ORIGINAL INVESTIGATION

Cranial Computed Tomography Before Lumbar Puncture

A Prospective Clinical Evaluation

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Objective: To prospectively identify which patients can safely undergo lumbar puncture (LP) without screening cranial computed tomography (CT).

Methods: Emergency department physicians examined patients before CT. Examiners recorded the presence or absence of 10 clinical findings and answered 8 additional questions. The criterion standard was noncontrast cranial CT interpreted by staff radiologists. Clinical findings were prospectively compared with those of CT.

Results: One hundred thirteen consecutive adults with the urgent need for LP (median age, 42 years) were studied. Fifteen percent of patients meeting entrance criteria had new CT-documented lesions, with 2.7% having lesions that contraindicated LP. Sensitivity, specificity, and likelihood ratios (LRs) were measured for the clinical findings. Three statistically significant predictors of new intracranial lesions were identified: altered mentation (positive LR, 2.2; 95% confidence interval [CI], 1.5-3.2), focal neurologic examination (positive LR, 4.3; 95% CI, 1.9-10), and papilledema (positive LR, 11.1; 95% CI, 1.1-115). No single item adequately predicted the absence of CT abnormalities, but the clinical screening items in aggregate significantly predicted the results (negative LR, 0; upper 95% confidence limit, 0.6). The overall clinical impression had the highest predictive value in identifying patients with CT-defined contraindications to LP (positive LR, 18.8; 95% CI, 4.8-43).

Conclusions: Because of the low prevalence of lesions that contraindicate LP, screening cranial CT solely to establish the safety of performing an LP typically provides limited additional information. Physicians can use their overall clinical impression and 3 clinical predictors to identify patients with the greatest risk of having intracranial lesions that may contraindicate LP.

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SHORTLY AFTER the lumbar puncture (LP) was introduced in 1891,[1] it was realized that devastating complications, such as uncal herniation, infrequently resulted from this apparently benign procedure.[2] Subsequently, numerous case reports and case series attempted to identify the patients at the highest risk for complications.[3-6] The advent of computed tomography (CT) of the brain gave hope that all potentially life-threatening complications of LP could be prevented.

The widespread availability of CT in the United States has made routine CT scanning of the brain before LP the medical standard of care in many emergency departments (EDs). In one series of 493 patients with meningitis, 71% of patients examined after 1975 underwent CT scanning before LP.[7] Many authors have stated that LP should not be performed without CT screening in suspected meningitis.[8,9] This practice, however, has led to a high percentage of normal CT scans. Despite the increasing concern for appropriate utilization of medical resources, no study has provided data that allow physicians to distinguish between patients who require and those who do not require a CT scan before LP. One group attempted to review the current data on the indications for CT in acute meningitis.[10] These investigators concluded that there was no evidence to indicate that CT should be performed before LP. Unfortunately, these authors cited no studies that assessed the risk of LP in meningitis nor clearly delineated which patients should be screened with CT. A second group endeavored to answer this question by retrospectively demonstrating the lack of correlation between CT findings and opening cerebrospinal fluid pressure in all patients undergoing both CT and LP in the ED.[11] This study of 42 patients, however, again did not attempt to determine which patients could safely undergo LP

PATIENTS AND METHODS

STUDY SAMPLE

The study was conducted in the ED of Duke University Medical Center (Durham, NC), a major teaching hospital serving the immediate urban and suburban community as well as the surrounding rural areas. Data for consecutive patients aged 18 years and older triaged to the medicine section of the ED were potentially evaluable. Patients were included if the physician determined that the patient needed an urgent LP (LP performed in the ED). Eligibility criteria were designed to represent the broad range of medical patients who come to an ED requiring LP. All patients were examined before CT by second- or third-year internal medicine house staff, overseen by ED attending physicians. As the study was a pragmatic trial, we did not assess the precision of the clinical examination with duplicate measures.

CLINICAL EVALUATION

The study investigators conducted a literature review and surveyed practicing neurologists and ED physicians to generate a list of candidate variables from the history and physical examination that would contraindicate LP without a previous CT scan. The list was designed to reflect the most likely clinical risk factors for intracerebral mass lesions.

Each physician received an outline of the objectives of the study and definition of terms, and they attended an orientation session. The physicians recorded the patient's age and temperature, indication for screening CT before LP, time the CT was ordered, time the LP was performed, and whether patients received antibiotics before the CT scan. They answered the following series of yes or no questions regarding the patient's history before CT: presence of risk factors for human immunodeficiency virus (HIV) (multiple or high-risk sexual partners, intravenous drug use, or blood transfusions), documented HIV positivity, any immunosuppressing conditions, history of malignant neoplasms, head trauma within the previous 72 hours, history of central nervous system (CNS) mass lesion, report of recent altered mental status, and seizures within the previous 72 hours. The specific physical examination findings recorded before the CT included an evaluation for papilledema and a search for focal neurologic findings. After answering the questions in the standardized format, the ED physicians recorded their perceived likelihood that the CT would contraindicate LP or disclose any new lesion.

CRITERION STANDARD

The results of the screening CTs were taken from the official radiology reports. The radiologists were not blinded to clinical information, and the radiographs were not reread as part of the study. The radiologists were, however, blinded to the objectives of the study. The CT findings were categorized as "positive, LP contraindicated" if the original report noted lateral shift of midline structures, loss of suprachiasmatic and basilar cisterns, obliteration of the fourth ventricle, or obliteration of the superior cerebellar and quadrigeminal plate cisterns with sparing of the ambient cisterns.[12] The CT was categorized as "positive, LP not contraindicated" if none of the above criteria was noted, but new mass, stroke, or hemorrhage was seen. The CT was categorized as "negative" if neither set of the above criteria was present. Data from the hospital computing system were reviewed to confirm that an LP had actually been performed, with cerebrospinal fluid sent for analysis.

STATISTICAL ANALYSIS

Data were initially entered into Microsoft Access 2.0 (Microsoft Corp, Redmond, Wash). Frequencies, means, and SDs were calculated with SAS software (SAS Institute, Cary, NC). Likelihood ratios (LRs), sensitivity, specificity, and 95% confidence intervals (CIs) were calculated in the usual fashion,[13] or by an iterative approach when cells in the data table had a value of 0.[14] A receiver operating characteristic curve described the overall ability of the number of clinical examination abnormalities as a diagnostic test for discriminating those with from those without CT abnormalities.[15]

without CT screening. Thus, with insufficient data, the clinician finds himself or herself caught between economic pressures, potential legal retribution, and the well-being of the patient.

In an attempt to clarify this dilemma, we asked ED physicians and upper-level internal medicine residents to prospectively record specific items from the patient's history and results from the physical examination to determine which patients could safely undergo LP without CT screening. We also attempted to identify patients at highest risk for intracerebral lesions, as well as to provide insight into the ability of clinicians to predict the CT findings. Finally, we evaluated any potential delay in antibiotic treatment caused by CT.

RESULTS

During the 18-month period, 111 of 113 consecutive patients were assessed. Two patients could not be assessed because of incomplete data. Neither of these patients had an abnormal cranial CT scan. The indications for urgent LP were to rule out meningitis (36.9%), to rule out subarachnoid bleeding (42.3%), and other reasons (20.7%). All LPs were preceded by screening cranial CT. Patients had a median age of 42 years, with a range of 19 to 77 years.

RADIOGRAPHIC FINDINGS

The most common radiographic finding was a normal or unchanged CT scan, in 84% of patients. The frequency of new radiographically documented lesions was 15.3% (17 patients): mass in 8, hemorrhage in 3, stroke in 2, and other in 4. Of this group, 3 patients (2.7%) had findings that absolutely contraindicated LP: subdural hematoma with mass effect, massive intracranial hemorrhage with herniation, and new ring enhancing lesion with mass effect and herniation. None of the 3 patients with abso-

Table 1. Performance Characteristics of Test Questions Predicting New Intracranial Lesions*

Test Question†	Frequency‡	Positive Likelihood Ratio (95% CI)	Negative Likelihood Ratio (95% CI)	Sensitivity, %	Specificity, %
HIV risk factors	29	1.8 (0.9-3.5)	0.76 (0.5-1.2)	41	77
HIV positive	23	1.2 (0.45-3.0)	0.96 (0.7-1.3)	24	80
Immunosuppressed	36	1.57 (0.88-2.9)	0.75 (0.48-1.2)	47	70
Malignant neoplasm	7	0.0 (0-3.5)	1.1 (0.8-1.1)	0	93
Head trauma <72 h	9	0.7 (0.09-5.2)	1.0 (0.9-1.2)	6	91
Prior CNS mass	5	3.7 (0.67-20.4)	0.91 (0.76-1.1)	12	97
Seizures <72 h	15	1.4 (0.4-4.4)	0.94 (0.75-1.2)	76	65
Altered mentation	46	2.2 (1.5-3.2)	0.36 (0.15-0.9)	12	99
Papilledema	3	11.1 (1.1-115)	0.89 (0.75-1.1)	18	87
Focal neurologic examination	16	4.3 (1.9-10.0)	0.64 (0.38-1.0)	41	90
≥1 Abnormal finding present	66	1.6 (1.2-1.9)	0 (0-0.6)	100	37

*CI indicates confidence interval; HIV, human immunodeficiency virus; and CNS, central nervous system.
†See the "Clinical Evaluation" subsection of the "Patients and Methods" section.
‡Number with finding present of 111 patients with complete data.

Table 2. Performance Characteristics of Physician Prediction of Computed Tomography Results*

Physician Prediction of Finding	Positive Likelihood Ratio (95% CI)	Negative Likelihood Ratio (95% CI)	Sensitivity, %	Specificity, %
Any new lesion	9.1 (2.4-34)	0.63 (0.4-1.0)	40	96
Lumbar puncture contraindicated	18.8 (4.8-43)	0.0 (0-0.7)	100	95

*CI indicates confidence interval.

lute contraindications to LP underwent LP, whereas all 14 of the remaining patients with new CT-defined lesions proceeded to LP.

OPERATING CHARACTERISTICS OF HISTORY AND PHYSICAL EXAMINATION

The frequencies, LRs, sensitivities, and specificities for each individual screening item predicting new intracranial lesions are expressed both individually and in aggregate in **Table 1**. Likelihood ratios express the odds that the history or physical examination finding would occur in a patient with as opposed to without an abnormal cranial CT.[16] When an LR is above 1.0, the probability of disease (abnormal CT) increases.[17] Three physical examination findings increased the LRs with CIs that excluded 1 (altered mentation: positive LR, 2.2; papilledema: positive LR, 11.1; focal neurologic examination: positive LR, 4.3). When looked at in aggregate, the presence of at least 1 abnormal history or physical finding increased the LR, but to a lesser degree ($LR_{n\geq1}$, 1.6; 95% CI, 1.2-1.9).

Of the individual test questions, the absence of altered mental status decreased the LR the most (LR, 0.36). In aggregate, the lack of any positive historical or physical finding had the greatest effect on the LR ($LR_{n=0}$, 0; upper 95% confidence limit, 0.63). None of the 35 patients with a negative response to each question had a new CT abnormality.

We constructed a receiver operating characteristic curve, assessing the number of abnormalities as a predictor of a new CT abnormality. The curve compares the sensitivity and 1 – specificity at each level of abnormalities. The area under the curve was only 0.68 (SE, 0.06), suggesting that the number of abnormalities inadequately distinguishes patients with normal CT scans from those who have new abnormalities.

We next examined the global assessment of the examiner in predicting the CT results. Physicians recorded their predictions of whether CT would contraindicate LP in 70% of patients examined (**Table 2**). These examiners were able to identify prospectively all 3 patients who proved to have absolute contraindications to LP. This prediction yielded a positive LR of 18.75 (95% CI, 4.8-43) for the overall clinical assessment. Physicians were less accurate in predicting which patients would have any new CT abnormalities (positive LR, 9.1; 95% CI, 2.5-31).

In addition, we evaluated the time delay imposed by CT scanning before LP. Lumbar puncture occurred a mean of 2.7 hours after a CT scan was ordered (SD, 1.6 hours; range, 0.5 to 9 hours). Two of the 3 patients with a positive cerebrospinal fluid culture did not receive antibiotics before LP while awaiting CT, resulting in a mean treatment delay of 2.8 hours (range, 1.5 to 4.0 hours).

COMMENT

We evaluated the operating characteristics of history and physical examination for CNS lesions in patients undergoing LP in medical EDs. The data identified 3 statistically significant predictors of new intracranial lesions: (1) the specific findings of papilledema, focal neurologic examination, and altered mental status; (2) the physician's overall impression; and (3) the presence of 1 or more positive responses on the screening question-

naire. The presence of positive HIV status, seizures, malignant neoplasms, immunosuppression, head trauma, or history of CNS mass did not individually predict positive CT findings. The clinical importance of these features, however, needs careful scrutiny in a much larger population.

EVEN MORE IMPORTANT than identifying patients with positive predictors for CNS lesions is the ability to determine which patients have sufficiently strong negative predictors to safely undergo LP without screening CT. No patient with entirely normal findings on the clinical examination had a new intracranial lesion. The sample size, however, suggests that the 95% CI for the LR could be as unacceptably high as 0.63. To show that the clinical examination can screen patients to lower the likelihood of a new intracranial lesion from the 2.7% prevalence we found, to less than 1%, would require a consecutive series of 1439 patients referred for CT before LP.[13] The long study period (18 months) in an academic medical center suggests that the answer can be obtained relatively quickly only through a multisite research cooperative group of emergency physicians.

The study did not directly measure major complications after LP by randomizing patients to undergo or not undergo screening CT. We were, thus, limited to the criterion standard of cranial CT and the generally accepted guidelines defining which patients would be at increased risk for herniation.[12] Cranial CT, however, has not been directly compared with complications after LP and may lack specificity. Furthermore, using the primary measurement as the ability to safely perform LP based on CT findings, we cannot generalize this approach to patients in whom there is a high clinical suspicion of a specific CT-definable process (eg, subarachnoid hemorrhage).

The overall impression of the examining physician in predicting which patients would have CNS lesions contraindicating LP was superior to any individual historical or physical examination finding. Predicting that the CT would (LR, 18.75) or would not (LR, 0.0) contraindicate LP significantly changed the likelihood of disease. Of note, physicians did not answer or were not confident enough to predict whether the CT would contraindicate LP in 30% of patients studied, potentially illustrating the difficulty in clinical decision making and the utility of clear predictive criteria. Although we do not know the percentage of physicians who simply neglected to complete this item, we suspect the large percentage of missing estimates reflected physician uncertainty. We infer that physicians who are confident in their estimate will efficiently use their clinical gestalt to predict the likelihood of a CNS lesion contraindicating LP. Based on the 2.7% prevalence of such lesions in this study, a clinical suspicion of the presence of a contraindicating lesion raises the probability to 33% (95% CI, 12%-54%). A clinical suspicion of no CNS lesion contraindicating an LP lowers the probability that such a lesion actually exists to less than 2%.

This study has several strengths. First, the patients studied represented a diverse group of symptoms, all with indications for LP. This broad base of patients may have avoided verification bias, in which patients with a high probability of disease are preferentially enrolled with the reference standard test.[18] Second, rather than using only a few examiners specifically interested in clinical predictors of CT abnormalities, we used the general ED staff and internal medicine house staff, which may more closely reflect the true clinical setting. These strengths improve the generalizability to other examiners and patient groups and, therefore, may more accurately represent the patients actually seen in the nonsurgical ED setting.[17] This approach removes the problem of context bias, in which radiologists are influenced by artificially increased prevalence of the abnormal finding created by reviewing a contrived sample of CT scans.[19] Most important, all patients were identified and examined prospectively with clinical data recorded before CT. This study design removes any bias that the CT results may impose on the clinical examiner and more closely represents true clinical practice. Although the radiologists could have been influenced by incorporation bias, as they were aware of clinical information, such bias usually leads to overly optimistic results. Our observation that the clinical predictors of HIV status, cancer history, head trauma, immunosuppression, and seizures did not reach statistical significance suggests limited effects attributable to incorporation bias. However, the overall findings of the study may reflect a lack of power resulting from a limited sample size rather than a true lack of significance. The low power makes it necessary to review CIs around estimates when inferences are made about the results.

Rather than simply demonstrating that CT provides minimal additional useful information regarding the ability to safely perform an LP in low-risk patients, it is more important to determine how these findings could alter the current standard of care. One obvious benefit could be cost savings. If the above criteria were implemented in our series of patients, 35 CT scans could have been eliminated, for a potential savings of $21 000 to $35 000 (at $600-$1000 per CT scan), assuming there were no adverse effects that could have been prevented by CT. More important than cost savings, though, the adoption of this approach can ultimately improve patient care. Two thirds of patients with meningitis did not receive antibiotics before CT, representing a mean delay of 2.8 hours before receiving therapy. Although patients in whom meningitis is strongly suspected should generally receive antibiotics immediately if there is to be any delay in LP, by eliminating the unnecessary step of CT before LP we can better expedite therapy in selected patients.

In summary, our data suggest 3 items that predict new CT findings. The first includes the clinical findings of papilledema, a focal neurologic examination, and altered mental status. The second, the clinician's overall impression, was the strongest positive predictor of CT-identified lesions contraindicating LP. The screening questionnaire as a whole was the third item predicting CT-identified lesions contraindicating LP. It identified

all patients with new CT findings and might be useful to "rule in" normality, so that selected patients in whom suspicion of a specific CT-definable process is low can safely have an LP without waiting for a CT. This does not, however, suggest that patients in whom suspicion of another specific CT-definable process is high forgo CT evaluation. Future investigations can focus on clinical predictors that may not have reached statistical significance in this study because of sample size, better defining the specificity of CT in this setting, as well as evaluating the outcomes of patients treated under this approach. Physicians who are uncertain after their clinical examination should evaluate all the items in Table 1 and systematically compare their performance with that of CT scanning to improve the yield of their clinical examinations.

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Correction

Error in Table. In the original article by Gopal et al titled "Cranial Computed Tomography Before Lumbar Puncture: A Prospective Clinical Evaluation," published in the December 13/27, 1999, issue of the ARCHIVES (1999;159:2681-2685), an error occurred in Table 1 on page 2683. The sensitivity and specificity for seizures less than 72 hours should have read 18% and 87%, respectively; for altered mentation, 76% and 65%, respectively; and for papilledema, 12% and 99%, respectively. The remainder of the table is correct.