The financial impact of health information exchange on emergency department care

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ABSTRACT

Objective To examine the financial impact health information exchange (HIE) in emergency departments (EDs).

Materials and Methods We studied all ED encounters over a 13-month period in which HIE data were accessed in all major emergency departments Memphis, Tennessee. HIE access encounter records were matched with similar encounter records without HIE access. Outcomes studied were ED-originated hospital admissions, admissions for observation, laboratory testing, head CT, body CT, ankle radiographs, chest radiographs, and echocardiograms. Our estimates employed generalized estimating equations for logistic regression models adjusted for admission type, length of stay, and Charlson co-morbidity index. Marginal probabilities were used to calculate changes in outcome variables and their financial consequences.

Results HIE data were accessed in approximately 6.8% of ED visits across 12 EDs studied. In 11 EDs directly accessing HIE data only through a secure Web browser, access was associated with a decrease in hospital admissions (adjusted odds ratio (OR)=0.27; $p<0001$). In a 12th ED relying more on print summaries, HIE access was associated with a decrease in hospital admissions (OR=0.48; $p<0001$) and statistically significant decreases in head CT use, body CT use, and laboratory test ordering.

Discussion Applied only to the study population, HIE access was associated with an annual cost savings of $1.9 million. Net of annual operating costs, HIE access reduced overall costs by $1.07 million. Hospital admission reductions accounted for 97.6% of total cost reductions.

Conclusion Access to additional clinical data through HIE in emergency department settings is associated with net societal saving.

Care delivery is often distributed across multiple settings and is the joint responsibility of many providers who do not have access to the same electronic medical record.[1–4] Access to a more comprehensive set of clinical data will be essential to improve care coordination as more care reimbursement shifts from fee-for-service to reimbursement plans exemplified by recent federal accountable care organization initiatives and Department of Health and Human Services meaningful use requirements.[5–10] Access to all data required for medical decision-making makes good sense. Such access should reduce medical error, improve healthcare quality, and lower medical costs.[11–13] Health information exchange (HIE) allows clinicians access to data originating from other sites of care or service. By our definition, HIE is a set of services that supports access among parties who are motivated by common interest and governed to ensure that the rights of patients and participants are protected. HIE can be achieved through services provided by one or more solitary health information organizations (HIO) and through direct, point-to-point communication among providers.[14 15]

The national experience with HIE is growing, both in terms of the number of sites exploring this technology[16 17] and the business models that rely on it. Unfortunately, because of the economic immaturity of HIE, most HIE benefits are estimates.[18–20] Reports of measurable financial benefit are few in number.[21 22]

Presenting convincing evidence is a challenge because of the relatively small but growing number of HIE efforts, the differences in HIE, the ways in which HIE is enabled and used, and the methodology challenge of measuring value in 'real world' settings. Although HIE among institutions usually takes place through a single intermediary HIO, as more organizations share data with one another on a point-to-point basis, measuring the marginal contribution of each external data source and thus the overall value of HIE will become even more problematical.[23]

As part of our 6-year effort providing access to clinical and administrative data through a single HIO supporting HIE for every consenting patient treated in any of the region's major hospitals and in some ambulatory care clinics, we conducted a 2-year study examining overall use, user perspectives, and a range of other factors.[24–26] We report here the direct financial impact study results by determining how HIE data access by emergency department (ED) physicians affected hospital admissions and diagnostic testing.

METHODS

Setting

Since 2005, the non-profit MidSouth eHealth Alliance has governed and managed HIE services among 16 major healthcare provider organizations in the Memphis, Tennessee, USA, metropolitan area. All 12 major hospitals provided hospital discharge summary notes, laboratory data, pathology reports, radiographic reports, other transcribed notes, and a range of other clinical and administrative documents. All participating clinics provided demographic information, registration information, and a limited number of clinical data types.

Clinicians began accessing health information exchange data in their EDs in May 2006 and later obtained access on hospital wards and in ambulatory clinics. HIE access in EDs was phased in over the study period; all major hospital ED had access to HIE before collecting HIE use data. As of 1 October 2010, clinicians had access to over 7.5 million encounter records on 1.7 million patients, 4.9 million chief complaints, 45 million laboratory tests, 5 million radiology reports, and 2.1 million other reports and documents. Clinical information was available for almost every patient whose data were accessed through the web HIE interface; the amount and type of data varied among patients based on the frequency and nature of their care in participating hospitals and clinics. Patients were offered the chance to 'opt out' from HIE participation at the time of every encounter at participating hospitals and clinics. The percentage of patients 'opting out' when consent was sought ranged from 1% to 3% across sites over the study period.

HIE services were based on technologies created by Vanderbilt University Medical Center and managed by a Vanderbilt University team until a local governing board and a free-standing HIE service provider assumed complete control in October 2010.[27] Data from contributing organizations were transmitted securely, tagged with meta-level descriptors, and stored in databases that allowed some organizational control and ensured access only when use complied with formal consent, data access, and data use policies.[28]

Eleven of the 12 participating hospital EDs accessed HIE data only through a separate, secure web portal designed specifically for this purpose. This portal displayed a 'white board' running list of patients registered in the ED over the previous 24 h, and displayed the number of encounter records available from other sites of care. It also supported direct queries for individual patients. HIE data were accessed in approximately 6.8% of ED encounters.[24]

ED physicians in the 12th hospital did not have access to the standard 'white board' until the 10th month of the HIE encounter data collection period. In earlier months, encounter summaries were printed by ED staff during triage. These summaries contained the dates of service, location of service, primary complaint, and International Classification of Disease, version 9 codes for every encounter in other hospitals. Physicians could obtain all of the information available to the other 11 sites through direct HIE query. This rarely happened. ED visits to this hospital constituted 20% of the total regional ED visits. Encounter forms were printed for 10–15% of ED visits (monthly percentages). When ED clinicians were given functionality identical to the direct access group, print encounter forms were abandoned and direct web access rates increased to regional norms.[24]

Study population

The study population was drawn from a Tennessee Hospital Association hospital billing database consisting of all ED visit records from the 2-year study period (January 2007 to December 2008). The initial HIE exposure group case record set consisted of all 20 285 ED visits in which HIE data access was documented through audit logs. The HIE access dates were from July 2007 to September 2008; 99.9% of HIE encounter records were from the 13-month period from August 2007 to August 2008. A matching set of no-HIE exposure group records was obtained by matching the case set with a corresponding number of ED visit records in which no HIE data access was found. Each HIE and no-HIE encounter record was matched on age (decile), gender, race, site of emergency care, presenting diagnosis, and primary payer source. The no-HIE encounter records were distributed across the entire 2-year study period to ensure adequate matching. The 11 ED settings using the web-based system for the entire collection period were labeled 'direct access site 1' to 'direct access site 11'. The 12th ED first using print encounter forms and later switching to the same web-based system was labeled the 'mixed access site' (table 1).

All research was conducted with institutional review board approval and under additional contractual restraints imposed by data-sharing agreements.

From a set of 20 285 HIE encounter records and a corresponding number of no-HIE encounter records, 4487 HIE encounter records and a corresponding number of matched no-HIE encounter records were excluded. Of these excluded records, 932 were of patients who had at least one ED visit record in both the HIE and no-HIE encounter record sets; another 3555 encounter records were for patients who had visited an ED during the study period but for whom their HIE data were accessed only in non-ED care settings. The final study population consisted of 15 798 HIE encounter records and 15 798 matched no-HIE encounter (figure 1).

The number of ED encounter records in both the HIE and no-HIE sets were greater than the number of unique patients because some patients sought ED care more than once (and often from more than one institution) over the 2-year study period. The 15 798 HIE encounter records represented 12 120 unique patients. The 15 798 no-HIE encounter records

Table 1 Study population characteristics

No (%) participants

Characteristic	HIE cases (n=15 798)	No-HIE controls (n=15 798)	p Value
Site of care			1*
Direct access site 1	30 (0.2%)	30 (0.2%)	
Direct access site 2	6 (0%)	6 (0%)	
Direct access site 3	3 (0%)	3 (0%)	
Direct access site 4	189 (1.2%)	189 (1.2%)	
Direct access site 5	46 (0.3%)	46 (0.3%)	
Direct access site 6	187 (1.2%)	187 (1.2%)	
Direct access site 7	184 (1.2%)	184 (1.2%)	
Direct access site 8	446 (2.8%)	446 (2.8%)	
Direct access site 9	982 (6.2%)	982 (6.2%)	
Direct access site 10	1718 (10.9%)	1718 (10.9%)	
Direct access site 11	1228 (7.8%)	1228 (7.8%)	
Total direct access group	5019 (31.8%)	5019 (31.8%)	
Mixed access site	10 779 (68.2%)	10 779 (68.2%)	
Average age (years)	40.4±22.7	40.4±22.7	0.925†
Gender			1*
Female	10 281 (65.1%)	10 281 (65.1%)	
Male	5517 (34.9%)	5517 (34.9%)	
Race			1*
Black	9267 (58.7%)	9267 (58.7%)	
Caucasian	6280 (39.8%)	6280 (39.8%)	
Other/not specified	251 (1.6%)	251 (1.6%)	
Insurance coverage			1*
Commercial (BC)	3755 (23.8%)	3751 (23.8%)	
Medicare	3874 (24.5%)	3874 (24.5%)	
Medicaid (TN)	5324 (33.7%)	5327 (33.7%)	
Self-pay/indigent	2482 (15.7%)	2483 (15.7%)	
All other	363 (2.3%)	363 (2.3%)	
Other characteristics‡			
Charlson index§	1.93±4.41	1.65±4.20	<0.001†

*Pearson's χ^2 test.
†Wilcoxon test.
‡Variable included in regression models but not in case–control matching.
§Mean±SD.
HIE, health information exchange.

represented 13 832 unique patients. In the HIE encounter record set, the number (%) of the 12 210 individuals seeking care one time, two times, or more than two times were 9728 (62%), 1704 (21%) and 688 (17%), respectively. Corresponding values for the no-HIE encounter records set were 12 479 (79%), 1014 (13%) and 339 (8%), respectively. Of the patients in the HIE encounter record set, 351 (2.8%) had visit records from care both in the direct web access group and the mixed access site. The number of corresponding patients in the no-HIE encounter record set was 200 (1.4%).

Analysis

The mixed access site differed from the 11-hospital direct access group both in the initial means of accessing HIE data and in different HIE use metrics resulting from employing printed encounter forms in the mixed access site. We therefore separately analyzed the direct web access group and the mixed access site. For each, we independently examined rates of outcome variables in both the HIE cohort and the no-HIE cohort. The outcome variables were: hospital admissions from the ED, head CT scans, body CT scans, chest radiographs, echocardiogram, outpatient surgery, the number of patients receiving one or more laboratory tests, admissions for observation, and ankle radiographs.

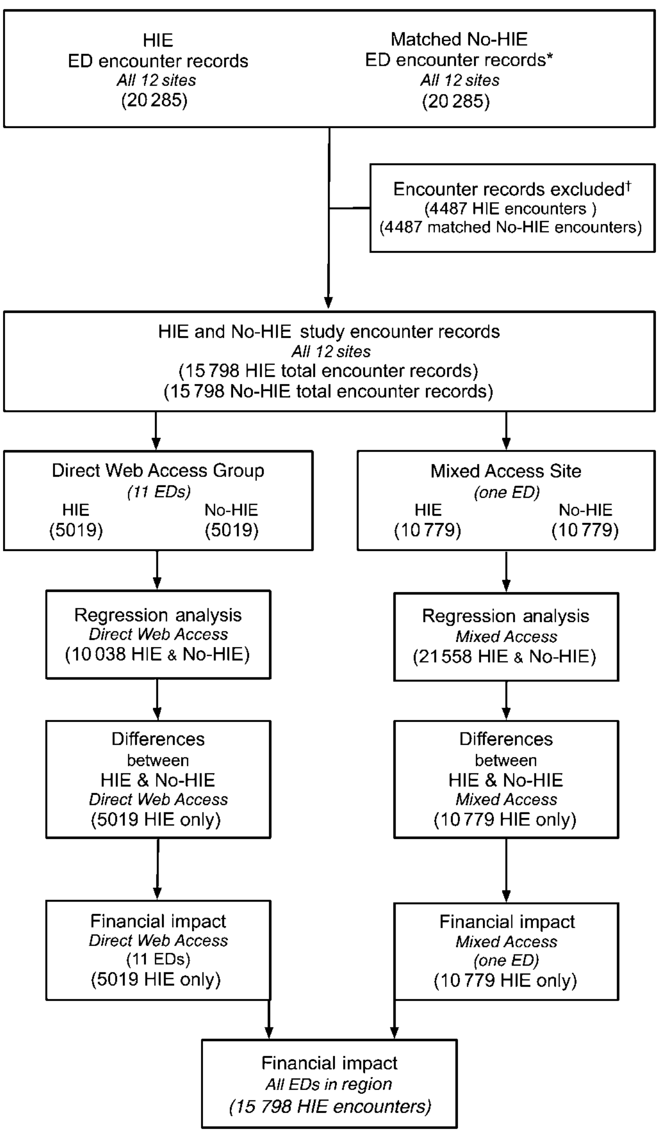

Figure 1 Study design. Exclusions, case–control matching, study cohorts, and analysis. *'No-HIE' records were matched on age, gender, race, payer, presenting diagnosis, and site of care. †Exclusions: case and control were same patients (932); case records were from non-ED settings (3555). Seventeen records (0.1%) had time stamp errors but were retained for regression analyses. ED, emergency department; HIE, health information exchange.

In light of the computational requirements for this large dataset and the need to obtain estimates efficiently, we matched each no-HIE exposure with a corresponding HIE exposure case on care delivery site, age group (decile), gender, race, primary discharge diagnostic code, and health plan status. Our subsequent regression model controlled for admission type, Charlson comorbidity index, age, health plan status, and length of stay (table 1).[29] To improve the calibration curve of our model, we applied a logarithmic transformation to the Charlson comorbidity index and applied a 0.1 shift on to eliminate zero values.

Some patients visited multiple EDs; the number of patients differed. To account for ED visit frequency differences, we used generalized estimating equations (GEE) employing a logit link function and a binomial distribution. This method allowed us to compare the marginal probability of each outcome variable.[30 31] Our GEE models adjusted for patient clustering initially through a working independent covariance matrix and subsequently by robust or sandwich SE adjustment to quantify the uncertainty of our estimates. The 95% CI of the OR were constructed by Wald statistics. We calculated the changes in each outcome variable by multiplying the differences in marginal probabilities of each outcome calculated from our fitted model by the total number of ED visits in which HIE was actually accessed. Analyses were conducted by using the R 2.10.1 statistical package (http://www.r-project.org). Two-sided p values less than 0.05 were considered statistically significant.

Financial impact analysis

In order to estimate the potential financial savings, we chose a conservative approach in order to avoid over-generalizing the results or overestimating the financial savings. In particular, the steps in our calculations were:

1. Let ε denote the set of patients with HIE exposure, and κ denote all the procedures with significant HIE effect;
2. For $i \in \varepsilon$, $j \in \kappa$, we insert the controlled variables for the i^{th} patient into the j^{th} procedure GEE model;
3. Assigning the HIE variable a value of 1 in the model, we obtain the probability of ordering the j^{th} procedure for the i^{th} patient if his/her care included access to HIE data. We denote the resulting probability as $p_{i,j,HIE}$;
4. Assigning the HIE variable a value of 0 in the model, we obtain the probability of ordering the j^{th} procedure for the i^{th} patient if his/her record care did not include access to HIE data. We denote the resulting probability as $p_{i,j,non\text{-}HIE}$;
5. We calculate the mean probabilities of undergoing the j^{th} procedure for patients whose care included HIE data access ($p_{j,HIE}$), and for the same patients is if their care did not include HIE data access ($p_{j,\ non\text{-}HIE}$);
6. Potential cost savings were then defined as:

$$
\begin{aligned}
&(\text{Total potential cost saving of the } j^{th} \text{procedure} = \\
&(\text{cost of the } j^{th} \text{procedure}) \times \\
&(\text{only the number of encounters in which} \\
&\text{HIE data were accessed}) \times (\text{p}_j, \text{non-HIE} - \text{p}_j, \text{HIE}).
\end{aligned}
$$

Costs were defined as median regional costs during the study period obtained from the Tennessee Hospital Association.

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Table 2 Direct web access group: differences in frequency of occurrence of characteristics (n=5019)*

Characteristic	Adjusted OR	p Value	95% CI	Marginal P_{HIE}†	Marginal $P_{non\text{-}HIE}$‡	Difference§
Hospitalized	0.271	<0.001	0.210 to 0.351	0.150	0.188	−191
Head CT	5.032	<0.001	3.074 to 8.236	0.019	0.004	74
Body CT	1.025	0.821	0.827 to 1.270	0.042	0.041	NS
Echocardiogram	1.858	0.407	0.430 to 8.027	0.001	0.000	NS
Outpatient Surgery	0.840	0.222	0.636 to 1.111	0.019	0.023	NS
Chest x-ray	4.367	<0.001	3.784 to 5.040	0.226	0.066	800
Laboratory tests	1.008	0.883	0.912 to 1.114	0.265	0.264	NS
24-h Admission	0.814	0.080	0.646 to 1.025	0.034	0.041	NS
Ankle x-ray	1.024	0.927	0.617 to 1.700	0.006	0.006	NS

*Logistic regression analysis using generalized estimating equations (logit link function and binomial distribution); controlled for admission type, age, health plan status, logarithmic transformation of the Charlson comorbidity index and length of stay.
†Marginal P_{HIE} = the mean probability of different healthcare procedures among HIE exposure patients.
‡Marginal $P_{non\text{-}HIE}$ = the mean probability of these procedures if patients with HIE exposure were not accessed by HIE.
§Difference = (number of encounters from HIE exposure patients) × (marginal P_{HIE}−marginal $P_{non\text{-}HIE}$).
HIE, health information exchange; NS, non-significant.

For both the 11-ED direct web access group and the single mixed access site we separately calculated the societal financial impact by summing the cost differences associated with each outcome variable in which statistically significant differences were observed.[32] We calculated annual savings from our 13-month results by multiplying the estimated total savings by (12/13). We constructed 95% CI on 1000 bootstrap samples. Our financial impact results are based only on the study ED encounters in which HIE was accessed.

RESULTS

The direct web access group

After controlling for all covariates through our regression model, HIE use in the direct web access group resulted in 191 fewer admissions than would have been predicted to occur without HIE use (OR 0.271; 95% CI 0.210 to 0.351; p<0.001). Similarly, HIE access resulted in 800 additional chest radiographs (OR 4.367; 95% CI 3.784 to 5.040; p<0.001) and 74 additional head CT studies (OR 5.032; 95% CI 3.074 to 8.236). The total financial savings were US$862 425 (95% CI US$671 884 to US$1 067 026). The calculated annual financial savings from the 11-hospital direct access group were approximately US$796 085 (table 2).

The mixed access site

After controlling for all covariates through our regression model, HIE use at the mixed access site resulted in 221 fewer admissions than would have been predicted to occur without HIE use (OR 0.478; 95% CI 0.402 to 0.568; p<0.001). Similarly, HIE access resulted in 103 fewer head CT (OR 0.913; 95% CI 0.842 to 0.991; p=0.029), 196 fewer body CT (OR 0.886; 95% CI 0.828 to 0.948; p<0.001), and 258 fewer instances in which laboratory tests were ordered (OR 0.880; 95% CI 0.828 to 0.935; p<0.001). The total financial savings were US$1 247 331 (95% CI US$991 927 to US$1 498 776). The calculated annual financial savings from the mixed access site were approximately US$1 151 382 (table 3).

Overall financial impact

Total annual societal savings were approximately US$1.95 million. Annual operating costs during the study period were approximately US$880 000. The net societal savings were therefore approximately US$1.07 million. Reduced admissions from EDs account for 97.6% of the total savings (table 4).

DISCUSSION

We present evidence that relatively limited use measured only in ED settings can confer net societal financial benefit across an entire region. We found approximately US$800 in annual savings within 11 hospital ED accessing HIE data through a simple web-based technology, and a total of US$1.9 million in annual savings if all regional hospital EDs accessing HIE through different means are included. Because HIE operational costs were kept very low (US$880 000 per year), net savings are over US$1 million. The Memphis ED we studied accounted for virtually all emergency care for the 1.2 million individuals in the metropolitan area. Assuming the per capita healthcare expenditures are similar to national estimates of US$8026, the investment to

Table 3 Mixed access site: differences in frequency of occurrence of characteristics (n=10 779)*

Characteristic	Adjusted OR	p Value	95% CI	Marginal P_{HIE}†	Marginal $P_{non\text{-}HIE}$‡	Difference§
Hospitalized	0.478	<0.001	0.402 to 0.568	0.217	0.238	−221
Head CT	0.913	0.029	0.842 to 0.991	0.124	0.134	−103
Body CT	0.886	<0.001	0.828 to 0.948	0.203	0.221	−196
Echocardiogram	1.239	0.407	0.747 to 2.056	0.003	0.003	NS
Outpatient Surgery	0.905	0.107	0.802 to 1.022	0.049	0.053	NS
Chest x-ray	0.973	0.370	0.917 to 1.033	0.403	0.408	NS
Laboratory tests	0.880	<0.001	0.828 to 0.935	0.311	0.335	−258
24-h Admission	1.084	0.213	0.955 to 1.230	0.045	0.042	NS
Ankle x-ray	0.939	0.669	0.705 to 1.252	0.008	0.008	NS

*Logistic regression analysis using generalized estimating equations (logit link function and binomial distribution); controlled for admission type, age, health plan status, logarithmic transformation of Charlson comorbidity index and length of stay.
†Marginal P_{HIE} = the mean probability of different healthcare procedures among HIE exposure patients.
‡Marginal $P_{non\text{-}HIE}$ = the mean probability of these procedures patients with HIE exposure were not accessed by HIE.
§Difference = (number of encounters from HIE exposure patients) × (Marginal P_{HIE}−Marginal $P_{non\text{-}HIE}$).
HIE, health information exchange; NS, non-significant.

Table 4 Study population societal savings over the 2-year study period

Characteristic	Cost (US$)	Direct access group (n=5019) Increase (decrease) in occurrence	Direct access group Savings (US$)	Mixed access group (n=10 779) Increase (decrease) in occurrence	Mixed access group Savings (US$)	Total (n=15 798) Increase (decrease) in occurrence	Total Savings (US$)
Hospitalized	4999	(191)	954 809	(221)	1 104 779	(412)	2 059 588
Head CT	416	74	(30 784)	(103)	42 848	(29)	12 064
Body CT	485	NS		(196)	95 060	(196)	95 060
Chest x-ray	77	800	(61 600)	NS		800	($61 600)
Laboratory tests	18	NS		(258)	4644	(258)	4644
Study societal savings over 13 months*			862 425		1 247 331		2 109 756
Approximate annual savings			796 085		1 151 382		1 947 467

*The month preceding and the month following the 13-month period contained 17 records (0.11%) of the total set.
NS, non-significant.

support HIE is only slightly more than one one-hundredth of the total per capita healthcare expenditures.

Seeking to measure impact across the entire region, we sought to identify a method of analysis that was both extremely conservative and at the same time accounted for the wide differences in patient populations, practice patterns, and uses of technology. Accordingly, we rigorously associated every HIE access encounter record with a matched no-HIE access record. We incorporated these records into regression analysis that also accounted for disease severity and other measurable factors. This model allowed us to estimate actual increases or decreases in specific activities based on whether or not HIE had been used. We used these differences to calculate the adjusted financial impact of HIE only on the patients for whom HIE data were accessed in the course of their care. We did not extrapolate to patients for whom HIE was not used.

Caution should be exercised when interpreting our findings. Access to HIE data was relatively low (6.8%) because the data were not integrated into and presented through the many different electronic health record (EHR) systems used within the region. Previous work in this population suggests there are differences between the study patients for whom HIE data were accessed and those for whom it was not.[24] Providers use HIE when they encounter clinical problems in which additional information may provide insight. The variation in intent among ED clinicians could not be comprehensively measured and incorporated into our study. We speculate that the small but significant increase in chest x-ray use in inner-city ED within the direct access group is an example of differences in provider motivation. Our observations support the findings of others who suggest that providers find HIE helpful in managing non-urgent chronic medical conditions—particularly for indigent populations seeking care in more than one setting.[22] As is the case across the country, many ED visits were for chronic or non-urgent medical conditions[33 34] Our HIE system was used more frequently for 'repeat visits'.[24] Our approach did not allow us to account for provider clustering effects. Such clustering effects would affect standard errors and CI but not the estimated increases or reductions in outcome variables.

Our findings suggest that widespread hospital support for HIE and initial deployment only in ED settings will still lower overall societal costs. In our case, these societal cost reductions were of sufficient magnitude to offset the entire cost of operations. Initial use of HIE data in urban ED settings confers immediate trust and value among key hospital stakeholders, but far greater financial and clinical benefit is anticipated when HIE is ubiquitous across a far wider array of care settings. If care delivery within a region is highly fragmented, collaborative HIE among an entire community may confer far greater benefit by improving care coordination, measuring and addressing hospital readmissions, and collectively developing more comprehensive quality metrics for both individuals and populations. As has been our own experience, we assume that basic HIE services can be provided inexpensively and that HIE once established can expand at relatively low cost to encompass a broader array of clinicians employing certified EHR. Federal efforts in EHR certification, national data standards, and meaningful use incentives will make the integration of medical practices into HIE networks far less costly than was the case when our effort began in 2004. Our study demonstrates a positive financial impact on communities, but we believe these savings will be only a fraction of the economic benefit that will be realized as our connected digital healthcare delivery system evolves.

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REFERENCES

1. **Burgeois FC,** Olson KL, Mandl KD. Patients treated at multiple acute health care facilities: quantifying information fragmentation. *Arch Intern Med* 2010;**170**:1989—95.
2. **Grumbach K,** Bodenheimer T. A primary care home for Americans: putting the house in order. *JAMA* 2002;**288**:889—93.
3. **Dixon BE,** Zafar A, Overhage JM. A framework for evaluating the costs, effort, and value of nationwide health information exchange. *J Am Med Inform Assoc* 2010;**17**:295—301.
4. **Hoffman C,** Rice D, Sung HY. Persons with chronic conditions. Their prevalence and costs. *JAMA* 1996;**276**:1473—9.
5. **Bodenheimer T.** Coordinating care — a perilous journey through the health care system. *N Engl J Med* 2008;**358**:1064—71.
6. **Blumenthal D.** Launching HITECH. *N Engl J Med* 2010;**362**:382—5.
7. **Blumenthal D,** Tavenner M. The "meaningful use" regulation for electronic health records. *N Engl J Med* 2010;**363**:501—14.
8. **Devore S,** Champion RW. Driving population health through accountable care organizations. *Health Aff (Millwood)* 2011;**30**:41—50.
9. **Goldsmith J.** Accountable care organizations: the case for flexible partnerships between health plans and providers. *Health Aff (Millwood)* 2011;**30**:32—40.
10. **Penfield SL,** Anderson KM, Edmund M, *et al*. *Toward Health Information Liquidity: Realization of Better, More Efficient Care from the Free Flow of Health Information*. Washington: Booz Allen Hamilton, 2009.
11. **Hillestad R,** Bigelow J, Bower A, *et al*. Can electronic medical record systems transform health care? Potential health benefits, savings, and costs. *Health Aff (Millwood)* 2005;**24**:1103—17.
12. **McClellan M,** McKethan AN, Lewis JL, *et al*. A national strategy to put accountable care into practice. *Health Aff (Millwood)* 2010;**29**:982—90.
13. **Walker J,** Pan E, Johnston D, *et al*. The value of health care information exchange and interoperability. *Health Aff (Millwood)* Health Affairs Web Exclusive, 19 January 2005.
14. **HIMSS HIE Guide Work Group.** *Topic Series: HIE Technical Models*, November, 2009. http://www.himss.org/content/files/2009HIETechnicalModels.pdf (accessed 23 Oct 2011).

15. **Office of the National Coordinator for Health Information Technology.** *Direct Project Home Page*. 2011. http://directproject.org/ (accessed 1 Jul 2011).
16. **Adler-Milstein J,** Bates DW, Jha AK. U.S. Regional health information organizations: progress and challenges. *Health Aff (Millwood)* 2009;**28**:483—92.
17. **Adler-Milstein J,** Bates DW, Jha AK. A survey of health information exchange organizations in the United States: implications for meaningful use. *Ann Intern Med* 2011;**154**:666—71.
18. **Hwang J,** Christensen CM. Disruptive innovation in health care delivery: a framework for business-model innovation. *Health Aff (Millwood)* 2008;**27**:1329—35.
19. **Fontaine P,** Ross SE, Zink T, *et al*. Systematic review of health information exchange in primary care practices. *J Am Board Fam Med* 2010;**23**:655—70.
20. **Frisse ME,** Holmes RL. Estimated financial savings associated with health information exchange and ambulatory care referral. *J Biomed Inform* 2007;**40**(6 Suppl):S27—32.
21. **Overhage JM,** Dexter PR, Perkins SM, *et al*. A randomized, controlled trial of clinical information shared from another institution. *Ann Emerg Med* 2002;**39**:14—23.
22. **Vest JR,** Zhao H, Jasperson J, *et al*. Factors motivating and affecting health information exchange usage. *J Am Med Inform Assoc* 2011;**18**:143—9.
23. **Johnson KB,** Gadd C. Playing smallball: approaches to evaluating pilot health information exchange systems. *J Biomed Inform* 2007;**40**(6 Suppl 1):S21—6.
24. **Johnson KB,** Unertl KM, Chen Q, *et al*. Health information exchange usage in emergency departments and clinics: the who, what and why. *J Am Med Inform Assoc* 2011;**18**:690—7.
25. **Gadd CS,** Ho YX, Cala CM, *et al*. User perspectives on the usability of a regional health information exchange. *J Am Med Inform Assoc* 2011;**18**:711—16.
26. **Unertl KM,** Johnson KB, Lorenzi NM. Health information exchange technology on the front lines of healthcare: workflow patterns, reasons for use, and provider outcomes. *J Am Med Inform Assoc* 2011. Published Online First: 14 October 2011. doi:10.1136/amiajnl-2011-000432.
27. **Frisse ME,** King JK, Rice WB, *et al*. A regional health information exchange: architecture and implementation. *AMIA Annu Symp Proc* 2008:212—16.
28. **Markle Foundation.** *The Connecting for Health Common Framework*. 2006. http://www.connectingforhealth.org/ (accessed 23 Feb 2007).
29. **Charlson M,** Szatrowski TP, Peterson J, *et al*. Validation of a combined comorbidity index. *J Clin Epidemiol* 1994;**47**:1245—51.
30. **Zeger SL,** Liang KY. Longitudinal data analysis for discrete and continuous outcomes. *Biometrics* 1986;**42**:121—30.
31. **Zeger SL,** Liang KY, Albert PS. Models for longitudinal data: a generalized estimating equation approach. *Biometrics* 1988;**44**:1049—60.
32. **Byford S,** Raftery J. Perspectives in economic evaluation. *BMJ* 1998;**316**:1529—30.
33. **California Health Care Foundation.** *Overuse of Emergency Departments Among Insured Californians Report*. 2007. http://www.chcf.org/documents/hospitals/EDOveruse.pdf (accessed 1 Jul 2011).
34. **Nolan L,** Havey J, Jones K, *et al*. *Urgent Matters: Assessment of the Safety Net in Memphis Tennessee*. George Washington University School of Public Health and Health Serivces, Department of Health Policy, 2004. http://urgentmatters.org/media/file/aboutProject_reports_Final_Memphis.pdf (accessed 1 Jul 2011).