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Electrodiagnostic approach to the patient with suspected myopathy

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Myopathies often pose a diagnostic challenge. These somewhat uncommon disorders have many potential causes. Yet, a precise diagnosis is important, since myopathies are often treatable or have genetic implications. Fortunately, much is known about the clinical manifestations and pathogenesis of many myopathies. Using this knowledge as a foundation, a clinician can build a rational approach to the patient with suspected myopathy.

First, the history and physical examination are used to narrow the diagnostic possibilities and to direct the rest of the evaluation. In particular, the pace and distribution of the illness, potential risk factors (especially systemic disorders and toxins), and family history must be ascertained. Next, the appropriate laboratory tests are requested. Genetic studies as well as measures of serum chemistries, endocrine, and immunologic functions may be obtained. In most patients, an electromyogram (EMG) is then performed to help confirm the diagnosis of myopathy, to further narrow the differential diagnosis, and often to help designate a muscle for biopsy. In fact, histologic evaluation of a muscle biopsy specimen is often the final step in this constructed approach.

This paper describes how these steps are utilized in approaching the patient with suspected myopathy, with an emphasis on the EMG findings.

Symptoms and signs of myopathy and differential diagnosis

The symptoms and signs of myopathy are listed in Table 1. Symptoms often precede the signs and are usually attributable to proximal weakness. Patients may have difficulty rising from a chair (Fig. 1), climbing stairs, or combing their hair. Most patients present with symmetric, painless, and progressive,

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Table 1
Symptoms and signs of myopathy

Symptoms	Signs
Most common	Most common
Proximal muscle weakness (e.g. difficulty rising from a chair, climbing stairs, walking, or using cthe arms above the head)	Limb-girdle weakness Neck flexor weakness Waddling gait Trunk weakness
Less common	Less common
Myalgias Cramps	Muscle tenderness to palpation
Uncommon	Uncommon
Diplopia	Extraocular muscle weakness
Ptosis	Ptosis
Dysphagia	Weak palate, tongue, or both
Dysarthria	Nasal speech
Distal weakness (e.g., foot drop, hand weakness)	Footdrop; forearm or intrinsic hand muscle weakness
Fatigue	
Shortness of breath	Diaphragm weakness
Impaired grip release	Grip or percussion myotonia

limb-girdle and neck flexor weakness. In addition, those with longstanding myopathies often exhibit a component of trunk weakness affecting paraspinal or abdominal muscles and leading to a hyperlordotic posture and the inability to perform a sit-up.

In some disorders such as mitochondrial myopathies, bulbar and extraocular muscle weakness may occur. Distal weakness is a prominent feature of only a few myopathies such as myotonic dystrophy, facioscapulohumeral dystrophy (FSHD), inclusion body myositis (IBM), distal dystrophies, congenital myopathies, myofibrillar myopathy [1], and limb-girdle muscular dystrophy 2G (with telethonin mutations) [2,3]. IBM and FSHD often also exhibit some asymmetry. Respiratory muscles may be weakened in severe inflammatory myopathies and in some inherited conditions, resulting in dyspnea and hypercapneic respiratory failure.

In contrast to neurogenic diseases, loss of muscle bulk and attenuation of tendon reflexes only occur late in the course of myopathies. On the other hand, calf pseudohypertrophy may be seen early in some muscular dystrophies. Fasciculations do not occur in diseases of muscle. Although there is no sensory loss, patients with myopathy occasionally have muscle pain. It is important to note, however, that most patients with myalgias and no weakness usually do not have an identifiable myopathy. In myopathies, pain can also occur in the form of cramps at rest or during exercise. Abnormal pain during exercise can be due to defects in glycogen or lipid metabolism or in mitochondrial function. Ischemia, spinal stenosis, and other disorders can also cause this symptom. Cramps also occur in other conditions, includ-

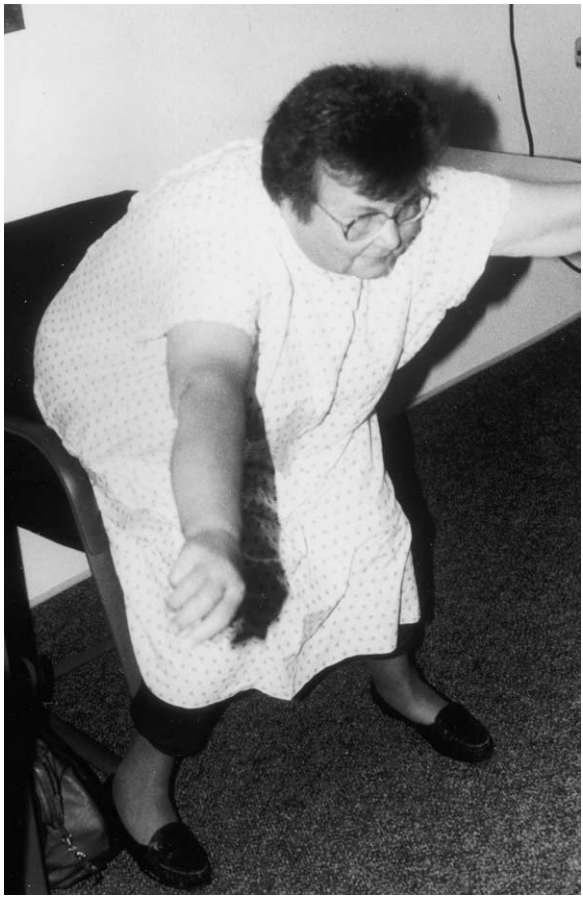

Fig. 1. A patient with proximal weakness from the myopathy of Cushing's syndrome exhibits difficulty rising from a chair. (*From* Lacomis D, Chad DA: Myopathic disorders. In: Sage JI, Mark NH, editors. Practical neurology of the elderly. New York: Marcel Dekker; 1996. p. 260, with permission.)

ing neuropathy and anterior horn cell disease and in metabolic conditions such as electrolyte disturbances. Sometimes, cramping (or stiffness) is actually a manifestation of myotonia.

Patients with myopathy may experience fatigue. Worsening of fatigue and weakness can occur later in the day, but this diurnal variation tends to be less prominent than in neuromuscular junction (NMJ) disorders. However, it may not be possible to differentiate a myopathy from a NMJ disorder without laboratory and electrodiagnostic testing. Although the presence of ocular or oropharyngeal involvement would favor a NMJ disorder such as myasthenia gravis (MG), such involvement also occurs in some myopathies. Alternatively, rare patients with MG have a purely limb-girdle

presentation [4]. In addition, Lambert-Eaton myasthenic syndrome (LEMS) may be misdiagnosed as a myopathy. However, LEMS patients usually have reduced tendon reflexes and autonomic symptoms such as a dry mouth while myopathy patients do not.

Some patients with suspected myopathy are asymptomatic. They may be referred to the neurologist because an elevated serum creatine kinase (CK) was incidentally discovered, or because a family member was found to have an inherited myopathy and the patient is at risk. Occasionally, an astute ophthalmologist or internist realizes that systemic symptoms, such as early onset cataracts (in myotonic dystrophies), cardiomyopathy (in some dystrophies), or impaired bowel motility (in mitochondrial neurogastrointestinal encephalomyopathy) may be the presenting features of an inherited myopathy, and requests a neurological consultation.

Laboratory testing

Typically, the most useful laboratory test available for identifying patients with possible myopathy is the serum CK. Almost all of the MM components (and most of the total measures) are derived from skeletal muscle. The CK is more specific to muscle than the serum aldolase, which is usually not worth measuring. The CK is usually elevated if there is muscle necrosis or a muscle membrane leak. Therefore, the majority of patients with inflammatory myopathies and aggressive muscular dystrophies have an elevated CK level (the degrees of elevated CK are noted in Table 2). It is important to note the CK levels may be normal in 3–36% of patients with inflammatory myopathies, especially after treatment, even if the disease is active. In contrast, some muscular dystrophy patients are asymptomatic despite an elevated CK [5].

The CK level is also elevated in some toxic myopathies and in hypothyroid myopathy. During rhabdomyolysis related to drugs, enzyme defects, infections, and other processes, CK levels are often elevated more than 50-fold. A minority of patients with mitochondrial myopathies [6,7] and almost all patients with acid maltase and debrancher deficiencies have an elevated CK level (Table 2) [8,9]. In other glycogen storage diseases, CK levels may be mildly to moderately elevated [10]. In lipid storage diseases, CK levels are normal to mildly elevated at rest [11]. The CK levels are normal in congenital myopathies and in chronic corticosteroid myopathy.

CK levels may be elevated after excessive exercise, intramuscular injections, seizures, and muscle trauma, and in viral illnesses, motor neuron disease (mild elevation), and malignant hyperthermia trait [12]. The CK level should not be measured soon after an EMG because the level may be elevated transiently; such increases are typically of low magnitude [13,14]. Athletes with elevated CK levels should not exercise for 7–10 days before the enzyme levels are reassessed [12].

Table 2
Creatine kinase (CK) levels and EMG findings in myopathies

Myopathy	Frequency of CK elevation[a]	Degree of CK elevation[b]	Typical EMG pattern (see text)
Inflammatory/Infectious			
PM/DM	+++–++++	+ to +++	1 or 2
IBM	++++	+ to ++	1 or 2[c]
Sarcoidosis	++	+ to ++	1 or 2
Viral	++++	++ to +++	1 or 2
Trichinosis	++++	+ to +++	1
Endocrine			
Hypothyroid	+++	+ to +++	1, 2, or 3
Hyperthyroid	0–+	NA	2
Cushing's syndrome	0	NA	2, rarely 1
Parathyroid disorders	0–+	NA	2
Toxic			
Chronic steroid myopathy	0	NA	2 or 4
Colchicine	++++	+ to +++	1 or 3 + neuropathy
Zidovudine/HIV	++++	+ to ++	1
Cholesterol-lowering agents	++++	to +++	1 or 3
Penicillamine	++++	+ to +++	1 or 2
Critical illness myopathy	++	+ to +++	1 or 2
Dystrophies			
Dystrophinopathies	++++	+++[d]	1
Emery-Dreifuss	++++	+ to +++	2 or 1
Limb-Girdle	++++	++ to +++	2 or 1
FSHD	+–++	+–++	2 or 1
Myotonic	+–++	+	3
PROMM	+++	+–++	3
Oculopharyngeal	+–++	+	2
Distal	++–+++	+–+++	2 or 1
Congenital myopathies	+	+	2[e]
Mitochondrial myopathies	+–++	+–++	1, 4
Acid maltase and debrancher deficiencies	++++	+–++	1, 2, or 3
Other glycogen storage diseases	+++	+–++[f]	1, 2, or 3
Carnitine and carnitine palmityl transferase deficiencies	+	+[f]	2 or 4

Abbreviations: DM, dermatomyositis; PM, polymyositis; IBM, inclusion body myositis; FSHD, facioscapulohumeral muscular dystrophy; PROMM, proximal myotonic dystrophy; NA, not applicable.

[a] 0 = never; + = <25%; ++ = 25–50%; +++ = 51–75%; ++++ = >75%.

[b] + = <fourfold; ++ = four- to tenfold; +++ = >tenfold.

[c] Long-duration high amplitude motor unit potentials often appear to be present.

[d] Declines with age.

[e] Except centronuclear myopathy (exhibits pattern 1).

[f] Highly elevated during episodes of myoglobinuria.

Patients are said to have idiopathic hyperCKemia if they have no muscle symptoms, normal strength, and normal electrodiagnostic and histological studies. In clinical practice, a muscle biopsy and even an EMG are considered optional in these patients depending upon one's index of suspicion that

a neuromuscular disease is present. Typically, these patients are males with 3- to 10-fold elevations in CK. Careful follow-up is indicated because about one-third of these patients are eventually diagnosed with a neuromuscular disorder [12].

In patients with a suspected myopathy, the other laboratory studies noted in the algorithm may be obtained (Fig. 2). Thyroid studies should be ordered in most patients. In patients with a suspicious body habitus or any other clinical features of Cushing's syndrome, a 24-hour urinary free cortisol level should be assessed. When a mitochondrial disorder is suspected, serum lactate and pyruvate should be measured. In selected patients, carnitine, vitamin E, and acid maltase (in WBCs) [8] could be assessed from blood samples. When an inflammatory myopathy is suspected, one can consider obtaining myositis-specific or myositis-associated antibodies, for example, anti-Jo-1 [15]. Human immunodeficiency virus (HIV) antibodies may be assessed in the appropriate setting. Ischemic exercise lactate testing may be useful in patients with exercise-induced myalgias or contractures if patients exercise appropriately during testing. However, the findings are nonspecific and a normal result does not exclude all inherited metabolic myopathies.

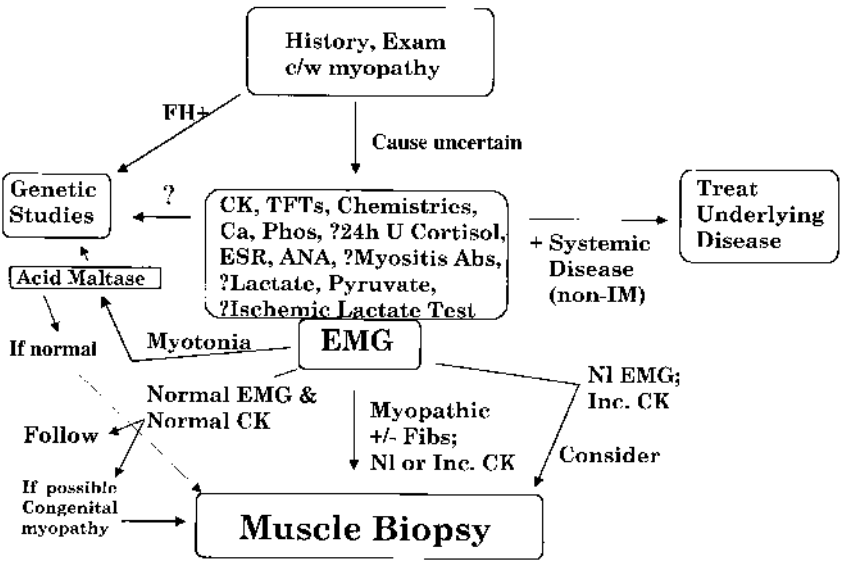

Fig. 2. An algorithmic approach to the evaluation of a patient with a suspected myopathy Other causes of weakness, such as neuromuscular junction disorders, central nervous system processes, disuse, connective tissue diseases, and orthopedic problems should also be considered initially. *Abbreviations:* c/w = consistent with; FH = family history; CK = creatine kinase; U = Urine; TFTs = thyroid function tests; ESR = erythrocyte sedimentation; ANA = antinuclear antibody; Abs = antibodies; IM = Inflammatory myopathy; Fibs = fibrillation potentials; Nl = normal; Inc = increased; ? = consider; + = present.

Based on the presence of any serologic abnormalities, a specific workup may be undertaken. For example, an elevation in calcium and reduction in phosphorus would prompt an evaluation for hyperparathyroidism. If a genetic disorder is highly suspected based on the clinical features, family history, and routine laboratory studies, DNA or protein testing may be the next appropriate test. For example, molecular testing is easily available on blood specimens for the following disorders: dystrophinopathies, myotonic dystrophy type 1, FSHD, oculopharyngeal dystrophy, and some mitochondrial syndromes. Molecular testing is available on a more limited basis for some glycogen storage diseases, calpain deficiency, and sarcoglycanopathies. For most other patients, EMG is the next step. Occasionally, musculoskeletal imaging is performed instead of or in addition to EMG.

Imaging studies

Skeletal muscle imaging has some utility in the evaluation of myopathies, especially in children [16]. Ultrasound may be used to detect evidence of neuromuscular disease and to select a site for muscle biopsy. Computed tomography can define anatomy and identify atrophy and hypertrophy patterns, and fatty replacement. However, magnetic resonance imaging (MRI) is the best imaging modality for skeletal muscle. In addition to defining anatomy, patterns of atrophy, and fatty infiltration, MRI also images in multiple planes and can detect changes of edema, inflammation, or necrosis. There is high sensitivity (89%) [17] for detecting abnormalities in inflammatory myopathies. Unfortunately, the changes are not disease specific and usually only one body region is imaged. Thus, EMG may be more advantageous because multiple sites can be sampled at equally high sensitivity. Although EMG findings are also nonspecific, there are a number of patterns that further narrow the differential diagnosis.

Electrodiagnostic testing

Nerve conduction studies (NCS) in patients with suspected myopathy should include at least one motor and one sensory recording. We typically examine one motor and sensory nerve in both an arm and a leg. The NCS are usually normal in proximal myopathies, especially since recordings are typically from distal muscles. If there has been substantial loss of muscle underlying the recording electrode, however, a low compound muscle action potential (CMAP) may be elicited. In addition, low CMAP amplitude may be present if there is an associated abnormality in muscle membrane depolarization.

In patients with low CMAP amplitudes and normal sensory responses, NMJ disorders, especially LEMS, and motor neuropathies and neuronopathies must be excluded. The needle EMG examination findings should distinguish a motor axonopathy or motor neuronopathy from a myopathy.

To assess for a NMJ disorder, 2–3 Hertz repetitive stimulation should be performed at baseline and after exercise. In addition, a single supramaximal shock should be delivered to a motor nerve at rest and after 10 seconds of exercise (LEMS test). The studies for LEMS and MG should be performed even if the motor responses are normal when there is a high index of suspicion and if the needle electrode examination findings do not explain the patient's weakness.

The needle EMG examination is the most important component of electrodiagnostic testing for myopathy; the four main components include assessment of (1) insertional activity, (2) spontaneous activity, (3) motor unit action potential (MUAP) morphology, and (4) recruitment [18]. The first two components are assessed with the muscle at rest. Damage to muscle fibers resulting from EMG needle movement leads to a brief electrical burst of insertional activity. Insertional activity can be abnormally prolonged if muscle is disconnected from the motor nerve terminal; (e.g., following denervation or muscle necrosis). It is also prolonged in some channelopathies, such as myotonic disorders, in the form of myotonic discharges [18]. Sometimes increased insertional activity is thought to be a normal variant, especially in muscular men [18]. Insertional activity can actually be decreased in periodic paralysis during an attack or if muscle is replaced by connective tissue as in chronic muscular dystrophies.

Except at the muscle endplate, spontaneous activity is abnormal and is due to the generation of action potentials from single muscle fibers that have lost their innervation (structurally or metabolically). It usually occurs in the form of *positive waves* and *fibrillation potentials*. Fibrillation potentials occur in denervating and myopathic diseases and are occasionally seen in NMJ and spinal cord disorders. They may also occur after muscle trauma. The types of myopathies in which fibrillation potentials occur tend to be more necrotizing, inflammatory, or both.

Complex repetitive discharges, (CRDs) due to ephaptic activation and discharge of groups of adjacent muscle fibers, are also a form of increased insertional activity. These occur in some chronic and inflammatory myopathies, but they are also seen in neurogenic disorders [18].

Evaluation of MUAPs is initially performed at low levels of voluntary activation so one or a few MUAPs are examined at a time. At least 20 MUAPs should be carefully examined. Each MUAP represents the summation of action potentials from a proportion of myofibers innervated by one axon from a single anterior horn cell (part of a motor unit). In myopathic processes, the duration of the MUAP is less than in normal muscles because of structural or functional loss of myofibers from a motor unit. For the same reason, the amplitude may also be reduced compared to normals. Due to a loss of synchrony in depolarization, the MUAPs are often polyphasic. In very chronic myopathies, such as IBM and chronic polymyositis, some long duration MUAPs may occur. Long duration MUAPs are more typical after reinnervation, but they may also be caused by desynchronization of single

fiber potentials within the motor unit, perhaps due to myofiber regeneration [19]. None of the above findings are specific to myopathy, but they are characteristic along with early recruitment (described later). NMJ disorders and nascent motor units undergoing early reinnervation, for example, may also exhibit short duration MUAPs.

It is relatively easy for an electromyographer to detect spontaneous activity. It is somewhat more difficult to recognize MUAP changes of myopathy. The findings are subtler in mild cases and in young patients in whom differences from normal to abnormal MUAP may not be profound. In addition, one must be familiar with normal MUAPs from many muscles from different age groups before knowing what is abnormal. This interpretation is generally subjective. Quantitative methods are available and will be discussed, but most EMG laboratories do not utilize such methods routinely.

The final component of the EMG is assessment of MUAP recruitment. In patients with myopathy, motor units are not lost; therefore, recruitment may be normal for a certain level of activation. In contrast to normals, however, more MUAPs are required to generate the same degree of force. Thus, recruitment of MUAPs may be *early* or *rapid*. Early recruitment is more recognizable subjectively as the degree of weakness increases. At the end stage of a myopathy, however, recruitment may actually be reduced.

Planning the EMG

The muscles that are most electrically affected are typically also the weakest. In most myopathies, these are the proximal muscles. Therefore, most studies should include several proximal muscles from an arm and a leg as well as a distal muscle. A paraspinal muscle, a most proximal muscle, should always be studied in patients with a suspected myopathy. Occasionally, paraspinal muscles alone may be electrically abnormal (as in some inflammatory myopathies, glycogen storage diseases, and neck extensor myopathy) [20–22]. Paraspinals may also harbor myotonia and CRDs in patients with myotonic and glycogen storage disorders when limb muscles do not. We typically examine one or more thoracic paraspinal muscles and avoid lumbar paraspinals since the latter are more typically affected by radiculopathy and may provide false positive results. In patients with distal involvement, more distal muscles (such as finger or forearm flexors in IBM) also warrant extensive study. In all patients, a unilateral study should be performed, allowing a potential muscle biopsy to be performed on the contralateral limb.

Quantitative studies

Especially in cases in which the needle EMG findings are equivocal, and it is not certain if the MUAPs are short in duration, quantitative studies may be helpful. Typically, duration is the MUAP parameter that is measured in myopathies, but amplitude, turns, polyphasia, and recruitment may all be quantitated [23]. Methods of computer-assisted quantitation are now widely

available on more sophisticated EMG machines. MUAPs must still be carefully isolated and recorded with a stable baseline; the concentric needle electrode must be close to the fibers of the motor unit resulting in a rise time of less than 500 microsecond (μs); the individual MUAP is captured; and typically the cursors must be placed appropriately before the measures are obtained by the computer. Twenty MUAPs are assessed and then mean and standard deviations for the parameters under study are generated. Age-matched normative data must also be available for comparison. More sophisticated automatic digital systems for quantitative analysis of waveforms and recruitment is available and used most frequently in research (reviewed by Dorfman and McGill [23]).

Single fiber EMG

Single-fiber EMG is usually not performed in myopathy evaluations, but it might be performed when the differential diagnosis includes a NMJ disorder. Increased jitter and blocking may be identified in myopathies, especially with inflammatory and necrotizing processes. Fiber density can be normal or increased [24].

EMG patterns with histopathologic correlation in various myopathies

The EMG findings of myopathy are not specific. They complement the clinical examination and laboratory tests. In general, there is a concordance (about 80–95%) of EMG and muscle biopsy findings. The largest quantitative study of 188 patients with myopathy disclosed that 87% had EMG features of myopathy and 79% had myopathic histopathology [25]. In another study assessing the accuracy of clinical diagnosis using histopathological features as the gold standard, the overall accuracy was only about 50%. However, more than 68% of patients with either an elevated CK or myopathic EMG had myopathic histologic changes on muscle biopsy specimens [26].

Although a myopathic EMG is not specific, there are patterns that point toward a certain disorder or group of disorders. These patterns are also predictive of muscle histopathologic findings. In these described patterns, myopathic MUAPs will refer to short duration, low amplitude, polyphasic MUAPs. However, as noted above, myopathic MUAPs may occur in other conditions.

Pattern 1: Myopathic MUAPs with fibrillation potentials (Table 2)

This pattern is most commonly seen with idiopathic inflammatory myopathies such as polymyositis (PM), dermatomyositis (DM), and IBM (Figs. 3 and 4). Essentially all patients with IBM and 45% to 74% of patients with PM and DM exhibit this pattern; the rest exhibit Pattern 2 (described below) [27,28]. Myotonic discharges or CRDs are sometimes seen also [29]. These

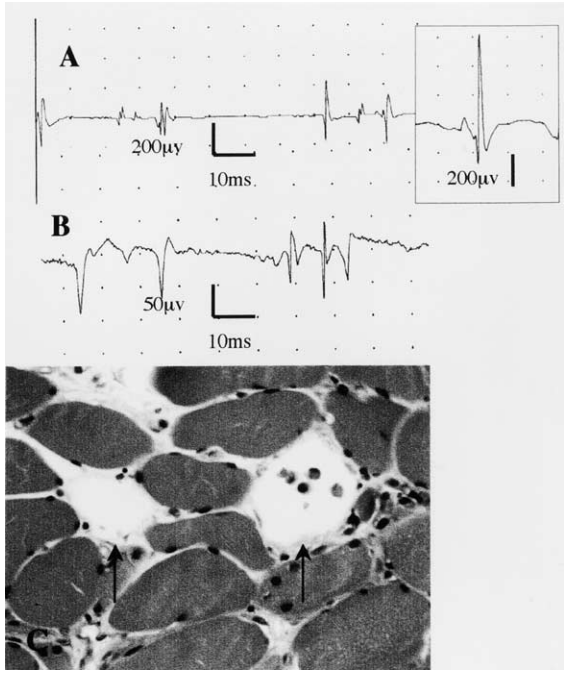

Fig. 3. EMG findings and histopathologic correlation in a patient with polymyositis (A) During voluntary activation, low amplitude, short duration motor unit potentials (MUAPs) are noted in the deltoid muscle. The insert illustrates a normal MUAP for comparison. (B) At rest, positive sharp waves and fibrillation potentials are seen. (C) A needle muscle biopsy specimen obtained from the deltoid muscle immediately after the EMG reveals two necrotic ghost fibers (*arrows*). One contains macrophages. A regenerating fiber is also present (below the necrotic fiber on the right). Mild endomysial inflammation was present elsewhere in the specimen.

disorders are differentiated based upon the histologic as well as EMG and clinical features. PM and IBM are both characterized by endomysial CD8 + inflammation. Vacuoles containing Congo red positive and filamentous material (ultrastructurally) occur in IBM (Fig. 4). DM is associated with a perivascular, perimysial B-cell inflammatory response and microangiopathy with perifascicular atrophy and degeneration.

Viral myositis, sarcoid myopathy [30], trichinosis [31], and penicillamine-induced inflammatory myopathy [32,33] might also exhibit this pattern, but childhood myositis from influenza may feature Pattern 2 [34]. Non-inflammatory necrotizing myopathies, such as cholesterol lowering agent myopathy [35], as well as hypothyroid myopathy, commonly produce Pattern 1 [36,37]. In hypothyroid myopathy, the fibrillation potentials are presumed to be due to sarcolemmal membrane instability. Fibrillation potentials are sometimes encountered in hyperthyroid myopathy [38], while histologic changes may be minimal. In patients with HIV infection with or without zidovudine treatment, Pattern One is seen [39–41]. In critical illness myopa-

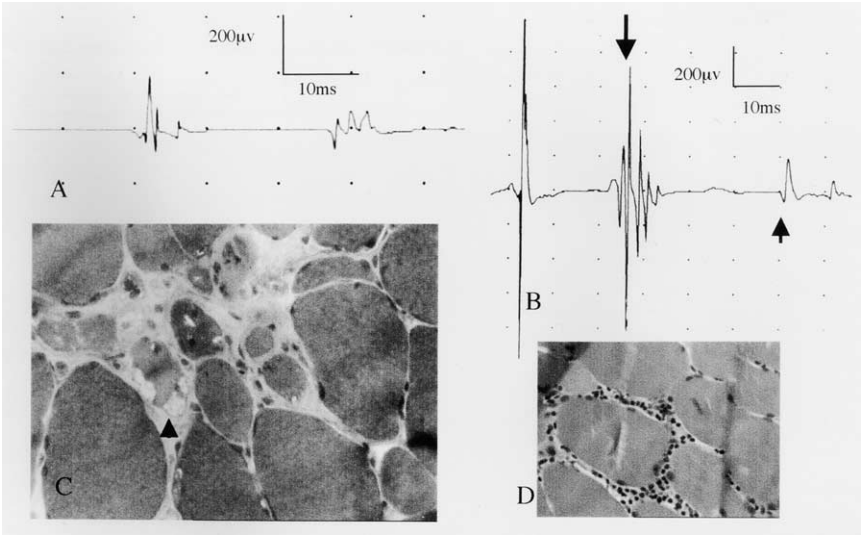

Fig. 4. EMG and histopathologic correlation from a patient with inclusion body myositis. (A) Short duration, polyphasic MUAPs are recorded from the biceps brachii. Positive waves and fibrillation potentials were also noted (not shown). (B) A mixed population of MUAPs was present in the vastus lateralis. A low amplitude, short duration MUAP (*short arrow*) is depicted. A polyphasic MUAP (*longer arrow*) has a normal duration for age (13ms), but it appears as a long duration MUAP (unless measured) when viewed adjacent to a short duration MUAP. (C) A muscle biopsy specimen from the biceps brachii reveals chronic changes (endomysial fibrosis and a variation in fiber sizes) and myofibers containing multiple rimmed vacuoles (*arrow*). (Gomori trichrome, cryostat section.) (D) Endomysial lymphocytic inflammation is shown on an H & E stained paraffin section.

thy, fibrillation potentials may or may not occur. When present, it is uncertain if the fibrillation potentials are caused by myonecrosis or muscle membrane dysfunction [42].

Of the inherited disorders, many muscular dystrophies exhibit this pattern [43–47]. They are often ultimately distinguished by immunohistochemical or molecular studies. Centronuclear myopathy is the only congenital myopathy featuring Pattern 1 [48]. Pattern 1 is also seen mainly with exacerbations of inherited metabolic disorders such as McArdle's Disease [10].

Additionally, patients with chronic inflammatory myopathies, especially IBM and sometimes chronic PM and DM, exhibit a combination of longer and short duration MUAPs (mixed pattern) in the same muscle (Fig. 4). However, quantitative studies may only identify a myopathic pattern [49]. A mixed pattern is also occasionally noted in muscular dystrophies in which long duration MUAPs are thought to be due to innervation of regenerating muscle fiber segments [46]. The combination of short and long duration MUAPs may also occur if there is a coexisting neurogenic process such as in colchicine neuromyopathy, amyloidosis (Fig. 5), or vasculitis. In this sce-

nario, the long duration MUAPs tend to occur in the reinnervated muscles, and nerve conduction studies reveal sensory as well as motor abnormalities.

Pattern 1 is also seen in very unusual disorders such as adult rod body, myofibrillar, and amyloid myopathies, and in carnitine deficiency. These disorders may also exhibit Pattern 2. Often, these disorders are not expected clinically, and they are diagnosed pathologically. Overall, the likelihood of making a specific histopathological diagnosis is probably highest in patients with this EMG pattern [26].

Pattern 2: myopathic MUAPs without fibrillation potentials (Table 2)

This pattern is most commonly seen in non-inflammatory, nonnecrotizing myopathies, including most of the endocrine myopathies [36–38,50,51], congenital myopathies, mitochondrial, and other metabolic myopathies [7,52,53], toxic myopathies [42,54], and some muscular dystrophies. The dystrophies typically include the following: oculopharyngeal dystrophy, FSHD,

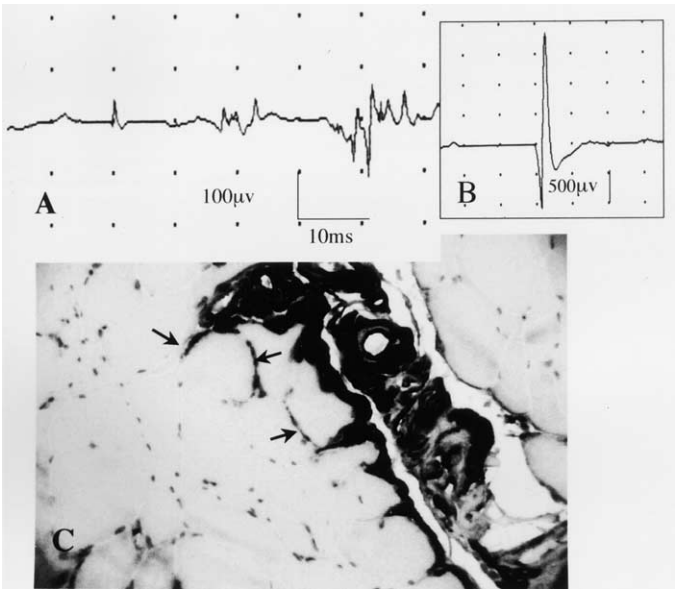

Fig. 5. EMG and histopathologic correlation from a patient with light chain amyloidosis and neuromyopathy. (A) Short duration, low amplitude, polyphasic MUAPs are present in the deltoid muscle. Early recruitment was also noted, but no fibrillation potentials were seen. (B) A high amplitude, slightly long duration MUAP from the tibialis anterior muscle is shown. Nerve conductions also revealed evidence of a length-dependent sensorimotor axonal polyneuropathy. (C) A muscle biopsy specimen from the deltoid muscle reveals the presence of lambda light chains (immunohistochemistry) in the perimysial connective tissue surrounding blood vessels and encasing myofibers (*arrows*). Necrosis or inflammation was not seen. Mild atrophy of Type 1 and Type 2 fibers is also present.

and some distal dystrophies [43,55,56]. Limb-girdle dystrophies, a heterogeneous group of autosomal dominant and recessive disorders, tend to be more indolent than the dystrophinopathies, and presumably are associated with less muscle necrosis. Hence, electrically, they exhibit Pattern 2 more often than Pattern 1 [57,58].

Treated inflammatory myopathies may also exhibit this pattern even if the myositis is active. Thus, Pattern 2 does not differentiate between active (partially treated) myositis and corticosteroid (CS) myopathy, but if Pattern 1 is seen in myositis patients treated with CS, then CS myopathy is excluded.

Pattern 3: myopathic MUAPs with myotonic discharges (Table 2)

This pattern is most commonly seen in myotonic dystrophies, either the classic myotonic dystrophy type 1 or the more recently identified proximal myotonic myopathy (PROMM) [59]. In these disorders, sarcolemmal membrane channel defects probably cause myotonia. However, the defects have not yet been clarified, especially in PROMM [60]. Myotonia, along with CRDs, is also seen more focally in acid maltase deficiency, especially in the paraspinal muscles. However, acid maltase deficiency often also manifests with Patterns 1 and 2 [8,61,62]. In infantile and childhood cases, pathologic studies reveal a myopathy with autophagic (acid phosphatase reactive) vacuoles containing glycogen. In adult cases, the biopsy findings may reveal a milder vacuolar myopathy, but normal findings are common [8,62]. The cause of the myotonia is not certain. Fiber splitting may lead to the CRDs. CRDs also occur with debrancher deficiency [52], and other glycogen storage diseases can exhibit this pattern focally [63].

Myotonia is also encountered focally in inflammatory myopathies, colchicine neuromyopathy [64,65], cholesterol-lowering agent, and less often hypothyroid myopathy. Myotonic discharges have also been reported in carnitine myopathy [11]. Myotonic discharges without myopathic MUAPs are seen in myotonia congenitas, paramyotonia congenita, and hyperkalemic periodic paralysis.

Pattern 4: Normal electromyogram (EMG) (Table 2)

About 35–50% of patients with mitochondrial myopathy have a normal EMG [6,7]. Normal studies may also occur in congenital myopathies, since subtle abnormalities may be harder to recognize due to the nature of the test and the difficulty performing extensive studies in children. Normal studies may also occur in lipid and glycogen storage disorders between attacks. Other myopathies sometimes associated with normal EMGs are listed in Table 2.

Clinical follow-up, a repeat EMG, or quantitative EMG is indicated in patients with a normal EMG and progressive or persistent weakness that could be of myopathic origin. Obtaining a muscle biopsy specimen is also a consideration (Fig. 2).

Summary

Uncovering the cause of a suspected myopathy may be challenging. However, a careful approach starts with utilizing the wealth of available information regarding the clinical and laboratory features of myopathy. Electrodiagnostic testing is then obtained (in most cases). Recognition of the pattern of EMG findings in light of the clinical and laboratory features should narrow the differential diagnosis and dictate the next steps in the evaluation. Histopathologic or molecular studies, or both may follow. Ultimately, this approach usually allows the clinician to make the correct diagnosis.

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