

Are your **MRI contrast agents** cost-effective?

Learn more about generic **Gadolinium-Based Contrast Agents**.



**FRESENIUS  
KABI**

caring for life

**AJNR**










**Predictive Value of Noncontrast Head CT  
with Negative Findings in the Emergency  
Department Setting**

A.L. Callen, D.S. Chow, Y.A. Chen, H.R. Richelle, J. Pao,  
M. Bardis, B.D. Weinberg, C.P. Hess and L.P. Sugrue

This information is current as  
of April 17, 2024.

*AJNR Am J Neuroradiol* published online 23 January 2020  
<http://www.ajnr.org/content/early/2020/01/23/ajnr.A6408>

# Predictive Value of Noncontrast Head CT with Negative Findings in the Emergency Department Setting

 A.L. Callen,  D.S. Chow,  Y.A. Chen,  H.R. Richelle,  J. Pao,  M. Bardis,  B.D. Weinberg,  C.P. Hess, and  L.P. Sugrue

## ABSTRACT

**BACKGROUND AND PURPOSE:** Noncontrast head CTs are routinely acquired for patients with neurologic symptoms in the emergency department setting. Anecdotally, noncontrast head CTs performed in patients with prior negative findings with the same clinical indication are of low diagnostic yield. We hypothesized that the rate of acute findings in noncontrast head CTs performed in patients with a preceding study with negative findings would be lower compared with patients being imaged for the first time.

**MATERIALS AND METHODS:** We retrospectively evaluated patients in the emergency department setting who underwent noncontrast head CTs at our institution during a 4-year period, recording whether the patient had undergone a prior noncontrast head CT, the clinical indication for the examination, and the examination outcome. Positive findings on examinations were defined as those that showed any intracranial abnormality that would necessitate a change in acute management, such as acute hemorrhage, hydrocephalus, herniation, or interval worsening of a prior finding.

**RESULTS:** During the study period, 8160 patients in the emergency department setting underwent a total of 9593 noncontrast head CTs; 88.2% (7198/8160) had a single examination, and 11.8% (962/8160) had at least 1 repeat examination. The baseline positive rate of the “nonrepeat” group was 4.3% (308/7198). The 911 patients in the “repeat” group with negative findings on a baseline/first CT had a total of 1359 repeat noncontrast head CTs during the study period. The rate of positive findings for these repeat examinations was 1.8% (25/1359), significantly lower than the 4.3% baseline rate ( $P < .001$ ). Of the repeat examinations that had positive findings, 80% (20/25) had a study indication that was discordant with that of the prior examination, compared with only 44% (593/1334) of the repeat examinations that had negative findings ( $P < .001$ ).

**CONCLUSIONS:** In a retrospective observational study based on approximately 10,000 examinations, we found that serial noncontrast head CT examinations in patients with prior negative findings with the same study indication are less likely to have positive findings compared with first-time examinations or examinations with a new indication. This finding suggests a negative predictive value of a prior noncontrast head CT examination with negative findings with the same clinical indication.

**ABBREVIATIONS:** ED = emergency department; NCHCT = noncontrast head CT

Use of CT in the emergency department (ED) has grown dramatically in recent years.<sup>1-5</sup> Factors contributing to this growth include greater availability of CT and an increased reliance on imaging for initial patient triage and evaluation.<sup>1,2</sup> In

patients presenting to the ED with neurologic symptoms, noncontrast head CT (NCHCT) is the diagnostic tool of choice to exclude acute intracranial pathology and its use has grown apace with other CT imaging.<sup>1-3</sup>

In the absence of focal neurologic deficits, however, the diagnostic yield of NCHCT in the emergency setting is relatively low. For example, in patients presenting with syncope or dizziness, positive findings on NCHCT range from 2% to 7%.<sup>6,7</sup> In addition, anecdotally, many neuroradiologists will attest that the yield is even lower in patients who have had a recent study with negative findings for a similar indication. This perception is

Received August 7, 2017; accepted after revision December 6, 2019.

From the Neuroradiology Section (A.L.C., C.P.H., L.P.S.), Department of Radiology and Biomedical Imaging, University of California, San Francisco, San Francisco, California; Neuroradiology Section (D.S.C., H.R.R., J.P., M.B.), Department of Radiology, University of California, Irvine, Irvine, California; Trillium Health Partners (Y.A.C.), University of Toronto, Toronto, Ontario, Canada; and Radiology and Imaging Sciences (B.D.W.), Emory University, Atlanta, Georgia.

Dr Chow was the *AJNR* Editorial Fellow during this study, and this is work related to his bibliometric study.

Previously presented at: Annual Meeting of the American Society of Neuroradiology and the Foundation of the ASNR Symposium, April 22–27, 2017; Long Beach, California under the title “Use and Yield of Repeat Noncontrast CT Head Exams in the Emergency Department.”

Please address correspondence to Leo P. Sugrue, MD, PhD, Neuroradiology Section, L-352, University of California, San Francisco, 505 Parnassus Ave, San Francisco, CA 94143; e-mail: leo.sugrue@ucsf.edu

<http://dx.doi.org/10.3174/ajnr.A6408>

undoubtedly shaped by experience with a subset of patients, so-called “frequent flyers,” who present repeatedly to the ED with similar symptoms and undergo head CTs on each presentation.<sup>8-10</sup>

Concerns about repeat imaging are not limited to these extreme cases. For example, a recent single-institution study found that up to one-third of ED CT examinations ordered were for patients who had a recent, potentially redundant, CT examination.<sup>11</sup> Data from the Center for Information Technology Leadership estimates that approximately 14% of imaging studies, reflecting up to \$20 billion in annual health care expenditure, may reflect unnecessary duplicate imaging.<sup>8</sup> Beyond financial considerations, there is increasing recognition that repeat CT imaging may tangibly increase cancer risk, especially in younger patients,<sup>1,8,12</sup> with estimates that up to 1.5%–2% of cancers in the United States may be caused by health care–related exposure to ionizing radiation.<sup>12,13</sup> In addition, excessive diagnostic testing may lead to incidental findings, which may initiate costly and, at times, unnecessary work-ups.

Prior work evaluating the use of chest CTs to rule out an acute pulmonary embolism demonstrated that repeat examinations performed within 90 days have a much lower rate of positive findings.<sup>14</sup> However, little-to-no quantitative data are available regarding the relative diagnostic value of repeat head CT imaging in the emergency setting.

The goal of this study was to quantify the predictive value of a prior negative head CT in the ED. We hypothesized that there would be a lower rate of acute findings for NCHCTs performed in patients who had a recent study with negative findings compared with patients who were being imaged for the first time or with a new clinical indication.

## **MATERIALS AND METHODS**

### **Patient Selection**

After institutional review board approval of this Health Insurance Portability and Accountability Act–compliant study, we conducted a retrospective query of the Radiology Information Systems data base at The University of California, San Francisco from January 2013 to December 2016. Informed consent was not required, and no financial support was received in this study. We included all noncontrast head CTs ordered by our emergency department that were identified by the Current Procedural Terminology (CPT) code 70450 “CT of the head without contrast.” Noncontrast head CTs performed as part of Code Stroke studies that included CT angiography and/or perfusion were not included. Our analysis was limited to adult patients, defined as 18 of age or older. We conducted a retrospective review of medical records to determine patient demographic information, including sex and age. We divided patients who underwent a single CT examination or multiple examinations during the study period into “nonrepeat” and “repeat” groups, respectively. For patients in the repeat group, we recorded the time interval between the first (baseline) and repeat examinations. Study indications included in the clinical history by the ordering provider were recorded for each examination. If the study indication for the repeat examination was discordant

with the baseline examination, this discordance was recorded as well.

### **Imaging Techniques**

All imaging was performed on a 64-section CT imaging system (Discovery CT750 HD; GE Healthcare, Milwaukee, Wisconsin) with an effective axial section thickness of 0.625 mm, reformatted in bone and soft-tissue windows in sagittal and coronal planes. All studies were interpreted by members of the neuroradiology faculty as part of the normal daily clinical workflow. The “Impression” section of the generated study reports served as the basis for categorizing a study as having positive or negative findings as further detailed below.

### **Definition of Examinations with Positive and Negative Findings**

Given the large number of cases, we used an automated classification workflow to identify examinations with negative findings. Specifically, the “Impression” section of each report was searched for the following keywords: “No acute,” “No significant,” “No interval,” “No new,” “No hemorrhage, hydrocephalus, herniation,” and so forth. These examinations were categorized as negative. Reports that could not be classified automatically were manually reviewed by a board-certified neuroradiologist (D.S.C., L.P.S., Y.A.C.) to determine whether they should be categorized as negative or positive. Positive was defined as any intracranial abnormality that would necessitate a change in acute management, including hemorrhage (both extra-axial and parenchymal), hydrocephalus, herniation, mass effect, or interval worsening of a prior finding. Finally, all “Impressions” were manually compared with their category to ensure the accuracy of classification.

### **Study Indication**

History or study indication or both were provided in the form of free text by the ordering clinician. At the time of analysis, we reviewed the history/indication provided for each study and used it to classify study indications according to a set of categories that covered the range of indications encountered in the data. This set of indications included the following: altered mental status, trauma, cancer, headache, seizure, vertigo, nausea, fever, syncope, psychosis, numbness, altered speech, weakness, facial droop, visual abnormalities, substance use, hydrocephalus, hypertension, and intracranial pressure/hemorrhage. A single study could be assigned  $\geq 1$  indication. When repeat studies were performed on the same patient, the clinical indications were compared between baseline and repeat examinations. Examination indications were considered concordant if the same study indication categories were used. Indications were considered discordant if different or additional categories were used. For example, if 2 studies had indications of “trauma, headache” and “headache” alone, the study indications were considered discordant.

### **Data Collection and Validation**

The rates of positive findings were compared for the nonrepeat and repeat groups, defined above. For the repeat group, we specifically examined the rate of positive findings for the first (baseline) examination and the rate of positive findings for subsequent repeat examinations in patients whose findings on the first/

**Table 1: Patient demographics and outcomes/indications for first examination in patients undergoing a single (nonrepeat) or serial (repeat) NCHCT examinations**

	Nonrepeat (n = 7198)	Repeat (n = 962)	P
Demographic information			
Proportion of men	0.478	0.486	.973
Age (yr)	57.9	64.1	<.001
Rate of positive findings on the first examination (%) (No.)	4.3 (308)	5.3 (51)	.16
Proportion of men	0.522	0.529	.995
Age (yr)	63.5	64.2	.832
Indications for positive first examination (%) (No.)			
Altered mental status	37.0 (114)	31.4 (16)	.442
Headache	17.2 (53)	19.6 (10)	.677
Trauma	17.2 (53)	39.2 (20)	<.001
Other	28.6 (88)	9.8 (5)	.005

baseline examination were negative. We recorded both the examination indication and findings for all examinations with positive findings in both the nonrepeat and repeat groups.

### Statistical Tests

The 2-sample test for proportions and the  $\chi^2$  assessment were performed using MedCalc for Windows, Version 12.2.1 (MedCalc Software, Mariakerke, Belgium). A *P* value < .05 was considered statistically significant.

## RESULTS

### Demographic Data

In total, 9593 CT examinations were identified among 8160 unique patients who met the inclusion and exclusion criteria during the study period (Table 1). Of unique patients, 88.2% (7198/8160) had a single examination and 11.8% (962/8160) had at least 1 repeat examination. The mean age of patients in the repeat group was significantly higher compared with patients in the nonrepeat group (64.1 versus 57.9 years, *P* < .001). There was no significant difference in sex between the 2 groups (*P* = .97).

### Positive Rate of Initial CT Examinations

A positive finding was identified in 4.4% (384/8160) of all first/baseline head CT examinations. There was no significant difference in the positive rate between patients in the nonrepeat group and the first examination of patients in the repeat group (4.3% [308/7198] versus 5.3% [51/962], *P* = .16). Among baseline studies with positive findings from the nonrepeat and repeat groups, there was no significant difference in either patient age (*P* = .99) or sex (*P* = .83) (Table 1).

The most common indications for positive findings on baseline CT examinations in the nonrepeat group were altered mental status (37.0%, 114/308), headache (17.2%, 53/308), trauma (17.2%, 53/308), and miscellaneous categories (28.6%, 88/308). For the repeat group, the most common indications for positive findings on baseline CT examinations were altered mental status (31.4%, 16/51), trauma (39.2%, 20/51), and headache (19.6%, 10/51). Among baseline studies with positive findings, there was no significant difference in the proportion of examinations with

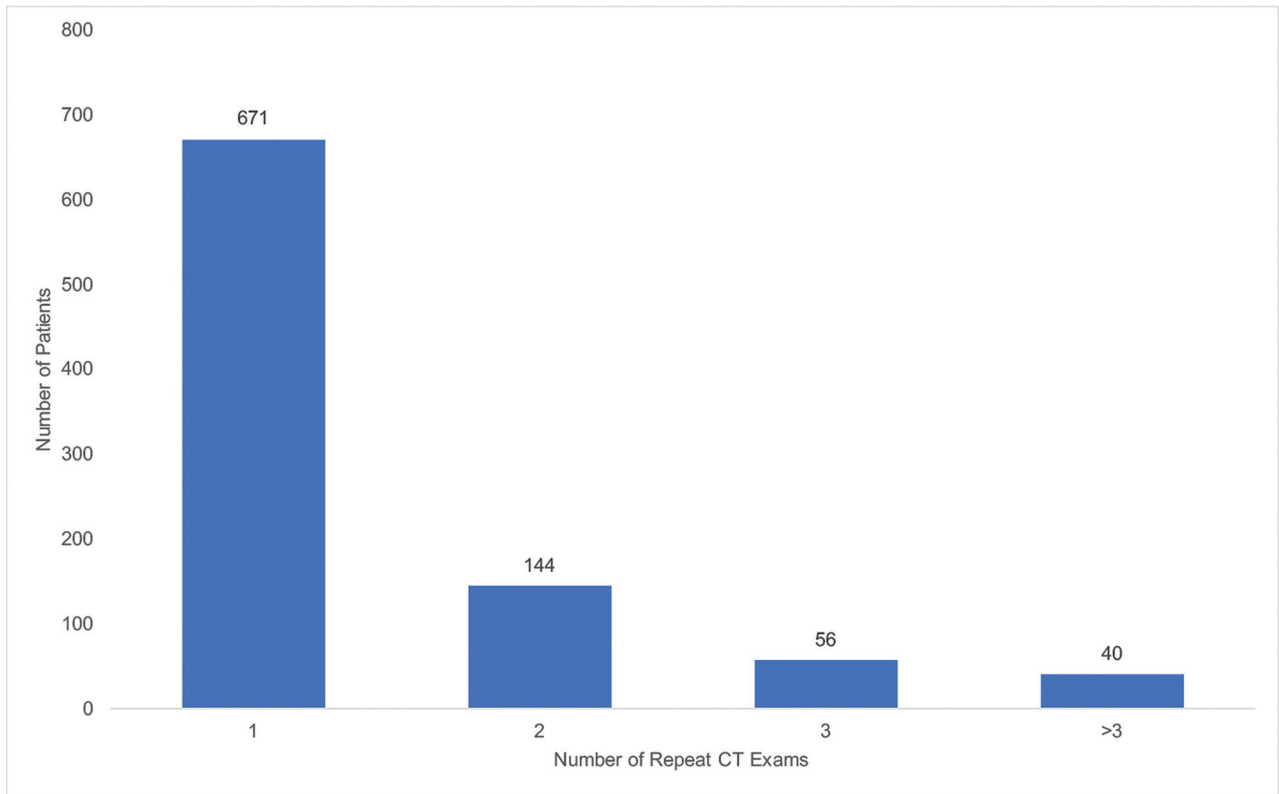
altered mental status or headache as the indication between the nonrepeat and repeat groups (*P* = .442 and *P* = .677, respectively). However, there was a significantly higher proportion of baseline examinations with positive findings with trauma as the indication in the repeat group (*P* = .003).

### Assessment of Patients with Repeat Examinations

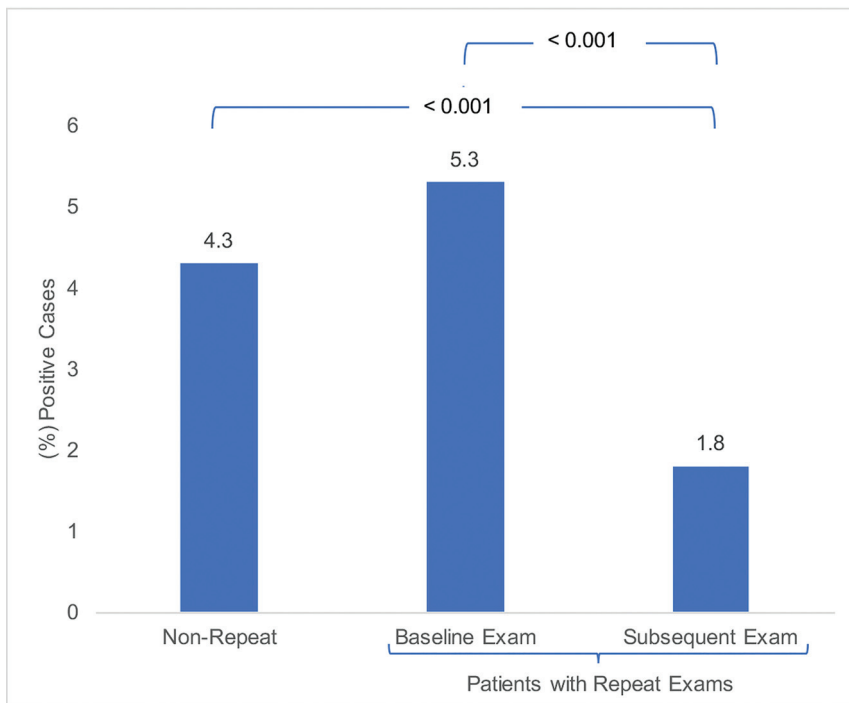
As described above, 962 patients underwent repeat head CT examinations during the study period; of these, 94.7% (911/962) had negative findings on the first (baseline) examination. A total of 1359 follow-up or repeat CTs were performed in these 911 patients. The average number of repeat examinations acquired per patient was 1.49 examinations, and the mean follow-up interval was 6.5 months. The proportions of patients with 1, 2, 3, and >3 repeat head CTs were, respectively, 73.7% (671/911), 15.8% (144/911), 6.2% (56/911), and 1.2% (40/911) (Fig 1). Of note, 3 patients had >10 studies with a maximum of 17. There was no significant difference in the rate of positivity in patients who had only 1 repeat compared with patients who had >1 repeat examination (20/671 [3%] versus 5/240 [2%], *P* = .45).

A positive finding was identified in 1.8% (25/1359) of all repeat head CTs that followed a first examination with negative findings, significantly different from the 4.3% positive rate in the nonrepeat group (*P* < .001) and the 5.3% positive rate for the first examination in the repeat group (*P* < .001) (Fig 2). Of patients in the repeat group who converted from negative to positive, the proportions who converted on the first, second, or third repeat examination were 80% (20/25), 16% (4/25), and 4% (1/25), respectively. Across the time scales relevant to this study, the interval between the first examination with negative findings and the follow-up did not substantially impact the probability of the repeat examination findings being positive: The proportions of repeat examinations with positive findings obtained within 30 days, 60 days, and 90 days of an initial negative head CT were 1.5% (5/344), 1.8% (8/491), and 1.7% (9/605), respectively (Table 2). For each interval, the proportion of examinations with positive findings was significantly lower than the 4.3% baseline positive rate. The 5 cases with positive findings obtained within 30 days of an initial head CT with negative findings included an acute on chronic subdural hemorrhage in a patient with altered mental status, new hemorrhagic metastasis in a patient with known metastatic lung cancer, new hydrocephalus in a patient with known leptomeningeal carcinomatosis, new subdural hemorrhage following a fall in an elderly patient, and new parenchymal hematoma in a patient on anticoagulation.

Across the 1359 repeat examinations, the proportion of examinations with positive findings varied by indication as follows (note that a given examination could have >1 indication): altered mental status 3% (8/300), trauma 2% (12/716), cancer 2% (1/44), headache 4% (2/252), seizure 0% (0/117), vertigo 2% (1/53), nausea 0% (0/32), fever 0% (0/8), syncope 2% (1/42), psychosis 0% (0/8), numbness 0% (0/21), altered speech 0% (0/22), weakness 5% (3/65), facial droop 0% (0/13), visual abnormalities 17% (1/6), substance use 0% (0/5), hydrocephalus 0% (0/6), hypertension 0% (0/1), and intracranial pressure/hemorrhage 0% (0/1).



**FIG 1.** Histogram showing the number of patients in the repeat group who had 1, 2, 3, and >3 repeat NCHCT examinations during the study period.



**FIG 2.** Rate of positive findings in first/baseline-versus-subsequent examinations. Repeat NCHCT examinations that followed a prior examination with negative findings had a much lower rate of positive findings (1.8%) than examinations in the nonrepeat group (4.3%) or the first examination of patients in the repeat group (5.3%). There was no significant difference between the rate of positive findings in the nonrepeat group and the first/baseline examination in the repeat group.

On a per-patient basis, 2.7% (25/911) of patients in the serially imaged group with negative findings on a first head CT ultimately went on to have at least 1 follow-up head CT with positive findings. Because it may include multiple follow-up examinations, this per-patient rate is higher than the positive rate for a single follow-up study; nevertheless, it is still significantly lower than the positive rate for the nonrepeat group ( $P = .02$ ) and for the first examination in the serially imaged group ( $P = .004$ ).

#### **Comparison of Clinical Indications between Study Groups**

Across all studies (baseline plus repeats), the most common indications for both positive and negative findings on CT examinations were similar. For positive findings, the most common indications were altered mental status (36%, 130/359), trauma (20%, 73/359), and headache (18%, 63/359). For negative findings, the most common indications were trauma (3341/



**Table 2: Outcome of repeat examination by interval since the examination with negative findings<sup>a</sup>**

Interval between CTs	No. of Positive Examinations	Total Repeat Examinations	% Positive	P Value <sup>b</sup>
<30 days	5	344	1.5	.011
<60 days	8	491	1.8	.007
<90 days	9	605	1.7	.002
<120 days	10	690	1.6	<.001
<180 days	11	804	1.5	<.001
>180 days	25	1359	1.8	<.001

<sup>a</sup> Outcome of repeat NCHCT examinations as a function of the interval (in days) since the prior examination with negative findings. The proportion of repeat examinations with positive findings remained between 1.5% and 1.8% (and significantly lower than the 4.3% positive rate of first/baseline examinations) for the durations (up to 1 year) considered in this study.

<sup>b</sup> The P value was taken against the 4.3% rate of first/baseline examinations.

9234, 36%), headache (1932/9234, 21%), and altered mental status (1686/9234, 18%).

Of the 911 patients who had negative findings on the baseline examination, there were 1359 total repeat examinations. Of the total 1359 repeat examinations, 613 (45%) had indications discordant with their baseline examination, and 746 (55%) had indications concordant with their baseline examination. The discordant repeat examinations had a significantly greater proportion of positive findings than in the concordant group, with 20/613 (3%) having positive findings, compared with only 5/746 (0.7%) in the concordant group ( $P < .001$ ). It follows that repeat examinations with positive findings tended to have a clinical indication discordant with the baseline examination. Specifically, of the follow-up examinations that had positive findings, 20/25 (80%) had indications discordant with the baseline examination. Of the follow-up examinations that had negative findings, 593/1334 (44%) had an indication discordant with the baseline examination ( $P < .001$ ).

## DISCUSSION

NCHCT examinations performed in the emergency department setting with the same study indication were significantly less likely to have positive findings if the patient had a recent prior NCHCT with negative findings. Among nearly 10,000 examinations performed during a 4-year period at a single academic medical center, we found that NCHCTs had positive findings in only 1.8% of patients who had a recent prior NCHCT with negative findings, compared with 4.3% in first-time (baseline) examinations, and they had positive findings in only 0.7% in patients for whom the indications for the baseline and repeat examinations were the same. This result corroborates prior work suggesting that NCHCT examinations performed in the emergency setting in patients without focal neurologic deficits largely have negative findings,<sup>6,7</sup> while extending the result to suggest that at a statistical level, there is a negative predictive value for a recent examination with negative findings with the same clinical indication.

We hypothesized that a repeat study that had the same clinical indication as its prior baseline examination would be associated with a lower rate of positive findings than a repeat study with a different indication. This hypothesis was confirmed by the data, with 80% of repeat examinations with positive findings having a

different clinical indication compared with the baseline examination, while only 44% of repeat examinations with negative findings had a different clinical indication.

We also hypothesized that the negative predictive effect of a prior study with negative findings might decline and the rate of positive findings might return to that of first-time examinations as the interval between a negative baseline and follow-up examination increased. At <30 days of follow-up, the positive rate was 1.5%, significantly lower than the first-time examination rate of 4.3%. Somewhat surprising, positive rates for follow-up examinations remained low (<2%, and significantly lower than that of first-time examinations) even as the time since the baseline study with negative findings increased up to 12 months. This finding suggests that the negative predictive effect of a NCHCT with negative findings is long-lasting, at least for the month-to-year time scale evaluated in this study.

The current study did not explore why a prior NCHCT with negative findings performed for the same indication has a negative predictive value. We speculate that for some patients presenting with vague neurologic symptoms, there may be no underlying anatomic/imaging correlate for their presenting symptom. For others, an anatomic correlate may exist, but CT may not be sensitive enough to detect it, meaning that the yield for repeat CT imaging for the same indication will remain low. These latter patients might benefit from a more sensitive diagnostic evaluation with MR imaging as has been shown to be the case in patients who present with dizziness.<sup>7</sup> Developing criteria to reliably discriminate between these 2 groups will be an important goal for future work.

During the past decade, many factors have contributed to the increased use of CT examinations in the emergency department setting. These include increased availability of CT; technologic advances that have reduced scan time, radiation dose, and cost; system-based cost-saving and outcome-focused initiatives that have emphasized earlier and more accurate diagnosis; as well as a general fear on the part of providers of missing something in an era of increasing malpractice litigation.<sup>2,15,16</sup> At a population level, CT scans undoubtedly help ED physicians arrive at earlier and more accurate diagnoses. Similarly, at a population level, increased CT imaging has a measurable cost, both in exposure to ionizing radiation and its associated cancer risk and in increased health care dollars spent on studies with limited diagnostic yield.

While crucially important from a public health and medical economics perspective, the cost-benefit of CT imaging at the population level does not necessarily help the practicing emergency department physician or radiologist determine the relative cost/benefit of a CT examination in any given patient. Our current results suggest that information easily available from the electronic medical record, such as the outcome and indications of prior imaging, has potential value in stratifying patients with respect to the appropriateness of NCHCT imaging. Such information, combined with decision-support systems, could be used to facilitate more personalized and effective imaging decisions.<sup>17-19</sup> Indeed, a prior retrospective study of ED CT use suggested that simply alerting ED physicians to the existence of prior relevant CT imaging could alter ordering practice.<sup>11</sup>

Our study has at least 2 important limitations. First, as a single-institution retrospective study, our results may not reflect the ordering practices or patient demographics of other centers and did not consider examinations that our patients may have undergone at other institutions during the study period. Second, our results suggest that the examination indication impacts the prior probability that a repeat examination will have positive findings. However, even though our study included ~10,000 patients, the low overall rate of CT examinations with positive findings precluded an analysis of the relationship between specific indications and positive findings on baseline and repeat examinations. Going forward, our goal is to conduct a larger multicenter study to validate these results across institutions and provide sufficient power to answer these more nuanced questions.

## CONCLUSIONS

We investigated the rate of positive findings in repeat noncontrast head CTs performed on patients presenting to the ED who had prior negative findings on NCHCT with the same or different indications and compared it with the rate of positive findings in patients being imaged for the first time. In this retrospective observational study based on approximately 10,000 eligible examinations, we found that, overall, serial NCHCT examinations in patients with a prior study with negative findings are much less likely to be positive compared with first-time examinations. Most important, this difference depends on whether the prior study had the same clinical indication. This finding suggests that when a patient returns to the emergency department with the same neurologic symptom, a repeat NCHCT may be of limited diagnostic benefit.

Disclosures: Leo P. Sugrue—UNRELATED: Board Membership: Research Radiology, Inc; Stock/Stock Options: Research Radiology, Inc.

## REFERENCES

- Hess EP, Haas LR, Shah ND, et al. **Trends in computed tomography utilization rates: a longitudinal practice-based study.** *J Patient Saf* 2014;10:52–58 [CrossRef Medline](#)
- Larson DB, Johnson LW, Schnell BM, et al. **National trends in CT use in the emergency department: 1995–2007.** *Radiology* 2011;258:164–73 [CrossRef Medline](#)
- Hussein W, Mullins PM, Alghamdi K, et al. **Trends in advanced computed tomography use for injured patients in United States emergency departments: 2007–2010.** *Acad Emerg Med* 2015;22:663–69 [CrossRef Medline](#)
- Levin DC, Rao VM, Parker L, et al. **Continued growth in emergency department imaging is bucking the overall trends.** *J Am Coll Radiol* 2014;11:1044–47 [CrossRef Medline](#)
- Levin DC, Parker L, Rao VM. **Recent trends in imaging use in hospital settings: implications for future planning.** *J Am Coll Radiol* 2017;14:331–36 [CrossRef Medline](#)
- Mitsunaga MM, Yoon HC. **Journal club: head CT scans in the emergency department for syncope and dizziness.** *AJR Am J Roentgenol* 2015;204:24–28 [CrossRef Medline](#)
- Lawhn-Heath C, Buckle C, Christoforidis G, et al. **Utility of head CT in the evaluation of vertigo/dizziness in the emergency department.** *Emerg Radiol* 2013;20:45–49 [CrossRef Medline](#)
- Kamat AB, Midgley S, Kimbrell K. **Duplication of radiology imaging studies in the emergency department: what is the cost?** *Emerg Med J* 2015;32:144–48 [CrossRef Medline](#)
- Anandalwar SP, Mau CY, Gordhan CG, et al. **Eliminating unnecessary routine head CT scanning in neurologically intact mild traumatic brain injury patients: implementation and evaluation of a new protocol.** *J Neurosurg* 2016;125:667–73 [CrossRef Medline](#)
- Grover CA, Close RJ, Villarreal K, et al. **Emergency department frequent user: pilot study of intensive case management to reduce visits and computed tomography.** *West J Emerg Med* 2010;11:336–43 [Medline](#)
- Wasser EJ, Prevedello LM, Sodickson A, et al. **Impact of a real-time computerized duplicate alert system on the utilization of computed tomography.** *JAMA Intern Med* 2013;173:1024–26 [CrossRef Medline](#)
- Brenner DJ, Hall EJ. **Computed tomography: an increasing source of radiation exposure.** *N Engl J Med* 2007;357:2277–84 [CrossRef Medline](#)
- Smith-Bindman R, Miglioretti DL, Johnson E, et al. **Use of diagnostic imaging studies and associated radiation exposure for patients enrolled in large integrated health care systems, 1996–2010.** *JAMA* 2012;307:2400–09 [CrossRef Medline](#)
- Kline JA, Courtney DM, Beam DM, et al. **Incidence and predictors of repeated computed tomographic pulmonary angiography in emergency department patients.** *Ann Emerg Med* 2009;54:41–48 [CrossRef Medline](#)
- Griffey RT, Jeffe DB, Bailey T. **Emergency physicians' attitudes and preferences regarding computed tomography, radiation exposure, and imaging decision support.** *Acad Emerg Med* 2014;21:768–77 [CrossRef Medline](#)
- Baker LC, Atlas SW, Afendulis CC. **Expanded use of imaging technology and the challenge of measuring value.** *Health Aff (Millwood)* 2008;27:1467–78 [CrossRef Medline](#)
- Marin JR, Mills AM. **Developing a research agenda to optimize diagnostic imaging in the emergency department: an executive summary of the 2015 Academic Emergency Medicine Consensus Conference.** *Acad Emerg Med* 2015;22:1363–71 [CrossRef Medline](#)
- Dunne RM, Ip IK, Abbett S, et al. **Effect of evidence-based clinical decision support on the use and yield of CT pulmonary angiographic imaging in hospitalized patients.** *Radiology* 2015;276:167–74 [CrossRef Medline](#)
- Sistrom CL, Dang PA, Weilburg JB, et al. **Effect of computerized order entry with integrated decision support on the growth of outpatient procedure volumes: seven-year time series analysis.** *Radiology* 2009;251:147–55 [CrossRef Medline](#)