Original Contributions

SENSITIVITY OF NEWER-GENERATION COMPUTED TOMOGRAPHY SCANNERS FOR SUBARACHNOID HEMORRHAGE: A BAYESIAN ANALYSIS

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Abstract—Background: Subarachnoid hemorrhage (SAH) is a life-threatening condition considered in patients presenting to the emergency department (ED) with acute and severe-onset headache. Currently, the practice pattern for suspected SAH is to perform a non-contrasted computed tomography (CT) scan of the head, followed by lumbar puncture (LP) if the CT is negative. Newer-generation 16-slice CT scanners have been shown in one study to be very sensitive for SAH. Objective: We sought to validate these findings at our institution by retrospectively analyzing the sensitivity of our 16-slice or better CT scanner and performing a bayesian analysis with the results. Methods: We utilized ED electronic medical records and the Department of Neurosurgery research database to search for patients admitted from the ED with a diagnosis of SAH from January 1, 2005 to December 31, 2008. We found a total of 134 patients admitted with SAH during this time frame. Results: Average age was 53.8 years; 62% were female. Presenting complaint was headache in 57%, paresthesia or weakness in 7%, unresponsive in 10%, confusion or altered mental status in 5%, and “other” in 10%. Sensitivity of 16-slice or better CT scanner in our study was 131/134, or 97.8% (95% confidence interval 93.1–99.4%). No patient with a negative CT had a lesion requiring intervention. Conclusion: Our study confirms the high sensitivity of 16-slice or better CT scanners for SAH. This calls into question the need for LP after negative head CT when 16-slice CT or better is used.

INTRODUCTION

It has been estimated that 2% of all emergency department (ED) visits are for a chief complaint of headache (1). Although most of these visits are ultimately primary headaches, an emergency physician is tasked with identifying the life-threatening causes of headaches in these patients. Subarachnoid hemorrhage (SAH) is certainly one of these causes, with a reported mortality of 40% (2). This makes SAH a commonly thought of, but rarely diagnosed, disease. Physicians spend a good deal of time investigating this diagnosis and attempting to minimize the misdiagnosis rate. However, despite the high awareness for SAH, it is still a commonly missed diagnosis (3). Experts believe there are three factors that lead to missed diagnoses: failure to consider SAH in the differential diagnosis, failure to perform computed tomography (CT) scan, and failure to perform and properly analyze the results of lumbar puncture (4–11).

The currently accepted procedure for the work-up of a patient with a possible SAH in the ED is a non-contrast CT scan of the head, followed by a lumbar

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puncture (LP) if the CT is negative for SAH (12). However, there are significant potential risks with performing LP, including its inherently invasive nature, high false-positive rate, difficult interpretation, and complications like persistent cerebral spinal fluid (CSF) leak, epidural hematoma, CSFoma (loculation of CSF near the tap site), epidural abscess, and meningitis. The most common complication of LP is persistent CSF leak, with up to 30–70% of LPs resulting in post-LP headaches (13–15). Use of pencil-point-type spinal needles may reduce these headaches. Additionally, there is patient anxiety and pain associated with the test.

Although the ideal LP provides clear evidence of red blood cells (RBC) that don’t clear in successive tubes with spectrographic xanthochromia, this can be difficult to interpret in a traumatic tap with large numbers of RBCs. Furthermore, the xanthochromia can require 12 h or more to develop as RBCs disintegrate in the CSF, leaving bilirubin pigment to color the fluid.

Sensitivity of CT for SAH has been reported to be from 90% to 100% (16–24). However, the studies that report lower sensitivities quite frequently use older-generation CT scanners with fewer slices instead of newer 16- to 64-slice scanners. A recent study by Lourenco et al. used only 16-slice CT scanners and reported the sensitivity of CT for SAH to be 97%, with 60/61 patients diagnosed by CT (19). The final patient was diagnosed by cerebral angiography. We sought to validate these recent results and help determine the sensitivity of newer-generation CT scanners by performing a bayesian analysis using this study by Lourenco et al. as the informed prior (19).

**METHODS**

The study was performed on patients admitted through the ED. The hospital is an urban referral center with a large catchment area. The annual ED census is >40,000 patients. We accessed the ED electronic medical records and the Department of Neurosurgery research database to identify all patients admitted from the ED with a diagnosis of SAH from January 1, 2005 to December 31, 2008. Although the CT scanner type from outside hospitals was not known, the CT scanner was upgraded from a 16-slice CT scanner to a 64-slice scanner in early 2005. Unfortunately, during this period, both scanners were used randomly according to CT tech preference and ED work flow. Therefore, it is impossible to identify which scanner was utilized for each patient because this was never documented or recorded.

We evaluated all patients admitted to the hospital with a diagnosis of SAH. The chart review was performed by a single junior physician (post-graduate year 1), with quality assurance (QA) performed on 20% of the charts by a principal investigator who reviewed those selected charts for agreement with initial categorization. No changes from the initial categorization were made on the selected charts. Chart review was performed using standard definitions and a standardized abstraction sheet. We met regularly to answer questions regarding the chart review and to provide feedback as needed. Additional QA was performed by three of the other lead investigators on all charts in which patients had an SAH but negative CT of the head. This QA was to ensure proper categorization of those patients with CT-negative SAH. All of these cases were deemed to be correctly categorized by the initial reviewer. The study protocol was approved by the Institutional Review Board at the hospital.

**Statistical Methods**

We employed bayesian methods to model remaining uncertainty regarding the location of the parameter of interest (the sensitivity of newer-generation CT for the detection of SAH) in light of prior beliefs and present data. We used the highly flexible family of beta probability distributions for this purpose, which are defined on the interval 0 and 1 (thus making them suitable for the modeling of a proportion) and can be fully described by two parameters, a and b, where a is the number of successes $(s + 1)$ and $b = \text{the total number of trials} (n) - s + 1$.

We used the only previous study we could find on the sensitivity of newer-generation CT scanners for SAH as the basis of an empirical prior (19). This smaller study reported the detection of SAH in 60/61 patients evaluated by CT. Thus, we used a beta distribution with $a = 61$ and $b = 2$ to represent prior beliefs regarding this parameter. This prior was combined with present data to arrive at a posterior probability distribution representing a mathematically coherent updated belief regarding the sensitivity of CT for SAH.

To compute and graph probability distributions, we used the freely available R statistical software (R 2.9.2, The R Foundation for Statistical Computing, Vienna, Austria). We report median values and 95% credible intervals (CrI) for all distributions. Credible intervals, unlike traditional confidence intervals, represent where a coherent individual would place 19:1 betting odds on the location of the parameter, given prior beliefs.

**RESULTS**

There were 134 patients admitted with the diagnosis of SAH during the study period. Presenting chief complaint was headache in 57%, paresthesia or weakness in 7%, unresponsive in 10%, confusion or altered mental status in 5%, and “other” in 10% (Figure 1).
Of these 134 patients, 131 had a positive CT by our 16-slice or better CT scanner. Without prior information, this would give a posterior probability distribution with a median sensitivity of 97.3% (95% CrI 91.3–99.6%). Of the 3 patients with a negative CT scan, none required surgical intervention. Two of these patients had no aneurysm on further evaluation and may represent a non-aneurysmal bleed, such as a perimesencephalic bleed, or a traumatic tap. The other one was found to have such a small aneurysm that no intervention was performed on it either.

As mentioned, 2 of the patients with negative CT of the head and positive LP were found to have no aneurysm upon further work-up. One of these had a negative head CT at an outside hospital, but then had an LP with 142 RBCs in tube 1 and 150 RBCs in tube 4. The patient was then transferred to our hospital for evaluation of possible SAH. At our hospital the patient had a negative non-contrast CT of his head, a negative CT angiogram (CTA), and two negative conventional angiograms. Therefore, it would seem that this was either a non-aneurysmal hemorrhage or a traumatic LP.

The other patient with a negative CT of the head, positive LP, and negative work-up for aneurysm had an LP showing RBCs of 3000 in tube 1 and 2200 in a later tube. The patient was then admitted for evaluation of possible SAH. This patient also had a negative CTA and negative conventional angiograms. The patient was then discharged home with Neurosurgery follow-up, and no complications were reported 1 year later.

When combined with the informed prior based on Lourenco et al., the median sensitivity of CT for SAH is 97.6 (95% CrI 94.9–99.2) (19). Figure 2 demonstrates graphically the influence of the prior and the likelihood (present data) on the posterior probability distribution. The posterior probability of a sensitivity > 95% was \( p = 0.97 \). The posterior probability of a sensitivity > 96% was \( p = 0.90 \).

As mentioned, the three bleeds that were missed required no interventions and were clinically insignificant. This makes the sensitivity of 16-slice or better CT scanners for SAH requiring intervention nearly 100% (median posterior sensitivity 99.6%, 95% CrI 98.1–100%).

**DISCUSSION**

The current strategy of CT scan followed by LP for the work-up of SAH has been recently questioned. One analysis found LP to be of minimal value in the work-up,
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and frequency of pathological diagnoses. Cephalalgia 2006;26:684–90.


ARTICLE SUMMARY
1. Why is this topic important?
Headache is a common complaint in the emergency department, and subarachnoid hemorrhage is a key life-threatening diagnosis that must be excluded by emergency physicians. The ever-improving imaging modality of computed tomography (CT) may have reached a point where the performance of potentially dangerous and painful lumbar punctures can be eliminated.

2. What does this study attempt to show?
This study attempts to show the high sensitivity of 16-slice or greater non-contrast CT of the head for subarachnoid hemorrhage (SAH) in our population.

3. What are the key findings?
Sensitivity of 16-slice or better CT scanner in our study was 131/134 or 97.8% (95% confidence interval 93.1–99.4%). No patient with a negative CT had a lesion requiring intervention. It also suggests that the very small false-negative rate of 16-slice CT for SAH represents a population with disease that may not be clinically significant.

4. How is patient care impacted?
It is unclear if lumbar puncture adds any additional clinically significant information in the work-up of SAH when a 16-slice or better CT scanner is used.