A Prediction Rule to Identify Low-risk Patients with Heart Failure

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Abstract

Objectives: To derive a prediction rule using data available in the emergency department (ED) to identify a group of patients hospitalized for the treatment of heart failure who are at low risk of death and serious complications. **Methods:** The authors analyzed data for all 33,533 patients with a primary hospital discharge diagnosis of heart failure in 1999 who were admitted from EDs in Pennsylvania. Candidate predictors were demographic and medical history variables and the most abnormal examination or diagnostic test values measured in the ED (vital signs only) or on the first day of hospitalization. The authors constructed classification trees to identify a subgroup of patients with an observed rate of death or serious medical complications before discharge <2%; the tree that identified the subgroup with the lowest rate of this outcome and an inpatient mortality rate <1% was chosen. **Results:** Within the entire cohort, 4.5% of patients died and 6.8% survived to hospital discharge after experiencing a serious medical complication. The prediction rule used 21 prognostic factors to classify 17.2% of patients as low risk; 19 (0.3%) died and 59 (1.0%) survived to hospital discharge after experiencing a serious medical complication. **Conclusions:** This clinical prediction rule identified a group of patients hospitalized from the ED for the treatment of heart failure who were at low risk of adverse inpatient outcomes. Model performance needs to be examined in a cohort of patients with an ED diagnosis of heart failure and treated as outpatients or hospitalized. **Key words:** heart failure; decision support techniques; emergency service; hospital. ACADEMIC EMERGENCY MEDICINE 2005; 12:514–521.

Heart failure affects five million people in the United States,[1] leading to one million hospital admissions each year with a primary discharge diagnosis of heart failure and another two million with this as a secondary discharge diagnosis.[2] The annual health care expenditure for heart failure is estimated to be $28 billion, most of which is attributable to hospital care.[1] These costs will likely increase over the next several decades as the elder population increases[3] and hospitalization rates for heart failure in the population aged 65 years and older continue to climb.[1]

Hospital admission rates for patients with heart failure vary widely across geographic regions and within small areas.[4–7] This variation is not explained fully by differences in disease severity,[6,7] suggesting that clinicians make hospital admission decisions in an inconsistent manner. In addition, evidence suggests that emergency physicians greatly overestimate the probability of short-term death or severe complications for patients with heart failure.[8] Moreover, higher estimates of risk were associated with patient treatment in more intense care settings.[8] An evidence-based clinical prediction rule to assess severity of illness in patients presenting with heart failure might improve physician risk assessment and the appropriateness of initial-site-of-treatment decisions.

The emergency department (ED) is an ideal site for the use of a heart failure prediction rule because the majority of hospitalized patients with a primary discharge diagnosis of heart failure are admitted from this source.[9,10] However, existing heart failure medical practice guidelines have limited use in this setting because they are based on narrowly defined patient subgroups rather than the broad spectrum of heart failure patients treated in the ED,[11–13] they rely on clinical data unavailable in this setting,[14] or they do not report nonfatal serious medical complications that would require hospitalization.[6,9,11–13,15–18] Our aim in this study was to derive a clinical prediction rule based on data readily available in the ED to identify patients with heart failure who are at low risk of inpatient death or serious medical complications. A secondary aim was to examine the rates of death and readmission within 30 days of the index hospitalization for patients identified by the rule as low risk.

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METHODS

Study Design. We used a retrospective cohort study design to derive a clinical prediction rule using patient data from existing databases. The study was approved for exempt status by our institutional review board.

Study Population. We identified our study cohort using two proprietary statewide databases for patients discharged from all Pennsylvania general acute care hospitals in 1999 with a diagnosis of heart failure. Heart failure was defined as an International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM)[19] hospital primary discharge diagnosis code consistent with heart failure (398.91, 402.11, 402.91, 404.01, 404.03, 404.11, 404.13, 404.91, 404.93, 428.0, 428.1, or 428.9). We included patients with these diagnoses if they were 18 years of age or older, Pennsylvania residents, and hospitalized from the ED during the study period. Only the first hospitalization of each patient in 1999 was included to obtain independent observations for the statistical modeling. We excluded patients who did not have pulse, systolic blood pressure, and respiratory rate data available from the ED.

We used administrative discharge diagnosis codes to identify patients with heart failure rather than standardized clinical criteria because the only widely accepted clinical criteria[20,21] were designed for apparently healthy populations; their diagnostic accuracy is limited in patients seeking emergent treatment for an acute episode of heart failure.[22,23] The validity of our patient identification strategy is supported by studies that confirmed, through independent review of medical charts, the diagnosis of heart failure in 83%–96% of patients assigned a primary hospital discharge diagnosis code of heart failure.[23–25] We assumed that ICD-9-CM codes for heart failure assigned to patients in our database by attending clinicians with access to their medical records, test results, and responses to heart failure treatment were similarly reliable. Exclusion of patient identifiers from our database precluded independent review of medical records in this study.

Study Databases. We used the most recently available data from the Pennsylvania Health Care Cost Containment Council (PHC4), Cardinal Health Information Companies (CHIC)-MediQual Systems Atlas Severity of Illness System (hereafter referred to as MediQual-Atlas System) databases, and Pennsylvania Department of Health Division of Vital Statistics. Pennsylvania hospitals are required by law to submit health care data to PHC4 using guidelines set forth by the Health Care Financing Administration. These data, obtained from the Uniform Billing Form (UB-92), include demographic information, hospital charges, and diagnosis and procedure codes using ICD-9-CM.

Pennsylvania hospitals are also required to use the MediQual-Atlas System to abstract more than 300 key clinical findings (KCFs) for each patient, including demographic, historical, physical examination, laboratory, electrocardiographic, and imaging data. All hospitals in Pennsylvania were required to abstract KCF data using MediQual-Atlas System standardized data collection instruments and documentation; chart reviewers were first required to achieve 95% agreement with data abstracted by a MediQual-Atlas System instructor.[26] There were 192 general acute care hospitals required to submit quarterly hospital discharge data to PHC4 in 1999. PHC4 excluded all discharges from 14 hospitals for one or more quarters because the data were noncompliant with submission criteria for UB-92 or Atlas data; these included 235 patients from seven hospitals that had at least one patient with a primary discharge diagnosis of heart failure (estimated from PHC4 documentation). The 1999 database we received from PHC4 consisted of 68,240 cases (99.5%) from 192 hospitals with at least one patient with a primary discharge diagnosis of heart failure. We excluded 2,545 discharges (3.5%) from the PHC4 database because they could not be linked to the Atlas database.

The Pennsylvania Department of Health Division of Vital Statistics matched mortality data for 1999 and the first 30 days of 2000 by linking patient social security number, age, and gender with PHC4 data. We used the state death index rather than the national death index because the former was more current, because the former could be linked to the PHC4 database, and because 98% of state resident deaths occurred within the state. We suspect even fewer residents hospitalized for the treatment of heart failure would travel and die out of state so soon after discharge. PHC4 stripped the final data set of any patient identifiers before forwarding it to the study team.

Predictor Variables. Table 1 lists the candidate predictor variables we selected to develop the rule; other studies found them to be prognostic of short-term or long-term adverse outcomes, and most are readily available in the ED. We included arterial blood gas findings even though they are not routinely ordered in the ED because this test has been found to be prognostic of adverse outcomes in other settings and can be readily obtained in the ED. We used the KCF values for pulse, systolic blood pressure, and respiratory rate collected in the ED for all patients and KCF values for diastolic blood pressure, temperature, and altered mental status variables when available from this source. Otherwise, we used the most extreme KCF value available on the day before or day of admission. We included values on the day before

TABLE 1. Variables Used to Construct the Clinical Prediction Rule

Category	Variables
Demographic	Age, gender, race
Historical	Anemia, angina, cerebral vascular accident, coronary artery bypass graft surgery, cancer, chronic liver disease, chronic renal disease, chronic lung disease, current smoker, diabetes, former smoker, heart failure, heart valve prosthesis, myocardial infarction, peripheral vascular disease, permanent pacemaker, percutaneous transluminal coronary angioplasty, seizure, syncope, transient ischemic attack
Physical examination	Altered mental status, cyanosis, diastolic blood pressure, gallop, murmur, pulse, respiratory rate, systolic blood pressure, temperature
Electrocardiographic	Acute myocardial infarction, atrial fibrillation, atrial flutter, atrioventricular conduction disturbance, intraventricular conduction disturbance, multifocal atrial tachycardia, myocardial ischemia, ventricular tachycardia
Laboratory	PaO_2, $PaCO_2$, arterial pH, aspartate aminotransferase, blood urea nitrogen, calcium, creatinine, direct bilirubin, hematocrit, hemoglobin, glucose, potassium, serum sodium, white blood cell count
Radiographic	Pleural effusion, cardiomegaly, pulmonary congestion

admission because hospital admission may have occurred on the calendar day following arrival at the ED.

We excluded from consideration variables not readily available in the ED, including echocardiography, cardiac catheterization, stress testing, hemodynamic monitoring, heart failure etiology, and pathology-related KCFs. We also excluded time-sensitive serum creatine kinase MB enzymes and troponin because peak values documented on the day of admission may have been measured after a patient had been discharged from the ED.

Outcome Measures. The primary outcomes were inpatient death or the combination of inpatient death or serious medical complications that occurred during the index hospitalization. KCF values were counted as outcomes if they occurred after the date of admission to the hospital; KCFs recorded on the date of admission were excluded as outcomes because they might represent the state of the patient in the ED rather than an outcome of care. However, death and the use of a lifesaving treatment were counted as outcomes whenever they occurred during hospitalization.

We counted a patient as having a serious medical complication if she or he experienced a life-threatening clinical condition (identified using ICD-9-CM secondary hospital discharge diagnosis codes) or received a lifesaving inpatient treatment (identified using ICD-9-CM hospital primary or secondary procedure codes unless otherwise noted). Life-threatening clinical conditions were an acute myocardial infarction (410.x0–410.x1), ventricular fibrillation (427.41), cardiogenic shock (785.51), and cardiac arrest (427.5). Lifesaving inpatient treatments were 1) resuscitation defined as intubation or mechanical ventilation not initiated during surgery (96.04, 96.05, and 96.70–96.72 in patients without coronary artery bypass graft surgery during hospitalization), cardiac compression (37.91, 99.60, and 99.63), resuscitation (KCF treatment code 9000), or defibrillation (99.62 and 99.69) and 2) reperfusion therapy defined as coronary artery bypass graft surgery (36.10–36.16), percutaneous transluminal coronary angioplasty (36.01–36.02, 36.05–36.06, 36.09), or intravenous thrombolytics (99.10 or KCF treatment code 9020).

Secondary study outcomes were death from any cause within 30 days of the index ED admission and the first hospital readmission during this interval with a primary hospital discharge diagnosis of heart failure. Thirty-day outcomes were examined because they are ascertained over a standardized time interval not subject to variation in hospital discharge practices and are commonly used indices of hospital quality of care. We used inpatient death rather than death within 30 days as the primary mortality outcome for model building because we judged the former to be temporally and clinically more relevant to ED provider assessment of risk and initial-site-of-treatment decisions than deaths among inpatients after discharge. We included hospital readmission as a secondary rather than a primary outcome for similar reasons.

Data Analysis. We constructed classification trees[27–29] using Answer Tree 2.0. Candidate trees were built by recursively splitting the data using cut points on predictor variables suggested by the software program. At each step of the splitting procedure, the program identified a set of variables prognostic of death or serious medical complications before hospital discharge ($p \leq 0.05$ as determined by Bonferroni-adjusted χ^2 statistics). From among these variables and cut points, we split nodes using a combination that made the most clinical sense in an ED setting. Data splitting was stopped when any of the following occurred: 1) the adjusted p-value for all possible splits was >0.05, 2) a node contained fewer than 200 patients or, if split, resulted in a node containing fewer than 100 patients, or 3) the risk of death or complications was $<2\%$ in a node and $<4\%$ in all subsequent splits. The second and third stopping criteria were included to limit model complexity and reduce the potential for overfitting the model without

failing to identify a substantial number of patients at higher risk. This procedure yielded several candidate trees that identified at least 10% of the entire cohort with <2% risk of our combined outcome. We excluded trees in which the rate of inpatient death among low-risk patients was ≥1%. Of those remaining, we chose the model that identified a subgroup of patients with the lowest rate of inpatient death or serious complications.

We used the entire cohort for derivation rather than splitting it into development and validation samples because we expected to have fewer than 50 deaths in the low-risk group by virtue of our definition of low risk for this outcome (<1% mortality). Subdividing the cohort would not allow sufficient precision of the adverse event rate in the low-risk group. Automated internal cross-validation could not be used because we developed our classification trees using a semi-automated technique involving clinical judgment that could not be coded and replicated. We estimated the precision and prediction errors of the observed primary and secondary outcome event rates in the identified low-risk patients through bootstrap resampling[30] and K-fold cross-validation[31] techniques using Stata (version 7.0; Stata Corp., College Station, TX). Measures of precision were 95% confidence intervals (CIs) around the observed event rates based on standard errors. We recalculated the upper 95% confidence limit of these event rates after accounting for estimated prediction error. Defined as the squared difference between observed and expected event rates, prediction error estimates the degree to which event rates observed and optimized in a derivation cohort used to fit the model underestimate the rates in a new patient cohort.[31]

RESULTS

Patient Characteristics. There were 47,107 heart failure hospitalizations from an ED in 1999, of which 43,531 (92.4%) had a documented pulse, systolic blood pressure, and respiratory rate measured in the ED. Of these, 33,533 (76.5%) were the initial hospitalization of patients from the ED (Table 2). The most common clinical characteristics of these patients were a history of heart failure (62.9%), diabetes (39.9%), or coronary artery disease (36.4%) and radiographic evidence of pulmonary congestion (56.2%) or cardiomegaly (41.1%). There were 32,121 patients (96%) with clinical findings consistent with a diagnosis of heart failure (i.e., a history of heart failure, radiographic evidence of pulmonary congestion or cardiomegaly, or peripheral edema). Electrocardiographic abnormalities documented at the time of presentation included acute myocardial infarction (17.1%) or myocardial ischemia not known to be old (14.4%). An arterial blood gas level was available for 9,752 patients (29.1%).

TABLE 2. Patient Demographic and Clinical Characteristics

Characteristic	
Demographic factors	
Age 65 years or older	83.1
Female gender	56.4
White race	80.2
Historical factors	
Heart failure	62.9
Myocardial infarction	25.3
Angina	36.4
PTCA or CABG	28.0
Lung disease	30.6
Renal disease	16.8
Diabetes	39.9
Peripheral vascular disease	12.6
Cerebrovascular disease	18.8
Physical examination findings	
Systolic blood pressure (mm Hg)	148 ± 32
Diastolic blood pressure (mm Hg)	82 ± 19
Pulse (beats/min)	90 ± 27
Respiratory rate (breaths/min)	21 ± 9
Temperature (°F)	97.2 ± 1.4
Radiographic abnormalities	
Pleural effusion	23.2
Cardiomegaly	41.2
Pulmonary congestion	56.2
Electrocardiographic abnormalities	
Atrial fibrillation/flutter	24.1
Myocardial ischemia	14.5
Acute myocardial infarction	17.1
Laboratory findings	
Sodium (mEq/L)	138 ± 5
Potassium (mEq/L)	4.3 ± 0.7
Blood urea nitrogen (mg/dL)	30 ± 19
Creatinine (mg/dL)*	1.6 ± 1.5
Glucose (mg/dL)	170 ± 88
White blood cell count (10^9/L)	9.8 ± 7.2
Arterial pH	7.39 ± 0.09

Data are given as percentage of patients unless otherwise indicated (mean ± SD). All patients had systolic blood pressure, pulse and respiratory rate data. The proportions of patients with data for the other variables were as follows: diastolic blood pressure, 99.5%; temperature, 97.2%; sodium, 96.2%; potassium, 95.9%; blood urea nitrogen, 95.9%; creatinine, 95.8%; glucose, 96.4%; white blood cell count, 96.6%; arterial pH, 29.0%.

PTCA = percutaneous transluminal coronary angiography; CABG = coronary artery bypass surgery

*Conversion factor between conventional and SI units for creatinine: 88.4 × mg/dL = μmol/L.

Overall, 1,498 patients (4.5%; 95% CI = 4.2 to 4.7) died during hospitalization and 2,269 (6.8%; 95% CI = 6.5 to 7.1) survived to hospital discharge after experiencing a serious medical complication. With respect to the secondary study outcomes, 2,633 patients (7.9%; 95% CI = 7.6 to 8.2) died and 2,369 (7.1%; 95% CI = 6.8 to 7.3) were readmitted at least once with a discharge diagnosis of heart failure within 30 days of the index hospitalization.

Derivation of the Prediction Rule. We first split the cohort into patients with and without electrocardiographic evidence of myocardial ischemia not known

TABLE 3. Heart Failure Clinical Prediction Rule Prognostic Factors

Category	Prognostic Factors
Demographic	Gender
Historical	Coronary artery disease, angina, percutaneous transluminal coronary angiography, diabetes, and lung disease
Vital signs	Systolic blood pressure, pulse, respiratory rate, and temperature
Laboratory*	Blood urea nitrogen, sodium, potassium, creatinine, glucose, white blood cell count, and arterial pH
Electrocardiographic	Acute myocardial infarction and acute myocardial ischemia
Radiographic	Pulmonary congestion and pleural effusion

*From serum.

to be old or an acute myocardial infarction. The node for patients without this finding was then split into patients for whom an arterial pH was available or unavailable. All remaining candidate predictor variables were used to split the arterial pH available node, and all but arterial blood gas findings were used to split the arterial pH unavailable node. The final classification tree assigned patients into 14 low-risk groups based on a total of 21 demographic and clinical prognostic factors (Table 3).

The heart failure clinical prediction rule classified 5,758 (17.2%) of 33,533 patients as low risk (Table 4). Within this subgroup, there were 19 (0.3%) inpatient deaths and 59 (1.0%) survivors to hospital discharge after a serious complication. The rate of death or survival to hospital discharge after a serious complication within low-risk subgroups ranged from 0.4% to 2.1%. The rate of death ranged from 0% to 1.3%; the rate of survival to hospital discharge after a serious complication ranged from 0.3% to 1.7%. The most frequent complication was acute myocardial infarction (0.4%). The upper 95% confidence limit for each outcome after accounting for prediction error was 0.7% for inpatient death, 1.3% for survival to hospital discharge after a serious complication, and 2.9% for the combination of inpatient death or survival to hospital discharge with a serious medical complication.

With respect to the secondary study outcomes, 114 patients (2.0%) within the low-risk subgroup died and 290 (5.0%) were readmitted at least once with a hospital discharge diagnosis of heart failure within 30 days of the index hospitalization. The upper 95% confidence limit for each outcome after accounting for prediction error was 4.0% for 30-day mortality and 9.7% for readmission within 30 days.

DISCUSSION

Our heart failure clinical prediction rule has several strengths compared with others.[9,11–15,17,18] It relies

TABLE 4. Percentage of Identified Low-risk and Higher-risk Patients with Primary Study Outcomes and 95% Confidence Intervals

Outcome	Low Risk (n = 5,758)	Higher Risk (n = 27,775)
Died	0.3 (0.2, 0.5)	5.3 (5.1, 5.6)
Serious complications in survivors	1.0 (0.8, 1.3)	8.0 (7.6, 8.3)
Acute myocardial infarction	0.3 (0.2, 0.5)	3.0 (2.8, 3.2)
Mechanical ventilation*	0.2 (0.1, 0.4)	4.0 (3.8, 4.2)
Resuscitation†	0.2 (0.1, 0.3)	1.1 (1.0, 1.3)
Ventricular fibrillation	0.1 (0, 0.2)	0.2 (0.1, 0.2)
Reperfusion therapy‡	0.3 (0.2, 0.5)	1.1 (0.9, 1.2)
Died or serious complication	1.4 (1.1, 1.7)	13.3 (12.9, 13.7)

Percentile-based bootstrap estimate of 95% confidence intervals.
*Mechanical ventilation or intubation not initiated during coronary artery bypass surgery.
†Includes cardiogenic shock, resuscitation, defibrillation, cardiac arrest, or cardiopulmonary resuscitation.
‡Includes coronary artery bypass graft, percutaneous transluminal coronary angioplasty, or intravenous thrombolytic therapy.

exclusively on variables readily available in the ED at the time of patient presentation. An individual patient can be identified as low risk based on the presence of a few prognostic factors without the need for complex equations[17] or scoring systems.[11,12,15] The potential generalization of our findings to other settings and the accuracy of the clinical prediction rule are supported by its derivation using a large standardized statewide set of data. Additionally, our rule explicitly identifies patients hospitalized from the ED for the treatment of heart failure who were at low risk of the combined outcome of death or a serious inpatient medical complication.

The risk factors in this heart failure clinical prediction rule are consistent with those of previous prognostic models.[11–13,17,18] Deranged vital signs and electrolytes, chest radiograph findings, and a history of diabetes, chronic lung disease, and coronary artery disease have all been associated with death or serious complications in patients with heart failure. Systolic blood pressures ≥150 mm Hg were prognostic of low risk in several branches of our classification tree, confirming previously reported positive associations between this measure and the survival of patients hospitalized for the treatment of heart failure.[15] The appearance of white blood cell count and temperature as risk factors in our rule was unexpected although not unprecedented; both variables were prognostic of inpatient death in a complex case-mix adjustment model derived using a heart failure patient database and cohort size similar to ours.[18] These variables may be surrogate markers of comorbid illnesses that either precipitated or accompanied a bout of acute heart failure.[12,32–34]

We excluded several specialized diagnostic tests with known prognostic value from our list of candidate predictors because they are often unavailable at the

time of the patient admission decision. In some cases, findings from an echocardiogram, cardiac catheterization, radionuclide imaging, exercise stress test, or other such tests may provide additional clinical information that alters provider assessment of risk from that suggested by our rule. Other factors may also alter initial-site-of-treatment decisions for low-risk patients, including patient functional status, an inadequate outpatient support system, patient or family preferences, or variables not included in the clinical prediction rule. Ultimately, the heart failure clinical prediction rule is intended to inform, not supersede, provider judgment of patient prognosis, treatment, and decisions regarding admission.

Previously derived heart failure clinical prediction rules have identified hospitalized heart failure patients at low risk of short-term patient death for the purpose of adjusting hospital mortality based on patient severity of illness.[6,9,15–17] Lee et al. derived and externally validated a clinical model prognostic of 30-day and one-year mortality using data routinely available at hospital presentation.[15] None of these rules determined whether patients at low risk of short-term death were also at low risk of nonfatal yet serious inpatient complications that would warrant hospitalization regardless of survival status. In contrast, our heart failure clinical prediction rule explicitly identifies patients at low risk of death, life-threatening events, or the administration of potentially lifesaving treatments or procedures. We used this combined set of outcomes rather than death alone to minimize classification of patients as low risk who survived to hospital discharge because they were the beneficiaries of crucial inpatient interventions. Among our heart failure inpatients, more had serious complications and survived than died during their hospitalization. These findings suggest that mortality-based models may classify as low risk patients with nonfatal outcomes of clinical interest (e.g., resuscitated cardiac arrest or mechanical ventilation).

One other heart failure clinical prediction rule was prognostic of both fatal and nonfatal inpatient outcomes.[11] Although it discriminated lower- from higher-risk patients, those without any risk factors still had a 6% probability of inpatient death or major complications with an estimated upper confidence limit of 11%. Chin and Goldman[11] concluded, and we suspect most would agree, that risk of this magnitude does not identify a truly low-risk group of patients with heart failure for whom outpatient therapy would be appropriate. We believe patients identified by our heart failure clinical prediction rule with a 0.3% rate of death or 1.3% rate of death or serious medical complications represent those ''truly'' at low risk for whom less intensive outpatient treatment could be appropriate. This speculation is supported by the 30-day mortality rate in these low-risk patients of 2%, a rate similar to that reported for patients diagnosed with heart failure in the ED and discharged for outpatient treatment.[10]

The classification tree that defines our heart failure clinical prediction rule is somewhat complex, as might be expected for a disease with many etiologies and prevalent in the elder population with comorbid illnesses (Figure 1; available as an online Data Supplement at http://www.aemj.org/cgi/content/full/12/6/514/DC1). Although the classification tree includes a total of 21 prognostic factors, risk can be ascertained for a case at hand on the basis of no more than nine variables. Even so, some may find it difficult to navigate a paper-based algorithm that starts with an ED diagnosis of heart failure, splits into multiple branches, and ends in 14 low-risk groups. Translation of this decision tree into a computerized algorithm (e.g., http://www.centerem.com/hfpr/) could simplify the identification of low-risk patients (the computerized algorithm is illustrated in Figure 2; available as an online Data Supplement at http://www.aemj.org/cgi/content/full/12/6/514/DC1).

LIMITATIONS

Our derivation of the heart failure clinical prediction rule using inpatient data only is a potential limitation. We chose this methodology for several reasons. First, 67%–80% of patients with an ED diagnosis of heart failure are hospitalized.[8,10] Second, we judged that the rate of short-term deaths or serious complications among outpatients would be considerably less than that of hospitalized patients; consequently, inclusion of outpatients would contribute few additional adverse outcomes and have a negligible impact on model building. The 30-day mortality rate of 7.9% within our inpatient cohort versus the 2.1% rate reported by Graff et al.[10] for outpatients supports our assumption. Third, derivation of a pneumonia clinical prediction rule using a PHC4 inpatient database similar to ours was successfully validated in a cohort of outpatients and inpatients and after follow-up implementation was found to safely reduce low-risk patient admissions from the ED.[35–37] We anticipate a similar pattern of performance for our heart failure clinical prediction rule. It would be premature to consider the rule ready for widespread application until its performance has been validated in a full complement of ED inpatients and outpatients and its safety demonstrated in controlled implementation trials.

The use of existing statewide databases to derive the rule imposed additional limitations. KCFs documented on the day of admission, other than patient vital signs, may have occurred up to 24 hours after patients had been discharged from the ED. We excluded time-sensitive serum creatine kinase MB enzymes and troponin for this reason and therefore cannot rule out the possibility that values measured in the ED for one or both of these markers were elevated

in some patients classified as low risk. It seems likely that patients with biomarkers indicative of acute myocardial injury would be hospitalized regardless of estimated risk; such decisions would be consistent with assignment by our rule of patients with electrocardiographic evidence of acute myocardial injury to a higher-risk category.

B-type natriuretic peptide (BNP) was not included in our analysis because it was not widely used and hospitals were not required to abstract it in 1999. Additionally, the role of singular BNP measurement in heart failure management is evolving; it clearly can aid diagnosis in select cases, but routine use is not currently supported.[38,39] Recently, the REDHOT trial data showed that extreme elevation of ED BNP values correlate to 90-day mortality and repeat need for ED or hospital care in heart failure patients better than unstructured emergency physician judgment.[40] However, as noted earlier, unstructured physician judgment often estimates risk incorrectly and variably in many diseases, including heart failure. The BNP values associated with increased death or return visits in the REDHOT trial overlapped with those not experiencing the same outcomes. The prognostic value of BNP with modest elevation (a common scenario) or its additional benefit when a risk-stratifying tool is used first is not clear. Finally, clinicians may desire a tool that predicts shorter-term (i.e., 30 day) outcomes or a tool predicting outcomes in addition to death or return ED visit/hospitalization (e.g., dysrhythmias, cardiac or other invasive procedures, and other outcomes noted in our serious medical complication category) when making disposition decisions in the ED. Given the design differences between our study and the REDHOT trial, comparisons between our rule and BNP measurement alone were not possible.

CONCLUSIONS

We derived a prediction rule based on clinical variables available in the ED that identifies patients hospitalized with a primary hospital discharge diagnosis of heart failure who are at low risk of death or serious medical complications. Projections from our derivation cohort suggest that 17% of patients with heart failure evaluated in the ED and managed with traditional inpatient care are at low risk of adverse short-term medical outcomes. Model performance needs to be examined in a cohort of ED patients with a diagnosis of heart failure treated with an initial course of either inpatient or outpatient therapy.

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