Association of Electronic Health Record Use With Quality of Care and Outcomes in Heart Failure: An Analysis of Get With The Guidelines—Heart Failure

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Background—Adoption of electronic health record (EHR) systems has increased significantly across the nation. Whether EHR use has translated into improved quality of care and outcomes in heart failure (HF) is not well studied.

Methods and Results—We examined participants from the Get With The Guidelines—HF registry who were admitted with HF in 2008 (N=21 222), using various degrees of EHR implementation (no EHR, partial EHR, and full EHR). We performed multivariable logistic regression to determine the relation between EHR status and several in-hospital quality metrics and outcomes. In a substudy of Medicare participants (N=8421), we assessed the relation between EHR status and rates of 30-day mortality, readmission, and a composite outcome. In the cohort, the mean age was 71±15 years, 49% were women, and 64% were white. The mean ejection fraction was 39±17%. Participants were admitted to hospitals with no EHR (N=1484), partial EHR (N=13 473), and full EHR (N=6265). There was no association between EHR status and several quality metrics (aside from β blocker at discharge) or in-hospital outcomes on multivariable adjusted logistic regression ($P>0.05$ for all comparisons). In the Medicare cohort, there was no association between EHR status and 30-day mortality, readmission, or the combined outcome.

Conclusions—In a large registry of hospitalized patients with HF, there was no association between degrees of EHR implementation and several quality metrics and 30-day postdischarge death or readmission. Our results suggest that EHR may not be sufficient to improve HF quality or related outcomes. **(*J Am Heart Assoc*. 2018;7:e008158. DOI: 10.1161/JAHA.117.008158.)**

Key Words: electronic health records • heart failure • quality • readmission

Adoption of electronic health record (EHR) systems has increased significantly across the nation. This has been, in part, driven by the implementation of the Health Information Technology for Economic Clinical Health Act, adopted in 2009 and enacted in 2011 to promote the meaningful use of health information technology systems. Under the Health Information Technology for Economic Clinical Health Act, healthcare providers were offered financial incentives to adopt EHR systems by 2015. The Health Information Technology for Economic Clinical Health Act recognizes numerous theoretical benefits of EHR use, including improvement of care coordination, reduction of healthcare disparities, decreased medication errors, and efficient and rapid analysis of quality measures. Heart failure (HF) is the most common admission diagnosis among Medicare recipients, and readmission rates unfortunately remain high.[1] The approach to reduce HF disease burden has been multifaceted, and use of the EHR may improve the HF morbidity and mortality through improved quality of care. Whether these theoretic benefits translate into actual improvements in patient care is of vital interest from clinical, economic, and policy perspectives.

Few data are available describing whether EHR use might improve the quality of care delivered and ultimately reduce readmissions in HF.[2] A prior study of patients with HF suggested that EHR adoption did not improve quality metrics, readmission, or mortality.[3] However, individual patient

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Clinical Perspective

What Is New?

- Few data are available describing whether electronic health record (EHR) use might improve the quality of care delivered and ultimately reduce readmissions in patients with heart failure.
- Using high-quality registry data from Get With The Guidelines—Heart Failure, we found that EHR use was not associated with improved quality of care, in-hospital outcomes, or postdischarge events.

What Are the Clinical Implications?

- Although the EHR offers numerous theoretical benefits, our study questions assumptions about EHR implementation and improved quality of care among patients with heart failure.
- Our work should encourage increasing attention to EHR optimization in the current era of EHR technology.

characteristics (important for adjustment in analyses) were lacking, minimal process measures were collected, and the study used older available data. In IMPROVE-HF (Registry to Improve the Use of Evidence-Based Heart Failure Therapies in the Outpatient Setting) study, EHR use among outpatient cardiology/multispecialty practices demonstrated modest differences in only a few metrics of quality improvement.[2] EHR use, in some studies, has increased "alert fatigue" and hindered workflow and provider interaction, which might temper any potential benefits.[4] In addition, implemented algorithms may not be adequate to achieve quality improvement goals. Therefore, the benefit of EHR implementation is not a foregone conclusion.

Therefore, we analyzed data from Get With The Guidelines—HF (GWTG-HF), a national registry of hospitalized patients with HF with comprehensive data on quality metrics. We sought to determine whether implementation of EHR was associated with improved quality of care and reduced mortality during hospital admission as well as lower 30-day risk of readmission or mortality in patients with HF.

Methods

Study Population and Design

Details about the method of GWTG-HF have been previously reported.[5] In brief, GWTG-HF is an ongoing in-hospital quality improvement program that aims to promote adherence to guideline-directed care for patients admitted with HF. Hospitals enroll in GWTG-HF on a voluntary basis and submit detailed clinical information for each consecutive patient admitted with the primary diagnosis of HF using an Internet-based Patient Management Tool (Quintiles, Cambridge, MA), in which patient data are deidentified. The centers participating in GWTG-HF are required to obtain institutional review board approval for the GWTG-HF protocol and are granted a waiver for informed consent under the common rule. The aggregate deidentified data are analyzed at the Duke Clinical Research Institute (Durham, NC), which serves as the data analysis center. Institutional review board approval was obtained for the analysis. Study data are confidential and cannot be shared, according to the terms of the contracts signed between participating hospitals and the American Heart Association, as well as terms governing the use of Medicare claims data. Therefore, the data, analytic methods, and study materials will not be made available to other researchers for purposes of reproducing the results or replicating the procedure.

We linked data on the use of EHRs from the American Hospital Association Health Information Technology annual survey[6] to the GWTG-HF database. Survey respondents report the degree of adoption for each of 24 individual electronic functionalities. Hospitals were considered to have full EHR implementation if they met the criteria for at least a basic EHR on the basis of 8 key functionalities, as defined in prior studies.[6,7]

We first analyzed patients admitted to the hospital in 2008 and excluded those patients admitted to hospitals with limited participation in GWTG-HF (identified by >25% missing medical history or sex), missing EHR status (N=4039), or nontraditional discharge (discharge to hospice, discharge status missing, left against medical advice, undocumented discharge status, or transfer out; N=1201), leaving 21 222 patients for analysis. To obtain longitudinal data for subgroup analysis on readmission rates and all-cause mortality, GWTG-HF registry was merged with claims from Centers for Medicare and Medicaid Services from February 1, 2008, through February 1, 2009, and follow-up was attempted through a 30-day period. A total of 8421 patients were successfully merged with Medicare Part A inpatient claims by admission and discharge dates, hospital, date of birth, and sex (as has been performed previously in GWTG analyses).[8]

Clinical Characteristics and Outcome Variables

Detailed patient-level information on demographics, insurance, comorbidities, medications, vital signs, length of stay, admission laboratory testing, ejection fraction, discharge treatment and counseling, discharge destination, and in-hospital mortality was collected. Hospital-level characteristics included number of beds, teaching hospital status, and rural versus urban location. Numerous quality checks for data abstraction have been previously described.[7]

The primary outcome of the study was a defect-free composite quality score. The defect-free care variable is a measure that required individuals receive all of the process measures for which they were eligible.[9] These process measures included the following: angiotensin-converting enzyme inhibitor or angiotensin receptor blocker at discharge, βblocker at discharge, aldosterone antagonist therapy at discharge, anticoagulation therapy for atrial fibrillation at discharge, smoking cessation counseling, and deep vein thrombosis prophylaxis.[9]

Secondary end points included the individual quality metrics, hospital length of stay, discharge location (home versus other), and in-hospital mortality. On longitudinal analysis, we also analyzed the postdischarge outcomes in the subgroup of Medicare beneficiaries measured at 30 days, including all-cause hospitalization or all-cause mortality, all-cause hospitalization, and all-cause mortality. If a patient has multiple hospitalizations logged in the registry, only the first hospitalization was considered for analysis. All-cause mortality was based on death dates in Medicare denominator files, and readmission was based on Medicare inpatient claims using diagnostic-related group codes.[8]

Statistical Analysis

Cross-sectional analysis

Patient- and hospital-level characteristics as well as performance measures were displayed by EHR use (none, partial, or full implementation). Data were compared between groups using ANOVA for normally distributed continuous variables (or nonparametric equivalent when appropriate). χ^2 Tests (or Fisher's exact test when appropriate) were used to compare categorical variables between groups. Trend tests were used for comparisons. Continuous data with a normal distribution were displayed as mean±SD. Skewed data were presented as median and 25th to 75th percentile.

To examine the association of EHR with hospital-level defect-free composite score and patient-level care measures, we performed unadjusted and adjusted multivariable logistic regression models with generalized estimating equations with the following rationale: Patients from a given hospital have shared commonalities (eg, same geographic area and treating physicians) compared with patients from a different hospital. Therefore, such a clustering of patients within specific hospitals necessitates the use of hierarchical models or mixed-effects models to provide unbiased and reliable estimates of the parameters of interest. The generalized estimating equations technique takes such a clustering of patients within hospitals into account to provide unbiased parameter estimates and robust variance estimations for statistical inference. For these analyses, the referent arm was no EHR use. Covariates for multivariable analysis included age, sex, race, medical history (anemia, ischemic history, cardiovascular accident or transient ischemic attack, diabetes mellitus, hyperlipidemia, hypertension, chronic obstructive pulmonary disease or asthma, peripheral vascular disease, renal insufficiency, and cigarette smoking in past year), vital signs on admission (systolic blood pressure, heart rate, sodium, blood urea nitrogen, and left ventricular ejection fraction), and hospital characteristics (region, teaching hospital status, number of beds, rural versus urban, and heart transplant center status).[10]

Survival analysis

To determine associations between EHR implementation and 30-day postdischarge outcomes (all-cause readmission or mortality, all-cause readmission, and mortality), we performed univariable and multivariable Cox proportional hazards analyses and used robust variance estimation to account for hospital clustering. The proportional hazard assumption was checked and confirmed, and the referent group included patients admitted to hospitals with no EHR. Patients who died before experiencing a hospitalization were censored for analyses using all-cause readmission as the single outcome. For readmission outcomes, the method of Fine and Gray was used to account for the competing risk of mortality. Kaplan-Meier curves were constructed for 30-day readmission and mortality.[11]

In all multivariable models, multiple imputation with 25 imputations was used to impute non–hospital-level missing covariates. Our multiple imputation method assumed that missing data are missing at random. Therefore, we used the multiple imputation by chained equations algorithm, which is flexible and can be used in many settings, especially in the absence of a clear monotone pattern of missing data.[12,13] Because of the missing at random assumption, we have multiply imputed missing patient-level covariates and outcomes (there were no missing hospital-level characteristics). A 2-sided $P \leq 0.05$ was considered statistically significant. The Duke Clinical Research Institute performed all analyses using SAS software, version 9.1.3 (SAS Institute, Cary, NC).

Results

Characteristics of Study Participants

Descriptive characteristics of the study sample are displayed in Table 1. A total of 21 222 patients met the inclusion criteria and were analyzed in the present study, of whom 1484 were admitted to a hospital with no EHR, 13 473 were admitted to a hospital with partial EHR, and 6265 were admitted to a hospital with a full EHR. The mean age of the cohort was 71±15 years, 49% were women, and 64% were

Table 1. Clinical Characteristics of the GWTG-HF Patients at Hospital Admission

Characteristics	Overall Cohort (N=21 222)	No EHR (N=1484)	EHR Partially Implemented (N=13 473)	EHR Fully Implemented (N=6265)	*P* Value
Demographics					
Age, y	71±15	68±17	72±14	70±15	<0.0001
Women, %	48.53	49.12	48.63	48.16	<0.0001
Race, %					<0.0001
White	64.17	53.71	68.22	57.95	
Black	24.14	22.10	21.84	29.59	
Asian	1.78	1.15	2.11	1.21	
Hispanic	7.19	20.49	5.04	8.63	
Other	2.73	2.56	2.80	2.61	
Insurance status, %					<0.0001
No insurance or not documented	5.74	16.08	4.46	6.04	
Medicare	55.39	46.06	56.67	54.86	
Medicaid	11.22	18.62	8.72	14.94	
Other	27.65	19.23	30.15	24.16	
Medical history, %					
Atrial fibrillation or flutter	32.44	27.28	33.37	31.66	0.98
COPD or asthma	28.64	22.56	28.97	29.27	0.004
Diabetes mellitus	42.95	39.54	41.56	46.45	<0.0001
Hyperlipidemia	43.49	35.61	44.56	43.00	0.22
Hypertension	76.87	75.31	75.94	79.07	<0.0001
Peripheral vascular disease	11.65	10.30	11.56	12.11	0.08
Prior CABG	17.96	15.57	18.60	17.17	0.38
Previous myocardial infarction	22.41	17.37	21.78	24.74	<0.0001
Stroke or transient ischemic attack	14.86	11.71	14.50	16.22	<0.0001
Dialysis	4.35	3.77	3.81	5.55	<0.0001
Smoking	17.66	19.78	16.47	19.59	0.0005
Medications before admission, %					
ACE inhibitor	37.90	39.59	38.48	35.83	0.001
ARB	14.56	14.79	14.92	13.54	0.048
Aldosterone antagonist	9.21	11.32	8.89	9.51	0.68
Blocker	63.44	64.38	64.49	60.34	<0.0001
Digoxin	16.15	18.10	16.15	15.59	0.08
Loop	56.52	55.37	57.70	53.63	0.0007
Nitrate	16.65	16.45	16.41	17.36	0.19
Hydralazine	6.83	5.12	6.37	8.55	<0.0001
Statin	41.98	38.51	43.38	39.17	0.008
Vital signs					
Body mass index, kg/m^2	29.2±7.7	29.0±6.6	29.2±7.8	29.3±7.7	0.40
Systolic blood pressure, mm Hg	141±31	142±30	140±30	143±32	0.0003
Diastolic blood pressure, mm Hg	77±19	79±20	76±18	78±20	0.0008
Heart rate, bpm	85±20	87±22	84±20	86±21	0.0009

Continued

Table 1. Continued

Characteristics	Overall Cohort (N=21 222)	No EHR (N=1484)	EHR Partially Implemented (N=13 473)	EHR Fully Implemented (N=6265)	*P* Value
Laboratory and echocardiographic data					
Sodium, mEq/L	138±9	138±7	138±11	137±6	<0.0001
Serum creatinine, mg/dL*	1.30 (1.00–1.90)	1.30 (1.00–1.90)	1.30 (1.00–1.80)	1.30 (1.00–1.90)	0.08
B-type natriuretic peptide, pg/mL*	778 (343–1647)	1020 (506–2060)	732 (309–1555)	879 (405–1885)	<0.0001
Left ventricular ejection fraction, %	39±17	40±18	40±17	38±17	<0.0001
Hospital characteristics					
Teaching hospital, %	76.45	49.33	73.96	88.22	<0.0001
No. of beds	447±185	337±168	443±197	481±148	<0.0001
Rural location (vs urban), %	3.03	1.08	4.66	0.00	<0.0001
Heart transplant hospital, %	12.05	19.81	14.09	5.83	<0.0001

Data are mean±SD unless otherwise indicated. ACE indicates angiotensin-converting enzyme; ARB, angiotensin receptor blocker; bpm, beats per minute; CABG, coronary artery bypass graft; COPD, chronic obstructive pulmonary disease; EHR, electronic health record; and GWTG-HG, Get With The Guidelines—Heart Failure.
*Presented as median (25th–75th percentile) because data are skewed.

white. More than half the patients were insured by Medicare. Comorbidities were common, including hypertension (77%), hyperlipidemia (43%), diabetes mellitus (43%), and atrial fibrillation or flutter (32%). Long-term medication use reflected standard therapies used in the comorbidities detailed in Table 1. Blood pressure was mildly elevated (141±31/77±19 mm Hg), and the mean body mass index was 29.2±7.7 kg/m^2. The median (25th–75th percentile) B-type natriuretic peptide level was 778 (343–1647) pg/mL, and most patients had a reduced ejection fraction (39±17%). Patients were admitted to mostly teaching hospitals (76%).

Table 2 shows unadjusted rates of implementation of several quality metrics as well as in-hospital outcomes by EHR status. Increasing EHR implementation was associated with improved patient outcomes (higher rates of discharge home and less frequent length of stay >4 days). However, increasing EHR implementation was also associated with worse rates of several achievement measures (smoking cessation counseling, aldosterone antagonist, anticoagulation for atrial fibrillation, and evidence-based β blockers).

Association of EHR With Quality Metrics and In-Hospital Outcomes

Table 3 shows the association of EHR status with predefined quality metrics and in-hospital outcomes on unadjusted and multivariable-adjusted analysis. The referent arm for comparison was admission to hospital with no EHR. There was no association between EHR status and any quality metric or in-hospital outcome on unadjusted logistic regression (P>0.05 for all comparisons). Adjustment for several potential confounders yielded similar results, aside from an association between β blocker at discharge when comparing partial EHR with no EHR (odds ratio, 2.65; 95% confidence interval, 1.17–5.98), although the association was not significant when comparing full EHR with no EHR (odds ratio, 1.87; 95% confidence interval, 0.78–4.48).

The Figure displays Kaplan-Meier curves by EHR status for 30-day outcomes (mortality, readmission, and a combined outcome) among Medicare participants. There was no difference in the 3 EHR groups with respect to each outcome (P>0.05 for all comparisons by log-rank test). Table 4 shows the hazard ratios comparing full and partial EHR status (compared with no EHR). All models were adjusted for the same covariates used in previous logistic regression. There was no association between EHR status and 30-day event rates (P>0.05 for all comparisons).

Discussion

In a large national registry of >20 000 participants admitted with HF, we found that there was no association between EHR status and patient-level quality metrics or in-hospital outcomes. In a subgroup of Medicare patients with available longitudinal data, we similarly found no association between EHR status and 30-day event rates, including death, readmission, or a combined outcome. Our study is one of the largest of EHR use in HF and provides insight into the use of EHR to improve patient care. Given the millions of patients with HF and its large toll on both patient quality of life and economic burden, our results suggest that the EHR may not be sufficient to improve HF-related outcomes.

EHR is a tool in increasingly complex hospital infrastructures, and recent studies have shown that providers spend a

Table 2. Outcomes and Achievement Measures by EHR Status

Variable	Overall Cohort (N=21 222)	No EHR (N=1484)	EHR Partially Implemented (N=13 473)	EHR Fully Implemented (N=6265)	*P* Value
Outcomes, %					
Discharged home	80.18	78.57	79.48	82.06	<0.0001
In-hospital mortality	2.54	2.49	2.55	2.54	0.97
Length of stay >4 d	44.31	47.23	44.48	43.28	0.012
Achievement measures at discharge, %					
ACEI/ARB	93.00	94.68	92.39	93.82	0.29
Any β blocker	94.89	94.98	95.03	94.61	0.44
Smoking cessation counseling	97.54	100.00	97.84	96.45	0.0003
Aldosterone antagonist at discharge	22.64	30.79	25.02	16.22	<0.0001
Anticoagulation for atrial fibrillation	62.24	69.41	65.50	54.01	<0.0001
DVT prophylaxis	45.40	40.87	45.01	49.79	0.089
Evidence-based specific β blockers	81.61	83.67	83.25	78.07	<0.0001

ACEI indicates angiotensin-converting enzyme inhibitor; ARB, angiotensin receptor blocker; DVT, deep venous thrombosis; and EHR, electronic health record.

substantial amount of daily workflow interacting with a more contemporary form of the EHR than studied herein.[14] Therefore, we do not contend, on the basis of our results, that EHR should not be adopted. Rather, our findings underscore the need for improved use of EHR or refinement of its clinical decision support and algorithm construction. For example, we now have several effective therapies in the treatment of HF (particularly HF with reduced ejection fraction), although implementation into clinical practice is still not uniform among patients eligible for therapy. As such, EHRs, through clinical decision support systems, hold substantial promise to increase delivery of these therapies.[15] However, our study showed improvement in only one metric (β blocker at discharge) associated with EHR use, but not in other quality metrics, in-hospital events, or postdischarge outcomes. Because adoption of EHR is an extremely costly endeavor and expected to grow, such analysis of the magnitude of its utility on quality improvement is crucial and provides ongoing feedback on public policy implementation.

Other studies of EHR use in the HF population have reported conflicting outcomes. In an analysis of outpatients with HF and reduced ejection fraction, there was only a modest association between EHR and several quality measures.[2] Although important, this analysis did not include in-hospital outcomes or postdischarge events. Our results are concordant with analyses involving general medical patients[16,17] as well as patients with stroke.[7] Why the EHR may not improve quality of care or outcomes in HF is possibly multifactorial. EHR, in itself, can have unintended effects on medication error risks,[18] mortality,[19] and provider satisfaction.[20] Therefore, although there may be benefits of EHR, including streamlining many facets of patient care or consolidation of patient-level data, more attention must be paid to these unintended adverse effects. Although there are some notable studies showing improvement in quality metrics with EHR use in a more general population, they are older and likely studied less sophisticated EHR systems.[21,22] In addition, secular trends in attention to quality metrics may marginalize the effects of the EHR system. For example, the implementation of a performance-improvement system increased the use of recommended HF therapies among outpatient cardiology practices. However, practices that used EHR did not achieve greater quality improvements than practices that were paper based.[23]

EHR adoption has increased substantially since the passing of the Health Information Technology for Economic Clinical Health Act in 2009. Adoption is near universal in GWTG-HF participating hospitals in the present day. Therefore, our analysis was limited to data from 2008, which allowed us to study the effects of the various degrees of EHR adoption and several quality metrics and outcomes. Our study questions assumptions about EHR implementation and improved quality of care and should draw increasing attention to EHR optimization in the current era of EHR technology.

Our results should be interpreted in the context of a few limitations. First, our study is limited to hospitals participating in GWTG-HF, a voluntary quality improvement program across the United States dedicated to improving outcomes for patients admitted with HF, as well as those hospitals participating in the American Hospital Association annual survey. Therefore, our results may not be generalizable to nonparticipating hospitals. For example, because the

Table 3. Association of EHR With Quality Measures and In-Hospital Outcomes on Unadjusted and Multivariable-Adjusted Analysis

Variable	No EHR Event Rate, n/N (%)	Partially Implemented EHR Event Rate, n/N (%)	Fully Implemented EHR Event Rate, n/N (%)	EHR Fully Implemented vs No EHR Unadjusted OR (95% CI)*	EHR Partially Implemented vs No EHR Unadjusted OR (95% CI)*	EHR Fully Implemented vs No EHR Adjusted OR (95% CI)*	EHR Partially Implemented vs No EHR Adjusted OR (95% CI)*
Quality measures							
Defect-free hospital care composite score†	NA	NA	NA	0.72 (0.41–1.28)	0.90 (0.53–1.53)	0.85 (0.42–1.72)	0.93 (0.49–1.78)
ACE inhibitor or ARB at discharge	534/564 (95)	4380/4741 (92)	2248/2396 (94)	1.04 (0.54–2.01)	0.95 (0.51–1.76)	1.08 (0.51–2.32)	1.05 (0.49–2.26)
Blocker at discharge	568/598 (95)	5351/5631 (95)	2649/2800 (95)	1.35 (0.59–3.07)	1.48 (0.68–3.23)	1.87 (0.78–4.48)	2.65 (1.17–5.98)
Aldosterone antagonist therapy at discharge	202/656 (31)	1413/5637 (25)	474/2923 (16)	0.78 (0.31–1.95)	1.23 (0.52–2.90)	0.79 (0.31–1.96)	1.45 (0.63–3.33)
Anticoagulation therapy for atrial fibrillation at discharge	261/376 (69)	2529/3861 (66)	1003/1857 (54)	0.82 (0.49–1.39)	0.83 (0.52–1.31)	0.59 (0.27–1.31)	0.95 (0.52–1.73)
Smoking cessation counseling	279/279 (100)	2088/2134 (98)	1169/1212 (96)	1.61 (0.60–4.28)	NA‡	0.47 (0.16–1.43)*	NA‡
Deep vein thrombosis prophylaxis	47/115 (41)	613/1362 (45)	119/239 (50)	1.61 (0.40–6.49)	0.90 (0.25–3.23)	1.20 (0.27–5.25)	0.95 (0.26–3.47)
Outcomes							
In-hospital mortality	37/1484 (2)	343/13 473 (3)	159/6265 (3)	1.10 (0.74–1.64)	1.10 (0.77–1.57)	1.11 (0.70–1.76)	1.01 (0.68–1.51)
Discharged home	1166/1484 (79)	10 708/13 473 (79)	5141/6265 (82)	1.16 (0.63–2.13)	0.92 (0.52–1.62)	1.26 (0.97–1.63)	1.19 (0.95–1.50)
Length of stay >4 d	657/1391 (47)	5643/12 688 (44)	2569/5936 (43)	0.98 (0.70–1.38)	0.94 (0.69–1.29)	0.88 (0.64–1.20)	0.93 (0.70–1.22)

ACE indicates angiotensin-converting enzyme; ARB, angiotensin receptor blocker; CI, confidence interval; EHR, electronic health record; NA, not applicable; and OR, odds ratio.

*Multivariable model adjusted for age, sex, race, anemia, ischemic history, stroke or transient ischemic attack, diabetes mellitus, hyperlipidemia, hypertension, chronic obstructive pulmonary disease or asthma, peripheral vascular disease, renal insufficiency, cigarette smoking in the past year (not for outcome of smoking cessation counseling), systolic blood pressure, heart rate, sodium, blood urea nitrogen, left ventricular ejection fraction, estimated glomerular filtration rate, and hospital region, teaching status, number of beds, rural vs urban location, and heart transplant center status.

†Because the defect-free hospital care composite score is a continuous variable, unadjusted and adjusted estimates only are shown.

‡In the no EHR group, there were no patients who did not receive smoking cessation counseling. Therefore, we grouped the no EHR and EHR partially implemented patients into one group to reach statistical convergence.

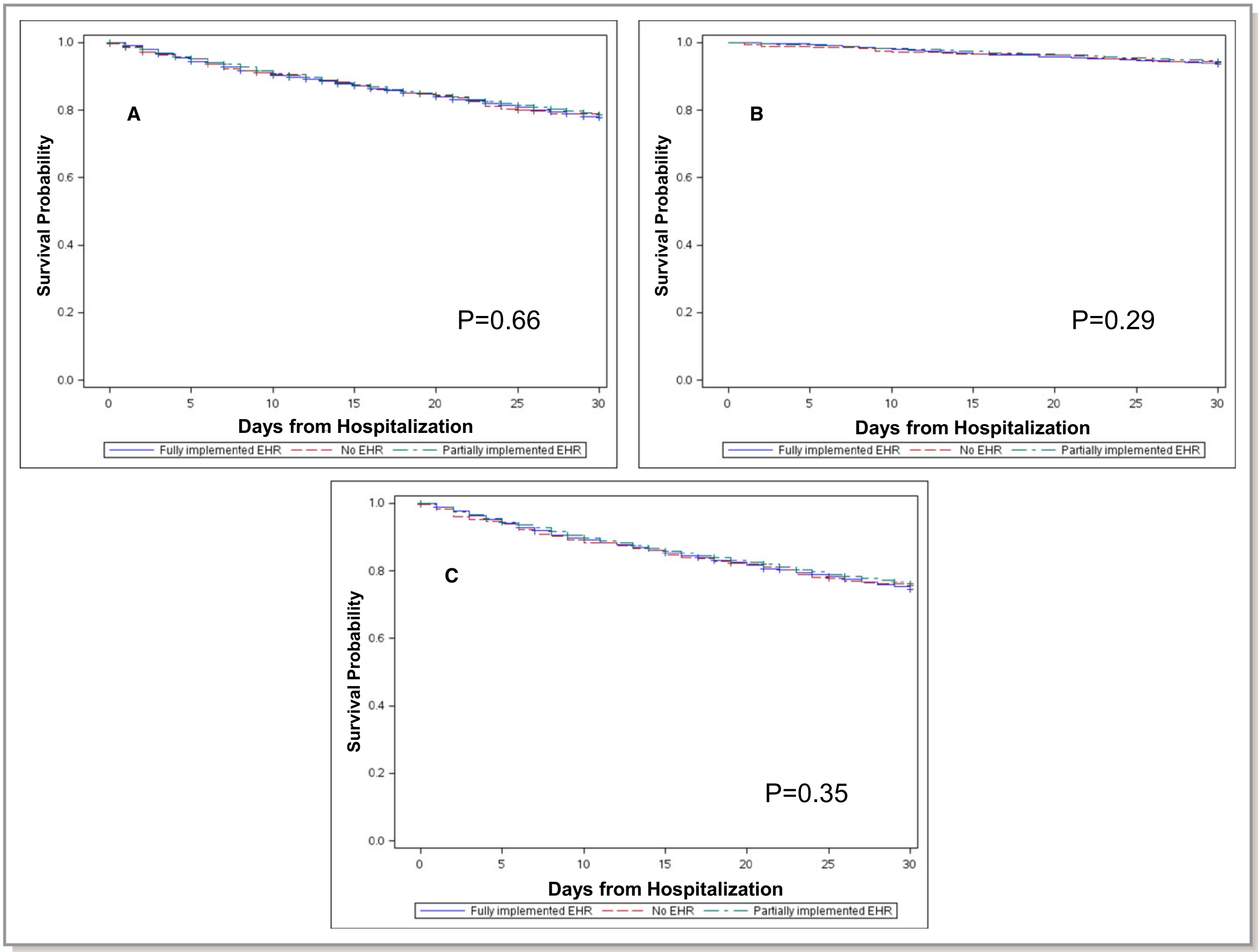

Figure. Kaplan-Meier curves of electronic health record (EHR) status and 30-day outcomes. Kaplan-Meier curves are depicted for Medicare recipients by EHR status (fully implemented, partially implemented, and not implemented) for 30-day events, including readmission (A), death (B), and death or readmission (C). *P* values shown for Wilcoxon log-rank test.

hospitals studied make a commitment to improving outcomes, these hospitals might have incorporated other means of improving quality of care for patients with HF (clinician education, admission of patients with HF to specialized services, or comprehensive review of patient medications by pharmacists). Also, this study did not evaluate gains or losses in patient health status and satisfaction nor gains or losses in clinician productivity, satisfaction, and turnover associated with EHR use. Finally, we did not have information on the specific EHR systems

Table 4. Association of EHR With 30-Day Outcomes Among Medicare Recipients on Multivariable-Adjusted Analysis

Variable	No EHR Event Rate, n/N (%)	Partially Implemented EHR Event Rate, n/N (%)	Fully Implemented EHR Event Rate, n/N (%)	EHR Fully Implemented vs No EHR Adjusted HR (95% CI)*	EHR Partially Implemented vs No EHR Adjusted HR (95% CI)*
Death	32/526 (6)	314 /5658 (6)	143/2237 (6)	1.27 (0.92–1.76)	1.00 (0.75–1.33)
All-cause readmission	96/526 (18)	1144/5658 (20)	465/2237 (21)	1.06 (0.85–1.32)	1.05 (0.87–1.26)
Death or readmission	111/526 (21)	1300/5658 (23)	541/2237 (24)	1.08 (0.92–1.27)	1.03 (0.90–1.19)

CI indicates confidence interval; EHR, electronic health record; and HR, hazard ratio.
*Multivariable model adjusted for age, sex, race, anemia, ischemic history, stroke or transient ischemic attack, diabetes mellitus, hyperlipidemia, hypertension, chronic obstructive pulmonary disease or asthma, peripheral vascular disease, renal insufficiency, cigarette smoking in the past year, systolic blood pressure, heart rate, sodium, blood urea nitrogen, left ventricular ejection fraction, estimated glomerular filtration rate, and hospital region, teaching status, number of beds, rural vs urban location, and heart transplant center status.

being used as well as information on order entry, clinical decision support, and other components.

Conclusions

In a large study of patients admitted with HF across the United States, EHR use was not associated with improved quality of care on the basis of several predefined metrics, in-hospital outcomes, or postdischarge events. Our results suggest the EHR may not be sufficient to improve HF-related outcomes. Further research is necessary to define optimal implementation of EHR technology in hospital practice.

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References

1. Benjamin EJ, Blaha MJ, Chiuve SE, Cushman M, Das SR, Deo R, de Ferranti SD, Floyd J, Fornage M, Gillespie C, Isasi CR, Jimenez MC, Jordan LC, Judd SE, Lackland D, Lichtman JH, Lisabeth L, Liu S, Longenecker CT, Mackey RH, Matsushita K, Mozaffarian D, Mussolino ME, Nasir K, Neumar RW, Palaniappan L, Pandey DK, Thiagarajan RR, Reeves MJ, Ritchey M, Rodriguez CJ, Roth GA, Rosamond WD, Sasson C, Towfighi A, Tsao CW, Turner MB, Virani SS, Voeks JH, Willey JZ, Wilkins JT, Wu JH, Alger HM, Wong SS, Muntner P; American Heart Association Statistics Committee and Stroke Statistics Subcommittee. Heart disease and stroke statistics-2017 update: a report from the American Heart Association. *Circulation*. 2017;135:e146–e603.
2. Walsh MN, Yancy CW, Albert NM, Curtis AB, Stough WG, Gheorghiade M, Heywood JT, McBride ML, Mehra MR, O'Connor CM, Reynolds D, Fonarow GC. Electronic health records and quality of care for heart failure. *Am Heart J*. 2010;159:635–642.e631.
3. DesRoches CM, Campbell EG, Vogeli C, Zheng J, Rao SR, Shields AE, Donelan K, Rosenbaum S, Bristol SJ, Jha AK. Electronic health records' limited successes suggest more targeted uses. *Health Aff (Millwood)*. 2010;29:639–646.
4. Morrison C, Jones M, Blackwell A, Vuylsteke A. Electronic patient record use during ward rounds: a qualitative study of interaction between medical staff. *Crit Care*. 2008;12:R148.
5. Hong Y, LaBresh KA. Overview of the American Heart Association "Get With the Guidelines" programs: coronary heart disease, stroke, and heart failure. *Crit Pathw Cardiol*. 2006;5:179–186.
6. Jha AK, DesRoches CM, Campbell EG, Donelan K, Rao SR, Ferris TG, Shields A, Rosenbaum S, Blumenthal D. Use of electronic health records in US hospitals. *N Engl J Med*. 2009;360:1628–1638.
7. Joynt KE, Bhatt DL, Schwamm LH, Xian Y, Heidenreich PA, Fonarow GC, Smith EE, Neely ML, Grau-Sepulveda MV, Hernandez AF. Lack of impact of electronic health records on quality of care and outcomes for ischemic stroke. *J Am Coll Cardiol*. 2015;65:1964–1972.
8. Cheng RK, Cox M, Neely ML, Heidenreich PA, Bhatt DL, Eapen ZJ, Hernandez AF, Butler J, Yancy CW, Fonarow GC. Outcomes in patients with heart failure with preserved, borderline, and reduced ejection fraction in the Medicare population. *Am Heart J*. 2014;168:721–730.
9. Hernandez AF, Fonarow GC, Liang L, Heidenreich PA, Yancy C, Peterson ED. The need for multiple measures of hospital quality: results from the Get With the Guidelines-Heart Failure registry of the American Heart Association. *Circulation*. 2011;124:712–719.
10. Peterson PN, Rumsfeld JS, Liang L, Albert NM, Hernandez AF, Peterson ED, Fonarow GC, Masoudi FA; American Heart Association Get With the Guidelines-Heart Failure Program. A validated risk score for in-hospital mortality in patients with heart failure from the American Heart Association get with the guidelines program. *Circ Cardiovasc Qual Outcomes*. 2010;3:25–32.
11. Fine JP, Gray RJ. A proportional hazards model for the subdistribution of a competing risk. *J Am Stat Assoc*. 1999;94:496–509.
12. Aloisio KM, Swanson SA, Micali N, Field A, Horton NJ. Analysis of partially observed clustered data using generalized estimating equations and multiple imputation. *Stata J*. 2014;14:863–883.
13. Resche-Rigon M, White IR. Multiple imputation by chained equations for systematically and sporadically missing multilevel data. *Stat Methods Med*

Res. 2016. Available at: http://journals.sagepub.com/doi/pdf/10.1177/0962280216666564. Accessed March 22, 2018.

14. Ouyang D, Chen JH, Hom J, Chi J. Internal medicine resident computer usage: an electronic audit of an inpatient service. *JAMA Intern Med*. 2016;176:252–254.
15. Bhatt DL, Drozda JP Jr, Shahian DM, Chan PS, Fonarow GC, Heidenreich PA, Jacobs JP, Masoudi FA, Peterson ED, Welke KF. ACC/AHA/STS statement on the future of registries and the performance measurement enterprise: a report of the American College of Cardiology/American Heart Association task force on performance measures and the society of thoracic surgeons. *J Am Coll Cardiol*. 2015;66:2230–2245.
16. Linder JA, Ma J, Bates DW, Middleton B, Stafford RS. Electronic health record use and the quality of ambulatory care in the United States. *Arch Intern Med*. 2007;167:1400–1405.
17. Romano MJ, Stafford RS. Electronic health records and clinical decision support systems: impact on national ambulatory care quality. *Arch Intern Med*. 2011;171:897–903.
18. Koppel R, Metlay JP, Cohen A, Abaluck B, Localio AR, Kimmel SE, Strom BL. Role of computerized physician order entry systems in facilitating medication errors. *JAMA*. 2005;293:1197–1203.
19. Han YY, Carcillo JA, Venkataraman ST, Clark RS, Watson RS, Nguyen TC, Bayir H, Orr RA. Unexpected increased mortality after implementation of a commercially sold computerized physician order entry system. *Pediatrics*. 2005;116:1506–1512.
20. Ash JS, Sittig DF, Poon EG, Guappone K, Campbell E, Dykstra RH. The extent and importance of unintended consequences related to computerized provider order entry. *J Am Med Inform Assoc*. 2007;14:415–423.
21. Kucher N, Koo S, Quiroz R, Cooper JM, Paterno MD, Soukonnikov B, Goldhaber SZ. Electronic alerts to prevent venous thromboembolism among hospitalized patients. *N Engl J Med*. 2005;352:969–977.
22. Garg AX, Adhikari NK, McDonald H, Rosas-Arellano MP, Devereaux PJ, Beyene J, Sam J, Haynes RB. Effects of computerized clinical decision support systems on practitioner performance and patient outcomes: a systematic review. *JAMA*. 2005;293:1223–1238.
23. Walsh MN, Albert NM, Curtis AB, Gheorghiade M, Heywood JT, Liu Y, Mehra MR, O'Connor CM, Reynolds D, Yancy CW, Fonarow GC. Lack of association between electronic health record systems and improvement in use of evidence-based heart failure therapies in outpatient cardiology practices. *Clin Cardiol*. 2012;35:187–196.