Research and Applications

Health systems' use of enterprise health information exchange vs single electronic health record vendor environments and unplanned readmissions

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ABSTRACT

Objective: Enterprise health information exchange (HIE) and a single electronic health record (EHR) vendor solution are 2 information exchange approaches to improve performance and increase the quality of care. This study sought to determine the association between adoption of enterprise HIE vs a single vendor environment and changes in unplanned readmissions.

Materials and Methods: The association between unplanned 30-day readmissions among adult patients and adoption of enterprise HIE or a single vendor environment was measured in a panel of 211 system-member hospitals from 2010 through 2014 using fixed-effects regression models. Sample hospitals were members of health systems in 7 states. Enterprise HIE was defined as self-reported ability to exchange information with other members of the same health system who used different EHR vendors. A single EHR vendor environment reported exchanging information with other health system members, but all using the same EHR vendor.

Results: Enterprise HIE adoption was more common among the study sample than EHR (75% vs 24%). However, adoption of a single EHR vendor environment was associated with a 0.8% reduction in the probability of a readmission within 30 days of discharge. The estimated impact of adopting an enterprise HIE strategy on readmissions was smaller and not statically significant.

Conclusion: Reductions in the probability of an unplanned readmission after a hospital adopts a single vendor environment suggests that HIE technologies can better support the aim of higher quality care. Additionally, health systems may benefit more from a single vendor environment approach than attempting to foster exchange across multiple EHR vendors.

Key words: health information exchange, electronic health records, hospitals, patient readmission policy

INTRODUCTION

A majority of hospitals and ambulatory practices now use electronic health records (EHRs) due in part to the \$26 billion Medicare and Medicaid EHR Incentive Program, commonly called Meaningful Use.^{1,2} Despite national certification criteria in 2012 requiring ex-

change capabilities and the declaration that “widespread exchange of health information” is a national objective,³ the patient information stored within EHRs is often not easily shared or is difficult to combine across different vendors' products.^{4,5} The inability to efficiently and effectively share patient data between EHRs is a particu-

larly acute problem for health systems.⁴ Health systems are responsible for individual patients seeking care across multiple points of service, but they can have different vendors supplying EHRs for inpatient and outpatient settings or the health system may be comprised of hospitals using different EHR vendors or products.^{6–8} Health systems need a strategy to improve internal information exchange among their disparate technological investments. Two principal technological strategies—enterprise health information exchange (HIE) and single vendor solutions—exist for health systems to improve information sharing and enhance access to patient information.

Health systems with EHRs from multiple vendors have often adopted enterprise HIE technology.^{9–11} The presence of different EHR vendors within a single organization may be a product of mergers and acquisitions involving other hospitals and provider groups¹² or the explicit choice to use 1 vendor for the inpatient setting and another for the outpatient settings.¹³ Enterprise HIE is an information-sharing network that connects the EHRs of a health systems' hospitals and affiliated providers (eg, owned practices or joint venture hospitals). Beyond these internal organizational members, health systems may extend enterprise HIE connectivity to any referring practices and other health care organizations with which the system wants to foster a more exclusive or stronger relationship.¹⁰ Enterprise HIE supports organizations' access to patient information through internal information exchange, which health system leaders anticipate will result in improved care and reductions in potentially avoidable utilization.⁷

Health systems may choose to pursue a single EHR vendor solution for all member hospitals and ambulatory care practices.¹⁴ By placing all providers of a health system's care settings into a single vendor's EHR, information accessibility within the organization may be improved. In addition, a single EHR may further support better care coordination, comprehensive patient information, easier scheduling, less complexity, standardized processes, providing an analytics platform for strategic decision-making, and use of a single sign-on environment for end users.^{15–17} Health systems with a single vendor often have a single EHR instance (ie, 1 environment that includes all patient data and functionality) serving all of the system's providers. However, even if a health system opts to use different EHR instances from the same vendor at 1 or more member sites, the inherent interoperability within a single vendor product continues to support the exchange of relevant patient information.¹⁸ A single EHR vendor environment is effective in fulfilling providers' information needs for patient history and prior results.¹⁹

Both enterprise HIE and a single EHR vendor environment improve access to the patient information created by the health system through care delivery. Better access to needed patient information at the point of care is the underlying mechanism by which HIE may produce beneficial results.²⁰ For example, better information-sharing supports more effective and efficient care delivery during patients' transitions across different settings.^{21,22} Likewise, access to comprehensive patient information supports medication safety,²³ and better information-sharing facilitates ambulatory care providers' access to specialists' information²⁴ or postdischarge reports.²⁵ Moreover, both approaches may better position health systems pursuing the financial benefits of, or avoiding the penalties associated with, current health policy initiatives. For example, the aggregated clinical data resulting from these approaches can support population health monitoring²⁶ as well as risk-based analytics.⁷ These capabilities directly address many of the challenges posed by the Hospital Readmissions Reduction Program,²⁷ Accountable

Care Organizations,²⁸ and Bundled Payments for Care Improvement.²⁹

However, the evidence indicating improvement in the quality of care associated with either enterprise HIE or a single vendor environment is generally limited.¹¹ Some evidence suggests that health systems' adoption of a single vendor environment creates efficiency gains.³⁰ Likewise, use of vendor-mediated exchange has documented decision-making benefits¹⁹ and enterprise HIE systems have been shown to reduce health care utilization.³¹ However, these examples are based on studies of a single institution or in an international setting, thereby limiting generalizability.

This study sought to determine the association between adoption of enterprise HIE vs a single vendor environment and unplanned readmissions among hospitalized adults in 7 states. We focus on readmissions due to their recognition and use as a measure of quality for numerous policy initiatives.³² In addition, because readmissions frequently result from poor communication during transitions of care,³³ they may be amenable to reductions through better information access due to HIE.²⁰

MATERIALS AND METHODS

In a longitudinal analysis covering a 5-year period (2010–2014), we examined unplanned readmissions among patients in health systems in 7 states, before and after adoption of enterprise HIE or a single vendor environment.

Data and sample

The analytic file was constructed from the American Hospital Association's (AHA) Annual Survey and Health Information Technology (HIT) Supplement Survey and the Healthcare Cost and Utilization Project's (HCUP) State Inpatient Databases from the Agency for Healthcare Research and Quality (AHRQ).³⁴

The study population included adult (≥ 20 years old) admissions to nonfederal hospitals in Arkansas, California, Florida, Iowa, Maryland, New York, and Washington. These 7 states were selected because each participates in HCUP by providing information on hospitalizations that includes readmission flags. Currently, California only provides information on hospitalizations through 2011, but additional years of data were obtained directly from the state's Office of Statewide Health Planning and Development. Additionally, these states reflect a wide geographic and socio-economic subset of the nation's population. Hospitals from these states meeting the following conditions were included in the sample: (1) the hospital had responded to 2 or more years of the AHA's Annual Survey and HIT Supplement Survey during the study period; (2) at baseline, it had not adopted at least a basic EHR,³⁵ but eventually adopted either enterprise HIE or a single vendor environment; (3) the hospital was a member of a system (as indicated by a system identifier in the AHA survey); and (4) it was not a children's or psychiatric hospital. The first 2 criteria allow for longitudinal measurement and estimation of the impact of a change in HIE status on readmissions. Also, because all hospitals at baseline did not have an EHR, none had prior experience with interoperable (ie, the ability to exchange information between different systems)^{36,37} health information technology. System membership was required because enterprise HIE connects affiliated hospitals and practices. We also excluded admissions related to labor and delivery, admissions where the patient died prior to discharge, and admissions with a length of stay of > 50 days to reduce the influence of outliers. To account for mergers, we

followed a previously used approach³⁸ of combining a hospital's premerger characteristics into the single postmerger entity for the entire study period. The final sample included 7956 515 admissions to 211 hospitals.

Determinants of interest

The primary determinants of interest were 2 binary measures reflective of a hospital's global adoption of an internal information exchange strategy in a given year based on AHA HIT survey responses: 1 for enterprise HIE and 1 for a single vendor environment. In our sample, all hospitals that adopted EHRs did so with 1 of these 2 strategies. Enterprise HIE adoption was defined based on a hospital meeting 3 criteria: (1) the hospital had an EHR; (2) the hospital reported exchanging or sharing at least 1 of 5 types of electronic information (demographics, laboratory results, medication history, radiology reports, or clinical care records/summaries) with another inpatient or outpatient member of the same health system (ie, intraorganizational exchange); and (3) members of the health system reported different EHR vendors for either inpatient or outpatient services.^{7,39,40} We aggregated all members of the same health system to establish concordance or differences among the reported inpatient and outpatient EHR vendors and included all types of information sharing (demographics, laboratory results, medication history, radiology reports, or clinical care records/summaries) recorded in the AHA HIT survey. Hospitals that were part of a single EHR vendor environment were identified through a similar process: (1) the hospital had an EHR; (2) the hospital reported at least 1 of 5 types of electronic sharing of information with another inpatient or outpatient member of the same health system; and (3) all other members of the health system reported the same EHR vendor. In order to ensure that adoption of either internal information exchange strategy occurred prior to outcomes experienced by patients, we lagged adoption by 1 time period (eg, using the prior year). By the end of the study period, all hospitals in the sample had adopted 1 of the 2 strategies. See the [Supplementary Appendix](#) for more details.

Outcomes

The primary outcome was a measure of an all-cause, unplanned hospital readmission within 30 days of discharge. Using synthetic identifiers for unique patients, these events were identified based on the Centers' for Medicare & Medicaid Services definition for an unplanned readmission.⁴¹ Following Agency for Healthcare Research and Quality's guidance,⁴² our readmission measure accounted for patient transfers between facilities and known state-specific issues with following patients across calendar years (see [Supplementary Appendix](#)). Admissions without record linkage identifiers (ie, the admission had insufficient information to accurately identify the patient) and records that included negative days until readmission were excluded from the analysis.⁴³

Covariates

Admission-level covariates included patient demographics (eg, age, gender, race/ethnicity), primary payer, Elixhauser comorbidity index,⁴⁴ length of stay, and whether the admission occurred on a weekend.⁴⁵ We characterized hospitals by size in terms of bed count, ownership, and rural location. We also used the health care system taxonomy to describe the various dominant combinations of service diversification and centralization of authority observed across health systems.⁴⁶ Because vertical integration between hospitals and outpa-

tient practices could improve coordination of care and subsequently lead to lower readmission rates,⁴⁷ we created annual indicators for any contractual or employment affiliations reported at the hospital or system levels.⁴⁸ The number of hospitals with common health system identifiers in the AHA survey was used as a proxy for overall health system size. External information exchange, the ability to share information with ambulatory care providers or hospitals outside the health system, was measured as self-reported participation in a regional health information organization or health information exchange and lagged by 1 period.

Analyses

We described the adoption of enterprise HIE and single vendor environments over time for the study sample. Next, we characterized the time-invariant and baseline characteristics using frequencies and percentages stratified by the type of internal information exchange strategy eventually adopted. A comparison of the characteristics of hospitals included in the sample with the characteristics of excluded hospitals is available in the [Supplementary Appendix](#).

To estimate the effect of adopting an enterprise HIE or a single EHR vendor environment, we used a hospital fixed-effects regression that compares the change in readmission probabilities among patients before and after a hospital adopted either approach between 2010 and 2014, while controlling for time invariant differences. The following model was used for estimation:

$$\text{Readmission}_{pict} = \alpha_0 + \beta_1 \text{SingleVendor}_{it} + \beta_2 \text{EnterpriseHIE}_{it} + T_i + H_i + P_{pt} + \epsilon_{pit}$$

Patients (ie, admissions) are indexed by p , hospitals by i , health systems by c , and time by t . SingleVendor_{it} is the binary measure of a hospital's adoption of a single EHR vendor approach to internal information exchange in a given year and $\text{EnterpriseHIE}_{it}$ is the binary measure of a hospital's adoption of an enterprise HIE in a given year (ie, hospitals may change approaches from year to year). T_i is a set of time dummies, H_i represents hospital fixed effects, P_{pt} includes time varying, patient-level factors, and ϵ_{pit} is the error term. Time invariant hospital and system level characteristics were controlled through the inclusion of respective fixed effects. β_1 provides the estimated effect of a hospital adopting a single EHR vendor environment and β_2 the effect of adopting an enterprise HIE approach, compared to no internal information sharing technology adoption. The difference between β_1 and β_2 represents the relative effect of adopting a single EHR environment compared to enterprise HIE. Estimates from a series of robustness checks for our primary modeling strategy are reported in the [Supplementary Appendix](#). Regression models were fitted using the REGHDFE module in Stata MP, version 15.1⁴⁹ and were estimated with robust standard errors adjusted for clustering at the level of the hospital.

Our primary analysis, described above, provides estimates for the overall effects of enterprise HIE and single EHR vendor adoption. In the following series of supplemental analyses, we explored the context and nature of information exchange in more detail. First, we assessed the overall effect of adopting either interoperability strategy using a binary measure of a hospital's adoption of either a single EHR vendor or enterprise HIE in a given year. Second, we controlled for annual counts of the types of information exchanged intraorganizationally and interorganizationally between ambulatory providers and hospitals. This provided estimated effects for enterprise HIE and vendor-mediated exchange adoption adjusted for the total types of information exchanged internally and externally.

Figure 1. Adoption of enterprise health information exchange and single electronic health record vendor environments among hospitals initiating health information exchange in Arkansas, California, Florida, Iowa, Maryland, New York, and Washington over the period 2010–2014.

Third, because enterprise HIEs may be used to connect any number of different EHR vendors, we created a categorical measure of: no adoption; enterprise HIE with 2 EHR vendors; and enterprise HIE with 3 or more different EHR vendors. This analysis was limited to hospitals that eventually adopted enterprise HIE. All models controlled for the same factors described for our primary analysis. Estimates were expressed as marginal means and graphed for ease of interpretation.

RESULTS

In our sample of hospitals, both adoption of enterprise HIE and single vendor environments increased over time, with enterprise HIE (75%) being the more common internal information exchange solution by the end of the study period (Figure 1). Hospitals in the sample were most commonly nonprofit and general acute care facilities; however, larger proportions of those adopting single vendor environments were public or specialty hospitals (Table 1). Hospitals adopting enterprise HIE were more likely to be members of larger health systems and to belong to decentralized systems, whereas those adopting single vendor environments tended to be part of a centralized system. In terms of patient admissions, those of single vendor environment hospitals had higher mean Elixhauser scores and longer average lengths of stay. Among hospitals in the first year of inclusion in the sample, readmission rates of those adopting enterprise HIE and of those adopting a single vendor environment were not statistically different. Adoption trends were similar for hospitals in all 7 states, but a larger proportion of those excluded from the sample were specialty and/or for-profit hospitals, and were more likely to be part of decentralized systems (see Supplementary Appendix).

In analyses adjusted for hospital, system, and time fixed effects (Table 2), adoption of a single EHR vendor environment was associated with a lower probability of an unplanned readmission ($\beta = -0.0077$; $P = .032$). The marginal effect was equivalent to a reduction in the readmission rate from 15.8% to 15.0%. The estimated marginal effect of enterprise HIE was equivalent to a reduction from a readmission rate of 15.8% to 15.5% ($\beta = -0.0030$; $P = .095$), but the estimate was not statistically significant at the 5% level. There was no statistically significant difference between the 2 information exchange approaches ($P = .210$).

The negative association between a single EHR vendor environment with unplanned readmissions persisted after adjusting for patient-level factors ($\beta = -0.0073$; $P = .043$), equivalent to a 0.7 percentage point reduction. Adoption of an enterprise HIE strategy was negatively associated with the probability of an unplanned readmission ($\beta = -0.0036$; $P = .110$), but was not statistically significant. In addition, the effect of enterprise HIE adoption did not differ significantly from the adoption of a single vendor environment ($P = .345$). The probability of an unplanned readmission was higher when Medicare or Medicaid was the payer, when the index admission was on a weekend, for higher Elixhauser scores, and for longer hospital stays. The results of our robustness checks were consistent with these findings (see Supplementary Appendix).

Our supplemental analyses provided additional insights into the relationships between adoption of enterprise HIE and/or a single vendor environment with readmissions. In our regression specification using a single indicator for adoption of either approach, internal information exchange adoption was associated with a 0.4 percentage point ($\beta = -0.0039$) reduction in the probability of an unplanned readmission ($P = .085$) after controlling for the same factors used in our primary analysis (Figure 2). After controlling for the count of types of information exchanged intraorganizationally and interorganizationally, the probability of an unplanned readmission was reduced by 0.75 percentage points ($\beta = -0.0075$; $P = .044$) among hospitals that adopted vendor-mediated exchange and 0.4 percentage points among those that adopted enterprise HIE ($\beta = -0.0042$; $P = .062$). In our analysis limited to hospitals that eventually adopted enterprise HIE, reductions in the probability of an unplanned readmission were 0.8 percentage points ($\beta = -0.0079$; $P = .010$) lower when only 2 EHR vendors were connected. When 3 or more EHR vendors were connected via enterprise HIE, no statistically significant difference was observed ($P = .173$).

DISCUSSION

Adoption of a single EHR vendor environment or an enterprise HIE are 2 approaches for hospitals to improve internal information exchange. In this 7-state, multiyear sample, decentralized health systems were more likely to pursue an enterprise HIE strategy and a single-vendor approach was more frequent among centralized sys-

Table 1. Characteristics of all hospitals and admissions in the study sample, as well as characteristics stratified by the adoption of enterprise health information exchange or single vendor environments

Hospital Characteristics	Total	Adopted enterprise HIE	Adopted single vendor ^a	P
	<i>n</i> = 211	<i>n</i> = 158	<i>n</i> = 53	
Control				
Public	13.3	10.1	22.6	.003
Non-profit	73.5	72.8	75.5	
Private	13.3	17.1	1.9	
Service Category				
General acute care	97.6	99.4	92.5	.004
Specialty	2.4	0.6	7.5	
Bed size				
< 50	16.6	15.8	18.9	.958
50–99	12.8	12.7	13.2	
100–299	38.9	39.2	37.7	
≥ 300	32.8	32.3	30.2	
System type				
Centralized	24.2	17.1	45.3	< .001
Moderately centralized	16.6	15.8	18.9	
Decentralized	44.5	52.3	20.8	
Independent system	11.8	12.7	9.4	
Unclassified	2.8	1.9	5.7	
Vertical integration	75.0	76.0	71.7	< .001
Hospitals in system (mean, sd)	16.69 (18.65)	19.93 (20.14)	7.04 (7.29)	< .001
Metropolitan location	75.8	75.3	77.4	.764
State				
AR	10.0	8.2	15.1	< .001
CA	25.1	30.4	9.4	
FL	21.3	15.2	39.6	
IA	15.2	13.9	18.9	
MD	6.6	7.0	5.7	
NY	19.0	24.5	11.3	
WA	2.8	3.8	0.0	
RHIO participant	28.9	29.8	26.4	.643
Admission Characteristics ^b				
Female gender	57.7	58.1	56.4	< .001
Race/ethnicity				
White	65.3	65.9	63.1	< .001
African American	14.4	14.0	16.0	
Hispanic	12.1	10.9	16.0	
Other/unknown	8.2	9.2	4.9	
Age				
< 45	24.4	24.4	24.4	< .001
45–64	30.6	30.5	30.9	
65–74	17.1	17.1	17.2	
74–85	17.1	17.1	17.0	
> 85	10.8	10.9	10.5	
Payer				
Medicare	49.2	48.9	50.1	< .001
Medicaid	14.6	14.7	13.9	
Private	27.8	28.4	25.7	
Other	8.5	7.9	10.3	
Weekend admission	20.4	22.8	13.2	.134
Unplanned readmission rate (mean, sd)	0.158 (0.364)	0.157 (0.364)	0.158 (0.365)	.379
Elixhauser (mean, sd)	12.94 (14.30)	12.85 (14.25)	13.26 (14.48)	< .001
Length of stay (mean, sd)	4.61 (4.93)	4.57 (4.91)	4.76 (4.99)	< .001

Abbreviations: RHIO, regional health information organization; sd, standard deviation.

^a45.3% Epic; 15.1% Cerner; 9.4% Meditech; 30.2% all others.^bAt hospital's first study year.

tems. Hospital adoption of a single EHR vendor strategy for internal information exchange was associated with a lower probability of an unplanned readmission, but adoption of an enterprise HIE strategy was not associated with the likelihood of readmission. These find-

ings suggest that interoperable health information technologies can support improved organizational performance.

Hospitals' adoption of technologies that foster internal information exchange has been increasing over time.⁵⁰ In our sample, the

Table 2. Association between enterprise health information exchange or single vendor environment adoption and unplanned 30-day readmissions^a

	Unplanned readmission	
	Unadjusted ^a	Adjusted
	n=5 766 952	n=5 765 210
Adopted single EHR vendor environment	−0.0077 (−0.0148, −0.0007)*	−0.0073 (−0.0144, −0.0002)*
Adopted enterprise HIE	−0.0030 (−0.0065, 0.0005)	−0.0036 (−0.0081, 0.0008)
RHIO participant	−0.0029 (−0.0036, 0.0094)	−0.0040 (−0.0029, 0.0111)
Vertical integration	−0.0013 (−0.0050, 0.0024)	−0.0004 (−0.0071, 0.0023)
Hospitals in system	0.0001 (−0.0001, 0.0001)	0.0001 (−0.0001, 0.0001)
Patient characteristics		
Female	−0.0335 (−0.0376, −0.0294)***	−0.0200 (−0.0239, −0.0161)***
Age		
< 45	Reference	Reference
45 – 64	0.0458 (0.0426, 0.0490)***	0.0080 (0.0049, 0.0111)***
65 – 74	0.0486 (0.0443, 0.0528)***	−0.0276 (−0.0337, −0.0215)***
74 – 85	0.0580 (0.0530, 0.0630)***	−0.0302 (−0.0374, −0.0230)***
> 85	0.0568 (0.0511, 0.0624)***	−0.0342 (−0.0420, −0.0264)***
Race/ethnicity		
White	Reference	Reference
African American	0.0276 (0.0238, 0.0314)***	0.0139 (0.0101, 0.0177)***
Hispanic	−0.0111 (−0.0155, −0.0066)***	−0.0075 (−0.0104, −0.0045)***
Other/unknown	−0.0320 (−0.0370, −0.0270)***	−0.0224 (−0.0275, −0.0173)***
Payer ^a		
Private	Reference	Reference
Medicare	0.0814 (0.0775, 0.0853)***	0.0611 (0.0558, 0.0665)***
Medicaid	0.0725 (0.0638, 0.0812)***	0.0566 (0.0491, 0.0642)***
Other	0.0127 (0.0076, 0.0177)***	0.0012 (−0.0024, 0.0047)
Weekend admission	0.0108 (0.0094, 0.0122)***	0.0052 (0.0041, 0.0063)***
Elixhauser (mean, sd)	0.0045 (0.0043, 0.0047)***	0.0036 (0.0035, 0.0038)***
Length of stay (mean, sd)	0.0085 (0.0078, 0.0093)***	0.0044 (0.0037, 0.0050)***

Abbreviations: HER, electronic health record; HIE, health information exchange; RHIO, regional health information organization; sd, standard deviation.

^aHospital and time dummies not reported. *** $P < .001$; * $P < .05$. **Figure 2.** Marginal means of unplanned readmission rates by different approaches and structures to intraorganizational information exchange.¹¹Adjusted for the factors (other than type of health information exchange) reported in Table 1, but omitted for readability (see Supplementary Appendix for full results)

Abbreviations: eHIE, enterprise health information exchange; her, electronic health record.

* $P < .05$ compared to other categories within the same panel.

predominant strategy for internal information exchange was enterprise HIE. The key characteristics distinguishing hospitals choosing an enterprise HIE approach over a single vendor environment were health system size and a decentralized taxonomy type. The potential influence of health system size is likely a reflection of the challenges of scale and a product of individual history. For health systems with a small number of member hospitals, the installation of a single vendor solution may be easier from an implementation standpoint. For larger systems, an enterprise HIE strategy may be a more pragmatic choice due to inherited legacy systems across member hospitals that joined through mergers and acquisitions.⁷ Likewise, decentralized health systems could be more prone to multivendor environments that require an enterprise HIE strategy, because the individual hospital members enjoy a greater degree of autonomy for decision-making and also tend to be geographically dispersed.⁴⁶ The opposite characteristics of centralized health systems, such as decision-making at the system level,⁵¹ may support the higher prevalence of single vendor environments observed in this study. Previous research has suggested that centralized systems are associated with greater information system interoperability regardless of strategy.⁵²

Whereas enterprise HIE was the more common strategy, adoption of a single vendor EHR environment was associated with a lower probability of an unplanned readmission. Single vendor approaches can lead to better access to information from multiple settings of care,¹⁸ and they have the potential to create a more uniform experience for providers, which are common reasons for switching to this strategy.⁵³ Additionally, a single EHR vendor environment can enable the aggregation of information into data warehouses to apply analytics to identify risk factors for patients.⁵⁴ Health care organizations rely heavily on their EHRs to support population health initiatives,⁵⁵ and because the single vendor environment provides a consistent user experience, this may allow organizations to efficiently and broadly introduce standardized workflows and interventions.^{18,56} In addition, the single vendor approach may represent a lower degree of complexity both in terms of training, customization, and implementation time compared to an enterprise HIE strategy, which must cope with differing needs of users across multiple EHRs. The negative association between readmissions and having 2 connected EHRs via enterprise HIE and the lack of a statistically significant reduction when 3 or more EHRs were connected, provides some evidence for this inference. In general, the fact that an enterprise HIE strategy can provide benefits through aggregated information and analytics^{11,57} may explain the consistent, though nonsignificant, negative relationship with unplanned readmissions found in our results.

A secondary, but important, finding was the overall negative association between hospitals' adoption of any internal interoperable EHR and the probability of an unplanned readmission. In the year after adopting an EHR with either strategy, the probability of readmission decreased by 0.4 percentage points, relative to the base of 15.3%. This finding provides among the strongest evidence supporting the potential for interoperable health information technology to reduce readmissions. Although many hospitals use EHRs as part of their strategy to reduce readmissions,⁵⁸ the results of earlier studies generally have not found a relationship between adoption of these systems and readmissions,^{59–64} with the exception of analyses based on cross-sectional or descriptive study designs.^{59,65,66} This study's focus on the general adult patient population, rather than specifically focusing on Medicare beneficiaries, may explain some of the difference in our findings, as has been the case with studies examining the relationship between EHRs and patient safety among a

broader adult population.⁶⁷ Similarly, the literature on EHR adoption and readmissions in ambulatory care settings is also mixed.^{68,69}

Our findings illustrate the difficulties of ongoing measurement and monitoring of hospitals' adoption of health information technologies. First, the health information technology landscape has changed dramatically in a short period of time and continues to evolve rapidly.⁷⁰ As such, our available secondary data sources and surveillance tools, while indispensable, are inevitably behind the curve of market and industry trends. Second, with this evolution, health information technology constructs are becoming more complicated and nuanced. For example, enterprise HIE and single vendor EHR environments are specific constructs defined by the combination of technology and organizational structure.⁷ Interoperability is multidimensional⁷¹ and, in general, reliable measurement of health information technologies as a basic structural feature has proven difficult.⁷² Problematically, as technologies evolve in complexity and their application becomes ubiquitous, detailed analyses of specific functions and characteristics will become increasingly important but likely more difficult to collect. This study is a case in point of this limitation of structural measurement: 1 that cannot account for differences in functionality or user experience between different products. Moreover, even well-defined constructs face the ongoing challenge of adoption not being equivalent to actual usage.⁷³ Benefits of HIE may be delayed or nonexistent,⁷⁴ multiple systems may be in use simultaneously,⁷⁵ and true interoperability may not really be present.⁵

Limitations

The primary limitation of our study is that we are unable to distinguish the effects of EHR adoption with and without an internal interoperability strategy. For such a comparison, we would need hospitals that adopted an EHR, but did not have any internal information exchange, which did not occur in a sufficient number of hospitals in our sample (less than 2% of all hospitals in our study states reported adopting a noninteroperable EHR). In addition, our focus on the internal information exchange strategies of enterprise HIE and single vendor environments necessarily limits the generalizability of our findings to system member hospitals. Further, since we tend to observe more centralized systems adopting single vendor systems and more decentralized systems adopting enterprise HIE, our results are not necessarily reflective of the experience of the average hospital in each of these system cluster types. Since system taxonomy is a time-invariant factor in our panel, we were not able to sufficiently explore its impact on readmissions. Although our fixed-effects approach controls for permanent differences between hospital systems, selection of an information exchange strategy is not a random choice and may be correlated with unobserved organizational factors that change over time such as the system's structure, broad information technology capability, or business and clinical goals. In terms of measurement, our identification of single vendor environments was based on self-report and we have no method of distinguishing between systems running single or multiple EHR instances. In addition, during the study period, numerous changes were occurring within the US health care system, such as the implementation of Medicare Accountable Care Organizations, the Hospital Readmissions Reduction Program, Bundled Payments for Care Improvement, among others. However, it is unlikely that hospitals' adoption of either internal information exchange approach systematically coincided with the timing of the implementation of these initiatives. Given that adoption of either enterprise HIE or a single vendor EHR environment is tied to

organizational strategy, adoption decisions may have implications for other areas of organizational performance, such as financial stability and aspects of care delivery. Also, while the Elixhauser comorbidity index is routinely used to risk-adjust readmissions in studies using HCUP data sets,⁷⁶ use of another type of risk-adjustment index could have influenced our estimates.

CONCLUSION

This is the first study to examine whether the implementation of enterprise HIE or a single vendor environment by a health system reduces hospital readmissions. Reductions in the probability of an unplanned readmission after a hospital adopts a single vendor environment suggests that health information exchange technologies can support the aim of higher quality care.

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AUTHOR CONTRIBUTIONS

JV, MU, SF, and KS conceived the research study. JV, MU, and SF led the data analysis. JV, MU, LC, and JS drafted the manuscript and reviewed for critical content.

ETHICS APPROVAL

This research was approved by the Indiana University Institutional Review Board.

SUPPLEMENTARY MATERIAL

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

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CONFLICT OF INTEREST STATEMENT

None declared.

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