in normal muscle, and do not show contrast enhancement after the intravenous administration of a gadolinium-based contrast agent. On MRN, the muscles and nerves demonstrate intermediate signal on