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EXTERNAL VALIDATION OF THE DIABETES EARLY RE-ADMISSION RISK INDICATOR (DERRI™)

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Abstract

Objective: The Diabetes Early Re-admission Risk Indicator (DERRI™) was previously developed and internally validated as a tool to predict the risk of all-cause re-admission within 30 days of discharge (30-day re-admission) of hospitalized patients with diabetes. In this study, the predictive performance of the DERRI™ with and without additional predictors was assessed in an external sample.

Methods: We conducted a retrospective cohort study of adult patients with diabetes discharged from two academic medical centers between January 1, 2000 and December 31, 2014. We applied the previously developed DERRI™, which includes admission laboratory results, sociodemographics, a diagnosis of certain comorbidities, and recent discharge information, and evaluated the effect of adding metabolic indicators on predictive performance using multivariable logistic regression. Total cholesterol (TC) and hemoglobin A1c (A1c) were selected based on clinical relevance and univariate association with 30-day re-admission.

Results: Among 105,974 discharges, 19,032 (18.0%) were followed by 30-day re-admission for any cause. The DERRI™ had a C-statistic of 0.634 for 30-day re-admission. TC was the lipid parameter most strongly associated with 30-day re-admission. The DERRI™ predictors A1c and TC were significantly associated with 30-day re-admission; however, their addition to the DERRI™ did not significantly change model performance (C-statistic, 0.643 [95% confidence interval, 0.638 to 0.647]; $P = .92$).

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DISCLOSURE

The authors have no multiplicity of interest to disclose.

Conclusion: Performance of the DERRI™ in this external cohort was modest but comparable to other re-admission prediction models. Addition of A1c and TC to the DERRI™ did not significantly improve performance. Although the DERRI™ may be useful to direct resources toward diabetes patients at higher risk, better prediction is needed.

Keywords

diabetes; hospital; readmission risk prediction

INTRODUCTION

Hospital re-admission within 30 days of discharge (30-day re-admission) is a high-priority healthcare quality measure and target for cost reduction (1–3). More than a quarter of hospital expenditures in the United States are incurred by patients with diabetes (4). In this population, up to 20% of hospitalizations are followed by a 30-day re-admission (5–10), corresponding to nearly 2 million discharges annually (11).

Interventions aimed at reducing the risk of 30-day re-admission of various populations tend to be more effective when focused on higher-risk patients (12,13); however, approaches tailored to patients with diabetes are needed (14). We therefore previously developed and internally validated the Diabetes Early Re-admission Risk Indicator (DERRI™) (10), a model to predict the risk of all-cause 30-day re-admission in hospitalized patients with diabetes based on easily obtained clinical and sociodemographic information available before hospital discharge. The DERRI™ identifies patients with diabetes at higher risk for 30-day re-admission, providing guidance for a targeted approach to interventions and enabling more efficient use of resources.

An important step in evaluating the generalizability of a predictive model is to test the model in a sample different from the one used to develop the model (i.e., external validation) (15). Herein, we present an external validation of the DERRI™ tool. In addition, we examined the effect of adding metabolic parameters (hemoglobin A1c [A1c] and cholesterol levels) on predictive performance. These parameters, which were not available in the data for the development of the DERRI™, are routinely collected on patients with diabetes, yet their association with re-admission is unclear for A1c (conflicting studies) (16,17) and unknown for cholesterol.

METHODS

Study Sample

The methods used to select the cohort (external validation sample), define variables, and analyze the data were similar to those used to develop the DERRI™ (10). A total of 105,960 hospital discharges were retrospectively selected from the electronic medical records of 42,800 patients hospitalized at two urban academic medical centers in Boston, Massachusetts (Massachusetts General Hospital and Brigham and Women’s Hospital) between January 1, 2000, and December 31, 2014, the time period for which data were available. Patients were included based on a diagnosis of diabetes defined by an

International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) code of 250.xx associated with a hospital discharge and receiving a diabetes-specific medication during that hospitalization. Index discharges of these patients were included based on a diagnosis of diabetes (ICD-9-CM code 250.xx) associated with hospital discharge or the presence of a diabetes-specific medication on the pre-admission medication list. Index discharges were excluded for patients aged less than 21 years on the date of admission, discharge by transfer to another hospital, discharge from an obstetric service (indicating pregnancy), inpatient death, outpatient death within 30 days of discharge, incomplete data or lacking 30 days of follow-up after discharge (discharged after December 1, 2014). All eligible index discharges were included in the analysis. Data from nonindex hospitalizations at three local community hospitals in the Partners HealthCare network were included in the assessment of covariates and re-admissions.

The Partners HealthCare and Temple University Institutional Review Boards approved the protocol. A waiver of informed consent was obtained for this large retrospective study.

Definition of Variables

The outcome to be predicted by the model was all-cause re-admission within 30 days of an index discharge. A total of 15 variables were evaluated as predictors of the outcome. The current dataset includes data on all 10 variables in the DERRI™, which were having a home zip code less than 5 miles from the hospital, employment status, pre-admission insulin use (yes or no), a diagnosis of one or more macrovascular diabetes complications, a diagnosis of anemia, admission hematocrit level, serum creatinine level, serum sodium level, having a discharge within 90 days before admission, and most recent discharge status up to 1 year before admission (discharge against medical advice, home, home with nursing care, to a subacute facility, or no discharge) (10). In addition to these 10 variables, total cholesterol, high-density-lipoprotein cholesterol (HDL-C), low-density-lipoprotein cholesterol (LDL-C), triglycerides, and A1c levels were evaluated for association with re-admission. For these new variables, the value closest to the admission date between 1 year before admission and up to discharge was used. In order to capture nonlinear associations with re-admission, the new variables were categorized into normal, high, and low values. Variables based on ICD-9-CM codes (current or prior diabetic ketoacidosis or hyperglycemic hyperosmolar syndrome, microvascular complications, macrovascular complications, schizophrenia or mood disorder, gastroparesis, pancreatitis, hypertension, chronic obstructive pulmonary disease or asthma, cardiac dysrhythmia, malignant neoplasm, and anemia) were considered for ever occurrence (during or before the index hospitalization) or current occurrence during the index hospitalization.

Statistical Analysis

Summaries of continuous variables included means and standard deviations or medians and interquartile ranges, while counts and percentages were used for categorical variables. To account for clusters of multiple hospitalizations per patient, univariate logistic regression with the generalized estimating equations (GEE) approach was used to model the association of each predictor with 30-day re-admission (18). In addition, distributions of characteristics of the external validation sample were compared to the previously published

internal validation sample using univariate logistic regression with GEE (10). A1c, total cholesterol, HDL-C, LDL-C, and triglycerides were categorized by clinically relevant cut-points and analyzed for univariate association with 30-day re-admission by chi-square. Total cholesterol was found to have the strongest association with re-admission among the lipid parameters and therefore selected for multivariable modeling. A1c was selected for multivariable modeling based on univariate statistical significance as well as clinical relevance.

Multivariable logistic regression with GEE was performed to determine the adjusted associations of the variables with all-cause 30-day re-admission. Data generated by three multivariable models are presented. The first is the previously published DERRI™, which was applied to the current external validation sample. The second is a model developed in the current study sample using the 10 DERRI™ variables to directly assess the effect of adding additional variables on model performance. The third model, also developed in the current sample, uses the DERRI™ variables plus total cholesterol and A1c.

Comparative performance of the models in the external and internal validation samples was assessed by discrimination, the ability of the model to distinguish high-risk from low-risk individuals (15). Discrimination was evaluated using the C-statistic (equivalent to the area under the receiver operating characteristic curve), a standard measure of the predictive accuracy of a logistic regression model, where higher values represent better discrimination (19). In addition, patients were stratified into quintiles of 30-day re-admission risk using the models to predict each patient's risk of re-admission as a number between 0 and 100%.

Because 46% of discharges were missing either total cholesterol or A1c values, a sensitivity analysis was performed only on discharges associated with complete A1c and cholesterol data.

SAS version 9.4 (SAS Institute, Cary, NC) was used for all analyses. A P value less than .05 was considered statistically significant.

RESULTS

There were 105,960 discharges in this external validation sample, of which 19,032 (18.0%) were associated with 30-day re-admission for any cause. Characteristics of the cohort are presented in Table 1. With the exception of gender, English fluency, and insurance status, most of the variables were associated with 30-day re-admission in univariate analysis. The most common reasons for re-admission were cardiovascular disease, infection, and diabetes (Table 2).

The C-statistic of the DERRI™ was 0.634 (95% confidence interval [CI], 0.629 to 0.638) in the external validation sample and 0.686 (95% CI, 0.677 to 0.696) in the previously published internal validation sample (P<.0001, Fig. 1 A) (10). Quintiles of mean predicted all-cause 30-day re-admission risk based on the DERRI™ were statistically significantly different between the external and internal validation samples (overall P = .013, Fig. 2 A). For example, the highest quintile had a 32 ± 7% risk of 30-day re-admission in the external validation sample and a 39 ± 7% risk in the internal validation sample.

Relationships of the DERRI™ predictors with 30-day re-admission were either attenuated or relatively unchanged by adding Alc and total cholesterol to the model (Table 3) (10). A hospital discharge within 90 days before the index admission remained the strongest predictor and was associated with nearly 2-fold greater odds of 30-day re-admission. Other relatively strong factors were status of the most recent prior hospital discharge and employment status. Unexpectedly, an A1c <6.5% (48 mmol/mol) and a total cholesterol <150 mg/dL were associated with higher odds of re-admission (1.06 [95% CI, 1.00 to 1.11] and 1.07 [95% CI, 1.01 to 1.12]). The only difference in the direction of associations generated by the model with Alc and total cholesterol versus the DERRI™ was found with the number of macrovascular complications. In the current model, having only one complication was associated with a 9% lower odds of re-admission and three or four complications with 9% or 14% higher odds of readmission, respectively, whereas in the DERRI™, an increasing number of macrovascular complications was associated with a progressively higher odds of re-admission.

Addition of Alc and total cholesterol to the DERRI™ predictors did not significantly change model performance in terms of the C-statistic (0.643 [95% CI, 0.638 to 0.647]; $P = .92$, Fig. 1 B) or mean predicted 30-day re-admission risk (overall $P > .999$; Fig. 2 B). The highest quintile had a 31 ± 4% mean predicted risk of 30-day re-admission. In the sensitivity analysis performed using records with complete A1c or total cholesterol data, results were unchanged (data not shown). In a post-hoc exploratory analysis, pre-admission statin use was added to the model with A1c and total cholesterol. Neither the odds ratio for low total cholesterol nor the C-statistic changed.

Characteristics of the external and internal validation samples were statistically significantly different for most variables, including sociodemographics and clinical parameters (Table 4). The external validation sample was older, more married, more white, more privately insured, and lived further away from the index hospital than the internal validation sample. Among the 10 DERRI™ predictors, the distributions of seven predictors were statistically significantly different between the two samples.

DISCUSSION

In this retrospective study of 105,960 discharges of patients with diabetes, we examined the external validity of the DERRI™, a previously developed and internally validated tool comprised of 10 parameters that predicts the 30-day re-admission risk of individual patients. In this sample, the DERRI™ had modest predictive performance based on a C-statistic of 0.634. Additionally, total cholesterol, HDL-C, LDL-C, triglycerides, and A1c levels were evaluated for association with re-admission. Although A1c and total cholesterol levels were independently associated with re-admission risk, inclusion of these variables with the DERRI™ predictors did not yield a model with significantly better predictive performance.

Discharges of patients with an Alc level <6.5% (48 mmol/mol) were at higher odds of re-admission than those with an Alc level between 6.5% (48 mmol/mol) and 8% (64 mmol/mol), whereas higher Alc levels were not associated with re-admission risk. Given the risk of hypoglycemia associated with lower A1c levels (20), it may be speculated that

hypoglycemia is underlying the associated risk of re-admission. Unfortunately, data are not available in this retrospective cohort to explore this hypothesis. These findings add to the conflicting literature on the association of A1c with re-admission risk. One study reported higher re-admission risk associated with elevated Alc levels (16), while another study found that higher A1c levels were associated with lower risk of re-admission (17). Therefore, the association between Alc and re-admission risk remains quite unclear and requires additional study to clarify.

Similar to A1c, discharges of patients with total cholesterol levels <150 mg/dL were at higher odds of re-admission than those with levels of 150 to 200 mg/dL, and higher total cholesterol levels were not associated with re-admission risk. To our knowledge, there is no previously published literature that describes the association between re-admission risk and total cholesterol. The mechanism underlying this pattern of association is not immediately apparent. It may be speculated that the association of lower total cholesterol levels and re-admission risk is due to confounding by indication, where aggressive lipid lowering is achieved in patients at high risk for cardiovascular events and thus re-admission. An alternative hypothesis is that low total cholesterol may reflect malnutrition or poor fat absorption, which may be associated with comorbidities. Interestingly, total cholesterol was found to have the strongest association with re-admission among the lipid parameters and was selected for multivariable modeling. Of note, the association of low cholesterol with re-admission was not affected by adjustment for pre-admission statin use.

In the current study, the DERRI™ demonstrated less predictive accuracy than in the internal validation sample. This discrepancy may be accounted for by the substantial population differences between the internal validation and external validation samples. Because of these differences, there is likely to be variation in the relative importance of re-admission risk factors between the two samples. Despite the somewhat lower value, 0.634 is comparable to the C-statistics of other models predicting re-admission risk among diabetes patients, which range from 0.635 to 0.822 (6,8,17,21,22). A key difference, however, between these other models and the DERRI™ is that only the DERRI™ can be used for a patient before hospital discharge. The other models include variables obtained after discharge, such as hospital length-of-stay, discharge disposition, and outpatient follow-up. In addition, most of them contain the number of recent prior emergency department visits or hospitalizations, which is not easily obtainable if patients have had acute encounters at multiple hospitals. Furthermore, two of them include a comorbidity index that is scored according to all of a patient's comorbidities (17,21). Such models are less practical for use at the point of care. Lastly, none of these other models were tested in an external validation sample, which tends to yield worse performance metrics than internal validation (15). Although performance of the DERRI™ is modest, evidence suggests that even moderately performing models tend to outperform clinical judgment (23,24).

Some limitations of our study should be acknowledged. Both the internal and external validation samples were drawn from urban academic medical centers in the Northeastern US; therefore, these findings may not be generalizable to hospitals with different characteristics. Despite these similarities between the academic medical centers, the external and internal validation samples were different for most variables, most notably age and race/

ethnicity. It is unknown whether or not the DERRI™ would perform better in another population that is more similar to the internal validation population. Data on other potential predictors of 30-day re-admission, including diabetes type and duration, could not be obtained in this retrospective study. In addition, the analyses of A1c and cholesterol are limited by the substantial proportion of records missing these data. However, it is re-assuring that the sensitivity analysis restricted to discharges that had complete A1c and cholesterol data yielded similar results. Finally, we were unable to capture 30-day re-admissions that may have occurred at hospitals outside of the Partners HealthCare system. However, when compared to rates reported in the literature for patients with diabetes, the 30-day re-admission rate in our study is on the higher end of the range of 10.0 to 20.4% (5–10); therefore, it seems unlikely that a significant number of patients were re-admitted elsewhere.

These study limitations are balanced by a number of strengths. The subject cohort was comprised of a relatively large sample size drawn from patients hospitalized at two academic medical centers. Re-admissions were captured at all of the Partners HealthCare hospitals in the region during the study period, including three community hospitals. A total of 15 sociodemographic and clinical characteristics were examined as potential predictors of 30-day re-admission, expanding the existing body of literature (5,6,8,9,21,25,26). To our knowledge, the association between lipid parameters and 30-day re-admission risk has not been previously reported. Lastly, this is the first external validation study of a re-admission risk prediction model in diabetes patients.

Future research could explore ways to improve the prediction of re-admission risk for patients with diabetes. Larger studies drawn from diverse populations and settings would better address issues of generalizability. We are currently conducting a prospective study to gather data on previously untested potential re-admission predictors. In addition, we are conducting a pilot randomized controlled trial that uses the DERRI™ to identify patients at high risk of re-admission and explores the feasibility and efficacy of a re-admission risk-reduction intervention, the Diabetes Transition of Hospital Care (DiaTOHC) Program (ClinicalTrials.gov Identifier: NCT03243383).

CONCLUSION

In summary, performance of the DERRI™ in this external cohort to predict early re-admission risk of patients with diabetes was modest. Although lower A1c and total cholesterol levels were found to be associated with higher re-admission risk, these parameters do not add significant predictive power to the DERRI™. Additional research is needed to identify better predictors of re-admission among patients with diabetes.

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An abstract of this study was presented at the 77th Scientific Sessions of the American Diabetes Association in June, 2017, San Diego, California. The Partners HealthCare and Temple University Institutional Review Boards approved the protocol. A waiver of informed consent was obtained for this large retrospective study.

Abbreviations:

A1c	hemoglobin A1c
CI	confidence interval
DERRI™	Diabetes Early Readmission Risk Indicator
GEE	generalized estimating equation
HDL-C	high-density-lipoprotein cholesterol
ICD-9-CM	International Classification of Diseases, Ninth Revision, Clinical Modification
LDL-C	low-density-lipoprotein cholesterol

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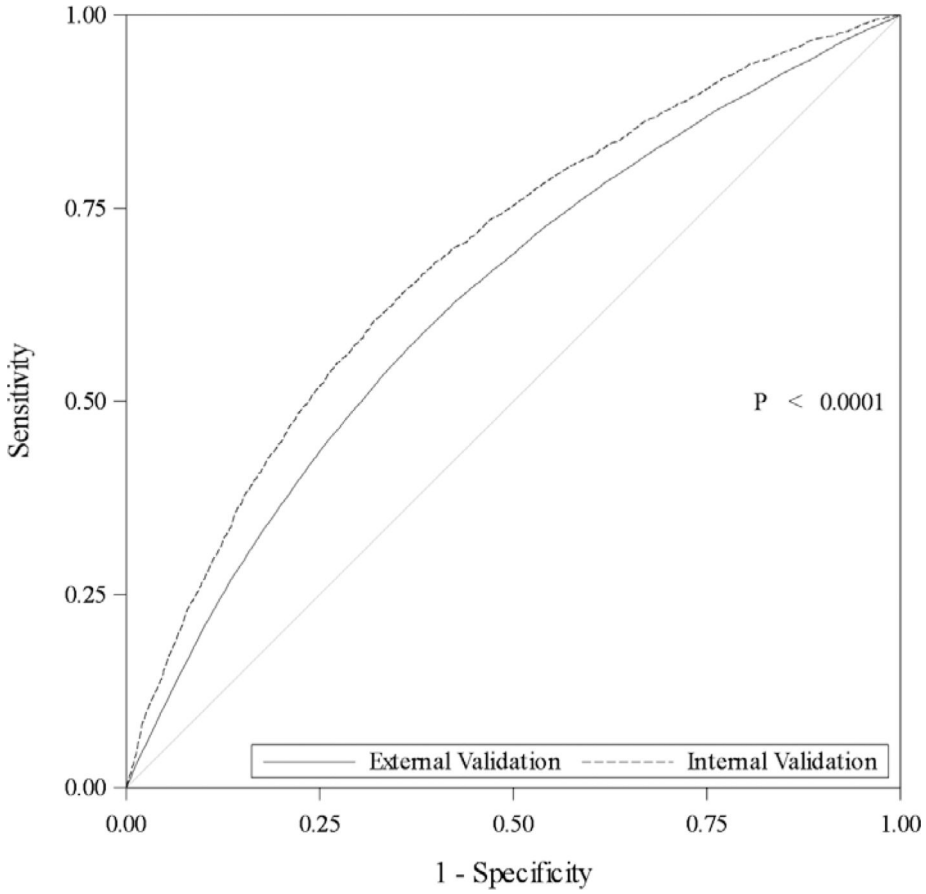

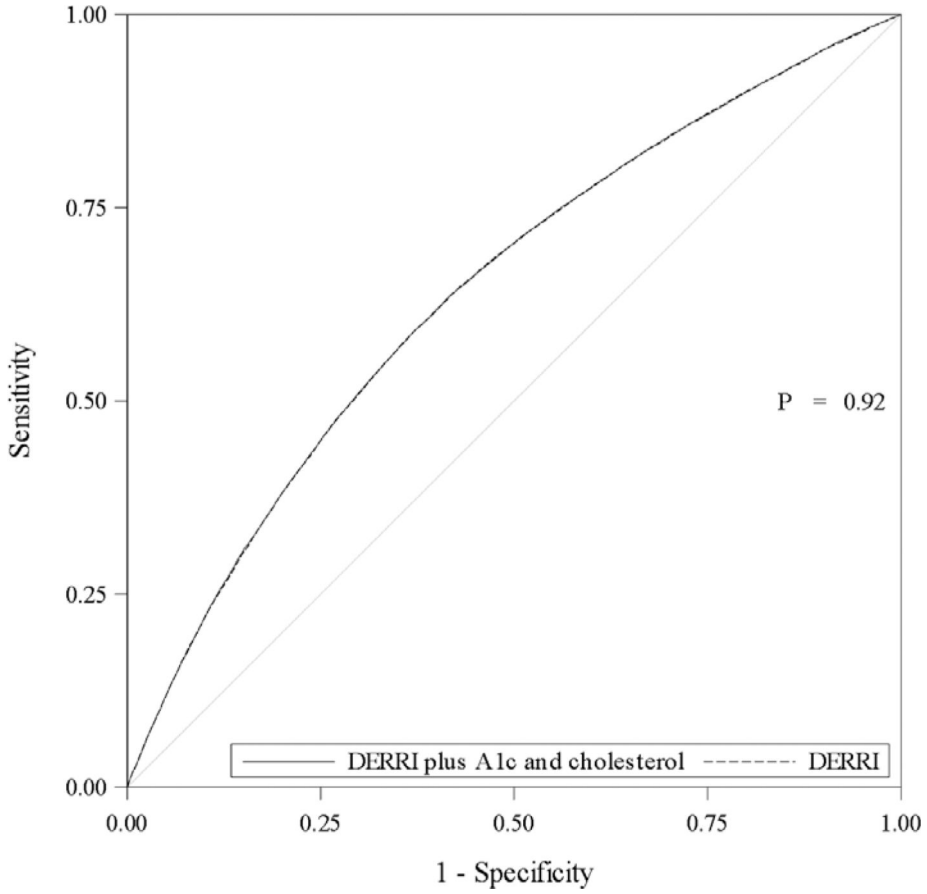

Fig. 1.

(*A*) Receiver operating characteristic (ROC) curves of all-cause 30-day re-admission predicted by the Diabetes Early Re-admission Risk Indicator (DERRI™) in internal and external validation samples. (*B*) ROC curves of all-cause 30-day re-admission predicted by the DERRI™ and DERRI™ plus hemoglobin A1c and total cholesterol in external validation sample.

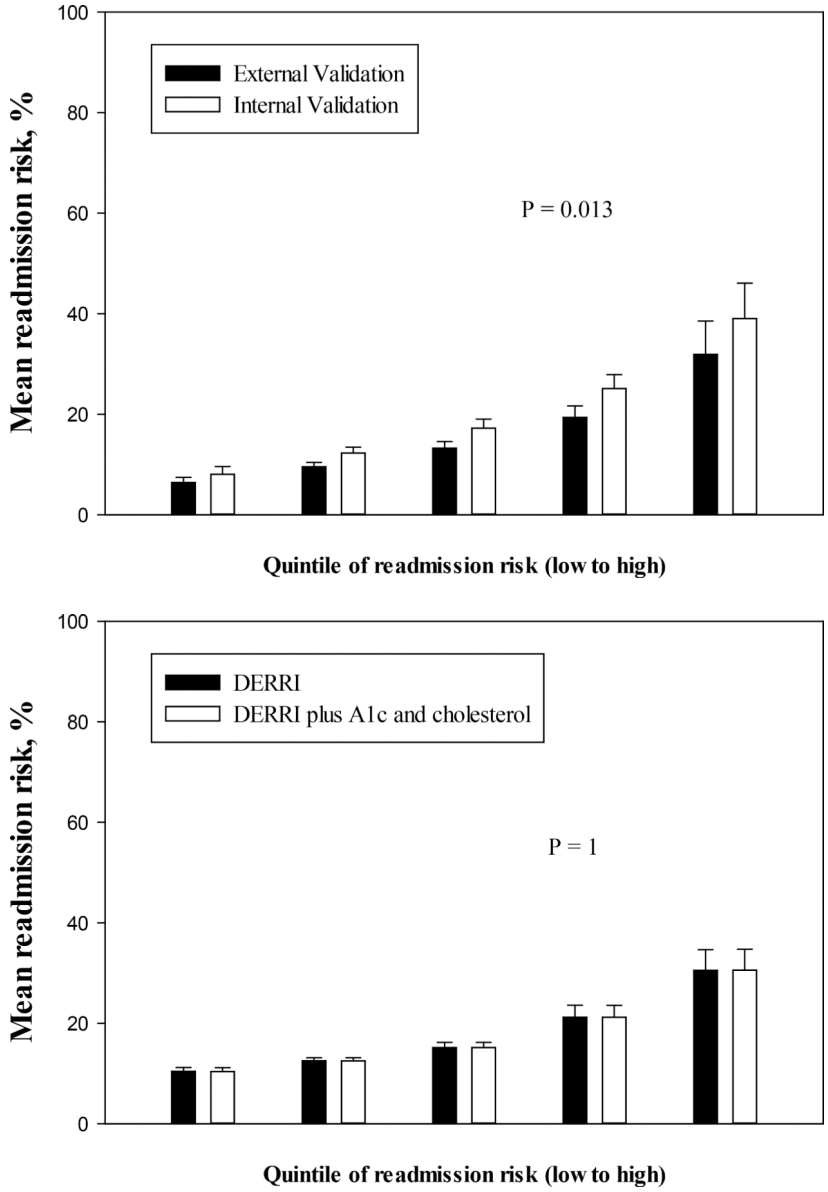

Fig. 2.

(*A*) Quintiles of all-cause 30-day re-admission risk predicted by the Diabetes Early Re-admission Risk Indicator (DERRI™) in internal and external validation samples. (*B*) Quintiles of all-cause 30-day re-admission risk predicted by the DERRI™ and DERRI™ plus hemoglobin A1c and total cholesterol in external validation sample.

Table 1

Characteristics of Hospitalized Patients With Diabetes in External Validation Sample by 30-Day Re-admission

Variable	All discharges N = 105,960	Followed by re-admission n = 19,032	No re-admission n = 86,928	*P* value
Age				<.0001
<50 years	6,857 (6.5)	1,465 (7.7)	5,392 (6.2)	
50–59 years	12,971 (12.2)	2,646 (13.9)	10,325 (11.9)	
60–69 years	25,989 (24.5)	5,076 (26.7)	20,913 (24.1)	
70+ years	60,143 (56.8)	9,845 (51.7)	50,298 (57.9)	
Gender				.55
Female	47,940 (45.2)	8,554 (45.0)	39,386 (45.3)	
Male	58,020 (54.8)	10,478 (55.1)	47,542 (54.7)	
Weight, kg, mean (SD)	85.9 (20.41)	85.0 (20.78)	86.1 (20.32)	<.0001
Marital status				.02
Married	49,165 (46.4)	8,605 (45.2)	40,560 (46.7)	
Single	52,716 (49.8)	9,730 (51.1)	42,986 (49.5)	
Other or not recorded	4,079 (3.9)	697 (3.7)	3,382 (3.9)	
Race/ethnicity				.001
Black	11,330 (10.7)	2,083 (10.9)	9,247 (10.6)	
Hispanic	5,914 (5.6)	1,238 (6.5)	4,676 (5.4)	
White	78,000 (73.6)	13,785 (72.4)	64,215 (73.9)	
Other	5,951 (5.6)	1,135 (6.0)	4,816 (5.5)	
Not recorded	4,765 (4.5)	791 (4.2)	3,974 (4.6)	
English speaking				.35
Yes	92,887 (87.7)	16,624 (87.4)	76,263 (87.7)	
No	13,073 (12.3)	2,408 (12.7)	10,665 (12.3)	
Insurance status				.22
Medicaid	1,834 (1.7)	332 (1.7)	1,502 (1.7)	
Medicare	52,913 (49.9)	9,445 (49.6)	43,468 (50.0)	
None	12,150 (11.5)	2,295 (12.1)	9,855 (11.3)	
Private	39,063 (36.9)	6,960 (36.6)	32,103 (36.9)	
Home zip code				<.0001
≥5 miles from hospital	73,372 (69.2)	12,662 (66.5)	60,710 (69.8)	
<5 miles from hospital	32,588 (30.8)	6,370 (33.5)	26,218 (30.2)	
Educational level				.026
Less than high school	12,575 (11.9)	2,361 (12.4)	10,214 (11.8)	
Any high school	28,047 (26.5)	5,209 (27.4)	22,838 (26.3)	
Some College	4,324 (4.1)	748 (3.9)	3,576 (4.1)	
College Graduate	19,156 (18.1)	3,277 (17.2)	15,879 (18.3)	
Not recorded	41,858 (39.5)	7,437 (39.1)	34,421 (39.6)	

Variable	All discharges N = 105,960	Followed by re-admission n = 19,032	No re-admission n = 86,928	*P* value
Employment				<.0001
Disabled	14,446 (13.6)	3,291 (17.3)	11,155 (12.8)	
Employed	18,218 (17.2)	2,787 (14.6)	15,431 (17.8)	
Retired	40,057 (37.8)	7,099 (37.3)	32,958 (37.9)	
Unemployed	6,755 (6.4)	1,419 (7.5)	5,336 (6.1)	
Other or not recorded	26,484 (25.0)	4,436 (23.3)	22,048 (25.4)	
Pre-admission sulfonylurea use				<.0001
Yes	15,722 (14.8)	2,419 (12.7)	13,303 (15.3)	
No	90,238 (85.2)	16,613 (87.3)	73,625 (84.7)	
Pre-admission metformin use				<.0001
Yes	21,355 (20.2)	3,067 (16.1)	18,288 (21.0)	
No	84,605 (79.9)	15,965 (83.9)	68,640 (79.0)	
Pre-admission thiazolidinedione use				<.0001
Yes	2,848 (2.7)	375 (2.0)	2,473 (2.8)	
No	103,112 (97.3)	18,657 (98.0)	84,455 (97.2)	
Pre-admission insulin use				<.0001
Yes	37,851 (35.7)	7,306 (38.4)	30,545 (35.1)	
No	68,109 (64.3)	11,726 (61.6)	56,383 (64.9)	
Pre-admission glucocorticoid use				<.0001
Yes	11,793 (11.1)	2,598 (13.7)	9,195 (10.6)	
No	94,167 (88.9)	16,434 (86.4)	77,733 (89.4)	
Current or prior DKA or HHS				.0043
Yes	4,247 (4.0)	903 (4.7)	3,344 (3.9)	
No	101,713 (96.0)	18,129 (95.3)	83,584 (96.2)	
Microvascular complications[a]				<.0001
0	74,613 (70.4)	12,029 (63.2)	62,584 (72.0)	
1	18,499 (17.5)	3,769 (19.8)	14,730 (17.0)	
2	7,952 (7.5)	1,962 (10.3)	5,990 (6.9)	
3	4,896 (4.6)	1,272 (6.7)	3,624 (4.2)	
Macrovascular complications[b]				<.0001
0	37,233 (35.1)	6,192 (32.5)	31,041 (35.7)	
1	31,312 (29.6)	5,030 (26.4)	26,282 (30.2)	
2	25,683 (24.2)	4,986 (26.2)	20,697 (23.8)	
3	9,285 (8.8)	2,201 (11.6)	7,084 (8.2)	
4	2,447 (2.3)	623 (3.3)	1,824 (2.1)	
Pre-admission BP meds				<.0001
None	45,840 (43.3)	8,230 (43.2)	37,610 (43.3)	
ACE-i or ARB	38,371 (36.2)	6,319 (33.2)	32,052 (36.9)	

Variable	All discharges N = 105,960	Followed by re-admission n = 19,032	No re-admission n = 86,928	*P* value
Non-ACE or ARB	21,749 (20.5)	4,483 (23.6)	17,266 (19.9)	
Pre-admission statin use				.0024
Yes	45,183 (42.6)	7,856 (41.3)	37,327 (42.9)	
No	60,777 (57.4)	11,176 (58.7)	49,601 (57.1)	
White blood cell count				<.0001
Low <4 K/μL	4,141 (3.9)	961 (5.1)	3,180 (3.7)	
Normal 4–11 K/μL	68,237 (64.4)	12,182 (64.0)	56,055 (64.5)	
High >11 K/μL	33,582 (31.7)	5,889 (30.9)	27,693 (31.9)	
Hematocrit, %, mean (SD)	35.5 (5.63)	34.5 (5.63)	35.7 (5.61)	<.0001
Serum sodium				<.0001
Low <135 mmol/L	27,048 (25.5)	5,462 (28.7)	21,586 (24.8)	
Normal 135–145 mmol/L	77,703 (73.3)	13,318 (70.0)	64,385 (74.1)	
High >145 mmol/L	1,209 (1.1)	252 (1.3)	957 (1.1)	
Serum potassium				<.0001
Low <3.1 mmol/L	1,866 (1.8)	369 (1.9)	1,497 (1.7)	
Normal 3.1–5.3 mmol/L	96,074 (90.7)	16,921 (88.9)	79,153 (91.1)	
High >5.3 mmol/L	8,020 (7.6)	1,742 (9.2)	6,278 (7.2)	
Creatinine, mg/dL, median (IQR)	1.2 (0.9–1.7)	1.3 (0.9–2.1)	1.2 (0.9–1.7)	<.0001
Discharged 90 days prior to index admission				<.0001
Yes	32,451 (30.6)	8,970 (47.1)	23,481 (27.0)	
No	73,509 (69.4)	10,062 (52.9)	63,447 (73.0)	
Length-of-stay, days, median (IQR)	5.0 (3.0–8.0)	5.0 (3.0–9.0)	5.0 (3.0–8.0)	<.0001
Discharge status of index admission				<.0001
Home	21,424 (20.2)	3,539 (18.6)	17,885 (20.6)	
Home with nursing care	38,789 (36.6)	7,006 (36.8)	31,783 (36.6)	
Sub-acute facility	21,853 (20.6)	3,990 (21.0)	17,863 (20.6)	
Against medical advice	803 (0.8)	208 (1.1)	595 (0.7)	
Other	1,219 (1.2)	203 (1.1)	1,016 (1.2)	
No status recorded	21,872 (20.6)	4,086 (21.5)	17,786 (20.5)	
Discharge 1 year prior to index admission				<.0001
Home	10,779 (10.2)	2,503 (13.2)	8,276 (9.5)	
Home with nursing care	18,419 (17.4)	4,531 (23.8)	13,888 (16.0)	
Subacute facility	10,016 (9.5)	2,358 (12.4)	7,658 (8.8)	
Against medical advice	441 (0.4)	129 (0.7)	312 (0.4)	
No discharge recorded	66,305 (62.6)	9,511 (50.0)	56,794 (65.3)	
Body mass index				<.0001
<18.5 kg/m^2	1,595 (1.5)	361 (1.9)	1,234 (1.4)	
18.5–24.9 kg/m^2	17,140 (16.2)	3,593 (18.9)	13,547 (15.6)	
25.0–29.9 kg/m^2	32,719 (30.9)	5,688 (29.9)	27,031 (31.1)	

Variable	All discharges N = 105,960	Followed by re-admission n = 19,032	No re-admission n = 86,928	*P* value
≥30.0 kg/m^2	54,506 (51.4)	9,390 (49.3)	45,116 (51.9)	
Depression or psychosis ever				<.0001
Yes	22,506 (21.2)	4,877 (25.6)	17,629 (20.3)	
No	83,454 (78.8)	14,155 (74.4)	69,299 (79.7)	
Gastroparesis ever				<.0001
Yes	3,415 (3.2)	996 (5.2)	2,419 (2.8)	
No	102,545 (96.8)	18,036 (94.8)	84,509 (97.2)	
Pancreatitis ever				<.0001
Yes	4,482 (4.2)	1,071 (5.6)	3,411 (3.9)	
No	101,478 (95.8)	17,961 (94.4)	83,517 (96.1)	
Hypertension ever				.03
Yes	74,179 (70.0)	13,145 (69.1)	61,034 (70.2)	
No	31,781 (30.0)	5,887 (30.9)	25,894 (29.8)	
COPD or asthma ever				<.0001
Yes	16,325 (15.4)	3,394 (17.8)	12,931 (14.9)	
No	89,635 (84.6)	15,638 (82.2)	73,997 (85.1)	
Cardiac dysrhythmias ever				<.0001
Yes	35,664 (33.7)	7,090 (37.3)	28,574 (32.9)	
No	70,296 (66.3)	11,942 (62.8)	58,354 (67.1)	
Malignant neoplasm ever				<.0001
Yes	18,741 (17.7)	4,279 (22.5)	1,4462 (16.6)	
No	87,219 (82.3)	14,753 (77.5)	72,466 (83.4)	
Anemia ever				<.0001
Yes	41,868 (39.5)	9,239 (48.5)	32,629 (37.5)	
No	64,092 (60.5)	9,793 (51.5)	54,299 (62.5)	
Hemoglobin A1c				<.0001
Low <6.5% (48 mmol/mol)	21,338 (20.1)	4,302 (22.6)	17,036 (19.6)	
Controlled 6.5–8% (48–64 mmol/mol)	32,459 (30.6)	5,874 (30.9)	26,585 (30.6)	
High >8.0% (65 mmol/mol)	23,690 (22.4)	4,178 (22.0)	19,512 (22.5)	
Unknown	28,473 (26.9)	4,678 (24.6)	23,795 (27.4)	
Total cholesterol				<.0001
Low <150 mg/dL	33,704 (31.8)	6,893 (36.2)	26,811 (30.8)	
Normal 150–200 mg/dL	22,041 (20.8)	3,844 (20.2)	18,197 (20.9)	
High >200 mg/dL	9,117 (8.6)	1,621 (8.5)	7,496 (8.6)	
Unknown	41,098 (38.8)	6,674 (35.1)	34,424 (39.6)	
LDL-C				<.0001
Low <70 mg/dL	26,001 (24.5)	5,352 (28.1)	20,649 (23.8)	

Variable	All discharges N = 105,960	Followed by re-admission n = 19,032	No re-admission n = 86,928	*P* value
Normal 70–100 mg/dL	21,163 (20.0)	3,788 (19.9)	17,375 (20.0)	
High >100 mg/dL	14,392 (13.6)	2,568 (13.5)	11,824 (13.6)	
Unknown	44,404 (41.9)	7,324 (38.5)	37,080 (42.7)	
HDL-C				<.0001
Low <70 mg/dL	30,299 (28.6)	5,895 (31.0)	24,404 (28.1)	
Normal 70–100 mg/dL	24,797 (23.4)	4,471 (23.5)	20,326 (23.4)	
High >100 mg/dL	6,378 (6.0)	1,181 (6.2)	5,197 (6.0)	
Unknown	44,486 (42.0)	7,485 (39.3)	37,001 (42.6)	
Triglycerides				<.0001
Low <100 mg/dL	20,722 (19.6)	4,120 (21.7)	16,602 (19.1)	
Normal 100–150 mg/dL	18,969 (17.9)	3,523 (18.5)	15,446 (17.8)	
High >150 mg/dL	25,657 (24.2)	4,896 (25.7)	20,761 (23.9)	
Unknown	40,612 (38.3)	6,493 (34.1)	34,119 (39.3)	

Abbreviations: ACE = angiotensin-converting enzyme; ACE-i = angiotensin-converting enzyme inhibitor; ARB = angiotensin receptor blocker; BP = blood pressure; COPD = chronic obstructive pulmonary disease; DKA = diabetic ketoacidosis; HDL-C = high-density-lipoprotein cholesterol; HHS = hyperglycemic hyperosmolar syndrome; IQR = interquartile range; LDL-C = low-density-lipoprotein cholesterol.

Data are n, (%) unless otherwise noted.

[a] Retinopathy, neuropathy, nephropathy.

[b] Coronary artery disease, heart failure, stroke, peripheral vascular disease; ever = current or prior.

Table 2

Most Common Reasons for Re-admission Based on Primary ICD-9-CM Code

ICD-9-CM Code[a]	Description	n (% of re-admissions)
414, 410, 440	Chronic ischemic heart disease, acute myocardial infarction, atherosclerosis	1,666 (8.8)
599.xx, 486.xx, 682.xx, 0.38.xx, 008.xx	Urinary tract infection, pneumonia, cellulitis, abscess, septicemia, intestinal infection	1,547 (8.1)
428.xx	Heart failure	1,443 (7.6)
250.xx	Diabetes mellitus	1,167 (6.1)
996.xx	Complication or infection of device, implant, graft, or indwelling urinary catheter	1,105 (5.8)
998.xx, 997.49, 997.6x	Postoperative complication, including infection, bleeding, and disruption of surgical wound[b]	677 (3.6)
577.xx, 572.xx, 578.xx, 560.xx	Disease of pancreas, liver abscess, chronic liver disease, gastrointestinal hemorrhage, intestinal obstruction	670 (3.5)
584.xx, 403.xx	Acute kidney failure, hypertensive kidney disease	576 (3.0)
V58.1	Antineoplastic chemotherapy and immunotherapy	496 (2.6)
786.5x, 786.0x	Chest pain, shortness of breath	370 (1.9)

Abbreviation: ICD-9-CM = International Classification of Diseases, Ninth Revision, Clinical Modification.

[a] Listed in order of frequency.

[b] Excludes 998.89, other postoperative or blood transfusion complications, which was 0.03% of re-admissions.

Table 3

Predictors of All-Cause 30-Day Re-admission According to DERRI™ Plus Hemoglobin A1c and Cholesterol in External Validation Sample

Predictor	Odds ratio (95% CI)	*P* value
Home zip code <5 miles from hospital	1.06 (1.02–1.11)	.0085
Employment status (vs. employed)		
Disabled	1.36 (1.26–1.46)	<.0001
Retired	1.05 (0.99–1.12)	.093
Unemployed	1.35 (1.23–1.49)	<.0001
Other or not recorded	1.03 (0.96–1.10)	.39
Pre-admission insulin use	1.04 (1.00–1.09)	.041
Macrovascular complications[a], n (vs. 0)		
1	0.91 (0.86–0.96)	.0002
2	0.99 (0.94–1.04)	.67
3	1.09 (1.02–1.17)	.016
4	1.14 (0.99–1.30)	.067
Admission hematocrit, per 5%	0.91 (0.89–0.93)	<.0001
Log (admission serum creatinine)	1.19 (1.15–1.23)	<.0001
Admission serum sodium (vs. normal)		
Low, <135 mmol/L	1.11 (1.06–1.15)	<.0001
High, >145 mmol/L	1.25 (1.08–1.45)	.0028
Discharged within 90 days before admission	1.89 (1.80–1.98)	<.0001
Most recent discharge status up to 1 year before admission (vs. home)		
Against medical advice	1.23 (0.97–1.56)	.089
Home with nursing care	1.06 (1.00–1.14)	.068
No discharge recorded	0.87 (0.81–0.92)	<.0001
Subacute facility	0.96 (0.89–1.04)	.37
Anemia, current or prior diagnosis	1.12 (1.08–1.17)	<.0001
Hemoglobin A1c (vs. 6.5–8.0%)		
<6.5%	1.06 (1.00–1.11)	.04
>8.0%	0.99 (0.94–1.05)	.84
Unknown	1.04 (0.99–1.10)	.14
Total cholesterol (vs. 150–200 mg/dL)		
<150 mg/dL	1.07 (1.01–1.12)	.012
>200 mg/dL	1.04 (0.96–1.12)	.35
Unknown	1.00 (0.95–1.05)	.95

Abbreviation: DERRI™ = Diabetes Early Re-admission Risk Indicator.

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

Table 4

Characteristics of Hospitalized Patients With Diabetes in Internal and External Validation Samples

Variable	All discharges N = 123,761	Internal validation n = 17,801	External validation n = 105,960	*P* value
Age				<.0001
<50 years	10,160 (8.2)	3,303 (18.6)	6,857 (6.5)	
50–59 years	17,190 (13.9)	4,219 (23.7)	12,971 (12.2)	
60–69 years	30,510 (24.7)	4,521 (25.4)	25,989 (24.5)	
70+ years	65,901 (53.3)	5,758 (32.4)	60,143 (56.8)	
Gender				<.0001
Female	56,951 (46.0)	9,011 (50.6)	47,940 (45.2)	
Male	66,810 (54.0)	8,790 (49.4)	58,020 (54.8)	
Weight (kg), mean (SD)	85.9 (20.41)	85.0 (20.78)	86.1 (20.32)	.0026
Marital status				<.0001
Married	54,881 (44.3)	5,716 (32.1)	49,165 (46.4)	
Single	64,458 (52.1)	11,742 (66.0)	52,716 (49.8)	
Other or not recorded	4,422 (3.6)	343 (1.9)	4,079 (3.9)	
Race/ethnicity				<.0001
Black	19,269 (15.6)	7,939 (44.6)	11,330 (10.7)	
Hispanic	8,572 (6.9)	2,658 (14.9)	5,914 (5.6)	
White	84,032 (67.9)	6,032 (33.9)	78,000 (73.6)	
Other	6,932 (5.6)	981 (5.5)	5,951 (5.6)	
Not recorded	4,956 (4.0)	191 (1.1)	4,765 (4.5)	
English speaking				<.0001
Yes	107,258 (86.7)	14,371 (80.7)	92,887 (87.7)	
No	16,503 (13.3)	3,430 (19.3)	13,073 (12.3)	
Insurance status				<.0001
Medicaid	5,914 (4.8)	4,080 (22.9)	1,834 (1.7)	
Medicare	61,731 (49.9)	8,818 (49.5)	52,913 (49.9)	
None	13,033 (10.5)	883 (5.0)	12,150 (11.5)	
Private	43,083 (34.8)	4,020 (22.6)	39,063 (36.9)	
Home zip code[d]				<.0001
≥5 miles from hospital	78,942 (63.8)	5,570 (31.3)	73,372 (69.2)	
<5 miles from hospital	44,819 (36.2)	12,231 (68.7)	32,588 (30.8)	
Educational level				<.0001
Less than high school	15,115 (12.2)	2,540 (14.3)	12,575 (11.9)	
Any high school	37,618 (30.4)	9,571 (53.8)	28,047 (26.5)	
Some college	5,472 (4.4)	1,148 (6.5)	4,324 (4.1)	
College graduate	21,960 (17.7)	2,804 (15.8)	19,156 (18.1)	
Not recorded	43,596 (35.2)	1,738 (9.8)	41,858 (39.5)	

Variable	All discharges N = 123,761	Internal validation n = 17,801	External validation n = 105,960	*P* value
Employment[d]				<.0001
Disabled	18,129 (14.7)	3,683 (20.7)	14,446 (13.6)	
Employed	19,964 (16.1)	1,746 (9.8)	18,218 (17.2)	
Retired	47,047 (38.0)	6,990 (39.3)	40,057 (37.8)	
Unemployed	11,574 (9.4)	4,819 (27.1)	6,755 (6.4)	
Other or not recorded	27,047 (21.9)	563 (3.2)	26,484 (25.0)	
Pre-admission sulfonylurea use				.039
Yes	18,580 (15.0)	2,858 (16.1)	15,722 (14.8)	
No	105,181 (85.0)	14,943 (83.9)	90,238 (85.2)	
Pre-admission metformin use				<.0001
Yes	26,368 (21.3)	5,013 (28.2)	21,355 (20.2)	
No	97,393 (78.7)	12,788 (71.8)	84,605 (79.9)	
Pre-admission thiazolidinedione use				<.0001
Yes	4,091 (3.3)	1,243 (7.0)	2,848 (2.7)	
No	119,670 (96.7)	16,558 (93.0)	103,112 (97.3)	
Pre-admission insulin use[d]				.30
Yes	44,382 (35.9)	6,531 (36.7)	37,851 (35.7)	
No	79,379 (64.1)	11,270 (63.3)	68,109 (64.3)	
Pre-admission glucocorticoid use				.0034
Yes	13,472 (10.9)	1,679 (9.4)	11,793 (11.1)	
No	110,289 (89.1)	16,122 (90.6)	94,167 (88.9)	
Current or prior DKA or HHS				<.0001
Yes	5,478 (4.4)	1,231 (6.9)	4,247 (4.0)	
No	118,283 (95.6)	16,570 (93.1)	101,713 (96.0)	
Microvascular complications[a]				.19
0	86,979 (70.3)	12,366 (69.5)	74,613 (70.4)	
1	21,853 (17.7)	3,354 (18.8)	18,499 (17.5)	
2	9,329 (7.5)	1,377 (7.7)	7,952 (7.5)	
3	5,600 (4.5)	704 (4.0)	4,896 (4.6)	
Macrovascular complications[b,d]				<.0001
0	44,973 (36.3)	7,740 (43.5)	37,233 (35.1)	
1	36,540 (29.5)	5,228 (29.4)	31,312 (29.6)	
2	29,242 (23.6)	3,559 (20.0)	25,683 (24.2)	
3	10,337 (8.4)	1,052 (5.9)	9,285 (8.8)	
4	2,669 (2.2)	222 (1.3)	2,447 (2.3)	
Pre-admission BP meds				<.0001
None	50,789 (41.0)	4,949 (27.8)	45,840 (43.3)	
ACE-i or ARB	46,966 (38.0)	8,595 (48.3)	38,371 (36.2)	

Variable	All discharges N = 123,761	Internal validation n = 17,801	External validation n = 105,960	*P* value
Non-ACE or ARB	26,006 (21.0)	4,257 (23.9)	21,749 (20.5)	
Pre-admission statin use				<.0001
Yes	53,754 (43.4)	8,571 (48.2)	45,183 (42.6)	
No	70,007 (56.6)	9,230 (51.9)	60,777 (57.4)	
White blood cell count				<.0001
Low <4 K/μL	4,934 (4.0)	793 (4.5)	4,141 (3.9)	
Normal 4–11 K/μL	81,937 (66.2)	13,700 (77.0)	68,237 (64.4)	
High >11 K/μL	36,890 (29.8)	3,308 (18.6)	33,582 (31.7)	
Hematocrit[d], %, mean (SD)	35.2 (5.63)	33.7 (5.34)	35.5 (5.63)	<.0001
Serum sodium[d]				<.0001
Low <135 mmol/L	29,061 (23.5)	2,013 (11.3)	27,048 (25.5)	
Normal 135–145 mmol/L	93,298 (75.4)	15,595 (87.6)	77,703 (73.3)	
High >145 mmol/L	1,402 (1.1)	193 (1.1)	1,209 (1.1)	
Serum potassium				.0003
Low <3.1 mmol/L	2,104 (1.7)	238 (1.3)	1,866 (1.8)	
Normal 3.1–5.3 mmol/L	112,376 (90.8)	16,302 (91.6)	96,074 (90.7)	
High >5.3 mmol/L	9,281 (7.5)	1,261 (7.1)	8,020 (7.6)	
Creatinine[d], mg/dL, median (IQR)	1.1 (0.9–1.7)	1.0 (0.7–1.4)	1.2 (0.9–1.7)	.027
Discharged 90 days prior to index admission[d]				.12
Yes	38,112 (30.8)	5,661 (31.8)	32,451 (30.6)	
No	85,649 (69.2)	12,140 (68.2)	73,509 (69.4)	
Length-of-stay, days, median (IQR)	5.0 (3.0–8.0)	3.7 (2.1–6.2)	5.0 (3.0–8.0)	<.0001
Discharge status of index admission				<.0001
Home	31,796 (25.7)	10,372 (58.3)	21,424 (20.2)	
Home with nursing care	42,237 (34.1)	3,448 (19.4)	38,789 (36.6)	
Subacute facility	25,307 (20.5)	3,454 (19.4)	21,853 (20.6)	
Against medical advice	1,195 (1.0)	392 (2.2)	803 (0.8)	
Other	1,352 (1.1)	133 (0.8)	1,219 (1.2)	
No status recorded	21,874 (17.7)	2 (0.01)	21,872 (20.6)	
Discharge 1 year prior to index admission[d]				<.0001
Home	17,198 (13.9)	6,419 (36.1)	10,779 (10.2)	
Home with nursing care	20,781 (16.8)	2,362 (13.3)	18,419 (17.4)	
Sub-acute facility	12,098 (9.8)	2,082 (11.7)	10,016 (9.5)	
Against medical advice	723 (0.6)	282 (1.6)	441 (0.4)	
No discharge recorded	72,961 (59.0)	6,656 (37.4)	66,305 (62.6)	
Body mass index				<.0001
<18.5 kg/m^2	2,017 (1.6)	422 (2.4)	1,595 (1.5)	

Variable	All discharges N = 123,761	Internal validation n = 17,801	External validation n = 105,960	*P* value
18.5–24.9 kg/m^2	20,147 (16.3)	3,007 (16.9)	17,140 (16.2)	
25.0–29.9 kg/m^2	37,644 (30.4)	4,925 (27.7)	32,719 (30.9)	
≥30.0 kg/m^2	63,953 (51.7)	9,447 (53.1)	54,506 (51.4)	
Depression or psychosis ever				<.0001
Yes	27,748 (22.4)	5,242 (29.5)	22,506 (21.2)	
No	96,013 (77.6)	12,559 (70.6)	83,454 (78.8)	
Gastroparesis ever				.0042
Yes	4,319 (3.5)	904 (5.1)	3,415 (3.2)	
No	119,442 (96.5)	16,897 (94.9)	102,545 (96.8)	
Pancreatitis ever				
Yes	5,456 (4.4)	974 (5.5)	4,482 (4.2)	.021
No	118,305 (95.6)	16,827 (94.5)	101,478 (95.8)	
Hypertension ever				<.0001
Yes	87,421 (70.6)	13,242 (74.4)	74,179 (70.0)	
No	36,340 (29.4)	4,559 (25.6)	31,781 (30.0)	
COPD[c] or asthma ever				<.0001
Yes	20,393 (16.5)	4,068 (22.9)	16,325 (15.4)	
No	103,368 (83.5)	13,733 (77.2)	89,635 (84.6)	
Cardiac dysrhythmias ever				<.0001
Yes	39,828 (32.2)	4,164 (23.4)	35,664 (33.7)	
No	83,933 (67.8)	13,637 (76.6)	70,296 (66.3)	
Malignant neoplasm ever				<.0001
Yes	20,459 (16.5)	1,718 (9.7)	18,741 (17.7)	
No	103,302 (83.5)	16,083 (90.4)	87,219 (82.3)	
Anemia ever[d]				.062
Yes	49,216 (39.8)	7,348 (41.3)	41,868 (39.5)	
No	74,545 (60.2)	10,453 (58.7)	64,092 (60.5)	

Abbreviations: ACE = angiotensin-converting enzyme; ACE-i = angiotensin-converting enzyme inhibitor; ARB = angiotensin receptor blocker; BP = blood pressure; COPD = chronic obstructive pulmonary disease; DKA = diabetic ketoacidosis; HHS = hyperglycemic hyperosmolar syndrome; IQR = interquartile range.

Data are n, (%) unless otherwise noted.

[a]Retinopathy, neuropathy, nephropathy.

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

[c]COPD, chronic obstructive pulmonary disease; Ever=current or prior.

[d]Included in the Diabetes Early Re-admission Risk Indicator.