Predictive Model for Heart Failure Readmission Using Nationwide Readmissions Database

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Abstract

Objective: To generate a heart failure (HF) readmission prediction model using the Nationwide Readmissions Database to guide management and reduce HF readmissions.

Patients and Methods: A retrospective analysis was performed for patients listed for HF admissions in the Nationwide Readmissions Database from January 1, 2010, to December 31, 2014. A Cox proportional hazards model for sample survey data for the prediction of readmission for all patients with HF was implemented using a derivation cohort (2010-2012). We generated receiver operating characteristic (ROC) curves and estimated area under the ROC curve at each time point (30, 60, 90, and 180 days) to assess the accuracy of our predictive model using the derivation cohort (2010-2012) and compared it with the validation cohort (2013-2014). A risk score was computed for the validation cohort. On the basis of the total risk score, we calculated the probability of readmission at 30, 60, 90, and 180 days.

Results: Approximately 1,420,564 patients were admitted for HF, contributing to 1,817,735 total HF admissions. Of these, 665,867 patients had at least 1 readmission for HF. The 10 most common comorbidities for readmitted patients included hypertension, diabetes mellitus, renal failure, chronic pulmonary disease, deficiency anemia, fluid and electrolyte disorders, obesity, hypothyroidism, peripheral vascular disorders, and depression. The area under the ROC curve for the prediction model was 0.58 in the derivation cohort and 0.59 in the validation cohort.

Conclusion: The prediction model will find clinical utility at point of care in optimizing the management of patients with HF and reducing HF readmissions.

Heart failure (HF) is a growing public health problem despite advances in diagnosis and management. Although there has been a slight improvement in survival after HF, primarily attributed to evidence-based approaches targeting HF risk factors and implementation of HF therapies, the benefits have not been proportional to the efforts invested in HF management. With almost 25% of patients with previous HF admissions readmitted in the next 30 days, HF readmissions accounted for $903 million in Medicare in 2008.

In 2005, Medicare reported that the 30-day readmission rates for HF were 6.2% and 17.6%, respectively, most of which were considered preventable. To curtail the formidable Medicare reimbursements, the Hospital Readmissions Reduction Program under the Affordable Care Act was created to penalize hospitals with high rates of readmissions by reducing hospital reimbursements. With the increased incentive to reduce readmission rates, it is important to identify factors associated with higher readmission risk. To that effect, many predictive models have been proposed. A notable example is the predictive model proposed by Chamberlain et al, which used the State Inpatient Database (SID) to develop a prediction model for HF readmissions on the basis of 4 states. Although accurate in its risk-assessment capacity, this model is limited in its generalizability, lacks several important cardiovascular health variables, and has not been validated.
In this study, we examined a large cohort of patients with HF from a national database to determine factors associated with hospital readmission that were used to develop a predictive risk model for HF readmission. This was compared with existing models to validate its risk-assessment capacity. This model may aid in determining interventions to decrease the risk of readmission before discharge by guiding preventative efforts and contributing to measures to reduce health care costs.

PATIENTS AND METHODS

We performed a retrospective review of patients listed for HF admission between January 2010 and December 2014 from the Nationwide Readmissions Database (NRD), which is drawn from the Healthcare Cost and Utilization Project SID and can be used to create estimates of national readmission rates for all patients, regardless of the expected payer for the hospital. Compared with the SID, which is state-based, the NRD is a national database that can be used to address a large gap in health care data—the lack of nationally representative information on hospital readmissions for all ages, thus improving generalizability. Additionally, this database includes data on various cardiovascular procedures common among patients with HF, which can impact readmission risk.

We used unique NRD_VisitLinks, which is a variable used to track multiple hospital admissions for the same patient across hospitals within a state within 1 year. All HF-related admissions, including potential multiple admissions of the same patient, were followed until a readmission. Discharges without a readmission within the same year were assumed to have been followed from the middle of the discharge month to December 31 of the corresponding year and censored at that time or at 345 days of follow-up, whichever was earlier. All analyses were adjusted for the survey design, including stratification factors, clustering by hospital ID, and NRD-provided discharge weights. For descriptive analyses, we used weighted Kaplan-Meier analysis to estimate the probability of readmission over time for subsets of admissions defined by the types of HF procedures performed at each admission. An admission that has multiple procedures would contribute to multiple subsets for these estimates. A multivariate Cox proportional hazards model for sample survey data to predict readmission for all patients with HF was implemented using a derivation cohort (2010-2012). All nonsignificant variables at 0.01 level were removed and a multivariate Cox proportional hazards model for sample survey data was refit using the derivation cohort. The score for each variable was calculated as log (hazard ratio) \times 10 rounded to the nearest integer. Variables with a small effect size were assigned a score of 0 as a result of this calculation and thus were not included in the final scoring model. This HF readmissions risk scale was then applied to the validation cohort.

Using an inverse probability of censoring weighting approach, we generated time-dependent receiver operating characteristic (ROC) curves and estimated area under the ROC curve (AUC) at each time point (30, 60, 90, and 180 days) to assess the accuracy of our predictive model using the derivation cohort and compared it with the validation cohort (2013-2014). Furthermore, we compared our predictive model to that developed by Chamberlain et al. Because of the small number of admissions in some score groups in the validation cohort, for reporting, some groups were combined such that each group has at least 100 HF admissions. On the basis of the total risk score in the validation cohort, we calculated the probability of readmission at 30, 60, 90, and 180 days using weighted Kaplan-Meier analysis. Analyses were performed using SAS 9.4 (SAS Institute).

RESULTS

Between January 2010 and December 2014, an average of 284,113 patients were admitted for HF each year, contributing 1,817,735 HF admissions for 1,420,564 unique NRD_VisitLinks. A total of 665,867 of the NRD_VisitLinks had at least 1 readmission for HF within the same year (Supplemental Table S1, available online at http://www.mcpiqojournal.org). Table 1 shows the demographic characteristics of all 1,817,735 HF admissions. The probabilities of readmission at 30 days in the derivation and validation cohorts were 0.242 and 0.228, respectively. The patients had a mean age of 72.8 years.
# TABLE 1. Demographic Characteristics of all 1,817,735 Heart Failure Admissions

| Variable                                      | Description                | N      | Weighted N | All admissions |
|-----------------------------------------------|----------------------------|--------|------------|---------------|
| N                                             |                            | 1,817,735 |            |               |
| Weighted N                                    |                            | 4,266,863 |            |               |
| Sex                                           | % (SE)                     |         |            |               |
| Female                                        |                            | 890,910 | 2,107,959  | 49.4 (0.1)    |
| Male                                          |                            | 926,825 | 2,158,904  | 50.6 (0.1)    |
| Age (y) at admission, mean                    |                            | 1,817,735 | 4,266,863  | 72.38 (0.089) |
| Age categories (y) at admission               |                            |         |            |               |
| 0-39                                          |                            | 42,465  | 101,454    | 2.38 (0.05)   |
| 40-49                                         |                            | 94,971  | 218,081    | 5.11 (0.07)   |
| 50-59                                         |                            | 221,239 | 507,828    | 11.9 (0.11)   |
| 60-69                                         |                            | 333,765 | 778,166    | 18.2 (0.08)   |
| 70-79                                         |                            | 426,452 | 1,000,804  | 23.5 (0.08)   |
| 80+                                           |                            | 698,843 | 1,660,530  | 38.9 (0.22)   |
| Heart failure category                        |                            |         |            |               |
| Heart failure                                 |                            | 464,307 | 1,073,076  | 25.1 (0.31)   |
| Systolic heart failure                        |                            | 653,039 | 1,525,770  | 35.8 (0.22)   |
| Diastolic heart failure                       |                            | 524,579 | 1,239,760  | 29.1 (0.18)   |
| Combined systolic and diastolic heart failure  |                            | 175,810 | 428,257    | 10 (0.12)     |
| Expected primary payer                        |                            |         |            |               |
| Medicare                                      |                            | 1,364,870 | 3,246,555 | 76.3 (0.2)    |
| Medicaid                                      |                            | 168,324 | 364,141    | 8.55 (0.13)   |
| Private insurance                             |                            | 183,964 | 433,401    | 10.2 (0.11)   |
| Self-pay                                      |                            | 50,857  | 114,091    | 2.68 (0.05)   |
| No charge                                     |                            | 5178    | 11,945     | 0.28 (0.02)   |
| Other                                         |                            | 40,101  | 86,718     | 2.04 (0.05)   |
| Median household income quartiles for patients by ZIP code | |         |            |               |
| First                                         |                            | 592,230 | 1,454,270  | 34.6 (0.43)   |
| Second                                        |                            | 446,097 | 1,073,297  | 25.5 (0.26)   |
| Third                                         |                            | 406,498 | 925,084    | 22 (0.25)     |
| Fourth                                        |                            | 344,113 | 750,377    | 17.9 (0.34)   |
| Length of stay (d), mean                      |                            | 1,817,735 | 4,266,863  | 5.032 (0.018) |
| Length of stay (d)                            | ≤2                          | 495,772 | 1,147,337  | 26.9 (0.12)   |
|                                               | 3                           | 335,132 | 793,969    | 18.6 (0.05)   |
|                                               | 4                           | 261,430 | 621,843    | 14.6 (0.04)   |
|                                               | 5                           | 186,217 | 442,546    | 10.4 (0.04)   |
|                                               | 6                           | 135,249 | 320,993    | 7.52 (0.03)   |
|                                               | ≥7                          | 403,935 | 940,175    | 22 (0.12)     |
| Total charges, mean                           |                            | 1,817,735 | 4,266,863  | 37.532 (336.4) |
| Elective admission                            |                            | 108,805 | 303,496    | 7.12 (0.17)   |
| Resident of the state in which hospital care was received | | 1,757,129 | 4,098,399 | 96.1 (0.14)  |
and 50.4% were men; 35.8% of admissions were for patients with systolic HF, the average length of stay was 5.0 days, and 96.1% were residents of the state in which hospital care was received. Most patients, 42.3% and 36.5%, were categorized under moderate likelihood of dying or major likelihood of dying, respectively. This is defined as the likelihood of in-hospital mortality on the basis of secondary diagnosis, age, principal diagnosis, and whether certain procedures were performed.12

The most readmissions any patient had within 1 year was 18. The top 10 most common comorbidities included hypertension (75.4%), diabetes mellitus (44.7%), renal failure (40.5%), chronic pulmonary disease (37.2%), deficiency anemia (29.2%), fluid and electrolyte disorders (28.9%), obesity (18.1%), hypothyroidism (16.4%), peripheral vascular disorders (11.8%), and depression (9.65%) (Table 2).12

Figure 1 illustrates the probability of readmission and the number at risk at each time point for subsets defined by the types of heart procedures performed at each admission. The procedures of interest included repair of the heart and pericardium; heart transplant; the placement of ventricular assist device, pacemaker, and automatic cardioverter/defibrillator; the implantation of leadless pressure

| TABLE 2. Top 10 Comorbidities of Total Heart Failure Admissions* |
|-----------------|-----------------|-----------------|
| Variables       | Description     | N      | Weighted N     |
| N               | 1,817,735       |       |                 |
| Weighted N      | 4,266,863       |       |                 |
| All patients refined DRG: risk of mortality subclassb | % (SE) |       |
| 0: No class specified | 44 | 107 | 0 (0) |
| 1: Minor likelihood of dying | 208,475 | 480,434 | 11.3 (0.09) |
| 2: Moderate likelihood of dying | 761,713 | 1,803,514 | 42.3 (0.11) |
| 3: Major likelihood of dying | 662,999 | 1,555,347 | 36.5 (0.1) |
| 4: Extreme likelihood of dying | 184,504 | 427,461 | 10 (0.07) |
| All patients refined DRG: severity of illness subclassc | % (SE) |       |
| 0: No class specified | 44 | 107 | 0 (0) |
| 1: Minor loss of function | 141,967 | 329,041 | 7.71 (0.06) |
| 2: Moderate loss of function | 699,800 | 1,656,786 | 38.8 (0.13) |
| 3: Major loss of function | 827,233 | 1,937,335 | 45.4 (0.12) |
| 4: Extreme loss of function | 148,691 | 343,594 | 8.05 (0.07) |
| AHRQ comorbidity measure | % (SE) |       |
| Deficiency anemia | 541,512 | 1,244,801 | 29.2 (0.14) |
| Chronic pulmonary disease | 669,999 | 1,585,487 | 37.2 (0.12) |
| Depression | 165,775 | 411,698 | 9.65 (0.08) |
| Diabetes, uncomplicated | 619,833 | 1,457,991 | 34.2 (0.11) |
| Diabetes with chronic complications | 197,756 | 446,011 | 10.5 (0.08) |
| Hypertension | 1,382,537 | 3,217,406 | 75.4 (0.15) |
| Hypothyroidism | 295,399 | 699,559 | 16.4 (0.09) |
| Fluid and electrolyte disorders | 526,249 | 1,231,392 | 28.9 (0.13) |
| Obesity | 328,886 | 770,234 | 18.1 (0.1) |
| Peripheral vascular disorders | 219,268 | 504,371 | 11.8 (0.09) |
| Renal failure | 744,033 | 1,729,780 | 40.5 (0.14) |

*DRG = Diagnosis related group; AHRQ = Agency for Healthcare Research and Quality.
1Risk of mortality subclass is defined as the likelihood of in-hospital mortality on the basis of secondary diagnosis, age, principal diagnosis, and whether certain procedures were performed.12
2Severity of illness subclass is defined as the extent of organ system loss of function or physiologic decompensation and is used to predict increased resource use because of the comorbidities and acute illness.12

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sensor (Cardiomems HF system, Abbott); and extracorporeal membrane oxygenation auxiliary to heart operation. A summary of *International Classification of Diseases, Ninth Revision, Clinical Modification* procedure codes for HF admissions can be found in Supplemental Table S2 (available online at http://www.mcpiqojournal.org). Readmission probabilities at 30 days in patients who underwent Cardiomems HF system implantation in the derivation and validation cohorts were 0 and 0.088, respectively. With the exception of the Cardiomems HF system implantation, Figure 1 shows a Kaplan-Meier curve for the proportion of readmission and number at risk stratified by procedure codes in both the derivation and validation cohorts. From Figure 2, it can be observed that patients who underwent the Cardiomems HF system implantation during admission had significantly lower rates of readmission at all time points (\(P=0.047\)). Patients who received a right heart catheterization or right and left heart catheterization at admission had significantly lower readmission probability than those who received other procedures (\(P<0.001\)) (Figure 3).

Multivariate analyses of factors predicting readmission for all patients with HF using a derivation cohort (2010-2012) can be found in Supplemental Table S3 (available online at http://www.mcpiqojournal.org). Parameters from the multivariate analysis with \(P<0.01\) were used to create the HF readmission scale, the values of which are tabulated in Table 3. Table 4 shows the probability of readmission at 30, 60, 90, and 180 days on the basis of the risk score. Figure 4 illustrates the ROC curve and AUC at each time point (30, 60, 90, 180 days, respectively) to assess the accuracy of the risk scale using the derivation cohort (2010-2012). Figure 5 illustrates the
ROC curve and AUC at each time point (30, 60, 90, 180 days, respectively) to assess the accuracy of the risk scale using the validation cohort (2013-2014).

DISCUSSION

In this study, we used a national database to generate a HF readmissions risk model that takes into account procedures performed at admission. It was observed that right heart catheterization and Cardiomems HF system implantation were protective factors against readmission, which is consistent with the current literature.13-15 Our study also found reproducibility of the Readmission After Heart Failure scale by Chamberlain et al9 despite the use of a different database with a larger population at different time points. Compared with the Readmission After Heart Failure scale, differences include the use of different databases (NRD vs SID), inclusion of HF surgical procedures, and incorporation of protective factors in our risk scale. Given the use of different databases and different timepoints, the respective models had similar AUC at all time intervals, which indicates the independence of time and similar predictions of readmission out through 180 days.

There exist many other HF prediction models with C-statistics ranging from poor to acceptable.16 This points to the fact that HF is a disease with complex pathophysiology and is often quite difficult to predict. Two notable models include the ones by Keenan et al17 and Krumholtz et al,18 on which the Centers for Medicare and Medicaid Services has based its readmission risk calculations, which provide risk-standardized readmission rates for hospital comparisons using the Medicare database.19 These initial prediction models have paved the way for others to follow. In a multisite study looking at predictors of clinical outcomes in acute decompensated HF, a simplified scoring system...
comprising only 5 commonly available clinical variables was able to discriminate the 30-day mortality risk from 0.5% to 53%.20 Despite great efforts in developing readmission risk models, a study looking at trends in all-cause 30-day readmission rates among 70 US hospitals concluded that only slight improvements in the rates have been made, with only a handful of hospitals seeing significant improvement.21 This points to the need for ongoing work.

To our knowledge, this is the first risk prediction model to include HF procedures. It was observed that, overall, the inclusion of certain HF procedures does not significantly affect our model. However, of note, patients who underwent a procedure for the placement of the Cardiomems HF system device were observed to have a significant decrease in readmission risk. This is consistent with the CHAMPION trial, which found that the use of the Cardiomems device has been shown to reduce HF hospitalizations and improve quality of life regardless of the ejection fraction.13 Lastly, our model included protective factors (ie, factors that reduced the risk of readmission) not seen in other risk models. Protective factors in our model included alcohol use, obesity, heart transplant, permanent pacemaker placement, implantable cardioverter/defibrillator placement, and extracorporeal circulation.

An important limitation of this study is the lack of data on patient race in the database. According to a study examining racial and gender disparities in approximately 5.5 million HF admissions using the National Inpatient Sample database, Caucasians had the highest mortality rate (3.55%), whereas African Americans had the lowest mortality rate (1.75%); however, African Americans had a younger average age of admission than Caucasians (63 vs 77 years).22 Moreover, the age-adjusted HF-related cardiovascular death rate and rate of hospitalization were approximately 2.5 times greater in African Americans than in Whites.23 There exists clear evidence of health care disparities across race and
ethnicity in HF. Although it could be attributed to health care access and socioeconomic status, genetic susceptibility, social determinants of health, and implicit bias may also explain such disparities. Another limitation of this study is inherent to its retrospective nature.

Future studies are needed to properly validate the model presented here by applying it prospectively in both a single-institution and multicenter design to identify high-risk patients to target preventative

### TABLE 3. Values for Components of Heart Failure Readmissions Risk Scale Created Using Derivation Cohort

| Characteristic                                      | Point value |
|-----------------------------------------------------|-------------|
| Age (y)                                             |             |
| 0-39                                                | 4           |
| 40-49                                               | 3           |
| 50-59                                               | 2           |
| 60-69                                               | 2           |
| 70-79                                               | 1           |
| 80+                                                 | 0           |
| Median household income quartiles for patients by ZIP code |       |
| Second/third/fourth                                 | −1          |
| Expected primary payer                              |             |
| Medicaid                                            | 1           |
| Private insurance                                   | −3          |
| Self-pay/no charge                                  | −4          |
| Other                                               | −2          |
| Length of stay (d)                                  |             |
| ≤2                                                  | 0           |
| 3-6                                                 | 1           |
| ≥7                                                  | 2           |
| Comorbidities                                       |             |
| Acquired immune deficiency syndrome                 | 3           |
| Alcohol abuse                                       | −1          |
| Anemia                                              | 1           |
| Arthritis, rheumatoid or collagen vascular disease  | 1           |
| Chronic blood loss anemia                           | 1           |
| Congestive heart failure                            | 1           |
| Chronic lung disease                                | 2           |
| Depression                                          | 1           |
| Diabetes mellitus, uncomplicated                    | 1           |
| Diabetes mellitus with chronic complications        | 1           |
| Drug abuse                                          | 2           |
| Liver disease                                       | 1           |
| Lymphoma                                            | 1           |
| Obesity                                             | −1          |
| Peripheral vascular disease                         | 1           |
| Psychoses                                           | 1           |
| Renal failure                                       | 2           |
| Solid tumor without metastasis                      | 1           |
| Procedures                                          |             |
| Heart replacement procedure                         | −3          |
| Pacemaker placement                                 | −1          |

**Continued on next column**

### TABLE 3. Continued

| Characteristic                                      | Point value |
|-----------------------------------------------------|-------------|
| Procedures, continued                               |             |
| Automatic cardioverter/defibrillator placement      | −3          |
| Extracorporeal circulation and procedure auxiliary to heart operation | −1          |

### TABLE 4. Probability of Readmission by 30, 60, 90, and 180 days in the Validation Cohort Estimated on the Basis of Weighted Kaplan-Meier Failure Curve

| Risk score | Day 30 | Day 60 | Day 90 | Day 180 |
|------------|--------|--------|--------|---------|
| −7 to −5   | 8%     | 15%    | 19%    | 28%     |
| −4         | 10%    | 16%    | 21%    | 30%     |
| −3         | 13%    | 19%    | 23%    | 32%     |
| −2         | 13%    | 20%    | 24%    | 32%     |
| −1         | 15%    | 23%    | 28%    | 37%     |
| 0          | 16%    | 24%    | 30%    | 41%     |
| 1          | 18%    | 27%    | 33%    | 44%     |
| 2          | 19%    | 29%    | 36%    | 47%     |
| 3          | 21%    | 32%    | 39%    | 50%     |
| 4          | 23%    | 35%    | 42%    | 54%     |
| 5          | 25%    | 38%    | 45%    | 57%     |
| 6          | 28%    | 41%    | 49%    | 60%     |
| 7          | 30%    | 44%    | 52%    | 64%     |
| 8          | 33%    | 47%    | 55%    | 67%     |
| 9          | 35%    | 49%    | 58%    | 70%     |
| 10         | 38%    | 53%    | 60%    | 73%     |
| 11         | 41%    | 57%    | 65%    | 76%     |
| 12         | 46%    | 62%    | 69%    | 80%     |
| 13         | 46%    | 57%    | 65%    | 77%     |
| 14-16      | 56%    | 68%    | 77%    | 89%     |

HEART FAILURE READMISSION MODEL
CONCLUSION

Heart failure is a major public health issue in the United States and worldwide. Although various methods have been implemented in an effort to reduce mortality and HF interventions. Further, effects of using the model should be explored to determine its clinical utility (eg, effect on the number of HF readmissions, health care costs, and general health of patients with HF).

FIGURE 4. A-D, Receiver operating characteristic curve (ROC) and area under the ROC curve at each time point (30, 60, 90, and 180 days) using the derivation cohort (year 2010-2012) to assess the accuracy of the risk scale. Model 1 was fitted using our risk scale from the model with procedure codes. Model 2 was fitted using our risk scale from the model without procedure codes. Model 3 was fitted using the Readmission After Heart Failure scale from Chamberlain et al.9
readmissions, such as the enactment of the Hospital Readmissions Reduction Program under the Affordable Care Act and development of various prediction models, it remains a significant burden on patients with HF and the health care system. Thus, establishing a useful risk model can identify those at high risk of readmission and provide a point-of-care tool to guide clinical decision making, reduce health care cost, guide appropriate use of resources, and improve health care outcomes. Our risk prediction model, which has been designed using a risk scale that incorporates procedure codes, has demonstrated a high degree of accuracy in predicting readmissions. The model’s performance has been validated using a cohort of patients from the years 2013 to 2014, and the results show that it can be effectively used in a point-of-care setting to guide clinical decision making.

**FIGURE 5.** A-D, Receiver operating characteristic (ROC) curve and area under the ROC curve at each time point (30, 60, 90, and 180 days) using the validation cohort (year 2013-2014) to assess the accuracy of the risk scale. Model 1 was fitted using our risk scale from model with procedure codes. Model 2 was fitted using our risk scale from model without procedure codes. Model 3 was fitted using the Readmission After Heart Failure scale from Chamberlain et al.9
shown to be independent of both time and databases, may aid in reducing HF readmissions and guide specific interventions to lower the mortality rate.

SUPPLEMENTAL ONLINE MATERIAL
Supplemental material can be found online at http://www.mcpiqojournal.org. Supplemental material attached to journal articles has not been edited, and the authors take responsibility for the accuracy of all data.

Abbreviations and Acronyms: AUC, area under the curve; HF, heart failure; NRD, Nationwide Readmissions Database; ROC, receiver operating characteristic; SID, State Inpatient Database

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