Health Information Technology in Heart Failure Care

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Structured Abstract

Purpose: To develop and test clinical decision support (CDS) recommending angiotensin converting enzyme (ACE) inhibitor utilization for hospitalized patients with heart failure.

Scope: Evidence-based therapy for heart failure remains underutilized at hospital discharge, particularly for patients with a secondary diagnosis of heart failure. We developed interruptive and non-interruptive versions of a CDS designed to address heart failure care in the hospital.

Methods: Hospitalizations were pseudo-randomized to have providers receive an interruptive or non-interruptive CDS alert based on even or odd medical record number (MRN), respectively. We compared discharge utilization of an ACE inhibitor or angiotensin receptor blocker (ARB) in the year prior to and following CDS implementation. We also assessed adoption and implementation fidelity of the CDS.

Results: Among 1,849 hospitalizations, ACE inhibitor or ARB utilization rates were 74.6% in the pre-CDS period and 76.8% in the post-CDS period ($p=0.71$). Utilization improved in the pre-CDS versus post-CDS periods among hospitalizations with an even MRN (73.6% vs. 79.6%, $p=0.04$) - particularly among those with a secondary heart failure diagnosis (71.1% vs. 79.8%, $p=0.01$) - but not among hospitalizations with an odd MRN. As compared to hospitalizations receiving the non-interruptive CDS, those receiving the interruptive alert were more likely to have had: an alert with any response (40.6% vs. 13.1%, $p<0.001$), contraindications reported (33.1% vs 11.3%, $p<0.001$), and an ACE inhibitor ordered within twelve hours of the alert (17.6% vs 10.3%, $p<0.01$). The response rate for the interruptive alert was 1.7%, and a median of 14 alerts were triggered per eligible hospitalization.

Key Words: clinical decision support, machine learning, heart failure, quality of care

Purpose

The primary objective of the study was to develop and test a clinical decision support (CDS) tool for hospitalized patients who have heart failure, regardless of reason for hospitalization. The first aim was to use machine learning to identify appropriate patients for care improvement that could be utilized for CDS. The second aim was to develop CDS using user-centered design and implementation science approaches. Our third aim was to assess the effectiveness of the CDS tool on adherence to guideline recommended care for heart failure patients and the comparative effectiveness of two implementation approaches of the CDS tool.

Scope

Although acute decompensated heart failure is the single most common reason for hospitalization among adults over 65 and accounts for over 1 million hospitalizations annually, the majority of hospitalizations and rehospitalizations of heart failure patients are for reasons other than acute heart failure. While the rate of hospitalization with a principal diagnosis of heart failure has been decreasing in recent years, the number of hospitalizations of heart failure patients for causes other than heart failure has not. This is notable as patients with heart failure who are hospitalized are at risk of poor outcomes, including high readmission and mortality rates, regardless of the reason for hospitalization. Furthermore, among patients with heart failure, patients for other causes are less likely to be discharged on evidence-based therapies than those hospitalized specifically for heart failure.

Clinical decision support (CDS) using health information technology (HIT) can be used to improve evidence based care. CDS uses such methods as computerized reminders, information, and order sets to recommend treatment for an individual patient.

We first developed and then implemented a CDS tool at NYU Langone Health, an urban academic medical center. The CDS tool targeted providers of patients with heart failure during hospitalization. The tool recommended prescribing an ACE inhibitor for patients who were not taking this medicine during hospitalization. In development, we used three main approaches to maximize uptake of the tool. First, we used a data driven approach to maximize appropriateness of the CDS tool. As part of this, we developed a machine learning algorithm that could correctly identify patients with heart failure at the point of care. The algorithm utilized both structured data and unstructured clinical notes to accurately identify patients and was found to have high accuracy, with an area under the receiver operating curve (AUC) of 0.97. We were specific of inclusion and exclusion criteria for triggering the CDS tool: which patients were eligible for therapy, which patients were not on therapy, and which patients had contraindications. These definitions were based on clinical guidelines and utilized EHR data to maximize the sensitivity and minimize inappropriate triggering the alert. Second, we employed a user-centered approach to development: we interviewed end-user providers for their thoughts about the CDS and incorporated their comments for initial development; we then performed usability testing of the initial CDS tool in a sandbox development environment and adjusted the CDS tool based on feedback.

Our third approach to maximize uptake was to employ two implementation approaches for the CDS tool: an interruptive alert, in which a pop-up displayed the information and recommendations to providers at time of order entry, and a non-interruptive alert, in which CDS was accessible through a sidebar in the patient chart. Non-interruptive alerts are appealing because they reduce cognitive load and burden on workflow as compared to interruptive alerts such as pop-up windows. However, non-interruptive alerts may be easier to ignore and, as a

result, may have less of an effect on provider behavior as compared to their interruptive counterparts. Nonetheless, studies examining the effect on non-interruptive on outcomes and utilization are limited and have had mixed results.

The purpose of the current study was to evaluate the implementation and effectiveness of the CDS tool and the comparative effectiveness of to two strategies for implementing the CDS tool.

Methods

Study Design

We performed a study of patients hospitalized at NYU Langone Medical Center, an urban academic medical center. We had two study cohorts: the first was the heart failure cohort, for whom we assessed overall effectiveness of introduction of CDS on utilization of ACE inhibitors; the second was the CDS cohort, for whom we assessed implementation of the CDS tool. The heart failure cohort included patients hospitalized with heart failure who were discharged between March 1, 2016 and March 31, 2018. Inclusion criteria for the heart failure group were an ejection fraction (EF)≤40% and the following labs or vital signs at time of discharge: potassium≤5.1mEq/L, estimated glomerular filtration rate (eGFR) ≥30mL/min/1.73m2, and systolic blood pressure≥90mmHg. Exclusion criteria for the heart failure group were: allergy to an ACE inhibitor, patients on the obstetrical service, and patients who died or were discharge to hospice care. For the CDS cohort, we included all hospitalized patients discharged before March 31, 2018 who had the CDS tool triggered for them after introduction of the CDS tool, on April 12, 2017.

CDS Intervention

We developed CDS to suggest providers prescribe an ACE inhibitor for appropriate inpatients with heart failure. The CDS tool was triggered for hospitalized patients with an EF≤40% who were not on an ACE inhibitor, ARB, or ARB-neprilysin inhibitor, were not pregnant, and had: blood pressure>100, eGFR>30, and potassium<5.1. Providers were alerted that the patient was not on an ACE inhibitor and that this therapy is recommended for patients with heart failure. The CDS tool also listed recent trends in the patient's blood pressure, potassium, and eGFR and displayed the most recent EF. Providers were given the option to order a low dose ACE inhibitor, order a contraindication, reassess the patient in 6 hours, or dismiss the alert. The order for the ACE inhibitor included a concurrent order for a follow up basic metabolic panel in 48 hours. The CDS tool was designed using standard functionality within the electronic health record (Epic, Epic Systems, Verona, WI). To maximize usability, we performed usability testing with inpatient providers during development, followed by refinement based on end-user feedback.

We developed two versions of the CDS tool, an interruptive and a non-interruptive alert. Patients were pseudo-randomized to each version of the alert based on last digit of the medical record number (MRN). For appropriate patients assigned to the interruptive CDS tool, providers received a pop-up alert whenever entering into the manage order pathway; the timing of the alert was chosen to target providers who write orders for the patient and to fit within the workflow of placing orders. The non-interruptive alert was available to all providers through notification in the daily provider checklist that is listed on the side of the patient chart and could also be accessed through a "best practice alert" section of the patient's chart. When a provider clicked the non-interruptive alert display, the same CDS would be accessed as seen in the interruptive

alert. Therefore, the only difference between the interruptive and non-interruptive alerts was in how they were accessed; the alerts were otherwise the same in content and view.

Outcomes

The primary outcome was effectiveness of the CDS tool, measured as the percent of patients in the heart failure cohort who were discharged on an ACE inhibitor or angiotensin receptor blocker (ARB).

Our implementation outcomes were informed by Proctor's taxonomy. We measured adoption as percent of hospitalizations in the CDS cohort that resulted in an alert that had a response, i.e. was not dismissed. We measured fidelity as the percent of hospitalizations with an alert that led to an order, and the percent of these hospitalizations that led to each of the three orders available in the CDS tool: an order for an ACE inhibitor, a contraindication reported, and an order for a basic metabolic panel. We also evaluated the percentage of hospitalizations that led to an order for an ACE inhibitor within twelve hours of the alert being triggered. Appropriateness was assessed by positive predictive value (PPV) and sensitivity of the alert. PPV was estimated as the number of hospitalizations in the heart failure cohort that had CDS triggered over the total number of hospitalizations that received CDS. Sensitivity was measured as the number of hospitalizations in the heart failure cohort that had CDS triggered alerts divided by these hospitalizations plus the number of hospitalizations in the heart failure cohort that were not discharged on an ACE inhibitor or ARB and did not received an alert.

For CDS patients whose providers received the interruptive alert, we also assessed adoption and fidelity at the individual alert level. Adoption was measured as number and the percentage of interruptive alerts that had any response. Fidelity was measured as the number and

percentage of interruptive alerts that led to any order, an order for an ACE inhibitor, or reporting of a contraindication.

Subgroups

We assess our outcomes of clinical effectiveness for hospitalizations with a principal diagnosis of heart failure and hospitalizations with a secondary diagnosis of heart failure, i.e. those with heart failure as a secondary but not principal diagnosis. Heart failure diagnosis was defined by standard International Classification of Diagnoses, Ninth Revision, Clinical Modification (ICD-9-CM) discharge diagnosis codes (402.01, 402.11, 402.91, 404.01, 404.03, 404.11, 404.13, 404.91, 404.93, and 428.*) or ICD-10-CM codes (I50.*, I11.0, I51.81, and I09.81).[1] We also evaluated hospitalizations in the heart failure cohort with an even MRN, and those with an odd MRN; even and odd MRNs represent hospitalizations eligible for the interruptive and non-interruptive alerts, respectively. We examined subgroups in the CDS cohort of hospitalizations with an even and odd MRN, equivalent to those that received the interruptive and non-interruptive alerts, respectively.

Statistical Analysis

We compared ACE inhibitor or ARB utilization at discharge for patients in the heart failure cohort in the pre-CDS period and the post-CDS periods using chi-squared tests. We used chi-squared tests to compare pre- and post-utilization for all subgroups: those hospitalized with a principal diagnosis of heart failure, those hospitalized with a secondary diagnosis of heart failure, those with an even MRN, those with an odd MRN, and the intersection of these subgroups.

We evaluated implementation metrics by calculating percentage of outcomes observed. We compared these outcomes between the interruptive and non-interruptive alerts using chi-squared tests. We calculated the median, mean, and standard deviation of the interruptive alert per hospitalization.

Limitations

The study should be interpreted in the context of its limitations. First, the CDS tool was implemented at a single hospital system and our results may not be generalizable. Second, the alert could be triggered at any time during hospitalization, while our gold standard measurement of appropriate patients used to determine PPV was determined at discharge. As a result, we may have underestimated our PPV.

Results

During the study period, there were 1,849 patients who were defined in the heart failure cohort, i.e. were eligible for an ACE inhibitor or ARB at discharge and did not have any exclusion to these therapies. Of these patients, 891 were seen prior to introduction of the alert and 958 were seen after introduction of the CDS tool.

Prior to introduction of the CDS, 74.6% of appropriate patients with heart failure received an ACE inhibitor or ARB at discharge. During this baseline period, patients with a principal diagnosis of heart failure were more likely than patients with a secondary diagnosis of heart failure to be discharged on an ACE inhibitor or an ARB (85.3% vs. 72.0%, $p<0.001$). Patients with a principal heart failure diagnosis were also more likely to have an ACE inhibitor

or ARB at discharge than patients without a diagnosis of heart failure at discharge (85.3% vs 70.4%, p=0.001).

In pre-CDS versus post-CDS analysis, the rate of ACE inhibitor or ARB utilization at discharge did not improve with introduction of the CDS for the overall cohort (p=0.27) or for patients with a principal diagnosis of heart failure (p=0.71; Table 1). We did observe a non-significant increase in utilization for patients with a secondary diagnosis of heart failure in the pre-CDS versus the post-CDS periods (72.0% versus 76.4%, P=0.08). We found that ACE inhibitor or ARB use increased from 73.6% in the pre-CDS period to 79.6% in the post-CDS period for hospitalizations with an even MRN, representing those eligible for the interruptive alert. The improvement with the interruptive alert was primarily observed among the subgroup of hospitalizations with a secondary diagnosis of heart failure, for whom compliance with an ACE inhibitor or ARB at discharged increased from 71.1% to 79.8% (p=0.01). We did not find any change in utilization of ACE inhibitors or ARBs for patients with an odd MRN, representing hospitalizations eligible for the non-interruptive alert. The difference in post-CDS utilization between hospitalizations with an even MRN versus an odd MRN did not quite reach statistical significant (79.6% vs 74.2%, p=0.05).

Table 1. Use of ACE inhibitor or ARB on discharge among eligible patients with heart failure, before and after introduction of the clinical decision support (CDS) intervention. Hospitalizations for patients with odd medical record numbers (MRNs) were eligible for the non-interruptive version of the CDS, while hospitalizations for patents with even MRNs were eligible for the interruptive alert.

	Pre-CDS (%)	Post-CDS (%)	p-value
Overall	74.6	76.8	0.27
Principal Heart Failure Diagnosis	85.3	83.9	0.71
Secondary Heart Failure Diagnosis	72.0	76.4	0.08
Even MRN	73.6	79.6	0.04
With Principal HF Diagnosis	82.8	85.9	0.58
With Secondary HF Diagnosis	71.1	79.8	0.01
Odd MRN	75.6	74.2	0.63
With Principal HF Diagnosis	87.8	81.7	0.27
With Secondary HF Diagnosis	73.0	73.4	0.91

With regards to CDS implementation, there were 822 hospitalizations that had the CDS triggered at least once. Among these hospitalizations, 74.0% never had a provider respond to an individual alert. At least one order was written from the CDS in 23.5% of hospitalizations, and 91.5% of these orders were to report a contraindication to therapy (Table 2). Only 2.2% of hospitalizations with a CDS triggered had an order placed for an ACE inhibitor through the CDS, although 13.8% of these hospitalizations had an ACE inhibitor ordered within 12 hours of an alert. Among the 822 hospitalizations that received an alert, 573 were in the heart failure cohort as appropriate for an ACE inhibitor at discharge; this represented a 70% positive predictive value (PPV, equivalent to precision) of the CDS. The sensitivity of the CDS was 93% (Table 2).

Table 2. Implementation characteristics of clinical decision support (CDS) tool, by type of alert

	All alerts	Interruptive alerts	Non-interruptive alerts	p-value
Number of hospitalizations that received the CDS	822	387	435	
Hospitalizations with any response to CDS (%)	26.0	40.6	13.1	<0.001
Hospitalizations with any order placed through CDS (%)	23.5	36.2	12.2	<0.001
Hospitalizations with ACE inhibitor ordered through CDS (%)	2.2	3.6	0.9	0.008
Hospitalizations with contraindication reported through CDS (%)	21.5	33.1	11.3	<0.001
Hospitalizations with basic metabolic panel ordered through CDS (%)	1.3	2.3	0.5	0.02
Hospitalizations with ACE inhibitor placed within 12 hours of CDS (%)	13.8	17.6	10.3	0.003
Positive predictive value of the alert	0.70	0.69	0.70	0.67
Sensitivity of the alert	0.93	0.91	0.94	0.31

Hospitalizations in which interruptive alerts triggered were more likely to have had a response to a CDS than hospitalizations in which the non-interruptive alert was triggered (40.6% vs. 13.1%, $p<0.001$; Table 2). Hospitalizations receiving the interruptive alert were also more likely to have had an ACE inhibitor ordered through the CDS (3.6% vs. 0.9%, $p<0.01$) as well as to have had an ACE inhibitor ordered within 12 hours of CDS being triggered (17.6% vs. 10.3%, $p<0.01$). As compared to hospitalizations receiving the non-interruptive alert, hospitalizations receiving the interruptive alert were significantly more likely to have a contraindication reported through the alert (33.1% vs. 11.3%, $p<0.001$).

A total of 10,034 interruptive alerts were triggered among the 387 hospitalizations that received this type of CDS, for a mean (standard deviation) of 25.9 (32.9) alerts per hospitalization. The distribution of alerts was skewed, and there were a median of 14 alerts for hospitalizations that had at least one interruptive alert triggered (Table 3). Only 170 of the

10,034 interruptive alerts resulted in a provider initiating an order, for a dismissal rate of 98.3%. Of these alerts, 143 resulted in an actual order being placed through the CDS tool. The majority of orders (n=128) were for a reported contraindication to therapy. Fifteen alert-based orders, representing 0.1% of all alerts, were for a provider ordering an ACE inhibitor; all nine alert-based orders for a basic metabolic panel accompanied an order for an ACE inhibitor (Table 3). In total, 76 orders for Lisinopril were placed within 12 hours of an interruptive alert being triggered, for an ordering rate of 0.8%.

Table 3. Frequency and provider responses to interruptive version of CDS tool.

	Alerts
Total number of alerts (N)	10,034
Median (25^{th}, 75^{th} percentile) alerts per hospitalization	14 (5,32)
Mean (SD) alerts per hospitalization	25.9 (32.9)
Alert responses (N)	
Any response to alert	170
Order placed within an alert	143
Contraindication reported	128
ACE inhibitor ordered	15
Basic Metabolic Panel ordered	9

Discussion

We found that a CDS tool developed to have high usability and specificity showed mixed results for improving evidence-based care. The CDS tool did not lead to any improvement in the primary outcome of ACE inhibitor or ARB utilization at discharge. However, introduction of the interruptive version of the CDS was associated with increased discharge utilization of these evidence-based therapies over time. In particular, the interruptive alert was associated with an 8% absolute increase in utilization of ACE inibitors or ARBs for the primary target patient population of our study, those discharged with a secondary diagnosis of heart failure. The interruptive alert also led to high rates of ordering an ACE inhibitor during hospitalization and

improved documentation of contraindications to this evidenced based therapy. However, these gains were at the cost of a high burden of triggered alerts.

Any effectiveness of the intervention was limited to the interruptive version of the alert. The non-interruptive alert was not associated with improved utilization of ACE inhibitor or ARB therapy at discharge. Furthermore, the non-interruptive version of the alert had lower rates of uptake than the interruptive alert. Many experts have suggested that non-interruptive alerts have less are less likely to be used that interruptive alerts. Three prior studies have prospectively analyzed the comparative benefit of these two approaches, with two finding some relative benefit to interruptive alerts. Although our study adds to the evidence of potential superiority of interruptive alert, further information is needed to understand why implementation of the non-interruptive alert failed. In development of the CDS tool, we found that providers found the non-interruptive alert to have high usability, fit well within their workflow, and generally preferable to the interruptive alert. However, many providers did not notice the non-interruptive alert in the testing environment, suggesting a lack of familiarity with this EHR feature. The non-interruptive alert was located within a sidebar that was built in the EHR to store non-interruptive alerts. Based on our preliminary work, we believe that the use of this sidebar has been limited overall. As a result, providers rarely noticed the sidebar, which likely led to failure of the non-interruptive version of the CDS tool. If this sidebar were to become part of a routinized checklist for providers, we believe uptake of the non-interruptive alert would be significantly improved.

The interruptive alert demonstrated some benefit in terms of the primary outcome of ACE inhibitor or ARB utilization at discharge and led to improvements of in-hospital prescription of these therapies as well as improved documentation of contraindications. However, these gains were partly a result of the alert having been triggered an average of over 25

times per hospitalization with a response rate of less than 2%. In evaluating any CDS, we need to consider is whether the benefits that lead to improved care delivery or changes in provider behavior are worth the costs, which include distraction, time, and increased cognitive burden. Although the issue of alert fatigue is commonly measured by response rate, we believe a better measure of the cost-benefit of an alert to be the number of triggers needed to change quality or safety; this cost-benefit ratio is comparable to the number needed to treat (NNT) in clinical trials. In the current study, we found the interruptive alert resulted in a 7.3% higher ordering of an ACE inhibitor within 12 hours as compared to the non-interruptive alert; we use the metric of ordering within 12 hours given possible delay in ordering following the clinical reminder. Given our sample size of 387, we therefore estimate that an additional 28 patients received this evidence-based therapy because of the interruptive alert. As there were 10,034 alerts fired, the number needed to improve quality was 358, i.e. the alert needed to be triggered 358 times in order to prescribe one additional ACE inhibitor.

As we consider the potential negative consequence of CDS, a metric such as number of triggers needed to change quality may be useful to consider when a CDS tool may be tailored to a certain population or to assess whether an alert is even worth using. Although there is no standardized cutoff for when the cost outweighs the benefits of an alert, we felt that 358 alerts per quality outcome were too high for an additional ACE inhibitor prescription in the inpatient setting. However, this cost-benefit ratio might be acceptable for an intervention associated with high immediate benefit for a patient with high risk, such as early treatment of sepsis. Concurrently, we are considering whether the lower number needed to change quality for patients with a secondary diagnosis of heart failure is acceptable for continued use of CDS for that population.

We observed improvements in utilization of ACE inhibitors or ARBs at discharge primarily among hospitalizations with a secondary diagnosis of heart failure. Similar to prior work, we found that utilization of these evidence-based therapies were higher among patients discharged with a principal versus secondary diagnosis of heart failure. The disparity between these two groups was part of our motivation in conducting the study, although we believed the intervention could benefit both groups. However, our ability to improve care for patients with a principal diagnosis of heart failure was limited for two reasons. First, other, more intensive hospital interventions were concurrently in place at this time; for instance, a nurse reviewed the care delivered for every patient hospitalized principally for heart failure and made recommendations to start ACE inhibitor or ARB therapy as appropriate. Second, given the high baseline rates of utilization of ACE inhibitors or ARBs among patients with a principal diagnosis of heart failure, there was likely a ceiling effect on use of these evidence based therapies as compared to patients with a secondary diagnosis of heart failure. Partly for this reason, CDS had a small effect in closing the quality gap between patients discharged with a principal versus secondary diagnosis of heart failure.

Conclusion

A CDS tool designed to have high usability and specificity did not increase overall utilization of ACE inhibitor therapy for patients with heart failure. However, an interruptive version of the alert did demonstrate some success, particularly for patients less likely to be discharged on evidence-based therapies: those with a secondary diagnosis of heart failure. These benefits occurred at the expense of high burden of the interruptive alert. We believe that tailoring

the CDS tool towards patients who may have the most benefit should enhance the cost-benefit ratio of CDS.

Career Development Implications

The study was also used as an approach to allow me (Dr. Blecker) to achieve my career development aims. These aims were: developing expertise in medical informatics, gain skills in human computer interactions, and develop expertise in implementation research. My successes in achieving these aims are described below.

My training in medical informatics was primarily under the guidance of mentor Gil Kuperman as well as working closely with collaborators in computer science, particularly David Sontag, an expert in machine learning in healthcare. Highlights of this academic training included participating in AMIA's 10x10 Course in Biomedical and Health Informatics, leading multiple manuscripts related to the use of machine learning for disease phenotyping, and my work in developing CDS. This training culminated in sitting was becoming board certified in Clinical Informatics from the American Board of Preventive Medicine.

My development of skills in user-centered design focused on working with Dr. Kuperman as well as Devin Mann, who has expertise in this area. Additionally, I benefited from both in person and remote education in this field, having attended a precourse at AMIA on usability as well as Audited course "Human Factors in Health Care" taught online by Andre Kushniruk at University of Victoria.

Finally, working closely with my mentor Donna Shelly, I developed expertise in implementation research. My primary formal training was through attending the NIH Training Institute for Dissemination and Implementation Research in Health. These skills have assisted in

both informing the implementation of the CDS and the evaluation described above. In both my current future work, I plan to combine these informatics and implementation skills to improve patient care.

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