AHRQ Grant Final Progress Report

Title of Project
Health Information Exchange Utilization and Inter-hospital Transfer Outcomes

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STRUCTURED ABSTRACT

Purpose: The long-term goal of this study was to measure the impact of Health Information Exchange (HIE) participation and actual use on the outcomes of patients who undergo interhospital transfer.

Scope: Patients who undergo inter-hospital transfer are unique in their medical complexity and have disproportionately high mortality. Inter-hospital transfers are complicated by incongruent information systems, indirect and asynchronous communication, and geographical distance in a setting of high patient complexity and acuity. Inter-hospital transfers are an ideal system to study efforts to improve interoperability between electronic health systems and improve communication.

Methods: We took a three-pronged approach to evaluate HIE participation and use on the mortality and cost of inter-hospital transfers. First, we evaluated the impact of new HIE adoption on transfer in a 6 state all-payer inter-hospital transfer cohort from 2011 through 2015. We then conducted a randomized stepped wedge trial of a multi-faceted intervention to improve the usability of a regional HIE for transfers to a single tertiary referral center. Finally, we examined impact of integration of two separate EHRs on transfers within a 11-hospital network accounting for both COVID-19 and non-COVID-19 admissions.

Results: Across all three studies, HIE participation had no consistent impact on in-hospital mortality, length of stay, cost of care. Information transfer was improved by HIE participation as proxied by reduced duplicated procedures, reduction in post transfer intensive care unit admission rates, as well as the effectiveness of pre-transfer hand-off documentation predicting subsequent outcomes. Adherence to HIE use was increased by a dedicated triaging physician.

Key Words: Health Information Exchange, Inter-hospital transfers, Inpatient mortality, Interoperability

PURPOSE

Objectives

Patients who undergo inter-hospital transfer experience a high-risk transition of care where information loss and miscommunication are common and potentially impactful.(1–3) Given the risk and complexity of patients who undergo an inter-hospital transfer, efforts to bridge communication such as health information exchanges (HIE) across hospitals holds great promise.(4,5)

The goal of this project was to test the following hypothesis: that improving communication through adoption of health information exchanges (HIE) will lead to reduced cost and improved outcomes in this high-risk population. In order to test this hypothesis, the proposed study addressed the following research questions to evaluate the use and impact of HIE in inter-hospital transfers across several settings.

Research Question 1 (RQ1): Is HIE participation associated with improved patient outcomes, and reduced cost at the population level?

Research Question 2a (RQ2a): Does utilization of tools to promote inter-operability between hospital and EHR systems improve outcomes that reduce cost of inter-hospital transfers at a single quaternary care facility?

Research Question 2b (RQ2b): To what degree does hand-off documentation predict subsequent outcomes following inter-hospital transfer.

Research Question 3 (RQ3): Does complete EHR integration improve the outcomes of patients transferred between hospitals within a previously merged 11 hospital network?

SCOPE

Background

Approximately 1.6 million patients are transferred between hospitals yearly.(6) This patient population is unique in its medical complexity and has disproportionately high mortality.(3,6,7) Inter-hospital transfers are complicated by incongruent information systems, indirect and asynchronous communication, and geographical distance in a setting of high patient complexity and acuity. This high-risk transition of care is a setting in which breakdowns in the diagnostic process are likely to occur and impact patient outcome.(1) This population is a representative microcosm of the care dispersion that occurs during a transition between healthcare settings: between skilled nursing facilities and hospitals, between primary care providers and hospitalists, and between specialists and inpatient consultants in the US care delivery system.(2,8)

Best practices in provider hand-offs are difficult to implement during a transfer between hospitals. In the ideal setting, hand-offs are face to face, with limited interruptions, clearly defined transition of patient care responsibilities, and augmented with objective written data that concisely depicts the patient clinical state that follows a patient across the transition period.(8) During a hospital-to-hospital transfer, face to face hand-offs are not possible. Hospitals often do not staff full time quarterbacking systems with dedicated accepting physician; thus, patient care responsibilities can always distract from a thorough hand-off.(9) The timing of transfer is highly variable and uncertain at the time of hand-off. More-over transfer of responsibilities does not happen at the time of hand-off, but when the patient arrives. Updates during this period of “limbo” are not standard practice and vary significantly from hospital to hospital. Finally, often this period occurs across shift changes, most commonly in the evening, such that the provider accepting the patient is not the one taking care of the patient on arrival.

Inter-hospital transfers are a unique opportunity to study the impact of Health Information Technology on improving patient outcomes. One of the primary goals of health IT is to improve communication across time and space. However, while implementation of electronic health records (EHR) has reached near ubiquity, this has occurred in fragmented fashion with over 107 different EHR systems. In fact, the most common EHR system by the US government Health IT dashboard is “other”. As such, interoperability between health care systems has lagged significantly behind. The most common form of communication in the 2015 American Hospital Association (AHA) health IT survey remained the fax machine.

Inter-hospital transfers additionally provide a unique opportunity to study the impact of communication on inpatient outcomes. Since inter-hospital transfers occur within a single day, and provide data from two unique assessments, there is an opportunity to capture documented changes with respect to diagnosis that may be associated with patient risk. In an optimal setting where documentation is timely, accurate, and continually updated, there is little reason that diagnoses should differ except when a condition evolves, or an error is made or discovered. Comparing diagnosis before and after transfer will provide a unique window into evolution of diagnosis in the inpatient setting. Mechanisms of diagnostic error include failure of information gathering and integration, data interpretation, establishing an explanation, and failure to communicate.(10) In this study we will focus on two components of the diagnostic process, establishing an accurate diagnosis and communicating that diagnosis to the accepting team.

To summarize, inter-hospital transfers are an important and understudied population that are particularly vulnerable to the effects of miscommunication. This population may significantly benefit from improvements in information flow, making it an optimal model system to investigate how EHR interoperability may improve outcomes.

Context, Setting, Participants

Overview

We investigated the impact of HIE participation across three settings: an epidemiologic study across 6 geographically disparate states (Aim 1, RQ1). In parallel we conducted the pilot followed by a randomized stepped wedge interventional trial to improve usability of a regional HIE for patients transferred to a single academic tertiary care facility (Aim 2, RQ2). Finally, we evaluated the impact of the merger of two separate EHRs across a 11-hospital integrated hospital system (Aim 3, RQ3).

Settings

RQ1: We included all inpatient-to-inpatient inter-hospital transfers across six states (GA, FL, IA, NY, VT, UT). We relied on the Healthcare Utilization Project (HCUP) State inpatient and State Emergency Databases as a source (2011-2015). These states were included due to the presence of a patient level identifier to track patients across hospitals for both Emergency visits and Inpatient visits as well as the ability to merge data on to the AHA Annual Hospital Survey Health IT supplement. These years were focused on to alleviate complications of ICD9 to ICD10 switch in administrative coding while capturing substantial changes in HIE participation.

RQ2: We investigated the impact of a multi-faceted intervention on consecutive transfers to the University of Minnesota Medical Center. University of Minnesota Medical Center (UMMC) is its flagship hospital and University of Minnesota Masonic Children’s Hospital is the region’s largest children’s hospital. UMMC is comprised of two hospitals, including an 874-bed tertiary trauma

Table 1: Characteristics of hospitals included in RQ2 and RQ3

Hospital	Urban/Rural	Teaching Status	Legacy hospital System	Yearly Admissions	Medicaid Admissions	Medicare Admissions
Grand Itasca Clinic and Hospital	Rural	Non-teaching	Fairview	1639	303	884
Range Regional Health Services	Urban	Non-teaching	Fairview	2403	702	1131
St. John's Hospital	Urban	Minor	Health East	11730	2714	4605
Fairview Ridges Hospital	Urban	Minor	Fairview	10807	1888	4547
Fairview Southdale Hospital	Urban	Minor	Fairview	17367	1856	8206
Fairview Northland Medical Center	Urban	Minor	Fairview	1720	328	769
Bethesda Hospital	Urban	Minor	Health East	1289	221	672
St. Joseph's Hospital	Urban	Minor	Health East	10767	2436	5080
Fairview Lakes Health Services	Urban	Non-teaching	Fairview	2842	406	1395
Woodwinds Health Campus	Urban	Minor	Health East	7408	1380	2507
University of Minnesota Medical Center	Urban	Major	Fairview	30886	12503	8681

center, a 390-bed level 3 three trauma center, a five-star rated Center for Medicare and Medicaid (CMS) hospital, and dozens of adult specialty clinics on both the East and West banks of the University of Minnesota campus in Minneapolis. Complete services range from primary care, emergency care, the delivery of thousands of babies each year, and to the care of patients with the most complex conditions. Areas of specialization include solid organ and blood and marrow transplantation, heart disease and cancer. Approximately 27% of all unplanned inpatient admissions arrive from outside hospitals. The pilot was conducted in 2017 and randomized stepped wedge interventional trial was conducted from 2018 through 2019.

RQ3: We evaluated transfers within a 12-hospital academic health system called MHealth Fairview. Fairview has significant market differentiation as a healthcare system for services throughout the care continuum including 12 hospitals, over 90 primary care practices, 55 specialty clinics, 54 senior housing locations, a home health and hospice agency, over 30 retail pharmacies, and a payer (Preferred One Health Plan). These are managed as a shared care delivery system led by a single leadership structure that includes academic physicians with a mission to heal, discover new treatments and cures, and educate the next generation of healthcare professionals. Of 12 hospitals, 11 were included in the study. The current health care network arose out of a merger between two healthcare systems and contained two separate instances of an EHR that did not directly communicate (Fairview and Health East). On average approximately 90 patients per month are transferred across the two legacy systems compared with 237 patients transferred within each system to support subspecialty care and capacity management (Table 1).

Patients

For each study we used the same selection criteria: (1) Patient underwent an inter-hospital transfer, and (2) patient was at least 18 years old. We excluded patients for RQ2 and RQ3 if they opted out of clinical research. A summary of patient characteristics is included in Table 2.

Table 2: Patient numbers and characteristics for each RQ.

	RQ1	RQ2	RQ3
n	211,906	4,394	17,142
Age years, mean (SD)	62.6 (17.4)	56.1 (16.8)	54.3 (24.8)
Male, n (percent)	115019 (54.3%)	2402 (54.7%)	9017 (52.6%)
Female, n (percent)	96887 (45.7)	1992 (45.3)	8125 (47.4)
White, n (percent)	136156 (64.3%)	3500 (79.7%)	13505 (78.8%)
Black, n (percent)	26912 (12.7%)	271 (6.2%)	1427 (8.3%)
Asian, n (percent)	2935 (1.4%)	89 (2%)	1158 (6.8%)
Native American/Pacific Islander, n (percent)	494 (0.2%)	199 (4.5%)	157 (0.9%)
Other Race/Missing, n (percent)	45409 (21.4%)	335 (7.6%)	895 (5.2%)
Hispanic, n (percent)	19794 (9.3%)	20 (0.5%)	461 (2.7%)

METHODS

Study design

RQ1: We conducted two parallel observational studies to determine trends and impact of HIE participation for inpatient interhospital transfers. First, we evaluated the natural trends of reported and likely use of HIE for individual hospitals and how necessary was it for both hospitals to participate in HIE use to be helpful for inter-hospital transfers. We then evaluated the prevalence for common reported barriers.

We then evaluated the impact of isolated HIE participation against matched controls. To do this, we identified hospitals with completely functional electronic health records with no reported change in EHR vendors, who reported no participation in HIE from 2012 to 2013 and reported HIE participation in 2014 to 2015. Outcomes were compared against a control group of hospitals which were matched against number of beds, teaching status, urban/rural location, number of transfers received, and the state of the location of the hospital.

RQ2: We instituted a multi-faceted intervention to improve the usability of a currently existing Health Information Exchange to support inter-hospital transfers to a single tertiary referral center. This intervention was piloted among a single general medicine service in 2017 and then implemented in 4 randomly selected blocks staggered in 4-month intervals. In order to simplify the intervention from a hospital operation standpoint (as staggering a complex intervention across 44 different inpatient divisions is not feasible) we randomized inpatient services into 1 of 4 groups, using block randomization, stratifying on 2 variables: intensive care unit (ICU) admitting privileges, and surgical versus non-surgical subspecialty. ICU admitting privileges serves a proxy for perceived illness severity, whereas surgical subspecialties is used as current staffing does not guarantee a dedicated triage physician available to review records at all hours. Additionally, groups of inpatient divisions were clustered to allow for better care coordination (such as the heart failure service, structural cardiac service, and cardiac surgery services). Randomization schedule is summarized in Table 3.

RQ3: We conducted a prospective observational study examining the merger of two separate instances of an EHR which relied on Epic Care-Everywhere to transmit information. We collected a 1-year prospective baseline from July 2020 through July 2021. The merger was considered complete following a one-month production validation phase from August to September 2021. We subsequently collected outcomes following the merger. We compared differences in trends between inter-hospital transfers that occurred across the two instances of the EHR against those conducted within each instance.(11)

Table 3: Block assignment for each inpatient service included in the project. Grey indicates surgical subspecialty; Bold indicates primary ICU service.

Block 1	Block 2	Block 3	Block 4
Cardiac ICU	**Medical ICU**	Neurosurgery	**Surgical ICU**
Heart Failure	Pulmonary Service	Neurology	Thoracic Surgery
General Cardiology	General Surgery	**Neuro ICU**	Orthopedics
Cardiac Surgery	Bariatric Surgery	ENT	Hematology/Oncology
Urology	Family Medicine	Plastic Surgery	Surgical Oncology
Colorectal Surgery	Vascular Surgery	Transplant Surgery	Gynecologic Oncology

Responding to COVID-19

Both clinical studies (the stepped wedge and analysis of EHR merging) occurred during 2019 and 2021 respectively, adjoining or during the COVID-19 pandemic. Given the design of each study and sensitivity to confounding, we needed to directly address the COVID-19 pandemic.

First, we discontinued data collection for the stepped wedge interventional trial December 31, 2020. At that point we had accrued adequate events for primary analysis, and beginning in February, the hospital began shifting efforts to plan for the pandemic. This included creating a centralized hub (systems operation center) to manage all inter-hospital transfers across the health system, and standardized all changes made as part of RQ2 into routine care. Second, in collaboration with the health system, we created a transfer scheme which allowed movement of all patients admitted with severe COVID-19 pneumonia to be relocated to a single centralized hospital. Finally, integration of EHRs across systems occurred during the tail end of the omicron surge and the beginning of significant staffing shortfalls and challenges with capacity management at all hospitals. As such, we split our efforts into studying the role of inter-operability (and more broadly inter-hospital transfers) in the care of patients with COVID-19, and those without.

Data Sources

RQ1: We used HCUP State Inpatient Databases (SID) from 2011 to 2015. Inter-hospital transfers were identified if they had the same discharge/admission day (captured by the 'daystoevent' variable) and at least one hospital reported a transfer to or from another acute care hospital. Data was merged with the AHA annual hospital survey and Health IT supplement. We harmonized questions from the Health IT supplement including HIE participation and EHR capabilities, and included only questions which were consistent from 2012 to 2015.

RQ2&3: In order to perform the work of both studies we created a novel data infrastructure in collaboration with the health system. This was necessary for two reasons. First, we required inclusion of data across two separate instances of the EHR (Epic). This included: linking individual patients across the EHRs with deduplication of medical records, harmonization of structured content with manual validation across both electronic health records, and across time. Since this was a new data resource, it required an additional step of cleaning (removal of data entry errors, laboratory errors, and coding errors). The data resource, which was created in close collaboration with the health system in addition to the University, was housed behind the health system firewall and mirrored into the University of Minnesota's secure data shelter.

The product: An acute care data-mart captured patient flow through the acute care domains of a 11-hospital network including community and academic hospitals and clinics, including all patients who presented to an acute care domain and all subsequent movement between hospitals within a 30-day window. In addition, this data resource included labs, vital signs, medical treatments, procedure coding, level of care, vaccinations, and 30- and 90-day all-cause mortality pulled from the Minnesota (MN) department of vital statistics. Critical measures for this project (including inter-hospital transfers coming from external sources) were manually validated with 200 randomly selected patients (50 randomly selected from 2015 to 2020). Average measures (patient volume, hospital quality metrics, length of stay, and in-hospital mortality) were compared against hospital reporting and found to be similar.

Exposure Variable/Interventions

RQ1: The primary Exposure variable was whether the transfer went to a hospital that recently adopted a Health Information Exchange (when transferring from a hospital also reporting a health information exchange). Outcomes were compared against transfers to a matched cohort of hospitals as well as hospitals who underwent transfer without a sending hospital participation in HIE.

RQ2: We conducted a multi-faceted intervention to improve usability of a local HIE: 1) Complete documentation from the outside hospital was obtained by administrative staff prior to any verbal hand-off and made available to the accepting provider. This was primarily achieved by obtaining Epic CareEverywhere informed consent prior to hand-off. Paper documentation was obtained and was scanned into the EHR in real time by a similar process. (2) The accepting provider was given time to review the chart. (3) A recorded verbal hand-off was made at that time, which was guided by a novel communication tool. This tool contains several important unique aspects of inter-hospital transfers to promote anticipation of future problems and provide feedback. (4) The communication tool and clinical narrative were placed in Epic as a progress note, to share among care providers with a majority using Smart-text technology making data available as structured content. (5) An active list of incoming patients was intended to be maintained by the service to provide flexibility in assigning bed priority.

RQ3: The primary exposure variable was complete integration of EHRs for patients who transferred across the two legacy health systems. This was compared against patients who were transferred within each system to adjust for temporal changes.

Measures:

RQ1: In-hospital mortality was the primary measure. Secondary measures included cause specific mortality including acute myocardial infarction, gastrointestinal bleed pneumonia, COPD, acute kidney injury, and cerebrovascular accident. Additionally, we evaluated length of stay (both pre-, post-, and total), total charges, and duplicated procedures pre- and post-transfer, and the discordance of chronic diagnoses between hospitals.

RQ2: In-hospital mortality was the primary measure, we additionally evaluated process adherence across each step (accessing data prior to hand-off, adhering to a structured hand-off, documenting prior to transfer, placing a patient on transfer list). We additionally evaluated transfer acceptance rates, 30-day all cause mortality for patients who were not accepted, length of stay, and proportion of patients transferred to the ICU within 24 hours.

Finally, we evaluated provider's satisfaction with the current transfer process. We distributed surveys to a convenience sample of 320 providers who had previously been an admitting provider to an inter-hospital transfer across each service line included in the study. We assessed barriers and facilitators to safe transfer and assessed usability of the current hand-off process across different service-line workflows. Since selection of a lower risk population could be a confounder, we evaluated whether a shared mental model of patient prioritization for transfer patterns existed across subspecialties.

RQ3: We evaluated transfer patterns in terms of volume, acceptance rates, and case-mix for COVID-19 and non-COVID-19 patients from 2020 through 2022. For COVID-19 specific transfers we evaluated length of stay, in-hospital, and 30-day all-cause mortality for critically ill and non-critically ill patients. We additionally evaluated quality of care among patients who were transferred across and within legacy health systems.

For non-COVID-19 transfers, in-hospital mortality was the primary outcome. We additionally evaluated length of stay, ICU transfer rate (within 24 hours post transfer), acceptance rate, procedure rate and duplicated procedure, and imaging post following transfer.

Limitations

This study has several limitations, most importantly related potential confounding. For all studies, risk stratification of inter-hospital transfers is challenging as patients are highly heterogenous in nature, more often are length of stay outliers or outliers in severity and complexity. As such, risk adjustment, particularly with administrative data is sub-optimal.

Second, hypotheses 2 and 3 are strongly impacted by time sensitive confounders. As COVID-19 presented in waves, which corresponded to ending Aim 2, and implementation of Aim 3, adjustment is challenging. As such, many trends observed may not be due to the primary intervention, and conclusions are limited.

Finally, our primary measure is inpatient or 30-day mortality for patients who were transferred. While this aligned with hospital and health system priorities as well as hospital quality reporting, this outcome under-emphasizes the importance of tertiary referral centers in community health. Since our focus was on patients who undergo transfer, selection of less sick patients is a possibility, which would simultaneously worsen community health while improving outcomes of transfers.

RESULTS

Principal Findings

We were able to successfully evaluate the impact of Health Information Exchange on inter-hospital transfers across three settings. First, we found that when controlling for the transfer patterns by using only hospitals who newly participated in an HIE. HIE participation was associated with reduced adjusted mortality and duplicated procedures, with no significant changes in length of stay or cost of care.

Across the stepped wedge interventional trial of a multi-disciplinary effort, we observed high adherence among patients admitted to a service with a dedicated triaging physician and very low adherence (<5%) among services without. We observed no impact on post-transfer in-hospital mortality, length of stay, and a small but statistically significant reduction in ICU admission within 24 hours of transfer.

Inter-hospital transfer to a dedicated hospital overall was associated with a significant improvement in COVID-19 mortality. COVID-19 care quality was higher among hospitals

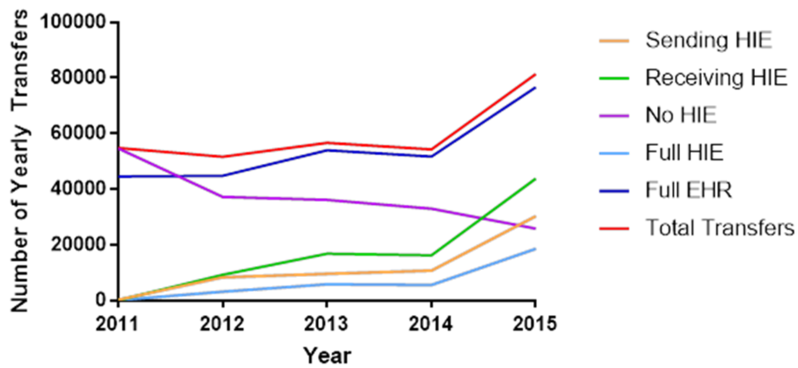


Figure 1: Trends in HIE and EHR capabilities among inpatient-to-inpatient inter-hospital transfers from 6 states.

transferred within a single system as opposed to across systems. Lack of inter-operability was an observable barrier to high quality COVID-19 care.

For non-COVID-19 transfers, volume significantly dropped, and severity of illness significantly rose shortly after COVID-19 pandemic resolved, aligning with nursing shortages and capacity management challenges that were common in 2022. We observed no statistically significant reductions in adjusted or unadjusted in-hospital mortality, length of stay, or procedure rates. We did observe a statistically significant reduction in duplicated procedures with EHR integration.

Outcomes:

Research Question 1: Is HIE participation associated with improved patient outcomes, and reduced cost at the population level?

Trends and impact of HIE participation on inpatient outcomes following inter-hospital transfer

We completed an epidemiologic evaluation of HIE participation using HCUP SID from 2012 through 2015, merging inter-hospital transfers with the AHA annual survey health IT supplement. Overall, the final cohort included 442,680 patients across each state. We find that while EHR meeting meaningful use criteria rose substantially during the study duration (81.25% in 2012 to 94.1% in 2015) HIE participation lagged. Of all inter-hospital transfers included in the cohort, the proportion of patients who underwent transfer where both hospitals reported HIE participation rose from 6.1% to 22.8% (Figure 1). Among receiving facilities, barriers to HIE implementation were universal (100% reported at least one barrier). Most commonly, transfers went to a hospital that reported that the referring facilities are unable to send (66.7%) or receive (60.6%) clinical data. 52.6% of hospitals reported it was difficult to match or identify the correct patient between systems. 37.1% felt the workflow to send or receive information was cumbersome. A small minority of hospitals (7%) stated they do not share patient data outside the system.

We subsequently identified treatment hospitals which met the following criteria: (1) Reported EHR which met meaningful use criteria during the duration of the study, (2) Reported no HIE participation in 2012 and 2013, and (3) report HIE participation in 2014 or 2015 or both. We included 426 hospitals in our final cohort (213 matched treatment and controls). Treatment and controls were effectively matched on number of beds, teaching status, transfer volume, and rural/urban split. All control hospitals also required EHR meeting meaningful use criteria throughout the duration of the study.

We performed two specific analyses: First, compared outcomes in a difference-in-differences analysis pre- and post-HIE adoption comparing transfers where both hospitals reported HIE participation versus those where the referring hospital did not have HIE capabilities.

Table 4: Association with HIE participation with transfer outcomes. Coefficient estimates and 95% CI of differences in differences analysis among hospitals newly participating in a HIE when transferred from a referring hospital which also participated in an HIE, adjusting for age, race, rural location, and Elixhauser comorbidities. Results shown for all patients and patients with specific admitting diagnoses. *** p < 0.001, ** p < 0.01, and * p,0.05.

		All cause admissions	AMI	GIB	PNA	COPD	AKI	CVA
In-hospital Mortality*		0.80 (0.74 to 0.89)***	0.92 (0.72 to 1.19)	0.78 (0.58 to 1.04)	0.75 (0.62 to 0.90)***	0.82 (0.67 to 1.00)*	0.75 (0.65 to 0.87) ***	0.84 (0.64 to 1.11)
Length of Stay	Pre	-0.03 (-0.27 to 0.19)	0.18 (-0.13 to 0.50)	-0.94 (-2.4 to 0.49)	-0.74 (-1.67 to 0.18)	-0.02 (-0.53 to 0.49)	-0.72 (-1.34 to -0.09)*	0.32 (-0.57 to 1.20)
	Post	0.25 (-0.04 to 0.54)	-0.23 (-0.80 to 0.37)	0.06 (-1.53 to 1.66)	-0.63 (-1.8 to 0.54)	0.13 (-0.57 to 0.83)	-0.68 (-1.5 to 0.13)	0.61 (-0.93 to 0.22)
	Total	0.21 (-0.18 to 0.61)	-0.02 (-0.74 to 0.71)	-1.3 (-3.6 to 1.1)	-1.5 (-3.1 to 0.12)	0.11 (-0.81 to 1.03)	-0.15 (-2.6 to -0.44)**	0.96 (-0.96 to 2.89)
Total charges	Pre	0.02 (-0.06 to 0.09)	-0.05 (-0.20 to 0.10)	0.02 (-0.13 to .19)	0.06 (-0.07 to 0.20)	0.06 (-0.05 to 0.17)	0.10 (-0.03 to 0.23)	0.05 (-0.10 to 0.19)
	Post	-0.10 (-0.19 to -0.01)*	-0.08 (-0.22 to 0.06)	0.06 (0.09 to 0.22)	-0.08 (-0.21 to 0.04)	-0.13 (-0.25 to -0.03)**	-0.04 (-0.17 to 0.07)	-0.17 (-0.32 to -0.25)**
	Total	0.023 (-0.04 to 0.09)	-0.08 (-0.19 to 0.03)	0.08 (-0.05 to 0.22)	-0.00 (-0.11 to 0.11)	-0.03 (-0.12 to 0.06)	0.04 (-0.05 to 0.15)	0.04 (-0.08 to 0.15)
Duplicate Procedures*		0.89 (0.32 to 0.95)***	1.16 (0.97 to 1.38)	1.15 (0.98 to 1.48)	0.85 (0.72 to 1.00)*	0.93 (0.79 to 1.09)	0.93 (0.81 to 1.07)	0.96 (0.75 to 1.24)

Since referring hospital EHR capabilities changed over-time, we also compared overall outcomes between experiment and control hospitals in a difference-in-differences (DiD) analysis. For each we relied on a multilevel mixed effects model adjusting for clustering at state, sending and receiving facilities. We adjusted for age (in decade), race, gender, and Elixhauser comorbidities.(12,13) For both analysis we found that HIE participation was associated with lower risk adjusted mortality, and lower duplicated procedure rates (Table 4). We found no association in length of stay or total charges. We additionally found no association between new HIE participation and transfer rates from common referring hospitals.

Research Question 2: Does utilization of tools to promote inter-operability between hospital and EHR systems improve outcomes that reduce cost of inter-hospital transfers at a single quaternary care facility?

The primary outcome of this study was inpatient mortality. While this measure has flaws, we felt this best reflected the worst outcome associated with transfers: patients are removed often far away from home for the hope of a successful intervention, and with failure are not able to be brought back home. Secondary measures included patient demographics, payer-mix, 30-day all-cause mortality achieved by merging MN department of vital statistics with the final transfer dataset, length of stay, cost of care, acceptance rate, and procedural rates. Finally, we investigated the rate of escalation or de-escalation of care within 24 hours of arrival.

Overall trends across all services including triage and emergency transfers were stable with no statistically significant trend in adjusted or unadjusted mortality. We then directly evaluated the impact of our multi-disciplinary intervention on 3 main outcomes: in-hospital mortality, length of stay, and escalation of care within 24 hours via difference-in-differences analysis. Overall, there was no significant effect of the intervention on in-hospital mortality nor length of stay. There was a small, however, statistically significant reduction in escalation of care within 24 hours (Table 5).

Table 5: Differences in patient outcomes following a multi-disciplinary intervention to improve the usability of a regional HIE.

	Pre-Intervention	Post-Intervention	p
N	2221	1110	
Inpatient mortality, n (%)	179 (7.78%)	110 (9.93%)	
Adjusted IP Mortality, (coef, 95% CI)	0.0 (Ref)	0.195 (-0.534 to 0.92)	0.53
Length of Stay, mean (SD)	7.85 (11.73)	8.65 (11.9)	
Adjusted Length of Stay, (coef, 95% CI)	0.0 (Ref)	0.14 (-0.34 to 0.63)	0.58
Escalation of Care within 24 hours, n (%)	40 (1.7%)	14 (1.2%)	
Escalation of Care, (coef, 95% CI)	0.0 (Ref)	-0.95 (-1.69 to -0.20)	0.012

There were additionally no significant changes in transfer acceptance rates, nor mortality of patients where transfer was initiated but not complete.

Among services without a dedicated triaging physician (meaning a provider with no or reduced clinical demands while fielding transfer hand-offs) adherence was 7% for accessing data prior to hand-off, 4% for following standard hand-off with documentation, and 12% for maintaining patients on a dedicated triage list. Among transfers with a dedicated triage physician, 47% had charts reviewed prior to hand-off, 89% had a structured hand-off with documentation prior to transfer, and 98% were placed on a dedicated transfer list. Despite high adherence, services with a dedicated triage physician did not observe significant reductions in mortality or length of stay following the intervention.

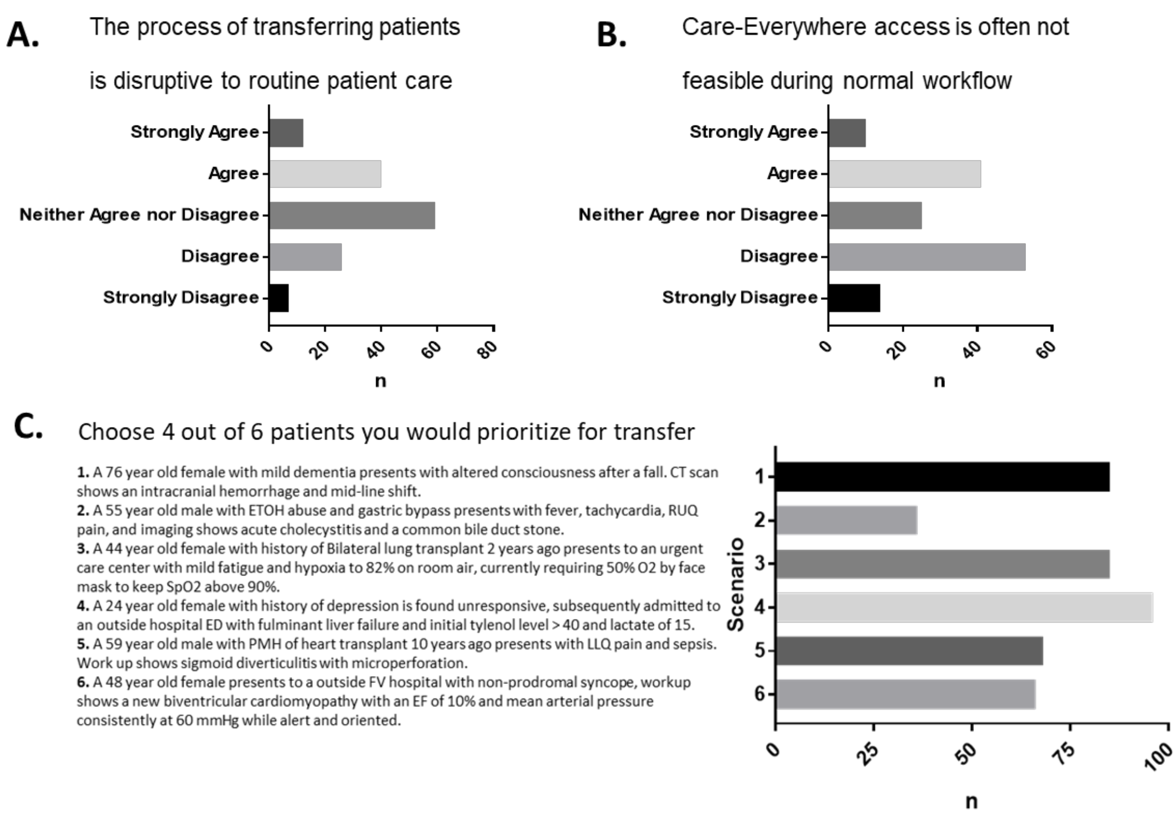
We evaluated a convenience sample of 999 transfer notes, of which 99% originated from medicine-triaging physicians. We determined to what degree information contained in the note predicted subsequent events. Specifically, we investigated whether physicians could accurately predict time to transfer, and how information correlated with early escalation of care and inpatient mortality by multivariate logistic regression. Overall, we found that prediction of transfer timing was fairly accurate with only 22% of transfers falling out of specified time windows. Similarly, information contained in the transfer note provided fair prediction of in-hospital mortality (Table 6). In fact, relying on information in the smart phrase and age alone predicted in-hospital mortality with an Area Under the Receiver Operating Characteristic Curve (AUROC) of 0.72, suggesting good prediction. Despite prediction of mortality, hand-off documentation did not predict early escalation of care. No single element within the smart phrase was related to escalation, and more than 6.2% of patient transfers identified as stable were transferred to the ICU within 24 hours of arrival suggesting a hand-off error.

Table 6: Association of structured documentation elements for pre-hospital transfer with post transfer in-hospital mortality.

	Odds Ratio	96% CI	p
Age at Admission	1.02	(1.01 - 1.03)	0.048
Patient would likely be stable throughout Transfer	0.34	(0.2 - 0.6)	<0.001
Recommendations were given	0.47	(0.26 - 0.87)	0.016
Critical Care physician consulted as part of transfer	2.99	(1.44 - 6.19)	0.003
Inpatient Transplant Evaluation	3.59	(1.25 - 10.3)	0.018

Pre-intervention and post-intervention: We evaluated attitudes regarding the transfer of patients relying on a modified Likert scale as well as text-based questions for qualitative assessment. Response rates were 54% pre-implementation and 45% post-implementation. Overall, the surveys demonstrated consensus across providers, demonstrating dissatisfaction with the current process, and not feeling engaged in the process. Similarly, both pre- and post-intervention, respondents demonstrated a consistently positive belief that improved communication (both through epic care everywhere and downstream documentation) could improve outcomes. There were several points of divergence, particularly in regards to process improvement and feasibility. 32.5% of providers noted that the transfer process was currently disruptive to routine care versus 20.8% who felt it was not disruptive. Similarly, 32% of respondents reported that review of Epic Care-Everywhere data prior to hand-off was not feasible.
Both in pre- and post-analysis respondents (15% of providers) noted feeling responsibility to accept patients regardless of clinical circumstance. During engagement a common priority, particularly among services staffing critical care and surgical subspecialties, was to get the patient here as fast as possible, and determining appropriateness of transfer was felt to be problematic in the face of uncertainty. There was a general recognition that lack of capacity management is a major barrier to efficient patient care. (75.6% of providers agreed with this statement.)

Figure 2: Provider perspectives on inter-hospital transfers. 162 respondents reported differences in impact of inter-hospital transfers on normal care using a modified Likert scale **(A),** feasibility of accessing electronic data **(B),** and differences in prioritization of hypothetical transfers **(C).**



We further explored how providers would prioritize patients by asking providers to pick 4 of 6 hypothetical patients extracted from real cases of transfers that were delayed due to capacity issues (Figure 2). Respondents showed general alignment for a few cases with the highest overall acuity. We found no evidence to suggest improved hand-offs was associated with lower pre-transfer risk of death.

Research Question 3: Does complete EHR integration improve the outcomes of patients transferred between hospitals within a previously merged 11 hospital network?

We prospectively evaluated within system transfers across an 11-hospital network from the 20 months leading up to July 7, 2021, and 20 months post-implementation. This duration was necessary to be able to adjust with waxing and waning patterns related to COVID-19 surges. We specifically evaluated transfers related to COVID-19 and those that were not.

COVID-19 specific transfers

As part of the response to COVID-19, and integrating findings in RQ2, a specific transfer protocol was developed to facilitate the cohorting of COVID-19 patients away from the general population. This required transferring patients to a dedicated COVID-19 hospital. We evaluated the overall impact of the transfer process and the impact of HIE interoperability on quality of health care delivery among COVID-19 patients.

A total of 2,121 patients admitted with severe COVID-19 who underwent interhospital transfer were compared against 3,670 patients who did not. The mortality rate was 11.6% (n = 241) at the dedicated hospitals compared with 8.0% (n = 274) at the other hospitals ($P < .001$). However, risk-adjusted in-hospital mortality was significantly lower for patients in the COVID-19–dedicated hospitals in the unmatched group (n = 2077; odds ratio [OR], 0.75; 95% CI, 0.59-0.95) and the propensity score–matched group (n = 1317; OR, 0.78; 95% CI, 0.58-0.99). The rate of overall complications in the propensity score–matched group was significantly lower (OR, 0.81; 95% CI, 0.66-0.99) and the use of COVID-19–specific therapeutics including deep vein thrombosis prophylaxis (83.9% versus 56.9%; $P < .001$), high-dose corticosteroids (56.1% versus 22.2%; $P < .001$), remdesivir (61.5% versus 44.5%; $P < .001$), and tocilizumab (7.9% versus 2.0; $P < .001$) was significantly higher (Figure 3). As the overall impact of inter-hospital transfers is difficult to capture,(14) COVID-19 demonstrated that well-coordinated inter-hospital transfers can be associated with improved outcomes at a population level.

Of patients who were transferred to a dedicated COVID-19 hospital, 43.7% were transferred from a hospital where EHR systems were seamlessly integrated compared with 56.3%, which originated from hospitals on a separate EHR system that used Epic care-everywhere to share patient information or providers accessing two instances of Epic simultaneously. Patients transferred from hospitals within the same EHR system were more racially diverse ($P < 0.001$). Length of stay, ICU utilization, and ventilator use were similar between groups. Unadjusted and adjusted mortality rates were observed to be lower when transferred from hospitals with seamless EHR integration, but these differences were not statistically significant. Of patients not transferred because of potential instability, fewer examples occurred at hospitals from the same EHR as the dedicated COVID-19 hospital. (27.8% versus a total of 48.4%, $P = 0.001$.)

	Propensity matched OR (95% CI)	All patients OR (95% CI)
In-hospital mortality	0.78 (0.61-0.99)	0.75 (0.59-0.95)
All complications	0.81 (0.66-0.99)	0.86 (0.73-1.02)
Pneumonia	0.75 (0.26-2.17)	0.73 (0.30-1.76)
Bacteremia	1.16 (0.84-1.60)	1.20 (0.92-1.57)
UTI	0.72 (0.46-1.13)	0.82 (0.57-1.19)
Stroke	1.11 (0.57-2.17)	1.19 (0.73-1.94)
Acute MI	0.48 (0.19-1.18)	0.51 (0.25-1.03)
Pulmonary embolism	0.89 (0.47-1.68)	0.85 (0.51-1.41)
Deep vein thrombosis	0.78 (0.61-0.99)	0.88 (0.52-1.50)
Acute kidney injury	0.88 (0.55-1.41)	1.05 (0.72-1.52)
Liver failure	0.45 (0.25-0.81)	0.52 (0.32-0.85)
Bleeding	0.68 (0.43-1.09)	0.90 (0.62-1.32)

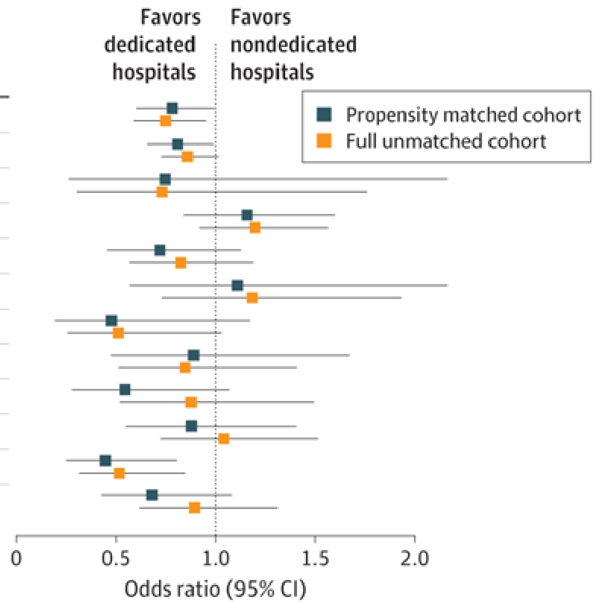


Figure 3: Impact of inter-hospital transfer to a dedicated COVID hospital on subsequent mortality and hospital complications.

Guideline adherence rates were higher when patients were transferred within the same EHR system: risk stratification (63.4% versus 72.4%, P = 0.014), anticoagulation (91.6% versus 96.6%, P = 0.007), and corticosteroids (74.8% versus 80.9%, P = 0.011) despite the availability of Epic care-everywhere. We compared trends in guideline adherence by EHR integration and whether they underwent transfer. Using difference-in-differences analysis, Improved adherence among risk stratification (P < 0.001), anticoagulation (P < 0.001), and dexamethasone (P < 0.001) was observed among patients who underwent transfer. No significant differences in care quality were observed in patients who did not undergo transfer.

Non-COVID Transfers and EHR Inter-operability

A total of 3,062 non-COVID across system transfers were observed pre-EHR integration and were compared against 2020 patients post EHR intervention. To adjust for temporal trends, we included 17,142 within system transfers. We observed substantial temporal variation in the number of inter-hospital transfers, both arriving from external systems and internally. Pre-COVID-19, 4.3% of all admissions originated as a transfer from an outside system, compared with 5.8% of transfers originating from within the system, and 1.1% of admissions being transfers from one legacy system to another (Figure 4). Post EHR integration external transfers made up 2.2% of all admissions, compared against 4.8% of internal transfers within systems and 1.8% of admissions occurring across legacy systems. These changes were associated with a significant spike in length of stay following transfer among external transfers but not internal transfers.

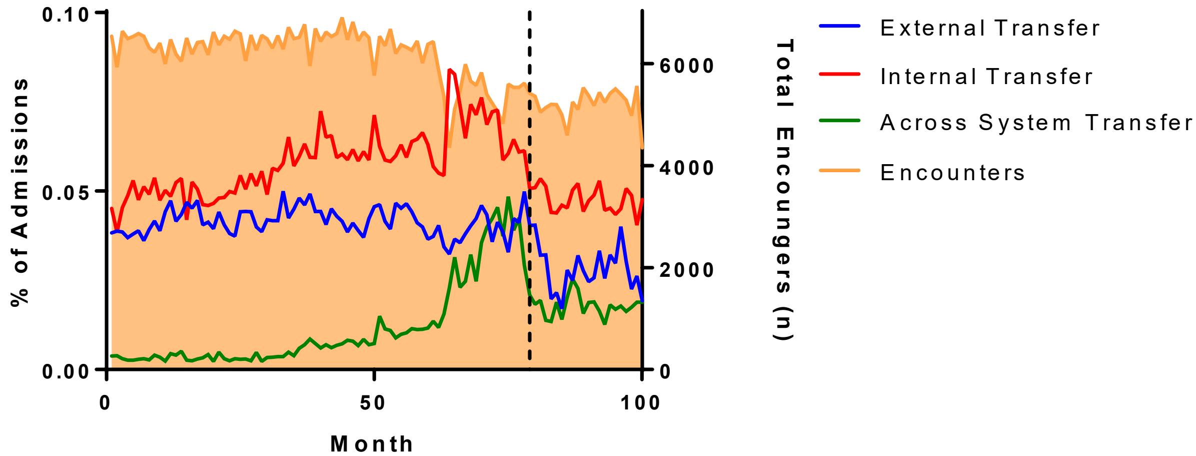


Figure 4: Trends in admission and inter-hospital transfers across the duration of the study. Complete EHR integration across two legacy health systems occurred at the dotted line.

Among internal transfers, EHR-interoperability was associated with no significant increase in LOS and increases in unadjusted inpatient and 30-day mortality but not adjusted mortality. Patient complexity also increased following EHR integration (Figure 5). Overall, the number of procedures and images did not change pre- and post- EHR integration, but the proportion of transfers with duplicate procedures dropped significantly.

A direct benefit of practice embedded research infrastructure on patient outcomes

An unexpected and unplanned outcome of this study involves the investment of research infrastructure by the health system. The initial purpose of this work was entirely pragmatic: in order to study inter-operability across health systems, a new data resource had to be developed, overcome multiple informatics barriers, created to be used efficiently and flexibly, and align with health system quality reporting. The creation of the first version of this data resource coincided with the onset of the COVID-19 pandemic.

As such, we were able to institute important innovations which were important for the care of COVID-19 patients. This included: harmonization of data management across multiple health systems in predicting hospital length of stay and capacity management. Implementation of an inter-hospital transfer system with a physician to serve as a bridge across health systems, and location of all COVID-19 patients within a single hospital. We found this was associated with improved patient safety, and reduced mortality. This resource allowed us to create early risk

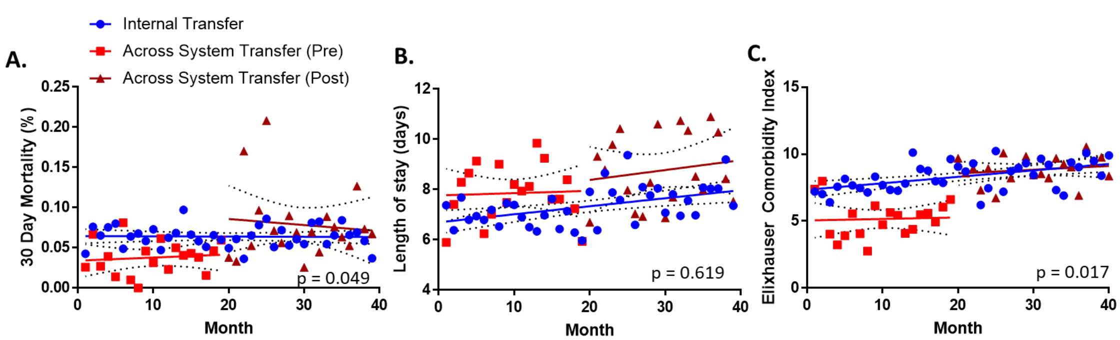


Figure 5: Trends and p values from a difference-in-differences analysis in unadjusted 30-day mortality (A), length of stay (B), and Elixhauser comorbidity index (C).

prediction models and efficiently integrate this information in the EHR to support transfer decisions. Finally, we were able to advise the Minnesota Department of Health on population level outcomes, healthcare capacity, and to assist with improving equitable allocation of scarce resources.

Discussion

Our work highlights the challenging nature of patient safety of inter-hospital transfers, and the role of inter-operability and Health Information Exchanges in improving inter-hospital transfer outcomes. We assessed the impact of improving interoperability in 3 settings: at the population level, improving usability at a single tertiary care facility, and within an 11-hospital network. We find that improvements in interoperability alone are not consistently associated with improved mortality, length of stay, or cost of care. While at the population level we observed reductions in adjusted mortality, we suspect this is due to improved documentation and coding of risk, rather than due to changes in patient outcomes.

However, we do find that efforts to improve inter-operability are associated with improvements in information flow. This was observed both by reduced duplication of labor and reductions in ICU admissions after transfer. This was more directly observed by the strong association of pre-transfer documentation elements with subsequent outcomes.

Usability and accessibility within the normal workflow of an accepting physician remains a critical barrier to high quality inter-hospital transfer that is unlikely to be overcome by technology alone. We observed increases in accessing documentation only when services had a dedicated triaging physician with a reduced clinical load. Providers reported that without a triage physician, accepting outside transfers was disruptive, and in many cases accessing clinical documentation prior to hand-off and transfer was not feasible.

There was an initial concern that improved information flow would be associated with transfers of lower risk patients. In fact, we find that the opposite was true. At the population level, we found no association with reduced risk, or reduced rate of transfers among hospital pairs which commonly transfer patients. Expected mortality increased with HIE adoption. When presented with a challenge to triage patients with limited capacity, providers chose the highest risk patient population. Following the complete integration of two EHRs, the predicted risk of patient transfers significantly increased. While this is more likely related to capacity restraints, this highlights the natural desire of providers at tertiary referral centers to prioritize the sickest patients.

We observed a good reason for this during the COVID-19 pandemic. For patients who underwent transfer to a single specialized center, we observed improved risk adjusted mortality and improved quality of care, even when accounting for barriers to EHR interoperability. Thus, while transfers are associated with higher adjusted mortality which may impact hospital quality reporting, this may be associated with lower mortality at referring hospitals and improved overall outcomes for patients. The impact of observed reductions in inter-hospital transfers following the COVID-19 pandemic is being actively investigated.

Finally, our study highlights the potentials of practice embedded research. The data resources created for the purposes of this study were done in direct collaboration with the health system. As the COVID-19 pandemic response became a priority of hospital systems, this data resource provided direct benefit to coordination, quality monitoring, capacity management, and guidance of local and regional partners. While this was not a primary goal of the project, it highlights the importance of direct partnership between clinical research efforts and health systems to advance the science of healthcare delivery. In this study’s case, this data resource was expanded and has become a center piece for the University of Minnesota's Center for Learning Health System Sciences.

Conclusions

Efforts to improve inter-operability are associated with improvements in information transfer and efficiency of care. HIE participation alone is not sufficient to reduce mortality, length of stay, or cost of care for this high-risk patient population. Efforts to improve interoperability must be paired with adequate support staff to facilitate high quality structured hand-offs both at initiation of transfer and ensure safety when the transfer occurs. Finally, while absolute mortality of this population is high, patients are transferred for highly specialized expertise which cannot be widely distributed. We observe a direct improvement to patient outcomes with COVID-19 when undergoing inter-hospital transfer. As such, quality reporting (such as cause specific mortality rates) should not be reported in a vacuum, without including data and attribution from referring hospitals.

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