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Original article

Contribution of muscle MRI for diagnosis of myopathy

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INFO ARTICLE

Keywords:
Whole-body muscle MRI
Congenital myopathy
Acquired myopathy
Involvement patterns

ABSTRACT

Inherited myopathies are a group of disease, which, although distinct from a genetic and prognostic point of view, can lead to non-specific clinical pictures due to phenotypic overlap. Acquired immuno-mediated myopathies may also pose the problem of clinically accurate etiological orientation. The assessment of fatty infiltration and pathological increase in water volume of the muscle contingent on whole-body muscle MRI is becoming increasingly important in aiding the initial diagnosis of inherited and acquired myopathies. MRI helps orientating the clinical diagnostic hypotheses thanks to the patterns of muscle involved (more or less specific according to the entities), which led to the development of decision-making algorithms proposed in the literature. The aim of this article is to specify the proper MRI protocol for the evaluation of myopathies and the basis of the interpretation and to provide a summary of the most frequently inherited and acquired myopathies described in the literature.

1. Introduction

Myopathy is a generic term for any pathological primary muscle damage, regardless of the pathogenic mechanism involved.

There are two main types of myopathies: inherited myopathies secondary to a genetic abnormality, and acquired myopathies, affecting an initially healthy muscle and not related to a genetic anomaly.

Inherited myopathies, are usually divided in three main categories, including multiple sub-categories (Fig. 1):

- muscular dystrophies, caused by genetic mutations that alter the primary structure of the muscle fibers, which will gradually break down;
- congenital myopathies, due to a defect in the development or maturation of muscle fibers during the fetal period, caused by a genetic anomaly;

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https://doi.org/10.1016/j.neurol.2022.12.002

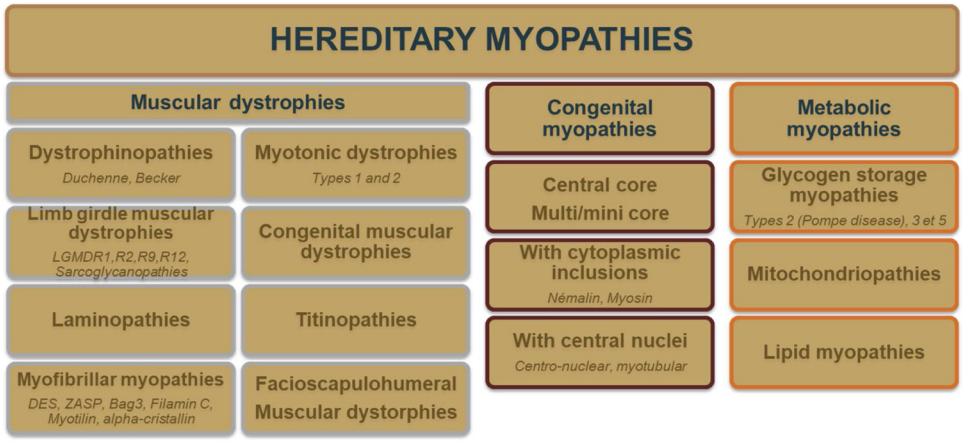

Fig. 1 – Classification of inherited myopathies.

- metabolic myopathies, due to a genetically determined dysfunction of the sugar degradation pathway, of the respiratory metabolic chain or of fat metabolism.

Acquired myopathies include four main categories (Fig. 2) [1]:metabolic myopathies, due to a genetically determined dysfunction of the sugar degradation pathway, of the respiratory metabolic chain or of fat metabolism.

- idiopathic inflammatory myopathies;
- toxic myopathies;
- infectious myopathies;
- endocrine myopathies.

Myopathies, and in particular inherited myopathies, are rare, with great phenotypic overlap between the different entities, and delayed genetic results. Thus, the final diagnosis often takes years, and any complementary diagnostic tool helping to achieve faster diagnosis is useful. Whole-body muscle magnetic resonance imaging (MRI) has acquired a growing role in the diagnosis and evaluation of myopathies, especially in inherited myopathies that often present a relatively orienting imaging pattern of damage. MRI is non-invasive, non-irradiating and allows an exhaustive analysis of all the body's muscle masses in a single examination. Technical improvements have enabled more precise, quicker and more accessible examinations. Whole-body MRI indications have grown over the last twenty years, both to assess initial diagnostic hypotheses and to monitor disease progression. This examination can be performed at any age but requires a rigorous acquisition and interpretation technique and must be performed by a trained team for better diagnostic yield.

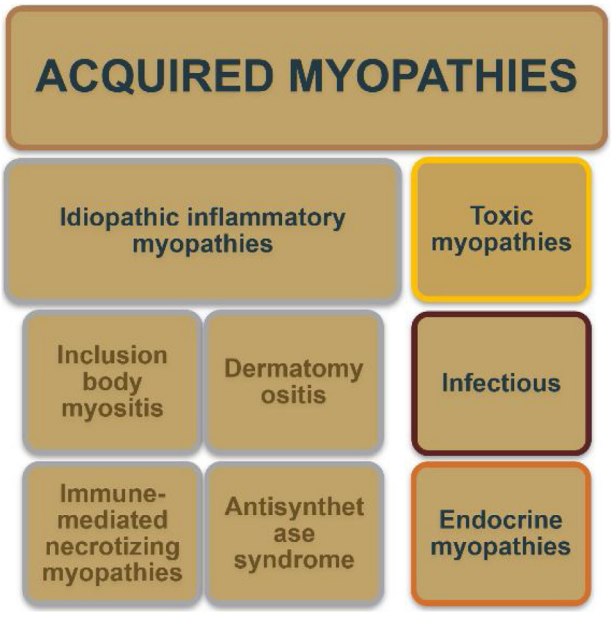

Fig. 2 – Classification of acquired myopathies.

2. Whole-body muscle MRI

2.1. *Indications in myopathy assessment*

Whole-body muscle MRI is useful for two main types of indications:

- to orientate the initial diagnosis, allowing a better prescription of additional examinations (genetic/biologic);
- to follow the disease course and monitor response to treatment.

2.1.1. *Initial diagnosis*

Whole-body muscle MRI can be valuable in several situations:

- when the phenotypic presentation points clinically towards several groups of myopathies due to non-specific symptoms, muscle MRI can show a characteristic pattern of muscle involvement restricting the genetic panels to be carried out to reach a final diagnosis. This examination also provides additional clues in favor or against a given myopathy by analyzing non-muscular structures (brain,

soft tissue) (abnormalities of the cerebral white matter pointing to certain pathologies, evidence of deep neoplasia in the assessment of dermatopolymyositis which may be of neoplastic origin);
- when the diagnosis of myopathy is clinically obvious, but the first confirmatory examinations (muscle biopsy, genetic panels) have not allowed a formal diagnosis. Muscle MRI can help guide further paraclinical investigations, for example by identifying muscle groups with inflammatory changes for which muscle biopsy is most likely to be cost-effective (or, similarly to what has been described above, by identifying a characteristic pattern of muscle damage that could redirect the genetic panels to be performed in order to reach a formal diagnosis);
- when the genetic analyses have revealed a variant of undetermined significance, access to the evaluation of deep muscle groups (clinically non-assessable) allowing the identification of clinically silent disorders can establish the diagnosis and direct toward proper management and early follow-up;
- quite similarly, when the clinical diagnosis of myopathy is not clearly established (subtle clinical lesions, normal routine paraclinical examinations) or when an investigation is carried out in asymptomatic relatives, the detection of clinically silent lesions can also help to correct the diagnosis.

2.1.2. *Follow-up*

Whole-body muscle MRI allows a more precise quantification than physical examination alone of the degree of muscle damage, by grading muscle fat infiltration, which is correlated with the patient's functional state and muscle strength. Not only useful at the individual patient level, longitudinal MRI monitoring of any myopathy also has an academic vocation, allowing a better understanding of their expression profile, and evaluating the effectiveness of available therapies.

2.1.3. *Contraindications and alternatives*

Alternative imaging methods have been proposed in case of contraindications for MRI (which are in practice rare and dominated by the presence of metallic foreign bodies or non-MRI-compatible medical devices, as well as severe respiratory insufficiency or major claustrophobia). They are mainly represented by computed tomography (CT) and ultrasound. The major disadvantage of CT is its irradiating nature, which should be avoided as much as possible in a population that is often young and highly likely to be exposed to iterative CT scans in the context of the complications specific to their disease. Ultrasound, which does not irradiate, is an easily accessible alternative with no contraindications for analysis of superficial muscle groups and for guidance of muscle biopsies but does not allow fine analysis of deeper muscle groups and is operator dependent.

2.2. *How it is performed*

2.2.1. *Examination environment*

The imaging team performing whole-body muscle MRI for the evaluation of inherited myopathies must be experienced in the management of these patients who are often severely disabled and may be very young. Particular attention should be given to reassuring claustrophobic patients or young children during the examination in order to achieve good image quality, with no movement artifacts. The presence of young patients' parents during the examination should be encouraged, as some MRI machines have large tunnels allowing one of the parents to lie next to the child during the examination. The use of general anesthesia should be avoided. In case of myopathic patients suffering from respiratory insufficiency, the imaging team must work in collaboration with the anesthesia-intensive care team to ensure that the examination is carried out in a safe environment (non-magnetic monitoring and assisted ventilation equipment, continuous medical surveillance).

2.2.2. *Equipment*

Both 1.5T and 3T magnetic fields can be used, with the advantage of a 3T MR system being to reduce acquisition time due to a larger signal reserve. For older equipment, a whole-body antenna can be integrated into the machine; for newer machines, coupling head/neck, lower limb and posterior antennas/surface antennas for trunk exploration is preferred.

2.2.3. *Acquisition technique [2,3]*

For muscle MRI, the field of exploration of must be wide, allowing exploration starting from the temporal muscles and heading to the muscles of the forefoot distally including the arms, forearms and hands.

In order to achieve good analysis of the upper limbs, the operator must check that they are correctly positioned within the field of exploration and the field of view (FOV) set for axial slices that must be sufficiently wide (50–55 cm).

Spatial resolution must be sufficient to allow fine analysis of each muscle group; therefore, joint sections with a thickness no greater than 5 mm should be acquired. The smaller the anatomical structure to be analyzed, the better should be the spatial resolution (this is particularly true in the analysis of the pediatric population).

2.2.4. *Protocol*

The protocol includes two types of sequences acquired in the axial plane, carried out successively, to be read in parallel (thus requiring, to be comparable and superimposable, the same acquisition parameters in terms of slice thickness and acquisition plane):

- ''anatomical'' sequences to study muscle morphology, volume and the degree of fat replacement (typically T1-weighted sequences);
- ''functional'' sequences allowing the visualization of a possible increase in the quantity of water within a muscle; these are typically T2-weighted sequences with saturation of the fat signal (using the Fat Sat or STIR method), that show inflammation changes in the muscle.

These axial sequences are acquired in several stages, going from head to toe, that are then merged to allow optimal reading comfort. For the levels concerning the trunk (thorax and abdomen), it is best to coordinate acquisition with breathing to reduce kinetic artefacts.

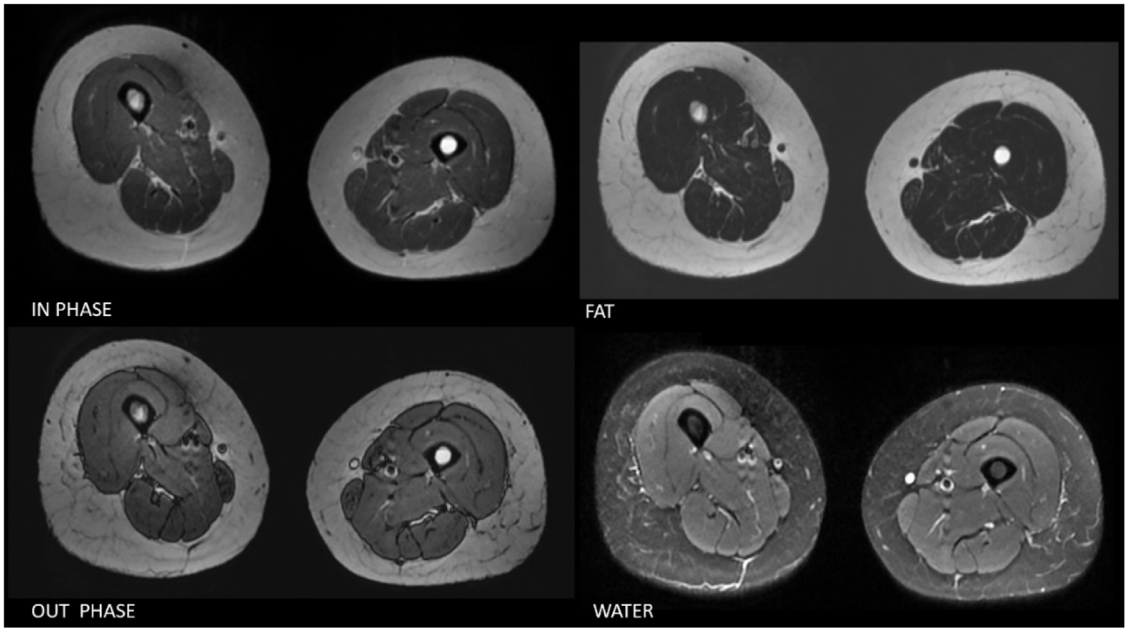

Fig. 3 – Four types of images acquired by Dixon method (Imaging Department, Raymond-Poincaré Hospital, Garches, AP–HP, 2022).

Nowadays, the Dixon method is widely used for acquisition instead of the traditional T1/T2 FS sequences. The Dixon method is a chemical shift-based method of fat and water separation; it is based on the fact that fat protons have a different (and lower) resonance frequency than water protons (difference of 3.25 ppm or 208 Hertz at 1.5T): As the resonance frequencies are shifted, the protons from these two tissues are periodically out of phase with each other over time (every 2.4 ms at 1.5T). It is possible to acquire two images artificially shifted by 2.4 mS, where in one series (''in-phase'') the water and fat protons are in-phase, and in the other series (''anti-phase'') the water and fat protons are out of phase and the fat proton signal is not collected. By reconstruction using a simple mathematical calculation, ''Water'' (showing only the signal from the water protons and thus ''equivalent'' to T2 STIR or Fat Sat sequences) and ''Fat'' (showing only the signal from the fat protons) images can be obtained. Thus, in a single acquisition, four complementary images are available (Fig. 3).

In current practice, a modern variant of the ''two-point'' Dixon method (described schematically above) called the ''three-point Dixon method'' and using an additional echo time is preferred because of its more robust quantification of intramuscular fat and water within a single pixel and its lesser sensitivity to magnetic field inhomogeneities. The Dixon method can be used with all possible ponderations (T1, T2 and DP).

In the context of whole-body muscle MRI, T2-weighted Dixon sequences offer several advantages over conventional T1/TS FS or STIR sequences: overall reduced examination time, homogeneous saturation of the fat signal even for large acquisition volumes (unlike ''Fat Sat'' methods), better signal-to-noise ratio, the possibility of quantifying intramuscular fat transformation and the obtention of strictly superimposable character of the ''anatomical'' imaging and the imaging objectifying the inflammation, since it is the same sequence.

A coronal plane should at best complete the examination if the patient's tolerance is good, ideally acquired in three dimensions, to allow multiplanar reconstructions in order to restore symmetry, an essential condition for a rigorous analysis, when the positioning of the patient cannot be optimal, to better assess spinal deformities and to allow better visualization of certain muscle groups (masticators, tongue, intercostals, psoas, long muscles of the extremities).

Under these conditions, the total examination time is between 30 and 45 minutes.

Injection of gadolinium chelates is not recommended in clinical practice as it increases acquisition time and provides little additional information compared to inflammation-sensitive sequences (apart from the analysis of enhancement kinetics during dynamic gadolinium injection, which are sequences whose interpretation is not yet clearly established).

2.3. *Interpretation*

The interpretation of a whole-body muscle MRI in the context of suspected myopathy must be orientated by the clinical and paraclinical context provided by the referring clinicians and requires above all a detailed knowledge of the anatomy and patterns of muscle damage, which may evolve with the progression of the disease.

Several points need to be analyzed.

2.3.1. *Fat replacement of the muscle contingent*

This is assessed on T1-weighted sequences or ''FAT'' imaging of the T2 Dixon sequence if this method is preferred. Although it is not specific (and can be encountered in various situations

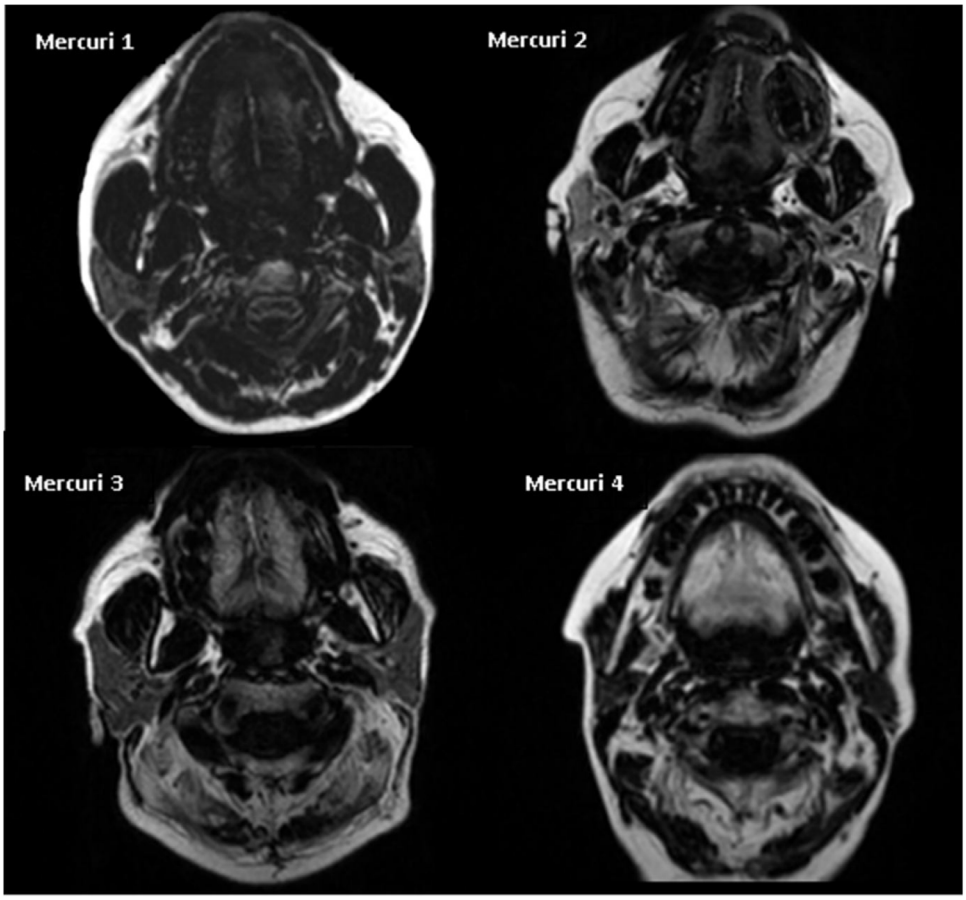

Fig. 4 – Example of Mercuri classification applied to the assessment of fatty degeneration for tongue muscles (Axial T2 "Fat" images, Imaging Department, Raymond-Poincaré Hospital, AP–HP 2019).

such as physiological aging, chronic treatment with corticosteroids, denervation situations, etc.), it is an important process to characterize in myopathies. The analysis must be carried out on the muscle group as a whole, and not just on a few sections, on the most suitable analysis plane. Healthy muscle tissue normally appears hypointense, while fat replacement is hyperintense; this process is often associated after a certain period of time with replacement by connective tissue (also hypointense and most often consisting of a thickening of the fibrous trabeculae and physiological facias) reflecting irreversible damage. To allow a more reproducible semi-quantitative scoring, it is customary to use the Mercuri classification (derived from the Goutallier and Bernageau classification used to score fatty replacement of rotator cuff muscles in the shoulder, and proposed in 2002 initially in patients with stiff spine syndrome) in four stages (Fig. 4) [4]:

- stage 1: normal;
- stage 2: less than 30% fat replacement;
- stage 3: estimated fat replacement between 30% and 60%;
- stage 4: fat replacement greater than 60%.

2.3.2. *Muscle group trophicity*

Muscle trophicity is best assessed on T1-weighted sequences or "FAT" images of the Dixon T2 sequence. It is a qualitative assessment, in the absence of available reference threshold values; it is necessary to look for a disparity in volume between a given muscle and the neighboring muscle groups. Muscle atrophy most often accompanies fat replacement of the muscle body but may rarely be the only abnormality noted on examination, particularly in young children with congenital muscular dystrophy in whom the intramuscular fatty infiltration may be very modest and sit inter- muscularly. Adaptive (reactionary) hypertrophy of the muscles adjacent to the pathological muscles may also be noted, in compensation for the induced deficit or in the case of an inflammatory process (myositis). Eventually, the increase in muscle volume due to fatty infiltration is called pseudohypertrophy.

2.3.3. *Existence of a specific pattern of damage to a given muscle group*

For example, the preservation of central muscle fascia on either side of significant fat replacement (centripetal involvement) may give the muscle a "tigroid" appearance characteristic of collagen 6-related myopathies.

2.3.4. *Existence of a pathological increase in the quantity of water within a muscle*

This is demonstrated by a hyperintensity on T2 STIR/FS/Dixon "Water" sequences. This hyperintensity is not specific but

may reflect the early and active nature of certain myopathies, preceding the occurrence of fatty changes by a few weeks: this is particularly true for DM1, FSH, the early phase of DMD and certain metabolic myopathies but also for most acquired myopathies. It may also be caused by denervation.

2.3.5. *Distribution and symmetrical nature of the damage*

A possible gradient of involvement (proximal/distal, anterior/posterior or lateral/medial) may help to orientate towards a subtype or type of pathology, even though there are few pathologies that exhibit sufficient correlation between imaging data and clinical/biological data. It is also necessary to specify whether there are selective atrophies (as in selenopathies where there may be selective atrophy of the semimembranosus muscle) or, on the contrary, selective hypertrophies. Similarly, the symmetrical or asymmetrical nature of the involvement can help to propose a restricted diagnostic range: certain pathologies classically give an asymmetrical involvement well documented in the literature, such as FSHD and certain limb-girdle myopathies.

Algorithms to orientate the diagnosis hypotheses have been published in the literature; they integrate all these data and make it possible to propose a more restricted diagnostic range [5,6]; these decision trees are, however, more precise for lower limb involvement. A study to be published conducted in our institution shows that paraspinal muscle involvement patterns can also help distinguish among inherited myopathies.

2.3.6. *Other elements*

The impact on the musculoskeletal system must be noted in order to adapt management (severe osteoarthritis or ankylosis due to immobility of the joint segments concerned).

Associated disorders must be noted: the existence of inflammatory changes in the soft tissues is important to note in the context of acquired myopathies (which may indicate for instance a dermatitis associated with a possible polymyositis). The evaluation of brain sections is also important to detect white matter abnormalities (allowing specific orientation towards certain inherited myopathies such as LAMA2).

2.4. *Key patterns in major myopathies*

2.4.1. *Inherited myopathies*

2.4.1.1. *Dystrophinopathies*. Dystrophinopathies are a group of muscular dystrophies caused by an X-linked mutation inducing an absence, insufficient production, or dysfunction of dystrophin, a key protein ensuring the strength of muscle fibers by allowing actin filaments (intracellular contractile apparatus) to bind to the structural proteins of the extracellular membrane. This group includes two main clinical entities according to disease severity, which is correlated with the amount of functional dystrophin.

2.4.1.1.1. *Duchenne myopathy*. Most severe clinical presentation. Whole-body muscle MRI is of limited use in the initial assessment because the clinical phenotype is suggestive. However, it is useful for monitoring disease progression and adapting the treatment if needed. MRI findings are consistent with the clinically observed impairment, showing symmetrical damage in a preferential proximal topography concerning the small and medium gluteal muscles as well as the large adductors, followed by the iliopsoas muscles, in an earlier and more severe manner, the gluteus maximus muscles and the quadriceps, certain hamstrings (biceps femoris and semitendinosus) and the muscles of the posterior calf lodges explaining the pseudohypertrophy noted clinically (soleus, lateral and medial gastrocnemius, fibular). The internal and external obturators, long adductors, semimembranosus, gracilis and sartorius muscles are preserved (Fig. 5) [7].

2.4.1.1.2. *Becker myopathy*. Less severe clinical involvement. On imaging [7], the damage is proximal and symmetrical, preferentially affecting the gluteal muscles, the semimembranosus muscles and the quadriceps. Pseudohypertrophy of the calves is also classically found. The upper limbs are usually spared; if there is any involvement, it is more likely to be of the biceps, triceps and round muscle. In this case, muscle MRI is sometimes diagnostic of a ''pseudo-LGMD'' presentation.

2.4.1.2. *Myotonic dystrophies (MD)*. This group includes two genetically distinct conditions: myotonic dystrophy type 1 (DM1, also known as Steinert's disease) and myotonic dystrophy type 2 (DM2, also known as PROMM for proximal myotonic myopathy). These two multi-systemic disorders are both autosomal dominants, and have three cardinal clinical signs in common:

- myotonia, i.e., abnormal slowness of muscle relaxation, clinically manifested by the persistence of a strong muscle contraction after percussion of the muscle and leading to an unpleasant but non-painful sensation of stiffness for the patient;
- muscle weakness;
- early cataract.

2.4.1.2.1. *Type 1 MD*. Whole-body MRI shows [8,9] skeletal muscle damage, predominantly distal, associating fatty involution, atrophy and sometimes inflammatory T2 hypersignal of the affected muscle bodies. In the lower limbs, the leg is usually more severely affected than the thigh; the anterior compartments are more affected than the posterior compartments. The pelvic girdle and the posterior tibial, gracilis and rectus femoris muscles are usually preserved. In the upper limbs, preservation of the muscles of the shoulder girdle is the rule. Moderate involvement of the forearm muscles may be seen. In the face and neck muscles: the sternocleidomastoid, masticatory muscles and muscles of the face are affected. Concerning the trunk: damage to the diaphragm is responsible for respiratory complications. Involvement of the erector spinae muscles may be noted, generally of moderate severity.

2.4.1.2.2. *Type 2 MD*. Whole-body MRI shows [8,9] predominantly proximal skeletal muscle damage with fatty involution and atrophy less marked than in type 1 MD. There is marked involvement of the paravertebral muscles (particularly at the cervical level) and the gluteus maximus, as well as the scapular and pelvic girdles. In general, there is no T2 hypersignal inflammation. In contrast to type 1 MD, the muscles of the face are spared and there is no involvement of the masticatory muscles or esophageal dilatation.

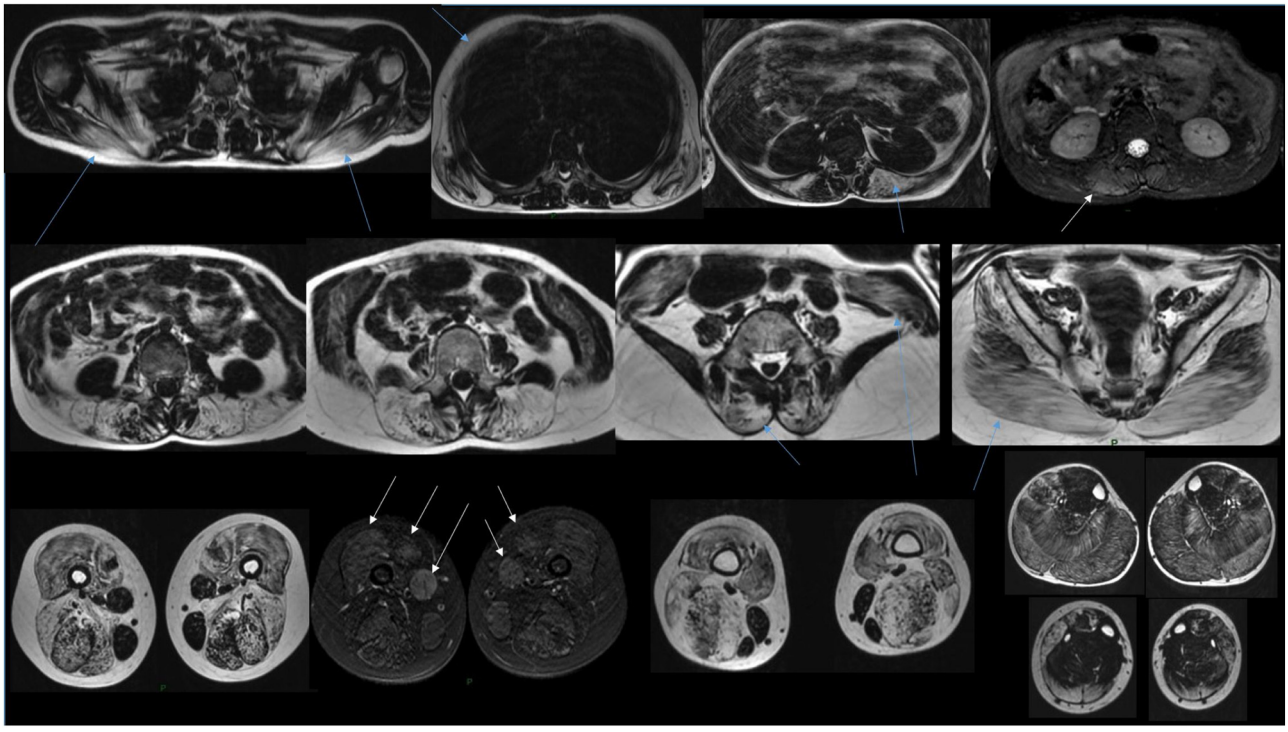

Fig. 5 – Whole-body muscle MRI in a patient with Duchenne dystrophy (Axial T2 Dixon "Fat" and "Water" images; Imaging Department, Raymond-Poincaré Hospital, AP–HP 2022). Note the symmetrical muscle damage, of proximal predominance. The muscle damage concerns mostly the pelvic girdle (particularly gluteus muscles), the quadriceps, the hamstrings (biceps femoris and semitendinosus) and the muscles of the posterior calf lodges (soleus, lateral and medial gastrocnemius but also the fibular) showing the classical "pseudohypertrophy" noted clinically. The scapular girdle and the axial paraspinal muscles are mildly affected. T2 hypersignal may be found in the active phase of the disease. The internal and external obturators, long adductors, gracilis and sartorius muscles are preserved.

2.4.1.3. *Limb-girdle muscular dystrophies (LGMD)*. Limb-girdle muscular dystrophies are genetic diseases that have in common the preferential clinical involvement of the muscles of the pelvic girdle (the most frequently affected) and the scapular girdle. This category includes several clinical entities that meet several common diagnostic criteria. The currently used classification of LGMD was established by a group of international experts at the 229th European Neuromuscular Centre (ENMC) international workshop held on 17–19 March 2017 [10]. It is based on:

- the mode of transmission: dominant (LGMD D) or recessive (LGMD R);
- a numbering system corresponding to the chronological order of description of the entity;
- the citation of the protein involved in the physiopathology of the entity.

Thus, for example, we will speak of LGMD R1 linked to calpain (of recessive transmission "R", described first among the LGMDs, hence the number "1" and "linked to calpain-3") instead of LGMD2A in the old classification, which was less explicit and based essentially on the recessive or dominant character and on the chronological order of description.

2.4.1.3.1. *LGMDR1 linked to calpain*. Whole-body muscle MRI shows (Fig. 6) [11,12] in particular the involvement of the posterior thigh, then the adductor magnus and vastus intermedius muscles. Leg involvement is predominantly in the medial gastrocnemius and soleus muscles. Involvement of the shoulder girdle is manifested by detachment of the scapulae and occurs after involvement of the pelvic girdle. The spinal erectors tend to be affected laterally in the extensor group (longissimus and ilio-costal muscles) compared to the medial rotator muscles (multifidus and rotators). A "pseudo collagen" pattern of involvement can be seen (central sparing zones in certain muscles) and is predictive of a longer and more severe disease course.

2.4.1.3.2. *LGMDR9 linked to fukutin related protein (FKRP) gene*. Whole-body muscle MRI shows (Fig. 7) [13,14] predominant involvement of the muscles of the posterior thigh and often signs of hypertrophy of the gracilis muscle. In the leg, there is diffuse involvement of all muscles, with the medial gastrocnemius being more affected than the lateral, and marked involvement of the fibular and tibialis anterior muscles.

2.4.1.3.3. *LGMDR2 linked to dysferlin*. Whole-body muscle MRI shows (Fig. 8) [15–17] severe involvement of the anterior and posterior thigh compartments with sparing of the sartorius and gracilis muscle. Early leg involvement is predominantly in the posterior compartment and initially spares the medial gastrocnemius muscle; the posterior tibial muscle is preserved. However, a recent series suggests that

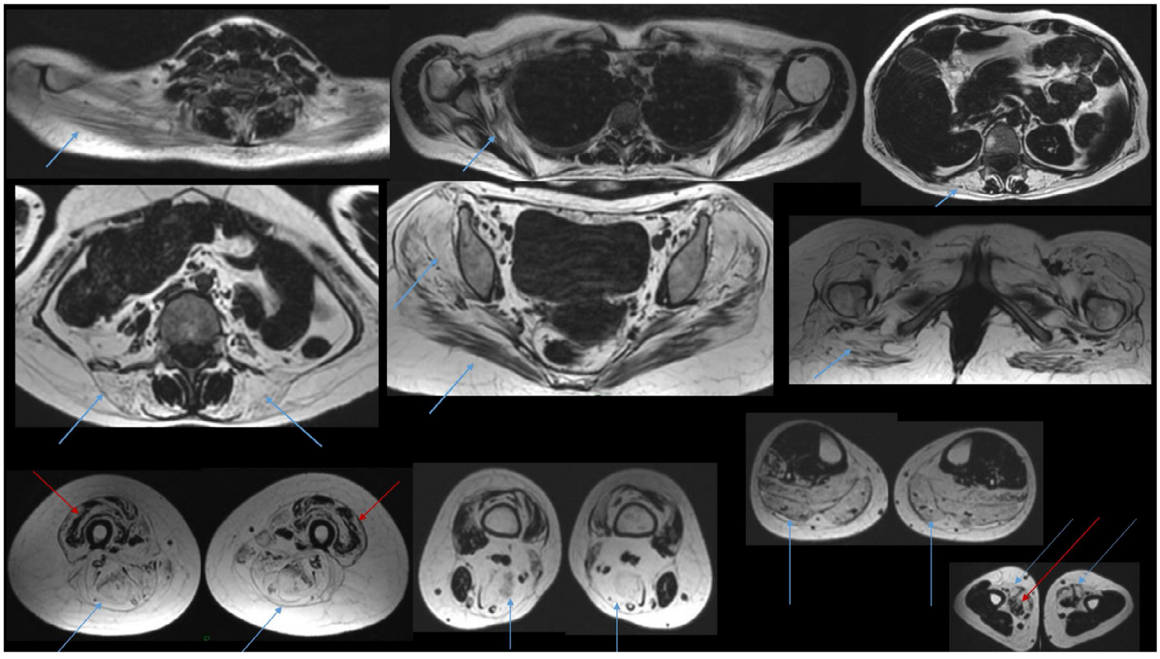

Fig. 6 – Whole-body muscle MRI in a patient with LGMDR1 linked to calpain (Axial T2 Dixon "Fat" images, Imaging Department, Raymond-Poincaré Hospital, AP–HP 2021). Note the symmetrical damage of the scapular girdle (especially trapezius and subscapularis muscles) and more severely the pelvic girdle (gluteus and adductor longus and brevis muscles mostly in this patient); the spinal damage is preponderant on extensor (lateral) muscles compared to rotator (medial) muscles. In the lower limbs, the involvement is marked in the posterior thigh (almost fully fatty) and extends anteriorly towards the quadriceps, especially the vastus intermedius and lateral muscles; note the presence of a "pseudo collagen" pattern of involvement (fatty infiltration sparing the central part of the muscle, see red arrow). Leg involvement concerns mostly the gastrocnemius and soleus muscles, with sparing of the anterior compartment.

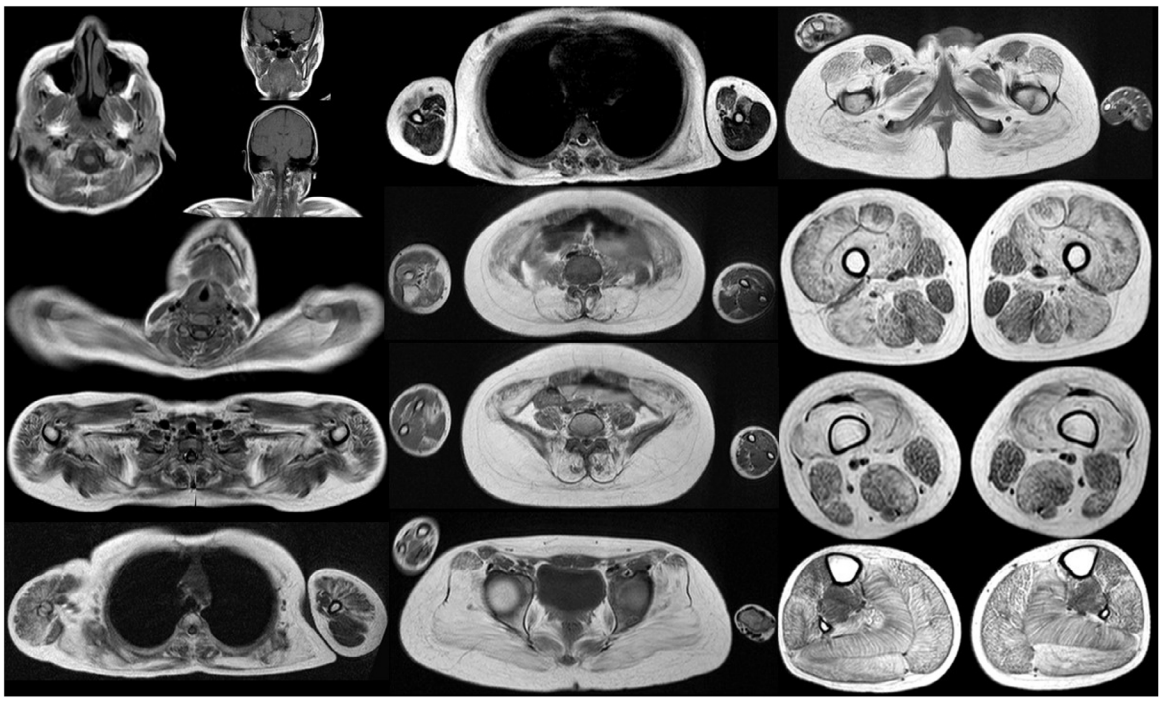

Fig. 7 – Whole-body muscle MRI in a patient with LGMDR9 linked to FKRP (Axial T1 images, Imaging Department, Raymond-Poincaré Hospital, AP–HP 2018). Note the symmetrical pattern of muscle fatty infiltration, affecting the scapular and pelvic girdles as well as the spinal muscles. In the thighs, both anterior and posterior compartments are involved; note the sparing (with relative hypertrophy) of the gracilis. In the legs, there is diffuse involvement of all muscles, with the medial gastrocnemius being slightly more affected than the lateral, and marked involvement of the fibular and tibialis anterior muscles.

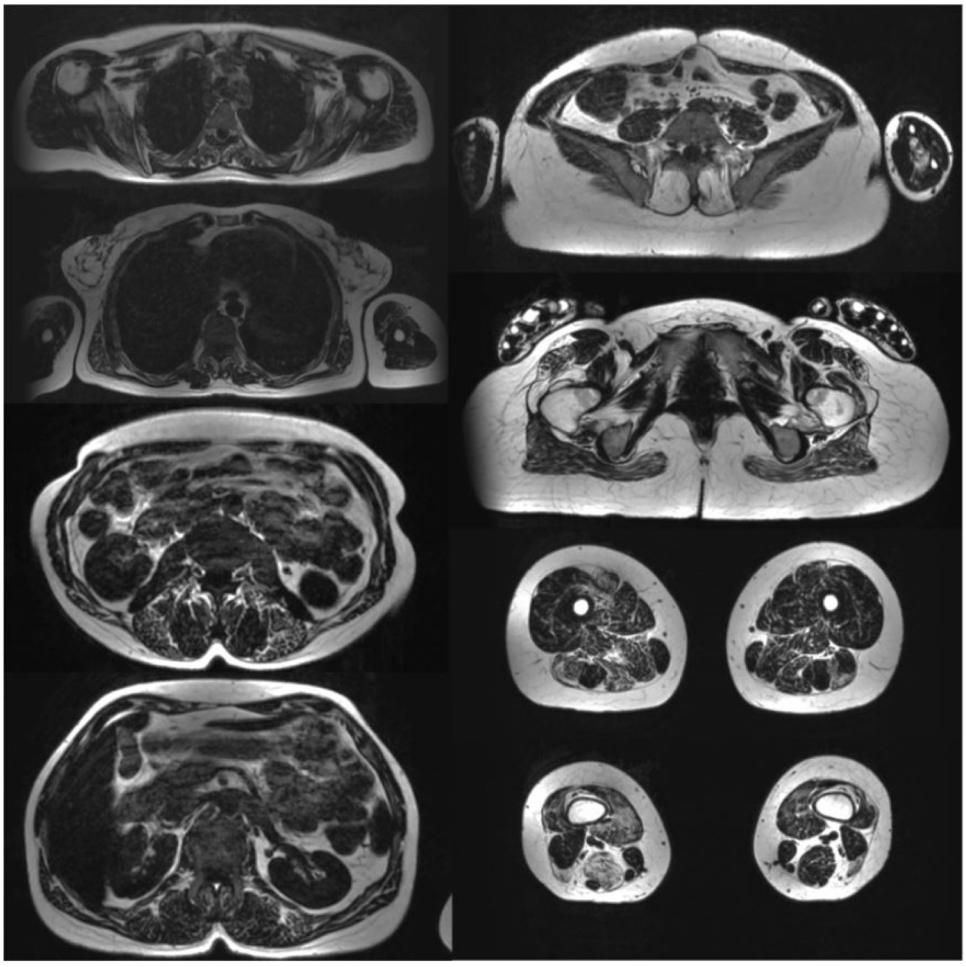

Fig. 8 – Whole-body muscle MRI in a patient with LGMDR2 linked to dysferlin (Axial T2 Dixon "Fat" images, Imaging Department, Raymond-Poincaré Hospital, AP–HP 2018). Whole-body muscle MRI shows involvement of the anterior and posterior thigh compartments with sparing of the sartorius and gracilis muscle. The scapular and pelvic girdles and the spinal muscles are also affected.

involvement of the medial gastrocnemius (later) as well as the soleus is suggestive of dysferlinopathy independently of the clinical phenotype. Cardiomyopathy and respiratory involvement are possible. A distal predominant pattern (called "Miyoshi distal myopathy") is another possible presentation of the same myopathy.

2.4.1.3.4. *Sarcoglycanopathies*. This group consists in many genetical and clinical entities [LGMDR3 related to α-sarcoglycan, the most common; LGMDR5 related to γ-sarcoglycan, LGMDR4 related to β-sarcoglycan and LGMDR6 related to δ-sarcoglycan (ex LGMD2C, D, E, F)] that are clinically similar, with onset of symptoms occurring at a variable age, mostly in childhood. Whole-body muscle MRI shows (Fig. 9) [15,18] involvement of the anterior thigh compartment (mainly the vastus intermedius). Leg involvement is predominantly in the fibular and soleus muscles. Hypertrophy of the gracilis and sartorius muscles and sometimes of the semitendinosus can be observed.

2.4.1.3.5. *LGMD R12 linked to anoctamin* 5. Whole-body muscle MRI classically shows (Fig. 10) [19,20] an initial preservation of the gluteal, psoas, iliac, sartorius, gracilis and rectus anterior muscles and moderate damage to the axial musculature, while the adductors and muscles of the posterior thigh (particularly the semitendinosus) are involved early, followed by the vastus muscles. In the leg, the medial gastrocnemius and soleus muscles are involved at an early stage, followed by the lateral gastrocnemius, fibular and tibialis anterior. An increase in water volume within the involved muscle groups may precede atrophy.

2.4.1.4. *Titinopathies*. Titinopathies are a group of diseases caused by mutations in the *TTN* gene encoding titin, located on chromosome 2. Titinopathies are inherited in an autosomal dominant or, more rarely, autosomal recessive manner. The clinical pictures generated are very varied, from a simple muscular discomfort with little or no progression to dramatic pictures with premature death in the child. Several clinical forms can be distinguished according to the onset of the symptoms, the most frequent being the Emery-Dreifuss-like myopathy. Whole-body MRI shows few specific patterns for other entities [21–23].

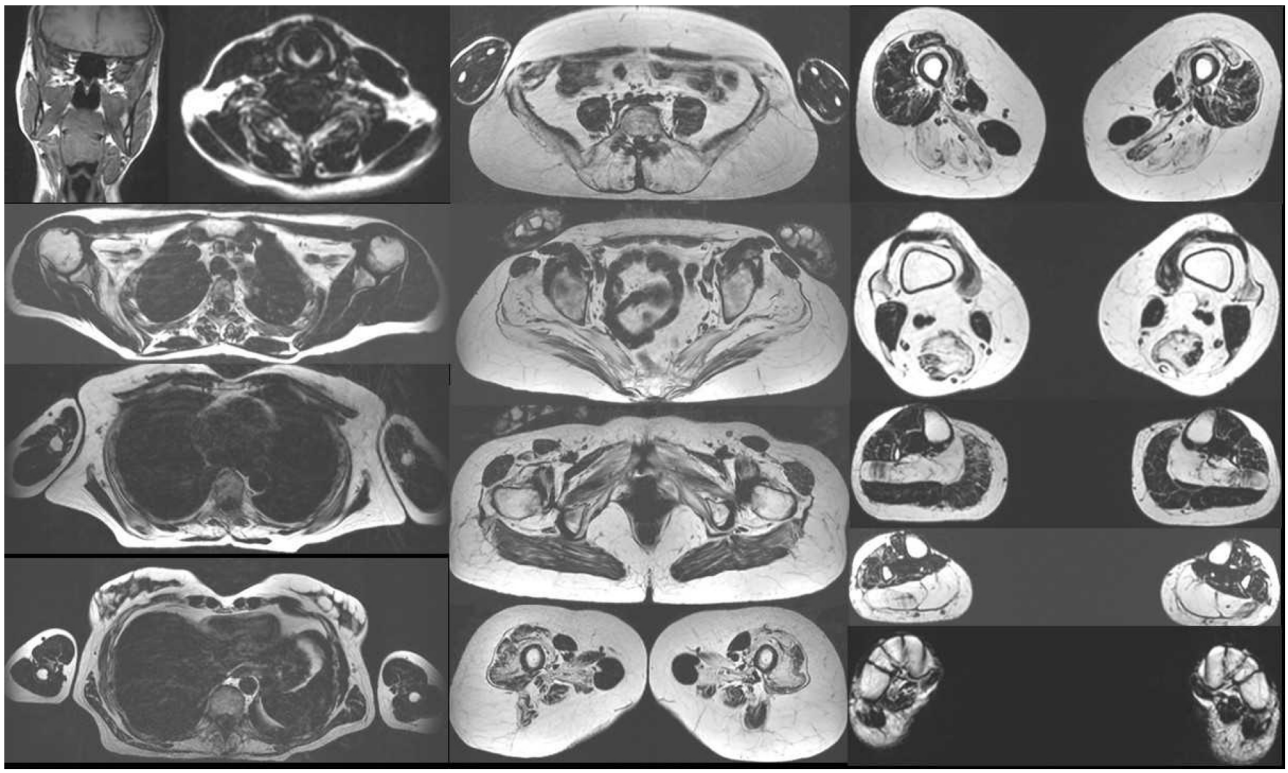

Fig. 9 – Whole-body muscle MRI in a patient with LGMDR3 related to α-sarcoglycan (Axial T2 Dixon "Fat" images, Imaging Department, Raymond-Poincaré Hospital, AP–HP 2018). Note the involvement of the scapular and pelvic girdles as well as the spinal muscles. In the thighs, the damage begins with the anterior compartment (mainly the vastus intermedius) and progress to the posterior compartment with severe fatty infiltration of the hamstrings; the sartorius and gracilis muscles are spared. Leg involvement is predominantly in the soleus and, to a lesser extent, fibular muscles with sparing of the gastrocnemius.

2.4.1.5. *Laminopathies*. The most common entity of this group of diseases, is type 2 autosomic-dominant Emery-Dreifuss myopathy, characterized by slowly progressive muscle weakness and atrophy (humeroperoneal then more diffuse), tendon retractions beginning in early childhood and later cardiac involvement, generally after the second decade, characterized by conductive and rhythmic disorders and dilated cardiomyopathy. Muscle imaging may show isolated involvement of the medial gastrocnemius, which is suggestive in the early stages of the disease [24].

2.4.1.6. *Myofibrillar myopathies (MMF)*. This group of dystrophies is genetically heterogeneous and includes multiple entities with the involvement of the loss of function of six main genes; however, they share a common point in their histological analysis: the intracellular accumulation of proteins originating for the most part from the Z-stripe and whose early disorganization is visible by electron microscopy.

Whole-body muscle MRI shows some specific findings for some entities [25].

2.4.1.6.1. *Desminopathies*. They are the most frequent forms of MMF in France. On whole-body MRI, there is usually early fatty degeneration of the leg muscles, particularly in the long fibular, then the tibialis anterior and the muscles of the posterior leg. At a later stage, there is involvement of the thighs with predominant involvement of the gracilis, sartorius and semitendinosus as well as involvement of the shoulder muscles.

2.4.1.6.2. *Zaspopathies*. They are the second most common cause of MMF in France. The classic clinical presentation of zaspopathy is a late-onset distal myopathy (about 45 years of age) slowly progressing with involvement of the intrinsic extensor muscles of the hand and wrist and then the proximal muscles of the limbs and trunk. Muscle imaging shows [26,27] predominant involvement of the muscles of the posterior compartment of the calf with early degenerative changes in the medial gastrocnemius and soleus; in the thigh, the posterior compartment (biceps femoris and semimembranosus) is predominantly involved while the semitendinosus, adductor magnus and gracilis are relatively unaffected.

2.4.1.6.3. *Alpha-crystallinopathies*. The phenotype is characterized by onset in adulthood (30–40 years) of progressive muscle weakness affecting both proximal (most upper limb) and distal (most lower limb) muscles. It is associated with respiratory failure (which can be severe), hypertrophic cardiomyopathy and cataracts, with phenotypic variability within and between families. Based on the few cases reported,

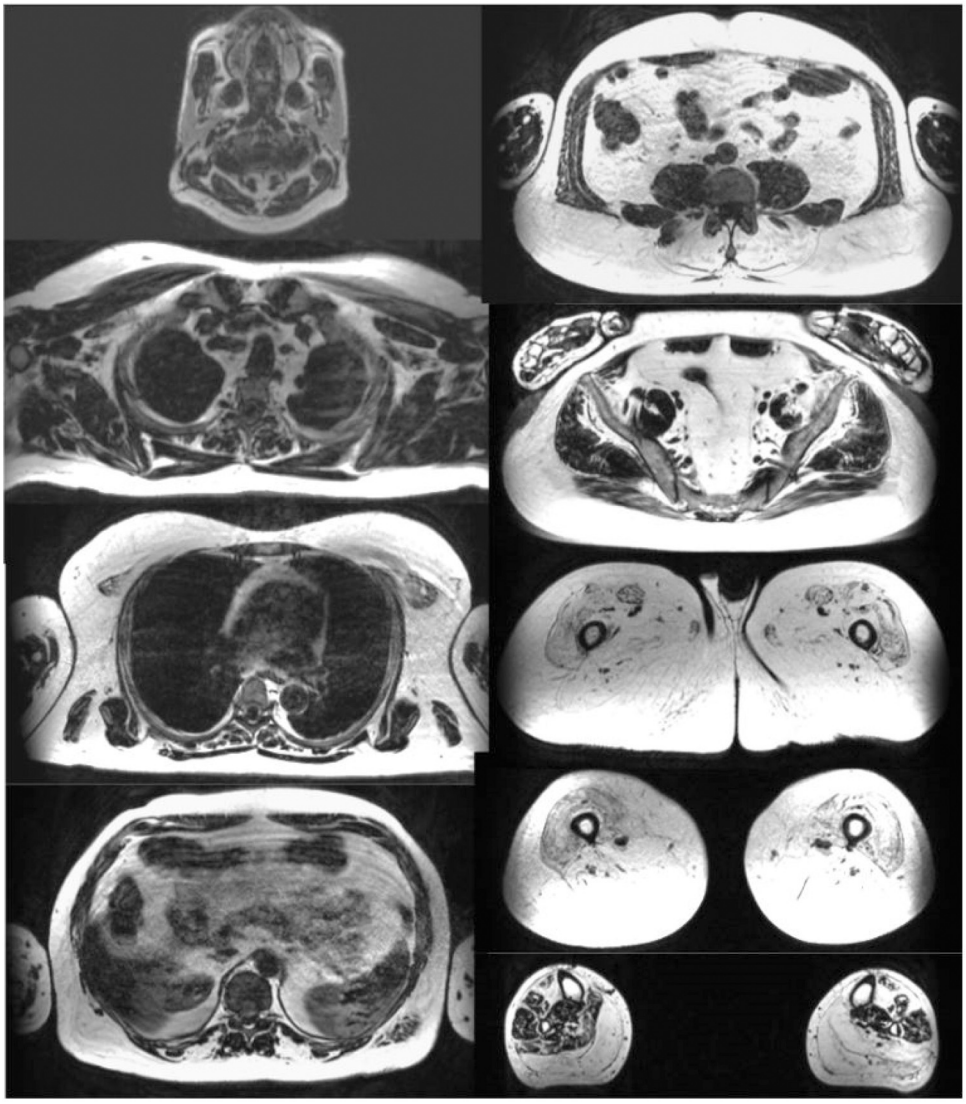

Fig. 10 – Whole-body muscle MRI in a patient with LGMDR12 linked to anoctamin 5 (Axial T2 Dixon "Fat" images, Imaging Department, Raymond-Poincaré Hospital, AP–HP 2019). Note the relatively moderate damage of the gluteal, psoas, axial musculature (except for the lumbar level) and shoulder girdle compared to the severe damage of the posterior compartments of the thighs; the anterior compartments of the thighs is less severely damaged too. In the leg, the gastrocnemius are severely involved, followed by the soleus and the tibialis anterior muscles.

muscle MRI may show distal fatty infiltration of the tibialis anterior and medial gastrocnemius muscles, and proximal involvement of the quadriceps, sartorius and tensor fascia lata [28].

2.4.1.6.4. *Myotilinopathies*. Muscle imaging shows [25] mainly fatty involution in the distal muscles, initially in the posterior leg compartment (particularly the soleus and medial gastrocnemius), and then in all other muscles including the tibialis anterior. When the thigh is involved, the pattern is less specific, with involvement of the semimembranosus, hip adductors and biceps femoris.

2.4.1.6.5. *C filaminopathies*. Muscle MRI shows [29] predominant involvement of the soleus and medial gastrocnemius in the leg and fatty degeneration of the semimembranosus, biceps femoris, adductor magnus, vastus intermedius and vastus medialis in the thigh, while the sartorius, gracilis, and rectus femoris were relatively spared.

2.4.1.6.6. *Bag3opathies*. The clinical picture is characterized by severe muscle weakness of variable topography (predominantly proximal, proximo-distal or distal), possibly associated with stiff spine syndrome. Cardiac and respiratory involvement is common and can be very severe. Symptoms begin in the first decades of life. Muscle MRI does not show any specific pattern of involvement.

2.4.1.7. *Distal myopathy due to VCP (valosin containing protein) gene mutation*. The p97/VCP protein is an ATPase involved in basal cell autophagy of cytosolic proteins ubiquitinated by the

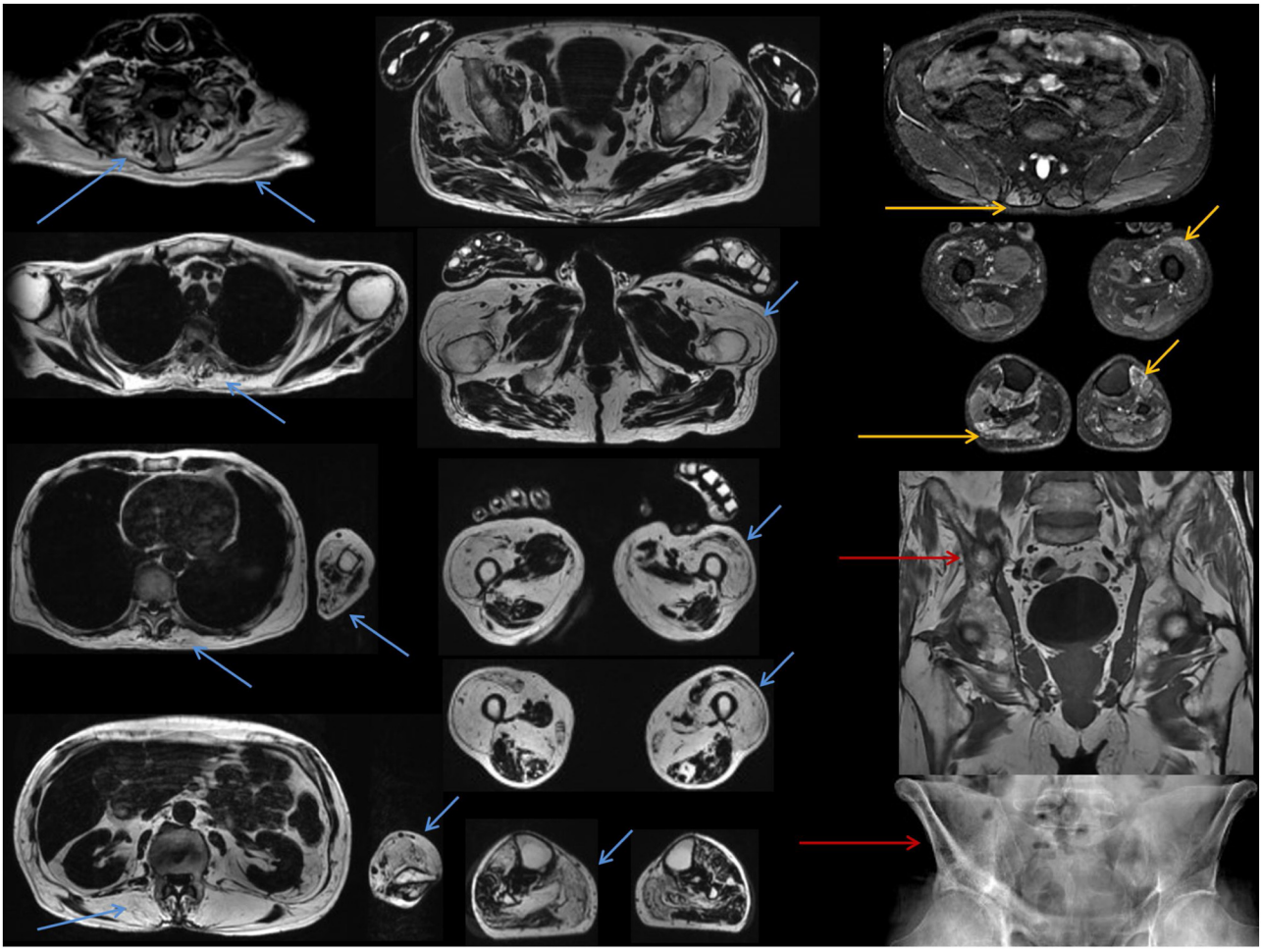

Fig. 11 – Whole-body muscle MRI in a patient with VCP myopathy (Axial T2 Dixon "Fat" and "Water" images, coronal T1 and frontal plain radiograph of the pelvis, Imaging Department, Raymond-Poincaré Hospital, AP–HP 2022). Note the symmetrical involvement (blue arrows) of the axial paraspinal muscles (extensors more severely than rotators), the shoulder girdle (trapezius, subscapularis), the deep common flexors of the fingers in the upper limbs and, in the lower limbs, the quadriceps, the gastrocnemius medius and the anterolateral compartment of the leg. T2 hyperintensity are noted in the paraspinal right muscle at lumbar level, the left vastus lateralis, the right lateral gastrocnemius and the left anterior tibialis (yellow arrows). This patient also presented a bone involvement with Paget disease of the right ilium (red arrows).

proteasome (Fig. 11). Its dysfunction (caused by genetic defects, more than 45 mutations having been described so far) leads to an accumulation of ubiquitin and TDP-43 positive protein clusters in vacuoles, called ''inclusion bodies'', in muscle cells, osteoclasts and neurons, hence the name ''IBMPFD'' for inclusion body myopathy, Paget and fronto-temporal dementia. The muscular manifestations are the most frequent symptoms (affecting 90% of individuals, with adult onset), followed by the bone disease (Paget disease, in 40% of individuals) and the cognitive impairment (fronto-temporal dementia in 30% of individuals, but also less frequently other types of dementia such as amyotrophic lateral sclerosis, Parkinson and Alzheimer's diseases). Whole-body muscle MRI classically shows [30,31] a symmetrical involvement of the axial paraspinal muscles (mostly concerning the extensors rather than the rotators), the quadriceps, the anterolateral compartment of the leg, as well as the deep common flexors of the fingers in the upper limbs (a distal predominance as classically been described, although proximal predominance can be found). As in facioscapulohumeral muscular dystrophy (FSH) (see below), the ''scapula alata'' sign can be found but facial muscle involvement is generally milder. T2 hypersignals in muscles involved (especially in the lower limbs) is frequently noted and precedes the installation of fatty degeneration.

2.4.1.8. Facioscapulohumeral muscular dystrophy (FSH). FSH is one of the most common muscular dystrophies in adults. Two genetic subtypes have been described. Whole-body muscle MRI (Fig. 12) [3,32] is of a particularly contributive for the initial diagnosis and shows data that is consistent with the clinical damage described, i.e. motor deficit and hypo-

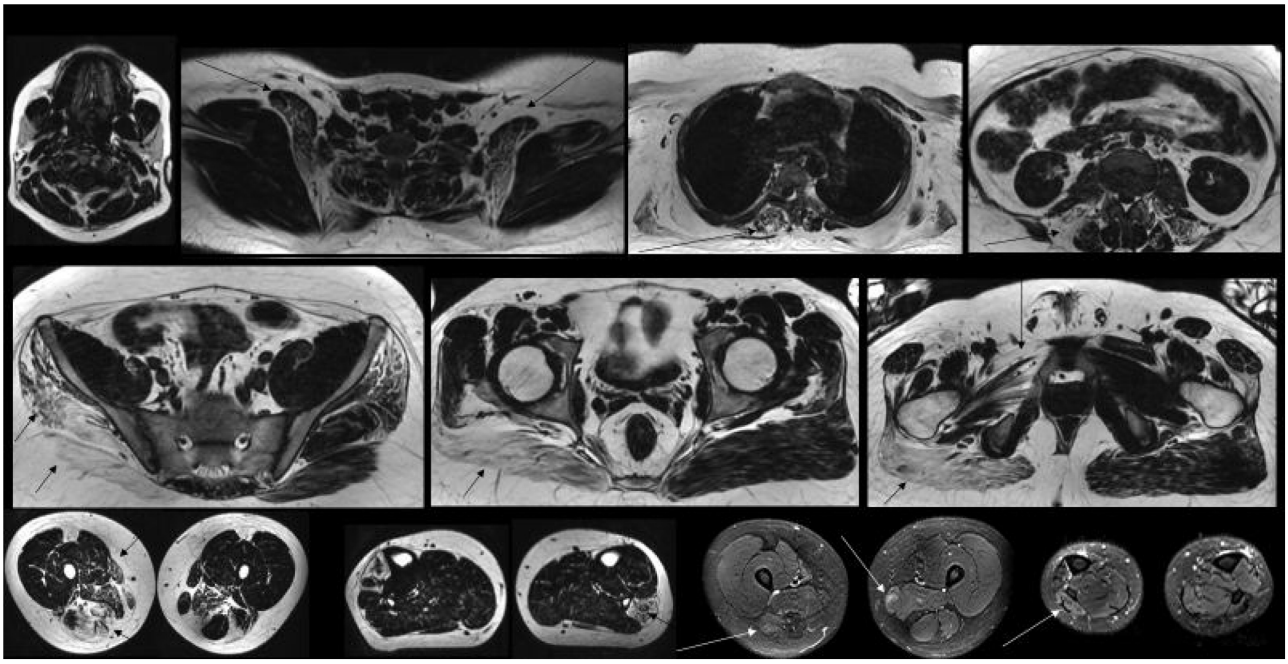

Fig. 12 – Whole-body muscle MRI in a patient with FSH dystrophy (Axial T2 Dixon "Fat" and "Water" images, Imaging Department, Raymond-Poincaré Hospital, AP–HP 2020). Note the asymmetrical pattern of fatty infiltration, concerning the facial muscles, the shoulder girdle (with damage predominating in the trapezius, serratus major, pectoralis major and dorsalis major with sparing of the rotator cuff and deltoid muscles), the axial muscles, the abdominal and pelvic girdle with the gluteus (severe involvement of the right side and almost complete sparing of the left side), the lower limbs with severe damage to the right adductors (marked for the adductor longus), the hamstrings, the right anterior tibialis and the left fibular muscle. Sparing of the vastus in the thighs and the posterior compartments of the legs is classically noted for a long time (as present in this patient). T2 hyperintensity in muscles are noted (white arrows, concerning the right biceps femoris, the left gracilis and the right lateral gastrocnemius).

trophy of asymmetric distribution, beginning with the facial muscles (difficulty in smiling, whistling, closing the eyes, with no swallowing disorders) and the muscles of the shoulder girdle (resulting in a suggestive symptom on clinical examination: detachment of the spinal edge and the tip of the scapula during antepulsion and abduction of the arm, also known as ''scapula alata''). The trapezius, serratus major, pectoralis major and dorsalis major muscles are affected more than the rotator cuff and deltoid muscles, which are preserved. The muscles of the forearm are also affected in the state phase. In the lower limbs, the damage starts with the adductors, hamstrings, rectus femoris, medial gastrocnemius and tibialis anterior, while the vastus thigh, lateral and posterior leg muscles are preserved for a long time. Involvement of the abdominal girdle muscles and the erector spinae muscles is frequently described, while the iliopsoas muscles are preserved. In addition to the asymmetrically distributed muscle damage, predominantly facial and scapular, described above, it can frequently show a pathological increase in the volume of intramuscular water within the affected muscle groups (particularly in the early phase), very suggestive of the diagnosis. It has been described that the lower limbs are more severely and frequently affected than the upper limbs, and the pathological increase in muscle water content is more intense in type 2 FSH compared to type 1.

2.4.1.9. Congenital muscular dystrophies. Congenital muscular dystrophies (CMDs) constitute a heterogeneous group of pathologies (on a clinical and genetic level) characterized by symptoms associating with varying degrees muscular weakness, amyotrophy, hypotonia, contractures or psychomotor retardation, the onset of which is early (from birth or during the first months of life). Within CMD, three major subgroups are distinguished according to the cellular level affected by the responsible mutation to which is added a group whose responsible mutations are not yet identified.

Whole-body muscle MRI can have a major impact on the orientation and prioritization of the genetic analyses carried out, finding highly suggestive or even characteristic disorders in three CMDs.

2.4.1.9.1. CMD with primary merosin deficiency. Skeletal muscle involvement is most common in the adductor magnus, posterior thigh muscles and soleus muscles; the small and medium gluteal muscles and the subscapular muscles may also be affected (Fig. 13). The sternocleidomastoid muscles are usually respected. Abnormalities of the cerebral white matter that may be associated should be detected on this examina-

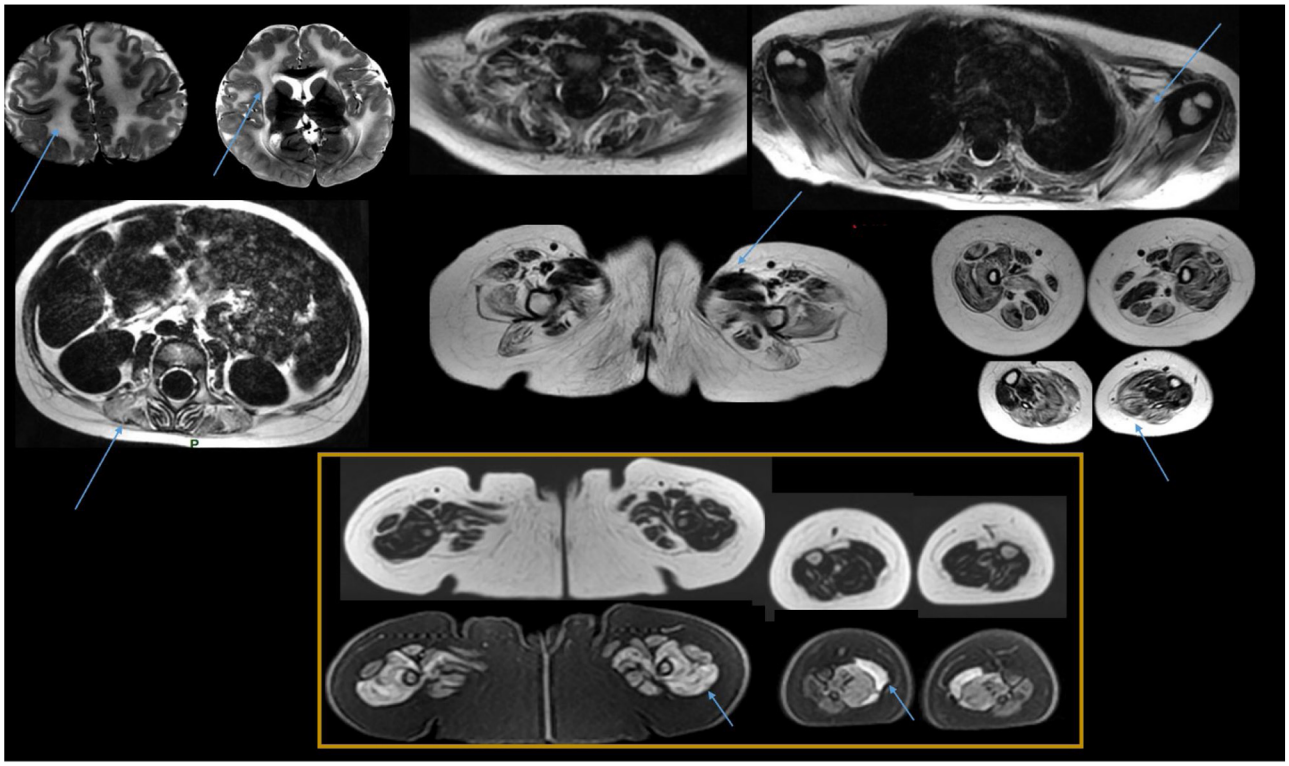

Fig. 13 – Whole-body muscle MRI in a patient with CMD with primary merosin deficiency (Axial T2 Dixon "Fat" and "Water" images, Imaging Department, Raymond-Poincaré Hospital, AP–HP 2016 for the yellow box and 2020 for the other images). Note the symmetrical damage concerning the subscapular muscles, the spinal muscles, the adductors, the anterior and posterior thigh muscles and the posterior leg compartment, more severe than the MRI realised 4 years before (yellow box) where T2 hyperintensities were noted. Also note the cerebral involvement with presence of T2 hypersignals in the periventricular and subcortical white matter.

tion, as they greatly orient the diagnosis when they are present; it consists in characteristic often asymptomatic T2 hypersignals in the periventricular and subcortical white matter; more rarely, polymicrogyria or focal cortical dysplasia preferentially in the occipital lobe may be found.

2.4.1.9.2. CMD with collagen VI impairment. This group includes two entities: Ullrich-type CMD, a severe form, and Bethlem-type CMD, a more moderate form (Fig. 14). The fatty infiltration of the affected muscles follows a characteristic ''concentric'' distribution, which is very useful for diagnosis, starting at the periphery of the muscle and progressing centripetally. Skeletal muscle involvement is diffuse and tends to begin in the axial musculature. Subsequently, it will concern in particular the sternocleidomastoid muscles, the muscles of the shoulder girdle (in particular the subscapular muscles), the upper limbs (in particular the triceps), the gluteus maximus muscles and all the muscles of the thigh, with the exception of the sartorius, gracilis and long adductor muscles, which are classically spared.

2.4.1.9.3. CMD with selenoprotein deficiency. This entity is also classified among the congenital myopathies (Fig. 15). It is characterized clinically by a stiff spine syndrome caused by severe damage of the axial musculature (a syndrome shared by many congenital myopathies and dystrophies, which is the reason why an algorithm has been described in the literature to help distinguish them), and severe ventilatory impairment often requiring recourse to permanent mechanical ventilation before adulthood. Peripheral skeletal muscle damage is preferentially and early on in the disease, involving the semimembranosus muscle (with relative respect for the other muscle groups of the thigh and leg at the beginning of the disease) and the lateral and medial gastrocnemius muscles (with sparing of the soleus and the tibialis anterior). As the disease progresses, all the muscles of the thigh and leg may be affected, with a predominant involvement of the anterior compartment of the thigh compared to the posterior compartment and the medial gastrocnemius muscle in the leg. Involvement of the sternocleidomastoid muscles is classic and severe. The masticatory muscles are preserved. The gluteus maximus muscles may also be affected [4,6].

2.4.1.10. Congenital myopathies. Congenital myopathies are a group of rare inherited myopathies comprising several entities defined based on characteristic lesions on muscle biopsy, e.g., protein inclusions, alterations in internal fiber structure or an increase in the number of centralized nuclei. Symptom onset is generally in the ante- or peri-natal period, but there are exceptions. More than thirty genes have been implicated in the pathogenesis of congenital myopathies; the mutations involved are of variable transmission (X-linked, autosomal

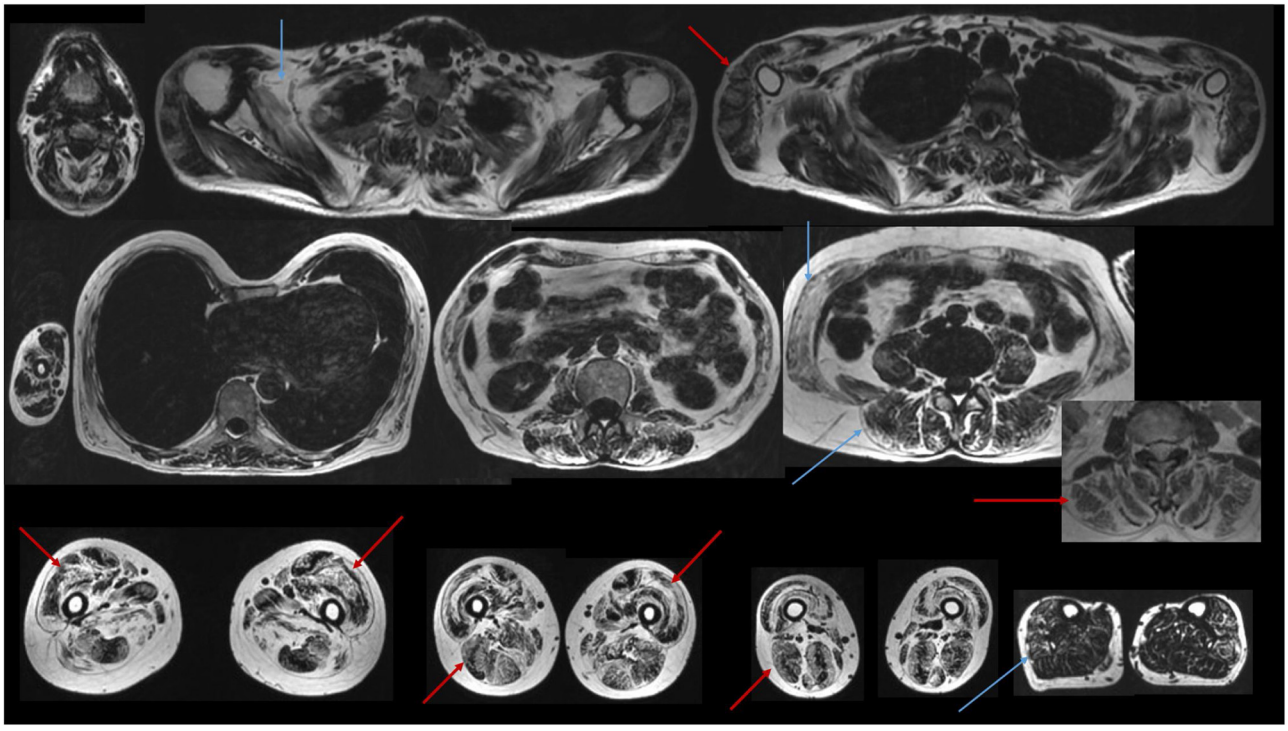

Fig. 14 – Whole-body muscle MRI in a patient with CMD with collagen VI impairment (Ullrich-type) (Axial T2 Dixon "Fat" images, Imaging Department, Raymond-Poincaré Hospital, AP–HP). Note (red arrows) the characteristic "concentric" distribution of the fatty degeneration for a given muscle (starting at the periphery of the muscle and progressing centripetally), very suggestive of this disease. Skeletal muscle involvement is diffuse, symmetrical, and concerns the axial musculature (rotator and extensor spinal muscles being equally involved), the sternocleidomastoid muscle, the subscapular and deltoid muscles for the shoulder girdle, the upper limbs and particularly the triceps, the abdominal girdle, and all the muscles of the thighs except for the gracilis, the sartorius and the long adductor muscles. Leg involvement is mild in this case and concerns the fibulars.

recessive or dominant). There are three main groups of congenital myopathies, according to the type of muscle fiber abnormality found under the microscope.

2.4.1.10.1. *Myopathies with cores*. Characterized by the presence of abnormal areas called "cores" within the muscle fibers, including two entities.

Myopathy with multi-minicores: same clinical and genetical entity as CMD with selenoprotein deficiency discussed above.

Myopathy with central cores: also called RYR 1 myopathy (named after the gene responsible for the disease). Symptoms usually develop in childhood but may develop at adult age. It is characterized by delayed motor development and signs of mild proximal weakness most pronounced in the pelvic girdle and hip. Orthopedic complications, in particular congenital hip dislocation and scoliosis, are common. A specific pattern of MRI involvement of the thighs has been described (Fig. 16), with involvement of the gluteus maximus, adductor magnus, vastus lateralis and intermedius and sartorius muscles; the rectus femoris, adductor longus, gracilis and semitendinosus muscles are spared. In the legs, there is almost selective involvement of the soleus muscles and, to a lesser extent, the fibulars. The posterior tibial, gastrocnemius and anterior tibial muscles are preserved. In the upper limbs, the biceps brachii, subscapularis and paravertebral muscles are affected, and more discreetly the masticatory muscles (lateral and medial pterygoid muscles, temporals, masseters). The sternocleidomastoid muscles are also spared [33].

2.4.1.10.2. *Myopathies with central nuclei*. Myopathies with central nuclei are characterized by an unusual location of the nuclei in the center of the muscle fibers. There are two entities.

Centronuclear myopathy: there are two forms: an autosomal dominant form (the most frequent) by mutation of the *DNM2* gene encoding dynamin 2 and an autosomal recessive form linked to a mutation of the *BIN1* gene encoding amphiphysin 2, which is very rare. In the *DNM2* form, whole- body muscle MRI shows thigh damage, which is moderate and affects the gluteus minimus, adductor longus and vastus intermedius muscles, and severe damage to the hamstrings (semitendinosus), while the vastus medialis and lateralis, sartorius and gracilis muscles are relatively unaffected. In the legs, there is severe distal damage to the medial gastrocnemius and soleus muscles. The posterior tibial muscle is spared. Concerning the facial and ear-nose-throat muscles, in severe phenotypes the temporal and lateral pterygoid muscles are affected, while the masseter and medial pterygoid muscles are spared. T2 signal abnormalities of the paraspinal and extensor muscles of the neck are possible. In the *BIN1* form, which is not well described in imaging, MRI may show diffuse involvement of the thigh

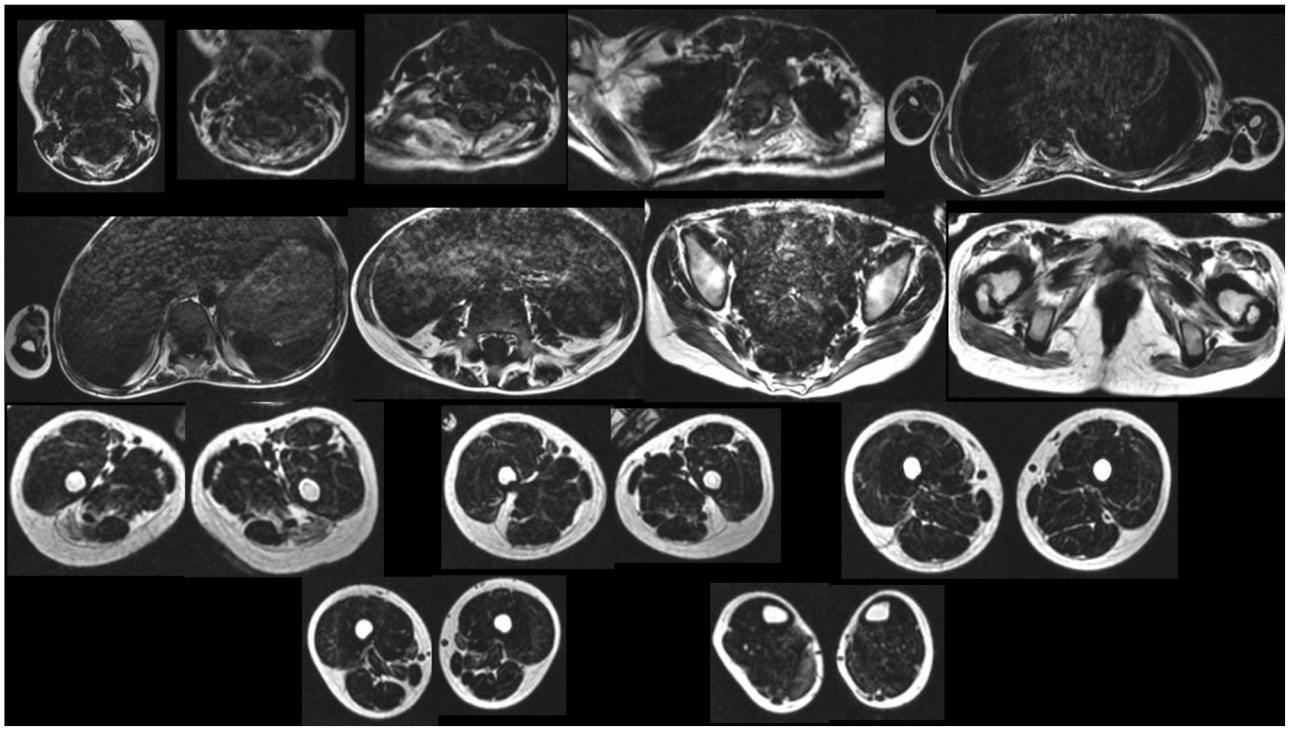

Fig. 15 – Whole-body muscle MRI in a patient with CMD with selenoprotein deficiency (Axial T2 Dixon "Fat" images, Imaging Department, Raymond-Poincaré Hospital, AP–HP, 2020). Note the severe scoliosis due to the damage of the axial musculature (predominating in the rotator muscles), causing the stiff spine syndrome noticed by the clinical examination. The sternocleidomastoid muscles are affected (which is a classical finding in this disease); The intercostal muscles are too. In the lower limbs, the semimembranosus muscles are severely affected (almost absents) with relative respect of the other muscles, especially the anterior compartment. The leg involvement begins with the gastrocnemius (with a mild fatty degeneration being present in the right medial gastrocnemius for this patient), sparing the soleus and the tibialis anterior.

muscles without topographical predominance. In the legs, involvement is predominant in the medial gastrocnemius, anterior tibial and fibular muscles, while the posterior tibial, soleus and lateral gastrocnemius muscles are relatively spared. The biceps brachii is damaged. The muscles of the face and the temporal muscles are spared.

Myotubular myopathy: in the thighs, the hamstring, adductor magnus, vastus medialis and vastus intermedius muscles are severely affected. The rectus femoris, gracilis, sartorius, adductor longus and vastus lateralis muscles are spared. In the legs, MRI shows predominantly soleus muscle involvement, while the medial gastrocnemius muscle is respected.

2.4.1.10.3. Myopathies with protein accumulation. Myopathies with protein accumulation characterized by the abnormal presence of protein clusters in the muscle fibers. There are two main classes.

Rod myopathies (nemaline): this entity covers a wide spectrum of congenital myopathies with the presence of nemaline bodies (rods) on muscle biopsy. About ten incriminating mutations have been described, of which three forms are the most frequent:

- Nemaline-2 myopathy by mutation of the gene coding for nebulin (the most common): MRI shows predominantly distal involvement with, in the leg, predominant involvement of the tibialis anterior (and to a lesser extent the soleus), while the gastrocnemius (especially the lateral) and fibularis are preserved. The thigh may not be affected (if affected, it predominates on the vastus intermedius and adductor magnus) [34]. Selective involvement of the lateral pterygoid (sometimes with tongue involvement) has been described [35];
- Nemalin-3 myopathy by mutation of the *ACTA1* gene encoding actin: MRI shows diffuse, moderate involvement, predominantly of the sartorius and adductor magnus muscles, while the gracilis and rectus muscles are usually spared. In the legs, the anterior tibial, fibular and posterior tibial muscles are predominantly affected, while the soleus muscle is less affected and the gastrocnemius muscles are spared;
- Nemaline-4 myopathy by mutation of the *TPM2* gene, encoding beta-tropomyosin: Rarely described in imaging, the deficit is thought to concern more particularly the masticatory muscles (temporal and pterygoid), the leg muscles (soleus and tibialis anterior); the rectus femoris, sartorius and gracilis muscles are relatively unaffected.

Myopathies with "cap" by accumulation of myosin storage: it is due to a mutation in the *MYH7* gene. On whole-body muscle MRI, the tibialis anterior muscle is the earliest and most

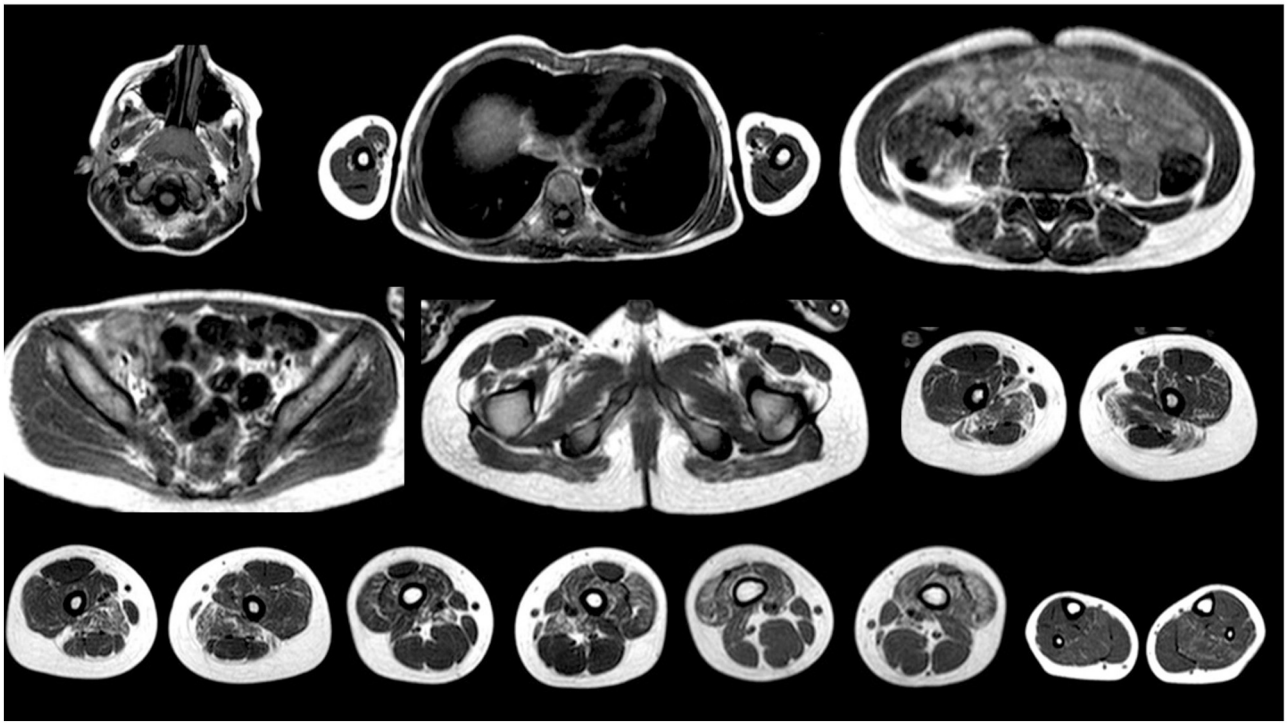

Fig. 16 – Whole-body muscle MRI in a patient with RYR 1 myopathy (central cores congenital myopathy) (Axial T2 Dixon "Fat" images, Imaging Department, Raymond-Poincaré Hospital, AP–HP, 2020). Note the symmetrical pattern of involvement, concerning the masticatory muscles (lateral and medial pterygoid muscles, temporals, masseters), the spinal muscles (mid involvement), the biceps brachii. The sternocleidomastoid muscles (not shown here) are spared. In the lower limbs, note for the thighs the involvement of the gluteus, adductor magnus, vastus lateralis and intermedius and sartorius muscles; the rectus femoris, adductor longus, gracilis and semitendinosus muscles are spared. In the legs, there is almost selective involvement of the soleus muscles (mildly affected in this patient and mostly in the left side) and, to a lesser extent, the fibulars. The posterior tibial, gastrocnemius and anterior tibial muscles are preserved.

severely affected, followed by the fibular, soleus and tibialis anterior muscles. In contrast, the lateral gastrocnemius is always spared. In the thigh, the vastus lateralis and intermedius muscles are the most affected, while the rectus femoris, adductor longus, sartorius and gracilis muscles are spared.

2.4.1.11. *Metabolic myopathies: the glycogenoses*. Glycogenoses are a group of diseases due to genetic abnormalities resulting in an alteration in the functioning of various key enzymes involved in glycogenolysis or glycogenesis, resulting in an abnormal elevation of glycogen or the production of structurally abnormal glycogen. Glycogen is essentially stored in the liver and muscles, and a distinction is made between forms with predominantly hepatic expression, characterized by repeated hypoglycemia and severe liver damage (these are glycogenoses type I, III, IV, VI, IX) and forms with a predominantly muscular expression producing a clinical picture of myopathies (glycogenoses of type II, III, V, VII, certain subtypes of IX, X, XIII, XIV, XV and 0). The most robust MRI pattern of damage has been described for type II glycogenosis, also called Pompe disease (Fig. 17) [36–38], and consists in characteristic muscle involvement of the tongue (tongue involvement is seen on MRI from the beginning of the disease, even when it is subclinical), paravertebral muscles, abdominopelvic girdle, shoulder girdle (involvement of the subscapularis and serratus major muscles in particular) and pelvic girdle (involvement of the adductor magnus muscle and of the glutei in particular). The thigh damage concerns mainly the muscles of the posterior thigh, vastus intermedius, vastus lateralis and vastus medialis. The leg muscles are classically spared in this disease.

2.4.2. *Acquired myopathies*

Given the frequently quite obvious context for toxic, endocrine and infectious myopathies, the aim of imaging them is mainly to guide needle biopsies, for follow-up or academic purposes. For idiopathic inflammatory myopathies, whole-body muscle MRI may (although not frequently) help distinguish between clinical entities, as some patterns of damage have been described [39].

2.4.2.1. *Inclusion body myositis*. It is the most common form of acquired myopathy in adults over 50 years of age. The disease manifests as a progressive (over years) loss of strength and atrophy, affecting asymmetrically the quadriceps, the

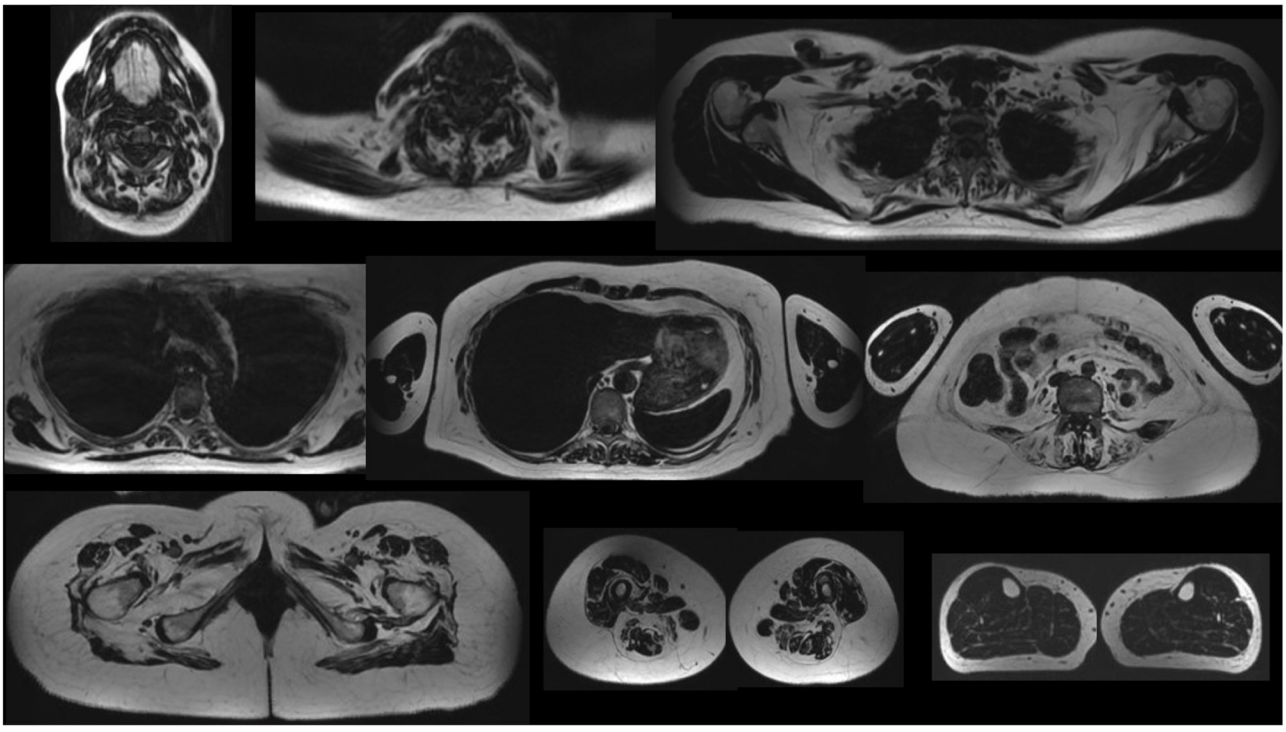

Fig. 17 – Whole-body muscle MRI in a patient with Pompe disease (Type 2 glycogenosis myopathy) (Axial T2 Dixon "Fat" images, Imaging Department, Raymond-Poincaré Hospital, AP–HP, 2022). Note the characteristic severe muscle involvement of the tongue (Mercuri 4, showing a totally fatty infiltration) but also the involvement of the shoulder girdle (concerning mostly the subscapularis and serratus major muscles with sparing of the deltoids and the other muscles of the rotator cuff), the paravertebral muscles, the abdominal and pelvic girdles (with involvement of the adductor magnus muscle and of the glutei in particular). The thigh damage concerns mainly the muscles of the posterior thigh and the vastus muscles. The leg muscles are spared (common finding in this disease).

finger flexors and foot extensors distally, the forearms, followed by involvement of the proximal muscles and of facial musculature with swallowing impairment. On MRI (Fig. 18), the fatty replacement is often significant (especially in the quadriceps) and inflammation in muscle fasciae might be seen.

2.4.2.2. *Dermatomyositis*. The clinical presentation consists in the association of skin involvement (which is frequent and may be the only manifestation of the disease) and a proximal symmetrical myopathy of acute or subacute onset. The skin involvement may be seen in the MRI, as well as the calcinosis that may complicate the disease. Regarding the muscle involvement, MRI shows a symmetrical perifascicular, perivascular and subcutaneous inflammation, as well as increase in intramuscular water volume on the T2 FS or STIR sequence. Although muscle fibers undergo necrosis and phagocytosis, there is little to no fat degeneration in muscles. The upward progression involves the neck flexors and pharyngeal muscles, and the muscle edema most commonly involves the quadriceps, triceps and deltoids. In the thighs, the damage concerns the three compartments (unlike selective anterior compartment involvement for inclusion body myositis).

2.4.2.3. *Immune mediated necrotizing myopathy*. This frequent myopathy affects mostly adults and presents as an acute, proximal and symmetrical muscle deficit. Except for cardiac involvement, there is traditionally no extra-muscular manifestations.

On muscle biopsy there are abundant necrotic fibers invaded or surrounded by macrophages and other regenerating basophilic fibers. Lymphocytic infiltrates are sparse. Anti-SRP and anti-HMGCoA reductase antibodies are specifically found in autoimmune myositis. On whole-body MRI, muscle inflammation is often extensive, especially in the lateral rotators, gluteals, medial and posterior compartment of the thigh. Pronounced edema in the vastus lateralis while the vastus intermedius is relatively unaffected, may be suggestive of anti-SRP autoimmune necrotizing myositis rather than other antibodies.

2.4.2.4. *Anti-synthetase syndrome*. Anti-synthetase syndrome is a systemic autoimmune disease associating pulmonary involvement, polyarthritis, fever, Raynaud's phenomenon and proximal and symmetrical subacute myopathic syndrome. Numerous anti-synthetase antibodies have been described in the literature, the most frequent being anti-Jo1, anti-PL-7, anti-PL-12, anti-OJ, anti-EJ, anti-KS, anti-Zo and anti-Ha.

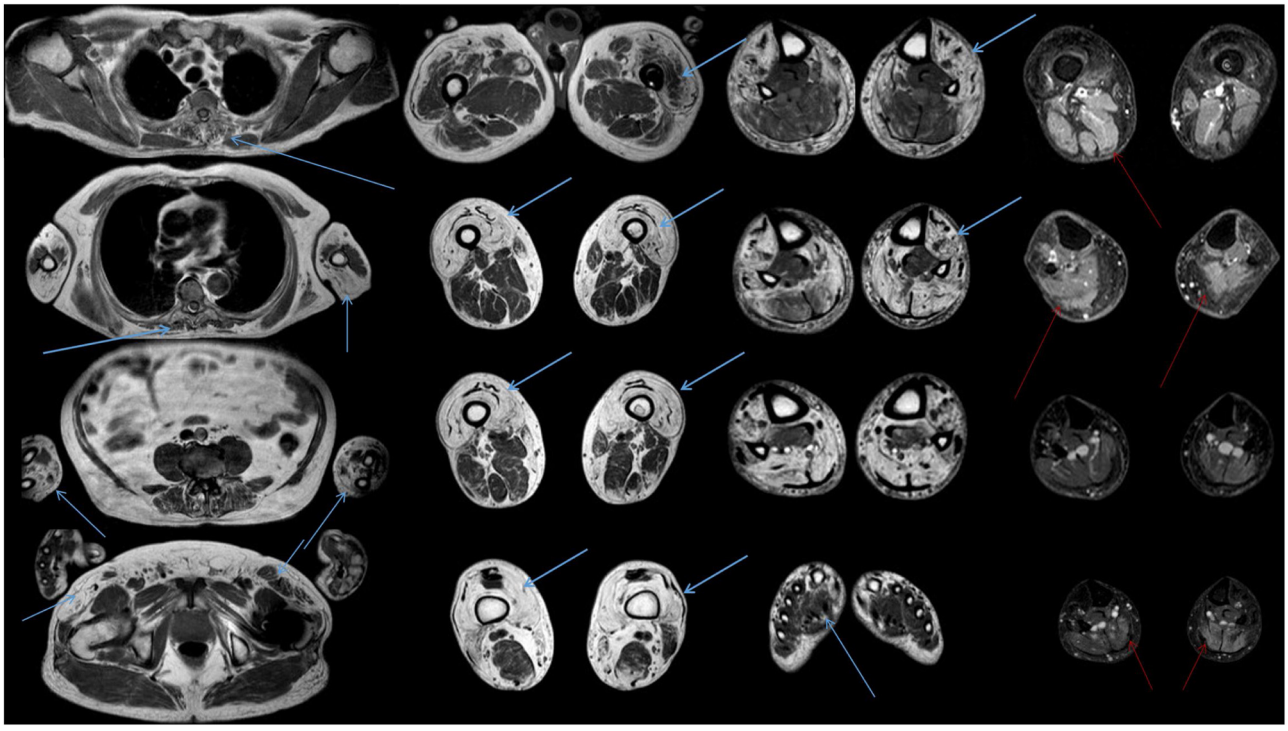

Fig. 18 – Whole-body muscle MRI in a patient with (Axial T2 Dixon "Fat" and "Water" images, Imaging Department, Raymond-Poincaré Hospital, AP–HP, 2022). Note the asymmetrical involvement of the quadriceps (most severe and common finding in this disease), the paraspinal muscles the forearms, the finger flexors and foot extensors distally. On "water" images, inflammation can be seen both in the muscle compartments affected and in the peri-muscular facias (red arrows).

3. Conclusion

Whole-body muscle MRI is very useful for the orientation of the diagnosis in suspected inherited and acquired myopathies. MRI protocols should allow exhaustive examination of the body musculature. A few patterns of involvement can efficiently guide diagnosis.

Disclosure of interest

The authors declare that they have no competing interest.

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