ORIGINAL RESEARCH

Does Health Information Exchange Reduce Unnecessary Neuroimaging and Improve Quality of Headache Care in the Emergency Department?

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BACKGROUND: Health information exchange (HIE) is advocated as an approach to reduce unnecessary testing and improve quality of emergency department (ED) care, but little evidence supports its use. Headache is a specific condition for which HIE has theoretical benefits.

OBJECTIVE: To determine whether health information exchange (HIE) reduces potentially unnecessary neuroimaging, increases adherence with evidence-based guidelines, and decreases costs in the emergency department (ED) evaluation of headache.

DESIGN: Longitudinal data analysis

SUBJECTS: All repeat patient-visits (N=2,102) by all 1,252 adults presenting with headache to a Memphis metropolitan area ED two or more times between August 1, 2007 and July 31, 2009.

INTERVENTION: Use of a regional HIE connecting the 15 major adult hospitals and two regional clinic systems by authorized ED personnel to access the patient's record during the time period in which the patient was being seen in the ED.

MAIN MEASURES: Diagnostic neuroimaging (CT, CT angiography, MRI or MRI angiography), evidence-based guideline adherence, and total patient-visit estimated cost.

KEY RESULTS: HIE data were accessed for 21.8 % of ED patient-visits for headache. 69.8 % received neuroimaging. HIE was associated with decreased odds of diagnostic neuroimaging (odds ratio [OR] 0.38, confidence interval [CI] 0.29–0.50) and increased adherence with evidence-based guidelines (OR 1.33, CI 1.02–1.73). Administrative/nursing staff HIE use (OR 0.24, CI 0.17–0.34) was also associated with decreased neuroimaging after adjustment for confounding factors. Overall HIE use was not associated with significant changes in costs.

CONCLUSIONS: HIE is associated with decreased diagnostic imaging and increased evidence-based guideline adherence in the emergency evaluation of headache, but was not associated with improvements in overall

costs. Controlled trials are needed to test whether specific HIE enhancements to increase HIE use can further reduce potentially unnecessary diagnostic imaging and improve adherence with guidelines while decreasing costs of care.

KEY WORDS: health information exchange; medical informatics; headache; headache disorders; migraine disorders; delivery of health care; emergency medicine; quality of health care; health services research.

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INTRODUCTION

Health information exchange (HIE), defined as the electronic sharing of health information across healthcare organizations within a region, community or hospital system, has been widely advocated as an essential approach to improve healthcare quality, safety, and efficiency.¹ HIE is increasingly utilized to unify patient medical records across disparate environments as a result of regional, state, and federal investments including state grants from the Office of the National Coordinator for Health Information Technology. HIE has potential to reduce unnecessary testing and improve care in the emergency department (ED) by making prior visit and test results from other hospitals readily available during the current visit. The American College of Emergency Physicians encourages hospital participation in HIE to reduce redundant testing, increase appropriate use of imaging, and improve quality and efficiency of emergency care.^{2,3} Despite theoretical benefits of HIE, to date little concrete evidence supports its use. Early evidence suggests that HIE may reduce fragmented care and unnecessary treatment.^{4–6} However, the extent to which specific ED clinical practices—such as the diagnostic evaluation and management of recurrent headache—may be altered by HIE has not been documented.^{5,6}

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Headache is an ideal condition to examine the potential benefit of HIE because it is commonly seen in the ED and overuse of discretionary diagnostic imaging is well documented. Headache accounts for 2.4 % of ED visits nationally, or over three million ED visits per year.^{7,8} While most headaches are benign,⁹ headache rarely can indicate a serious neurologic condition and neuroimaging is sometimes required.^{7,10–12} Evidence-based guidelines recommend emergency neuroimaging only after a thorough clinical examination and only for a small subset of patients with high-risk headaches.^{11–14} However, ED physicians are ordering increasing numbers of computed tomography scans (CT), CT angiography (CTA), magnetic resonance imaging (MR), and MR angiography (MRA) to evaluate headache.¹⁵ Research suggests that many of these studies are duplicative or otherwise unnecessary.¹⁶ Imaging is costly and CTs subject patients to dangerous ionizing radiation, increasing risk of malignancy.¹⁷ Yet little is known regarding best methods for reducing unnecessary neuroimaging and improving adherence with evidence-based guidelines.

This study is among the first to examine the effect of HIE on patient care in the ED.^{5,6} The study is designed to determine whether HIE by ED personnel in the evaluation of patients with headache reduces use of neuroimaging, increases adherence with guidelines, and/or reduces costs of emergency evaluation of headache in the ED. We hypothesized that HIE use in the ED will decrease discretionary neuroimaging, increase guideline adherence, and reduce costs of care.

METHODS

Study Design

This longitudinal data analysis utilized electronic medical record data extracted from the MidSouth e-Health Alliance (MSeHA). The MSeHA HIE connects the 15 major adult hospitals and two regional clinic systems in the four most populous counties of the Memphis Metropolitan Statistical Area (MSA). The MSeHA began exchanging patient demographic, diagnosis, all hospital radiologic and laboratory reports, most procedure reports, and discharge summaries through a centralized system in 2007.¹⁸ ED providers have read-only access to data from participating hospitals and clinics following login using a secure token and password through a Web portal separate from each facility's electronic health record system.⁶ The study was approved by the University of Tennessee Health Science Center Institutional Review Board.

Subjects

From an original HIE extract including all 16,630 patient-visits to MSeHA-participating hospital EDs with a principal

diagnosis of headache by 14,267 unique patients of all ages, a total of 2,101 visits for 1,252 patients were determined to be eligible for the study (Fig. 1). Inclusion criteria were designed to select repeat visitors to the ED for headache based on the hypothesis that the effect of HIE would be largest for patients with data available for review in the MSeHA HIE system. Eligible visits included those that met the following criteria: 1) patient age 18 and older; 2) a second or subsequent emergency visit to a MSeHA-participating general hospital's ED between the dates August 1, 2007 and July 31, 2009 with a primary discharge diagnosis of primary headache disorder (International Classification of Disease, 9th Revision, Clinical Modification [ICD-9-CM] codes 346.0, 346.1, 346.9 and 784.0); and 3) no discharge diagnosis of stroke (ICD-9-CM 430–438), brain cancer (ICD-9-CM 191.x, 225.0 and V10.85), traumatic injury, motor vehicle accident, poisoning, or fall.

Primary headache disorder (Appendix Table 4) was defined to be a primary diagnosis of “migraine” (ICD-9-CM 346.0, 346.1, and 346.9) or “headache not otherwise specified” (NOS). Headache NOS (ICD-9-CM 784.0) was included because the literature suggests that the majority of these cases are migraine.¹⁹ We explicitly excluded patient-visits with a primary diagnosis of “variants of migraine” (346.2), “hemiplegic migraine” (346.3), “chronic migraine” (346.7), “other forms of migraine” (346.8), and “tension headache” (307.81, 339.1) because evidence-based guidelines for neuroimaging for these conditions are less well established.

Each subject's first visit to the ED was excluded because of guidelines that suggest neuroimaging should be considered when a patient complains of “first or worst” headaches.^{13,14} This study focused solely on second or subsequent ED visits for headache.

Independent Variables

Independent variables and interaction terms were selected a priori and pre-specified based on clinical grounds and review of the literature. The primary independent variable, “Any HIE use” indicates whether the HIE was used to access the patient's record during the time period in which the patient was being seen in the ED (Y/N) regardless of the identity of the authorized user or duration of HIE system use. Secondary analyses employed the independent variables “HIE use by physician or nurse practitioner” and “HIE use by administrative/nursing staff” (registration and other support staff) to assess for potential effects of type of HIE user. The HIE electronically records in the patient's record the precise time, date, and location from which the HIE is accessed, and the identity of the user of the HIE whenever the HIE is accessed for a patient. Thus, despite absence of a published formal validation study, the HIE use variables for

Figure 1. Selection of eligible patient-visits.

this study were designed to achieve 100 % measurement accuracy.

We also tested whether the effect of HIE on the use of neuroimaging and adherence with guidelines was dependent on data availability from previous ED headache visits in the HIE system by including “HIE use * previous visits” interaction terms in the main model and secondary analyses focused on type of HIE user. The “previous visits” term was assigned a minimum value equal to zero for those study subjects with the minimum value of one previous visit required to be included in the study.

Control variables included: patient demographics (age, gender, and race), comorbidity, hospital system, and number of previous ED visits. Comorbidity was assessed using the University of Manitoba SAS Macro for the Charlson index.^{20,21} In addition, presence of substance abuse (any ICD-9-CM codes 303–305, excluding 305.1x) was assessed based on previous research suggesting that this comorbidity might independently affect likelihood of obtaining neuroimaging.²²

Outcome Measures

Three major outcomes were assessed: use of diagnostic neuroimaging (CT, CT angiography, MRI or MRI angiography), evidence-based guideline adherence, and estimated patient-visit cost. Use of diagnostic neuroimaging in the evaluation of headache was assessed using presence of radiologic reports available through HIE.

Adherence with evidence-based guidelines for diagnostic neuroimaging was assessed as a binary indicator using an algorithm derived directly from U.S Headache Consortium and American College of Emergency Physicians guidelines shown in Appendix Table 5.^{13,14} According to these guidelines there is only solid (Level B) evidence for neuroimaging in acute headache for patients with new abnormal findings on neurological exam, patients with new sudden-onset severe headache, and HIV-positive patients with a new type of headache. For this study, adherence with guidelines is defined more broadly to include several risk

factors for which there is only fair (level C) evidence for neuroimaging. Specifically, evidence-based guideline adherence is defined as either no use of neuroimaging or use of neuroimaging with one or more of the ICD-9-CM diagnostic codes listed in Appendix Table 5 that increases a priori expectations of serious pathological findings: abnormal neurological findings, systemic symptoms or illness, and patients with HIV or other immunodeficiency.¹⁴ All visits in which neuroimaging was obtained without one or more of the diagnostic codes listed in Appendix Table 5 were classified as non-adherent.

Cost to the payer was estimated for each ED patient-visit by summing: 1) the Tennessee Medicare physician/professional fees associated with any major headache-related diagnostic imaging procedures, 2) the Tennessee Medicare professional fee for a level 3 (CPT 99283) evaluation and management emergency visit (since this is the most common CPT code used for evaluation and management of headache in the ED), 3) the national Medicare ambulatory payment classification (APC) hospital payments for headache-related diagnostic imaging procedures multiplied by 0.95 (since all hospitals receive approximately 95 % of the national APC payment rate), and 4) the national APC hospital payment for a level 3 ED visit (APC code 0614) multiplied by 0.95. ED patient-visit costs were inflated to 2009 dollars using annual Consumer Price Indices (Medical Care component) published by the US Bureau of Labor Statistics. In addition, costs were adjusted for rate of time preference using the standard rate of 3 % per year recommended by the Panel on Cost-Effectiveness in Health and Medicine.²³

Statistical Analyses

Longitudinal data analyses were used to assess the effect of HIE on use of neuroimaging, guideline adherence, and costs of emergency care. The effect of HIE on neuroimaging and guideline adherence was modeled using the generalized estimating equation (GEE) method of SAS 9.2 (SAS Institute Inc., Cary, NC) to adjust for repeated measures (since some subjects had more than one visit) and for clustering of subjects within hospital system.²⁴ Since each hospital submitted non-standardized names for radiologic examinations to the HIE, each distinct test name was mapped to a corresponding Current Procedural Terminology (CPT) code and assigned a standard name following American Medical Association nomenclature.²⁵

Average costs were also adjusted for confounding variables including differences by hospital system using the GEE method and then compared for patient-visits using the Z-test. Estimated cost savings were calculated as the difference between adjusted average costs times the number of visits in which HIE was used.

RESULTS

Of the 14,378 ED patient-visits for a qualifying headache by patients 18 and older, 2,101 patient-visits (14.6 %) were for 1,252 unique patients who had two or more visits in the two-year study period. These 1,252 repeat users of the ED for headache averaged 2.7 ED visits for headache during the study period (range 2–47 visits) as shown in Table 1. The mean age for these patients at the time of visit was 39.0 years (range 18–93 years). Overall, 81.1 % of all repeat visits were by female patients. Sixty-two percent of the emergency visits were by patients of black race and 23 % of visits were covered by private insurance.

The HIE was accessed for 21.9 % of ED visits for headache in the study sample (Table 1). Administrative/nursing staff use accounted for the majority of total HIE use

Table 1. Characteristics of Headache Patient-Visits

Characteristics	No. (%) [*] n=2,101
Gender	
Female	1703 (81.1)
Male	398 (18.9)
Race	
Black	1293 (61.5)
White	785 (37.4)
Unknown/other	23 (1.1)
Insurance status	
Medicare	139 (10.7)
Medicaid	412 (31.8)
Private insurance	297 (23.0)
Self-pay	432 (33.4)
Charity	1 (0.1)
Other	13 (1.0)
Hospital system	
A	1089 (51.8)
B	710 (33.8)
C	249 (11.9)
D	53 (2.5)
HIE access	
Any HIE use	459 (21.9)
HIE use by administrative/nursing staff	326 (15.6)
HIE use by physician or nurse practitioner	133 (6.3)
Neuroimaging*	
CT with and/or without contrast	1412 (67.2)
CT angiography	27 (1.3)
MRI	139 (6.6)
MR angiography	83 (4.0)
None	635 (30.2)
Evidence-Based Guideline Adherence*	
Guideline adherent CT scan/CTA obtained	139 (6.6)
Guideline adherent MRI/MRA obtained	25 (1.2)
Overall guideline adherence with CT guidelines	774 (36.8)
Overall guideline adherence with any neuroimaging	782 (37.2)
Headache diagnosis (ICD-9-CM)	
Migraine with aura (346.0)	26 (1.2)
Migraine without aura (346.1)	82 (3.9)
Migraine, unspecified (346.9)	627 (29.8)
Headache, NOS (784.0)	1364 (64.9)
Comorbidity	
Charlson index (percent 0)	1804 (85.9)
Opioid drug dependence or abuse	1 (0.1)
Any substance dependence or abuse	26 (1.2)
Other variables	Mean (range)
Age (years)	39.0 (8–93)
Previous ED visits for headache (No.)	1.7 (1–46)

^{*}Categories may not total to 100 % since some patient-visits may have had more than one type of imaging

(71.0 %) while physicians and nurse practitioners (NP) accounted for 29.0 %. Neuroimaging of repeat users of the ED for headache was extremely common during the time of this study. Over two-thirds of patient-visits (69.8 %) received some sort of imaging (CT, CT angiography, MRI, or MR angiography). Of the 1,466 cases with imaging, 1,412 had at least one CT of the head (96.3 %).

The main multivariate results (Table 2) show increased odds of neuroimaging by subjects of older age, black race, and higher comorbidity. HIE was associated with 62 % lower odds of neuroimaging, and each additional previous visit was associated with 7 % lower odds of neuroimaging, even after controlling for other factors. The “HIE use * previous visits” interaction term was associated with a 5 % increase in neuroimaging, indicating that the impact of previous visits is attenuated in patients in whom HIE was used (net effect is only 2 % lower odds of neuroimaging associated with each additional previous visit).

Secondary multivariate analysis looking at effect of type of HIE use demonstrated that administrative/nursing staff HIE use (Odds Ratio [OR] 0.25, Confidence Interval [CI] 0.18–0.34) was associated with decreased neuroimaging. But physician/NP HIE use and the interaction terms “administrative/nursing staff HIE use * previous visits” and “physician/NP HIE use * previous visits” were not significantly associated with neuroimaging.

Table 2. Multivariate Odds Ratios for Any Neuroimaging and Evidence-based Guideline (EBG) Adherence

	Any neuroimaging odds ratio (95 % CI)	EBG adherence odds ratio (95 % CI)
Demographic characteristics		
Age (10 year increase)	1.19 (1.08–1.32)*	0.92 (0.84–1.01)
Female gender	0.84 (0.61–1.16)	0.86 (0.63–1.17)
Black race	2.35 (1.81–3.06)*	0.91 (0.70–1.18)
Comorbidity		
Charlson index	2.32 (1.62–3.30)*	1.66 (1.24–2.24)*
Any substance dependence or abuse	3.19 (0.95–10.66)	0.79 (0.26–2.42)
Health information exchange (HIE) use		
Any HIE use	0.38 (0.29–0.50)*	1.33 (1.02–1.73)*
Hospital system		
A	n/a ^Δ	11.23 (8.19–15.42)*
B	1	1
C	n/a ^Δ	1.08 (0.64–1.83)
D	n/a ^Δ	3.04 (1.44–6.40)*
Other visit characteristics		
Number of previous visits	0.93 (0.89–0.98)*	1.07 (1.02–1.11)*
Any HIE use * previous visits interaction	1.05 (1.01–1.09)*	1.00 (0.97–1.03)

*Significant *P*-value (*P* < 0.05)

^ΔSAS was unable to estimate the model parameters for the “Any Neuroimaging” outcome variable when hospital system was included in the model. Also, the results shown above for both outcomes do not adjust for clustering within hospital system. ORs in multivariate GEE for EBG adherence with and without adjustment for clustering within hospital system differed by less than 10 % for all variables, except Hospital System C (1.00 vs. 0.83)

HIE was also independently associated with increased guideline adherence (Table 2). Specifically, HIE was associated with 33 % higher odds of adherence with guidelines, and each additional previous visit was associated with 7 % higher odds of guideline adherence, even after controlling for other factors. The “HIE use * previous visits” interaction term was not significantly related to adherence with guidelines. Secondary multivariate analysis demonstrated that physician/NP HIE use, and administrative/nursing staff HIE use, and the interaction terms “administrative/nursing staff HIE use * previous visits” and “physician/NP HIE use * previous visits” were not associated with guideline adherence.

Analysis of estimated cost for each patient-visit (Table 3) revealed an estimated total cost of \$566,036 for the 2,101 study patient-visits. Visits without HIE use cost \$440,631 or \$249 cost/visit (adjusted for age, gender, race, comorbidity, substance abuse, hospital system, and previous visits), while visits with HIE use cost \$125,405 or \$254 adjusted cost/visit. Estimated cost increase per visit was \$254–\$249=\$5, but it did not reach statistical significance. Adjusted cost/visit was highest when physician/NPs used the HIE at \$280/visit compared to \$244/visit when physician/NPs did not use HIE. Estimated cost savings per visit were \$244–\$280=–\$36, suggesting higher overall costs associated with physician/NP HIE use (*p*=0.0019). In contrast, estimated cost was lowest when administrative/nursing staff used the HIE at \$257 adjusted cost/visit compared to \$266/visit when administrative/nursing staff did not use HIE. Estimated cost savings per visit was \$266–\$257=\$9, suggesting lower costs associated with administrative/nursing staff HIE use, but this difference was not statistically significant (*p*=0.1503). Further analysis revealed that higher overall costs with HIE use and physician/NP HIE use resulted from increased use of costly MRIs when physician/NPs used the HIE.

COMMENT

Despite major national investments in HIE, its effect on quality and costs is not well documented. This study is among the first to study the effect of HIE in the emergency setting. Our research demonstrates that HIE is associated with increased adherence with evidence-based guidelines and reduced use of diagnostic neuroimaging for headache. Consistent with other research, we found low HIE use rates.^{6,26} HIE was accessed for repeat headache visitors only 21.9 % of the time. Previous research suggests that low use is related to both system factors and time constraints.^{27,28} Despite low use of the HIE system, we estimate—based on the number of diagnostic CT scans obtained in the study population and the odds of neuroimaging with HIE—that HIE use resulted in the avoidance of 163 head CTs in a two-year period. If HIE had been used

Table 3. Estimated Costs of Emergency Department Patient-visits for Headache with and Without use of HIE

	Total cost (\$)	Unadjusted cost/visit (\$)	Adjusted cost/visit ^o (\$)	Cost savings/visit ^Δ (\$)	Total cost savings (\$)
ED visits without HIE (n=1,642)	440,631	268	249	0	0
ED visits with HIE (n=459)	125,405	273	254	-5	-7,344
ED visits with physician or nurse practitioner HIE use (n=133)	45,220	340	280	-36*	-4,788
ED visits with administrative/nursing HIE use (n=326)	80,196	246	257	9	2,934
All ED visits (n=2,101)	566,036	269	n/a	n/a	n/a

^oAdjusted costs/visit are adjusted for age, gender, race, comorbidity, substance abuse, hospital system, and previous visits

^ΔCost savings for each ED personnel subtype is calculated by comparing the adjusted costs for each subtype to the adjusted costs associated with all other visits and since each comparison is independent the differences in costs for different rows may not directly sum to total adjusted costs

*Difference in cost savings per visit significant at $p \leq 0.05$

in all cases we estimate that as many as 748 CT scans could have been avoided.

This study documents that over two-thirds of repeat visitors to the ED for headache received a head CT. This is consistent with numerous studies documenting increasing rates of CT scan use. In 2006 an estimated 19 million CT scans were performed in the US.²⁹ Head CTs in the ED increased 51 % from 2000–2005 and 13 % of all ED encounters received a head CT.¹⁵ National guidelines suggest a high percentage of these CT scans are unnecessary. CT and MRI neuroimaging are very low yield and costly in chronic headache patients with no other neurological findings on exam.^{30,31} Our study demonstrates that many CT scans could be avoided by making patient records available through HIE.

Our study also found that more than 15 % of ED patient-visits for headache were made by repeat visitors some of whom had as many as 46 previous visits to multiple EDs for headache in a two-year period. Other studies show that although only 1 % of severe headache patients are frequent ED visitors, frequent visitors account for 51 % of all ED visits.¹⁶ Recurrent CTs place these frequent ED visitors at increased health risk from radiation exposure.³² For these frequent visitors less is more: fewer head CTs often means better care. Although we were unable to assess potential harms resulting from reduced CTs with HIE use, given our stringent inclusion criteria, it is unlikely that the repeat visitors for primary headache disorders included in the study would have experienced benefits from a CT through the detection of a unsuspected mass or hemorrhage.

Overall HIE use was not associated with a reduction in costs of emergency care for headache in this study. This finding is likely secondary to confounding by indication; providers chose to access the HIE for patients posing greater diagnostic challenges. Post-hoc analysis demonstrated that patients in whom physician/NPs chose to use HIE had higher Charlson index comorbidity scores. And a previous cross-sectional survey of providers using the MSeHA HIE confirms that providers access HIE data primarily for problematic clinical cases.²⁷ Even though fewer CT scans were obtained and guidelines were more frequently followed when physician/NPs used the HIE, analysis revealed that higher costs associated with overall

HIE use and HIE use by physician/NPs were driven by increased use of MRI when physician/NPs used HIE on an “as needed” basis. Alternatively, systematic HIE use by administrative/nursing staff was associated with larger cost savings. This suggests that the way HIE is used matters. Further controlled studies are needed to explicitly test whether certain ways of employing HIE are more effective in improving quality and decreasing costs.

The implications of the current study are significant. This study is among the first to demonstrate that HIE reduces potentially avoidable neuroimaging, improves adherence with guidelines, and thereby protects patients from harm. The one previous randomized trial of HIE did not assess use of diagnostic tests.⁴ Frisse’s case-control study of the MidSouth eHealth Alliance in Tennessee similarly demonstrated overall reductions in diagnostic testing with HIE but lacks specificity and merits replication in homogeneous disease-specific populations.⁵ One-third of diagnostic CT studies in adults are of the head exposing the adult brain to approximately 20 mSV of radiation.¹⁷ As much as 2 % of all cancers in the United States may result from the use of CT scans.¹⁷ This study demonstrates that HIE is associated with reduction of head CTs by 50 % in patients at high risk for repeated scans. Such major potential benefit provides strong support for HIE adoption.

Reduction in risk of adverse consequences of ionizing radiation by HIE does not come at the consequence of decreased quality of care. To the contrary, the current study demonstrates that HIE in combination with number of previous visits is associated with a 65 % increase in odds of guideline adherence. This study suggests that HIE is an important tool that supports physicians in delivering evidence-based care.

The current study is subject to the usual limitations inherent in epidemiological studies. The associations seen between HIE use and diagnostic testing, guideline adherence, and costs are not necessarily causal. We were unable to adjust for potential physician-level effects, and it is possible that physician characteristics associated with their propensity to use HIE could account for some of the effects seen. Only a randomized clinical trial of HIE use would fully eliminate this potential source of bias. However, increased propensity of providers to use HIE for more

complex patients would be expected to diminish the effect of any HIE use, making the demonstrated positive effects of HIE use more remarkable.

The evidence-based guideline algorithm employed may have overestimated non-adherence. We were unable to exclude certain important headache presentations such as "thunderclap", "worst", or "pattern change" that can justify imaging from the non-adherence group. However, this potential bias should not have applied differently to cases with and without HIE use. Our study may also underestimate cost savings associated with HIE. Only ED visit and imaging information was used to impute costs based on standard Medicare reimbursement rates and other costs were not considered. Additionally, since Medicare reimbursement rates are lower than those of other payers, the reported cost savings are very conservative. Average U.S. costs are \$1,150 for CT and \$2,550 for MRI³³ compared with Medicare reimbursement rates of approximately \$300 for CT and \$500 for MRI. Although we estimate that HIE use by administrative/nursing staff was associated with a modest cost savings, the true potential cost savings may be significantly higher.

Many professional groups advocate HIE based on perceived potential benefits.^{2,3} However, this study is among the first to demonstrate significant benefits associated with investment in HIE. This study suggests that ongoing federal support for HIE is warranted, but that funding should be tied to ongoing demonstration of meaningful HIE use.³⁴ Further studies are needed to assess alternative methods for improving HIE use and to determine the effect of HIE on potentially avoidable testing and admissions, guideline adherence, and costs in other disease-specific patient populations. Reducing potentially avoidable diagnostic imaging through HIE represents an opportunity to improve quality and patient safety. HIE is proving an important resource to assist practitioners by providing critical patient information at the right time and place to enhance patient care and reduce unnecessary healthcare spending.

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Conflict of Interest: The authors declare that they do not have a conflict of interest.

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REFERENCES

1. Overhage JM, Evans L, Marchibroda J. Communities' readiness for health information exchange: the national landscape in 2004. *J Am Med Inform Assoc: JAMIA*. 2005;12:107–12.
2. American College of Emergency Physicians. Health information technology. *Ann Emerg Med*. 2008;52:595.
3. Walker J, Pan E, Johnston D, Adler-Milstein J, Bates DW, Middleton B. The value of health care information exchange and interoperability. *Health Aff (Millwood)*. 2005;Suppl Web Exclusives:W5-10-W5-8.
4. Overhage JM, Dexter PR, Perkins SM, et al. A randomized, controlled trial of clinical information shared from another institution. *Ann Emerg Med*. 2002;39:14–23.
5. Frisse ME, Johnson KB, Nian H, et al. The financial impact of health information exchange on emergency department care. *J Am Med Inform Assoc: JAMIA*. 2011; doi:10.1136/amiajnl-2011-000394.
6. Johnson KB, Unertl KM, Chen G, et al. Health information exchange usage in emergency departments and clinics: the who, what, and why. *J Am Med Inform Assoc: JAMIA*. 2011;18:690–7.
7. Lucado J, Paez K, Elixhauser A. Headaches in U.S. hospitals and emergency departments, 2008. In: *Healthcare Cost and Utilization Project (HCUP) Statistical Brief*. May 2011 ed. Rockville, MD: Agency for Healthcare Research and Quality; 2011.
8. 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.
9. Rasmussen BK, Jensen R, Schroll M, Olesen J. Epidemiology of headache in a general population—a prevalence study. *J Clin Epidemiol*. 1991;44:1147–57.
10. Newman LC, Lipton RB. Emergency department evaluation of headache. *Neurol Clin*. 1998;16:285–303.
11. Detsky ME, McDonald DR, Baerlocher MO, Tomlinson GA, McCrory DC, Booth CM. Does this patient with headache have a migraine or need neuroimaging? *JAMA*. 2006;296:1274–83.
12. Ward TN, Levin M, Phillips JM. Evaluation and management of headache in the emergency department. *Med Clin N Am*. 2001;85:971–85.
13. Edlow JA, Panagos PD, Godwin SA, Thomas TL, Decker WW. Clinical policy: critical issues in the evaluation and management of adult patients presenting to the emergency department with acute headache. *Ann Emerg Med*. 2008;52:407–36.
14. Silberstein SD. Practice parameter: evidence-based guidelines for migraine headache (an evidence-based review): report of the Quality Standards Subcommittee of the American Academy of Neurology. *Neurology*. 2000;55:754–62.
15. Broder J, Warshawer DM. Increasing utilization of computed tomography in the adult emergency department, 2000–2005. *Emerg Radiol*. 2006;13:25–30.
16. Friedman BW, Serrano D, Reed M, Diamond M, Lipton RB. Use of the emergency department for severe headache. A population-based study. *Headache*. 2009;49:21–30.
17. Brenner DJ, Hall EJ. Computed tomography—an increasing source of radiation exposure. *N Engl J Med*. 2007;357:2277–84.
18. Frisse ME, King JK, Rice WB, et al. A regional health information exchange: architecture and implementation. *AMIA Annu Symp Proc*. 2008:212–6.
19. Blumenthal HJ, Weisz MA, Kelly KM, Mayer RL, Blonsky J. Treatment of primary headache in the emergency department. *Headache*. 2003;43:1026–31.
20. Guan H, Sundararajan V, Halfon P, et al. Coding algorithms for defining comorbidities in ICD-9-CM and ICD-10 administrative data. *Med Care*. 2005;43:1130–9.
21. Guan H. ICD-9-CM enhanced Charlson SAS code. In: Winnepeg, Canada: Manitoba Centre for Health Policy; 2006.

22. Dietemann JL, Botelho C, Nogueira T, et al. Imaging in acute toxic encephalopathy. *J Neuroradiol*. 2004;31:313–26.
23. Weinstein MC, Siegel JE, Gold MR, Kamlet MS, Russell LB. Recommendations of the Panel on Cost-effectiveness in Health and Medicine. *JAMA: J Am Med Assoc*. 1996;276:1253–8.
24. Liang KY, Zeger S. Longitudinal data analysis using generalized linear models. *Biometrika*. 1986;73:13–22.
25. Beebe M, Dalton G, Duffy C, et al. Current Procedural Terminology CPT 2003: AMA Press; 2003.
26. Vest JR, Jasperson S, Zhao H, Gamm LD, Ohsfeldt RL. Use of a health information exchange system in the emergency care of children. *BMC Med Inform Decis Mak*. 2011;11:78.
27. Gadd CS, Ho YX, Cala CM, et al. User perspectives on the usability of a regional health information exchange. *J Am Med Inform Assoc: JAMIA*. 2011;18:711–16.
28. Vest JR, Zhao H, Jasperson J, Gamm LD, Ohsfeldt RL. Factors motivating and affecting health information exchange usage. *J Am Med Inform Assoc: JAMIA*. 2011;18:143–9.
29. Mettler FA Jr, Bhargavan M, Faulkner K, et al. Radiologic and nuclear medicine studies in the United States and worldwide: frequency, radiation dose, and comparison with other radiation sources—1950–2007. *Radiology*. 2009;253:520–31.
30. Tsushima Y, Endo K. MR imaging in the evaluation of chronic or recurrent headache. *Radiology*. 2005;235:575–9.
31. Frishberg BM. The utility of neuroimaging in the evaluation of headache in patients with normal neurologic examinations. *Neurology*. 1994;44:1191–7.
32. Sodickson A, Baeyens PF, Andriole KP, et al. Recurrent CT, cumulative radiation exposure, and associated radiation-induced cancer risks from CT of adults. *Radiology*. 2009;251:175–84.
33. New Choice Health Medical Cost Comparison. New Choice Health, Inc. 2011. (Accessed April 11, 2012, at <http://www.newchoicehealth.com>).
34. Vest JR, Jasperson J. What should we measure? Conceptualizing usage in health information exchange. *J Am Med Inform Assoc: JAMIA*. 2010;17:302–7.

APPENDIX

Table 4. ICD-9-CM Codes used for Primary Headache Disorders*

Headache disorder	ICD-9 codes
Migraine	
Migraine with aura	346.0
Migraine without aura	346.1
Unspecified (no documentation of presence or absence of aura)	346.9
Headache, NOS	784.0

*ICD-9-CM diagnostic codes derived from Version 24 for the period October 1, 2006–September 30, 2007, from Version 25 for October 1, 2007–September 30, 2008, and Version 26 for October 1, 2008–September 30, 2009

Table 5. Diagnostic Codes Used to Identify Appropriate Patients for Neuroimaging According to Evidence Based Guidelines

Indicators of serious underlying pathology	ICD-9-CM diagnostic codes
Neurologic signs or symptoms	
General symptoms	Alteration of consciousness (780.0x); hallucinations (780.1); syncope and collapse (780.2) characterized as blackout, fainting, (near) (Pre)syncope, and vasovagal attack; convulsions (780.3x); dizziness and giddiness (780.4); memory loss (780.93); altered mental status (780.97)
Symptoms involving nervous and musculoskeletal system	Any codes for abnormal involuntary movements (781.0), disturbances of sensation of smell and taste (781.1), abnormality of gait (781.2), lack of coordination (781.3), transient paralysis of limb (781.4), meningismus (781.6), neurological neglect syndrome (781.8), ocular torticollis (781.93), and facial weakness (781.94)
Hemiplegia, hemiparesis, and paralysis	Hemiplegia and hemiparesis (342.x), other paralytic syndromes (344.x)
Other nonspecific abnormal findings	Any codes for abnormal reflex (796.1) or other abnormal clinical findings (796.4)
Disorders of optic nerve and visual pathways	Any codes for papilledema (377.0x), optic neuritis (377.3x), other disorders of optic nerve (377.4x), disorders of optic chiasm (377.5x), disorders of visual cortex (377.7x), unspecified disorder of optic nerve and visual pathways (377.9)
Epilepsy and recurrent seizures	Any codes for generalized nonconvulsive epilepsy (345.0x), generalized convulsive epilepsy (345.1x), petit mal status (345.2), grand mal status (345.3), localized-related (focal) (partial) epilepsy and epileptic syndrome (345.4x), localized-related (focal) (partial) epilepsy and epileptic syndromes with simple partial seizure (345.5x), infantile spasms (345.6x), epilepsia partialis continua (345.7x), other forms of epilepsy and recurrent seizures (345.8x), epilepsy, unspecified (345.9x)
Additional risk factors	
Systemic symptoms or illness	Any ICD-9 codes for fever (780.6), meningismus (781.6), neurosyphilis (094.xx),
Immune deficiency	Any ICD-9 codes for HIV (042, 795.71, V08), other immunodeficiency syndromes (279.xx, 284.xx, 288.0x–288.2x, 288.5x, 289.83), transplant (996.8x, V42.x)
Cancer	Malignant neoplasms (140.x–172.x, 174.x–198.x, 200.x–208.x), neuroendocrine tumors (209.x), personal history of malignant neoplasms (V10.x)