ORIGINAL CONTRIBUTION

Computed Tomography Use for Adults With Head Injury: Describing Likely Avoidable Emergency Department Imaging Based on the Canadian CT Head Rule

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ABSTRACT

Background: Millions of head computed tomography (CT) scans are ordered annually, but the extent of avoidable imaging is poorly defined.

Objectives: The objective was to determine the prevalence of likely avoidable CT imaging among adults evaluated for head injury in 14 community emergency departments (EDs) in Southern California.

Methods: We conducted an electronic health record (EHR) database and chart review of adult ED trauma encounters receiving a head CT from 2008 to 2013. The primary outcome was discordance with the Canadian CT Head Rule (CCHR) high-risk criteria; the secondary outcome was use of a neurosurgical intervention in the discordant cohort. We queried systemwide EHRs to identify CCHR discordance using criteria identifiable in discrete data fields. Explicit chart review of a subset of discordant CTs provided estimates of misclassification bias and assessed the low-risk cases who actually received an intervention.

Results: Among 27,240 adult trauma head CTs, EHR data classified 11,432 (42.0%) discordant with CCHR recommendation. Subsequent chart review showed that the designation of discordance based on the EHR was inaccurate in 12.2% (95% confidence interval [CI] = 5.6% to 18.8%). Inter-rater reliability for attributing CCHR concordance was 95% (κ = 0.86). Thus, we estimate that 36.8% of trauma head CTs were truly likely avoidable (95% CI = 34.1% to 39.6%). Among the likely avoidable CT group identified by EHR, only 0.1% (n = 13) received a neurosurgical intervention. Chart review showed none of these were actually "missed" by the CCHR, as all 13 were misclassified.

Conclusion: About one-third of head CTs currently performed on adults with head injury may be avoidable by applying the CCHR. Avoidance of CT in such patients is unlikely to miss any important injuries.

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Computed tomography (CT) imaging has greatly improved the diagnosis and treatment of patients since its introduction in the 1970s; however, many studies suggest CT imaging is substantially overused.[1–3] Ensuring appropriate use is important, as failure to perform a CT when needed can lead to preventable adverse health outcomes. On the other hand, performing a CT that is extremely unlikely to produce information that can benefit a patient is not only financially irresponsible, but can cause medical harm. CT scanning is the single largest contributor to the recent sixfold increase in patient exposure to radiation from medical imaging,[2] which is expected to be the cause of many future cancers.[4–6] Inappropriate imaging in an emergency department (ED) can also harm other patients by delaying their access to the scanner and can direct attention away from other patients with time-sensitive, life-threatening conditions.[7–9] Probably more important still is the downstream harm from subsequent unhelpful tests and procedures associated with false-positive findings, "incidentalomas," and overdiagnosis.[10–12]

Nearly one-third of the 80 million CTs performed annually in the United States are ordered from the ED, about 50% of which involve the brain, leading to substantial scrutiny.[2,3,13,14] A large number of groups have highlighted the need to reduce "unnecessary" head CT scanning as part of their recommendations for the Choosing Wisely campaign.[15] However, despite calls for improved stewardship, the extent of likely avoidable head CT use among adults with minor trauma seen in community EDs is not known.

Several validated clinical decision instruments can guide evaluation of adult head trauma patients, perhaps the most studied of which is the Canadian CT Head Rule (CCHR), which is also the published clinical standard of the Kaiser Permanente Southern California (KPSC) community EDs participating in this study.[16–19] We felt it important to understand to what extent ED providers are currently performing likely avoidable CT imaging after head trauma. For the purposes of this study, we defined imaging that is discordant with high-risk CCHR recommendations as likely avoidable to determine whether further attention to this problem and the development of new policies to improve stewardship of diagnostic imaging is warranted.

This study aims to describe the scope of overuse of CT imaging by ED providers in cases where application of key components of a validated clinical decision instrument (in this case the CCHR) could have avoided imaging. Such imaging is unlikely to provide information beneficial to patients.[20] Secondarily, we sought to determine the extent to which our identified likely avoidable CTs, if averted, would have resulted in "missed" intracranial hemorrhages (ICHs) requiring a neurosurgical intervention.

METHODS

Study Design

This is an observational study of adult ED trauma encounters within KPSC from January 2008 to June 2013. Our administrative database captures all electronic health record (EHR) information from encounters at our 14 EDs; it also captures out of network claims, to identify any adverse patient outcomes among those seen out of network. For this study, EHR data were extracted by trained staff experienced in the collection and analysis of the KPSC structured data. Human subjects approval was obtained through the KPSC Institutional Review Board.

We first used diagnosis codes to identify ED trauma patients with a documented Glasgow Coma Scale (GCS) score and procedure codes to detect those who received a head CT scan. Among these encounters we identified those receiving a head CT scan likely discordant with the recommendations of the high-risk CCHR (Figure 1). The KP EHR can readily identify three of the high-risk CCHR criteria (age, GCS score, and vomiting; see Table 1) based on discrete data fields routinely used in patient care, as well as those currently taking anticoagulant medications (clopidogrel, warfarin, etc.). The EHR does not capture the other two physical examination criteria (open depressed skull fracture or evidence of basilar skull fracture) of the high-risk CCHR; thus using the EHR alone could misclassify patients whose CT was in fact adherent with the high-risk CCHR. We suspected, however, that this would have very little impact on our results, as overt physical examination findings suggesting skull fractures are extremely rare, and only 0.9% of trauma patients in our EDs are diagnosed with a skull fracture after CT.

To estimate the accuracy of our EHR-derived data and to capture details relevant to the CCHR not identified in discrete fields, we next undertook an explicit chart review of a random sample of 100 encounters classified by EHR review as nonadherent with the CCHR. This allowed us both to identify the rate of misclassification in that smaller sample and to evaluate

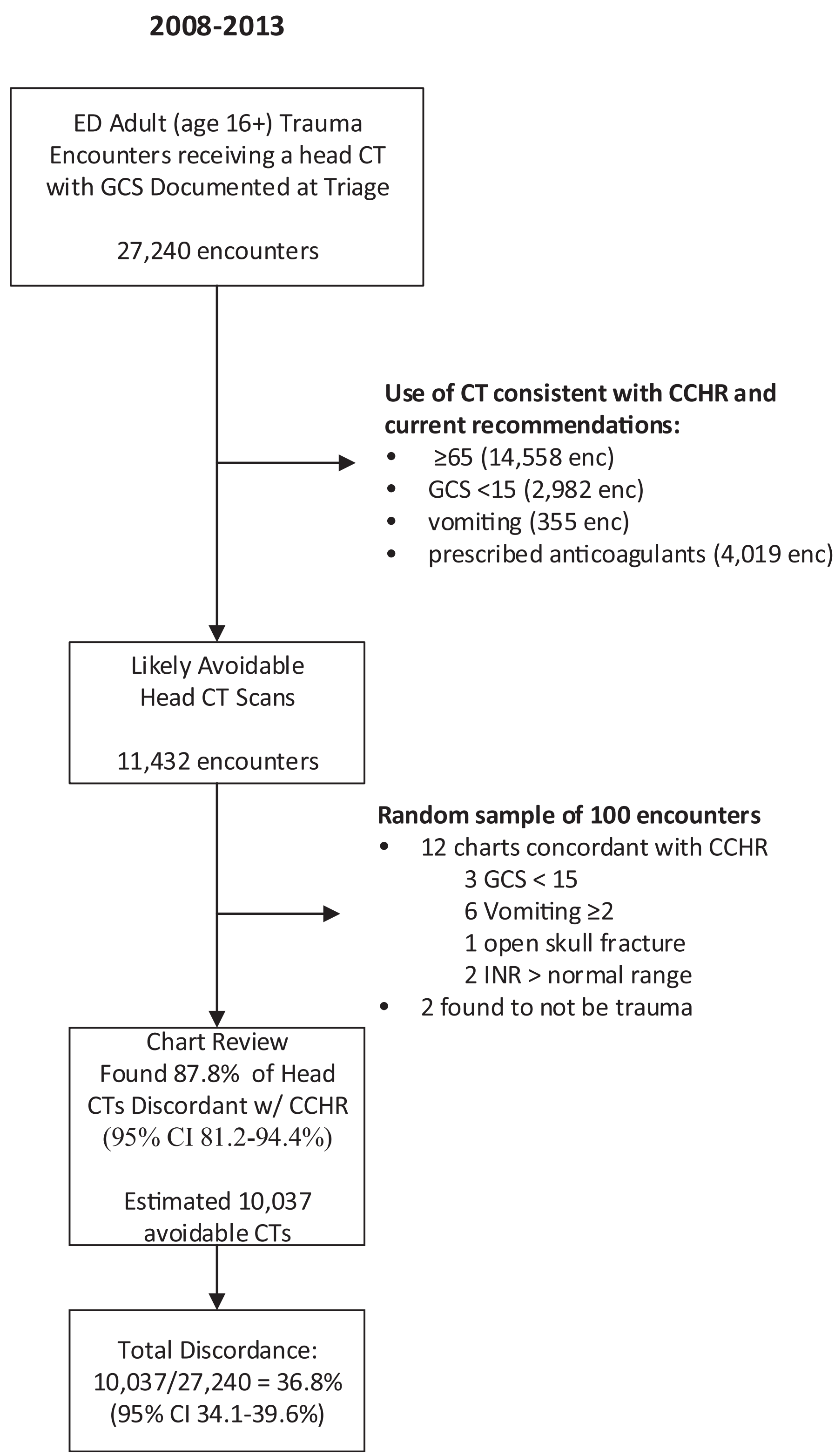

Figure 1. Flow chart depicting the ED sample used to assess the use of head CT imaging contrary to the CCHR. The sample derived from adult ED encounters at 14 community EDs with a documented GCS at nursing triage. More than one-third of head CTs for adult ED trauma encounters are likely avoidable by applying the CCHR. CCHR = Canadian CT Head Rule; CT = computed tomography; GCS = Glasgow Coma Scale.

whether misclassification bias was likely to substantially affect the findings of our EHR review.

We had no prespecified power constraints to dictate the "right" number of charts needed for review. Due to resource constraints, it was infeasible to perform chart review on tens of thousands of charts. Our aim was to review a sufficient number of charts to create 95% confidence intervals (CIs) offering

Table 1
List of the High-risk CCHR Criteria[17]

1. GCS score < 15 at 2 h after injury 2. Suspected open or depressed skull fracture 3. Sign of basal skull fracture (hemotympanum, "raccoon" eyes, cerebrospinal fluid otorrhea/rhinorrhea, or Battle's sign) 4. Vomiting ≥ 2 episodes 5. Age ≥ 65 y
These criteria are designed to identify patients at risk for serious intracranial injury requiring neurosurgical intervention. If a patient meets any of these criteria, the CCHR classifies the patient as high risk and recommends that a head CT scan be performed. CCHR = Canadian CT Head Rule; GCS = Glasgow Coma Scale.

estimates < 10% above and below our calculated EHR accuracy. Had our initial 100 chart reviews not accomplished this goal, we would have reviewed additional charts until the target was achieved. We considered this strategy appropriate given that our primary goal was to describe the general extent of CT overuse in community EDs, not to define exactly the amount of over imaging. Use of the EHR data set allowed us to obtain information for a large number of cases, far in excess of the number of high-quality chart reviews we were able to perform. Our EHR review offers a unique opportunity to evaluate key information for a large volume of patients, which is not available in most other large administrative data sets. It would have been impossible, however, based on EHR review alone, to know to what extent the results were affected by misclassification bias. Combining EHR review of a large sample with methodologically rigorous chart review in a limited number of cases allowed us to take advantage of the relative strengths of each method.

We also used chart review to evaluate the number of EHR classified discordant patients who underwent a neurosurgical intervention within 30 days. This allowed us to better understand the safety of applying the CCHR to our study cohort and to quantify the number of patients who may be at risk given strict adherence to a clinical decision rule. Therefore, in addition to the random sample of 100 likely discordant cases, we also reviewed the charts of every patient in this cohort who received a neurosurgical intervention within 30 days.

Study Setting and Population

KPSC is a large integrated healthcare system that serves approximately 4 million members representative of the diverse population of Southern California. There are 14 KPSC EDs ranging in annual volume from 25,000 to 90,000, totaling 900,000 visits per year. None of the EDs had a trauma-level designation during the study period.

We included all adult KPSC members with an ED trauma encounter (International Classification of Diseases, 9th revision, codes 800–897 and 900–959, or e-code 880–888) resulting in a noncontrast head CT (Common Procedural Terminology 70450). We limited the sample to KPSC members to ensure complete 30-day outcomes because our data sets are only able to identify neurosurgical interventions for out-of-network encounters for members through claims, but not others. An adult was defined, as in the CCHR, as any patient 16 years of age or older.[17]

Study Protocol

The CCHR uses five high-risk criteria to recommend a head CT for adults with trauma (see Table 1). If a patient meets any of these criteria, the CCHR classifies the patient as high risk and recommends that a head CT scan be performed. We did not consider whether patients would have been classified as medium risk by CCHR because, while patients classified as medium risk are at increased risk of "intracranial injury" on CT, these patients are not more likely to need neurosurgical intervention. Classification as high risk, on the other hand, increases the likelihood of needing surgical intervention.[17,18]

We used the EHR data to capture patient age ≥65 years, and discrete click box documentation to capture GCS < 15 and vomiting; these are routinely documented for patients within our EHR. Although this only allowed us to determine if there was *any* vomiting (rather than at least two episodes of vomiting), we scored all patients with vomiting as CCHR concordant. This may have falsely classified some patients as requiring a CT scan when they actually did not, but this liberalized version of the CCHR would err on the side of underestimating CT overuse. We also considered head CTs for trauma patients concordant if any patient was imaged while having a prescription for an anticoagulant medication (warfarin, heparin, clopidogrel, dabigatran, rivaroxaban, or apixaban), as such patients are at higher risk.[21–23] These patients were excluded from the original CCHR study and, while this again could lead to some underestimate of the prevalence of nonconcordance, this is not problematic as actual overuse would thus again be at least as high as the prevalence that we are able to determine.

The other two CCHR criteria—signs of open or depressed fracture or of basilar skull fracture—cannot be identified from discrete fields in our EHR. Each is a relatively rare finding, and thus unlikely to change the classification of many patients. Nevertheless, we performed a structured, in-depth chart review on a random sample of 100 patients classified as receiving likely avoidable imaging to identify any missed physical examination findings. The chart review also allowed us to assess the reliability of our initial data collection method, and to report the extent of misclassification.

Chart reviews followed standard recommendations to limit bias.[24] Charts for review were randomly chosen from the group of encounters in whom the CT scan was identified as likely discordant with CCHR (Figure 1). Two abstractors independently reviewed each chart using a standard abstraction form, recording presence or absence of each of the five CCHR high-risk criteria, as well as any other findings that would have excluded a patient from suitability for evaluation by the CCHR (e.g., trauma not within 24 hours, seizure, absence of head trauma).[25] Reviewer performance was monitored, and differences were discussed as a team to come to a consensus regarding CCHR concordance. A third abstractor, blinded to our study's goals, independently reviewed 20 of the 100 charts, to evaluate inter-rater reliability of determination of CCHR concordance between our consensus review and blinded review. The blinded abstractor also reviewed every patient ($n = 13$) identified in the likely avoidable cohort who had a neurosurgical intervention. Abstractors were trained to classify an encounter as adherent to the CCHR if there was conflicting information regarding the criteria anywhere in the chart (to minimize any chance of falsely increasing the prevalence of discordance). On the other hand, when the chart contained no information about one of the criteria, this was recorded, and the criterion was then considered to be absent. Primary analyses assumed that missing data were symptoms/signs not present and a sensitivity analysis assumed that all missing data were symptoms present during the encounter and therefore concordant with the CCHR.

Finally, we used the sampling fraction to estimate the variance of the proportion of CCHR-concordant head CTs for those 100 patients for whom chart review was done. This estimate was obtained using standard formulas routinely used for survey sampling research[26] and then used to construct 95% confidence limits for the entire cohort. These statistics permit inference about the range of possible values we might expect for the proportion of head CTs discordant with the CCHR in the entire sample.

Table 2
Patient Demographics for the Entire Cohort and Those Likely Discordant With the CCHR Based on Variables Identifiable From Structured Data (Age < 65 Years, No Use of Anticoagulant Medications, Normal GCS, and No Documented Vomiting)

Patient Characteristic	All (N = 27,240)	Discordant (n = 11,432)
Age (y), mean (±SD*)	61.4 (±23.7)	38.9 (±15.5)
Sex		
Female	56.5	37.7
Race, %		
White	47.9	40.4
Black	13.7	47.3
Hispanic	29.2	58.7
Asian/Pacific Islander	7.1	40.4
Other	2.1	78.8
Elixhauser index, mean (±SD*)	3.5 (±3.0)	1.6 (±2.1)

CCHR = Canadian CT Head Rule; GCS = Glasgow Coma Scale.

Measurements and Key Outcomes Measured

Our primary outcome was discordance with the CCHR among adult patients receiving a CT for head injury (likely avoidable imaging).[17,25] Our secondary outcome was the number of patients in the discordant cohort who ultimately had a neurosurgical intervention (ICD-9-CM codes 01.09, 01.10, 01.18, 01.23–01.26, 01.31, 01.39, 01.59, 02.02, 02.12, 02.2, 02.34, 02.39, 02.92, 02.99) within 30 days of the index ED visit. These procedure codes have been previously used to describe neurosurgical procedures or operations used to treat severe traumatic brain injuries (intracranial pressure monitor placement, craniotomy, ventriculostomy, etc.).[27]

Data Analysis

The primary outcome required only descriptive reporting of the use of CT imaging after head trauma discordant with the high-risk CCHR. To report accuracy of our attribution of CCHR concordance based on discrete data captured in our EHR, we used weighted estimates of population proportions from in-depth chart review, along with 95% CIs for both weighted and sample statistics for CCHR concordance, where both the total proportion and the variance were weighted by sampling fractions.[28,29] Inter-rater reliability between the consensus review and the blinded reviewer was determined based on percent raw agreement and calculation of the kappa statistic. A sensitivity analysis was performed based on missing data found through chart review, attributing all missing values abnormal and thus making the CT concordant with the CCHR. Similar estimates of accuracy were calculated and attributed to our sample based on missing values assumed to be abnormal to create an overly conservative lower estimate of possible CT overuse. All analyses were conducted using SAS (version 9.3, SAS Institute).

RESULTS

Characteristics of Study Subjects

A total of 27,240 ED trauma visits with head CTs were included in the sample (Figure 1). The mean age was 61.4 years; 56.5% were female with a mean Elixhauser index of 3.5. The sample had the following race distribution: 47.9% White, 29.2% Hispanic, 13.7% Black, 7.1% Asian or Pacific Islander, and 2.1% other (Table 2).

Main Results

Based on EHR data, 41.9% (11,432/27,240) of head CTs included in the sample were likely avoidable based on the CCHR criteria (Figure 1). We identified ED-level variation in the proportion of potentially avoidable CTs which ranged from 32.4% to 59.1% in the 14 EDs. Structured, in-depth chart review of 100 encounters found that 12 were in fact concordant with CCHR recommendations and two were unrelated to trauma, meaning the discordance estimates from the structured data were accurate in 86 of 98 cases (87.8%, 95% CI = 81.2% to 94.4%). Applying these findings to the overall sample of adult head CTs for trauma, we estimate 36.8% (95% CI = 34.1% to 39.6%) of head CTs for trauma might be avoided with strict application of the CCHR. Inter-rater reliability for our chart review data appeared to be high, with the 20 charts reviewed by a blinded reviewer compared to consensus review yielded 95% (19/20) agreement regarding CCHR discordance ($\kappa = 0.86$, 95% CI = 0.59 to 1).

Among the 11,432 encounters in which the CT was likely discordant based on EHR, only 0.1% ($n = 13$) resulted in a neurosurgical intervention, compared to 0.5% ($n = 145$) in the overall sample. Blinded chart review found that none of these encounters would have been missed by appropriate application of the CCHR. Each of these encounters were included in the discordant group due to a limitation of the EHR's ability to detect either a physical examination finding (e.g., hammer assault to head with obvious open depressed skull fracture) or a CCHR exclusion criteria (e.g., remote trauma > 24 hours prior to ED arrival). Sensitivity analyses based on the assumption that all missing data were in fact abnormal estimated 67.3% (95% CI = 61.2% to 72.8%) accuracy of the EHR-based attribution of CCHR-discordance; if this were true, as many as 28.2% of CTs (95% CI = 25.7% to 30.6%) could actually have been safely avoided.

DISCUSSION

The availability of a very large EHR database allowed us to address the extent to which "likely avoidable" head CT scanning is currently being done for adult trauma encounters. Although increasing CT use[30,31] has been interpreted by many to mean "overuse," our results are much more specific than previous reports and are able to estimate the extent of avoidable head CT imaging for ED trauma encounters in a community setting. In our KPSC healthcare system, clinicians are encouraged to use the CCHR to help identify such likely avoidable patients. In addition, our EHR allows us to capture electronically the presence or absence of the three CCHR findings that are most influential in categorizing patient risk. Because the other two findings included in CCHR (but not in our EHR) are known to be uncommon (0.9% of our 27,240 encounters), and therefore unlikely to change CCHR categorization of more than a very few patients, we first classified patients into CCHR risk categories based on the EHR database. At the same time, we knew that sole reliance on the EHR would be to some extent inaccurate and, therefore, added an explicit chart review in a subgroup of study subjects. For these encounters we were able to estimate, with reasonable confidence, the degree to which use of the EHR database alone would be likely to misclassify individual patients.

It would have been impossible to include a large sample size had we relied entirely on chart review because of the resource intensity required for such an effort. Combining these two methodologies, however, allows us to study our research question reliably among a substantially larger sample.

We found that more than one-third of head CTs ordered in our system are identifiable as “likely avoidable” and that none of these scans led to an important clinical intervention. This confirms the widely held belief that CT imaging for head trauma is substantially overused. Such overuse occurs despite aligned agreement from national physician organizations and patient advocacy groups that providers should decrease likely avoidable imaging. Our research also demonstrates a way to use easily recognizable data elements, inherent in an EHR, to estimate likely avoidable imaging with reasonable accuracy (88%).

There are limitations to any database review/chart review study, even when done using methods to reduce bias, and we therefore recognize that our methods are not able to provide a precise estimate of CT overuse. We designed the study to ensure that our estimate of overuse was a conservative one, such that the actual degree of overuse is likely to be *at least* as large as our results suggest. First, with regard to the explicit chart review, we performed a sensitivity analysis in which we assumed that all missing data were abnormal, such that the CT would be classified as concordant with the CCHR in every patient with missing data; this is likely to provide an extreme overestimate of CCHR concordance. Nevertheless, even under these conditions the lower 95% confidence limit of discordance was 26%. Although we do not claim that our data can provide a precise estimate of the amount of overuse, we are confident from our results that there is substantial misuse of likely avoidable CT imaging for adults with head trauma.

Our findings are consistent with the hypothesis that many patients currently undergoing imaging are highly unlikely to have a clinically important finding on CT imaging and, indeed, in our series none of these patients actually required an intervention based on CT findings. It is important not to misinterpret our findings so as to make any claims about clinical use of the CCHR. First, there are a number of alternate ways that clinicians can identify likely avoidable patients with similar accuracy, including several other decision instruments[32,33] and clinical judgment. Secondly, we did not evaluate the cohort of patients who did not receive a CT scan—and it is certainly possible that use of the CCHR would have led to the unintended consequence of increasing CT imaging in that group; indeed, there is evidence that implementing the CCHR into clinical practice does not decrease head CT ordering.[25,34] There are various possible explanations for this, but in any case, the question of how best to address the substantial overuse of CT scanning in likely avoidable circumstances will require future study.

LIMITATIONS

Our findings must be interpreted in the context of our study design. As noted, the EHR, which we used for most of our sample, does not capture all CCHR elements. For example, we used the initial triage GCS as we were not able to assess if this was 2 hours from the event, as done in the initial CCHR study. We were, however, able to estimate the extent to which our EHR review may have led to misclassification by doing an explicit chart review for a subgroup of patients. Nevertheless even using a review methodology designed to limit bias as much as possible, especially with regard to imprecise, conflicting, or subjectively interpreted data, our results remain subject to potentially important error because of missing data. For this reason, as noted, we performed a sensitivity analysis that categorized all missing data as abnormal. This can only bias our results in the direction opposite to our hypothesis (that many CT scans are being done in likely avoidable patients)—such that our results almost certainly represent the lowest estimate of the rate of likely avoidable CT scans that were done.

Our chart review found that 2% of charts had trauma diagnoses, but were not head trauma based on clinical documentation. Since the CCHR is not designed for decision making beyond head trauma, it is reasonable to assume these were “appropriate” CTs. Even using 86/100 (86.0%, 95% CI = 79.0% to 92.9%), instead of 86/98 (87.8%, 95% CI = 81.2% to 94.4%), to estimate avoidable imaging, our conclusions would not change, but would approximate 36.1% of imaging was avoidable (vs. 36.8%).

Our study design does not identify or address patients who may be moderate risk for having an ICH based on the CCHR, which includes mechanism of injury or prolonged amnesia prior to the event for ≥ 30 minutes as additional criteria. Although this is a valid limitation, this is likely a small concern due to a recent report that even the majority of patients with a traumatic ICH have no need for any critical intervention.[35] Our methods also prevent us from understanding trauma encounters not receiving CT imaging, and therefore we cannot make any inferences regarding the potential underutilization of CT in that cohort.

Our study cannot define best practice, either in deciding precisely which patient should not have a CT scan or in addressing the effect of implementation of a particular algorithm (including a decision instrument like the CCHR). Future research is critical to address these questions; nevertheless, because no such large prospective studies are currently being done (or are likely to be done in the foreseeable future), we believe that our results should be useful to help policy-makers and clinical leaders identify an important target for improvement, consistent with a number of Choosing Wisely recommendations.[15]

CONCLUSION

Approximately one-third of head computed tomography scans performed on adults with head injury in our community EDs may be avoided by applying a validated clinical decision instrument (Canadian CT Head Rule). Furthermore, had computed tomography been avoided in the many patients in our cohort who had no high-risk indicators per this decision instrument, no clinically relevant interventions would have been inappropriately withheld.

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Supporting Information

The following supporting information is available in the online version of this paper:

Appendix S1. This chart review abstraction form shows the variables used to determine the applicability of the Canadian CT Head Rule (CCHR), as well as the concordance rates for the 113 charts reviewed.