Health Information Exchange and the Frequency of Repeat Medical Imaging

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ABSTRACT

Objectives

Medical imaging, which is expensive, is frequently repeated for the same patient within a relatively short period of time due to lack of access to previous images. Health information exchange (HIE) may reduce repeat imaging by facilitating provider access to prior images and reports. We sought to determine the effect of an HIE system on the occurrence of repeat imaging.

Study Design and Methods

We conducted a cohort study of adult patients who consented to participate in a community-based HIE system in an 11-county region in New York. Using data from 2009 to 2010, we linked log files of provider HIE usage to administrative claims data from 2 commercial health plans. Using generalized estimation equations, we measured the association between HIE system access and repeat imaging within 90 days.

Results

Of 196,314 patients in the cohort, 34,604 (18%) of patients had at least 1 imaging procedure, which was equivalent to a rate of 28.7 imaging procedures per 100 patients. Overall, 7.7% of images were repeated within 90 days. If the HIE system was accessed within the 90 days following an initial imaging procedure, imaging was significantly less likely to be repeated (5% repeated with HIE access vs 8% repeated without HIE access, $P < .001$). HIE system access reduced the adjusted odds of a repeat image by 25% (95% CI, 13%-35%).

Conclusions

Use of the HIE system to access previous patient information was associated with a reduction in repeated imaging.

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Medical imaging is common and costly,[1,2] and is also often repeated over time for a given patient. Repeat imaging may be appropriate if it is being used to determine a change in a patient's clinical condition. However, some repeat imaging is ordered because providers do not have easy access to previous medical images.[3-5] In those cases, repeat images may be ordered even if access to existing images would have provided sufficient clinical information.[6,7]

Previous studies estimate that between 9% and 40% of all medical images are repeated, regardless of the reason for the repeat imaging.[8-12] These estimates have some limitations because they were derived from the experiences of single institutions, consider only 1 type of imaging, or are based on consensus reports. The frequency and timing of repeat imaging in typical community-based settings, where the majority of healthcare is delivered, are not clear. These are important statistics, however, because knowing the frequency and timing of repeat imaging could inform the design of interventions to reduce repeat imaging and inform expectations of their effects.

One important intervention that could reduce the frequency of repeat medical imaging is electronic health information exchange (HIE). HIE allows providers electronic access to their patients' clinical information, including images and radiologists' reports interpreting those images, even if it was collected by providers in other healthcare organizations.[13] HIE has been implemented in several communities across the United States, but the effectiveness of HIE for reducing the frequency of repeat medical images is not clear. The results of previous studies have been mixed: some studies found that technology that enabled access to prior patient information was associated with fewer repeat images while other studies found no effect.[14-19] Previous studies have also not compared the relative effects of HIE across different imaging modalities (eg, computed tomography [CT] and ultrasound).

Our objectives were: 1) to measure the frequency and timing of repeat imaging in a community-based setting, and 2) to determine the association between provider usage of an HIE system and repeat imaging, including by type of medical imaging. Our study may be highly generalizable because it took place in a multi-payer, multi-provider community that used a commercially available HIE system.

Take-Away Points

Health information exchange (HIE) systems allow providers electronic access to patient information from other sources. Current federal policies support the adoption of these types of systems in order to change healthcare utilization patterns. Repeated imaging is a type of utilization that is potentially common and costly.

- In an 11-county community, 7.7% of medical imaging procedures were repeated within 90 days.
- The community has a regional health information organization that facilitates access to prior patient information at the point of care.
- Use of the HIE system was associated with a 25% lower odds of repeat imaging.

METHODS

We conducted a longitudinal cohort study of patients and their medical imaging procedures in 2009-2010 in the Rochester, New York, region. This study was part of a broader evaluation of New York's Health Care Efficiency and Affordability Law for New Yorkers (HEAL NY) Capital Grants program by the multi-institutional Health Information Technology Collaborative.[20] The Institutional Review Boards of Weill Cornell Medical College and the University of Rochester approved the study protocol.

Setting

This study evaluates an HIE system implemented by the Rochester Regional Health Information Organization (RHIO).[21] Supported in part with funding from the New York State Department of Health under the HEAL NY Capital Grants program, the Rochester RHIO is a nonprofit organization that facilitates information exchange among more than 70 healthcare organizations in western New York.[22] The Rochester RHIO has implemented an HIE system to enable authorized user access at the point of care to patient information collected from multiple providers and locations.

Users access the HIE system via a Web-based portal and can view data on patients' demographic information, diagnoses, medication history, radiology reports, laboratory results, and discharge summaries from participating providers.[23,24] The HIE receives data from a variety of sources, including insurance providers, hospital systems, ambulatory practices, radiology groups, reference laboratories, and others. The system, which operates with an opt-in model for patient consent, became fully operational in March 2009 and now includes more than 800,000 patients. At the time of the study, the system had 1318 users in 156 different outpatient, emergency, inpatient, and long-term care settings. More than two-thirds of the region's hospitals and physicians participate.[25]

Data

First, we used healthcare claims from 2 commercial health plans, which insure approximately 60% of the Rochester area population. We included patients 18 years and older who were continuously enrolled in one of these plans from 2009 to 2010. Additionally, patients had to have provided consent during the same period to the Rochester RHIO to have their data in the HIE system viewed by providers. Providers may only access data after patients provide consent, except in emergency situations. The claims data were then submitted by the plans to a third-party data aggregator. Then the data aggregator used a roster of consented patients, provided by the Rochester RHIO, to select patients' claims. We required that patients have at least 1 encounter (eg, an office visit, hospitalization, or emergency department [ED] visit) with a provider participating in the HIE in the 6 months following the patient's date of consent. The data aggregation company categorized Current Procedural Terminology (CPT) codes by modality (such as ultrasound) and body region (see **eAppendix**).

The second data source was the Rochester RHIO itself, which provided us with the system log files from the HIE system for the same time period as the claims file data set. The HIE system automatically records user activities, such as the patient record viewed and date of access. We matched these log files to the claims based on a common patient identifier, the dates of usage, and the dates of the imaging procedures.

Measures

We defined a single imaging procedure as the unique combination of modality and body region on a calendar day for a given patient. Because one imaging procedure may be documented by multiple claims, we created a single indicator for a procedure regardless of the number of CPT codes used in billing. For example, if a female patient had 3 different CPT codes associated with mammography on a single calendar day, we classified these discrete CPT codes as belonging to a single imaging procedure. In contrast, if a patient had multiple imaging procedures for different body regions on the same day (eg, a CT of the pelvis and a CT of the abdomen), these were classified as 2 different procedures. Only those procedures during the first 3 months (out of the rolling 6-month time period for each patient) were eligible to be index procedures; this strategy ensured that every imaging procedure could be followed for 90 days. The selection of imaging procedures for inclusion in the study is illustrated in the Appendix.

Our outcome of interest was a repeat imaging procedure. We applied a 90-day follow-up period to every index imaging procedure, and looked for the first occurrence of an additional imaging procedure using the same modality for the same body region. We selected 90 days as the primary time period for repeat imaging based on previous studies from the literature.[11,26]

The primary independent variable for our analysis was any usage of the HIE system for a patient who received imaging. We defined usage as any access of the HIE system after the initial imaging procedure (starting on the next calendar day) and before either the repeated procedure date (if any) or the 90-day mark, whichever came first.

From the claims files, we also collected patient characteristics and healthcare utilization. Patient characteristics included age, gender, and insurance status (grouped into private payer, Medicare managed care, or Medicaid managed care/state-subsidized private insurance product). We measured patient disease severity as the count of major Aggregated Diagnostic Groups (ADGs) in the 12-month period prior to consent, using the Johns Hopkins Adjusted Clinical Groups Case-Mix System.[27,28] ADGs are non–mutually exclusive groupings of diagnoses, so we did not include diagnoses elsewhere in our models. Additionally, we calculated the number of primary care visits, specialty care visits, ED/urgent care visits, and admissions that occurred in the 90 days after the initial procedure or up until the imaging procedure was repeated.

Analysis

We structured the data set as a procedure-level data set, allowing each patient to contribute multiple imaging procedures. We calculated both the frequency of imaging and repeat imaging overall and by modality. We also calculated when (in days) during the follow-up period any repeat imaging occurred.

We measured the frequency with which providers accessed HIE data overall. We then determined whether the characteristics of patients whose data were accessed via the HIE were different from the characteristics of patients whose data were not accessed, using *t* tests for continuous variables and χ^2 tests for dichotomous variables.

We modeled the binary outcome of repeat imaging using a binary logit model with generalized estimating equations. We chose this method because it accounts for the clustering that occurs with repeated measures. With the exception of the patient, we treated all other measures as fixed effects. We exponentiated parameter coefficients to express odds ratios (ORs). We adjusted for the following clinically relevant patient-level variables: payer type, age, gender, number of primary care visits, number of specialty care visits, number of ED/urgent care visits, number of admissions, and the count of major ADGs. We conducted stratified analyses for the 3 modalities with sufficient sample sizes: CT, ultrasound, and radiographs.

RESULTS

Frequency of Medical Imaging and Repeat Imaging

The entire cohort consisted of 196,314 patients. The first 3 months of claims for the patient cohort included 68,296 claims for imaging procedures. After de-duplication (removing multiple claims associated with the same imaging procedure and those that had no body region identified), we were left with 56,306 imaging procedures. Overall, 17.6% (n = 34,604) of patients had at least 1 imaging procedure, equivalent to a rate of 28.7 imaging procedures per 100 patients. As displayed in **Table 1**, the most common imaging modalities were radiographs (43.7% of all imaging procedures), CT (16.4%), ultrasound (16.4%), mammography (10%), and magnetic resonance imaging (MRI) (6.8%). Although we considered 23 different modalities, these 5 accounted for more than 90% of all imaging procedures.

Overall, 7.7% of medical imaging procedures (n = 4316) were repeated within 90 days. As indicated in Table 1, that percentage varied widely by modality. The rate of repeat imaging was highest for ultrasounds: 15.5%. Similarly, 8.6% of radiographs, 4.7% of mammograms, 3.8% of CTs, and 2.5% of MRIs were repeated. Other procedures with high rates of repeats included echocardiography (12.5%) and urography (7%), although the absolute numbers of these tests were lower. For 2 other modalities, less than 1% each were repeated; another 8 modalities had no repeat imaging.

The timing of the repeat imaging occurred at various points over the course of the 90-day follow-up period (**Figure**). Overall, half of the repeated procedures occurred within the first 30 days after the initial medical image. By 60 days, a total of 80% of the repeated procedures had occurred.

Table 1. Frequency of Medical Imaging Procedures Among Adults by Modality, Overall and for Imaging Repeated Within 90 Days

	Overall		Repeated Within 90 Days	
Modality	**n**	**% of total**	**n**	**%**
Radiographs	24,590	43.67	2127	8.65
Computed tomography	9226	16.39	353	3.83
Ultrasound	9223	16.38	1434	15.55
Mammography	5629	10.00	264	4.69
Magnetic resonance imaging	3833	6.81	96	2.50
Nuclear imaging	1306	2.32	23	1.76
Single-photon emission computed tomography	767	1.36	1	0.13
Not classified	402	0.72	0	0.00
Computed tomographic angiography	373	0.66	0	0.00
Magnetic resonance angiography	172	0.31	2	1.16
Videography	141	0.25	0	0.00
Cystography	106	0.19	1	0.94
Angiography	101	0.18	2	1.98
Myelography	99	0.18	0	0.00
Catheterization	86	0.15	4	4.65
Cholangiography	80	0.14	0	0.00
Urography	71	0.13	5	7.04
Aortography	42	0.07	1	2.38
Venography	26	0.05	0	0.00
Echocardiography	24	0.04	3	12.50
Diskography	9	0.02	0	0.00
Total	56,306	100	4316	7.67

The majority of the imaging procedures (73%) were among women and among the privately insured (59%, Table 2). The average patient age was 57.2 years, and the average number of total healthcare encounters in the 90 days after the initial imaging procedure was 2.7.

Use of the HIE System

Overall, providers accessed the HIE system within 90 days after 11.8% of imaging procedures. As displayed in Table 2, when providers accessed the HIE system, those procedures were more likely to be for patients in Medicare managed care, for older patients, and for sicker patients, with higher counts of major ADGs. In addition, accessing the HIE system was more likely to occur with higher numbers of healthcare encounters.

Association Between HIE Usage and Repeat Medical Imaging

We found that if the HIE system was accessed within the 90 days following an initial imaging procedure, the imaging was less likely to be repeated (5.2% of imaging procedures were repeated when the HIE system was accessed versus 8% repeated when the HIE system was not accessed). The unadjusted odds of repeat imaging were 44% lower if the HIE system was accessed after the initial procedure (OR = 0.56; 95% CI, 0.49-0.65; Table 3).

After controlling for patient characteristics and utilization, provider access of the HIE system after the initial imaging was independently associated with 25% lower odds of repeat imaging (OR = 0.75; 95% CI, 0.65-0.87). Given the rate of repeated imaging observed in this population (7.7%), out of every 36 images, HIE access would prevent 1 repeated image that would have occurred otherwise.

These results persisted when we considered ultrasounds alone and radiographs alone (Table 4). Provider access of the HIE system reduced the adjusted odds of both a repeat ultrasound by 44% and a repeat radiograph by 21%. HIE usage was not associated with the odds of a repeat CT, although the sample size of repeat CTs was much smaller than that of the other 2 tests, limiting power for that comparison.

Figure. Cumulative Proportion of Repeated Procedures by Days Since Initial Procedures

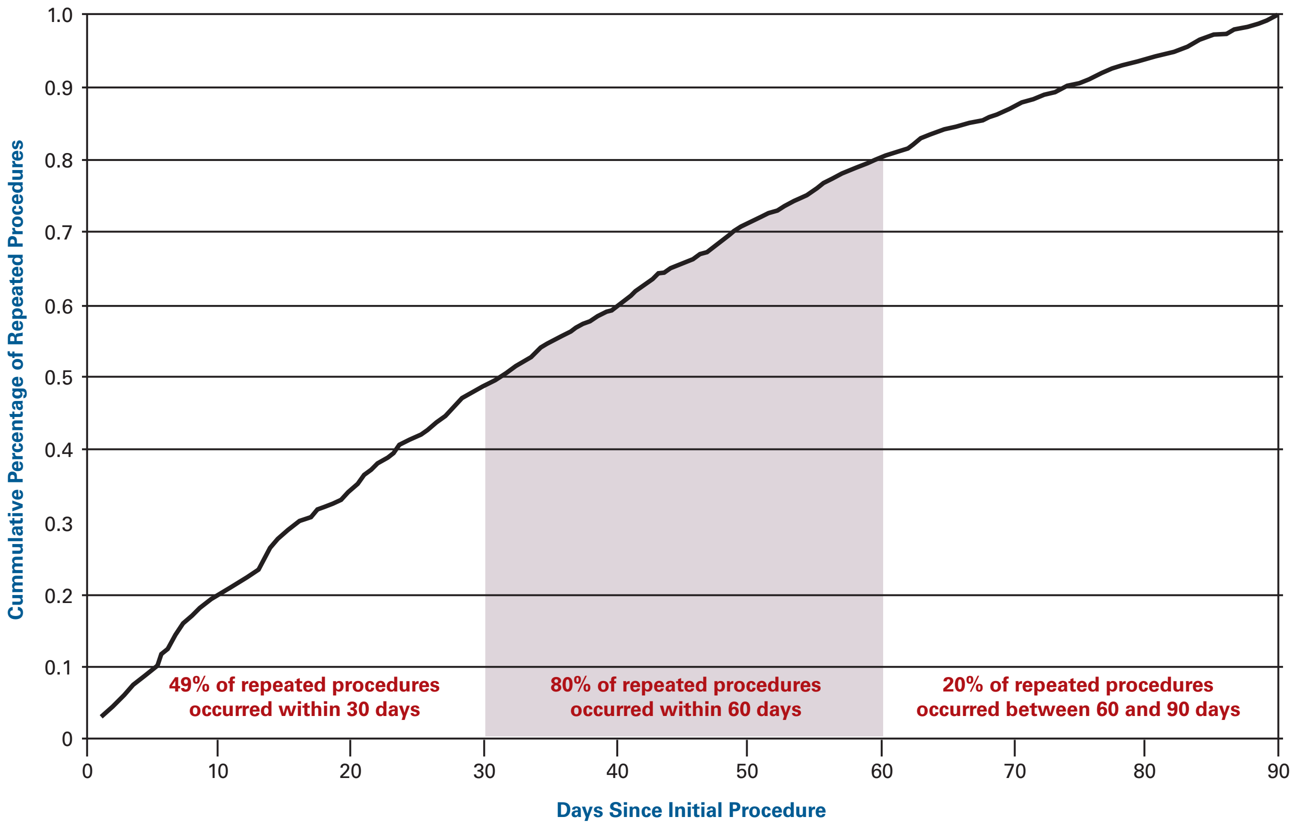

Table 2. Characteristics of Medical Imaging Procedures, Overall and Stratified by Whether the Patient's Clinical Data Were Accessed After the Procedure via the HIE

		HIE Access		
	Total, n (%)	Yes, n (%)	No, n (%)	*P*
Male	15,190 (27.0)	1859 (28.1)	13,331 (26.81)	.031
Insurance				
Commercial	33,467 (59.4)	3814 (57.6)	29,653 (59.7)	<.001
Medicaid[a]	6548 (11.6)	651 (9.8)	5897 (11.9)	
Medicare	16,290 (28.9)	2154 (32.5)	14,136 (28.45)	
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	
Age, y	57.2 (17.7)	58.8 (16.9)	57.0 (17.8)	<.001
Encounters[b]				
Total	2.66 (3.1)	4.01 (3.1)	2.48 (3.0)	<.001
Inpatient	0.14 (0.5)	0.22 (0.6)	0.13 (0.4)	<.001
ED	0.21 (0.8)	0.34 (1.3)	0.19 (0.7)	<.001
Primary care	1.07 (1.7)	1.39 (2.0)	1.03 (1.6)	<.001
Specialist care	1.23 (1.9)	2.06 (2.5)	1.13 (1.8)	<.001
Major ADG count	1.15 (1.3)	1.30 (1.4)	1.14 (1.3)	<.001

ADG indicates Aggregated Diagnostic Group; ED, emergency department; HIE, health information exchange.
[a]Includes state-subsidized insurance plan.
[b]Patient encounters occurring in the interval after the initial test.

Table 3. Factors Associated With Medical Imaging Procedures Repeated Within 90 Days Among Adults

Variable	Unadjusted Odds Ratio (95% CI)	Adjusted Odds Ratio[a] (95% CI)
Health information exchange system access	0.56 (0.49-0.65)[b]	0.75 (0.65-0.87)[b]
Male vs female	0.76 (0.7-0.82)[b]	0.95 (0.88-1.04)
Age	0.98 (0.98-0.98)[b]	0.98 (0.98-0.98)[b]
Medicare vs commercial	1.46 (1.33-1.61)[b]	1.13 (1.02-1.26)[c]
Medicaid vs commercial	0.83 (0.77-0.9)[b]	1.50 (1.35-1.68)[b]
Number of primary care visits	0.62 (0.58-0.65)[b]	0.66 (0.62, 0.70)[b]
Number of specialist visits	0.73 (0.7-0.76)[b]	0.84 (0.81-0.87)[b]
Number of ED visits	1.03 (0.99-1.08)	1.11 (1.06-1.17)[b]
Number of inpatient admissions	0.9 (0.82-1.00)[d]	1.08 (0.98-1.19)
Major count of diagnostic groups, as measured by the ADG index	0.99 (0.97-1.02)	1.23 (1.19-1.26)[b]

ADG indicates Aggregated Diagnostic Group; ED, emergency department.
[a]Controlling for all listed factors and test modality.
[b]*P* <.001.
[c]*P* <.01.
[d]*P* <.05.

DISCUSSION

In our community-based study, we found a rate of 28.7 imaging procedures completed for every 100 patients over a 6-month period. We also found that 7.7% of all imaging procedures were repeated within 90 days. When repeat imaging was done, it tended to occur quickly, with nearly 50% of all repeated imaging completed within 30 days and 80% completed by 60 days.

We found that if the community-based HIE system was accessed by providers within the 90 days following an initial imaging procedure, the imaging was significantly less likely to be repeated, with 5.2% of imaging procedures repeated when the HIE system was accessed, compared with 8% repeated when the HIE system was not accessed. Adjusting for potential confounders, the odds that an imaging procedure was repeated decreased by 25% with HIE access.

This study provides one of the few estimates of the frequency of repeat imaging for multiple modalities in a multi-payer, multi-provider community. Our finding of a 7.7% rate of repeat imaging is slightly lower than rates found by other investigators, such as 9%, 13%, and 20%.[8,9,29] Unlike previous studies, our study included multiple settings of care and a broad, community-based patient population. Previous work supports this distinction, as imaging is overall less frequent in the ambulatory setting than in the inpatient or ED settings.[30-32] Additionally, several previous estimates were derived from patient populations in which multiple and frequent imaging is to be expected (eg, trauma or neurological). Our sample is likely more representative of the overall adult population.

There are few interventions that have been tried for reducing the frequency of medical imaging. Payers have tried prior authorization for certain imaging procedures, but it is not always clear that the cost of the prior authorization program is outweighed by savings from fewer images.[33] Other interventions that have been tried are conceptually close to information exchange, such as electronic decision support for ordering physicians (which often includes access to prior results) and picture archiving and communication systems (PACS) for electronic sharing of actual images.[34,35] Electronic decision support for ordering imaging is still an emerging tool, and PACS systems have typically been installed within a single institution. Other approaches to image sharing, like digital media transfers, may also be effective, but those approaches can be cumbersome and tend not to include breadth of clinical data about the patient, as is found in the Rochester RHIO system.[4,7,36-38]

The existing literature on the effects of HIE on patient healthcare utilization, in general, is sparse,[39] and the few studies that examine the effects on imaging do not present a consistent picture. A series of studies among ED patients at one RHIO reported similar reductions in imaging utilization for select patients, modalities, and locations when an HIE system was utilized at the point of care.[14,16,17] Other reports of information-sharing technology also suggest that reductions in repeated and overall imaging usage are possible.[40,41] Conversely, other examinations have found

Table 4. Health Information Exchange Usage and Other Factors Associated With Repeated CT, Ultrasound, and X-rays Within 90 Days Among Adult Patients

	Ultrasound		Radiograph		CT	
Variable	**OR (95% CI)**	**aOR (95% CI)**	**OR (95% CI)**	**aOR (95% CI)**	**OR (95% CI)**	**aOR (95% CI)**
Health information exchange system access	0.37 (0.28-0.48)[a]	0.56 (0.41-0.76)[a]	0.78 (0.67-0.91)[a]	0.79 (0.67-0.94)[a]	1.01 (0.7-1.46)	0.89 (0.47-1.69)
Male vs female	0.13 (0.09-0.18)[a]	0.30 (0.2-0.45)[a]	1.31 (1.19-1.44) [a]	1.19 (1.08, 1.31)[a]	1.19 (0.92-1.55)	1.12 (0.85-1.47)
Age	0.93 (0.92-0.93)[a]	0.93 (0.92-0.93)[a]	1.01 (1.01-1.01)[a]	1.01 (1.0-1.01)[a]	1.00 (0.99-1.00)	1.00 (0.99-1.01)
Medicare vs commercial	1.43 (1.23-1.66)[a]	0.78 (0.65-0.93)[b]	1.32 (1.13-1.53)[a]	1.25 (1.06-1.47)[b]	0.98 (0.65-1.48)	0.79 (0.48-1.29)
Medicaid vs commercial	0.10 (0.07-0.15)[a]	1.88 (1.21-2.93)[b]	1.44 (1.3-1.58)[a]	1.04 (0.92-1.17)	0.86 (0.65-1.15)	0.85 (0.57-1.26)
Number primary care visits	0.31 (0.26-0.37)[a]	0.49 (0.42-0.57)[a]	0.8 (0.76-0.85)[a]	0.75 (0.71-0.79)[a]	0.65 (0.52-0.82)[b]	0.66 (0.54-0.81)[a]
Number specialist visits	0.41 (0.35-0.47)[a]	0.70 (0.61-0.8)[a]	0.92 (0.89-0.95)[a]	0.91 (0.88-0.94)[a]	0.84 (0.72-0.98)[c]	0.89 (0.79-1.00)[c]
ED visit[d]		0.81 (0.62-1.06)	2.69 (2.42-3.00)[a]	2.82 (2.46-3.24)[a]	2.32 (1.53-3.52)[a]	3.42 (2.21-5.29)[a]
Inpatient admissions[d]		0.17 (0.11-0.26)[a]	1.47 (1.36-1.59)[a]	1.06 (0.95-1.18)	1.08 (0.75-1.55)	0.82 (0.58-1.14)
Major ADG count	0.67 (0.62, 0.72)[a]	1.18 (1.09-1.29)[a]	1.23 (1.19-1.26)[a]	1.18 (1.14-1.22)[a]	1.05 (0.97-1.15)	1.08 (0.97-1.21)

ADG indicates Aggregated Diagnostic Group; aOR, adjusted odds ratio; CT, computed tomography; ED, emergency department; OR, odds ratio.
[a] $P < .001$.
[b] $P < .01$.
[c] $P < .05$.
[d] Due to sample size restrictions, variables could not be modeled in equations limited to ultrasounds and therefore were omitted. In the radiograph and CT models, the occurrence of any ED visit or admission (binary) is modeled, instead of the count of encounters.

that adoption of exchange-capable health information technology is not associated with reductions in the rates of imaging ordering.[18,19] However, those studies differ from this investigation, as they did not measure actual usage of the system.

Our study has several limitations. First, from our secondary sources, we could not determine the appropriateness of the imaging procedures. Our study measured all repeat imaging observed; we were not able to distinguish between procedures that were clinically appropriate and those that were potentially unnecessary. Some of the repeated procedures are clearly clinically appropriate and expected. For example, clinicians may need to determine changes in status or decide if new interventions are warranted. Further research could move toward separating the potentially unnecessary from the potentially appropriate imaging. Second, we were not able to adjust for all potential confounders at the provider level due to the fact that claims data do not consistently include the ordering provider. However, we tried to overcome this limitation through our procedure-level analysis, and it is likely that the same providers accessed the HIE for some of their patients and not for others; this would minimize the impact of any provider variables. Third, we know that providers accessed the HIE, but we cannot tell which particular data element may have affected their medical decision making. Understanding which pieces of information influenced changes to decision making would require alternative study designs.

Our study has several strengths, including objective measure of technology usage. We do not rely on self-reported usage, which is a different and independent construct that does not always accurately reflect actual system usage.[42,43] We are also not using aggregated organizational-level measures of adoption, which can obscure individual usage of systems.[44] Our study represents care for nearly 200,000 patients in a multi-county area with multiple payers. We capture healthcare utilization in multiple settings, including outpatient, inpatient, ED, and long-term care settings. Our study also reflects the effectiveness of a commercially available HIE product as used in a real-world setting.

CONCLUSIONS

When a patient comes to a radiology facility for an imaging procedure, previous similar studies often exist but are inaccessible at the point of care. The federal government and many states are investing heavily in health information technology that can address this issue. Strong incentives exist for providers to adopt and meaningfully use electronic health records that have the capacity to exchange data. Also, the federal government has supported state-level programs to implement HIE (which can be community-wide portals like the one studied here). This study demonstrates that a community-wide portal is effective for reducing the frequency of repeat imaging. Thus suggesting a technology-driven improvement in care that represents both higher quality and potentially lower costs.

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REFERENCES

1. 2013 Comparative Price Report: Variation in Medical and Hospital Prices by Country. International Federation of Health Plans website. http://www.ifhp.com/s/2013-iFHP-FINAL-4-14-14.pdf. Published 2014. Accessed December 17, 2014.

2. Smith-Bindman R, Miglioretti DL, Larson EB. Rising use of diagnostic medical imaging in a large integrated health system. *Health Aff (Millwood).* 2008;27(6):1491-1502.

3. Sung JC, Sodickson A, Ledbetter S. Outside CT imaging among emergency department transfer patients. *J Am Coll Radiol.* 2009;6(9): 626-632.

4. Sandberg JC, Ge Y, Nguyen HT, et al. Insight into the sharing of medical images: physician, other health care providers, and staff experience in a variety of medical settings. *Appl Clin Inform.* 2012;3(4): 475-487.

5. Swensen SJ. Patient-centered imaging. *Am J Med.* 2012;125(2): 115-117.

6. Laine C. High-value testing begins with a few simple questions. *Ann Intern Med.* 2012;156(2):162-163.

7. Lu MT, Tellis WM, Fidelman N, Qayyum A, Avrin DE. Reducing the rate of repeat imaging: import of outside images to PACS. *AJR Amer J Roentgenol.* 2012;198(3):628-634.

8. 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 Excl:W5-10-W5-18.

9. Jha AK, Chan DC, Ridgway AB, Franz C, Bates DW. Improving safety and eliminating redundant tests: cutting costs in U.S. hospitals. *Health Aff (Millwood).* 2009;28(5):1475-1484.

10. Bates DW, Boyle DL, Rittenberg E, et al. What proportion of common diagnostic tests appear redundant? *Am J Med.* 1998;104(4):361-368.

11. Ip IK, Mortele KJ, Prevedello LM, Khorasani R. Repeat abdominal imaging examinations in a tertiary care hospital. *Am J Med.* 2012;125(2):155-161.

12. Haley T, Ghaemmaghami V, Loftus T, Gerkin RD, Sterrett R, Ferrara JJ. Trauma: the impact of repeat imaging. *Am J Surg.* 2009;198(6):858-862.

13. HIMSS Health Information Exchange Best Practices Task Force. *Health Information Exchanges: Similarities and Differences - HIMSS HIE Common Practices Survey Results White Paper.* Chicago, IL: Healthcare Information & Management Systems Society; 2009.

14. Bailey JE, Wan JY, Mabry LM, et al. Does health information exchange reduce unnecessary neuroimaging and improve quality of headache care in the emergency department? *J Gen Intern Med.* 2013;28(2):176-183.

15. Flanagan PT, Relyea-Chew A, Gross JA, Gunn ML. Using the Internet for image transfer in a regional trauma network: effect on CT repeat rate, cost, and radiation exposure. *J Am Coll Radiol.* 2012;9(9):648-656.

16. Bailey JE, Pope RA, Elliott EC, Wan JY, Waters TM, Frisse ME. Health information exchange reduces repeated diagnostic imaging for back pain. *Ann Emerg Med.* 2013;62(1):16-24.

17. Frisse ME, Johnson KB, Nian H, et al. The financial impact of health information exchange on emergency department care. *J Am Med Inform Assoc.* 2012;19(3):328-333.

18. McCormick D, Bor DH, Woolhandler S, Himmelstein DU. Giving office-based physicians electronic access to patients' prior imaging and lab results did not deter ordering of tests. *Health Aff (Millwood).* 2012;31(3):488-496.

19. Ross SE, Radcliff TA, LeBlanc WG, Dickinson LM, Libby AM, Nease DE Jr. Effects of health information exchange adoption on ambulatory testing rates. *J Am Med Inform Assoc.* 2013;20(6):1137-1142.

20. Kern LM, Kaushal R. Health information technology and health information exchange in New York state: new initiatives in implementation and evaluation. *J Biomed Inform.* 2007;40(6 suppl):S17-S20.

21. The Rochester RHIO. Greater Rochester Regional Health Information Organization website. http://www.grhio.org. Published 2014. Accessed December 17, 2014.

22. About Rochester RHIO. Greater Rochester Regional Health Information Organization website. http://www.grrhio.org/about/default.aspx. Published 2009. Accessed January 10, 2013.

23. The Virtual Health Record links you to clinical reports, medication histories, radiology images and more from across the region. Greater Rochester Regional Health Information Organization website. http://www.grrhio.org/providers/~/media/VHR%20Sell%20Sheet.ashx. Published 2012. Accessed January 10, 2013.

24. Vest JR, Grinspan ZM, Kern LM, Campion TR Jr, Kaushal R; HITEC Investigators. Using a health information exchange system for imaging information: patterns and predictors. *AMIA Annu Symp Proc.* 2013;2013:1402-1411.

25. New York eHealth Collaborative. NYeC & Service QEs Progress. Presentation at the New York eHealth Collaborative Board Meeting. New York State Department of Health; 2012.

26. Chen RC, Chu D, Lin HC, Chen T, Hung ST, Kuo NW. Association of hospital characteristics and diagnosis with the repeat use of CT and MRI: a nationwide population-based study in an Asian country. *AJR Am J Roentgenol.* 2012;198(4):858-865.

27. The Health Services Research & Development Center at The Johns Hopkins University, Bloomberg School of Public Health. *The Johns Hopkins ACG System: Technical Reference Guide Version 10.0.* Baltimore, MD: The Johns Hopkins University; 2011.

28. Baldwin LM, Klabunde CN, Green P, Barlow W, Wright G. In search of the perfect comorbidity measure for use with administrative claims data: does it exist? *Med Care.* 2006;44(8):745-753.

29. Frisse ME, Holmes RL. Estimated financial savings associated with health information exchange and ambulatory care referral. *J Biomed Inform.* 2007;40(6 suppl):S27-S32.

30. National Hospital Ambulatory Medical Care Survey: 2009 Emergency Department Summary Tables. National Center for Health Statistics, CDC website. http://www.cdc.gov/nchs/data/ahcd/nhamcs_emergency/2009_ed_web_tables.pdf. Published 2012. Accessed January 10, 2013.

31. National Hospital Ambulatory Medical Care Survey: 2009 Outpatient Department Summary Tables. National Center for Health Statistics, CDC website. http://www.cdc.gov/nchs/data/ahcd/nhamcs_outpatient/2009_opd_web_tables.pdf. Published 2012. Accessed January 10, 2013.

32. Moser JW, Applegate KE. Use of inpatient imaging services by persons without health insurance. *J Am Coll Radiol.* 2012;9(1):42-49.

33. Hendee WR, Becker GJ, Borgstede JP, et al. Addressing overutilization in medical imaging. *Radiology.* 2010;257(1):240-245.

34. You JJ, Yun L, Tu JV. Impact of picture archiving communication systems on rates of duplicate imaging: a before-after study. *BMC Health Serv Res.* 2008;8:234.

35. Blackmore CC, Mecklenburg RS, Kaplan GS. Effectiveness of clinical decision support in controlling inappropriate imaging. *J Am Coll Radiol.* 2011;8(1):19-25.

36. Yeager D. Swamped with CDs. *Radiology Today.* 2011;12(2):12-14.

37. Robinson JD, McNeeley MF. Transfer patient imaging: a survey of members of the American Society of Emergency Radiology. *Emerg Radiol.* 2012;19(5):447-454.

38. Sodickson A, Opraseuth J, Ledbetter S. Outside imaging in emergency department transfer patients: CD import reduces rates of subsequent imaging utilization. *Radiology.* 2011;260(2):408-413.

39. Hincapie A, Warholak T. The impact of health information exchange on health outcomes. *Appl Clin Inform.* 2011;2(4):499-507.

40. Bredfeldt C. PS1-51: effect of integrated health information exchange on the duplication of radiological services. *Clin Med Res.* 2012;10(3):165.

41. Mäenpää T, Asikainen P, Gissler M, et al. Outcomes assessment of the regional health information exchange: a five-year follow-up study. *Methods Inf Med.* 2011;50(4):308-318.

42. Szajna B. Empirical evaluation of the revised technology acceptance model. *Management Science.* 1996;42(1):85-92.

43. Barnett T, Kellermanns FW, Pearson AW, Pearson RA. Measuring information system usage: replication and extensions. *Journal of Computer Information Systems.* 2006;47(2):76-85.

44. Devaraj S, Kohli R. Performance impacts of information technology: is actual usage the missing link? *Management Science.* 2003;49(3):273-289. ■

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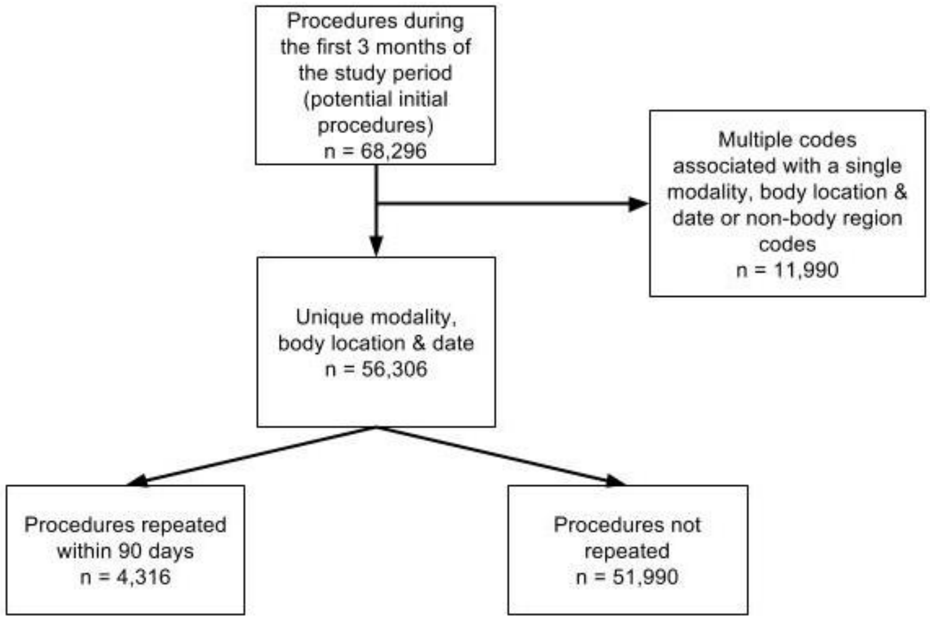
eAppendix.

Appendix Figure. Flow chart describing the identification and selection of repeat and non-repeated imaging procedures from all available imaging claims in the study sample.



Appendix Table. Body regions identified by the third party data aggregation company using descriptions of Current Procedural Terminology (CPT) codes.

Abdomen	Lower extremity
Blood/lymph	Pacemaker
Bone	Pelvis
Breast	Pregnant uterus
Cardiac	Pulmonary
Chest	Renal
Extremity	Spine
Gastrointestinal tract	Thyroid
Head/neck	Upper extremity
Hepatic	Urology
Joint	Vascular