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Predicting Readmission Risk of Patients with Diabetes Hospitalized for Cardiovascular Disease: A Retrospective Cohort Study

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Abstract

Objective—To develop and validate a tool that predicts 30d readmission risk of patients with diabetes hospitalized for cardiovascular disease (CVD), the Diabetes Early Readmission Risk Indicator-CVD (DERRI-CVD™).

Methods—A cohort of 8,189 discharges was retrospectively selected from electronic records of adult patients with diabetes hospitalized for CVD. Discharges of 60% of the patients (n=4,950) were randomly selected as a training sample and the remaining 40% (n=3,219) were the validation sample.

Results—Statistically significant predictors of all-cause 30d readmission risk were identified by multivariable logistic regression modeling: education level, employment status, living within 5 miles of the hospital, pre-admission diabetes therapy, macrovascular complications, admission serum creatinine and albumin levels, having a hospital discharge within 90 days pre-admission, and a psychiatric diagnosis. Model discrimination and calibration were good (C-statistic 0.71). Performance in the validation sample was comparable. Predicted 30d readmission risk was similar in the training and validation samples (38.6% and 35.1% in the highest quintiles).

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Conclusions—The DERRI-CVD™ may be a valid tool to predict all-cause 30d readmission risk of patients with diabetes hospitalized for CVD. Identifying high-risk patients may encourage the use of interventions targeting those at greatest risk, potentially leading to better outcomes and lower healthcare costs.

Keywords

Keywords: readmission risk; cardiovascular disease; diabetes

1. Introduction

Hospital readmissions within 30 days of discharge (30d readmissions) are a high-priority health care quality measure and target for cost reduction [1-3]. For patients with diabetes, the cost of hospital care was approximately $124 billion in 2012 in the United States (US) [4]. Although individuals with diabetes represent an estimated 9% of the US population [5], they account for approximately 25% of hospitalizations annually [6]. About 25-30% of hospitalizations among patients with diabetes are due to cardiovascular disease (CVD) [7, 8]. Diabetes patients admitted for CVD are likely to be at particularly high-risk of 30d readmission [9-11]. However, readmission rates and predictors of readmission for this specific group of patients have not been reported to our knowledge.

Although interventions to reduce the risk of 30d readmission in various populations have achieved some success [12], approaches specifically for patients with diabetes and CVD are needed [13]. Interventions designed to reduce 30d readmission risk among patients with chronic disease have not consistently been effective [12, 14]. Focusing on a specific set of patients, such as those with diabetes admitted for CVD, may improve the effectiveness of readmission reduction interventions. Furthermore, if readmission risk could be predicted, then interventions could be targeted to those patients at greatest risk, enabling more efficient and effective use of resources.

Recently we published on the development and validation of the Diabetes Early Readmission Risk Index, (DERRI™) [15], a tool that predicts all-cause 30d readmission risk for all hospitalized patients with diabetes. The DERRI™ has modest predictive power, reflected by a C-statistic of 0.70. The aim of the present study was to build a predictive model in the subset of diabetes patients hospitalized for CVD. We hypothesized that a model developed in a more homogeneous population than all hospitalized patients with diabetes would be more accurate than the DERRI™. We therefore developed and validated a tool to predict the risk of all-cause 30d readmission in patients with diabetes hospitalized for CVD, the DERRI-CVD™, and compared its performance to the DERRI™.

2. Subjects, Materials and Methods

2.1 Subjects

A cohort of hospitalized patients was retrospectively selected from the electronic medical records of an urban academic medical center (Boston Medical Center) between January 1, 2004 and December 31, 2012, the time period for which data were available. Inclusion

criteria were twofold: 1) a primary discharge diagnosis of CVD, defined as myocardial infarction (410.xx – 412.xx, or 414.xx), heart failure (428.xx), ischemic stroke (434.xx, 435.x, 437.1, 438.xx, or 997.02), or peripheral vascular disease (250.7x, 440.xx, 443.xx, or 444.xx) according to International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) codes and 2) a diagnosis of diabetes mellitus defined by an ICD-9-CM code of 250.xx or the presence of a diabetes-specific medication on the pre-admission medication list. The study sample was drawn from a parent cohort used to develop and validate the DERRI™ that was not restricted to patients with a primary discharge diagnosis of CVD (N=44,203 discharges), and the methods employed to create and analyze the CVD subset were similar to those of the parent cohort [15]. Index discharges were excluded for patients aged less than 18 years, discharge by transfer to another hospital, discharge from an obstetric service (indicating pregnancy), inpatient death, outpatient death within 30 days of discharge, or incomplete data. Readmissions that occurred within 8 hours of an index discharge were considered false positive and merged with the discharge. All eligible discharges were included in the analysis.

Two samples were randomly selected from the study cohort: a training sample and a validation sample [16]. The training sample, which comprised 60% of the eligible patients in the study cohort, was used to develop the DERRI-CVD™. The validation sample included the remaining 40% of patients and was used to test the performance of the DERRI-CVD™.

2.2 Definition of Variables

All-cause readmission within 30 days of the index discharge was the outcome predicted by the model. Forty-six variables were evaluated as predictors of the outcome (Table 1). All variables were based on data obtained prior to hospital discharge. For all but one of the laboratory parameters (serum albumin), the first value available during the time period starting 24 hours before the time of admission was used. This sampling allowed for inclusion of values obtained in the immediate pre-admission time period (usually obtained in the Emergency Department). For serum albumin, the value closest to the date and time of admission was used up to 30 days before or during the admission. For weight, the first value obtained during the index hospitalization or, if unavailable, the value closest to the date and time of admission was used up to 1 year before admission. Missing weights were imputed based on height, age, race, and sex. Missing heights were imputed based on age, race, and sex [17]. Variables based on ICD-9-CM codes were considered for ever occurrence (during or before the index hospitalization) or current occurrence during the index hospitalization (Supplemental Table 1). No variables were based on summary statistics of laboratory values or combinations of diagnostic codes in order to maximize ease of use. The most common reasons for 30d readmission based on primary ICD-9-CM code were described.

2.3 Statistical Analysis

Summaries of categorical variables included counts and percentages, while means and standard deviations or medians and interquartile ranges were used for continuous variables. Readmitted patients were compared to non-readmitted patients by chi-squared tests for categorical variables and 2-sample t-tests or Wilcoxon rank sum tests for continuous variables. Non-normally distributed continuous variables were log transformed for

modelling procedures. The generalized estimating equations (GEE) approach was used to model the association of the predictors with 30d readmission.[18] In contrast to logistic regression without GEE, which assumes independence of each observation, the GEE method accounts for clustering of repeat observations, in this case, multiple discharges per patient. The initial model included all the variables associated with 30d readmission in univariate analyses in the training sample ($p<0.01$). Multivariable logistic regression with GEE was performed to determine the adjusted associations of the variables with all-cause 30d readmission. The model that optimized the balance of the fewest variables with good predictive performance was selected as the final DERRI-CVD™ model. Clinical relevance, ease of use and collinearity were considered in developing the model.

Assessment of model performance was based on discrimination, the ability of the model to distinguish high risk from low risk individuals, and calibration, the ability of the model to correctly estimate risk across the range of potential risk.[19, 16] Discrimination was evaluated using the C-statistic, which represents the area under the receiver operating characteristic (ROC) curve,[20] where higher values represent better discrimination.[21] Calibration was assessed by the Hosmer-Lemeshow test, for which a p-value greater than 0.05 indicates adequate calibration.[16] Using the DERRI-CVD™ to predict each patient's risk of readmission as a number between 0% and 100%, patients were stratified into quintiles of 30d readmission risk. The C-statistics of the DERRI-CVD™ and the DERRI™ in the validation sample were compared to assess the relative performance of the two models.

All analyses were performed using SAS version 9.4 (SAS Institute, Cary, NC). A p-value less than 0.05 was considered statistically significant.

The protocol was approved by the Boston Medical Center and Temple University Institutional Review Boards.

3. Results

3.1 Descriptive Statistics and Univariate Analyses

There were 8,189 discharges in the study sample, of which 1,626 (19.9%) were associated with 30d readmission for any cause. Characteristics of the training sample (n=4,950 discharges) are presented in Table 1. More than 70% of the patients were aged 60 years or older. The sample was well distributed across racial/ethnic backgrounds. A majority had government supported health insurance (Medicaid or Medicare), no college education, were retired, unemployed, or disabled, and lived within 5 miles of the hospital. Slightly more than half were male, a majority was overweight or obese, and a significant minority (17.3%) did not speak English. Insulin users comprised 36.5% of the sample. More than 30% of the patients had at least 1 documented microvascular complication, whereas more than half had 2 or more macrovascular complications. The most common non-diabetes related comorbidities were hypertension, cardiac dysrhythmias, anemia, and schizophrenia or mood disorders. A majority of the variables were associated with 30d readmission in univariate analysis (Table 1). The variables not associated with 30d readmission were age, gender, fluency in English, inpatient diabetes consultation, body mass index, malignant neoplasm,

pancreatitis, drug abuse and current complication of a device, graft, or implant. The most common primary diagnoses for 30d readmission were diabetes, heart failure, chronic ischemic heart disease, shortness of breath, chest pain, peripheral arterial disease, and acute kidney failure (Table 2).

3.2 The DERRI-CVD™

The DERRI-CVD™ is composed of 10 statistically significant predictors (Table 3). Patients discharged within 90 days before the index admission were at 2-fold greater odds of having a 30d readmission than patients without a recent prior discharge. Certain sociodemographic factors, such as not being employed, lower educational attainment, and living within 5 miles of the hospital predicted greater odds of 30d readmission. Diabetes-related factors also predicted readmission risk, in that having more macrovascular complications and pre-admission sulfonylurea therapy were associated with greater readmission risk, while metformin therapy was associated with lower readmission risk. Two admission laboratory parameters were included in the model: higher serum creatinine and lower serum albumin predicted higher readmission risk. Lastly, patients with a diagnosis of schizophrenia or a mood disorder were at 31% greater odds of 30d readmission compared to patients without these psychiatric diagnoses. Discrimination of the model was acceptable (C-statistic 0.71), and the model was well calibrated (Hosmer-Lemeshow test p=0.38).

Using the DERRI-CVD™, the training sample was stratified into quintiles of predicted all-cause 30d readmission risk (Figure 1). The highest quintile had 38.6% predicted mean risk of 30d readmission and accounted for 39.1% of 30d readmissions.

3.3 Validation Sample

The validation sample included 3,219 discharges, of which 645 (20.0%) were associated with a 30d readmission. Characteristics of the validation and training samples were similar for all variables except employment status, ever hypertension, having a blood product transfusion during the admission, and use of a sulfonylurea before admission (Table 4). Although these differences reached statistical significance, the absolute differences between the validation and training samples were less than 5% across all characteristics. Discrimination and calibration of the DERRI-CVD™ in the validation sample remained acceptable (C-statistic 0.68 ± 0.01, Hosmer-Lemeshow test p=0.052). Predicted 30d readmission risk was also similar between the training and validation samples (Figure 1). Furthermore, the C-statistic of the DERRI™ in the validation sample (0.69 ± 0.01) was not significantly different from the C-statistic of the DERRI-CVD™ (p=0.82).

4. Discussion

4.1 Summary of Results

In this retrospective cohort study of 8,189 discharges of patients with diabetes hospitalized for CVD, the all-cause 30d readmission rate was 19.9%. Many patient characteristics were associated with 30d readmission among patients in the training sample. From these characteristics we developed a set of 10 statistically significant predictors of 30d readmission to form the DERRI-CVD™. The strongest predictor was having a discharge

within 90 days before the index admission. Diabetes-related characteristics such as pre-admission metformin or sulfonylurea treatment and the number of macrovascular complications were also important factors associated with 30d readmission. Other predictors were living within 5 miles of the hospital, lower educational attainment, employment status, admission serum creatinine and albumin, and a diagnosis of schizophrenia or a mood disorder. This novel predictive model successfully stratified patients into quintiles of 30d readmission risk, where the highest quintile had a 39.3% risk of 30d readmission. The model had acceptable discrimination and calibration in both the training and validation samples. However, performance of the DERRI-CVD™ was not significantly different from the performance of the DERRI™, which was developed and validated in the parent cohort of patients with diabetes hospitalized for any cause, not only CVD.

4.2 Comparison to Prior Literature

Other studies of patients with diabetes report all-cause 30d readmission rates ranging from 10.0 to 21.0% [22-27]. The relatively high readmission rate found in our study may be related to the following 2 reasons: (1) differences in design from studies that excluded high risk patients [25], and (2) sociodemographic differences [28, 15]. Our sample was drawn from an urban, academic medical center that serves as the safety net hospital for its region. Most other relevant studies were not performed at safety net institutions or in urban settings and may have examined populations at lower risk of readmission.

The most common reasons for readmission according to primary discharge diagnoses were diabetes, heart failure, chronic ischemic heart disease, shortness of breath, chest pain, peripheral arterial disease, and acute kidney failure. These are similar to the reasons for readmission in the parent cohort, with the exception of chronic ischemic heart disease and peripheral arterial disease [15]. To our knowledge, only one other group has presented primary diagnoses of 30d readmissions among diabetes patients, also reporting diabetes, renal disease, heart failure, and ischemic heart disease [29]. Unlike our study, however, the analysis by Jiang et al. was limited to readmissions for diabetes-related conditions and did not present a model of readmission risk.

Not surprisingly, there is considerable overlap among the predictors in the DERRI-CVD™ and the DERRI™, the 30d readmission risk indicator for patients with diabetes not restricted to those hospitalized for CVD [15]. Discharge within 90 days before admission, macrovascular complications, admission serum creatinine, employment status, and living within 5 miles of the hospital are included in both models. These shared predictors of 30d readmission among patients with diabetes with or without active CVD likely represent the most important markers of readmission risk. In contrast, educational attainment, admission serum albumin, pre-admission treatment with metformin or a sulfonylurea, and a diagnosis of schizophrenia or a mood disorder were stronger predictors of risk among patients with diabetes hospitalized for CVD than among the broader population of patients with diabetes.

Although discharge within 90 days prior to admission has not specifically been reported by other groups, prior hospitalizations and emergency department visits have been shown to predict 30d readmission risk [25, 22, 30]. Likewise, diabetes complications have not been previously isolated in published studies as predictors of 30d readmission, however several

other groups have demonstrated that comorbidity burden is associated with readmission risk [23, 25, 22, 31, 30]. In addition, educational attainment has not been previously associated with 30d readmission. We found that patients who had not graduated from college were at higher risk of readmission than college graduates. Lower educational attainment may reflect worse health literacy and more limited access to health care, or possibly a lower degree of social connectedness, which has been linked to poor health outcomes [32]. This is consistent with a qualitative study we performed in which poor health literacy and social determinants of health were related to 30d readmissions among patients with diabetes [33].

4.3 Study Limitations and Strengths

Some limitations of the study deserve acknowledgment. This was a single-center study conducted at an urban academic medical center, and the DERRI-CVD™ may not be generalizable to other settings or populations. Because the study was retrospective and some data were unavailable, certain potential readmission predictors of interest could not be examined, including hemoglobin A1c (53% of index discharges lacked an associated value), diabetes type, and diabetes duration. In addition, 30d readmissions that may have occurred at other hospitals were not captured. It seems unlikely, however, that a significant number of patients were readmitted elsewhere because the 30d readmission rate in our study is relatively high within the range reported for patients with diabetes. Data on more direct measures of socioeconomic status (SES) such as income were not available. However, given the location of Boston Medical Center, proximity to the hospital served as a proxy for SES whereby patients living within 5 miles of the hospital were generally at lower SES than those living further away. Lastly, ICD-9-CM codes, which were used to assess the presence of diabetes, CVD and other comorbid conditions, have since been replaced by ICD-10-CM codes in the United States. Because all applicable ICD-9-CM codes were used to define a given condition, it is unlikely that use of the comparable ICD-10-CM codes would substantially alter performance of the model.

The study limitations are offset by several strengths, including a relatively large sample size and examination of more than 40 sociodemographic and clinical characteristics as potential predictors of 30d readmission. Furthermore, the DERRI-CVD™ performed similarly in the training and validation samples. In addition, we are unaware of any previously published model that predicts 30d readmission risk specifically for patients with diabetes admitted for CVD, the most common cause of death in this population [34].

4.4 Application of Results and Direction for Future Research

Some of the predictors in the DERRI- CVD™ may help inform interventions to reduce 30d readmission risk. Because patients at lower education levels were at higher risk, discharge instructions and processes should designed at the appropriate health literacy level. The finding that metformin therapy was associated with lower readmission risk while sulfonylurea therapy was associated with higher readmission risk could be taken into consideration when diabetes regimens are determined upon hospital discharge. Lastly, patients with schizophrenia or mood disorders, who were at higher risk for readmission, could be given post-hospital follow-up to address these conditions. Whether or not such

interventions reduce the risk of readmission among patients with diabetes hospitalized for CVD would need to be tested in randomized controlled trials.

5. Conclusions

Using a retrospective cohort of hospitalized patients with diabetes admitted for CVD, we developed a valid model (DERRI-CVD™) to predict all-cause 30d readmission risk that displays acceptable predictive power. Performance of the DERRI-CVD™ was not significantly different from the performance of the DERRI™. Either model could be used to identify patients with diabetes admitted for CVD at higher risk of 30d readmission before hospital discharge because all of the predictors are easily obtained at the time of admission. Stratifying patients by readmission risk may enable interventions to be focused on those at greatest risk, potentially leading to better outcomes and lower costs by reducing hospital utilization.

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References

1. Axon RN, Williams MV. Hospital readmission as an accountability measure. JAMA. 2011; 305(5): 504–5. [PubMed: 21285430]
2. Stone, J., Hoffman, G. Congressional Research Service. Penny Hill Press; 2010. Medicare Hospital Readmissions: Issues, Policy Options and PPACA.
3. Epstein AM. Revisiting Readmissions — Changing the Incentives for Shared Accountability. New England Journal of Medicine. 2009; 360(14):1457–9. DOI: 10.1056/NEJMe0901006 [PubMed: 19339727]
4. ADA. Economic Costs of Diabetes in the U.S. in 2012. Diabetes Care. 2013; doi: 10.2337/dc12-2625
5. Centers for Disease Control and Prevention. National Diabetes Statistics Report: Estimates of Diabetes and Its Burden in the United States, 2014. Atlanta, GA: U.S. Department of Health and Human Services; 2014.
6. Agency for Healthcare Research and Quality (AHRQ); 2014. HCUP Nationwide Inpatient Sample (NIS) 2012. http://hcupnet.ahrq.gov/HCUPnet.jsp [Accessed Accessed June 15, 2014]
7. Cook CB, Tsui C, Ziemer DC, Naylor DB, Miller WJ. Common reasons for hospitalization among adult patients with diabetes. Endocrine practice: official journal of the American College of Endocrinology and the American Association of Clinical Endocrinologists. 2006; 12(4):363–70.
8. Cook CB, Tsui C, Ziemer DC, Naylor DB, Miller WJ, Hentz JG. Common reasons for hospitalization in urban diabetes patients. Ethnicity & disease. 2006; 16(2):391–7. [PubMed: 17682240]
9. Dunlay SM, Weston SA, Killian JM, Bell MR, Jaffe AS, Roger VL. Thirty-Day Rehospitalizations After Acute Myocardial InfarctionA Cohort Study. Annals of Internal Medicine. 2012; 157(1):11–8. DOI: 10.7326/0003-4819-157-1-201207030-00004 [PubMed: 22751756]

10. Lichtman JH, Leifheit-Limson EC, Jones SB, Watanabe E, Bernheim SM, Phipps MS, et al. Predictors of Hospital Readmission After Stroke: A Systematic Review. Stroke. 2010; 41(11): 2525–33. DOI: 10.1161/strokeaha.110.599159 [PubMed: 20930150]
11. Betihavas V, Davidson PM, Newton PJ, Frost SA, Macdonald PS, Stewart S. What are the factors in risk prediction models for rehospitalisation for adults with chronic heart failure? Australian Critical Care. 2012; 25(1):31–40. doi:http://dx.doi.org/10.1016/j.aucc.2011.07.004. [PubMed: 21889893]
12. Hansen LO, Young RS, Hinami K, Leung A, Williams MV. Interventions to reduce 30-day rehospitalization: a systematic review. Ann Intern Med. 2011; 155(8):520–8. DOI: 10.1059/0003-4819-155-8-201110180-00008 [PubMed: 22007045]
13. Draznin B, Gilden J, Golden SH, Inzucchi SE, Baldwin D, Bode BW, et al. Pathways to quality inpatient management of hyperglycemia and diabetes: a call to action. Diabetes Care. 2013; 36(7): 1807–14. DOI: 10.2337/dc12-2508 [PubMed: 23801791]
14. Weinberger M, Oddone EZ, Henderson WG. Does increased access to primary care reduce hospital readmissions? Veterans Affairs Cooperative Study Group on Primary Care and Hospital Readmission. N Engl J Med. 1996; 334(22):1441–7. DOI: 10.1056/nejm199605303342206 [PubMed: 8618584]
15. Rubin DJ, Handorf EA, Golden SH, Nelson DB, McDonnell ME, Zhao H. Development and Validation of a Novel Tool to Predict Hospital Readmission Risk Among Patients With Diabetes. Endocr Pract. 2016; 22(10):1204–15. DOI: 10.4158/e161391.or [PubMed: 27732098]
16. Altman DG, Vergouwe Y, Royston P, Moons KGM. Prognosis and prognostic research: validating a prognostic model. BMJ. 2009; 338:1432–5. DOI: 10.1136/bmj.b605
17. Conn JM, Lui KJ, McGee DL. A model-based approach to the imputation of missing data: Home injury incidences. Statistics in Medicine. 1989; 8(3):263–6. DOI: 10.1002/sim.4780080305 [PubMed: 2711059]
18. Hanley JA, Negassa A, Edwardes MDd, Forrester JE. Statistical Analysis of Correlated Data Using Generalized Estimating Equations: An Orientation. Am J Epidemiol. 2003; 157(4):364–75. DOI: 10.1093/aje/kwf215 [PubMed: 12578807]
19. Abbasi A, Peelen LM, Corpeleijn E, Schouw YTvd, Stolk RP, Spijkerman AMW, et al. Prediction models for risk of developing type 2 diabetes: systematic literature search and independent external validation study. BMJ. 2012; 345:1–16. DOI: 10.1136/bmj.e5900
20. Chambless LE, Diao G. Estimation of time-dependent area under the ROC curve for long-term risk prediction. Stat Med. 2006; 25(20):3474–86. DOI: 10.1002/sim.2299 [PubMed: 16220486]
21. Royston P, Moons KGM, Altman DG, Vergouwe Y. Prognosis and prognostic research: Developing a prognostic model. BMJ. 2009; 338:b604.doi: 10.1136/bmj.b604 [PubMed: 19336487]
22. Robbins JM, Webb DA. Diagnosing diabetes and preventing rehospitalizations: the urban diabetes study. Med Care. 2006; 44(3):292–6. [PubMed: 16501402]
23. Bennett KJ, Probst JC, Vyavaharkar M, Glover SH. Lower rehospitalization rates among rural Medicare beneficiaries with diabetes. J Rural Health. 2012; 28(3):227–34. DOI: 10.1111/j.1748-0361.2011.00399.x [PubMed: 22757946]
24. Chen JY, Ma Q, Chen H, Yermilov I. New bundled world: quality of care and readmission in diabetes patients. J Diabetes Sci Technol. 2012; 6(3):563–71. [PubMed: 22768887]
25. Eby E, Hardwick C, Yu M, Gelwicks S, Deschamps K, Xie J, et al. Predictors of 30 day hospital readmission in patients with type 2 diabetes: a retrospective, case–control, database study. Current Medical Research and Opinion. 2015; 31(1):107–14. DOI: 10.1185/03007995.2014.981632 [PubMed: 25369567]
26. Healy SJ, Black D, Harris C, Lorenz A, Dungan KM. Inpatient diabetes education is associated with less frequent hospital readmission among patients with poor glycemic control. Diabetes Care. 2013; 36(10):2960–7. DOI: 10.2337/dc13-0108 [PubMed: 23835695]
27. Rubin, DJ., Handorf, E., McDonnell, M. ENDO 2013: The Endocrine Society's 95th Annual Meeting. 2013. Predicting Early Readmission Risk among Hospitalized Patients with Diabetes (7796).
28. Rubin DJ. Hospital Readmission of Patients with Diabetes. Curr Diab Rep. 2015; 15(4):1–9. DOI: 10.1007/s11892-015-0584-7

29. Jiang HJ, Andrews R, Stryer D, Friedman B. Racial/ethnic disparities in potentially preventable readmissions: the case of diabetes. American journal of public health. 2005; 95(9):1561–7. DOI: 10.2105/AJPH.2004.044222 [PubMed: 16118367]

30. Rico F, Liu Y, Martinez DA, Huang S, Zayas-Castro JL, Fabri PJ. Preventable Readmission Risk Factors for Patients With Chronic Conditions. J Healthc Qual. 2015; :1–16. DOI: 10.1097/01.jhq.0000462674.09641.72

31. Zapatero A, Gomez-Huelgas R, Gonzalez N, Canora J, Asenjo A, Hinojosa J, et al. Frequency of hypoglycemia and its impact on length of stay, mortality, and short-term readmission in patients with diabetes hospitalized in internal medicine wards. Endocrine Practice. 2014; 20(9):870–5. DOI: 10.4158/EP14006.OR [PubMed: 24641928]

32. Shaya FT, Chirikov VV, Howard D, Foster C, Costas J, Snitker S, et al. Effect of social networks intervention in type 2 diabetes: a partial randomised study. Journal of Epidemiology and Community Health. 2014; 68(4):326–32. DOI: 10.1136/jech-2013-203274 [PubMed: 24297971]

33. Rubin DJ, Donnell-Jackson K, Jhingan R, Golden SH, Paranjape A. Early readmission among patients with diabetes: a qualitative assessment of contributing factors. Journal of Diabetes and Its Complications. 2014; 28(6):869–73. DOI: 10.1016/j.jdiacomp.2014.06.013 [PubMed: 25087192]

34. Seshasai SRKS, Thompson A, Di Angelantonio E, Gao P, Sarwar N, Whincup PH, Mukamal KJ, Gillum RF, Holme I, Njølstad I, Fletcher A, Nilsson P, Lewington S, Collins R, Gudnason V, Thompson SG, Sattar N, Selvin E, Hu FB, Danesh J. Diabetes Mellitus, Fasting Glucose, and Risk of Cause-Specific Death. New England Journal of Medicine. 2011; 364(9):829–41. DOI: 10.1056/NEJMoa1008862 [PubMed: 21366474]

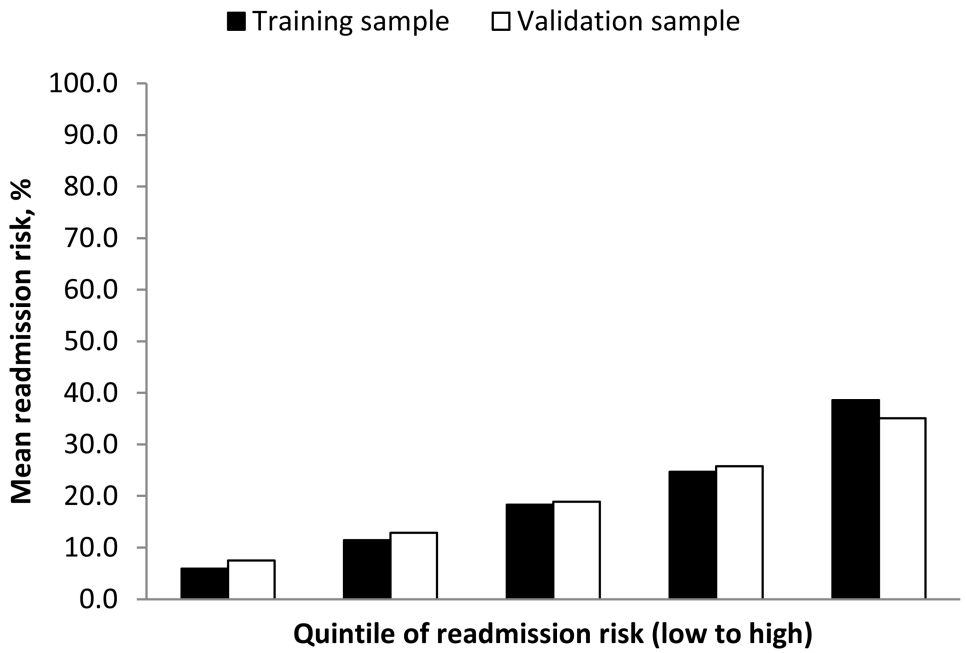

Figure 1. Quintiles of all-cause 30d readmission risk predicted by the DERRI-CVD™ in training and validation samples

Table 1
Characteristics of patients in training sample by 30d readmission status

Variable	All Discharges N=4950	Followed by Readmission N=978	No Readmission N=3972	P value
Age, N (%)				0.47
<50 years	415 (8.4)	99 (10.1)	316 (8.0)	
50-59 years	955 (19.3)	172 (17.6)	783 (19.7)	
60-69 years	1541 (31.1)	282 (28.8)	1259 (31.7)	
70+ years	2039 (41.2)	425 (43.5)	1614 (40.6)	
Gender, N (%)				0.54
Female	2322 (46.9)	474 (48.5)	1848 (46.5)	
Male	2628 (53.1)	504 (51.5)	2124 (53.5)	
Marital status, N (%)				<0.001
Married	1969 (39.8)	373 (38.1)	1596 (40.2)	
Single	2842 (57.4)	593 (60.6)	2249 (56.6)	
Other or unknown	139 (2.8)	12 (1.2)	127 (3.2)	
Race/ethnicity, N (%)				<0.001
Black	1497 (30.2)	365 (37.3)	1132 (28.5)	
Hispanic	463 (9.4)	95 (9.7)	368 (9.3)	
White	1778 (35.9)	252 (25.8)	1526 (38.4)	
Other or unknown	1212 (24.5)	266 (27.2)	946 (62.0)	
English speaking, N (%)				0.35
Yes	4092 (82.7)	814 (83.2)	3278 (82.5)	
No	858 (17.3)	164 (16.8)	694 (17.5)	
Insurance status, N (%)				
Medicaid	574 (11.6)	125 (12.8)	449 (11.3)	<0.001
Medicare	2258 (45.6)	440 (45.0)	1818 (45.8)	
None	119 (2.4)	13 (1.3)	106 (2.7)	
Private	1074 (21.7)	173 (17.7)	901 (22.7)	
Unknown	925 (18.7)	227 (23.2)	698 (17.6)	
Home zip code, N (%)				<0.001
≥5 miles from hospital	2090 (42.2)	263 (26.9)	1827 (46.0)	
<5 miles from hospital	2860 (57.8)	715 (73.1)	2145 (54.0)	
Education level, N (%)				<0.001
Less than high school	589 (11.9)	122 (12.5)	467 (11.8)	
Any high school	2456 (49.6)	603 (61.7)	1853 (46.7)	
Some college	339 (6.9)	67 (6.9)	272 (6.9)	
College graduate	862 (17.4)	120 (12.3)	742 (18.7)	
Unknown	704 (14.2)	66 (6.8)	638 (16.1)	
Employment, N (%)				<0.001
Disabled	850 (17.2)	232 (23.7)	618 (15.6)	
Employed	533 (10.8)	56 (5.7)	477 (12.0)	
Retired	2439 (49.3)	515 (52.7)	1924 (48.4)	

Variable	All Discharges N=4950	Followed by Readmission N=978	No Readmission N=3972	P value
Unemployed	915 (18.5)	166 (18.1)	749 (18.9)	
Other or unknown	213 (4.3)	9 (0.9)	204 (5.1)	
Pre-admission sulfonylurea use, N (%)				0.015
Yes	765 (15.5)	180 (18.4)	585 (14.7)	
No	4185 (84.6)	798 (81.6)	3387 (85.3)	
Pre-admission metformin use, N (%)				<0.001
Yes	1283 (25.9)	197 (20.1)	1086 (27.3)	
No	3667 (74.1)	781 (79.9)	2886 (72.7)	
Pre-admission thiazolidinedione use, N (%)				0.014
Yes	358 (7.2)	60 (6.1)	298 (7.5)	
No	4592 (92.8)	918 (93.9)	3674 (92.5)	
Pre-admission insulin use, N (%)				<0.001
Yes	1807 (36.5)	444 (45.4)	1363 (34.3)	
No	3143 (63.5)	534 (54.6)	2609 (65.7)	
Pre-admission glucocorticoid use, N (%)				<0.001
Yes	330 (6.7)	110 (11.3)	220 (5.5)	
No	4620 (93.3)	868 (88.8)	3752 (94.5)	
Most extreme blood glucose level, N (%)				<0.001
40-69 or 181-300 mg/dL	2422 (48.9)	482 (49.3)	1940 (48.8)	
70-180 mg/dL	1757 (35.5)	308 (31.5)	1449 (36.5)	
<40 or >300 mg/dL	771 (15.6)	188 (19.2)	583 (14.7)	
Diabetes inpatient consultation, N (%)				0.30
Yes	743 (15.0)	145 (14.8)	598 (15.1)	
No	4207 (85.0)	833 (85.2)	3374 (84.9)	
Current or prior DKA or HHS, N (%)				<0.001
Yes	142 (2.9)	57 (5.8)	85 (2.1)	
No	4808 (97.1)	921 (94.2)	3887 (97.9)	
Microvascular complications,[a] N (%)				<0.001
0	3411 (68.9)	550 (56.2)	2861 (72.0)	
1	918 (18.6)	214 (21.9)	704 (17.7)	
2	398 (8.0)	135 (13.8)	263 (6.6)	
3	223 (4.5)	79 (8.1)	144 (3.6)	
Macrovascular complications,[b] N (%)				<0.001
1	2258 (45.6)	315 (32.2)	1943 (48.9)	
2	1956 (39.5)	454 (46.4)	1502 (37.8)	
3	570 (11.5)	160 (16.4)	410 (10.3)	
4	166 (3.4)	49 (5.0)	117 (3.0)	
Pre-admission BP meds, N (%)				<0.001
None	1085 (21.9)	125 (12.8)	960 (24.2)	
ACE-i or ARB	2630 (53.1)	553 (56.5)	2077 (52.3)	
Non-ACE or ARB	1235 (25.0)	300 (30.7)	935 (23.5)	

Variable	All Discharges N=4950	Followed by Readmission N=978	No Readmission N=3972	P value
Pre-admission statin use, N (%)				<0.001
Yes	2931 (59.2)	655 (67.0)	2276 (57.3)	
No	2019 (40.8)	323 (33.0)	1696 (42.7)	
White blood cell count, N (%)				0.004
Low <4 K/μL	128 (2.6)	39 (4.0)	89 (2.2)	
Normal 4-11 k/μl	4099 (82.8)	794 (81.2)	3305 (83.2)	
High >11 K/μL	723 (14.6)	145 (14.8)	578 (14.6)	
Serum hematocrit (%), mean (SD)	33.8 (5.4)	32.9 (5.2)	34.1 (5.4)	<0.001
Serum albumin, N (%)				<0.001
4+ g/dL	1478 (29.9)	244 (25.0)	1234 (31.1)	
<4 g/dL	2728 (55.1)	626 (64.0)	2102 (52.9)	
Unknown	744 (15.0)	108 (11.0)	636 (16.0)	
Serum sodium, N (%)				<0.001
Low <135 mmol/L	387 (7.8)	90 (9.2)	297 (7.5)	
Normal 135-145 mmol/L	4500 (90.9)	872 (89.2)	3628 (91.3)	
High >145 mmol/L	63 (1.3)	16 (1.6)	47 (1.2)	
Serum potassium, N (%)				0.006
Low <3.1 mmol/L	27 (0.6)	3 (0.3)	24 (0.6)	
Normal 3.1-5.3 mmol/L	4625 (93.4)	895 (91.5)	3730 (93.9)	
High >5.3 mmol/L	298 (6.0)	80 (8.2)	218 (5.5)	
Creatinine (mg/dL), median (iQR)	1.1 (0.9, 1.7)	1.4 (0.9, 2.2)	1.1 (0.8, 1.5)	<0.001
Discharged 90 days prior to index admission, N (%)				<0.001
Yes	1401 (28.3)	477 (48.8)	924 (23.3)	
No	3549 (71.7)	501 (51.2)	3048 (76.7)	
Urgent or emergent admission, N (%)				<0.001
Yes	4179 (84.4)	869 (88.9)	3310 (83.3)	
No	771 (15.6)	109 (11.2)	662 (16.7)	
Intensive care admission, N (%)				0.024
Yes	935 (18.9)	164 (16.8)	771 (19.4)	
No	4015 (81.1)	814 (83.2)	3201 (80.6)	
Blood transfusion given, N (%)				0.019
Yes	759 (15.3)	158 (16.2)	601 (15.1)	
No	4191 (83.8)	820 (19.6)	3371 (84.9)	
Parenteral or enteral nutrition, N (%)				0.022
Yes	99 (2.0)	31 (3.2)	68 (1.7)	
No	4851 (98.0)	947 (96.8)	3904 (98.3)	
Discharge 1 year prior to index admission, N (%)				<0.001
Home	1633 (33.0)	394 (40.3)	1239 (31.2)	
Home with nursing care	726 (14.7)	211 (21.6)	515 (13.0)	
Sub-acute facility	459 (9.3)	136 (13.9)	323 (8.1)	

Variable	All Discharges N=4950	Followed by Readmission N=978	No Readmission N=3972	P value
Against medical advice	59 (1.2)	24 (2.5)	35 (0.9)	
No discharge recorded	2073 (41.9)	213 (21.8)	1860 (46.8)	
Body mass index, N (%)				0.097
<18.5 kg/m^2	70 (1.4)	21 (2.2)	49 (1.2)	
18.5 – 24.9 kg/m^2	632 (12.8)	131 (13.4)	501 (12.6)	
25.0 – 29.9 kg/m^2	1505 (30.4)	277 (28.3)	1228 (30.9)	
≥30.0 kg/m^2	2743 (55.4)	549 (56.1)	2194 (55.2)	
Schizophrenia or mood disorder ever, N (%)				<0.001
Yes	1011 (20.4)	282 (28.8)	729 (18.4)	
No	3939 (79.6)	696 (71.2)	3243 (81.7)	
Gastroparesis ever, N (%)				0.0053
Yes	139 (2.8)	59 (6.0)	80 (2.0)	
No	4811 (97.2)	919 (94.0)	3892 (98.0)	
Pancreatitis ever, N (%)				0.34
Yes	68 (1.4)	11 (1.1)	57 (1.4)	
No	4882 (98.6)	967 (98.9)	3915 (98.6)	
Hypertension ever, N (%)				0.0014
Yes	3938 (79.6)	819 (83.7)	3119 (78.5)	
No	1012 (20.4)	159 (16.3)	853 (21.5)	
COPD or asthma ever, N (%)				<0.001
Yes	926 (18.7)	262 (26.8)	664 (16.7)	
No	4024 (81.3)	716 (73.2)	3308 (83.3)	
Cardiac dysrhythmias ever, N (%)				<0.001
Yes	1693 (34.2)	408 (41.7)	1285 (32.4)	
No	3257 (65.8)	570 (58.3)	2687 (67.6)	
Malignant neoplasm ever, N (%)				0.41
Yes	213 (4.3)	45 (4.6)	168 (4.2)	
No	4737 (95.7)	933 (95.4)	3804 (95.8)	
Anemia ever, N (%)				<0.001
Yes	1961 (39.6)	524 (53.6)	1437 (36.2)	
No	2989 (60.4)	454 (46.4)	2535 (63.8)	
Drug abuse, N (%)				0.19
Never	4163 (84.1)	828 (84.7)	3335 (84.0)	
History	682 (13.8)	125 (12.8)	557 (14.0)	
Current	105 (2.1)	25 (2.6)	80 (2.0)	
Current infection,[c] N (%)				<0.001
Yes	727 (14.7)	183 (18.7)	544 (13.7)	
No	4223 (85.3)	795 (81.3)	3428 (86.3)	
Current complication of device, graft, or implant, N (%)			0.94	
Yes	115 (2.3)	22 (2.3)	93 (2.3)	

Variable	All Discharges N=4950	Followed by Readmission N=978	No Readmission N=3972	P value
No	4835 (97.7)	956 (97.8)	3879 (97.7)	
Current fluid or electrolyte disorder, N (%)			<0.001	
Yes	579 (11.7)	157 (16.1)	422 (10.6)	
No	4371 (88.3)	821 (84.0)	3550 (89.4)	

[a] Retinopathy, neuropathy, nephropathy

[b] Coronary artery disease, heart failure, stroke, peripheral vascular disease

[c] Pneumonia, urinary tract infection, septicemia, skin or subcutaneous infection; COPD, chronic obstructive pulmonary disease

Table 2

Most common reasons for readmission in training and validation samples based on primary ICD-9-CM code

ICD-9-CM Code	Description	Training sample n (% of readmissions)	Validation sample n (% of readmissions)
428.xx	Heart failure	262 (26.9)	180 (28.1)
250.xx	Diabetes mellitus	69 (7.1)	35 (5.5)
414.xx	Chronic ischemic heart disease	45 (4.6)	22 (3.4)
786.0x or 786.5x	Chest pain or shortness of breath	41 (4.2)	31 (4.8)
440.xx	Peripheral arterial disease	38 (3.9)	27 (4.2)
584.xx	Acute kidney failure	37 (3.8)	24 (3.7)

Table 3
DERRI-CVD™ predictors of all-cause 30d readmission in training sample

Predictor	Odds Ratio (95% CI)	P value
Home zip code <5 miles from hospital	1.52 (1.25-1.85)	<0.001
Employment status (vs. Employed)		
Unemployed	1.37 (0.99-1.89)	0. 056
Retired	1.45 (1.08-1.94)	0.012
Disabled	1.61 (1.16-2.24)	0.004
Education level (vs. College graduate)		
Less than high school	1.15 (0.85-1.56)	0 .36
Any high school	1.43 (1.14-1.81)	0.002
Some college	1.38 (1.01-1.88)	0.044
Pre -admission metformin	0.79 (0.64-0.97)	0.022
Pre-admission sulfonylurea	1.28 (1.04-1.59)	0.022
Macrovascular complications[a], # (vs. 0)		
2	1.27 (1.07-1.51)	0. 008
3	1.42 (1.11-1.81)	0.005
4	1.22 (0.79-1.90)	0.37
Log (admission serum creatinine)	1.23 (1.07-1.41)	0.004
Serum albumin (vs. >4 g/dL)		
Low, <4 g/dL	1.23 (1.03-1.46)	0. 021
Schizophrenia or mood disorder, current or prior	1.31 (1.07-1.60)	0.008
Discharged within 90 days before admission	2.00 (1.69-2.36)	<0.001

[a]Coronary artery disease, heart failure, stroke, peripheral vascular disease;

DERRI-CVD, diabetes early readmission risk index-cardiovascular disease

Table 4

Characteristics of patients with statistically significant differences between training and validation samples

Variable	All Discharges N=8,189	Training N=4,950	Validation N=3,219	P value
Employment, N (%)				0.009
Disabled	1,365 (16.7)	850 (17.2)	515 (16.0)	
Employed	834 (10.2)	533 (10.8)	301 (9.4)	
Retired	3,927 (48.1)	2,439 (49.3)	1,488 (46.2)	
Unemployed	1,667 (20.4)	915 (18.5)	752 (23.4)	
Other or unknown	376 (4.6)	213 (4.3)	163 (5.1)	
Pre-admission sulfonylurea use, N (%)				0.033
Yes	1,356 (16.6)	765 (15.5)	591 (18.4)	
No	6,813 (83.4)	4,185 (84.6)	2,628 (81.6)	
Blood transfusion given, N (%)				0.033
Yes	1,320 (16.2)	759 (15.3)	561 (17.4)	
No	8,012 (98.0)	4,191 (84.7)	2,658 (82.6)	
Hypertension ever, N (%)				0.019
Yes	6,395 (78.3)	3,938 (79.6)	2,457 (76.3)	
No	1,774 (21.7)	1,012 (20.4)	762 (23.7)	