How Do I Perform a Lumbar Puncture and Analyze the Results to Diagnose Bacterial Meningitis?

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PATIENT SCENARIO

A previously healthy 70-year-old woman presents to the emergency department with a 3-day history of fever, confusion, and lethargy. She is unable to cooperate with a full physical examination, but she has neck stiffness upon neck flexion. Her score on the Glasgow Coma Scale is 13 (eye, 4; verbal, 4; motor, 5). The findings from a chest radiograph and urinalysis are normal.[1] You seek consent from her husband to perform a lumbar puncture (LP).

Why Is This Diagnostic Procedure Important?

In a previous Rational Clinical Examination article, Attia and colleagues[1] discussed the above scenario and recommended proceeding to LP for definitive testing of the cerebrospinal fluid (CSF). Cerebrospinal fluid is a clear, colorless fluid that fills the ventricles and subarachnoid space surrounding the brain and spinal cord.[2] Lumbar puncture allows this fluid to be sampled, facilitating the diagnosis of various conditions.

Since it was first described by Quincke[3] in 1891, the LP has become

See also Patient Page.

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Context Diagnostic lumbar punctures (LPs), commonly used to rule out meningitis, are associated with adverse events.

Objective To systematically review the evidence about diagnostic LP techniques that may decrease the risk of adverse events and the evidence about test accuracy of cerebrospinal fluid (CSF) analysis in adult patients with suspected bacterial meningitis.

Data Sources We searched the Cochrane Library, MEDLINE (using Ovid and PubMed) from 1966 to January 2006 and EMBASE from 1980 to January 2006 without language restrictions to identify relevant studies and identified others from the bibliographies of retrieved articles.

Study Selection We included randomized trials of patients aged 18 years or older undergoing interventions to facilitate a successful diagnostic LP or to potentially reduce adverse events. Studies assessing the accuracy of biochemical analysis of the CSF for possible bacterial meningitis were also identified.

Data Extraction Two investigators independently appraised study quality and extracted relevant data. For studies of the LP technique, data on the intervention and the outcome were extracted. For studies of the laboratory diagnosis of bacterial meningitis, data on the reference standard and test accuracy were extracted.

Data Synthesis We found 15 randomized trials. A random-effects model was used for quantitative synthesis. Five studies of 587 patients compared atraumatic needles with standard needles and found a nonsignificant decrease in the odds of headache with an atraumatic needle (absolute risk reduction [ARR], 12.3%; 95% confidence interval [CI], −1.72% to 26.2%). Reinsertion of the stylet before needle removal decreased the risk of headache (ARR, 11.3%; 95% CI, 6.50%-16.2%). The combined results from 4 studies of 717 patients showed a nonsignificant decrease in headache in patients who were mobilized after LP (ARR, 2.9%; 95% CI, −3.4 to 9.3%). Four studies on the accuracy of biochemical analysis of CSF in patients with suspected meningitis met inclusion criteria. A CSF–blood glucose ratio of 0.4 or less (likelihood ratio [LR], 18; 95% CI, 12-27]), CSF white blood cell count of 500/μL or higher (LR, 15; 95% CI, 10-22), and CSF lactate level of 31.53 mg/dL or more (≥3.5 mmol/L; LR, 21; 95% CI, 14-32) accurately diagnosed bacterial meningitis.

Conclusions These data suggest that small-gauge, atraumatic needles may decrease the risk of headache after diagnostic LP. Reinsertion of the stylet before needle removal should occur and patients do not require bed rest after the procedure. Future research should focus on evaluating interventions to optimize the success of a diagnostic LP and to enhance training in procedural skills.

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an important diagnostic tool, particularly when considering the diagnosis of meningitis. Evaluation of CSF can help establish a diagnosis and guide antimicrobial therapy. Less commonly, LP is used as part of the diagnostic workup of patients with suspected subarachnoid hemorrhage, demyelinating disease, and leptomeningeal metastasis.[4,5]

What Adverse Events Can Result From an LP?

Bier was the first to report the technique of spinal anesthesia and also provided (through personal experience!) the first description of post-LP headache.[6] Headache and backache are the most frequently reported adverse events associated with LP. Headache can occur in up to 60% of patients who undergo the procedure, although estimates vary due to differences in inclusion criteria and definitions of headache.[7-9] Headache can be severe and debilitating[10] and is believed to occur because of CSF leakage through the dural puncture site.[11] Backache is less common but can occur in up to 40% of patients following LP.[7] Rare adverse events include cerebral herniation, intracranial subdural hemorrhage, spinal epidural hemorrhage, and infection.[11]

What Are the Contraindications to Performing an LP?

Clinicians often worry that an undetected mass lesion or ventricular obstruction causing raised intracranial pressure pose risks for cerebral herniation following an LP.[4] However, no conclusive evidence supports that the risk can be reduced with universal neuroimaging prior to LP. Instead of universal neuroimaging, clinicians can use the clinical examination to guide the decision to obtain neuroimaging. In a prospective study, 113 patients were examined by internal medicine residents (overseen by emergency physicians) prior to undergoing computed tomography (CT) of the brain and subsequent LP.[12] The median age of patients was 42 years, 36% were immunocompromised, and 46% of patients had altered mentation. Altered mentation (likelihood ratio [LR], 2.2;

95% confidence interval [CI], 1.5-3.2), focal neurological finding (LR, 4.3; 95% CI, 1.9-10), and papilledema (LR, 11; 95% CI, 1.1-115) increased the likelihood of an intracranial lesion.[12] Overall clinical impression (not defined in the study) was able to identify patients with a CT-defined contraindication to LP (LR, 19; 95% CI, 4.8-43). In a second prospective study of 301 patients with suspected meningitis, 235 underwent a CT scan prior to LP.[13] The mean age of patients was 40 years (16% were ≥60 years), 25% were immunocompromised, and 27% of patients had a Charlson comorbidity score of more than 1. Patients were assessed clinically by an emergency physician or general internist. The absence of a number of clinical features at baseline was able to identify those who were unlikely to have an abnormal CT result (LR, 0.10; 95% CI, 0.03-0.31). The absence of all of the following baseline characteristics was associated with this low LR: age 60 years or older, immunocompromised state, history of central nervous system disease, and seizure within 1 week of presentation. In addition, there could be none of the following physical examination findings: abnormal level of consciousness, inability to answer 2 questions correctly, inability to follow 2 consecutive commands correctly, gaze palsy, abnormal visual fields, facial palsy, arm drift, leg drift, and abnormal language. Using the pretest probability of an abnormal CT finding from this study (23.8%), the absence of all of these features would reduce the probability of an abnormal finding to 3.0%. The findings from these 2 studies have not been validated prospectively in other independent populations.

Local infection at the puncture site is also a contraindication to completing an LP but this occurs infrequently.[4] More frequently, clinicians are concerned about coagulation defects and use of anticoagulants, which may increase the risk of epidural hemorrhage. In 1 study of post-LP complications, outcomes were compared in 166 patients receiving anticoagulation with 171 of those who were not receiving

therapy. There was a trend toward increased risk of paraparesis in the anticoagulated patients (relative risk, 11.0; 95% CI, 0.60-199) with 5 patients in the anticoagulation group experiencing an adverse event compared with none in the control group. In all patients who experienced paraparesis, anticoagulation had been started within an hour of the procedure.[14] A survey of 246 pediatric and adult neurology department chairpersons and residency program directors found that 45% of respondents ordered platelet and anticoagulation studies prior to LP.[15] We were unable to find any data evaluating the safety of LP in patients with low platelet counts. In a case series of 66 patients with acute leukemia, patients with lower platelet counts ($<50 \times 10^3$/μL) had higher risk of a traumatic procedure as defined by the presence in the CSF of more than 500 red blood cells per high-powered field.[16] However, LPs were not performed in patients with platelet counts lower than 20×10^3/μL in this study.

We conducted a systematic review to identify studies of interventions that enhance the success of an LP and that minimize adverse events. Based on review of the evidence and its integration with expert opinion, we provide a best-practice approach for LP in adults. Because a clinician's interpretation of the LP results is tightly coupled to the clinical examination findings, we also reviewed the literature that addresses the accuracy of common CSF tests for bacterial meningitis. Tests for diagnosing viral meningitis were not included in this review. Although there are other indications for LP and CSF analysis, this article focuses on CSF analysis for suspected bacterial meningitis because it requires immediate action and is one of the most common diagnoses that generalist physicians consider when performing this procedure.

METHODS

Searches of the Cochrane Library, MEDLINE (using Ovid and PubMed) from 1966 to January 2006, and EMBASE from 1980 to January 2006

were completed to identify relevant studies. The search strategy used the terms *lumbar puncture*, *spinal puncture*, *dural puncture*, *headache*, *headach**, *spinal needle**, *cerebrospinal fluid*, *spinal fluid*, and *meningitis*. Intervention studies were limited to randomized controlled trials using the terms *randomized controlled trial*, *controlled clinical trial*, *clinical trial*, *random allocation*, and *random**. No language restrictions were used. Additional articles were identified from searching the bibliographies of retrieved articles. Details on the search strategies are available on request.

Randomized trials of patients (≥18 years) undergoing interventions to potentially reduce headache and backache at the time of diagnostic LP were included. However, if no randomized studies of a particular intervention were identified, studies of lower quality—including cohort, case-control, and case series—were retrieved. Studies assessing patients undergoing LP during spinal anesthesia or myelography were excluded because these procedures are clinically different from a diagnostic LP. Smaller amounts of fluid are removed during spinal anesthesia and myelography than with diagnostic LP and fluids are inserted during these other procedures. Moreover, the risk of headache is greater with diagnostic LP than with spinal anesthesia.[7] Interventions of interest included those that could be used at the time of LP, such as immediate mobilization, atraumatic needles, and reinsertion of the stylet. We also attempted to identify studies that assessed the impact of positioning of the patient and experience of the operator. The outcome of interest included headache occurring up to 7 days after LP.

To examine the accuracy of CSF analysis in patients with suspected acute bacterial meningitis, we included studies of predominantly adult populations and those that described use of an appropriate reference standard (eg, CSF culture or bacterial antigen) in all patients. In addition, primary data or appropriate summary statistics had to be available in the studies.

Two reviewers (S.E.S. and J.M. H-L.) independently reviewed and selected relevant publications that met the inclusion criteria from the search results. Disagreements were resolved by consensus. In cases of doubt, full-text articles were retrieved for review and discussion. Full-text articles of all abstracts that met the inclusion criteria were retrieved.

The 2 reviewers independently read all full-text articles to confirm that inclusion criteria were met. The investigators also assessed study quality. For intervention studies, a specially designed data collection form was used to extract data on study quality including the method of randomization, the presence of blinding, and the method used for outcome assessment. Data were also extracted on the intervention and the dichotomous outcome variable of post-LP headache. The minimum inclusion criteria for randomized studies of interventions to prevent adverse events were the description of randomization and the ability to extract relevant patient data. For studies of test accuracy, data were extracted on the reference standard, the presence of blinding, the index test, and the population characteristics. Minimum inclusion criteria for studies of test accuracy in patients with suspected meningitis were the completion of an appropriate reference standard in all patients and the ability to extract relevant data. Differences in assessment by the reviewers were resolved through discussion, and a third investigator (K.E.T.) was available if necessary.

For the intervention studies, statistical heterogeneity was assessed using the method described by Woolf.[17] A random-effects model (DerSimonian and Laird) was used for quantitative data. For the studies of test accuracy, LRs were calculated using the random-effects model. Statistical analyses were conducted using *R: A Language and Environment for Statistical Computing* and the *rmeta* contributed package. R is an open-source dialect of the S language (S was developed by AT&T) that is maintained by a core team (http://www

.r-project.org). A 2-tailed *P* value of <.05 was considered statistically significant.

RESULTS

We found 537 citations of potential interventions to optimize LP technique. Review of these led to retrieval of 22 full-text articles for assessment, 15 of which were subsequently identified for inclusion. Reasons for excluding trials were lack of randomization (5 studies[18-22]), repeat publication (1 study[23]), and inability to obtain outcomes data (1 study[24]). Studies were categorized by intervention including needle type, needle size, reinsertion of stylet, mobilization after LP, and use of supplemental fluids. No studies of other interventions—such as positioning of the patient during LP, direction of bevel, volume of CSF removed, or prophylactic use of an epidural blood patch—met the inclusion criteria.

Description of Studies

Fifteen randomized trials were identified with sample sizes ranging from 44 to 600 people. Eight studies had sample sizes of 100 patients or fewer.

Performing the Procedure

Experience of Operator. We were unable to identify any randomized studies that evaluated the impact of the experience of the clinician performing LPs on clinical outcomes. Some studies we identified included experienced neurologists,[23] whereas others involved students under the supervision of physicians.[25] In a case series of LPs performed at an urban university-affiliated hospital, the incidence of traumatic LP was 15% using a definition of more than 400 red blood cells per high-powered field and 10% using a definition of more than 1000 red blood cells.[26] However, the level of training and specialty of all physicians were not recorded. One retrospective study compared the incidence of traumatic LP at the end of the resident academic year when housestaff are more experienced with that at the start of the next year when new housestaff begin training. Using a cut-

off of 1000 red blood cells/µL, there was no difference in risk of traumatic LP between experienced housestaff (14%) and inexperienced housestaff (12%).[27] In a prospective cohort of 501 patients who underwent LP either by a nurse, physician, resident, or medical student, there was no significant difference in the risk of post-LP headache among the 3 groups.[28] We found no data on the number of LPs required to demonstrate or maintain proficiency.

Positioning of Patient. We were unable to identify any studies that evaluated the success of LP with different patient positions or the impact of patient positioning on the risk of adverse events. One study assessed the interspinous distance to determine the impact of positioning. Measurement of the interspinous distance was conducted in 16 patients who were placed in 3 positions (lateral recumbent with knees to chest; sitting and bent forward over an adjustable bedside stand; and sitting with feet supported and chest resting on the knees).[29] The interspinous distance was greatest when the patient was placed in the sitting position with feet supported.

Needle Choice and Number of Attempts. Five studies with data from 587 patients compared atraumatic Sprotte or Pajunk needles with standard Quincke needles (**FIGURE 1**) during diagnostic LP.[30-34] One of these studies[32] described the randomization method and 4 studies[30-33] described the use of blinded outcomes assessment. Three studies provided data for intention-to-treat analysis.[30-32]
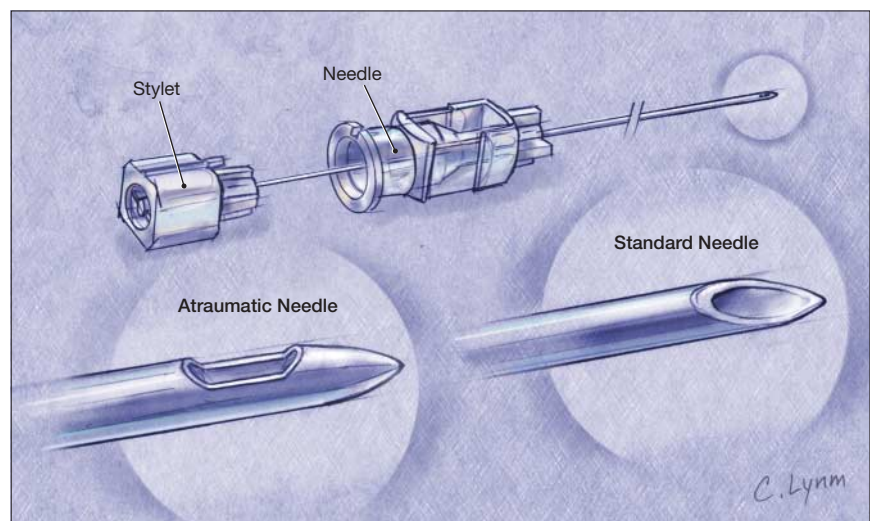
There was a nonsignificant decrease in the risk of headache among patients who underwent diagnostic LP with an atraumatic needle (absolute risk reduction [ARR], 12.3%; 95% CI, –1.72% to 26.2%]). There was statistically significant heterogeneity among these trials ($\chi^2_4=13.3, P<.01$). The heterogeneity appeared to be due primarily to the small study (n=61) by Lenaerts and colleagues (**FIGURE 2**) with only 9 outcome events.[30] One study[32] included data on severe headache and found this risk significantly decreased with atrau-

matic needles (ARR, 23%; 95% CI, 6%-40%). There are no data available on how often an introducer was used with atraumatic needles or its impact.

Three of these studies, which involved 296 patients, included data on the number of attempts required to complete the LP when using an atraumatic needle.[31-33] There was no significant heterogeneity among these studies ($\chi^2_2=0.46, P=.80$). There was a nonsignificant increase in the risk of requiring 2 or more attempts when an
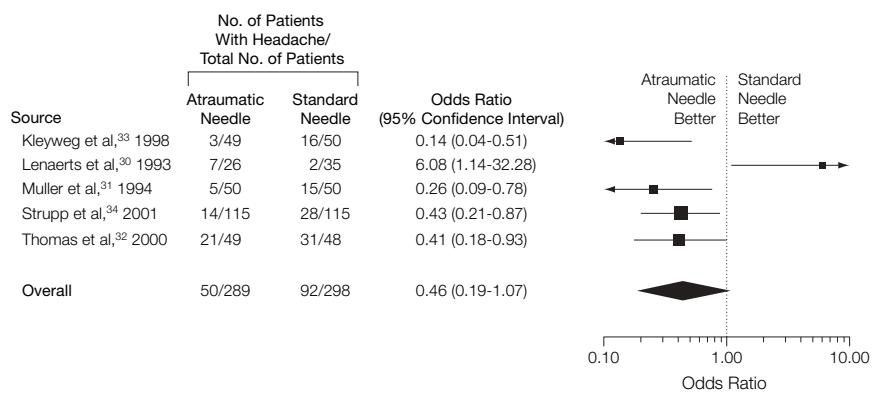
atraumatic needle was used (ARI, 4.9%; 95% CI, –13% to 3.4%).[31-33] One study found an increased risk of requiring 4 attempts with an atraumatic needle compared with standard needle (ARI, 14%; 95% CI, 3.1%-25%).[32] This study also included data on backache and found no increased risk with the atraumatic needle (ARR, 7.4%; 95% CI, –12% to 27%) despite requiring more attempts with an atraumatic needle. These data on backache and number of attempts required with an atraumatic
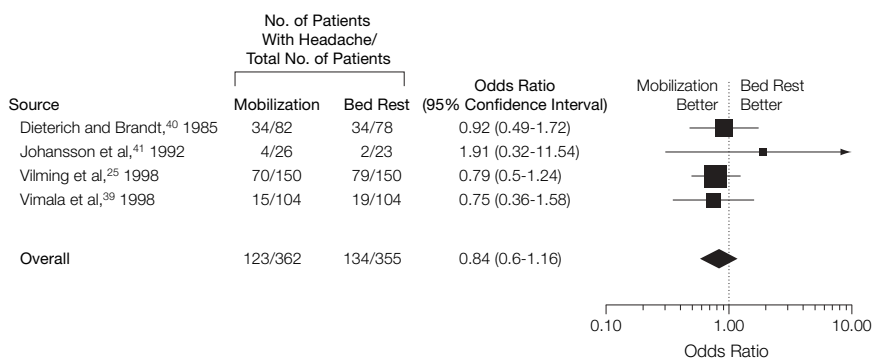
Figure 1. Types of Lumbar Puncture Needles

Two types of lumbar puncture needles are available—the atraumatic (Sprotte or Pajunk) needle and the standard (Quincke) needle. Either the 22-gauge or 20-gauge atraumatic needle, with or without an introducer, can be used for diagnostic lumbar puncture. Use of an atraumatic needle compared with a standard needle and use of a 26-gauge standard needle compared with a 22-gauge standard needle have been shown to be associated with reduced risk of headache after lumbar puncture.[37,38]

Figure 2. Atraumatic vs Standard Needles and Occurrence of Any Headache

Source	No. of Patients With Headache/ Total No. of Patients		Odds Ratio (95% Confidence Interval)
	Atraumatic Needle	Standard Needle	
Kleyweg et al,[33] 1998	3/49	16/50	0.14 (0.04-0.51)
Lenaerts et al,[30] 1993	7/26	2/35	6.08 (1.14-32.28)
Muller et al,[31] 1994	5/50	15/50	0.26 (0.09-0.78)
Strupp et al,[34] 2001	14/115	28/115	0.43 (0.21-0.87)
Thomas et al,[32] 2000	21/49	31/48	0.41 (0.18-0.93)
Overall	50/289	92/298	0.46 (0.19-1.07)

The size of the data markers reflects the size of the study.

Figure 3. Mobilization vs Bed Rest and Occurrence of Any Headache

The size of the data markers reflects sample size of the study.

Table 1. Reference Values for Adult Cerebrospinal Fluid[52]

Cerebrospinal Fluid Variable	Value
Pressure	60 to 180 mm H_2O; 6 to 14 mm Hg
Glucose	45-80 mg/dL (2.5-4.4 mmol/L)
Protein	15-45 mg/dL
Blood-glucose ratio	≥0.6
White blood cell count	<5/μL
Gram stain	No organisms
Cytology	No atypical cells

needle were secondary outcomes of this study and should be further evaluated in larger trials.

Recently published guidelines from the American Academy of Neurology support the use of atraumatic needles when completing diagnostic LPs to reduce the risk of post-LP headache.[35] In an earlier version of this guideline, they reported that LP trays containing the Sprotte needle are the same price as those containing the Quincke.[36]

One study of 100 patients compared use of a 26-gauge Quincke needle vs a 22-gauge Quincke needle.[37] Blinded outcomes observers were used and data were provided for intention-to-treat analysis. The risk of headache was significantly reduced with a smaller needle (ARR, 26%; 95% CI, 11%-40%).

Reinsertion of Stylet

Strupp and colleagues studied 600 patients and compared the effects of reinsertion of the stylet before removing the atraumatic needle with no reinser-

tion.[38] No details were provided on the method of randomization or the use of blinded outcomes assessment. Fewer patients who underwent LP with reinsertion of the stylet experienced headache (ARR, 11%; 95% CI, 6.5%-16%). It is postulated that a strand of arachnoid could enter the needle along with the out flowing CSF and if the stylet is not replaced, the strand may be threaded back through the dura during removal of the needle, producing prolonged leakage of the CSF. By replacing the stylet before removing the needle, the strand would be pushed out and cut, reducing the risk of continued leakage and the resulting headache.[38]

Bed Rest After the Procedure

Four studies with data from 717 patients compared immediate mobilization with bed rest lasting 4 hours for reducing post-LP headache.[25,39-41] One study provided some details on the method of randomization.[25] This study also described use of blinded outcomes assessors. Two of the 3 studies provided data for an intention-to-treat analysis.[25,40]

There was no significant heterogeneity among these studies ($\chi_3^2 = 1.04$, $P = .79$). There was a nonsignificant decrease in the risk of headache in patients who were mobilized after LP (ARR, 2.9%; 95% CI, ARI 3.4%-ARR 9.3%]; **FIGURE 3**) Three studies looked at head positioning during bed rest, but given that there was no significant effect from

bed rest, the results of these studies were excluded from further analysis.[42-45]

Supplementary Fluids

In a study of 100 patients undergoing diagnostic LP, Dieterich assessed the effects of drinking 1.5 L vs 3 L of fluids per day on risk of post-LP headache.[45] No details were provided on the method of randomization or the use of blinded outcomes assessors. The number of outcomes events was too small to detect a difference between these groups (risk difference, 0.0; 95% CI, ARI 18.8%-ARR 18.8%). Sudlow and Warlow[46] conducted a systematic review of mobilization and fluids for preventing post-LP headache and found no effect on post-LP headache.

Interpreting the Results

Maneuvers During the Procedure. Normal resting CSF pressure is assumed to be 60 to 180 mm of H_2O or 6 to 14 mm Hg.[47,48] In the single identified study, CSF pressure changed little (<1.1 mm of water) with flexion of the lower extremities.[49] Various maneuvers, such as compressing the abdomen or the jugular vein (Queckenstedt's maneuver[50]), can increase CSF pressure.[51] An obstruction to CSF flow prevents the normal rise and fall in pressure (positive Queckenstedt), but we were unable to find any studies describing the accuracy of this maneuver for detection of CSF outflow obstruction.

Laboratory Tests

Although CSF samples can be subjected to various analyses, we focused on test results immediately relevant and useful to generalist physicians when evaluating a patient suspected of having bacterial meningitis. Normal CSF values are listed in **TABLE 1**, but these values may vary across different laboratories.[52] We found 460 diagnostic articles in our literature search, and 6 met inclusion criteria (**TABLE 2**). One expert suggests that the white blood cell count be corrected for the presence of red blood cells by subtracting 1 white blood cell from the total white blood cell count in the CSF for every 700 red

blood cells.[2] He also states that a single polymorphonuclear cell in the CSF with a white blood cell count of less than 5 µL is considered normal. Steele and colleagues suggest rapid analysis of CSF and noted that neutrophil counts can decrease by 50% within 2 hours of collection.[59]

We found 3 studies that met the inclusion criteria and that described the accuracy of CSF Gram stain for diagnosing bacterial meningitis.[53-55] None of these studies appeared to be prospective. All studies reported sensitivity of Gram stain and 1 study reported specificity of this test[53] (**TABLE 3**). If bacteria are seen on Gram stain, it helps diagnose bacterial meningitis but if this test is negative, bacterial meningitis cannot be ruled out.

We identified 4 studies that met the inclusion criteria and that reported on the accuracy of biochemical analysis of CSF in patients with suspected central nervous system infection[55-58] (Table 2 and **TABLE 4**). Only 1 study of CSF white blood cell counts met our strict inclusion criteria. A CSF white blood cell count of 500/µL or higher increases the likelihood of meningitis (LR, 15; 95% CI, 10-22), whereas a count less than 500/µL lowers the likelihood (LR, 0.3; 95% CI, 0.2-0.4).[56]

A CSF–blood glucose ratio of 0.4 or less was accurate for diagnosing bacterial meningitis (LR, 18; 95% CI, 12-27), whereas a normal CSF–blood glucose ratio made this diagnosis less likely (LR, 0.31; 95% CI, 0.21-0.45).[56,57] A CSF lactate level of 31.53 mg/dL or more (≥3.5 mmol/L) was accurate for diagnosing bacterial meningitis (LR, 21; 95% CI, 14-32[55-57]; Table 4), whereas a CSF lactate level of less than 31.53 mg/dL (<3.5 mmol/L) makes the diagnosis of bacterial meningitis less likely (LR, 0.12; 95% CI, 0.07-0.23).

Prediction Models

Spanos and colleagues[60] developed a prediction rule for diagnosing bacterial meningitis. This rule (**TABLE 5**) was derived from a retrospective chart review of patients with a final diagnosis of acute meningitis. The sample was di-

vided into a derivation and validation set, but data from a large number of charts (94/214) in the derivation set had missing data and were excluded from the analysis. And, the technique used for CSF cell count changed during the study period, which could influence the results of this study. The accuracy as measured by the area under the receiver operating curve (AUC) was 0.97 for the validation set.

Hoen and colleagues[61] attempted to validate the above rule in a retrospective review and used the same data to generate their own decision rule (Table 5) that included 4 different clinical variables. In their validation of the work by Spanos and colleagues, the AUC was 0.98 while that for their derived equation was 0.99. In another retrospective review of patients with meningitis, Leblebicioglu and colleagues[62] assessed the rules by Hoen and Spanos and the AUC was 0.99 and 0.95, respectively.

McKinney and colleagues[63] obtained similar results in their retrospective review.

In the only prospective validation that we were able to identify, Baty and colleagues[64] assessed Hoen's rule in a sample of 109 patients aged 1 to 85 years with acute community-acquired meningitis. Data are only available in patients with bacterial and viral meningitis, and thus the specificity of the model cannot be calculated. The sensitivity of their computed model was 80% for the diagnosis of bacterial meningitis. For this decision rule to be recommended in clinical practice, it needs to be validated prospectively in larger populations with broader disease spectrum.[65]

Brivet and colleagues[66] completed a retrospective study and found that the presence of at least 1 sign of severity of disease at the time referral and a CSF neutrophil count of more than 1000/µL

Table 2. Studies Assessing Cerebrospinal Fluid Analysis in Patients With Suspected Central Nervous System Infection

Source	Study Design	Sample Size	Age	Reference Standard
Dunbar et al,[53] 1998	Retrospective	2635 CSF samples	Adults	Positive CSF culture
Wasilauskas and Hampton,[54] 1982	Retrospective	80 CSF samples	Adults	Positive CSF culture or bacterial antigen
Lannigan et al,[55] 1980	Cohort (not clear if prospective)	434	16-86 y	Positive CSF culture
Lindquist et al,[56] 1988	Prospective cohort	710	>2 mo but majority adults	Positive CSF culture or bacterial antigen
Briem,[57] 1983	Cohort (not clear if prospective)	266	90% 15 y or older	Positive CSF culture or bacterial antigen
Komorowski et al,[58] 1986	Retrospective	562	Adults	Positive CSF culture

Abbreviation: CSF, cerebrospinal fluid.

Table 3. Accuracy of Cerebrospinal Gram Stain in Patients With Suspected Bacterial Meningitis*

Study	Sensitivity, % (95% CI)	Specificity, % (95% CI)	Likelihood Ratio for Positive Test (95% CI)	Likelihood Ratio for Negative Test (95% CI)
Dunbar et al,[53] 1998	86 (74-92.6)	100 (lower 95 confidence limit 99.7)	737 (230-2295)	0.14 (0.08-0.27)
Wasilauskas and Hampton,[54] 1982	60 (47-71)	. . .	. . .	. . .
Lannigan et al,[55] 1980	56 (34-75)	. . .	. . .	. . .

Abbreviation: CI, confidence interval.
*Ellipses indicate that data are not available.

Table 4. Accuracy of Cerebrospinal Fluid Biochemical Analysis in Patients With Suspected Bacterial Meningitis

CSF Test	Positive Likelihood Ratio (95% CI)	Negative Likelihood Ratio (95% CI)
White blood cell count ≥500/μL[56]	15 (10-22)	0.30 (0.20-0.40)
Glucose >39.6 mg/dL (>2.2 mmol/L)[56]	23 (13-40)	0.50 (0.40-0.60)
Blood glucose ratio ≤0.4[56]	18 (12-27)	0.31 (0.21-0.45)
Blood glucose ratio <0.4 Briem,[57] 1983*	145 (20.4-1029)	0.25 (0.15-0.40)
Lactate >27 mg/dL (>3 mmol/L) Komorowski et al,[58] 1986	2.9 (2.4-3.5)	0.20 (0.06-0.50)
Lactate ≥31.5 mg/dL (≥3.5 mmol/L) Lannigan et al,[55] 1980	13 (8.6-20)	0.20 (0.06-0.50)
Lindquist et al,[56] 1988	25 (16-38)	0.12 (0.06-0.20)
Briem,[57] 1983†	38 (15-94)	0.01 (0.001-0.20)
Summary	21 (14-32)	0.12 (0.07-0.23)

Abbreviations: CI, confidence interval; CSF, cerebrospinal fluid.
*n = 245.
†n = 218.

were predictors of bacterial meningitis. Severity was defined by the presence of at least 1 of the following: altered consciousness, seizure, focal neurological findings, and shock. Because this study was retrospective, relevant laboratory data was not available for all patients. And, this model has not been prospectively validated in an independent population.

How Should the Procedure Be Performed?

Ideally, a successful LP should meet the following criteria: (1) obtain sufficient CSF on the first attempt, (2) occurs without trauma (ie, CSF containing <1000 red blood cells per high powered field), (3) occurs with minimal discomfort to the patient during and after the procedure, and, (4) occurs without serious adverse events such as cerebral herniation. The following description of the method to perform an LP considers the best available evidence and expert opinion to facilitate successful LP completion.

The procedure and its risks should be explained to the patient and informed consent obtained if relevant in the practice setting. The description should include how the procedure will be performed, why it is being performed, what complications may occur, and how these can be treated. For example, patients can be told that on average, 6 out of 10 people may develop a transient headache after LP and that up to 4 out of 10 people can experience temporary backache. Patients should be asked if they are allergic to any medications including local anesthetic. For the anxious patient, some experts suggest that a small dose of anxiolytic (eg, lorazepam) may be given prior to the procedure if the patient wishes.

In the absence of any focal neurological findings, altered mentation or papilledema, the LP can be performed without first completing a CT scan.[12,13] If a CT scan is requested before the LP when bacterial meningitis is suspected, antibiotic therapy should be started immediately and should not await completion of the CT scan. If possible, blood cultures should be taken prior to starting antibiotics.

The LP is usually completed with the patient in the lateral recumbent position with his/her back at the edge of the bed to minimize curving of the spine (**FIGURE 4**). Both legs should be flexed toward the chest and the neck should also be slightly flexed. The patient's shoulders and pelvis should be vertical to the bed. In this position, an imaginary line connecting the patient's posterior superior iliac crests would cross the L4-L5 interspace (Figure 4). Lumbar puncture can occur in the L3-L4, L4-L5, or L5-S1 interspace.[67] It should

not be attempted at higher levels in order to avoid the conus medullaris. There is no evidence to guide the clinician about whether the L3-L4 or L4-L5 interspace is the optimal site for the initial attempt, which is a topic highlighted for future research. The performance of LP may occur at L5-S1 because there are fewer nerve roots and a relatively larger interspace. The spinous process superior to the chosen interspace should be palpated. The needle should be inserted about 1 cm inferior to the tip of this process.[68]

Wearing sterile gloves and a mask, the clinician should cleanse the puncture site with an antiseptic solution by applying it in a circular motion that starts at the center of where the puncture will occur. Sterile drapes can be applied, leaving the puncture site exposed. Palpate the identified spinous process again and with 2 to 3 mL of local anesthetic (eg, lidocaine), infiltrate the patient's skin and deeper tissues allowing 1 to 2 minutes for this to take effect. An atraumatic needle does not have the same cutting edge as a standard needle so it may be preferable to use an introducer to puncture the skin prior to insertion of the needle if this needle type is used. Introduce the spinal needle (using the same track that was used for the anesthetic) and advance it horizontally while aiming toward the umbilicus to a depth of about 2 cm. If bone is encountered, withdraw the needle to the subcutaneous position and reinsert at a slightly different angle. Continue to advance the needle until a pop is felt, indicating penetration of the ligamentum flavum. The needle should now be in the subarachnoid space. When the stylet is withdrawn, clear fluid should drip. If no fluid emerges, rotate the needle to ensure that no flap of dura is blocking flow of CSF. If there is still no fluid, reinsert the stylet and advance the needle slightly, withdrawing the stylet after each movement. Pain radiating down either leg indicates that the needle is too lateral and has touched nerve roots. If this occurs, immediately withdraw the

Table 5. Studies That Developed and/or Validated Prediction Rules for Diagnosing Bacterial Meningitis*

Study	Study Design	No. of Patients	Age	Model	Accuracy
Spanos et al,[60] 1989	Retrospective chart review	Derivation set, 120	>1 mo	$PABM = \dfrac{1}{(1+e^{-L})}$ †	AUC 0.97
Hoen et al,[61] 1995	Retrospective chart review	500	>1 mo	$PABM = \dfrac{1}{(1+e^{-L})}$ ‡	AUC 0.99
Leblebicioglu et al,[62] 1996	Retrospective chart review	40	NA	Assessed models by Hoen and Spanos	AUC 0.95 by Spanos§ AUC 0.99 by Hoen
McKinney et al,[63] 1994	Retrospective chart review	170	>17 y	Assessed model by Spanos	AUC 0.98
Baty et al,[64] 2000	Prospective‖	109	1-85 y	Assessed model by Hoen	Sensitivity 80%

Abbreviations: AUC, area under the curve; CSF, cerebrospinal fluid; NA, not available; PABM, probability of acute bacterial meningitis; PMN, polymorphonuclear leukocytes.
*Reference standard: bacterial meningitis is present when CSF, urine, or blood tests positive or when bacterial antigen is detected in blood, urine, or CSF.
†Where L = 0.52 × number of months from August 1 −12.76 × CSF: blood glucose ratio (if ratio >0.6, use 0.6) + 0.341 × (PMNs in CSF × 10^6/1)$^{0.333}$ + 2.29 × age + 2.79 (if age ≤1 y), −2.71 × age + 7.79 (if 1 y <age ≤2 y), −0.159 × age + 2.69 (if 2 y <age ≤22 y), or + 0.1 × age = 3.01 (if age >22 y).
‡Where L = 32.13 × 10^{-4} × CSF PMN count (10^6/L) + 2.365 × CSF protein (g/L) + 0.6143 × blood glucose (mmol/L) + 0.2086 × leukocyte count (10^9/L) −11.
§Note the units used in the equation: glucose 1 mg/dL. To convert to mmol/L, multiply by 0.0555.
‖Excluded those with encephalitis and in those for whom the diagnosis was obvious (eg, cloudy CSF or positive Gram stain).

needle almost to the skin, recheck the patient's position, and reinsert the needle in the mid line. If this process fails, move down 1 interspace and try again. If this fails, the procedure should be attempted by another person; alternatively it can be done under fluoroscopic guidance. If the LP attempt is unsuccessful with the patient in the lateral position, it may be attempted with the patient sitting upright.[50] However, this position does not permit accurate measurement of the CSF pressure.[50,69]

When flow of CSF is seen, pressure can be measured by connecting a manometer directly to the needle or via a 2- or 3-way stopcock. The 0 mark on the manometer should be held at the level of the spinal needle and the tube held vertically. Normally, there will be variation in the pressure with respiration.

The manometer contents can be released for collection and analysis. Additional CSF can be collected for the required investigations. Typically, the examiner prepares 3 to 4 collection tubes. The initial CSF sample is placed into a tube labeled for biochemistry, and tube number 2 is for bacterial studies (Gram stain, culture, and sensitivity). Cell counts can be done on tube number 3, and the fourth tube can be used for cytology or for other tests that might be done when considering other diagnoses. These tests will vary depending on the differential diagnosis for the individual patient. Once CSF collection

has been completed, the stylet should be reinserted prior to removal of the needle. A bandage may be applied to the puncture site and the patient allowed to ambulate.

How Should This Procedure Be Taught or Learned?

Recent surveys of clinical practice suggest variation in LP technique. A 1996 survey of senior registrars in all departments of neurology and neurosurgery in the United Kingdom found that 15% of respondents reported using atraumatic needles and that 73% recommended bed rest for up to 6 hours after completion of the LP.[70] A similar survey of 2287 practicing neurologists in the United States found that 2% used atraumatic needles.[70] Neurologists did not use atraumatic needles due to lack of knowledge of them or because the needles were not available for use in their institution.[71]

The American Board of Internal Medicine recommends 3 to 5 LPs as a minimum standard for ensuring competence in completing LPs.[72] However, trainees report that they needed to complete 6 to 10 procedures to feel comfortable with their performance.[72]

Based on the evidence reviewed in this article, some targets could be suggested to help clinicians assess the quality of their LP performance. A successful LP would be indicated by obtaining sufficient CSF fluid for analysis on the first attempt and by achieving risks of

post-LP headache of less than 60% and of backache of less than 40%. However, these figures represent the average risk of these events and thus cannot be considered as benchmarks.[73]

To date, there is little evidence to guide the teaching of this procedure. Simulators have been developed, but they have not been rigorously evaluated.[74] In one randomized trial of a Web-based educational tool, 14 novice trainees were randomized to receive Web-based training or no training.[75] The Web-based training module provided virtual simulation of an LP. Both groups completed pre- and post-LPs on a synthetic mannequin. Investigators found an improvement in performance of LP with completion of the training module. There was no assessment of the procedural skills on patients or of the risk of post-LP complications. This evidence highlights the need to evaluate teaching the performance of LP to ensure clinical competence is achieved and maintained.
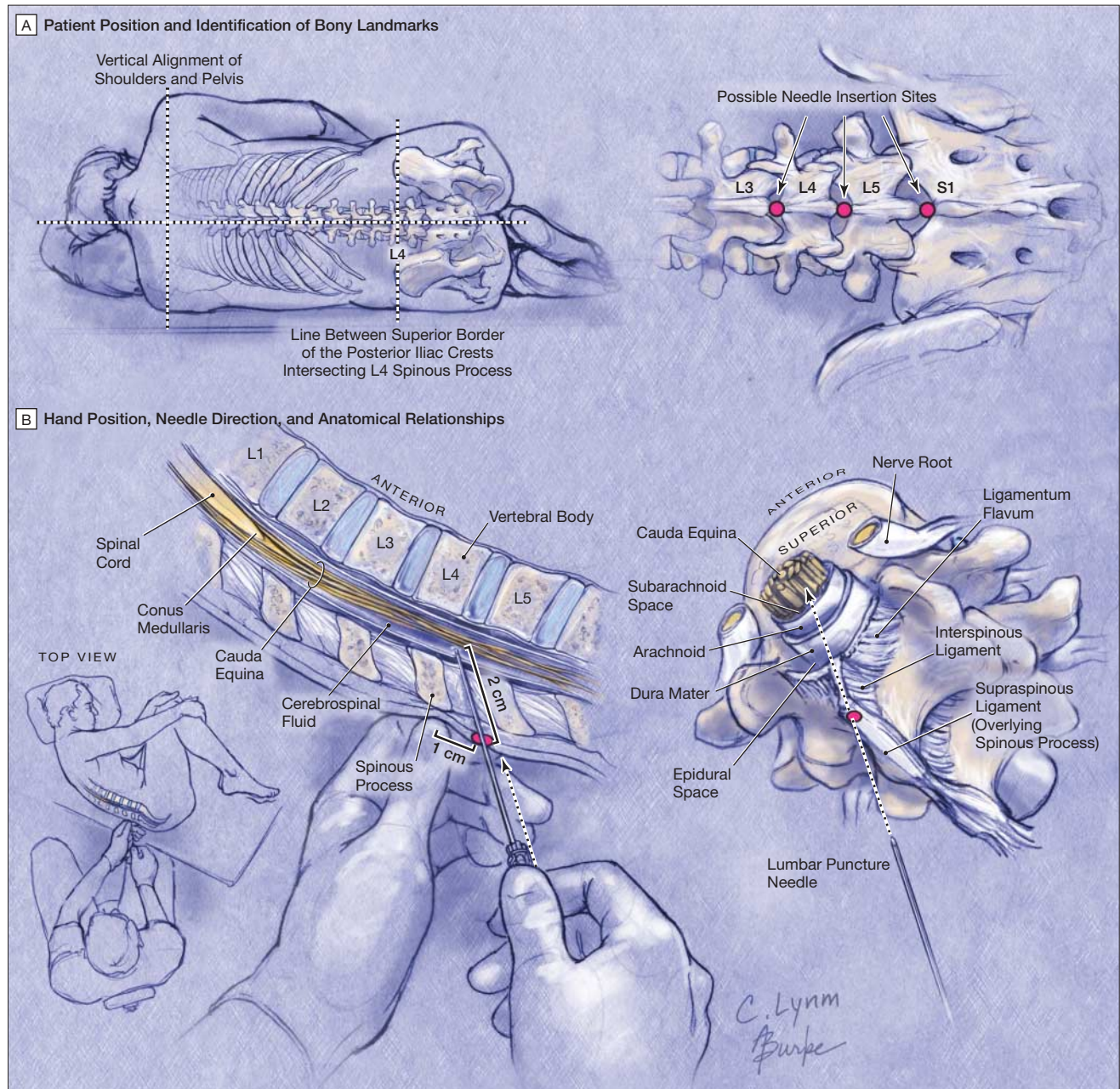
SCENARIO RESOLUTION

Our patient had a fever, confusion, and neck stiffness. Many clinicians might proceed immediately to LP to rule out meningitis. However, we weren't able to complete a full neurological examination because our patient was unable to cooperate with the assessment. As discussed in this article, evidence suggests that her altered mental state and age and our inability to confirm the ab-

sence of a focal neurological finding are appropriate indications for a CT scan to rule out an intracranial lesion. This situation describes a common clinical conundrum even though the incidence of intracranial lesions with such presentations is low. Because our clinical findings were strongly suggestive of meningitis, we obtained blood work including complete blood count, glucose, and cultures and initiated immediate antibiotic therapy. We decided to

Figure 4. Anatomical Considerations During Lumbar Puncture

Lumbar puncture is usually performed with the patient in the lateral recumbent position. To avoid rotation of the vertebral column, align the patient's shoulders and pelvis in a plane perpendicular to the bed. A line connecting the superior border of the posterior iliac crests intersects the L4 spinous process or the L4-L5 interspace. Insert the lumbar puncture needle in the midline of the L3-L4, L4-L5 (most commonly), or L5-S1 vertebral interspace. These interspaces are below the end of the spinal cord, which terminates at the level of L1. Angle the needle towards the patient's umbilicus and advance it slowly. The needle will penetrate the ligamentum flavum, dura, and arachnoid to enter the subarachnoid space, where cerebrospinal fluid is located.

obtain a CT scan (on which no mass lesion was noted) before performing an LP. Given her confusion and uncertain neurological status, we suggested ambulation with assistance. We used an atraumatic needle and completed the procedure with the patient in the left lateral recumbent position. Cerebrospinal fluid was sent for cell count, Gram stain, culture, protein, glucose, and lactate. Results showed a white blood cell count of 5000/µL and a CSF–blood-glucose ratio of 0.2, helping us to diagnose bacterial meningitis.

BOTTOM LINE

Lumbar punctures to assess meningitis in adults should be performed under sterile conditions with the patient placed in the lateral recumbent position and their knees flexed. Alternatively, the patient could sit up and lean forward with his/her feet supported to increase the interspinous space. For most patients, a CT scan of the head to rule out mass lesion is not required before the LP and the clinical examination can guide the decision about neuroimaging.

The following procedures may decrease the risk of post-LP headache:

1. Use of small-gauge atraumatic needles for diagnostic LPs is preferred but may require more needle pass attempts,

2. Reinsertion of the stylet prior to the removal of the spinal needle,

3. Mobilization of patients after completing the LP.

In patients suspected of having bacterial meningitis, the following laboratory tests can be considered along with appropriate cultures, Gram stain and serologic studies:

1. CSF–blood glucose ratio of 0.4 or less (LR positive, 18; 95% CI, 12-27; LR negative, −0.31; 95% CI, 0.21-0.45).

2. CSF white blood cell count of 500/µL or higher (LR positive, 15; 95% CI, 10-22; LR negative, 0.30; 95% CI, 0.20-0.40).

3. CSF lactate level of 31.5 mg/dL or less (≥3.5 mmol/L; LR positive, 21; 95% CI, 14-32; LR negative, 0.12; 0.07-0.23).

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