

Lyme Disease Testing by Large Commercial Laboratories in the United States

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Background. Laboratory testing is helpful when evaluating patients with suspected Lyme disease (LD). A 2-tiered antibody testing approach is recommended, but single-tier and nonvalidated tests are also used. We conducted a survey of large commercial laboratories in the United States to assess laboratory practices. We used these data to estimate the cost of testing and number of infections among patients from whom specimens were submitted.

Methods. Large commercial laboratories were asked to report the type and volume of testing conducted nationwide in 2008, as well as the percentage of positive tests for 4 LD-endemic states. The total direct cost of testing was calculated for each test type. These data and test-specific performance parameters available in published literature were used to estimate the number of infections among source patients.

Results. Seven participating laboratories performed approximately 3.4 million LD tests on approximately 2.4 million specimens nationwide at an estimated cost of \$492 million. Two-tiered testing accounted for at least 62% of assays performed; alternative testing accounted for <3% of assays. The estimated frequency of infection among patients from whom specimens were submitted ranged from 10% to 18.5%. Applied to the total numbers of specimens, this yielded an estimated 240 000 to 444 000 infected source patients in 2008.

Discussion. LD testing is common and costly, with most testing in accordance with diagnostic recommendations. These results highlight the importance of considering clinical and exposure history when interpreting laboratory results for diagnostic and surveillance purposes.

Keywords. lyme disease; infection; United States; diagnostic testing; cost.

Lyme disease (LD) is caused by *Borrelia burgdorferi*, a bacterium transmitted through the bite of infected *Ixodes* species ticks. Nearly 30 000 confirmed cases were reported to the Centers for Disease Control and Prevention (CDC) in 2008 [1], ranking LD among the 10 most commonly reported nationally notifiable diseases in the United States. LD is a geographically focal illness, occurring predominantly in the northeastern and north-central states.

LD diagnosis is based on clinical manifestations and the potential for exposure to infected ticks [2]. For the majority (70%–80%) of cases, the disease begins with a characteristic erythema migrans (EM) rash and accompanying flu-like symptoms [3]. Left untreated, *B. burgdorferi* can disseminate over days to weeks, and develop into multiple EM rashes, acute neuroborreliosis (eg, meningitis, facial palsy, or radiculopathy), or Lyme carditis. After months, untreated LD may manifest as intermittent attacks of oligoarticular arthritis [4, 5]. After months to years, untreated LD may develop into late neuroborreliosis (eg, Lyme encephalopathy, radiculoneuropathy, or paresthesias) [6–11].

Serologic testing can be helpful when evaluating patients with suspected LD. The CDC recommends a 2-tiered approach to LD serologic testing [12]. The first tier consists of an immunoassay (enzyme-linked

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immunosorbent assay [ELISA] or enzyme immunoassay [EIA] using whole-cell, recombinant, or synthetic peptide antigens or, rarely, an immunofluorescence assay (IFA). If the results of the first test are positive or indeterminate, supplementary Western blot analysis for immunoglobulin G (IgG) or immunoglobulin M (IgM) anti-*Borrelia burgdorferi* antibodies are performed to increase testing specificity. As with other serologic tests, the sensitivity and specificity of this 2-tiered approach vary by stage of disease. Two-tiered testing is relatively insensitive (<40%) during early illness, characterized by EM rash. It is reasonably sensitive (>87%) and specific (99%) when used for diagnostic testing of disseminated LD [13]. For this reason, the CDC recommends this 2-tiered approach primarily for patients having signs and symptoms of disseminated disease. Although not generally recommended or cleared by the US Food and Drug Administration (FDA), alternative tests (eg, polymerase chain reaction [PCR], urine antigen test) are used by some providers [14].

In this article, we present the results of a survey regarding LD testing performed by large commercial laboratories in the United States. These data were originally collected as part of a larger survey of tick-borne diseases (Connally et al, manuscript in preparation). Collaborators included investigators participating in the TickNET program, a network of public health partners created in 2007 to foster collaboration on surveillance, research, education, and prevention for tick-borne diseases. Primary outputs of the current study were (1) total number and type of LD tests performed nationwide by large commercial laboratories, and (2) percentage of positive tests submitted from 4 states where LD is endemic. We used these data to establish a baseline for laboratory testing practices, compare reported practices to published recommendations, estimate the cost of LD testing in the United States, and provide a national estimate of the number of infections among source patients from whom samples were submitted.

METHODS

Representatives from 7 large commercial laboratories (ARUP, Clinical Laboratory Partners, Focus Diagnostics, Laboratory Corporation of America [LabCorp], Mayo Clinic Laboratories, Quest Diagnostics, and Specialty Laboratories) were asked to participate. These laboratories accounted for >76% of LD tests reported to health departments in the 4 endemic states (Connecticut, Maryland, Minnesota, and New York), in 2008. In addition, we attempted to include laboratories known to provide alternative methods of LD testing. Representatives at participating laboratories were asked to complete a written survey regarding the number of tests performed by their laboratory in 2008 for 14 different serologic assays or assay combinations (eg, ELISA/EIA with reflex to Western blot), 7 PCR tests distinguished by specimen type (blood, skin, cerebrospinal fluid

[CSF]/synovial fluid, urine, semen, breast milk, and other), and 4 culture tests distinguished by specimen type (skin, synovial fluid, skin/synovial fluid, or other). In addition, respondents were asked to report the number of direct visualization, urine antigen, CSF antibody, and any other diagnostic tests performed for LD. Respondents were asked to report the percentage of tests positive by diagnostic assay for residents of 4 endemic states (Connecticut, Maryland, Minnesota, and New York). The number of tests and percentage positive by test type were compiled across all laboratories. This research was considered exempt from human subjects review by the CDC and Yale University ethics committees.

To estimate the total direct cost of LD testing, median charges by commercial laboratories for each of the following test types were obtained from Wormser et al [15]: whole-cell ELISA (\$127), C6 ELISA (\$180), and IgM and IgG Western blot tests (\$264 combined). These costs were applied to the number of reported tests. For this analysis, we assumed the IFA test to equal the cost of whole-cell ELISA, and the individual Western blot tests to cost exactly half (\$132) of the total combined test. We calculated the cost of 2-tiered testing as the cost of the first tier plus the cost of the second tier when first tier testing was positive.

The frequency of positive results as reported by laboratories reflects a combination of true-positive, false-positive and false-negative test results. Therefore, to estimate the true frequency of infection among all specimens submitted to participating laboratories, it was necessary to correct the reported rate of positive tests (observed percentage positive) for the sensitivity and specificity of the assays used (see [Supplementary Data](#) for methods). The result, the percentage of true infections, was multiplied by the total number of specimens tested by participating laboratories to estimate the total number of infections among source patients nationwide.

RESULTS

All 7 large commercial laboratories agreed to participate; none of the laboratories known to perform alternative testing agreed to participate. Responding laboratories performed a total of 3 351 732 LD tests on 2 432 396 specimens in 2008 (Table 1). Sixty-two percent of tests were conducted using a 2-tiered approach and 38% were conducted as stand-alone tests. As individual tests, PCR, CSF antibody, stand-alone C6 peptide ELISA, IFA, culture, and urine antigen tests accounted for ≤1% of assays performed. For Western blot tests alone (without preceding ELISA/EIA), 48% were IgM Western blots, 49% were IgG Western blots, and 3% were IgM/IgG combination Western blot tests.

Laboratory testing in the 4 endemic states accounted for 1 053 445 (31%) tests conducted nationwide by participating

Table 1. Lyme Disease Tests Conducted in the United States at Large Commercial Laboratories, by Test Type, 2008^a

Test Type	No. of Tests Conducted	%
Two-tiered approaches		
Whole-cell ELISA/EIA ^b	2 026 117	60
C6 peptide ELISA ^b	71 257	2
Stand-alone tests		
Western blot	887 616	26
Whole-cell ELISA/EIA	298 058	9
C6 peptide ELISA	3790	<1
IFA—IgG	2031	<1
IFA—IgM	1101	<1
PCR	40 761	1
CSF antibody	20 908	1
Culture	74	<1
Urine antigen	19	<1
Total	3 351 732	

Abbreviations: CSF, cerebrospinal fluid; EIA, enzyme immunoassay; ELISA, enzyme-linked immunosorbent assay; IFA, immunofluorescence assay; IgG, immunoglobulin G; IgM, immunoglobulin M; PCR, polymerase chain reaction.

^a Data aggregated from 7 US commercial laboratories.

^b Denotes reflex to supplementary Western blot.

laboratories. For comparison, these 4 states accounted for 36% of all LD cases reported to the CDC during 2007–2009 [1, 16, 17]. The majority (68%) of tests were 2-tiered ELISA/EIA with Western blot reflex (Table 2). As with the national data, $\leq 1\%$ of each of the following diagnostic LD tests was conducted: PCR, CSF antibody test, stand-alone ELISA (whole-cell and C6 peptide), and culture. There were no urine antigen tests conducted for residents of these states. Five laboratories (responsible for >48% of all tests conducted by participating laboratories) reported complete data on percentage positive for all test types for the 4 states. Aggregate results from these laboratories are presented in Table 2. For the 2-tiered tests, the percentage positive for tests from the 4 states was 5.8% when using the ELISA/EIA as a first tier. For the Western blot stand-alone tests, 10.5% were positive for IgM antibodies and 6.5% for IgG. Stand-alone ELISA/EIA tests were positive on 11.4% of sera. The percentage positive was lowest ($\leq 3.1\%$) for PCR, CSF antibody, and culture.

Given an overall frequency of positive first-tier assays of 11.89% (Table 3), the estimated total direct cost for 2-tiered tests was approximately \$336 million. Additionally, expenditures for stand-alone Western blot and ELISA/IFA/C6 tests totaled \$117 and \$39 million, respectively. Taken together, these figures amount to \$492 million.

Presented in Table 3 are the frequency of positive 2-tiered and EIA/ELISA tests reported by 5 national laboratories for specimens from Connecticut, Maryland, Minnesota, and

Table 2. Lyme Disease Tests at Large Commercial Laboratories by Type and Percentage Positive, in 4 US States, 2008^a

Test Type	No. of Tests	% of Tests	% Positive ^b
Two-tiered whole-cell ELISA/EIA or C6 ELISA ^c	701 006	68	5.8
Stand-alone tests			
IgG Western blot	155 800	15	6.5
IgM Western blot	155 584	15	10.5
IgM/IgG combination	82	<1	...
Whole-cell ELISA/EIA	3616	<1	11.4
C6 peptide ELISA	1655	<1	...
PCR ^d	7637	<1	3.1
CSF antibody ^e	3055	<1	...
Culture	7	<1	0
Total	1 053 445		

Abbreviations: CSF, cerebrospinal fluid; EIA, enzyme immunoassay; ELISA, enzyme-linked immunosorbent assay; IgG, immunoglobulin G; IgM, immunoglobulin M; PCR, polymerase chain reaction.

^a Data aggregated from 7 US commercial laboratories. Includes specimen testing data from providers in Connecticut, Maryland, Minnesota, and New York.

^b Percentage positive results are presented from 5 laboratories. CSF antibody not performed by these laboratories.

^c Positive results for C6 (stand-alone) not reported.

^d PCR testing of blood, cerebrospinal fluid, and/or synovial fluid.

^e No urine antigen tests were reported for these 4 states.

New York. Also included are the parameters used to estimate the percentage of true infections [18–23]. The overall estimated percentage of true infections among patients for whom samples were tested was 12% (see [Supplementary Data](#)). Sensitivity analysis indicates that this overall value is robust, remaining relatively stable regardless of the proportion of specimens derived from patients with early vs later stages of infection. When the data were evaluated for individual states by laboratory, the estimated percentage of true infections varied from 10% in Maryland to 18.5% in Minnesota. Multiplying these percentages by the total number of specimens tested yielded an estimate of 288 000 infected source patients in the United States (range, 240 000–444 000).

DISCUSSION

In this survey, we found that approximately 3.4 million LD tests were conducted by participating laboratories in 2008, at an estimated cost for laboratory services of \$492 million. Most LD testing was in accordance with current recommendations; at least 62% of tests conducted nationwide utilized the 2-tiered procedure recommended by the US Public Health Service agencies and the Infectious Diseases Society of America [2]. For samples tested by Western blot alone, it is possible that some

Table 3. Lyme Disease Testing Volume Data, Sensitivity and Specificity Values, and Observed and Predicted Percentage Positive, by Test Type, for Large Commercial Laboratories in 4 Endemic US States

Test Type	No. of Tests	Sensitivity, Localized Disease ^a	Sensitivity, Disseminated Disease ^a	Specificity	Observed % Positive ^b	Predicted % Positive ^c	Observed–Predicted % Difference
Two-tiered whole cell	297 619	37.0%	87.0%	99.4%	5.79	5.76	0.03
EIA/IFA stand-alone or first tier ^d	287 595	66.9%	93.3%	96.1%	11.89	11.89	0.00

Abbreviations: EIA, enzyme immunoassay; IFA, immunofluorescence assay.

^a Sensitivity and specificity values derived from listed references [6, 18–24].

^b Observed percentage of positive values were derived by combining data from 5 large commercial laboratories for residents of 4 endemic states (Connecticut, Maryland, Minnesota, New York; see [Supplementary Data](#)).

^c Predicted percentages of positive values were iteratively derived using data on the number of tests performed, sensitivity and specificity of tests, an estimate for proportion of tests run from patients having localized/early disease, and an estimate for the true rate of infection (see [Supplementary Data](#)).

^d Based on EIA/IFA stand-alone combined with first tier of 2-tiered assays.

were first evaluated by EIA/ELISA at a smaller (eg, hospital-based) laboratory before being sent to a participating laboratory. Therefore, the true percentage of samples tested using a 2-tiered approach may be higher than 62%. These results may not be generalizable to laboratories that did not participate in the survey. In particular, the frequency of testing by alternative methods is expected to be higher at laboratories that did not participate in the survey.

A previous analysis using marketing data from 1995 estimated that <\$100 million dollars was spent annually on LD tests [24–26]. In a more geographically limited study, Strickland et al reported that nearly 30 000 LD tests were conducted for Maryland residents in 1995, at a cost of >\$2 million [27]. We estimated a total direct laboratory cost of \$492 million. This value reflects the amount charged by commercial laboratories that is ultimately paid by insurance companies, Medicare/Medicaid, the patient, and/or the ordering medical center (eg, hospitals, clinics). It does not include additional handling charges that may be incurred by patients, discounts offered by laboratories, charges for PCR or other less common tests, or tests performed by non-participating laboratories. Recently, Branda et al proposed using 2 EIAs as an alternative to the standard 2-tiered approach as a means of preserving the sensitivity and specificity of testing, while reducing costs [28]. Based on our findings, this approach would reduce the national cost estimate by approximately \$57 million per year.

Overall, participating laboratories tested 2.4 million specimens for LD. When multiplied by the estimated percentage of true infections (12%), this yields 288 000 infected source patients in the United States, approximately 10 times higher than the number of cases reported to the CDC in 2008. Under-reporting is a common feature of routine surveillance, and the values here are consistent with what has been previously reported for LD [29–32]. It should be noted that our estimate of the

percentage of true infections was relatively insensitive to assumptions regarding the frequency of early infection among source patients (see [Supplementary Data](#)).

Our estimate of infected source patients is subject to several limitations. First, the observed percentage of positive tests is based on samples from 4 states. The remaining samples are assumed to have come mostly from patients in other endemic states who have a similar risk of infection. This assumption is supported by the observation that the 4 states account for 31% of all samples and 36% of LD cases reported nationwide, confirming that diagnostic samples are generated in proportion to where the disease occurs. Second, we used the percentage of positive values for tests conducted by only 5 large commercial laboratories in 4 endemic states (representing approximately 15% of nationwide data). These were the only laboratories that provided complete responses to all questions. Results from these laboratories may not be representative of results from all other large commercial laboratories, and the percentage of positive values found for these states may not be representative. However, together, these laboratories conducted a substantial proportion (>45%) of all the tests performed by the participating laboratories. Last, to calculate the percentage of true infections, we computed an average value for sensitivity and specificity for each test using data presented in the published literature. This method does not account for the variability that might exist between laboratories or test kits.

Two study limitations may have led to overestimating the number of infected source patients. We assumed that 1 specimen was submitted for every patient; however, it is likely that multiple specimens may have been submitted for at least some patients. For example, if 85% of patients had a single specimen, 10% had 2 specimens, and 5% had 3 specimens tested, then the overall estimate would be reduced by 17%. Also, the estimate is potentially influenced by individuals who were

seropositive as a result of previous infection but did not have active infection at the time of testing. At least 1 study indicates that some successfully treated individuals can maintain a seropositive status for up to 10 years [33].

There are also several factors to suggest that 288 000 is an underestimate of the total number of infections that occurred in the United States in 2008. First and foremost, it does not address infection in individuals for whom no testing is sought (ie, persons diagnosed clinically based on the presence of an EM rash) or for whom no testing data were available. In addition, this estimate is based on numbers of specimens submitted for LD testing at only those participating laboratories (the source population). Our analysis did not consider testing done at smaller laboratories, clinics, hospitals, etc. Data from a related survey indicate that these smaller facilities account for at least another 14% of tests run for residents of the 4 endemic states (unpublished data, CDC). Serologic testing for the diagnosis of LD has been complicated by inappropriate and excessive use and may be a substantial misuse of healthcare resources [34, 35]. Even when serologic testing is ordered in endemic areas, it may be unwarranted clinically. The low percentage of positive values reported in this study for tests conducted in 4 endemic states support this claim. A study by Fix et al found that the majority of patients who presented with a tick bite had serologic tests ordered for the detection of antibodies to *B. burgdorferi*, although none of the patients ever developed LD symptoms [36]. Serologic tests conducted for LD at the time of tick bite are not useful because the patient has not yet developed a detectable antibody response to infection. Given the large volume of testing nationally, small differences in test specificity would be expected to have a large impact on the number of false-positive results generated, possibly promoting misdiagnosis. False-positives may occur more often for self-referred patients, and for those presenting with nonspecific symptoms from nonendemic areas where the pretest likelihood of disease is low [37, 38]. Such results can lead to unnecessary antibiotic treatment, which in turn may be associated with adverse events [25, 39].

In conclusion, this survey of laboratories has provided a baseline for laboratory testing practices and the cost of LD testing in the United States, and has provided a national estimate of the number of infected source patients. Given the large number of tests for LD and potential for false results, it is important to consider clinical and exposure history in conjunction with laboratory results for diagnosis and classification of LD for surveillance purposes.

Supplementary Data

Supplementary materials are available at *Clinical Infectious Diseases* online (<http://cid.oxfordjournals.org>). Supplementary materials consist of data

provided by the author that are published to benefit the reader. The posted materials are not copyedited. The contents of all supplementary data are the sole responsibility of the authors. Questions or messages regarding errors should be addressed to the author.

Notes

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References

- Centers for Disease Control and Prevention. Summary of notifiable diseases, United States, 2008. *Morb Mortal Wkly Rep* **2010**; 57:26.
- Wormser GP, Dattwyler RJ, Shapiro ED, et al. The clinical assessment, treatment, and prevention of Lyme disease, human granulocytic anaplasmosis, and babesiosis: clinical practice guidelines by the Infectious Diseases Society of America. *Clin Infect Dis* **2006**; 43:1089–134.
- Steere AC, Malawista SE, Hardin JA, Ruddy S, Askenase W, Andiman WA. Erythema chronicum migrans and Lyme arthritis. The enlarging clinical spectrum. *Ann Intern Med* **1977**; 86:685–98.
- Steere AC, Bartenhagen NH, Craft JE, et al. The early clinical manifestations of Lyme disease. *Ann Intern Med* **1983**; 99:76–82.
- Steere AC, Schoen RT, Taylor E. The clinical evolution of Lyme arthritis. *Ann Intern Med* **1987**; 107:725–31.
- Aguero-Rosenfeld ME, Nowakowski J, Bittker S, Cooper D, Nadelman RB, Wormser GP. Evolution of the serologic response to *Borrelia burgdorferi* in treated patients with culture-confirmed erythema migrans. *J Clin Microbiol* **1996**; 34:1–9.
- Halperin JJ, Luft BJ, Anand AK, et al. Lyme neuroborreliosis: central nervous system manifestations. *Neurology* **1989**; 39:753–9.
- Logigian EL, Kaplan RF, Steere AC. Chronic neurologic manifestations of Lyme disease. *N Engl J Med* **1990**; 323:1438–44.
- Pachner AR, Duray P, Steere AC. Central nervous system manifestations of Lyme disease. *Arch Neurol* **1989**; 46:790–5.
- Steere AC. Lyme disease. *N Engl J Med* **1989**; 321:586–96.
- Steere AC, Taylor E, McHugh GL, Logigian EL. The overdiagnosis of Lyme disease. *JAMA* **1993**; 269:1812–6.
- Centers for Disease Control and Prevention. Recommendations for test performance and interpretation from the Second National Conference on Serologic Diagnosis of Lyme Disease. *Morb Mortal Wkly Rep* **1995**; 44:590–1.
- Aguero-Rosenfeld ME, Wang G, Schwartz I, Wormser GP. Diagnosis of Lyme borreliosis. *Clin Microbiol Rev* **2005**; 18:484–509.
- Bunikis J, Barbour AG. Laboratory testing for suspected Lyme disease. *Med Clin North Am* **2002**; 86:311–40.
- Wormser GP, Levin A, Soman S, Adenikinju O, Longo MV, Branda JA. Comparative cost effectiveness of two-tiered testing strategies for the serodiagnosis of Lyme disease with noncutaneous manifestations. *J Clin Microbiol* **2013**; 51:4045–9.
- Centers for Disease Control and Prevention. Summary of notifiable diseases, United States, 2009. *Morb Mortal Wkly Rep* **2011**; 58:34.

17. Centers for Disease Control and Prevention. Summary of notifiable diseases, United States, 2007. *Morb Mortal Wkly Rep* **2009**; 56:28.
18. Bacon RM, Biggerstaff BJ, Schriefer ME, et al. Serodiagnosis of Lyme disease by kinetic enzyme-linked immunosorbent assay using recombinant VlsE1 or peptide antigens of *Borrelia burgdorferi* compared with 2-tiered testing using whole-cell lysates. *J Infect Dis* **2003**; 187:1187–99.
19. Branda JA, Aguero-Rosenfeld ME, Ferraro MJ, Johnson BJ, Wormser GP, Steere AC. 2-tiered antibody testing for early and late Lyme disease using only an immunoglobulin G blot with the addition of a VlsE band as the second-tier test. *Clin Infect Dis* **2010**; 50:20–6.
20. Dressler F, Whalen JA, Reinhardt BN, Steere AC. Western blotting in the serodiagnosis of Lyme disease. *J Infect Dis* **1993**; 167:392–400.
21. Engstrom SM, Shoop E, Johnson RC. Immunoblot interpretation criteria for serodiagnosis of early Lyme disease. *J Clin Microbiol* **1995**; 33:419–27.
22. Peltomaa M. The VlsE(IR6) peptide ELISA in the serodiagnosis of Lyme facial paralysis. *Otol Neurotol* **2004**; 25:838–41.
23. Wormser GP, Schriefer M, Aguero-Rosenfeld ME, et al. Single-tier testing with the C6 peptide ELISA kit compared with two-tier testing for Lyme disease. *Diagn Microbiol Infect Dis* **2013**; 75:9–15.
24. Johnson BJ, Robbins KE, Bailey RE, et al. Serodiagnosis of Lyme disease: accuracy of a two-step approach using a flagella-based ELISA and immunoblotting. *J Infect Dis* **1996**; 174:346–53.
25. Ramsey AH, Belongia EA, Chyou PH, Davis JP. Appropriateness of Lyme disease serologic testing. *Ann Fam Med* **2004**; 2:341–4.
26. Migliara/Kaplan Associates. Projected annual market for rapid direct tests. Rapid testing for infectious diseases: competitive advantage in a turbulent market. Owings Mills, MD: Migliara/Kaplan, **1993**:277.
27. Strickland GT, Karp AC, Mathews A, Pena CA. Utilization and cost of serologic tests for Lyme disease in Maryland. *J Infect Dis* **1997**; 176:819–21.
28. Branda JA, Linskey K, Kim YA, Steere AC, Ferraro MJ. Two-tiered antibody testing for Lyme disease with use of 2 enzyme immunoassays, a whole-cell sonicate enzyme immunoassay followed by a VlsE C6 peptide enzyme immunoassay. *Clin Infect Dis* **2011**; 53:541–7.
29. Meek JI, Roberts CL, Smith EV Jr, Cartter ML. Underreporting of Lyme disease by Connecticut physicians, 1992. *J Public Health Manag Pract* **1996**; 2:61–5.
30. Naleway AL, Belongia EA, Kazmierczak JJ, Greenlee RT, Davis JP. Lyme disease incidence in Wisconsin: a comparison of state-reported rates and rates from a population-based cohort. *Am J Epidemiol* **2002**; 155:1120–7.
31. Orloski KA, Campbell GL, Genese CA, et al. Emergence of Lyme disease in Hunterdon County, New Jersey, 1993: a case-control study of risk factors and evaluation of reporting patterns. *Am J Epidemiol* **1998**; 147:391–7.
32. Young JD. Underreporting of Lyme disease. *N Engl J Med* **1998**; 338:1629.
33. Hammers-Berggren S, Lebech AM, Karlsson M, Svenungsson B, Hansen K, Stiernstedt G. Serological follow-up after treatment of patients with erythema migrans and neuroborreliosis. *J Clin Microbiol* **1994**; 32:1519–25.
34. Qaseem A, Alguire P, Dallas P, et al. Appropriate use of screening and diagnostic tests to foster high-value, cost-conscious care. *Ann Intern Med* **2012**; 156:147–9.
35. Trevejo RT, Krause PJ, Sikand VK, et al. Evaluation of two-test serodiagnostic method for early Lyme disease in clinical practice. *J Infect Dis* **1999**; 179:931–8.
36. Fix AD, Strickland GT, Grant J. Tick bites and Lyme disease in an endemic setting: problematic use of serologic testing and prophylactic antibiotic therapy. *JAMA* **1998**; 279:206–10.
37. Tugwell P, Dennis DT, Weinstein A, et al. Laboratory evaluation in the diagnosis of Lyme disease. *Ann Intern Med* **1997**; 127:1109–23.
38. Porwancher R. A reanalysis of IgM Western blot criteria for the diagnosis of early Lyme disease. *J Infect Dis* **1999**; 179:1021–4.
39. Ettestad PJ, Campbell GL, Welbel SF, et al. Biliary complications in the treatment of unsubstantiated Lyme disease. *J Infect Dis* **1995**; 171:356–61.