Dermatomyositis Associated with Lyme Disease: Case Report and Review of Lyme Myositis

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Myositis due to the etiologic agent of Lyme disease, *Borrelia burgdorferi,* has been reported nine times in the English-language literature; there has been but a single report of exacerbation of dermatomyositis due to *B. burgdorferi* in a patient with known dermatomyositis. Multiple infectious agents, but not *B. burgdorferi,* have been hypothesized to trigger dermatomyositis. We report the first case of dermatomyositis that appears to have been triggered by *B. burgdorferi.* This case involved an individual from Westchester County, NY, who presented with skin lesions suggestive of erythema migrans and who was seropositive for Lyme disease. He soon developed a clinical syndrome suggestive of dermatomyositis: periorbital edema, dysphagia, proximal muscle weakness, and a markedly elevated level of creatine phosphokinase. We also review the clinical presentation and response to treatment of patients with Lyme myositis.

Lyme disease is caused by the spirochete *Borrelia burgdorferi* and is the most common tick-borne disease in the United States [1]. It is a multisystem disease affecting the skin, the joints, the cardiovascular system, and the central and peripheral nervous systems. The reticuloendothelial and gastrointestinal systems are less commonly involved [1, 2]. Although myalgias are common presenting symptoms [2], only nine cases of myositis have been reported in the English-language literature [3–8]. We present a case of early-stage Lyme borreliosis in a patient who subsequently rapidly developed dermatomyositis despite treatment with antibiotics for Lyme disease, and we review the literature on Lyme myositis.

Case Report

A 52-year-old male resident of Westchester County, NY, was in his usual state of health until 15 days prior to admission (in July 1989), when he developed fever, chills, and a single area of rash (round, red eruption) on the posterior aspect of his right elbow. Three days before the onset of these symptoms, he had mowed his lawn and grass clippings had blown onto his skin. No tick bite was observed. Two days after onset he had a tooth extracted but did not receive antibiotic prophylaxis. Eight days prior to admission he went to a local medical clinic because of fever and multiple, discrete rashes. Serologic testing for Lyme disease was performed, but no antibiotic therapy was initiated. The following day the patient was seen in a private clinic by one of the authors (N. G.), at which time a clinical diagnosis of Lyme disease was made and another test for antibodies to *B. burgdorferi* was performed. At that time 12 erythema migrans lesions measuring ≤ 20 cm^2 were noted; there was no evidence of facial swelling. The patient started receiving therapy with doxycycline (100 mg orally twice a day). Six days later (16 July 1989), with the development of periorbital edema and neck swelling, he was admitted to Westchester County Medical Center. At the time of admission the patient had no complaints of muscular weakness and noted pains only on the right side of the neck. He had no known drug allergies and on admission was taking doxycycline (100 mg twice daily) and terfenadine (60 mg three times daily).

Physical examination revealed a temperature of 38°C. There were discrete, annular, hot, edematous, erythematous macules over the right side of the face and neck as well as massive edema and erythema of the periorbital area bilaterally (figure 1). The right aspect of his neck was edematous and tender. The pharynx appeared to be normal. He had other discrete, annular, erythematous macules over his trunk and extremities. A total of 12 lesions (all larger than 10 cm^2) were found. The presence of a dark, purplish rash over the knuckles of his left hand was consistent with Gottron's sign. No edema or weakness in his extremities, cardiac murmur, or evidence of periodontal or other dental disease was noted.

Laboratory studies done on admission showed a white blood cell count of 5.1×10^9/L with a normal differential count. No eosinophilia was noted. The hemoglobin level was 155 g/L and the platelet count was 256×10^9/L. Electrolyte levels were all within normal limits. Liver function studies revealed the following values: aspartate aminotransferase, 123 U/L; alanine aminotransferase, 44 U/L; and lactate dehydrogenase, 482 U/L. The creatine phosphokinase (CPK) level was 5,335 U/L (100% MM fraction). Results of coagulation studies were normal, and the erythrocyte sedimentation rate (ESR) was 46 mm/h. A test for antinuclear antibody

Received 26 April 1993; revised 29 June 1993.

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Clinical Infectious Diseases 1994;18:166–71

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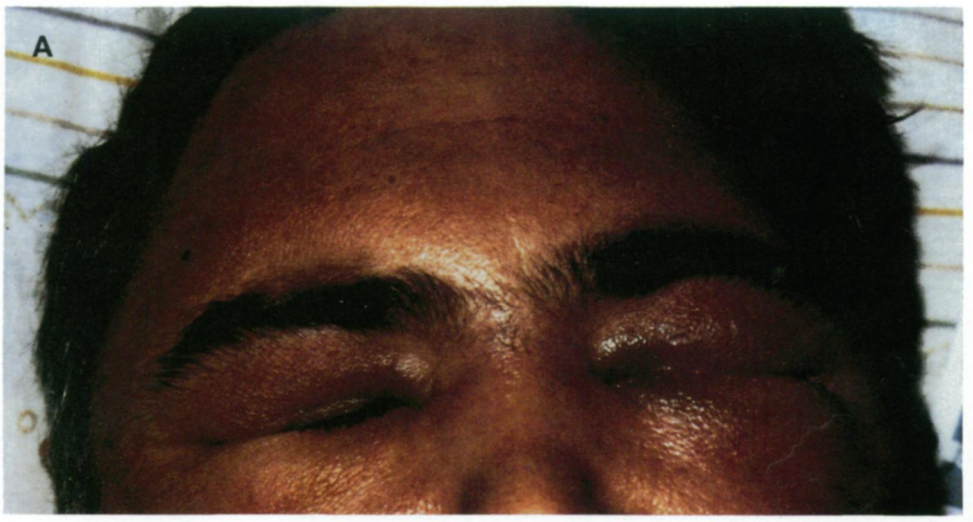


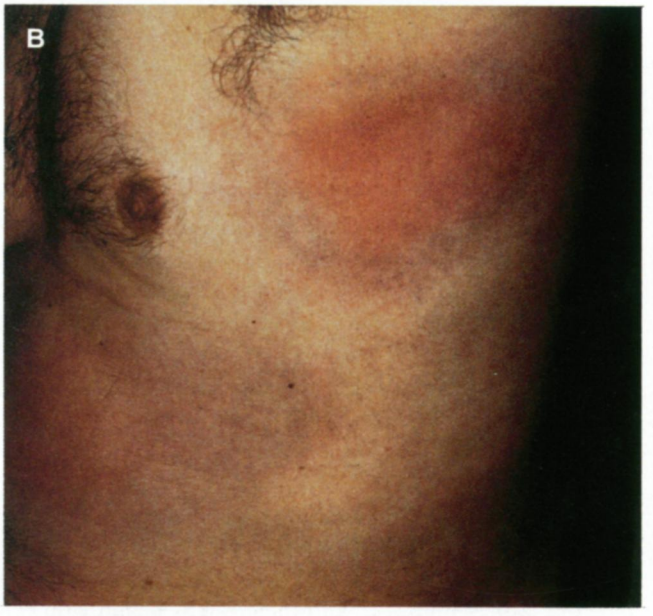
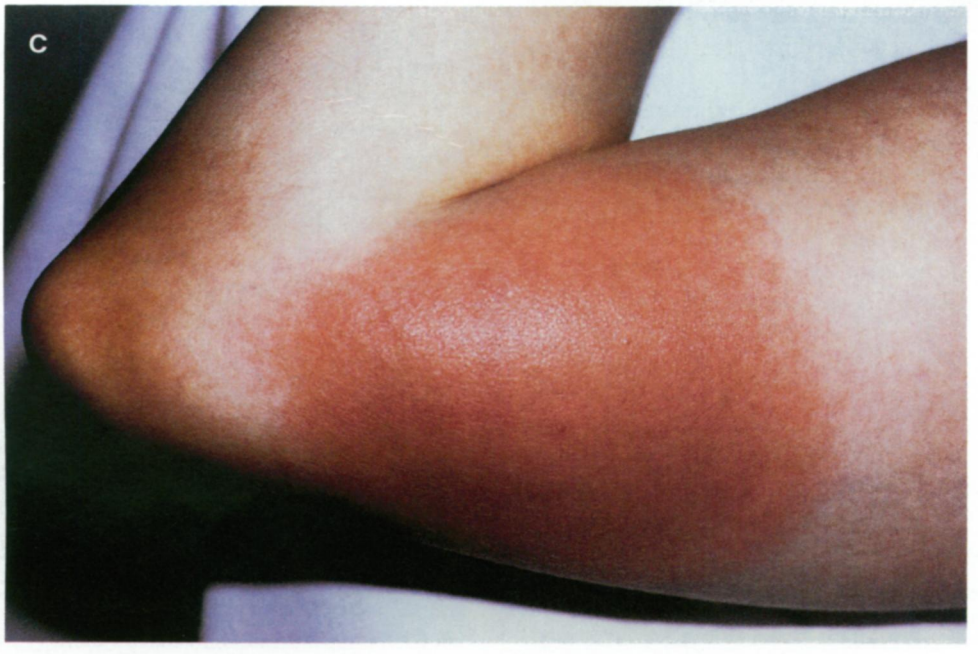


Figure 1. *A*, periorbital erythema and edema, suggestive of heliotrope rash; *B*, multiple erythema migrans lesions on the trunk; *C*, close-up of erythema migrans lesion on arm.



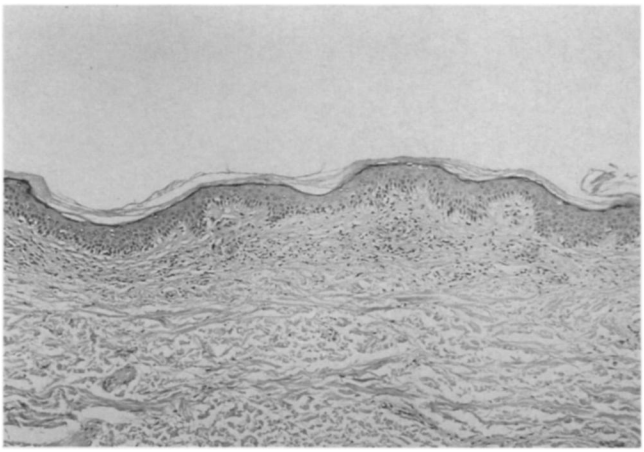


Figure 2. A photomicrograph of the skin biopsy specimen shows intact epidermis, mild basal-layer vacuolation, and papillary dermal perivascular lymphocytic infiltration (stain, hematoxylin and eosin; original magnification, × 100).

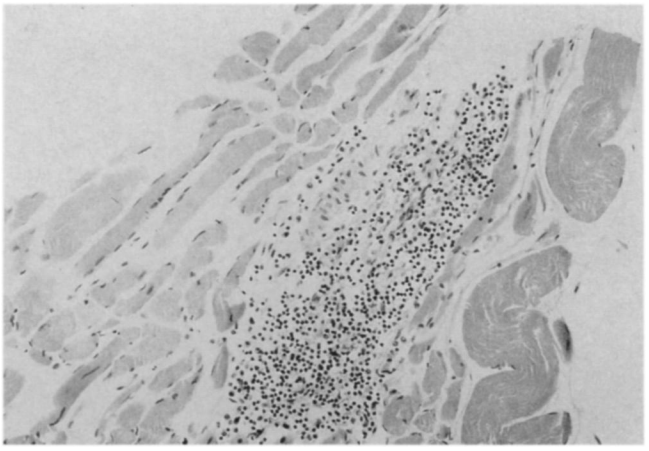


Figure 3. A photomicrograph of the deltoid muscle biopsy specimen shows an aggregate infiltrate of lymphoid cells and macrophages (stain, hematoxylin and eosin; original magnification, × 200).

(ANA) was positive at 1:320 and produced a speckled pattern. The urinalysis revealed no abnormalities and was negative for myoglobin. Chest radiographic findings were normal, and an electrocardiogram revealed a normal sinus rhythm with a left anterior fascicular block; there were no changes suggestive of myocarditis.

At the time of admission, a diagnosis of Lyme disease was made on clinical grounds. Both of the ELISAs for evidence of Lyme disease that had been performed prior to hospitalization were positive, as was a subsequent ELISA for antiborrelial IgM (titer, 682; titer of >100 considered positive). Coincident collagen vascular disease was suspected because of the skin findings and the high CPK level. Doxycycline and terfenadine were withdrawn, and therapy was begun with ceftriaxone (1 g iv every 12 hours), diphenhydramine (50 mg iv every 6 hours), and methylprednisolone (40 mg·iv every 6 hours).

A skin biopsy on day 2 of hospitalization revealed an intact epidermis with a dermal lymphoid cell response and a perivascular lymphocytic infiltrate (figure 2). Dieterle's stains of the skin preparation were negative. Results of serial serologies for Lyme disease by ELISAs (Clinical Sciences, Whippany, NJ) are noted in table 1. A western blot (Mardex Diagnostics, Carlsbad, CA) was positive for both IgM (41- and 39-kD bands) and IgG (75-, 66-, 60-, 41-, 39-, 31-, and 20-kD bands and others).

Table 1. Results of serial ELISAs for IgG and IgM.

Date of ELISA	Titer of IgM*	Titer of IgG†
18 July 1989	682	314
31 July 1989	355	420
24 August 1989	<40	358

* Titer of ≥100 considered positive.
† Titer of ≥130 considered positive.

Ceftriaxone was withdrawn after 3 days, and penicillin G (3 million units iv every 4 hours) was administered instead for 11 days. The skin lesions began to fade by day 5, but he continued to have erythema and edema on his face and neck and was unable to open his eyes because of periorbital edema. On day 6 he began to complain of dysphagia and dysphonia, and 4 days later he first noted proximal muscle weakness. A neurological examination revealed grade 4/5 weakness of the proximal upper and lower extremities. No sensory loss was observed. The CPK rose to a peak level of 11,130 U/L on day 9. A biopsy of the deltoid muscle performed 12 days after admission demonstrated an increased number of mononuclear inflammatory cells in the interstitium and several minute inflammatory aggregates, composed mostly of lymphoid cells, in the perimysial collagen (figure 3). Dieterle's staining of the specimen did not reveal spirochetes. Histochemical studies of the muscle revealed no evidence of a primary dystrophy or primary muscular metabolic abnormality. An electromyogram and a nerve conduction study of the left leg demonstrated a lumbosacral radiculopathy of the L4-L5 segment. Gallium scan findings were normal. Cultures of the patient's blood and the skin and muscle biopsy specimens in modified Barbour-Stoenner-Kelly medium that were held for 6 months were negative for *B. burgdorferi*.

The patient's dysphagia worsened, and a feeding tube was required. Esophageal motility testing revealed decreased contractility in the pharynx, 3–4 cm proximal to the upper esophageal sphincter. Upper gastrointestinal endoscopy revealed an esophageal ulcer 2 cm in diameter and 1.5 cm deep. Biopsy showed a benign ulcer. Therapy with ranitidine (150 mg/d), sucralfate (1 g 4 times per day), and antacids (as needed) was started. The steroid therapy was changed to ad-

Table 2. Laboratory evaluation of 10 cases of Lyme Myositis.

Case no. [reference]	CPK level	Electromyographic findings*	Findings of Lyme serology (method)	Histopathology (site, finding)	Results of silver staining	Culture results
1 [3]	183 U/L	+	IgM + (IIFT)	Right biceps, nodular myositis	NR	NR
2 [4]	43 U/L	+	IgG + (ELISA)	Left quadriceps, nodular myositis	+	NR
3 [5]	>7,500 U/L	+	IgM+ (IFA)	Left quadriceps, necrotizing myositis	NR	NR
4 [6]	Normal	+	IgM+ (IIFT, WB)	Right rectus femoris, nodular myositis	−	− (muscle)
5 [6]	201 U/L	Normal	IgG+ (IIFT)	Right gastrocnemius, nodular myositis	−	+ (skin), − (muscle)
6 [6]	401 U/L	NR	IgG+ (IF)	Right thigh, interstitial myositis	NR	NR
7 [6]	400 U/L	NR	IgG+ (IFA)	Right quadriceps, interstitial myositis	NR	NR
8 [7]	NR	NR	IgM+	NR	NR	NR
9 [8]	44 U/L	NR	IgM+, IgG+	NR	NR	NR
10 [PR]	11,130 U/L	Normal	IgM+, IgG+ (ELISA); IgM+, IgG+ (WB)	Right deltoid, nodular myositis	−	− (muscle, skin, blood)

NOTE. IIFT = indirect immunofluorescence test; NR = not reported; + = positive; IFA = indirect fluorescent antibody; WB = western blot; − = negative; IF = immunofluorescence; PR = present report.

* In cases 2 and 9, a gallium scan was positive.

ministration of methylprednisolone at a dosage of 80 mg iv every 12 hours. The patient's musculoskeletal weakness and facial edema slowly resolved. He began to tolerate a soft diet, the facial swelling subsided, and the CPK level returned to normal. He was discharged after 6 weeks of hospitalization and continued therapy with prednisone (20 mg every 8 hours) and ranitidine (300 mg every day). He received a total of 3 weeks of antibiotic therapy directed at *B. burgdorferi.*

Two weeks after discharge the patient was admitted to another hospital with a complaint of increasing dysphagia. He underwent placement of a percutaneous endoscopic gastrostomy feeding tube. While in the hospital he developed bilateral lower-extremity edema, and he died unexpectedly 5 days after admission. An autopsy revealed the cause of death to be multiple pulmonary emboli. No evidence of endocarditis or neoplastic disease was found on gross and histologic autopsy studies. Microscopic examination of a 5 × 4 cm area of erosion that was noted at the lower esophageal sphincter showed chronic inflammation. Skeletal muscle sections were microscopically demonstrated to have mild nonspecific abnormalities, mostly atrophy of type II fibers. No abnormalities of the peripheral nerves or brain were found.

Discussion

This is the tenth reported case of myositis occurring in association with Lyme disease and the first associated with the new onset of dermatomyositis. This patient fulfilled the criteria for Lyme disease established by the Centers for Disease Control and Prevention (Atlanta) [9]. He lived in an area of endemicity, had a rash clinically suggestive of erythema migrans, and had positive serologies (including positive western blot studies) for *B. burgdorferi*, all of which were suggestive of acute Lyme disease. The patient developed a clinical syndrome that was also highly suggestive of dermatomyositis because of the heliotrope rash, periorbital edema, Gottron's sign, clinically apparent muscle weakness, and dysphagia [10, 11]. The elevated CPK level, increased ESR, and positive ANA test are also consistent with a diagnosis of dermatomyositis [10]. Although the electromyogram did not reveal myositis, electromyographic findings for 10% of patients with myositis are normal [10]. None of the drugs that the patient was taking when admitted are associated with inflammatory myopathies [12].

Pathological findings in the skin and muscle biopsies were nonspecific yet consistent with Lyme disease. However, the muscle pathologies associated with Lyme myositis and dermatomyositis may be indistinguishable [2, 6]; pathological examinations may demonstrate perivascular lymphoid infiltrates but lack of direct muscle-fiber invasion by *B. burgdorferi* (table 2). Of the 8 cases for which histologic findings have been reported, focal nodular myositis was prevalent in 5 (cases 1, 2, 4, 5, and 10), interstitial myositis in 2 (cases 6 and 7), and necrotizing myositis in 1 (case 3) (table 2).

The Dieterle's silver stains of muscle specimens did not reveal spirochetes. Silver stains have demonstrated *B. burgdorferi* in only one (case 2) of three other cases of Lyme myositis in which results of such stains were reported (table 2). Frequently, staining does not reveal the presence of *Borrelia* species in biopsy specimens [6]. It is known that these organisms are randomly distributed in sparse numbers in human tissues [2]. Attempts to culture *B. burgdorferi* from the blood and the skin and muscle biopsy specimens from our patient were negative. However, these specimens were all taken at least 8 days after the initiation of antibiotic treatment. Although 86% of the time *B. burgdorferi* can be cul-

Table 3. Clinical manifestations of Lyme myositis.

Case no. [reference]	Patient age (y)/sex	Muscle group affected	EM (time to onset of myositis)	Antibiotic therapy	Steroid therapy	Outcome
1 [3]	52/F	Proximal muscles of both arms, face (bilateral peripheral paresis)	+ (4 w)	PCN iv, 5×10^6 U qid × 14 d, 4 mo after onset of symptoms	. . .	Muscle strength improvement within 6 w; partial resolution of facial paresis
2 [4]	53/M	Temporomandibular joint, shoulder, lower back, thigh	–	TCN po, 2 g qd × 2 mo, at onset of myositis	PRD po, 40 mg/d, tapered over 10 d	Complete resolution
3 [5]	22/F	Proximal muscles of upper and lower extremities; dysphagia, dysphonia	+ (6 mo)	PCN iv, 20×10^6 U qd × 8 d; then TCN, po 2 g qd × 10 d, at onset of myositis	MPL po, 1.5 mg/(kg·d) × 10 d	Complete resolution in 6 w
4 [6]	66/F	Right iliopsoas, left gluteus medius, glutei maximi, both hamstrings	+ (Concurrent)	PCN iv, 2×10^6 U qd × 4 d, then 20×10^6 U × 10 d; then MINO, 200 mg qd × 10 d, then 100 mg × 2 w	. . .	Complete resolution in 8 mo
5 [6]	61/M	Right leg	–	CTAX iv, 2 g tid × 5 d; then CTRI iv, 2 g tid × 9 d, 1 y after onset of symptoms	. . .	Complete resolution in 3 mo
6 [6]	36/M	Right thigh	+ (14 d)	PCN po, 500 mg bid × 21 d, at onset of myositis	. . .	Improvement
7 [6]	37/M	Left leg	+ (1 y duration)*	NR	. . .	Weakness in left lower extremity
8 [7]	5/F	Eye (erythema of eyelid, orbital pain, proptosis in right eye, diplopia)	+ (6 mo)	AMP po, OXA po, and topical CHL × 4 d	DXM iv, 10 mg × 1 dose; then PRD po, 30 mg/d × 11 w	Complete resolution in 4 mo
9 [8]	41/M	Left lower leg, heart	–	TCN po; then PCN 6 iv, 5 × 106 U qid × 10 d, at onset of myositis	. . .	Resolution within 3 w
10 [PR]	52/M	Proximal muscles of upper and lower extremities; orbital edema, dysphagia	+ (Concurrent)	DOX po, 100 mg bid × 7 d; then CTRI iv, 1 g bid × 3 d; then PCN iv, 18×10^6 U qd × 11 d	MPL iv, × 6 w; then PRD po	Improvement after 3 w of therapy, then condition worsened; death 2 mo after onset of symptoms

NOTE. EM = erythema migrans; + = present; PCN = penicillin; qid = four times daily; ellipses = not administered; – = none; TCN = tetracycline; qd = every day; PRD = prednisone; MPL = methylprednisolone; MINO = minocycline; CTAX = cefotaxime; tid = thrice daily; CTRI = ceftriaxone; bid = twice daily; NR = not reported; AMP = ampicillin; OXA = oxacillin; CHL = chloramphenicol; DXM = dexamethasone; PR = present report; DOX = doxycycline.
* Start date unknown but myositis had been present 1 year before biopsy was performed.

tured from active erythema migrans lesions before treatment [13], cultures become negative within 3 days of antibiotic treatment [14]. Muscle tissue cultures were negative for the two other patients with myositis (cases 4 and 5) whose culture results have been reported (table 2).

Polymerase chain reaction (PCR) amplification for detection of *B. burgdorferi* in histologic specimens was not performed in this case because the tissue was unavailable. In the testing of active erythema migrans lesions that are culture-positive for *B. burgdorferi*, PCR has been demonstrated by Schwartz et al. to have a sensitivity of 62% [15]. However, after antibiotic treatment, only 22.2% (2 of 9) of those authors' initially culture-positive patients were found to be positive by PCR [15]. No attempt was made to detect *B. burgdorferi* by means of direct or indirect immunochemical staining of tissue specimens. These techniques remain experimental, and silver staining techniques appear to be as sensitive as specific-antibody studies [16].

Myositis may occur early in the course of Lyme disease or at a much later date. Erythema migrans has been noted within 1 month of myositis in 4 cases, 6 months prior to myositis in 2 cases, and 1 year prior to myositis in 1 case (table 3). In three cases (cases 2, 5, and 9) no preceding erythema migrans lesion was noted. In all cases of myositis, at least one serological study demonstrating antibodies to *B. burgdorferi* has been positive (table 2). After appropriate antibiotic treatment, complete resolution of the Lyme myositis generally occurs. However, improvement in the patient's condition frequently takes months (table 2). The role of steroids in treatment of Lyme myositis has not been determined. Patients in four of the reported 10 cases have been treated with steroids, but resolution occurs without their use.

Lyme disease–related myositis is probably underreported because of the frequency of arthralgias and myalgias in the early stages of this disease. Elevations in CPK levels at the time of diagnosis of erythema migrans may be noted in up to 15% of cases; levels greater than twice the upper limit of normal have been found to occur in 3.7% (three of 81 cases) (H.W.H., unpublished data). In five cases of Lyme myositis (cases 1–4 and the present case) multiple muscle groups appeared to be involved clinically, and in eight of the nine cases for which CPK values were reported, they were elevated. Our case most closely resembles case 3 because of involvement of the pharyngeal muscles and the marked elevation in the CPK level, in sharp contrast to other cases reported in the literature. In both cases, improvement occurred only slowly with administration of antibiotics plus steroids, and CPK values rose initially during treatment. However, the histologic findings in these cases differed (table 2).

Although it is possible that Lyme disease and dermatomyositis occurred simultaneously and independently in this patient, this case raises the question of whether the *B. burgdorferi* infection triggered the development of dermatomyositis. To date, no cases of *B. burgdorferi*–induced dermatomysitis have been reported. However, Fraser et al. reported a case in which the dermatomyositis of a patient with a long-standing history of the disease was exacerbated after treatment for erythema migrans [17]. The authors suggested that exacerbation of the disease may have been related to persistent infection by *B. burgdorferi* [17]. It is unlikely that nonspecific polyclonal antibodies caused by B cell activation or cross-reactive antibodies due to acute dermatomyositis in this patient resulted in a false-positive Lyme serology, a scenario similar to that seen in regard to some patients with subacute bacterial endocarditis [18]. In the case reported by Fraser et al. [17], the presence of antibodies to borreliae was not demonstrated. Moreover, we have tested five patients with polymyositis and dermatomyositis by ELISA and western blotting for antibodies to *B. burgdorferi* and found none.

Although the etiology of dermatomyositis is unknown, numerous infectious agents—including rickettsiae, mycobacteria, parasites, and viruses—have been associated with inflammatory myopathies [12]. In most instances myositis appears to result from a systemic immunologic reaction, although some infectious agents may directly invade the muscle. It remains uncertain whether the infecting organism is triggering an immunologic reaction or whether the agent is altering the muscle fiber antigens so that an autoimmune reaction occurs against the muscle itself [10]. In the case of *B. burgdorferi* infection, the sparsity of organisms found in the muscle would suggest that an immunologic phenomenon is responsible for the myositis [19]. *B. burgdorferi* should be included among those infectious agents that may be an inciting factor in the development of inflammatory myopathies. Testing for Lyme disease should be considered for patients who present with such syndromes, particularly if they reside in or have visited an area in which Lyme disease is endemic.

Acknowledgments

The authors thank Barbara Moreland for help in manuscript preparation; Charles Pavia, Susan Bittker, and Denise Cooper for performance of serological and lymphoproliferative assays; and Gary P. Wormser for critical review of the manuscript.

References

1. Steere AC. Lyme disease. N Engl J Med **1989**;321:586–96.
2. Duray PH, Steere AC. Clinical pathologic correlations of Lyme disease by stage. Ann N Y Acad Sci **1988**;539:65–79.
3. Schmutzhard E, Willeit J, Gerstenbrand F. Meningopolyneuritis Bannwarth with focal nodular myositis: a new aspect in Lyme borreliosis. Klin Wochenschr **1986**;64:1204–8.
4. Atlas E, Novak SN, Duray PH, Steere AC. Lyme myositis: muscle invasion by *Borrelia burgdorferi*. Ann Intern Med **1988**;109:245–6.
5. Schoenen J, Sianard-Gainko J, Carpentier M, Reznik M. Myositis during *Borrelia burgdorferi* infection (Lyme disease). J Neurol Neurosurg Psychiatry **1989**;52:1002–5.
6. Reimers CD, Pongratz DE, Neubert U, et al. Myositis caused by *Borrelia burgdorferi:* report of four cases. J Neurosci **1989**;91:215–26.
7. Seidenberg KB, Leib ML. Orbital myositis with Lyme disease. Am J Ophthalmol **1990**;109:13–6.
8. Kengen RAM, Linde M, Sprenger HG, Piers DA. Scintigraphic evaluation of Lyme disease: gallium-67 imaging of Lyme myositis. Clin Nucl Med **1989**;14:728–9.
9. CDC case definitions for public health surveillance. Lyme disease. MMWR Morb Mortal Wkly Rep **1990**;39(Suppl RR-13):19–21.
10. Bradley WG, Tandan R. Inflammatory diseases of muscle. In: Kelley WN, Harris ED Jr, Ruddy S, Sledge CB, eds. Textbook of rheumatology. 3rd ed. Vol 2. Philadelphia: WB Saunders, **1989**:1263–88.
11. Dicken CH. Periorbital edema: an important physical finding in dermatomyositis. Cutis **1991**;48:116–7.
12. Plotz PH, Dalakas M, Leff RL, Love LA, Miller FW, Cronin ME. Current concepts in the idiopathic inflammatory myopathies: polymyositis, dermatomyositis, and related disorders [NIH conference discussion]. Ann Intern Med **1989**;111:143–57.
13. Berger BW, Johnson RC, Kodner C, Coleman L. Cultivation of *Borrelia burgdorferi* from erythema migrans lesions and perilesional skin. J Clin Microbiol **1992**;30:359–61.
14. Nadelman RB, Nowakowski J, Forseter G, et al. Failure to isolate *Borrelia burgdorferi* after antimicrobial therapy in culture-documented Lyme borreliosis associated with erythema migrans: report of a prospective analysis. Am J Med **1993**;94:583–8.
15. Schwartz I, Wormser GP, Schwartz JJ, et al. Diagnosis of early Lyme disease by polymerase chain reaction amplification and culture of skin biopsies from erythema migrans lesions. J Clin Microbiol **1992**;30:3082–8.
16. Aberer E, Duray PH. Morphology of *Borrelia burgdorferi*: structural patterns of cultured borreliae in relation to staining methods. J Clin Microbiol **1991**;29:764–72.
17. Fraser DD, Kong LI, Miller FW. Molecular detection of persistent *Borrelia burgdorferi* in a man with dermatomyositis. Clin Exp Rheumatol **1992**;10:387–90.
18. Kaell AT, Volkman D, Redecha PB, et al. Thirty cases of nonspirochetal subacute bacterial endocarditis (SBE): the occurrence of antibodies reactive to *B. burgdorferi* (Bb) [abstract no. B 91]. Arthritis Rheum **1991**;34(suppl):S113.
19. Defosse DL, Duray PH, Johnson RC. The NIH-3 immunodeficient mouse is a model for Lyme borreliosis myositis and carditis. Am J Pathol **1992**;141:3–10.