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Original Contributions

IMPLEMENTATION OF A COMPUTERIZED DECISION SUPPORT SYSTEM FOR COMPUTED TOMOGRAPHY SCAN REQUESTS FOR NONTRAUMATIC HEADACHE IN THE EMERGENCY DEPARTMENT

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☐ **Abstract—Background: Nontraumatic headache is a frequent complaint in the emergency department (ED). Cranial computed tomography (CT) is a widely available test for the diagnostic work-up, despite the risk of exposure to ionizing radiation. Objectives: We sought to develop and evaluate a cranial CT request computerized decision support system (CDSS) for adults with their first presentation of unusual severe nontraumatic headache in the ED. Methods: Electronic database searches identified clinical decision and prediction rules and studies delineating risk factors in nontraumatic headache. A long list of risk factors extracted from these articles was reduced by a 30-member multidisciplinary expert panel (radiologists, emergency physicians, methodologists), using a 90% agreement threshold. This shortlist was used to develop the algorithm for the cranial CT request CDSS, which was implemented in March 2016. Impact evaluation compared CT scan frequency and diagnostic yield of pathologic findings before (March–August 2015) and after (March–August 2016) implementation. Results: From the 10 selected studies, 10 risk factors were shortlisted to activate a request for cranial CT. Before implementation, 377 cranial CTs were ordered (15.3% of 2469 CT scans) compared with 244 after (9.5% of 2561 CT scans; pre–post difference 5.74%; 95% confidence interval [CI] 3.92–7.56%; $p < 0.001$), corresponding to a 37.6% relative reduction in the test ordering rate (95% CI 25.7–49.5%; $p < 0.001$). Despite the reduction in cranial CT scans, we did not observe an increase in pathological findings after introducing the decision support system (70 cases before [18.5%] vs. 35 cases after [14.3%]; pre–post difference −4.0% [95% CI −10.0 to 1.6%]; $p = 0.170$). Conclusion: In nontraumatic headache among adults seen in the ED, CDSS decreased the cranial CT request rate but the diagnostic yield did not improve.**

☐ **Keywords—algorithm; CDSS; cranial CT; emergency department; nontraumatic headache**

INTRODUCTION

Nontraumatic headache, a frequent reason for consultation in the emergency department (ED), accounts for 1–4.5% of all cases and is differentiated into primary and

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secondary headaches (1–3). Most primary cases are benign, but secondary cases, representing 19% of all cases, are life-threatening cases. While cranial computed tomography (CT) is the diagnostic test of choice, it involves avoidable exposure to ionizing radiation, and its unnecessary use in the ED can delay the diagnosis and treatment of other patients who need CT scans. This work focuses on the diagnostic management of secondary headaches.

The use of cranial CT has been progressively increasing in EDs (4,5). However, when the request for this test is not justified, the resultant inefficiency in the health care system increases costs. The need to develop a strategy to optimize the request for CT scans in the ED for diagnosing headache is well-recognized. International initiatives, such as the "Choosing Wisely" campaign or the "Do not do" recommendations, offer guidelines for reducing unnecessary diagnostic procedures (6,7). In Spain, the Improvement of the Adequacy in the Clinical Care and Practice initiative aims to improve the adequacy of the application of radiographs and CT in the ED (8).

We designed a computerized decision support system (CDSS) to improve the adequacy of cranial CT requests at first presentation with unusual severe nontraumatic headache in the ED. The system was developed using existing clinical decision rules (CDRs) or clinical prediction rules (CPRs), as well as studies of relevant pathological risk factors (9,10). We evaluated the impact on service use and diagnostic yield before and after the implementation of the CDSS.

MATERIALS AND METHODS

In an electronic search in MEDLINE (from 1946 to 2015) and EMBASE (from 1980 to February 2015), we combined the term nontraumatic headache and its synonyms with terms for clinical suspicions that lead to the request for a CT scan. We did not include terms referring to other suspicions, such as stroke or cranial trauma, because in our ED we already have specific protocols in place for these events (i.e., stroke and cranial trauma clinical pathways). We focused our study on the most frequent clinical suspicions for CT scan request in headache: subarachnoid hemorrhage (SAH), brain tumor, and infections, such as encephalitis, meningitis, and cerebritis. The scope of the search was limited to the ED setting and methodological search filters for clinical prediction models were used (11) (Appendix). This search was complemented by manual searches of the American College of Radiology Appropriateness Criteria and computerized searches of the ACCESSSS metasearch engine, which conducts literature searches simultaneously in several evidence-based information services, yielding content that is hierarchically organized (12–14).

The selection of the studies was carried out by two methodologists who resolved any discrepancies by consensus. The selection criteria were articles that described a CDR or CPR for secondary nontraumatic headache in any phase of development and testing in the ED setting in adult patients (10). A CDR was defined as a decision-making tool, derived from original research that incorporated ≥3 variables from history, physical examination, or simple tests. A CPR was designed to help physicians with diagnostic or therapeutic decisions at the bedside. We excluded articles in pediatric patients or patients with a repeat presentation with primary headache.

Three investigators (2 radiologists and 1 emergency physician) extracted a list of risk factors associated with an urgent request for a CT scan. This was reduced by a 30-member multidisciplinary expert panel (radiologists, emergency physicians, and methodologists) who gave their input anonymously. The final shortlist was drawn up using a 90% agreement threshold.

The consensus recommendations were subsequently implemented into the software for requesting diagnostic tests from the ED (H-P HIS system; HP Spain Inc., Barcelona, Spain). At the time of requesting a cranial CT scan for nontraumatic secondary headache consultation, a pop-up window appeared with the list of selected risk factors identified in the electronic searches and shortlisted by the multidisciplinary panel. As part of implementation of the CDSS, several training sessions were held to inform emergency physicians and radiologists about the new procedure for requesting CT scans.

To assess the impact of the CDSS on the frequency and appropriateness of CT scan requests, the baseline number of CT scans requested for unusual severe nontraumatic secondary headache during the 6 months before the implementation of the recommendations (March–August 2015) was recorded. After implementation in March 2016, the same measurements were repeated during the same 6 months of the following year (March–August 2016) to avoid seasonality bias.

A chi-squared test was performed to statistically compare the pre–post difference in the proportion of CTs due to headache with respect to the total number of CTs requested in the two periods. To compare the pre–post difference in diagnostic yield, the findings observed in the images according to the radiologists' reports were classified into 4 categories: 1) no pathological finding, 2) incidental finding of no consequence to therapeutic patient management, 3) pathological finding corresponding to the reason for headache consultation, and 4) pathological finding suggestive of another diagnosis. We compared the proportion of pathological findings (either

Table 1. Characteristics of the 10 Selected Studies for the Synthesis Phase

Study, Year	Step in the Process of Development of a CDR*	Considered Outcomes or CT Scan Findings	Study Characteristics (Design, Inclusion Criteria, No. of Patients)	High-Risk Clinical Characteristics That Increase Pretest Probability	Performance of CDR/ Algorithms: Sensitivity and Specificity % (95% CI)
Tung et al., 2014 (15)	Step 2: modified Rothrock criteria	Intracranial pathology: acute cerebral infarction, intracranial hemorrhage, malignancy, infection, cerebral edema, or hydrocephalus	Retrospective cohort; patients undergone urgent cranial CT scan with no head trauma, no age limit; N = 346	Age ≥60 years; new onset focal neurological deficit; headache with vomiting; Reaction Level Scale ≥2 (GCS <14)	Sen: 97.1 (85.1–99.9) Spe: 25.1 (20.4–30.3)
Matloob et al., 2013 (16)	Step 2: Canadian SAH CDR	SAH	Retrospective case note review; all adult patients (>16 years) presenting with acute headache; N = 112	Rule 1—age >40 years; complaint of neck pain or stiffness; witnessed loss of consciousness; onset during exertion Rule 2—arrival by ambulance; age ≥45 years; vomiting at least once; diastolic blood pressure ≥100 mm Hg Rule 3—arrival by ambulance; systolic blood pressure ≥160 mm Hg; complaint of neck pain or stiffness; age 44–55 years	Rule 1—Sen: 100 (40–100); spe: 43 (33–52) Rule 2—Sen: 100 (40–100); spe: 27 (19–36) Rule 3—Sen: 100 (40–100); spe: 37 (28–47)
Perry et al., 2013 (17)	Step 2: Canadian SAH CDR and Ottawa SAH Rule	SAH	Prospective multicenter cohort; consecutive adults with a headache peaking within 1 h and no neurologic deficits; N = 2131	Age ≥40 years; neck pain or stiffness; witnessed loss of consciousness; onset during exertion; thunderclap headache (instantly peaking pain); limited neck flexion on examination	Sen: 100 (97.2–100); spe: 15.3 (13.8–16.9)
Perry et al., 2010 (18)	Step1: Canadian SAH CDR	SAH	Prospective multicenter cohort; alert patients (GCS = 15) aged ≥16 years who presented to an emergency department with a chief complaint of nontraumatic headache peaking within 1 h or of syncope associated with a headache; N = 1999	Rule 1—age >40 years; complaint of neck pain or stiffness; witnessed loss of consciousness; onset with exertion Rule 2—arrival by ambulance; age >45 years; vomiting at least once; diastolic blood pressure >100 mm Hg Rule 3—arrival by ambulance; systolic blood pressure >160 mm Hg; complaint of neck pain or stiffness; age 45–55 years	Rule 1—Sen: 100 (97.1–100); spe: 28.4 (26.4–30.4) Rule 2—Sen: 100 (97.1–100); spe: 36.5 (34.4–38.8) Rule 3—Sen: 100 (97.1–100); spe: 38.8 (36.7–41.1)

(*Continued*)

Table 1. Continued

Study, Year	Step in the Process of Development of a CDR*	Considered Outcomes or CT Scan Findings	Study Characteristics (Design, Inclusion Criteria, No. of Patients)	High-Risk Clinical Characteristics That Increase Pretest Probability	Performance of CDR/ Algorithms: Sensitivity and Specificity % (95% CI)
Grimaldi et al., 2009 (19)	Step 2: Cortelli algorithm based on 4 clinical scenarios	Serious headache scenarios: SAH, neoplasm, ischemic stroke, meningitis Benign headaches: scenario 4	Prospective multicenter cohort; consecutive alert patients ≥18 years of age who presented to the ED with nontrauma headache; N = 256	Scenario 1 (Malignant secondary headache): Adult patients admitted to ED for severe headache (“worst headache”): - with acute onset (thunderclap headache), or - with neurological signs (or nonfocal as decreased level of consciousness), or - with vomiting or syncope at the onset of headache Scenario 2 (Malignant secondary headache): Adult patients admitted to ED for severe headache: - with fever or neck stiffness Scenario 3 (Malignant secondary headache): Adult patients admitted to ED for: - headache of recent onset (days or weeks), or - progressively worsening headache, or persistent headache Scenario 4 (Benign primary headaches): Adult patients with a previous history of headache: -complaining of a headache very similar to previous attacks in term of intensity, duration and associated symptoms	Sen: 100 (81–100); spe: 64 (56–71)
Locker et al., 2006 (20)	Step 1: diagnostic performance of clinical features	Serious intracranial pathology (carbon monoxide poisoning, central retinal artery occlusion, cerebellar cyst, cerebral infarct, glaucoma, hydrocephalus, hypertension/hypertensive encephalopathy, intracerebral hemorrhage, meningitis, neoplasia, SAH, single demyelinating episode, temporal arteritis, TIA, or vertebral artery dissection)	Prospective cohort; consecutive alert patients (GCS = 15) >15 years of age who presented to the ED with nontrauma headache; N = 558	Age >50 years; sudden onset of headache; abnormality on neurological examination	Sen: 98.6, spe: 34.4

(*Continued*)

Table 1. Continued

Study, Year	Step in the Process of Development of a CDR*	Considered Outcomes or CT Scan Findings	Study Characteristics (Design, Inclusion Criteria, No. of Patients)	High-Risk Clinical Characteristics That Increase Pretest Probability	Performance of CDR/ Algorithms: Sensitivity and Specificity % (95% CI)
Cortelli et al., 2004 (21)	Step 1: Cortelli algorithm	Guideline for diagnostic and therapeutic management of adult patients presenting with nontraumatic headache at ED	Secondary research; literature search and consensus statement	Scenario 1 (Malignant secondary headache): adult patients admitted to ED for severe headache ("worst headache"): - with acute onset (thunderclap headache), or - with neurological signs (or nonfocal as decreased level of consciousness), or - with vomiting or syncope at the onset of headache Scenario 2 (Malignant secondary headache): adult patients admitted to ED for severe headache: - with fever or neck stiffness Scenario 3 (Malignant secondary headache): adult patients admitted to ED for: - headache of recent onset (days or weeks), or - progressively worsening headache, or persistent headache Scenario 4 (Benign primary headaches): adult patients with a previous history of headache: -complaining of a headache similar to previous attacks in term of intensity, duration, and associated symptoms	Not available
Rothman et al., 1999 (22)	Step 1	New focal lesions on head CT scans in HIV-infected patients	Prospective cohort; convenience sample of HIV-infected patients (>15 years of age) with any new or changed neurologic sign or symptom into ED and had a head CT; N = 110	New seizure; depressed or altered orientation; headache (different in quality); headache (prolonged, ≥3 days)	Sen: 100; spe: not available
Ramirez-Lassepas et al., 1997 (23)	Only univariate approach	Intracranial pathologic findings: SAH, tumor, ICH, meningitis, cerebral acute infarction, and herpes encephalitis	Case-control study; cases: N = 139 hospitalized patients as a direct result of an ED visit for headache; controls: N = 329 randomly selected patients who went to the ED for headache and were discharged	Acute onset; occipitonuchal location; associated symptoms; age >55 years	Not available
Reinus et al., 1993 (24)	Step 1	Predictors of an intracranial CT abnormality	Retrospective multicenter cohort; consecutive ED patients who underwent cranial CT csn (from 2 trauma centers); N = 1174	Unresponsiveness; focal neurologic deficit; hypertension (diastolic >90 mm Hg); trauma; loss of consciousness; headache; dizziness	Not available

CDR = Clinical Decision Rule; CT = computed tomography; ED = emergency department; GCS = Glasgow Coma scale; ICH = intracranial hemorrhage; SAH = subarachnoid hemorrhage; sen = sensitivity; spe = specificity; TIA = transient ischemic attack.
* Steps in the process of development of a CDR: Step 1: creating or deriving the rule; Step 2: testing or validating the rule; Step 3: assessing the impact of the rule on clinical behavior (impact analysis) (10).

related to headache or suggestive of another diagnosis) observed in the 2 time periods using a chi-squared test.

To assess safety of the CDSS, we selected all patients presenting with unusual severe nontraumatic secondary headache during the September 2016–February 2017 period, excluding patients with other reasons for consultation that may involve headache (e.g., stroke or head injury). We then identified the number of deaths and any hospital admission in the following 90 days for reasons related to headache and compared the mortality rate and hospital admission rate between patients with a cranial CT scan and patients without.

The level of significance was set at 0.05 and statistical tests were 2-tailed. We estimated the differences in proportion between the 2 periods along with their corresponding 95% confidence intervals (CIs). The analyses were performed with the statistical package Stata (version 15.1; StataCorp LLC, College Station, TX).

RESULTS

Search and Selection

The literature database searches identified 120 potentially relevant citations, of which 11 were selected after screening of titles and abstracts. The ACCESSSS search and follow-up of the references identified 6 more potentially relevant articles. After the 2 reviewers read the full text of these 17 articles, 10 were selected for the synthesis phase (Table 1). We did not find any work that evaluated the clinical impact of using a CDR or CPR. Four studies described the testing or validation phase of a CPR (15–17,19). The rest of the studies described the first step in the development of a CPR or a univariate approach for exploring risk factors (18,20–24).

Synthesis of Risk Factors

The multidisciplinary panel agreed upon a shortlist of 10 risk factors associated with intracranial pathology findings in the cranial CT scan (Table 2). To maximize sensitivity of the decision algorithm, the presence of ≥1 of these factors was used to activate the request for a cranial CT scan (Figure 1).

Implementation

The CDSS was implemented as follows: when an emergency physician initiated the request for a cranial CT scan in a patient with unusual severe nontraumatic secondary headache, the system produced a pop-up window with the risk factors. The system prompted the physician to select the patient's risk factors. If the patient did not have any of the risk factors, the system showed a message discouraging the performance of the test. In the presence of ≥1 risk factor, the request for the test was processed.

Table 2. Ten Risk Factors Associated With Intracranial Pathology Findings in a Cranial Computed Tomography Scan

For Adult Patients with Unusual Severe Headache (not like Previous ones), without Traumatic Brain Injury Who Come to the Emergency Department. Perform a cranial Computed Tomography Scan if ≥ 1 of the following Factors is Present:
1. Age >40 years
2. Neck pain or stiffness
3. Loss of consciousness/neurological focus
4. Onset with exertion
5. Thunderclap headache (instantly peaking pain)
6. Fever (not explained in the clinical context)
7. Meningism observed
8. HIV or immunosuppression
9. Progressive worsening of headache or permanent pain
10. First episode in a cancer patient
The presence of ≥1 of these factors recommends the performance of a cranial computed tomography scan.

Evaluation of Impact

During the 6 months before implementation, 377 cranial CT scans (15.3% of 2469 CT scans) were performed, compared with 244 in the 6 months postimplementation (9.5% of 2561 CT scans; pre–post difference 5.74% [95% CI 3.92–7.56%]; $p < 0.001$). This corresponded to a 37.6% relative reduction in the test ordering rate (95% CI 25.7–49.5%; $p < 0.001$). The demographic and clinical characteristics of patients in both groups are shown in Table 3. Table 4 shows the radiological findings of cranial CT scans requested, classified into groups of no findings, incidental irrelevant finding, and pathological finding. In the preimplementation period, there were 70 cases with pathological findings (18.5% of the total cranial CT scans requested because of headache), while after implementation, pathological findings were found in 35 cases (14.3%). These differences were not statistically significant (pre–post difference −4% [95% CI −10 to 1.6%]; $p = 0.170$).

Evaluation of Safety

During the 6-month safety evaluation period, 1275 patients presented to the ED with unusual severe nontraumatic secondary headache as the reason for consultation. A CT scan was requested for 369 patients (28.9%). Of these, 249 CT scans followed the implemented CDSS and 120 did not. Pathological findings were present in 47 patients (12.7%), 34 findings in the 249 CT scans with risk factors that were ordered using the CDSS (13.7%), and 13 of 120 patients (10.8%) who

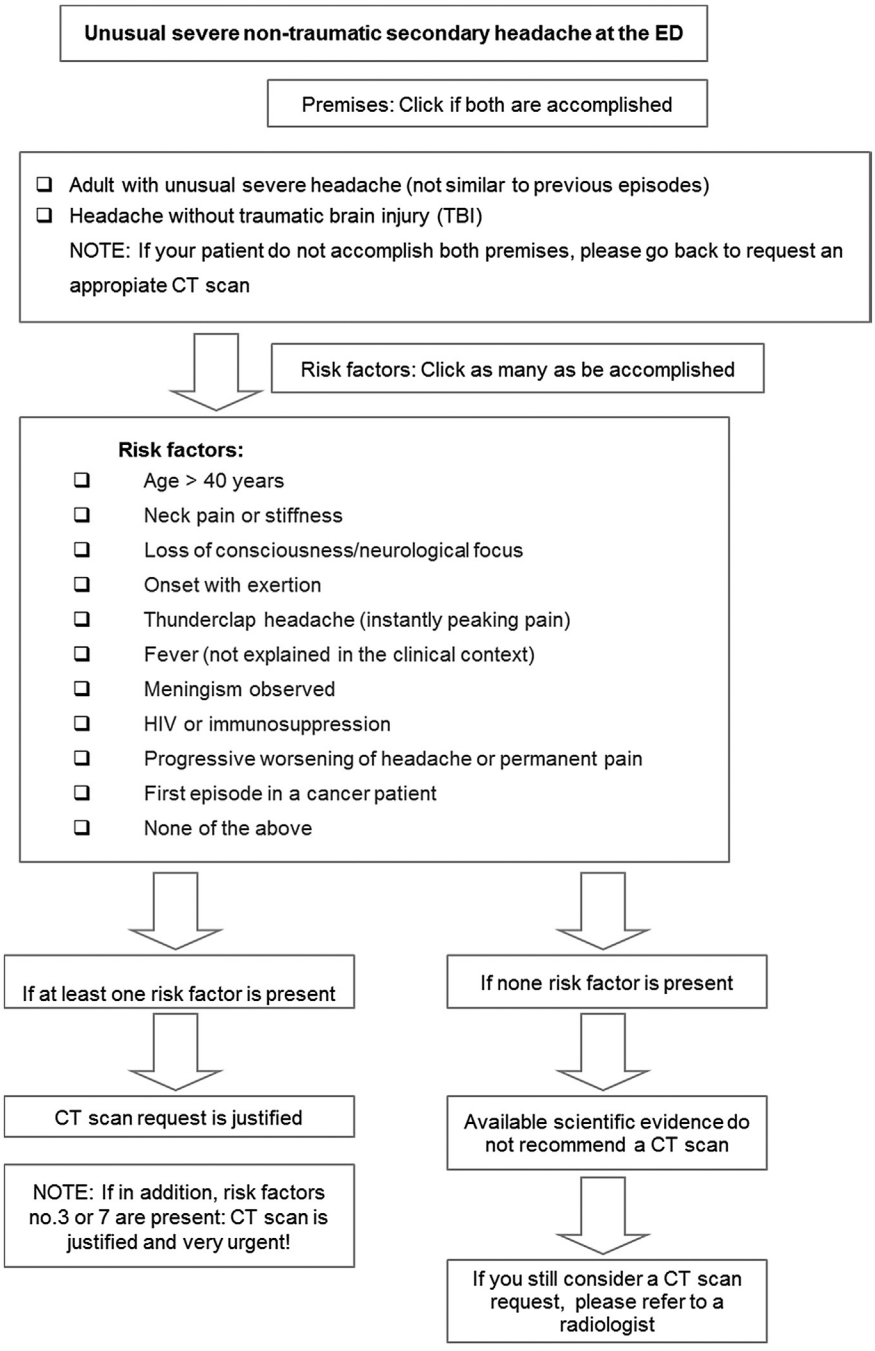

Figure 1. Clinical algorithm implemented when a cranial CT scan is requested for an unusual severe non-traumatic secondary headache at the ED. CT = computed tomography; ED = emergency department.

did not follow the algorithm to undergo CT. We did not find any statistically significant difference when comparing rates of new ED visits during the next 90 days (33.2% in patients without CT request compared to 35.7% in patients with a CT request via the CDSS, and 35.0% in patients with a CT scan ordered without following the algorithm, $p = 0.731$).

Patients with no CT scan request had fewer hospital admissions than patients with a CT scan (6% vs. 12%, $p = 0.001$). The rate of admission was similar independent of whether the CT was ordered using the decision support or not. There were 7 deaths (0.78%) in the group with no CT scan request and 4 (1.1%) in the group with a CT request (2 in each group). Only 2 patients died from

Table 3. Characteristics of Patients who Received Computed Tomography Scans before and after Computerized Decision Support System Implementation

	Patients Who Received CT Scans before Implementation (March–August 2015), n = 377	Patients Who Received CT Scans after Implementation (March–August 2016), n = 244
Mean age, y (SD)	56.1 (21.2)	54.8 (20.3)
Females, n (%)	258 (68.4)	149 (61.0)
Neck pain or stiffness, n (%)	36 (9.5)	59 (24.2)
Loss of consciousness/neurological focus, n (%)	88 (23.3)	59 (24.2)
Onset with exertion, n (%)	15 (4.0)	6 (2.5)
Thunderclap headache (instantly peaking pain), n (%)	71 (18.8)	66 (27.1)
Fever (not explained in the clinical context), n (%)	36 (9.5)	24 (9.8)
Meningism observed, n (%)	9 (2.4)	10 (4.1)
HIV or immunosuppression, n (%)	16 (4.2)	5 (2.1)
Progressive worsening of headache or permanent pain, n (%)	78 (20.7)	123 (50.4)
First episode in a cancer patient, n (%)	37 (9.8)	21 (8.6)

CT = computed tomography; SD = standard deviation.

causes related to headache, 1 in each group. The patient who died in the group with no CT scan had brain metastases diagnosed before the ED visit.

DISCUSSION

We found that in unusual severe nontraumatic secondary headache among adults seen in the ED, implementing a CDSS decreased the cranial CT scan request rate but did not increase the diagnostic yield. The algorithm aimed to target cases with a greater probability of having 1 of the 3 main causes of potentially serious secondary headache (subarachnoid hemorrhage, intracranial tumor, or intracranial infection). As a proof of concept, this decision algorithm has changed our clinicians' behavior and we have observed fewer requests for CT scans but there has been no increase in the diagnostic yield of CT scans. The algorithm was based on the presence of clinical features selected by a multidisciplinary expert panel in a way that maximized the sensitivity of the CDSS to reduce the risk of false negatives. However, given that the diagnostic yield did not increase, we cannot rule out the possibility that some pathology was missed after decision support implementation. Future implementations of this CDSS will require close local monitoring of its clinical impact on patients.

We have also found that the likelihood of a hospital admission was higher in patients with a cranial CT scan performed compared with patients without cranial CT scan. This could be a consequence of the presence of risk factors that could have prompted not only a request for a cranial CT scan but also a hospital admission and could also have been triggered by CT scan findings.

Other authors have previously published CPRs for the management of patients with headache. Perry et al. created the Canada and Ottawa rules for the detection of patients with suspected subarachnoid hemorrhage based on the characteristics of the headache, and this was subsequently validated by Matloob et al. (16–18). However, these guidelines do not cover conditions other than subarachnoid hemorrhage, limiting their general usefulness. Cortelli et al. did address other conditions, but their presentation in the form of clinical scenarios makes this algorithm unwieldy and difficult for an ED to

Table 4. Comparison Between the Number of Computed Tomography Scan Findings for Headache During the Pre- and Postimplementation Periods

	Computed Tomography Scans, n (%)	
	Preimplementation Period	Postimplementation period
No pathological finding	187 (49.6)	105 (43.0)
Pathological finding but irrelevant	120 (31.8)	104 (42.6)
Pathological finding according to the reason of headache consultation or suggestive of another diagnosis	70 (18.6)	35 (14.3)
Total	377 (100)	244 (100)

adopt (19,21). None of these proposed rules have had their impact evaluated postimplementation, as in our study.

LIMITATIONS

Our study has limitations. The number of cranial CT scans performed has decreased, but contrary to our expectation, the proportion of positive findings has not increased. Reducing the number of CT scan requests after the CDSS implementation should have been followed by an increase in the rate of pathological findings. However, we did not observe such an effect. Although the numbers are small for drawing firm conclusions, we cannot rule out the possibility that some cases were underdiagnosed after CDSS implementation. This should be carefully monitored in future evaluations of any CDSS implementation. The resistance of health care professionals to change in the ED is one of the limitations that could have negatively affected the impact of our CDSS. Despite the training sessions held in the ED, the clinicians may have failed to adhere to the protocol, and we cannot rule out that some episodes of nontraumatic secondary headache were managed by a diagnostic work-up undertaken outside the CDSS. In fact, we found that in the safety analysis period, some of the cranial CT scans for a headache episode were indeed performed outside the CDSS. Unfortunately, the safety analysis period encompasses a different season than the pre–post intervention assessment periods, which included summer, when much fewer patients attend the ED. This fact could explain the apparent rebound in the number of CT scans ordered in the safety period. The pre–post comparison of the pathological findings may be limited by the low frequency of events, precluding us from obtaining meaningful conclusions about changes in diagnostic yield.

On the other hand, it is possible that the CDSS had a positive impact on the confidence and certainty with which clinicians selected imaging tests in our study. This is because the CDSS that we developed used a set of simple, easy-to-identify risk factors based on scientific evidence of varying levels of quality and the consensus of a multidisciplinary panel of experts. The degree of satisfaction with the use of the system has not been evaluated, and we will appraise this factor in future studies. Finally, we conducted the study in a single ED of a tertiary care academic hospital. It is unclear whether this system will transfer to other settings and whether acceptability and impact will be similar. These factors should be investigated in future studies.

Regarding safety, we compared death and hospital admission rates in the 90 days after the event in the 2 groups—those with CT scan requested and those without. For a more comprehensive evaluation of safety, future studies would need to evaluate the misdiagnosis rate in patients who do not undergo a CT scan.

CONCLUSION

Cranial CT scans should be performed urgently in adult patients attending the ED with unusual severe nontraumatic secondary headache who present with any of the following risk factors: >40 years of age, neck pain or stiffness, loss of consciousness or neurologic focus, onset during exertion, sudden onset of pain, presence of fever that is not explained in the clinical context, meningism observed on physical examination, HIV or immunosuppression, progressive worsening of headache or permanent pain, and first episode in a patient with cancer.

The implementation of the CDSS using these criteria had a significant impact by reducing the frequency of cranial CT scan requests for headache; however, we did not find an improvement in the diagnostic yield of the test. Extending the system to include reasons for consultation other than headache will favor progress toward optimizing the overall use of ionizing radiation for testing in the ED.

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SUPPLEMENTARY DATA

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REFERENCES

1. Chu KH, Howell TE, Keijzers G, et al. Acute headache presentations to the emergency department: a statewide cross-sectional study. Acad Emerg Med 2017;24:53–62.
2. Goldstein JN, Camargo CA Jr, Pelletier AJ, Edlow JA. Headache in United States emergency departments: demographics, work-up and frequency of pathological diagnoses. Cephalalgia 2006;26:684–90.
3. Headache Classification Committee of the International Headache Society (IHS). The International Classification of Headache Disorders, 3rd edition (beta version). Cephalalgia 2013;33:629–808.
4. Welch HG, Skinner JS, Schroeck FR, Zhou W, Black WC. Regional variation of computed tomographic imaging in the United States and the risk of nephrectomy. JAMA Intern Med 2018;178:221–7.
5. Smith-Bindman R. Use of advanced imaging tests and the not-so-incidental harms of incidental findings. JAMA Intern Med 2018; 178:227–8.
6. Choosing Wisely website. An initiative of the American Board of Internal Medicine Foundation. Available at: http://www.choosingwisely.org/. Accessed August 28, 2019.
7. National Institute for Heald and Care Excellence website. NICE guidance. Available at: http://www.nice.org.uk/guidance. Accessed August 28, 2019.
8. Divulgación de Iniciativas para Analizar la Adecuación en Salud website. Available at: http://www.dianasalud.com/index.php/. Accessed August 28, 2019.
9. Stiell IG, Wells GA. Methodologic standards for the development of clinical decision rules in emergency medicine. Ann Emerg Med 1999;33:437–47.
10. McGinn TG, Guyatt GH, Wyer PC, Naylor CD, Stiell IG, Richardson WS. Users' guides to the medical literature: XXII: how to use articles about clinical decision rules. Evidence-Based Medicine Working Group. JAMA 2000;284:79–84.
11. Keogh C, Wallace E, O'Brien KK, et al. Optimized retrieval of primary care clinical prediction rules from MEDLINE to establish a Web-based register. J Clin Epidemiol 2011;64:848–60.
12. American College of Radiology Appropriateness Criteria. Headache. Available at: https://acsearch.acr.org/docs/69482/Narrative/. Accessed August 28, 2019.
13. ACCESSSS website. Available at: http://plus.mcmaster.ca/ACCESSSS/About.aspx. Accessed August 28, 2019.
14. DiCenso A, Bayley L, Haynes RB. ACP Journal Club. Editorial: Accessing preappraised evidence: fine-tuning the 5S model into a 6S model. Ann Intern Med 2009;151. JC3–2, JC3–3.
15. Tung C, Lindgren A, Siemund R, van Westen D. Emergency room decision-making for urgent cranial computed tomography: selection criteria for subsets of non-trauma patients. Acta Radiol 2014; 55:847–54.
16. Matloob SA, Roach J, Marcus HJ, O'Neill K, Nair R. Evaluation of the impact of the Canadian subarachnoid haemorrhage clinical decision rules on British practice. Br J Neurosurg 2013;27:603–6.
17. Perry JJ, Stiell IG, Sivilotti MLA, et al. Clinical decision rules to rule out subarachnoid hemorrhage for acute headache. JAMA 2013;310:1248–55.
18. Perry JJ, Stiell IG, Sivilotti MLA, et al. High risk clinical characteristics for subarachnoid haemorrhage in patients with acute headache: prospective cohort study. BMJ 2010;341:c5204.
19. Grimaldi D, Nonino F, Cevoli S, Vandelli A, D'Amico R, Cortelli P. Risk stratification of non-traumatic headache in the emergency department. J Neurol 2009;256:51–7.
20. Locker TE, Thompson C, Rylance J, Mason SM. The utility of clinical features in patients presenting with nontraumatic headache: an investigation of adult patients attending an emergency department. Headache 2006;46:954–61.
21. Cortelli P, Cevoli S, Nonino F, et al. Evidence-based diagnosis of nontraumatic headache in the emergency department: a consensus statement on four clinical scenarios. Headache 2004;44:587–95.
22. Rothman RE, Keyl PM, McArthur JC, Beauchamp NJ, Danyluk T, Kelen GD. A decision guideline for emergency department utilization of noncontrast head computed tomography in HIV-infected patients. Acad Emerg Med 1999;6:1010–9.
23. Ramirez-Lassepas M, Espinosa CE, Cicero JJ, Johnston KL, Cipolle RJ, Barber DL. Predictors of intracranial pathologic findings in patients who seek emergency care because of headache. Arch Neurol 1997;54:1506–9.
24. Reinus WR, Erickson KK, Wippold FJ. Unenhanced emergency cranial CT: optimizing patient selection with univariate and multivariate analyses. Radiology 1993;186:763–8.

ARTICLE SUMMARY

1. Why is this topic important?

The unnecessary use of cranial computed tomography (CT) scans can involve avoidable exposure to ionizing radiation and delay the diagnosis and treatment of other patients who need a CT scan.

2. What is this study trying to show?

This study aims to optimize cranial CT scan request rates in unusual severe nontraumatic secondary headaches by implementing a computerized decision support system based on a list of 10 risk factors.

3. What are the key findings?

In patients with unusual severe nontraumatic secondary headaches, requesting a cranial CT scan only in those cases with $\geq$1 risk factor significantly reduces the CT scan request rates by 38%. There is no reduction in the rate of pathological findings.

4. How is patient care affected?

This study shows that implementation of the computerized decision support system with these criteria had a significant impact by reducing the frequency of cranial CT scan requests for headache; however, we did not find an improvement in the diagnostic yield of the test.