

# Enhanced Risk Prediction Model for Emergency Department Use and Hospitalizations in Patients in a Primary Care Medical Home

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Changing the payment incentives to improve the organization of care delivery, including accountable care organizations, has led to a reorganization of delivery of care focusing on patient-centered medical homes.<sup>1</sup> Many patient-centered medical homes stratify their populations and try to align the level of care with the needs of their patients. Providers manage the most complex patients with increased resources to avoid adverse outcomes requiring high-cost care in acute settings.

Two key questions need to be answered: Who is likely to have utilization, and what can be done for these patients? These medically complex patients could be better managed through care coordination programs that are integrated within the delivery system, such as Guided Care, which incorporates specially trained nurses to supplement primary care in a comprehensive care model that provides coordinated, patient-centered primary care for patients with complex needs.<sup>2</sup> Different methods for identifying these patients have been developed, including provider identification and referral.<sup>3</sup> A hybrid system that utilizes provider selection and an automated risk stratification model may be ideal. Most of the currently available public and proprietary risk models and instruments to identify the population for inclusion in more intensive management programs are based on number and combination of comorbidities. These instruments include self-administered tools such as the Predicting Risk of Admission (PRA) survey, which incorporates self-rated health and comorbid conditions as well as prior healthcare utilization.<sup>4</sup> Another model utilizing medical record data is the Elder Risk Assessment (ERA) index, which determines risk of hospitalization based upon increasing age and previous hospitalization as well as comorbid health conditions.<sup>5</sup>

A third risk model, Adjusted Clinical Groups (ACG), uses medical care claims data and stratifies patients based on age and existing chronic conditions.<sup>6</sup> The state of Minnesota pays medical homes a care management fee based on Minne-

## ABSTRACT

**Objectives:** With the advent of healthcare payment reform, identifying high-risk populations has become more important to providers. Existing risk-prediction models often focus on chronic conditions. This study sought to better understand other factors to improve identification of the highest risk population.

**Study Design:** A retrospective cohort study of a paneled primary care population utilizing 2010 data to calibrate a risk prediction model of hospital and emergency department (ED) use in 2011.

**Methods:** Data were randomly split into development and validation data sets. We compared the enhanced model containing the additional risk predictors with the Minnesota medical tiering model. The study was conducted in the primary care practice of an integrated delivery system at an academic medical center in Rochester, Minnesota. The study focus was primary care medical home patients in 2010 and 2011 ( $n = 84,752$ ), with the primary outcome of subsequent hospitalization or ED visit. A total of 42,384 individuals derived the enhanced risk-prediction model and 42,368 individuals validated the model. Predictors included Adjusted Clinical Groups–based Minnesota medical tiering, patient demographics, insurance status, and prior year healthcare utilization. Additional variables included specific mental and medical conditions, use of high-risk medications, and body mass index.

**Results:** The area under the curve in the enhanced model was 0.705 (95% CI, 0.698–0.712) compared with 0.662 (95% CI, 0.656–0.669) in the Minnesota medical tiering-only model. New high-risk patients in the enhanced model were more likely to have lack of health insurance, presence of Medicaid, diagnosed depression, and prior ED utilization.

**Conclusions:** An enhanced model including additional healthcare-related factors improved the prediction of risk of hospitalization or ED visit.

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### Take-Away Points

- Many risk models that predict hospitalization or emergency department (ED) use are based on comorbid health burden.
- We investigated other potential predictors, including previous utilization, and found an association of higher hospitalization and ED use with the following: Minnesota medical tiering, 2 prior ED visits, warfarin use, no insurance or Medicaid, being aged over 70 years, and obesity stage 3.
- These findings help to develop new models for determining patients at risk for adverse health outcomes. They focus on potential future areas of clinical practice and research on social determinants of health.

sota medical tiering. Minnesota medical tiering is a system of classifying and counting comorbidities originally based on collapsing chronic diseases from ACGs into a body system count.<sup>7</sup> This system can also be manually applied without the proprietary software. Our clinical practice uses Minnesota medical tiering to identify appropriate patients for care management. Our prior work comparing these instruments, including Minnesota medical tiering, indicates that these instruments are similar in terms of predicting the risk of hospitalization or emergency department (ED) visit; however, the ACG performed slightly better while the Charlson Comorbidity Index performed worse.<sup>8</sup> Although the administrative data-based risk identification methods have been validated and can predict hospitalization with C statistics of 0.67-0.73,<sup>8</sup> other potential predictors may improve current risk prediction models and could provide information useful in developing tailored interventions to manage a patient's condition.

Our clinical experience indicates that coordinating the management of multiple chronic conditions is important in reducing rehospitalizations among geriatric patients with multimorbidity, but other factors may also be important in predicting and managing an individual's risk.<sup>9</sup> In our practice, many patients predicted to be high risk are excluded from care management interventions because they have concurrent mental health or social conditions that care coordinators are unprepared to address. Body mass index (BMI), medication use,<sup>10</sup> living environment, English as a second language, previous healthcare use including specialty visits, insurance, and mental health status<sup>11</sup> might all be important factors. Patients with those issues may need a different approach, including more support from social services, pharmacy, and psychology.

Obesity is known to influence utilization, but it is widely underdiagnosed and so may be missed in many comorbidity counts.<sup>12</sup> The use of anticoagulation therapy, pain, and diabetic medications can lead to an increased need for unplanned acute care and may be amenable to pharmacy consultation.<sup>13</sup> Patients living on their own or in dysfunctional families may not be able to cope with increased treatment

burdens and may benefit from social services.<sup>14,15</sup> Similarly, those who need language interpretation services may need extra assistance. Patients with a high number of specialty visits may have uncoordinated care and may need help in coordinating their care. Lack of insurance and lower socioeconomic status are associated with increased rates of hospitalization.<sup>16</sup> Patients experiencing mental health issues such as depression can also have higher readmission rates.<sup>7,17</sup>

Providers and systems with established comorbid health models should understand the potential roles of these additional predictors for hospitalization.

It is unclear how well these additional factors would predict hospitalization when added to an already established clinical model based on administrative data. To answer this question, we performed a retrospective cohort study comparing a standard risk stratification model of Minnesota medical tiering with an enhanced model containing additional predictors of demographics, selected use of medications, mental health conditions, other specific chronic medical conditions, prior healthcare utilization, and insurance status. We sought to understand how well the enhanced model predicts hospitalization and ED use in a subsequent year.

## METHODS

### Design

We constructed a retrospective cohort study to develop and validate a clinical prediction model for hospitalization. The study was approved by the Mayo Clinic Institutional Review Board.

### Setting

The study was conducted at an academic medical center in Rochester, Minnesota. The population came from the primary care medical practice, Employee and Community Health (ECH), which includes 4 primary care clinics in Dodge and Olmsted Counties, Minnesota. Primary care is provided by family medicine, primary care internal medicine, and community pediatric and adolescent medicine.

### Patient Population

Patients 18 years or older who were assigned to a primary care provider within any of the primary care clinics for all 12 months in 2010 (base year) and throughout 12 months or until death in 2011 (assessment year) were included in the analysis. Subjects were excluded if they

refused consent for medical record review in accordance with Minnesota state law. Of the 90,411 patients within the ECH program, as of December 31, 2010, 84,752 (93.7%) gave consent for medical record review.

### Data Collection

All information for enrolled ECH patients was electronically abstracted from the electronic medical record (EMR) and administrative databases for 2010 and 2011.

### Outcomes and Predictors

We modeled a combined binary outcome of hospitalization and/or ED visit (hereafter: hosp/ED) at St. Mary's Hospital or Rochester Methodist Hospital in the assessment year. Hospitalization was defined as any elective or emergent overnight. To avoid double counting, ED visits exclude those resulting in a hospitalization.

Demographic variables—age, gender, marital status, and socioeconomic status—were collected at the end of the base year. Age was grouped into 6 categories: 18 to 29 years, 30 to 39 years, 40 to 49 years, 50 to 59 years, 60 to 69 years, and 70 years or older. Socioeconomic status was determined by insurance type (Medicaid or no insurance versus other insurance type).

As Minnesota medical tiering is the basis for care coordination payments for patient-centered medical homes in Minnesota, we used it as the basis for our risk model development. Medical conditions are based on diagnosis codes billed by clinical providers.<sup>18</sup> Minnesota medical tiering has 5 categories from 0 with no conditions to tier 4 with more than 10 conditions. In our care management program, high-risk patients possess Minnesota medical-tiering scores of 3 or 4.

Candidate predictors for identifying high-risk patients included primary speaking language not being English; high-risk medications (warfarin, insulin, narcotics); and previous healthcare utilization in specific settings (ED visits, hospitalization, specialty provider visits). Medications were based on the presence of outpatient pharmacy orders in 2010 written by any healthcare providers within the system. Medication use was determined from the EMR, not from filled prescriptions. The medications included warfarin, narcotics and insulin. Non-English speaking status was assigned to those patients needing an interpreter, which was documented within the electronic health record. We included all diagnosis codes (*International Classification of Diseases, Ninth Revision, Clinical Modification* [ICD-9-CM]) from hospitalizations, ED visits, and primary and specialty care visits to identify comorbid mental health and medical conditions, based on a published method.<sup>19</sup> Each outpa-

tient visit had 4 potential ICD-9-CM codes and inpatient visits had 25 ICD-9-CM codes.

BMI—recorded as weight (kilograms) / height (meters)<sup>2</sup>—was also included as a potential predictor. BMI was assessed as being the most recent value in the record within 2 years prior to January 1, 2011. Specific BMI categories followed standard World Health Organization criteria: underweight (BMI <18.5); normal weight (BMI 18.5-24.9); overweight (BMI 25-29.9); stage 1 obesity (BMI 30-34.9); stage 2 obesity (BMI 35-39.9); and stage 3 obesity (BMI >40).<sup>20</sup>

### Statistical Analysis and Model Building

We developed the enhanced model to identify those patients at high risk of hosp/ED within the next year. The 2 models compared in the analysis consisted of Minnesota medical tiering and the enhanced model, which incorporated additional candidate factors. Data were randomly divided into development (50%) and validation cohorts.

We derived the final enhanced model from a stepwise logistic regression followed by a sensitivity analysis seeking stability in the predictors determined by the severity of the outcome variable. Predictors in the saturated model consisted of 72 main factors as well as all possible 1-way and 2-way interaction terms. We determined stability of the variables by changing the number of ED visits or inpatient (IP) visits in the outcome variable. We performed the saturated stepwise model while incrementally increasing the number of ED visits or IP visits. The final set of variables for each change in outcome variable was captured. We then considered a count of how many times a variable had a *P* value  $\leq .05$  in the model. Finally, we included any variable that remained significant in 4 or more of the 11 models considered.

The stepwise regression was repeated 100 times and each repetition considered the variables in random order to determine if order affected the results of the stepwise algorithm. Each iteration produced the same model. Effects were entered into and removed from the model so that each forward selection step could be followed by a backward elimination step. The algorithm stopped when no further effects could be added to the model or if the current model was identical to a previous model.

Comparisons between prediction models focused on predictability and precision. We used C statistics (area under the receiver operating characteristic [ROC] curve [AUC]) as our measure of predictability. For assessment of precision, we compared the sets of high-risk patients found within the tier 3 and 4 groups in Minnesota medical tiering with an equal number of high-scoring patients from the enhanced model. Statistical analysis was performed using SAS version 9.3 (SAS Institute, Cary, North Carolina).

RESULTS

Patient Characteristics

A total of 42,384 and 42,368 patients were included in the development and validation samples, respectively. The development and validation data sets were similar. There were no differences in sex, age decile, BMI, marital status, insurance status, prior healthcare utilization, comorbid health status, or Minnesota medical tiering (Table 1). In addition, the 2 samples had similar rates of hospitalization and ED visits with 18.2% of the development sample and 17.6% of the validation sample having a hospitalization or ED visit in the subsequent year.

Initial Univariable Model

Those patients who belonged to the highest category of Minnesota medical tiering (4) had the greatest odds of incurring any hospitalization or ED visit with an odds ratio of 18.2 (95% CI, 15.6-21.24) compared with the lowest tier category (0). Next most important was prior utilization of 2 or more ED visits with an odds ratio of 7.13 (95% CI, 6.34-8.01) for predicting hosp/ED. Similarly, 2 or more previous hospital stays had an odds ratio of 4.28 (95% CI, 3.90-4.69) for predicting hosp/ED. Mental health conditions, including substance abuse, personality disorder or dementia, each had odds near 3 for predicting hosp/ED. Specifically, depression had an odds ratio of 2.92 (95% CI, 2.71-3.15). Among other medical conditions, cardiac disease with heart failure and pulmonary heart disease had odds ratios over 5. All specific conditions with odds ratios over 2 are reported in Table 1. All specific conditions are listed in Table 2. Patients in each of the medication categories had odds ratios greater than 2, as did those utilizing 3 or more specialist visits in the prior year. Patients with a language interpreter did not have elevated risk of hosp/ED (Table 2).

Multivariable Model

The multivariable enhanced tiering model is presented in Table 3. The final model included 30 main effects (representing 16 factors) and 4 2-way interaction terms (more detailed results are available from the authors).

Of notable mention, being in the highest medical tier remains the strongest predictor for hosp/ED after the addition of other factors with an odds ratio of 3.50 (95% CI, 2.78-4.42). More than 1 previous ED visit also resulted in an increased odds ratio of 3.17 (95% CI, 2.78-3.60). Several significant interaction terms are noted in Table 3. In the validation cohort, the C statistic for the enhanced multivariable model was 0.711 (95% CI, 0.704-0.717) compared with a C statistic for the Minnesota medical tiering alone model of 0.667 (95% CI 0.660-0.673). These C statistics were actually

Table 1. Characteristics of the Development and Validation Cohorts<sup>a</sup> of 84,752 Patients in a Medical Home Program

	Validation (N = 42,368)	Development (N = 42,384)	P
Gender			.72
Female	23,095 (54.5%)	23,155 (54.6%)	
Male	19,273 (45.5%)	19,229 (45.4%)	
Age group, years			.30
18-29	8802 (20.8%)	8774 (20.7%)	
30-39	7250 (17.1%)	7340 (17.3%)	
40-49	7639 (18.0%)	7414 (17.5%)	
50-59	8055 (19.0%)	8054 (19.0%)	
60-69	4897 (11.6%)	5036 (11.9%)	
≥70	5725 (13.5%)	5766 (13.6%)	
BMI			.46
Underweight	217 (0.5%)	228 (0.5%)	
Normal	8985 (21.2%)	8932 (21.1%)	
Overweight	9638 (22.7%)	9609 (22.7%)	
Obese 1	5764 (13.6%)	5903 (13.9%)	
Obese 2	2672 (6.3%)	2550 (6.0%)	
Obese 3	1712 (4.0%)	1762 (4.2%)	
Unknown	13,380 (31.6%)	13,400 (31.6%)	
Married			.14
No	18,137 (42.8%)	17,932 (42.3%)	
Yes	24,231 (57.2%)	24,452 (57.7%)	
No insurance or presence of Medicaid			.05
No	29,755 (70.2%)	29,503 (69.6%)	
Yes	12,613 (29.8%)	12,881 (30.4%)	
Prior ED visits			.06
No prior ED visits	37,034 (87.4%)	36,816 (86.9%)	
1 prior ED visit	4182 (9.9%)	4351 (10.3%)	
≥2 prior ED visits	1152 (2.7%)	1217 (2.9%)	
Prior hospitalization			.87
No prior hospitalization	37,020 (87.4%)	37,002 (87.3%)	
1 prior hospitalization	3310 (7.8%)	3352 (7.9%)	
≥2 prior hospitalizations	2038 (4.8%)	2030 (4.8%)	
≥3 specialists seen in 2010			.39
No	36,616 (86.4%)	36,543 (86.2%)	
Yes	5752 (13.6%)	5841 (13.8%)	
MN tier score			.42
Tier 0 (0 conditions)	10,217 (24.1%)	10,184 (24.0%)	
Tier 1 (1-3 conditions)	20,322 (48.0%)	20,117 (47.5%)	
Tier 2 (4-6 conditions)	8658 (20.4%)	8831 (20.8%)	
Tier 3 (7-9 conditions)	2320 (5.5%)	2387 (5.6%)	
Tier 4 (≥10 conditions)	851 (2.0%)	865 (2.0%)	

(continued)

**Table 1.** Characteristics of the Development and Validation Cohorts<sup>a</sup> of 84,752 Patients in a Medical Home Program (*continued*)

	Validation (N = 42,368)	Development (N = 42,384)	P
Depression			.54
No	39,013 (92.1%)	38,979 (92.0%)	
Yes	3355 (7.9%)	3405 (8.0%)	
Substance-related disorders			.42
No	41,968 (99.1%)	41,961 (99.0%)	
Yes	400 (0.9%)	423 (1.0%)	
Narcotic prescription order			.18
No	27,159 (64.1%)	26,981 (63.7%)	
Yes	15,209 (35.9%)	15,403 (36.3%)	
Epilepsy			.28
No	42,123 (99.4%)	42,162 (99.5%)	
Yes	245 (0.6%)	222 (0.5%)	
Hyperlipidemia			.75
No	36,578 (86.3%)	36,560 (86.3%)	
Yes	5790 (13.7%)	5824 (13.7%)	
Warfarin prescription order			.50
No	41,244 (97.3%)	41,228 (97.3%)	
Yes	1124 (2.7%)	1156 (2.7%)	

BMI indicates body mass index; ED, emergency department.  
<sup>a</sup>There were no significant differences between the validation and the development cohorts.

slightly higher in the validation cohort than in the development cohort (enhanced model: 0.705 [95% CI, 0.698-0.712]; Minnesota medical tiering: 0.662 [95% CI, 0.656-0.669]). The differences between the ability of the enhanced model to predict hospitalization and ED use and Minnesota medical tiering are displayed in the ROC curves found in the **Figure**.

Many different patients were identified as being high-risk in the enhanced model as compared with those in the original Minnesota medical tiering model (tier 3 or 4). **Table 4** presents the characteristics of high-risk patients identified with both models as well as those unique to the 2 approaches. We found that patients identified as high-risk in the enhanced model were much more likely to experience hospital utilization in 2011 than those in the Minnesota medical tiering-only model ( $P < .001$ ). Patients identified as high-risk based only on the enhanced model, compared with those identified only through Minnesota medical tiering, were of younger age, had higher previous healthcare utilization, and had more frequent mental health conditions. Many of the high-risk enhanced model patients were aged less than 40 years compared with only 11% of patients being aged less than 40 years in the Minnesota medical tiering model.

## DISCUSSION

In this retrospective cohort of patients receiving care within the ECH, several variables were important in predicting hosp/ED in addition to the number of chronic comorbidities currently used in Minnesota medical tiering and our care coordination identification. We found that age, BMI, previous healthcare utilization, mental health conditions, anemia, heart failure, epilepsy, hyperlipidemia, warfarin use, and narcotic use all simultaneously contributed to the prediction of hospitalization and ED visits in the next year. This enhanced model had an AUC of 0.711 (95% CI, 0.704-0.717) for predicting hosp/ED, as compared with 0.667 (95% CI, 0.660-0.673) found in the model utilizing only Minnesota medical tiering. Previous work comparing different risk stratification methods for hospitalization determined slight superiority of ACG compared with the ERA, Hierarchical Condition Categories, Minnesota medical tiering, and chronic care counting instruments.<sup>8</sup> The enhanced model takes into consideration previous hospitalization, specific high-risk illnesses, mental health conditions, and high-risk medication use (eg, warfarin, narcotics) that are not universally accounted for in other models. In comparing high-risk groups of the same size from both models and excluding patients identified in both models, 47% of the patients in the enhanced model experienced hosp/ED compared with 32.5% of patients from the Minnesota medical tiering model. The enhanced model accounts for factors in a younger population (eg, mental health and previous utilization) that are not detected in the Minnesota medical tiering model.

Previous hospital and ED utilization served as strong predictors for hosp/ED in the following year. Specifically, 2 or more prior ED visits presented an odds ratio (OR) close to 3 while 1 prior hospital stay resulted in an OR of 1.79 (95% CI, 1.66-1.93). Together, hospitalization and ED visits often indicate a medically complex individual or an individual with severe illness. Many risk stratification models have utilized previous healthcare usage as a predictor for future healthcare use. The PRA incorporates previous hospitalization within the past year as a factor predictive of future hospitalization.<sup>4</sup> Similarly, the ERA also includes previous hospital days to calculate a risk score for future hospitalization.<sup>5</sup> Previous ED visits as well as previous hospitalization have been associated with increased hospital admission in a multi-centered VA study of 1378 patients designed to identify factors of hospitalization.<sup>21</sup>

Concurrent mental health conditions also proved indicative of potential hospitalization and utilization. In the multivariable analysis, patients who had depression and

**Table 2.** Univariable Outcomes for Hospitalization or Emergency Department Visit in Subsequent Year by Candidate Predictors in the Development Cohort (N = 42,384)

Effect	Odds Ratio	95% CI	Effect	Odds Ratio	95% CI
Age	1.01	1.01-1.01	Conduction disorders/cardiac dysrhythmias	3.56	3.18-3.98
Male	0.73	0.69-0.77	Congestive heart failure	6.44	5.31-7.80
Married	1.13	1.07-1.18	Cerebrovascular disease	2.48	2.07-2.97
Interpreter use in 2010	0.99	0.70-1.39	Peripheral atherosclerosis	3.50	2.95-4.16
No insurance or presence of Medicaid	1.45	1.37-1.52	Asthma/COPD	2.78	2.52-3.07
BMI			Esophageal disorders	1.98	1.53-2.57
Underweight vs normal	1.78	1.33-2.38	Diverticulosis	2.01	1.77-2.29
Overweight vs normal	1.06	0.98-1.14	Chronic renal failure	4.71	3.92-5.65
Obese 1 vs normal	1.13	1.04-1.23	Ovarian/uterine/reproductive	1.64	1.44-1.86
Obese 2 vs normal	1.41	1.27-1.56	Chronic ulcer of skin	2.27	1.89-2.73
Obese 3 vs normal	1.82	1.62-2.04	Rheumatoid arthritis	2.25	1.85-2.74
Unknown vs normal	0.65	0.61-0.70	Osteoarthritis	2.23	2.03-2.44
Total comorbid count	1.30	1.29-1.32	Back problems	2.38	2.06-2.75
MN tier score			Congenital anomalies	2.24	1.88-2.67
Tier 1 (1-3 conditions) <sup>a</sup>	2.08	1.92-2.25	Thyroid/parathyroid/pituitary disorders	1.88	1.68-2.10
Tier 2 (4-6 conditions) <sup>a</sup>	3.87	3.55-4.22	Degenerative eye problems	1.72	1.54-1.92
Tier 3 (7-9 conditions) <sup>a</sup>	7.31	6.55-8.14	Gout and other crystal arthropathies	2.94	2.1-3.99
Tier 4 (≥10 conditions) <sup>a</sup>	18.20	15.6-21.24	Hepatitis	3.19	1.52-6.68
≥3 specialists seen in 2010	2.83	2.66-3.01	Immunity disorders	3.07	1.93-4.89
Prior ED visits			Multiple sclerosis	1.25	0.78-2.01
1 prior ED visit vs none	2.68	2.50-2.87	Other and ill-defined heart disease	4.19	3.44-5.10
≥2 prior ED visits vs none	7.13	6.34-8.01	Other central nervous system diseases	3.24	2.82-3.71
Prior hospitalization			Parkinson's disease	2.83	1.92-4.16
1 prior hospitalization vs none	2.38	2.20-2.58	Pulmonary heart disease	5.36	4.14-6.93
≥2 prior hospitalizations vs none	4.28	3.90-4.69	Obesity	2.34	2.10-2.60
Medications			Major intestinal disorder	2.61	1.87-3.65
Warfarin use in 2010	3.03	2.68-3.42	Migraines	2.58	2.24-2.98
Insulin use in 2010	2.21	2.06-2.37	Aneurysm	2.93	2.20-3.91
Narcotic use in 2010	2.23	2.12-2.34	Other vascular disease	2.71	2.23-3.30
Specific conditions			Allergic rhinitis/sinusitis	1.49	1.32-1.68
Malignancies	1.73	1.58-1.89	Chronic liver disease	2.98	2.38-3.74
Diabetes	2.01	1.85-2.19	Other kidney disease	3.73	3.12-4.45
Hyperlipidemia	1.53	1.43-1.63	Lupus	2.37	1.70-3.29
Anemia	4.99	3.22-7.75	Other chronic conditions	2.84	1.90-4.24
Substance-related disorders	4.84	3.99-5.87	BPH	2.15	1.77-2.60
Paralysis	4.67	3.31-6.57	Dementia	3.41	2.88-4.05
Epilepsy	3.45	2.64-4.51	Behavior problems	2.27	1.86-2.76
Heart valve disorders	3.20	2.63-3.90	Anxiety disorders	2.62	2.35-2.92
Hypertension	1.93	1.82-2.06	Other mental disorders	1.50	0.64-3.53
Acute myocardial infarction	3.45	2.38-5.01	Personality disorders	4.33	3.74-5.07
Coronary atherosclerosis	2.72	2.45-3.02	Depression	2.92	2.71-3.15

BMI indicates body mass index; BPH, benign prostatic hyperplasia; COPD, chronic obstructive pulmonary disease; ED, emergency department; MN, Minnesota.  
<sup>a</sup>Versus Tier 0 (no conditions).

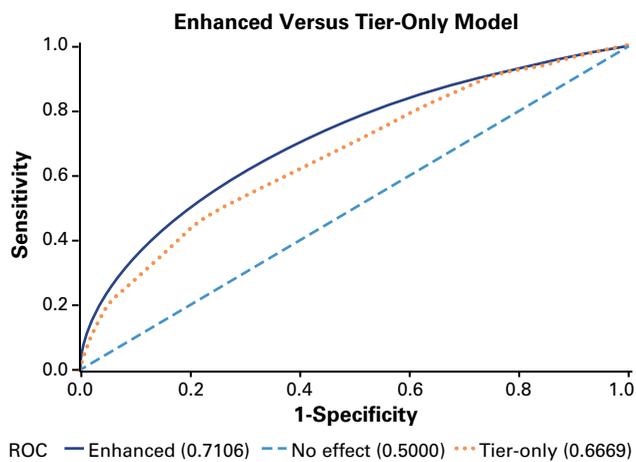
**Table 3.** Odds Ratios for the Multivariable Enhanced Model in Development Cohort of 42,384

Effect	Odds Ratio	95% CI
Age group, years		
18-29 vs 40-49	1.50	1.36-1.65
30-39 vs 40-49	1.24	1.13-1.09
50-59 vs 40-49	0.99	0.91-1.37
60-69 vs 40-49	1.05	0.94-1.17
≥70 vs 40-49	1.56	1.41-1.72
Male	0.94	0.88-1.01
No insurance or presence of Medicaid	1.33	1.24-1.43
Married	1.17	1.08-1.27
BMI		
Obese 1 vs normal	1.07	0.98-1.17
Obese 2 vs normal	1.27	1.13-1.42
Obese 3 vs normal	1.43	1.26-1.62
Overweight vs normal	1.04	0.96-1.13
Underweight vs normal	1.31	0.95-1.79
Unknown vs normal	1.07	0.99-1.16
MN tier score		
Tier 1 (1-3 conditions) <sup>a</sup>	1.57	1.43-1.72
Tier 2 (4-6 conditions) <sup>a</sup>	2.06	1.84-2.30
Tier 3 (7-9 conditions) <sup>a</sup>	2.54	2.17-2.97
Tier 4 (≥10 conditions) <sup>a</sup>	3.50	2.78-4.42
Depression	1.09	0.97-1.22
Substance abuse	1.49	1.19-1.86
Narcotic use	1.30	1.18-1.43
Epilepsy	1.55	1.15-2.09
Hyperlipidemia	0.75	0.69-0.82
≥3 specialists seen in 2010	1.08	0.99-1.17
1 prior ED visit	1.79	1.66-1.93
≥2 prior ED visits	3.17	2.78-3.60
1 prior hospitalization	1.09	1.00-1.20
≥2 prior hospitalizations	1.39	1.24-1.56
Number of total comorbidities	1.11	1.08-1.13
Warfarin use	2.25	1.63-3.09
Depression X <sup>b</sup> saw a specialist in 2010	1.28	1.08-1.53
Male X <sup>b</sup> insurance	0.79	0.70-0.89
Married X <sup>b</sup> narcotic use	0.78	0.70-0.87
Warfarin use X <sup>b</sup> MN tier score	0.80	0.70-0.91

BMI indicates body mass index; ED, emergency department; MN, Minnesota.  
<sup>a</sup>Versus Tier 0 (no conditions).  
<sup>b</sup>X indicates "interaction" terms where both factors are being considered. For example, married individuals with narcotics use are less likely to be have subsequent hospital/ED use than nonmarried individuals with narcotics use.

saw a specialist had an association with increased hosp/ED. Patients with substance abuse had higher risk of hosp/

**Figure.** Enhanced Model and Minnesota Medical Tier Model for Outcome of Hospitalization or ED Visit in 2011 in 42,368 Patients in Validation Cohort



ED indicates emergency department; ROC, receiver operating characteristic.

ED. Previous studies have also shown increased risk of hospitalization with concurrent mental health disorders. In a study of 771 patients with dementia, 48% of patients had a hospital admission during the study.<sup>22</sup> In 8812 hypertensive patients, mood disorders and personality disorders resulted in higher ORs of hospitalizations of 1.3 and 1.2, respectively.<sup>23</sup> The identification of mood disorders as a potential risk for hospitalization or ED visits can help providers initiate specific care plans. In particular, the Depression Improvement Across Minnesota, Offering a New Direction care management model has been very successful in assisting depressed patients, with 6-month depression remission rates at 27% compared with 0% to 11% in controls.<sup>24</sup>

Medication use continues to serve as an important predictor of hospitalization. We found that warfarin use had more than a 2-fold increase in hosp/ED compared with those patients not on warfarin. We also found narcotics in the final model as a significant factor. These medications underscore the potential importance of anticoagulation and pain medications in predicting hospitalization. In a study of 5077 cases of hospitalization following an ED visit, investigators found that 67.0% (95% CI, 60.0-74.1) of hospitalizations directly resulted from 4 drug classes (warfarin, anti-platelet agents, insulin, and oral diabetic agents).<sup>25</sup> Many risk stratification models, including Minnesota medical tiering, PRA,<sup>4</sup> and ERA<sup>5</sup> do not incorporate use of specific medications. The clinical utility of our findings indicate possible expansion of medication therapy management, which is an important part of the Medicare part D program.<sup>26</sup>

Other factors included in the final model possess biological plausibility. Many patients did not have elec-

**Table 4.** Comparison of Characteristics of High-Risk Patients Identified by Minnesota Medical Tiering Model Only, Enhanced Model Only, and Both Models

	Enhanced Model Patients Only (N = 1324)	Tier Model Patients Only (N = 1324)	Enhanced and Tier Model Patients (N = 2648)
ED or hospitalization in 2011	640 (48.3%)	402 (30.4%)	1042 (39.4%)
Female	962 (72.7%)	796 (60.1%)	1758 (66.4%)
Age group, years			
18-29	418 (31.6%)	40 (3.0%)	458 (17.3%)
30-39	248 (18.7%)	99 (7.5%)	347 (13.1%)
40-49	113 (8.5%)	172 (13.0%)	285 (10.8%)
50-59	133 (10.0%)	287 (21.7%)	420 (15.9%)
60-69	69 (5.2%)	307 (23.2%)	376 (14.2%)
≥70	343 (25.9%)	419 (31.6%)	762 (28.8%)
BMI			
Underweight	20 (1.5%)	8 (0.6%)	28 (1.1%)
Normal	299 (22.6%)	297 (22.4%)	596 (22.5%)
Overweight	323 (24.4%)	418 (31.6%)	741 (28.0%)
Obese 1	201 (15.2%)	313 (23.6%)	514 (19.4%)
Obese 2	130 (9.8%)	132 (10.0%)	262 (9.9%)
Obese 3	138 (10.4%)	87 (6.6%)	225 (8.5%)
Unknown	213 (16.1%)	69 (5.2%)	282 (10.6%)
Married	653 (49.3%)	980 (74.0%)	1633 (61.7%)
No insurance or presence of Medicaid	760 (57.4%)	379 (28.6%)	1139 (43.0%)
Prior emergency visits			
No prior ED visits	224 (16.9%)	1202 (90.8%)	1426 (53.9%)
1 prior ED visit	544 (41.1%)	119 (9.0%)	663 (25.0%)
≥2 prior ED visits	556 (42.0%)	3 (0.2%)	559 (21.1%)
Prior hospitalizations			
No prior visits	738 (55.7%)	875 (66.1%)	1613 (60.9%)
1 prior visit	241 (18.2%)	358 (27.0%)	599 (22.6%)
≥2 prior visits	345 (26.1%)	91 (6.9%)	436 (16.5%)
≥3 specialists seen	592 (44.7%)	772 (58.3%)	1364 (51.5%)
MN tier score			
Tier 1 (1-3 conditions)	226 (17.1%)	0 (0.0%)	226 (8.5%)
Tier 2 (4-6 conditions)	1098 (82.9%)	0 (0.0%)	1098 (41.5%)
Tier 3 (7-9 conditions)	0 (0.0%)	1271 (96.0%)	1271 (48.0%)
Tier 4 (≥10 conditions)	0 (0.0%)	53 (4.0%)	53 (2.0%)
Depression	448 (33.8%)	179 (13.5%)	627 (23.7%)
Substance-related disorders	130 (9.8%)	9 (0.7%)	139 (5.2%)
Narcotic	1070 (80.8%)	949 (71.7%)	2019 (76.2%)
Epilepsy	42 (3.2%)	4 (0.3%)	46 (1.7%)
Hyperlipidemia	145 (11.0%)	575 (43.4%)	720 (27.2%)
Warfarin	162 (12.2%)	87 (6.6%)	249 (9.4%)

BMI indicates body mass index; ED, emergency department; MN, Minnesota.

tronically retrievable BMI assessments; however, those patients were significantly less likely to have hosp/ED. Patients with obese BMI experienced significantly increased risk of hosp/ED. In a study of 20,985 type 1 diabetics, obesity increased hospitalization rates with a hazard ratio of 2.90 (95% CI, 1.92-4.37) for BMI ≥35 kg/m<sup>2</sup> compared with normal BMI.<sup>27</sup> Lack of insurance or presence of Medicaid coverage placed the patient at risk of hosp/ED. A recent meta-analysis indicated that having no insurance and low socioeconomic status increased readmission rates.<sup>28</sup> Improving access to care as well as providing community support may be important practice measures in treating patients with Medicaid or no insurance.

### Limitations

There are inherent weaknesses and challenges to this study. For example, it is possible that we missed some outcomes because some patients may seek care outside of the academic healthcare medical system. The predictor variables—demographics, comorbidities, medications, prior utilization, and BMI—should be readily obtainable from clinical and administrative sources. However, generalizability of our model could be limited in that not every healthcare system may have all variables readily available. There are some potential biases with self-report and potential for miscoded or missing data. Despite these limitations, the utility of administrative indexes to identify potentially high-risk individuals is very high. The clinical applications of previous administrative indexes have been seen within our institution.<sup>5</sup> Lastly, the generalizability of our findings may be limited as Olmsted County has a largely white and educated population.<sup>29</sup>

### CONCLUSIONS

The enhanced model identifies a large subset of high-risk individuals not easily identified by comorbid health burden alone. Some factors significant in the pre-

diction model can be modified and other factors can possibly be addressed with specific actions. Future work will focus on identifying high-risk individuals with characteristics that may be modified by aspects of care coordination models. In particular, further studies or clinical models could include medication management, care transitions after hospitalization, and new models of co-management of mental health conditions. Mental health professionals and pharmacists could have expanded roles on care management teams. The potential to individualize the care model for high-risk patients increases with the enhanced model.

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