
Research and Applications

Health information exchange associated with improved emergency department care through faster accessing of patient information from outside organizations

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ABSTRACT

Objective: To assess whether electronic health information exchange (HIE) is associated with improved emergency department (ED) care processes and utilization through more timely clinician viewing of information from outside organizations.

Materials and Methods: Our data included 2163 patients seen in the ED of a large academic medical center for whom clinicians requested and viewed outside information from February 14, 2014, to February 13, 2015. Outside information requests were fulfilled via HIE (Epic's Care Everywhere) or fax/scan to the electronic health record (EHR). We used EHR audit data to capture the time between the information request and when a clinician accessed the data. We assessed whether the relationship between method of information return and ED outcomes (length of visit, odds of imaging [computed tomography (CT), magnetic resonance imaging (MRI), radiographs] and hospitalization, and total charges) was mediated by request-to-access time, controlling for patient demographics, case mix, and acuity.

Results: In multivariate analysis, there was no direct association between return of information via HIE vs fax/scan and ED outcomes. HIE was associated with faster outside information access (58.5 minutes on average), and faster access was associated with changes in ED care. For each 1-hour reduction in access time, visit length was 52.9 minutes shorter, the likelihood of imaging was lower (by 2.5, 1.6, and 2.4 percentage points for CT, MRI, and radiographs, respectively), the likelihood of admission was 2.4 percentage points lower, and average charges were \$1187 lower ($P \leq .001$ for all).

Conclusion: The relationship between HIE and improved care processes and reduced utilization in the ED is mediated by faster accessing of information from outside organizations.

Key words: health information exchange, timeliness of care, quality of care, emergency department

INTRODUCTION

In our fragmented health care system, clinicians struggle to gain timely access to relevant information about their patients that is generated in other health care organizations.^{1,2} To address this

challenge, the federal government has incentivized the adoption of electronic health records (EHRs) that can engage in electronic health information exchange (HIE).^{3,4} Clinicians currently encounter a patchwork of connectivity: they are electronically connected to

some outside health care organizations and rely on phone, fax, and mail to access information from others. When clinicians access patient information from outside organizations using electronic versus nonelectronic access methods, information should be available in a more reliable, timely, and usable way. These benefits may decrease the likelihood of unsafe or duplicative care⁵⁻⁷ and are likely to be particularly evident in the emergency department (ED) setting, where patient information is often incomplete and time pressures are acute.⁸⁻¹¹

Despite intuitive benefits from HIE, the growing empirical evidence on its effect on care processes and outcomes is mixed: some studies find benefits from HIE in the ED and elsewhere, while others find no effect, and a few report worse outcomes.¹²⁻¹⁵ These findings suggest that current approaches to HIE may not be fulfilling the hypothesized benefits and reveal the need to study the specific mechanisms through which HIE may improve care. Prior studies have hypothesized that one key mechanism through which HIE can improve care is by providing more timely access to critical information.¹⁶⁻¹⁹ By decreasing the time interval between clinicians seeking and obtaining information, HIE could improve the likelihood that information is incorporated into clinical decisions. Empirical data is needed to assess whether current HIE solutions are implemented in ways that provide timely access to information, and whether more timely access improves care.

HIE may also result in improved care by other mechanisms, such as making information from outside organizations available more routinely (ie, ensuring that requested information is returned at all, regardless of timeliness) and improving the usability of information from outside organizations (ie, presenting information in a way that makes it easier to incorporate into clinical decisions). Investigations that reveal the mechanisms through which HIE is currently improving care, and where it may not be performing well, will enable provider organizations and policymakers to pursue HIE in clinically beneficial ways.

OBJECTIVE

In this study, our primary objective was to assess whether use of an HIE system was associated with improved care through more timely access to information in the ED relative to standard telephone- and fax-based approaches to information retrieval from outside organizations. We focused on one of the largest and most rapidly growing approaches to HIE, Epic Systems' Care Everywhere HIE platform, which is available to ~20% of hospitals nationwide.²⁰ We developed a conceptual model (Figure 1) to assess whether the relationship between HIE and ED outcomes is mediated by the time between request of outside information and when it is viewed by the clinician.

Secondarily, we sought to assess whether information is returned more routinely via Care Everywhere vs standard telephone and fax, and whether, after controlling for timely access, there was an additional impact of Care Everywhere on ED outcomes that would suggest improved usability of information. We considered these secondary analyses because they are more specific to how Care Everywhere supports HIE and are therefore likely to differ depending on the approach to HIE. In contrast, our primary analysis, focused on time between information request and viewing as a mediator between HIE and ED outcomes, captures a generalizable relationship.

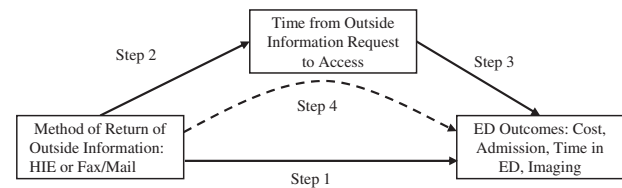


Figure 1. Conceptual model: time between outside information request and access as a mediator between HIE and ED outcomes.

MATERIALS AND METHODS

Setting and data source

To access the detailed data required to achieve our objectives, we examined a large academic medical center. In this setting, use of HIE or fax to retrieve patient information is determined by whether or not patients had previously been seen at organizations that used Epic, not their clinical condition or other factors likely to be associated with ED outcomes. Specifically, study data come from the University of Michigan Health System (UMHS) adult and pediatric EDs. UMHS is a large, statewide-referral, quaternary care academic medical center with about 100 000 annual ED visits. In 2012, UMHS implemented Epic Systems' EHR in the EDs and in 2014 activated Epic's HIE module, Care Everywhere.

When treating a patient, an ED clinician could request outside information via an "order" within the EHR. Clinicians indicated the type of information that should be retrieved and the organization from which it should be retrieved. ED unit clerks then carried out the request in 1 of 2 ways. If the outside organization was connected to Care Everywhere, the clerk made an electronic query, and if the query was successful, the information was then available for the clinician to review in the EHR. If the outside organization was not connected to Care Everywhere (either because it used an EHR from a different vendor or did not have an EHR), the clerk contacted the outside organization and information was returned by fax and scanned into the EHR. After information was returned via either mechanism, the requesting clinician was notified by page. The choice of information retrieval method was therefore determined by whether or not the outside institution had Epic, and not clinician preference or patient clinical factors. As a result, we were able to identify the effects of Care Everywhere isolated from many factors that might have biased the relationship.

If the outside information request is fulfilled by Care Everywhere, a new tab within the patient's record links to all the information made available by the outside organization (ie, not only the specific information requested). This information is structured and searchable to allow navigation at the discretion of the user to find key pieces of information, including appointments, visit summaries, laboratory and radiology results, allergies, and medications. In contrast, when information is returned via fax, it is scanned and loaded into a different tab, called the media tab. A link allows access to a PDF document containing all the pages in the original document(s) sent from the outside organization.

A custom dataset was created for this study that included all patients in the EDs for whom a request for outside information was placed between February 14, 2014 (3 weeks after the Care Everywhere go-live date in the EDs), and February 13, 2015. Data came from 2 sources. Data on patient demographics and clinical outcomes came from fields within the EHR. Meta-data on outside information requests, whether the request was fulfilled (ie, for Care Everywhere, was the query successful, and for non-Care Everywhere, whether any information was faxed and scanned), viewing of returned

information, and patient time in ED, came from EHR task and audit logs. This study was approved by UMHS's Institutional Review Board and received a waiver of patient consent.

Measures

We created a binary variable to capture how outside information was retrieved, either through HIE via Care Everywhere or by fax. Then, using audit log data, for Care Everywhere requests we determined whether or not the query was successful, and for non-Care Everywhere requests, whether or not any information was faxed back, scanned, and available in the media tab. For the subset of requests that resulted in a successful return of information, we determined whether the information was viewed by an attending physician, resident, nurse practitioner, or physician's assistant. For those that were viewed, we used time-stamps to calculate the minutes between the submission of the request for outside information and the clinician subsequently viewing what was returned (information request-to-access time).

We also captured the relationship between the method of information return and the speed at which information was *first available* in the system, regardless of when it was actually viewed (ie, how many minutes between submission of the outside information request and return of that information by either HIE or fax/scan). We used this measure because it is possible that information returned via Care Everywhere was accessed more quickly than information returned by fax for some reason unrelated to the method of information return, such as clinician workload, an unmeasured dimension of patient acuity, or some other unobserved confounder that could cause a delay in clinicians viewing the information returned by fax. Unlike request-to-access time, this time increment is unlikely to be biased by unobserved factors that might be associated with different clinician access speeds for the 2 methods of information return. While this measure more directly captures the inherent timeliness of the 2 methods of information return, we used it as a secondary measure because ED outcomes would only be impacted after a clinician views the information.

We captured 6 outcome measures related to the quality and efficiency of ED care that we hypothesized would be sensitive to HIE: ED length of stay, utilization of common diagnostic imaging tests (computed tomography [CT], magnetic resonance imaging [MRI], radiographs), hospitalization rates, and charges. ED length of stay was defined as the time in minutes from first clinician encounter to when the patient left the ED (and therefore did not include wait time prior to first evaluation by a clinician). Our measure of charges included both ED and hospitalization charges for those admitted. We observed extreme outliers for charges, ED length of stay, and order-to-access time. Because these outliers had the potential to unduly influence our analyses, we censored these variables to the 95th percentile before running our models.

We created a set of covariates that could confound the relationship of interest. These included patient demographic characteristics (age, gender, race, and insurance status); visit case-mix factors (Charlson comorbidity index); acuity (ED triage score ranging from 1 [resuscitation] to 5 [minor] and dichotomous variables indicating whether the patient experienced an abnormal vital sign for systolic or diastolic blood pressure, temperature, pulse, respiratory rate, or pulse oximetry); patient interaction with the health system; and visit time (whether the patient was seen on a weekend or outside of normal business hours).

Analysis

We first assessed the proportion of outside information requests that were attempted via Care Everywhere vs fax/scan. Then, within each

group, we calculated the proportion of requests that successfully resulted in returned information. This result addressed our secondary study objective of determining whether Care Everywhere returns information more routinely compared to fax/scan. Finally, we calculated the proportion of successful requests that were viewed by a clinician.

For our primary analysis, examining request-to-access time as a mediator between HIE and outcomes, we had to restrict our sample to ED encounters with information requests that were viewed by a clinician (in order to be able to calculate time between request and viewing). We also dropped a small number of encounters with additional missing data ($n=98$). The resulting sample comprised 2163 ED encounters for 2127 unique patients. In this sample, we compared the covariates for the Care Everywhere and fax/scan groups to confirm our assumption that the groups would be similar.

We then performed our mediation analysis in 4 steps. First we estimated the direct relationship between method of information retrieval (HIE or fax/scan) and our 6 process- and utilization-related outcomes. The model included all covariates, but excluded information request-to-access time. Second, we assessed whether HIE was associated with shorter information request-to-access times; the model included request-to-access time as the dependent variable, and method of retrieval (HIE or fax/scan) and covariates as predictors. Third, we ran a model predicting ED outcomes with both request-to-access time and method of retrieval included, along with covariates. If HIE was associated with shorter request-to-access time in step 2 and shorter request-to-access time was associated with improved ED process outcomes in step 3, this signified a mediating relationship between HIE and ED outcomes through shorter request-to-access time. In the fourth step, we compared the coefficient on the method of information retrieval in the models that did and did not include request-to-access time. Evidence consistent with a mediation effect would be observed if including request-to-access time altered the relationship between the method of information retrieval and outcomes.^{21,22} For instance, a mediation effect would be observed if using Care Everywhere was associated with a shorter length of stay when request-to-access time was not in the model, but inclusion of request-to-access time in the model attenuates the association between Care Everywhere and length of stay while request-to-access time itself is associated with the outcome. If there were benefits from Care Everywhere vs fax/scan beyond improved timeliness of information return, in the third model, which included request-to-access time, we would expect a negative significant relationship between method of information retrieval and ED outcomes. This would suggest usability benefits of Care Everywhere that lead to improved outcomes independent of time, fulfilling our secondary study objective.

All models used ordinary least squares regression. Because the influence of information retrieval method on 2 measures, ED length of stay and charges, may differ for patients discharged from the ED than for those admitted to the hospital, for these measures we repeated our mediation analysis only for patients who were discharged from the ED. As an extension to our primary analysis, we examined the correlation between request-to-access time and request-to-availability time to assess whether quicker return of information resulted in quicker clinician viewing.

RESULTS

Of the 4451 outside information requests, 786 (18%) were attempted to be fulfilled via Care Everywhere and 3665 (82%) by fax/scan (Figure 2). Of Care Everywhere queries, 72% were successful and resulted in returned information, compared to 84% of

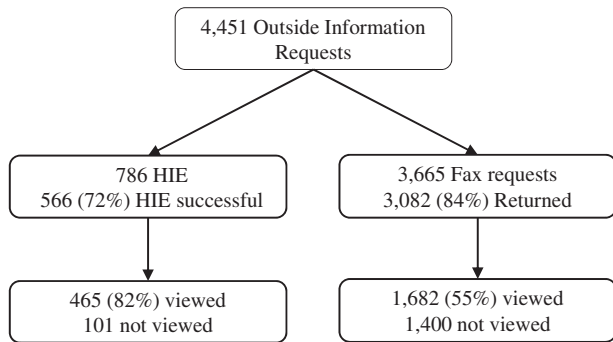


Figure 2. Amount of outside information requested, returned and viewed by HIE method.

fax/scan requests. When information was returned via Care Everywhere, 82% were viewed by a clinician compared to 55% of fax/scan information. Patients in these 2 groups were indistinguishable on measures of acuity, case mix, visit time, and prior interaction with the health system (Table 1). This is likely because use of HIE was not determined by patient clinical factors.

In the first step of our mediation analysis, we did not observe a relationship between method of information retrieval and any of our 6 outcomes, except that patient time in the ED was statistically significant at the 10% level (Table 2, row 1). Specifically, for patients whose information was returned via HIE, it took 26.9 fewer minutes from when they were first seen by a clinician and when they left the ED ($P = .099$).

In the second step of our mediation analysis, we found a strong relationship between HIE and information request-to-access time: when information was returned and viewed, information returned via Care Everywhere compared to fax/scan was viewed 51.0 minutes ($P < .001$) faster. (Bivariate relationship shown in Figure 3; multivariate model results not shown.)

In the third step of our mediation analysis, we found a strong relationship between faster request-to-access time and better outcomes: for every hour saved in accessing outside information, patients' ED length of stay was 52.9 minutes ($P < .001$) shorter, which is 10.5% of the mean length of 503 minutes (Table 2, row 2). The likelihood of receiving at least 1 of each type of imaging exam at the study institution was 2.5 percentage points ($P < .001$), or 7.4% of the mean, lower for CT; 1.6 percentage points ($P < .001$), or 18.0% of the mean, lower for MRI; and 2.4 percentage points ($P < .001$), or 4.2% of the mean, lower for radiographs. The likelihood of being admitted to the hospital was lower by 2.4 percentage points ($P < .001$), or 4.4% of the mean, and estimated charges were lower by \$1187 ($P < .001$), or 6.3% of the mean. When we limited the sample to discharged patients for the 2 outcomes that might be most affected by patient admission, we observed a similar relationship: for every hour saved in accessing outside information, time in the ED decreased by 54.5 minutes ($P < .001$), or 13.1% of the mean, and charges were reduced by \$482 ($P < .001$), or 10.5% of the mean.

In the final step of our mediation analysis, we compared the coefficients on method of information retrieval in the models with and without request-to-access time. We observed evidence consistent with a mediation effect for all 6 outcomes (Table 2, row 4). For example, in the model predicting time in the ED, the coefficient on

Table 1. Patient characteristics by method of return of outside information: fax/scan or HIE (Care Everywhere)

Patient Characteristics	Outside information returned via fax/scan (n = 1726) (%)	Outside information returned via health information exchange (n = 437) (%)	P-value
Patient demographics			
Age	47.4	44.4	0.09
Female	57.0%	58.8%	0.50
Race			
Native American	0.3%	0.5%	0.11
Asian	0.6%	1.8%	
Black	16.2%	14.2%	
Pac-Island	0.1%	0.2%	
Other	2.4%	4.1%	
Unknown	0.2%	0%	
White	79.7%	78.9%	
Insurance Type			
Commercial	61.2%	68.6%	0.05
Military	0.9%	0.5%	
Medicaid	5.6%	5.0%	
Medicare	28.5%	23.6%	
Self-pay	3.7%	2.3%	
Case mix and acuity measures			
Charlson index	0.23	0.18	0.12
Triage status ^a	2.5	2.5	0.55
Abnormal systolic BP	42.2%	44.6%	0.35
Abnormal diastolic BP	17.2%	18.5%	0.58
Abnormal temp	1.8%	1.6%	0.70
Abnormal pulse OX	17.3%	17.2%	0.79
Abnormal respiration rate	13.3%	15.1%	0.18
Abnormal pulse	24.6%	26.8%	0.32
Prior interaction with health system^b			
No. of prior inpatient visits	1.31	1.33	0.85
No. of prior outpatient visits	20.1	18.9	0.54
No. of prior ED visits	1.75	1.52	0.24
Visit time			
Seen on weekday	76.9%	74.6%	0.30
During business hours	58.6%	59.0%	0.86
Outcomes			
Minutes in ED	508.7	479.4	0.08
CT performed	33.3%	34.6%	0.62
MRI performed	9.1%	8.9%	0.91
Radiograph performed	58.5%	54.4%	0.13
Admitted from ED	54.0%	54.2%	0.95
Charges (\$, encounter total ^c)	19 172	18 130	0.38

98 observations dropped due to missing data, resulting in a total sample size of 2,163.

^aLower triage status means that the patient is in more urgent need of care: triage status of 1 corresponds to a status of resuscitation, 2 = emergent, 3 = urgent, 4 = non-urgent, and 5 = minor.

^bThe aggregate number of visits to UMHS facilities between February 1, 2012, and July 13, 2015.

^cThe available measure of charges includes all charges associated with patient encounters, including inpatient charges for patients who are omitted; when limited to patients who were not admitted, the averages are \$4510 for fax/scan and \$4312 for HIE ($P = .4663$).

P-values from chi-squared test of independence by type method of information exchange.

Table 2. Relationship between method of outside information return and ED outcomes: multivariate OLS

Explanatory Variable	Length of stay (minutes) (P-value) n = 2163	Likelihood of CT (percentage points) (P-value) n = 2163	Likelihood of MRI (percentage points) (P-value) n = 2163	Likelihood of X-ray (percentage points) (P-value) n = 2163	Likelihood of admission (percentage points) (P-value) n = 2118	Charges (dollars) (P-value) n = 2143	Discharged only: length of stay (minutes) (P-value) n = 912	Discharged only: charges (dollars) (P-value) n = 963
Model without request-to-access time								
Outside information returned via HIE relative to fax/scan	-26.9 (.099)	2.0 (.41)	0.1 (.94)	-3.3 (.18)	0.4 (.88)	-811 (.43)	13.6 (.38)	4 (.99)
Model with request-to-access time								
Outside information request-to-access time (60-min increments)	52.9 ($<.001$)	2.5 ($<.001$)	1.6 ($<.001$)	2.4 ($<.001$)	2.4 ($<.001$)	1187 ($<.001$)	38.3 ($<.001$)	482 ($<.001$)
Outside information returned via HIE relative to fax/scan	24.0 (.14)	4.4 (.078)	1.7 (.29)	-1.0 (.71)	2.7 (.25)	339 (.75)	49.4 (.0015)	479 (.094)
Mediation test ^a								
Change in effect of HIE on outcomes in model without and with request-to-access time	50.9 ($<.001$)	2.4 ($<.001$)	1.6 (.001)	2.3 ($<.001$)	2.3 ($<.001$)	1150 ($<.001$)	35.8 ($<.0001$)	455 ($<.0001$)

Multiple regression models included control variables accounting for patient demographic characteristics, visit case mix, acuity, patient interaction with the health system, and visit time.

Minutes in ED and charges censored at 95th percentile.

^aTest of mediation conducted using seemingly unrelated estimates to compare the coefficients on the variable indicating if outside information was returned via HIE relative to fax/scan.

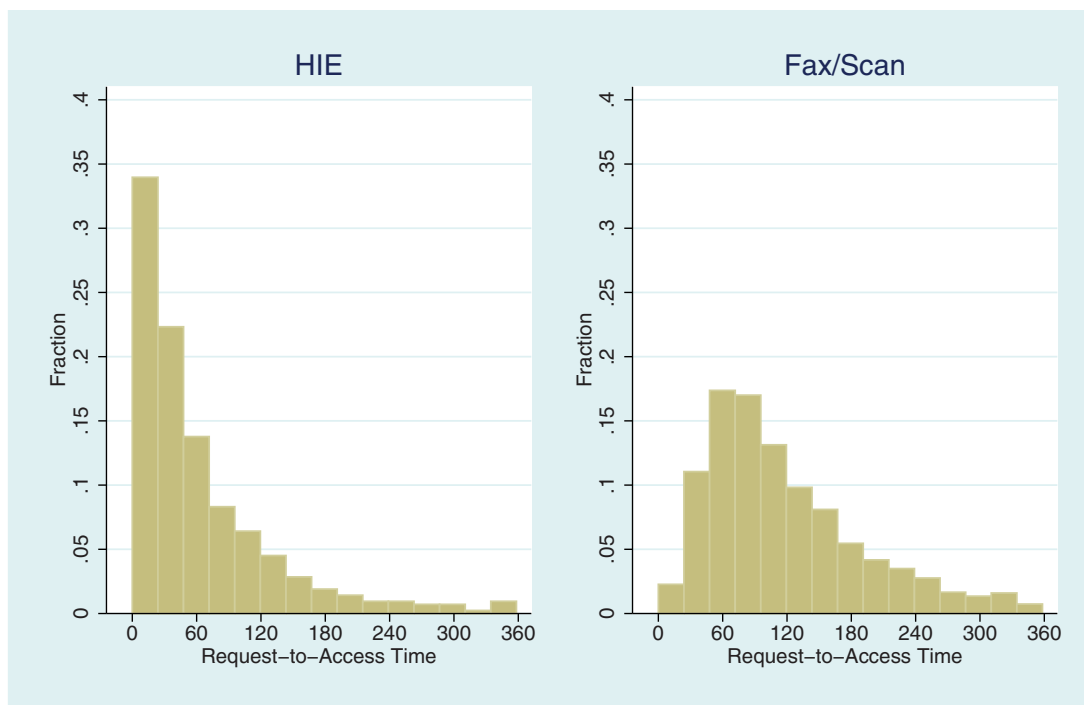


Figure 3. Distribution of time (in minutes) from physician outside information request to access: information returned via HIE (Epic Care Everywhere) vs fax/scan.

HIE increased from -26.9 minutes to 24.1 minutes, and post hoc tests showed that these coefficients were statistically different ($P < .0001$). The mediation effect indicates that differences in the time from information request to access is a key component of the

relationship between the method of information retrieval and outcomes. However, in the model with request-to-access time, none of the relationships between method of information retrieval and outcomes were statistically significant (Table 2, row 3), suggesting that

there is no additional benefit of Care Everywhere as compared to fax/scan, beyond improved timeliness of information return.

Finally, in the extension to the mediation analysis, we found that faster request-to-access time was correlated with faster request-to-availability time ($r=0.59$; Appendix Figure A1). For every minute faster information was available, on average it was accessed by physicians nearly a minute sooner. This suggests that, to a large degree, faster clinician access time is due to the fact that HIE returns information more quickly.

DISCUSSION

In this study, we isolated a specific mechanism through which use of HIE compared to traditional phone-/fax-based information retrieval can benefit patients in the ED: by giving clinicians faster access to patient information from outside organizations. In secondary analyses, we showed that, for one major approach to HIE, Epic's Care Everywhere, information is returned somewhat less often (72% vs 84% for phone/fax) and that there appeared to be no benefit from improved usability of information. Our findings come on the heels of substantial national investment in EHR and HIE capabilities, and help us understand how these solutions are impacting care. Our study focused on the EDs of a large quaternary-care academic medical center, which allowed us to access detailed data that capture the exact timing of events related to requesting, returning, and accessing patient information from outside organizations. We were also in a strong position to isolate the specific impact of HIE, because the selection of information retrieval method was not related to patient clinical factors or clinician preference.

We found that increases in timely access to outside information related to use of HIE produced meaningful changes in the care provided. Using estimated effects from our models, for the 437 patients for whom HIE was used, more timely access to outside information saved 385 hours of patient time in the ED. Similarly, improved timeliness was associated with avoiding CT for 11 patients who otherwise would have received at least 1, MRI for 7 patients, radiograph for 11 patients, and admission for 11 patients. Finally, improved timeliness was associated with a reduction of \$519 000 in charges.

While our study focuses on one type of HIE, Care Everywhere, it is likely that the benefits from faster access to information could be realized using different approaches to HIE. In past studies, efficiency resulting from faster access to information was one of the key benefits clinicians expected from HIE^{19,23}; clinicians reported that use of HIE could replace more cumbersome forms of communication.²⁴ However, studies also point to concerns that requesting/searching for information via HIE may require more time than traditional phone/fax approaches: 1 study found that physicians expected that HIE might increase the time in the ED.²⁵ While we found evidence that HIE speeds access to information, improvements in design might allow for further efficiency in requesting and using outside information. Nevertheless, the benefits that we observed from HIE are consistent with prior studies examining a variety of approaches that found reduced repeat imaging^{10,14,26,27}; our study suggests that more timely access to information is the likely mechanism.

If all outside information requests had been fulfilled via HIE, our estimates of the benefits would have increased 5-fold, because only about 1 in 5 outside information requests used HIE. Prior studies have found that lack of data availability can limit the usefulness of HIE,^{28,29} and our finding that HIE was not the dominant method of information return reflects the fact that Care Everywhere did not connect the ED to all necessary sources of information. This

underscores the importance of ensuring that clinicians have electronic access to information from all outside provider organizations, regardless of which vendors are involved.

Our results also raise the potential for additional benefits by ensuring that all requested information is returned and that clinicians view information that is retrieved from outside organizations. In 14% of cases, information was never returned. For Care Everywhere, this may have been due to challenges with the data precision and agreement needed for the patient-matching algorithm to be successful. For fax/scan, patient-matching issues can often be resolved by human intervention, which may boost the match rate but is labor intensive. Even when information was returned, it was never viewed in 18% of encounters that used Care Everywhere, and it was viewed even less often for fax/scan, in 45% of encounters. It is hard to know whether or not these represent missed opportunities. On the one hand, clinicians may have correctly determined that the information was no longer valuable. On the other hand, it is possible that suboptimal workflows, shift changes, or uncertainty about who should be notified about information availability³⁰ impeded viewing of valuable information, which could be addressed by efforts to redesign clinician workflow and enhance team-based care.³¹ More broadly, it is unclear what the optimal level of HIE use is and how to incorporate HIE into care in ways that improve outcomes. While not specifically addressed in our study, a key question is whether greater benefits from HIE could be realized by ensuring that clinicians are always aware of when information from outside clinicians exists. That is, a request for outside information may not have been placed for many patients who would have benefited from one, because patients may not relay information to clinicians. If so, an approach to HIE that automatically searches for information about patients from outside organizations would result in greater benefit.³²

Notably, in our analyses we did not observe an additional benefit from Care Everywhere beyond its effect on timely access to information. In concept, HIE has the potential to improve usability of information from outside organizations, such as by making it easier for clinicians to find the specific information they are seeking, by presenting that information more clearly, and by integrating outside information into the EHR. However, prior work suggests that, in practice, there is considerable room for improvement in the usability of HIE solutions in terms of how they return and present information from outside providers.^{13,28,29} These design limitations may hinder the ability of providers to incorporate the information into clinical decisions and ultimately improve care outcomes. For instance, Care Everywhere queries are designed to retrieve all available information held by the queried organization, not only the information requested by the clinician. This could lead to an overwhelming amount of information, making it challenging to find and use what is most relevant. Achieving additional benefit from HIE likely requires not only improved workflows, but also improvements in the selection and display of information.

Several limitations should be considered when assessing the results of this study. First, the benefits that we found are within the subset of outside information requests that are viewed. We do not know whether there are similar opportunities for improved outcomes in the broader sample in which information was never returned or returned but never viewed. In the latter case, benefits would be less if clinicians only viewed available data when there was an opportunity for the data to inform clinical decision-making. Second, generalizability may be limited by the fact that our data come from a single health system and capture one form of HIE that

is used by ~20% of US hospitals, Epic's Care Everywhere platform. This is what prompted us to focus on request-to-access time as the mediator between HIE and ED outcomes in the primary analysis, since this is the most generalizable relationship. However, there may have been institution-specific factors that influenced the magnitude of benefit; notably, UMHS worked to make fax-based information retrieval as seamless as possible, such that our estimates may understate the benefits possible at other organizations. Third, our study is a retrospective cohort study, and we could only assess associations, not causal relationships. While the study setting and robust set of covariates reduced the influence of confounders, we cannot be certain that patients for whom HIE was used did not systematically vary in unobserved ways from those for whom fax retrieval was used. We also do not know if the information that was returned was different for HIE vs fax/scan. For our primary objective, we attempted to bolster causal inference by ensuring that HIE was associated with faster availability of information. Fourth, we could not assess whether reduced utilization (imaging and admissions) was redundant; it is possible that reductions resulted in downstream negative consequences that we did not observe. We also were only able to examine hospital charges, not costs, and charges may not reflect true resource use or inputs. Finally, we relied on data drawn from the EHR that was not gathered for research purposes. While use of this type of EHR data is becoming more common, it could include inaccuracies, and this is particularly likely for data entered by hospital staff (eg, triage scores) as opposed to audit-log data that is automatically captured by the EHR.

CONCLUSION

Our study provides strong suggestive evidence that HIE can improve a diverse set of meaningful ED outcomes through faster access to information from outside organizations. Provider organizations are therefore likely to benefit from investing in forms of HIE and associated workflows that ensure that ED clinicians can view information from outside organizations in a timely manner. For policymakers, our study helps to reconcile prior conflicting findings on HIE benefits by focusing on one mechanism through which HIE is expected to improve care. Given the substantial public investment in EHRs and ongoing focus on increasing HIE, future policies that ensure that HIE solutions integrate well into clinician workflows are likely to be key in ensuring consistent realization of benefits.

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CONFLICTS OF INTEREST

Dr. Adler-Milstein is on the advisory board of QPID Health.

CONTRIBUTORS

Mr Everson and Dr Adler-Milstein conceived the study. Mr Everson, Dr Adler-Milstein, and Dr Kocher developed the study design. Mr Everson drafted the article, and Dr Adler-Milstein and Dr Kocher provided critical revisions. All authors approve of the version to be published.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *Journal of the American Medical Informatics Association* online.

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