

# Which Patients Are Persistently High-Risk for Hospitalization?

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The development of advanced healthcare analytics allows large healthcare organizations to use risk stratification as a population management strategy to proactively identify patients at high risk for poor health outcomes. These high-risk patients may benefit from customized interventions with the goals of improving outcomes and providing healthcare more efficiently.<sup>1</sup> Risk stratification or risk prediction tools are often based on historical administrative claims and utilization data.<sup>2</sup> However, the stability of risk estimates over time is uncertain. Programs that target patients identified as being high-risk at one point in time do not take into account the dynamic nature of changing risk over time; therefore, such programs may vary in effectiveness across patients.<sup>1</sup> Different clinical interventions may be indicated for patients who are persistently versus temporarily high-risk.<sup>3-5</sup>

Studies have supported the notion that many high-cost, high-needs patients are just temporarily high-risk.<sup>3-5</sup> Documented predictors of hospital and emergency department (ED) utilization include schizophrenia, homelessness, opioid prescriptions, depression, substance use, social isolation, and heart failure.<sup>6-8</sup> However, little information exists to characterize patients who remain persistently high-risk for hospitalization. Prediction of persistent high risk over time may enhance risk stratification as a population management strategy and inform efforts to target and tailor resource-intensive clinical interventions.

The Veterans Health Administration (VHA) incorporated risk stratification measures into practice nationally in 2012. It reports weekly estimates of the probability of patient hospitalization in the next 90 days for the entire primary care patient population for use by primary care teams to inform clinical decision making.<sup>9-11</sup> We aimed to inform population management programs for high-risk patients<sup>12</sup> by following a cohort of high-risk patients over a 2-year period. Our objectives were to identify and describe groups of high-risk patients with distinct longitudinal risk score patterns and identify baseline characteristics that predicted which patients were likely to remain high-risk over time.

## ABSTRACT

**OBJECTIVES:** Many healthcare systems use prediction models to estimate and manage patient-level probability of hospitalization. Patients identified as high-risk at one point in time may not, however, remain high-risk. We aimed to describe subgroups of patients with distinct longitudinal risk score patterns to inform interventions tailored to patients' needs.

**STUDY DESIGN:** Retrospective national cohort study.

**METHODS:** Using a previously validated prediction algorithm, we identified a cohort of 258,759 patients enrolled in the Veterans Health Administration (VHA) who were in the top 5% of risk for hospitalization within 90 days. During each of the following 24 months, patients were placed in 1 of 6 categories: death, hospitalized, no VHA care, persistently high-risk for hospitalization ( $\geq 10\%$  probability), initially high-risk then persistently low-risk ( $< 10\%$  probability), and intermittently high-risk. We used multivariable logistic regression to identify characteristics predictive of being persistently high-risk through the last study month.

**RESULTS:** After 2 years, 17.7% had died, 13.8% had remained persistently high-risk for hospitalization, 41.5% had become persistently low-risk, and 19.9% were intermittently high-risk. Predictors of being persistently high-risk included urban residence, chronic medical comorbidities, auditory and visual impairment, chronic pain, any cancer diagnosis, and social instability.

**CONCLUSIONS:** Few patients who were high-risk for hospitalization at baseline remained so. Nonrandomized evaluations of interventions that identify patients based on a single high-risk score may spuriously appear to have positive effects. Clinical interventions may need to focus on individuals who are persistently high-risk.

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## METHODS

### Data Sources

Data for this study were obtained from the VHA Corporate Data Warehouse, which included patient demographics, clinical diagnoses, admission and discharge status, patient risk scores, and utilization records.<sup>13</sup> We also obtained data from the VHA Vital Status file to ascertain patients' dates of death.

### Study Sample

We identified a national cohort of 258,759 patients who had a 10% or greater absolute probability of 90-day hospitalization on our index date (November 23, 2012), were assigned to a VHA primary care provider, and were not hospitalized in the VHA on the index date, because risk scores are not generated for hospitalized patients. We followed patients for 2 years after the index date.

### Measurement of Risk

We obtained patients' monthly risk using the predicted probability of hospitalization in the next 90 days in the Care Assessment Need (CAN) model, a validated risk prediction algorithm.<sup>9</sup> The CAN model (eAppendix Table 1 [eAppendix available at [ajmc.com](http://ajmc.com)]) uses demographics, utilization of VHA health services, comorbidities, prescribed medications, vital signs, and veteran-specific variables.<sup>9</sup>

Risk scores were generated on a weekly basis for all patients in VHA primary care. Patient-month measures of risk were calculated

## TAKEAWAY POINTS

Many patients identified as high-risk for near-term hospitalizations using a risk prediction model at baseline did not remain high-risk over a 2-year period.

- ▶ After 2 years, just 14% remained persistently high-risk for hospitalization. Of the remainder, 20% were intermittently high-risk, 42% became persistently low-risk, and 18% had died.
- ▶ Predictors of being persistently high-risk included age, gender, urban residence, chronic pain, any cancer diagnosis, chronic medical comorbidities, and social instability.
- ▶ Nonrandomized evaluations of interventions that target patients based on a single high-risk score may spuriously appear to improve patient outcomes due to natural decreasing risk over time.

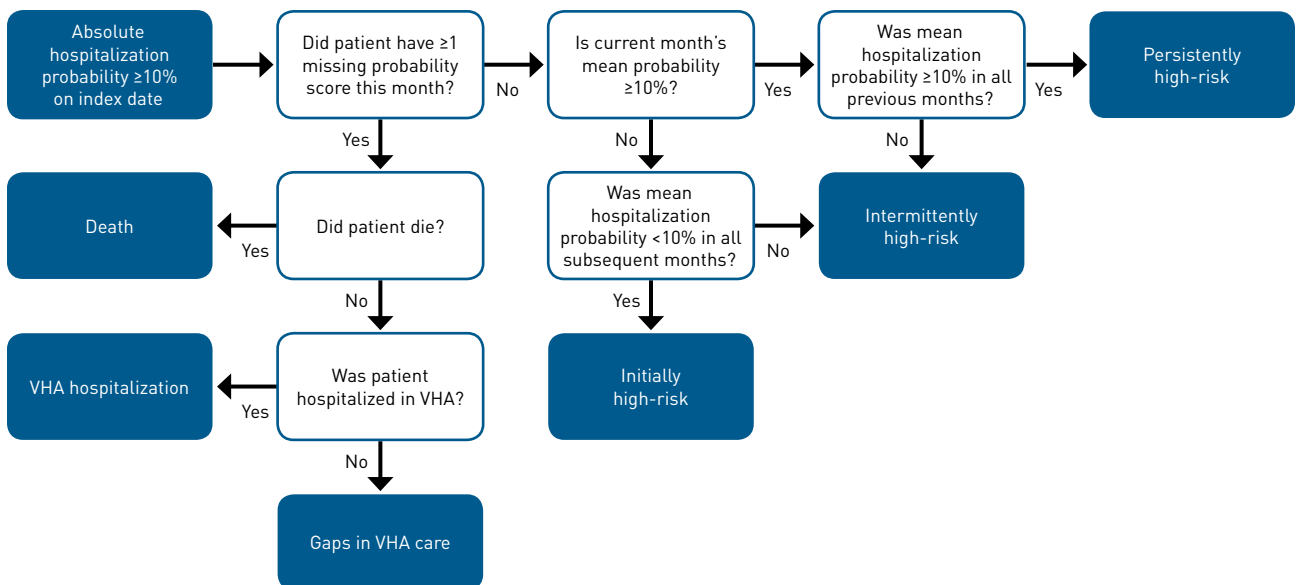
as the mean of weekly probabilities for that calendar month, and missing values occurred when veterans were hospitalized (including acute care, residential treatment facility admission, nursing home admission, or hospice admission) or dropped out of VHA care.

### Dependent Variables

We defined patients as "high-risk" if the probability of 90-day hospitalization was 10% or greater, which corresponds to approximately the top 5% of VHA patients (n = 258,759). Our main dependent variable was a patient-month measure of risk persistence, defined hierarchically (Figure 1).

Patients with at least 1 missing CAN probability in a calendar month were categorized into 1 of the following mutually exclusive outcomes: death, hospitalization in VHA, or dropped out of VHA care (no VHA encounters in previous 24 months). By definition, patients can move into and out of the "hospitalization" or "dropped

**FIGURE 1.** Process Map of Monthly Categorization of High-Risk Patients in VHA\*



VHA indicates Veterans Health Administration.

\*All patients except those who had died were recategorized the following month.

out of care” categories. All patients except those who died were recategorized the following month.

We categorized patients with nonmissing CAN scores as persistently high-risk, intermittently high-risk, or initially high-risk then persistently low-risk for every month based on all patient-month observations in the study period. Patient-month observations were coded as “persistently high-risk” if hospitalization probability was 10% or greater during the current month and all prior months. “Initially high-risk” was defined as probability less than 10% during all subsequent months. “Intermittently high-risk” was defined as having a combination of high ( $\geq 10\%$ ) and low ( $< 10\%$ ) hospitalization risk across the months and not meeting the criteria for persistently high-risk or initially high-risk. These categorizations ignore the patient-months designated as “hospitalization” or “dropped out of care.” By definition, patients can only move out of the persistently high-risk group, patients can only move into the initially high-risk group, and patients may move into or out of the intermittently high-risk group.

### Patient Characteristics and Utilization

We examined patient characteristics measured at baseline: demographics (age, gender, marital status, ethnicity, urban vs rural residence), medical and psychiatric comorbidities, any cancer diagnosis, and markers of social instability.<sup>14</sup> Markers of social instability included discharges against medical advice<sup>4</sup>; number of zip code changes in the year prior<sup>4</sup>; *International Classification of Diseases, Ninth Revision (ICD-9)* diagnosis of nonadherence to medical treatment; and homelessness. Homelessness was measured by use of housing services<sup>15</sup> or *ICD-9* diagnosis codes indicating lack of housing. *ICD-9* diagnoses for comorbidities were adapted from previously published research<sup>16</sup> and from the VHA Health Economics Resource Center<sup>17</sup> ([eAppendix Table 2](#)). Numbers of hospitalizations and outpatient visits and no-show rates were calculated from the index date over the subsequent 2 years. No-shows were recorded for each instance in which a patient did not arrive to a scheduled appointment.<sup>18</sup>

For outpatient visits during the follow-up period, we counted VHA encounters that occurred face-to-face or by telephone with any healthcare provider (eg, physician, nurse, psychologist). We categorized outpatient visits based on the specific type of service (ie, primary care, mental health, palliative care, ED).<sup>19</sup> Mental health visits included primary care–mental health integration encounters.<sup>20</sup> Inpatient admissions were categorized into medical, surgical, and psychiatric admissions.<sup>19</sup>

### Analyses

Our dependent variable in bivariable and multivariable analyses was the patient’s risk category (ie, persistently high, intermittently high, or initially high) in the final study month ( $n = 194,597$ ). We used analysis of variance to examine whether there were differences in means among the continuous variables (inpatient/outpatient utilization, ED visits, and zip code changes) across the high-risk

categories. In bivariable analyses, we performed ordered logit regression to estimate a single equation for each independent variable over the 3 ordered levels of the dependent variable: persistently, intermittently, and initially high-risk. Proportional odds ratios (ORs) were generated from the ordered logit models to estimate the change in odds in each predictor for patients at (1) persistently high-risk versus intermittently high-risk and (2) intermittently high-risk versus initially high-risk.

We performed multivariable logistic regression to predict being persistently high-risk versus the other 2 groups after adjusting for independent variables found to be statistically significant ( $P < .05$ ) from the ordered logit regression analyses described previously. Model covariates included age, gender, and race/ethnicity, and we excluded variables used to calculate the CAN probabilities ([eAppendix Table 1](#)).

For continuous independent variables that are not normally distributed (ie, number of discharges against medical advice, palliative care encounters, mental health visits, and zip code changes), we applied a log (base 10) transformation to create a less skewed distribution. As a result, one would need to have a 10-fold increase in the independent variables to achieve the ORs indicated for the transformed variables.

Because the ordered logit model assumes proportional odds, we also estimated a generalized ordered logistic regression in sensitivity analysis. This model estimates ORs for variables that violate the proportional odds assumption separately for each comparison.<sup>21</sup> OR estimates from the generalized ordered logit model were of similar size and significance as those from the ordered logit model ([eAppendix Table 3](#)). In sensitivity analyses, we also used a multinomial logit model to compare patients who were persistently high-risk with those who were intermittently high-risk and to compare those who were persistently high-risk with those who were initially high-risk. Directionality and significance were similar to the ordered logit model ([eAppendix Table 4](#)).

We conducted stratified analyses by age group ( $\geq 65$  years and  $< 65$  years) to examine whether there were differences in risk patterns between VHA enrollees eligible for Medicare and younger veterans; results were similar for both age groups ([eAppendix Table 5](#)), so we report only the combined results.

Analyses were conducted with SAS version 9.4 (SAS Institute Inc; Cary, North Carolina) and SAS Enterprise Miner.

### Institutional Review Board

This evaluation was designed to support VHA operations and quality improvement for the VHA Offices of Primary Care and Clinical Systems Development and Evaluation and was exempt from institutional review board approval or waiver.<sup>22,23</sup>

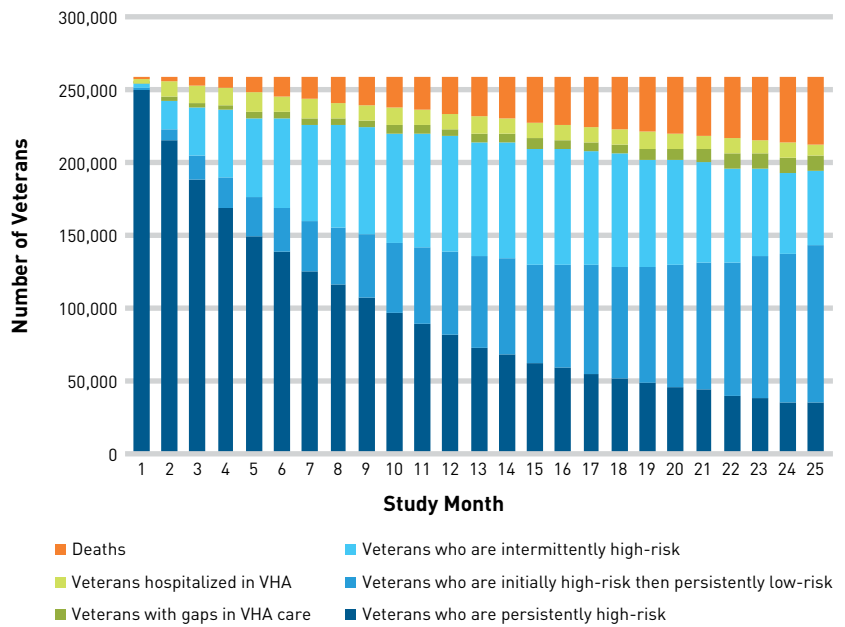
## RESULTS

[Figure 2](#) shows the monthly risk status of the high-risk patient cohort over a 24-month period (quantitative results in [eAppendix](#)

**Table 6).** After 1 year, 28.6% (n = 74,060) were persistently high-risk for hospitalization, 10.3% (n = 26,541) had died, 23.8% (n = 61,556) were initially high-risk for hospitalization, and 30.6% (n = 79,078) were intermittently high-risk for hospitalization. By the end of the 2-year period, just 13.8% (n = 35,770) remained persistently high-risk for hospitalization; 17.7% (n = 45,805) had died, 41.5% (n = 107,473) were initially high-risk, and 19.9% (n = 51,354) were intermittently high-risk, and the remaining 7.1% (n = 18,357) were hospitalized or left VHA care at study end.

Patients who were older than 45 years, male, unmarried, black, and living in an urban area had greater odds of being persistently high-risk for hospitalization (vs intermittently high-risk) and of being intermittently high-risk for hospitalization (vs initially high-risk) (Table 1). Patients with nearly all medical and mental comorbidities had greater odds of being persistently or intermittently high-risk for hospitalization. The largest differences between the risk categories were found with congestive heart failure (OR, 2.60; 95% CI, 2.55-2.65), chronic kidney disease (OR, 2.48; 95% CI,

**FIGURE 2.** Monthly<sup>a</sup> Risk Status of Patients Who Had a 10% or Greater Absolute Probability of 90-Day Hospitalization on Index Date (N = 258,759)<sup>b</sup>



VHA indicates Veterans Health Administration.  
<sup>a</sup>Each study month constituted the calendar month from November 23, 2012, to November 22, 2014. The first and last months had partial weekly Care Assessment Need probabilities.  
<sup>b</sup>The corresponding quantitative results can be reviewed in eAppendix Table 6.

**TABLE 1.** ORs Using Ordered Logistic Regression Among Persistently High-Risk, Intermittently High-Risk, and Initially High-Risk Patients, Unadjusted<sup>a</sup>

	Persistently High-Risk (n = 35,770)		Intermittently High-Risk (n = 51,354)		Initially High-Risk (n = 107,473)		OR Estimate <sup>b</sup>	Lower CL	Upper CL
	n	%	n	%	n	%			
<b>Demographics</b>									
<b>Age in years</b>									
<45	1051	2.9	1952	3.8	6785	6.3	Ref	Ref	Ref
45-65	17,521	49.0	23,560	45.9	49,116	45.7	1.91	1.83	2.00
>65	17,199	48.1	25,842	50.3	51,569	48.0	1.87	1.79	1.96
<b>Gender</b>									
Female	2079	5.8	3278	6.4	7517	7.0	Ref	Ref	Ref
Male	33,692	94.2	48,076	93.6	99,954	93.0	1.16	1.12	1.20
<b>Marital status</b>									
Married	10,364	29.0	17,426	33.9	38,438	35.8	Ref	Ref	Ref
Unmarried	25,407	71.0	33,928	66.1	69,033	64.2	1.22	1.20	1.24
<b>Ethnicity</b>									
White, non-Hispanic	20,653	62.8	31,139	65.7	66,776	67.7	Ref	Ref	Ref
Black, non-Hispanic	8668	26.4	11,508	24.3	22,008	22.3	1.19	1.17	1.22
Hispanic	2140	6.5	2930	6.2	6102	6.2	1.08	1.04	1.13
Other	1427	4.3	1852	3.9	3786	3.8	1.14	1.09	1.19
<b>Rural/highly rural</b>									
Rural/highly rural	8976	25.1	14,695	28.7	33,201	31.2	0.81	0.80	0.83
Urban	26,743	74.9	36,585	71.3	73,153	68.8	Ref	Ref	Ref

(continued)

**TABLE 1.** (Continued) ORs Using Ordered Logistic Regression Among Persistently High-Risk, Intermittently High-Risk, and Initially High-Risk Patients, Unadjusted<sup>a</sup>

	Persistently High-Risk (n = 35,770)		Intermittently High-Risk (n = 51,354)		Initially High-Risk (n = 107,473)		OR Estimate <sup>b</sup>	Lower CL	Upper CL
	n	%	n	%	n	%			
<b>Medical and Behavioral Comorbidities</b>									
Hypertension	31,161	87.1	42,959	83.7	80,919	75.5	1.86	1.82	1.90
Diabetes	20,813	58.2	26,796	52.2	45,853	42.7	1.63	1.60	1.66
Asthma or COPD	19,611	54.8	23,396	45.6	33,064	30.8	2.19	2.15	2.23
Congestive heart failure	15,299	42.8	15,888	30.9	19,136	17.8	2.60	2.55	2.65
Coronary artery disease	16,499	46.1	20,916	40.7	32,192	30.0	1.74	1.71	1.77
Cancer	10,262	28.7	13,150	25.6	21,646	20.2	1.45	1.42	1.48
Chronic kidney disease	3656	10.2	3196	6.2	3636	3.4	2.48	2.39	2.58
Depression	21,207	59.3	26,772	52.1	48,014	44.8	1.54	1.51	1.57
Anxiety	10,529	29.8	12,437	24.5	22,508	21.2	1.39	1.36	1.41
Bipolar disorder	4292	12.0	5116	10.0	8799	8.2	1.37	1.34	1.41
Schizophrenia	3758	10.5	3891	7.6	6253	5.8	1.61	1.56	1.66
Dementia	5963	16.7	6236	12.1	8357	7.8	1.95	1.90	2.00
Alcohol abuse	10,856	30.4	12,878	25.1	20,633	19.3	1.59	1.56	1.62
Tobacco use disorder	15,096	42.2	19,574	38.1	35,121	32.8	1.36	1.34	1.39
Visual impairment	2882	8.1	3390	6.6	5209	4.9	1.52	1.47	1.58
Hearing impairment	10,637	29.7	14,383	28.0	25,387	23.7	1.29	1.26	1.31
Chronic pain	4280	12.0	4258	8.3	6116	5.7	1.85	1.79	1.91
Neck and back pain	22,171	62.0	29,712	57.9	53,453	49.9	1.48	1.45	1.51
Headache	6719	18.8	7918	15.4	12,837	12.0	1.50	1.47	1.54
Arthritis	24,921	69.7	33,517	65.3	60,818	56.7	1.56	1.53	1.58
<b>Utilization</b>									
Any VHA ED visits in 2 years	33,216	92.9	44,260	86.2	61,310	57.1	6.09	5.94	6.24
Any VHA hospitalizations in 2 years	31,959	89.3	38,522	75.0	44,117	41.1	6.27	6.14	6.40
<b>Markers of Social Instability</b>									
Homelessness	4519	12.6	5354	10.4	8911	8.3	1.60	1.54	1.66
Nonadherence	4541	12.7	3931	7.7	4737	4.4	2.42	2.34	2.50
	Mean (SD)		Mean (SD)		Mean (SD)		OR Estimate <sup>b</sup>	Lower CL	Upper CL
Number of zip code changes in 2 years	1.76 (1.25)		1.63 (1.11)		1.47 (0.93)		1.21	1.20	1.22
	%		%		%		OR Estimate <sup>b</sup>	Lower CL	Upper CL
Outpatient visits as no-shows, median	13.8		12.1		12.0		0.98	0.92	1.04
Patients with 0 no-shows in 2 years	1.6		4.2		10.3		0.27	0.26	0.28

CL indicates confidence limit; COPD, chronic obstructive pulmonary disease; ED, emergency department; OR, odds ratio; ref, reference; VHA, Veterans Health Administration.

<sup>a</sup>All variables except for rate of no-shows are statistically significant ( $P < .05$ ) using unadjusted ordered logistic regression model.

<sup>b</sup>Changes in odds when comparing the persistently high-risk group with the intermittently high-risk group or comparing the intermittently high-risk group with the initially high-risk group are statistically significant ( $P < .05$ ) for all characteristics. High risk is 10% or greater probability of risk for hospitalization in the next 90 days.

2.39-2.58), and dementia (OR, 1.96; 95% CI, 1.90-2.00). Patients with social instability, such as discharges against medical advice, number of zip code changes, and diagnoses of nonadherence, had greater odds of being both persistently and intermittently high-risk for hospitalization. Median no-show rates in a given year were similar for all risk categories.

Patients who were persistently high-risk for hospitalization were more likely than those who were intermittently high-risk or

initially high-risk to have a VHA hospitalization (89%, 75%, and 41%, respectively) or ED visit (93%, 86%, and 57%, respectively) during the follow-up period (Table 2). Also, persistently high-risk patients had more frequent VHA hospitalizations per year than the initially high-risk group, with a mean (SD) of 1.9 (3.5) hospitalizations per year; most (1.5 [3.1]) of these admissions were medical.

Patients who were persistently high-risk for hospitalization also had higher rates of outpatient utilization: They had a mean (SD) of

83.2 (81.2) total VHA outpatient encounters (telephone and in-person visits) per year, almost double the number of outpatient encounters per year among patients who were only initially high-risk for hospitalization (Table 2). Persistently high-risk patients had a mean (SD) of 10.6 (15.9) encounters in primary care, 18.1 (64.9) encounters in mental health, and 0.1 (1.9) encounters in palliative care per year. In contrast, patients who were only initially high-risk for hospitalization had, on average, 44.4 (58.4) outpatient encounters per year, 6.7 (11.0) in primary care, 9.5 (41.1) in mental health, and 0.02 (0.8) in palliative care. Intermittently high-risk patients had mean utilization in between the persistently high-risk and initially high-risk groups.

In multivariable analyses, we identified 20 statistically significant ( $P < .05$ ) predictors of being persistently high-risk for hospitalization, including age, gender, urban residence, visual and hearing impairment, chronic pain (back and neck pain, arthritis, and headache), chronic medical comorbidities (chronic kidney disease, coronary artery disease, congestive heart failure, diabetes, hypertension, and nicotine use), number of visits to palliative care, cancer diagnosis, number of mental health visits, and all markers of social instability (Table 3).

## DISCUSSION

In this study, we examined the patterns of risk status over time among a population of high-risk patients receiving continuous VHA care. Consistent with findings of prior research on costs and readmissions,<sup>3,24</sup> the majority of these patients did not remain persistently high-risk during 2 years of follow-up; just 29% were persistently high-risk after 1 year, and 14% remained persistently high-risk after 2 years. Almost half (42%) were classified as being persistently low-risk by study end.

These findings may partly explain seemingly positive results from interventions that enroll patients who are high-risk at baseline but that report pre–post findings without a comparison group. The improvement in patient outcomes could, in fact, be due to naturally decreasing risk over time rather than due to the intervention itself. Several randomized studies of care management interventions for high-need, high-cost patients have found no differences in cost and utilization between intervention and usual-care groups.<sup>25–27</sup>

We found significant and meaningful differences in socio-demographics, clinical comorbidities, and utilization among the 3 trajectory groupings of high-risk patients. The presence of chronic medical or behavioral conditions (particularly heart failure and chronic kidney disease), a nonadherence diagnosis, and higher VHA utilization rates were associated with greater

duration of remaining persistently high-risk for hospitalization, which indicates that programs for high-risk patients can focus efforts on patients with these characteristics. Persistently and intermittently high-risk patients used a remarkable amount of VHA services—as many as an average of 63 to 83 outpatient visits and 0.9 to 1.9 admissions per year—suggesting that they were actively engaged with ambulatory care providers. Some acute care may be unavoidable despite high utilization of outpatient services, especially for patients who rapidly decompensate or cannot be managed effectively with ambulatory care alone.<sup>28</sup> Persistently high-risk patients were more likely to live in urban areas, but many (30%) lived in rural areas, indicating that smaller, rural community clinics or virtual care modalities may have an important role to play in mitigating risk for these patients.

Our results confirm published findings described in other predictive models for high utilization, readmission, and mortality: Age, gender, number of zip code changes, number of discharges against medical advice,<sup>6,7,29</sup> frequent use of outpatient medical and mental health services,<sup>6</sup> chronic pain,<sup>6</sup> nonadherence, and tobacco use<sup>29</sup> significantly predicted long-term persistence of high risk. Other known predictors of high utilization (eg, socioeconomic status, depression, alcohol use disorder, marital status) were not included in our model due to endogeneity. Unlike previous studies, we report that hearing and visual impairment, cancer diagnosis, and palliative care utilization were also predictors of patients being persistently high-risk. Interestingly, unlike prior studies<sup>6,29</sup> that preceded the VHA comprehensive primary care teams for homeless patients,<sup>30</sup> our findings show that homeless patients who used housing support services were less likely to be persistently high-risk. It is possible

**TABLE 2.** Inpatient and Outpatient Utilization Rates Observed Over a 2-Year Period Among Persistently High-Risk, Intermittently High-Risk, and Initially High-Risk Patients, Unadjusted<sup>a</sup>

	Persistently High-Risk (n = 35,770)	Intermittently High-Risk (n = 51,354)	Initially High-Risk (n = 107,473)	P
ED visits per year, mean (SD)	3.6 (7.2)	1.9 (4.3)	0.8 (2.7)	<.0001
Discharges against medical advice per year, mean (SD)	0.1 (0.5)	0.0 (0.3)	0.0 (0.2)	<.0001
Total hospitalizations per year, mean (SD)	1.9 (3.5)	0.9 (1.9)	0.3 (1.2)	<.0001
Medical, mean (SD)	1.5 (3.1)	0.7 (1.6)	0.2 (1.0)	<.0001
Surgical, mean (SD)	0.2 (0.7)	0.1 (0.5)	0.1 (0.4)	<.0001
Psychiatric, mean (SD)	0.2 (1.3)	0.1 (0.7)	0.0 (0.4)	<.0001
Outpatient visits <sup>b</sup> per year, mean (SD)	83.2 (81.2)	63.1 (67.8)	44.4 (58.4)	<.0001
Primary care, mean (SD)	10.6 (15.9)	8.8 (13.0)	6.7 (11.0)	<.0001
Mental health, <sup>c</sup> mean (SD)	18.1 (64.9)	13.0 (51.2)	9.5 (41.1)	<.0001
Palliative care, mean (SD)	0.1 (1.9)	0.1 (1.2)	0.0 (0.8)	<.0001

ED indicates emergency department.

<sup>a</sup>All characteristics are significantly different across the 3 levels of risk (persistently high-risk, intermittently high-risk, and initially high-risk) using analysis of variance.

<sup>b</sup>Includes both in-person and telephone encounters.

<sup>c</sup>Includes both mental health and primary care–mental health integration encounters.



**TABLE 3.** Predictors of Patients Being Persistently High-Risk (compared with intermittently high-risk and initially high-risk) (n = 35,770)<sup>a</sup>

Predictor	Estimate	Standard Error	OR Estimate
Coronary artery disease	0.09	0.01	1.21**
Congestive heart failure	0.51	0.01	2.75**
Chronic kidney disease	0.45	0.02	2.47**
Hypertension	0.17	0.01	1.40**
Diabetes	0.19	0.01	1.47**
Chronic pain	0.18	0.01	1.44**
Back and neck pain	0.11	0.01	1.25**
Headache	0.18	0.01	1.43**
Arthritis	0.13	0.01	1.31**
Nonadherence	0.31	0.01	1.85**
Cancer	0.26	0.01	1.69**
Tobacco use disorder	0.18	0.01	1.45**
Visual impairment	0.14	0.02	1.31**
Hearing impairment	0.05	0.01	1.12**
Reside in urban area	0.11	0.01	1.24**
Homeless	-0.07	0.02	0.86**
Number of discharges against medical advice <sup>b</sup>	2.82	0.11	16.84**
Number of palliative care encounters <sup>b</sup>	1.76	0.07	5.81**
Number of visits to mental health <sup>b</sup>	0.62	0.01	1.87**
Number of zip code changes <sup>b</sup>	0.92	0.07	2.52**
Age	0.01	0.0009	1.01**
Gender (male vs female)	0.10	0.02	1.23**
White, non-Hispanic (vs Hispanic)	-0.05	0.02	0.92*
Black, non-Hispanic (vs Hispanic)	0.01	0.02	0.98
Other race (vs Hispanic)	0.01	0.03	0.98
Intercept	-2.29	0.08	-

OR indicates odds ratio.

\**P* < .01; \*\**P* < .001.

<sup>a</sup>Analysis conducted using a logistic regression model, adjusted for age, gender, and race/ethnicity.

<sup>b</sup>Due to the log[10] transformation of the independent variable, a 10-fold increase in the independent variable is needed to produce the OR effect.

that VHA programs that address housing instability were able to effectively change the duration for which a patient is high-risk.

Developing effective programs for high-risk patients has proved challenging because most randomized trials in this area have not shown improvement in outcomes.<sup>26,31,32</sup> One possibility is that high-risk patients are so heterogeneous that a one-size-fits-all approach may not be effective. Different clinical interventions may be more suitable for patients who are persistently high-risk versus those who are only initially or intermittently high-risk or for patients with various combinations of factors that predict risk.<sup>33,34</sup> For instance, persistently high-risk patients may benefit from longitudinal primary care programs tailored for specific vulnerable populations (eg, primary care for homeless, homebound, or elderly patients; those receiving dialysis; those with chronic pain or serious mental illness); other high-risk patients may benefit from

time-limited care management models that augment primary care, such as collaborative care models for high-needs patients.<sup>26,35</sup> Large healthcare systems may find it helpful to use empiric clustering models to further distinguish subgroups of high-risk patients based on clinical characteristics.<sup>4,5,36,37</sup>

Our findings suggest ways to tailor care management interventions for patients with sustained needs. Although the extent to which a patient’s underlying risk for hospitalization is modifiable remains unclear, evidence-based practices can be implemented to possibly reduce a patient’s risk for hospitalization. For instance, interventions to target housing instability, such as the Housing First model, may reduce a patient’s risk for future hospitalization.<sup>30</sup> Healthcare teams who target persistently high-risk patients could include behavioral health specialists familiar with managing treatment nonadherence, holistic approaches to chronic pain, and guideline-concordant care for ambulatory care-sensitive conditions (eg, congestive heart failure, diabetes, hypertension). Comprehensive assessments could identify depression and patient factors underlying nonadherence and social instability in high-risk patients and then prioritize which patients should receive the most intensive interventions to reduce future risk. Future studies could examine whether intervening on predictors of persistent high risk is effective in changing a patient’s risk trajectory.

**Limitations**

Measures of socioeconomic status, including income, employment status, and education status, were likely predictors of risk persistence, but they were not included due to lack of availability in VHA administrative data.<sup>29</sup> To avoid a problem in tautology, we excluded VHA risk prediction model variables (eg, mental health conditions, cognitive impairment) from our model to predict whether or not patients remain at high risk. However, we do report some clinical characteristics not included in the risk prediction model that contribute to hospitalization risk, such as chronic pain conditions, markers of social instability, and sensory impairments. Lastly, our sample is limited to the VHA population, which includes veterans who are less likely to have childhood-onset medical conditions due to military medical eligibility, are more likely to have psychiatric conditions, and may use services in multiple healthcare settings, not just the VHA.<sup>38</sup> We were unable to draw from non-VHA data sources for this analysis to account for healthcare services that were not paid by the VHA. Although the actual percentage of persistently high-risk patients might differ by payer,<sup>39</sup> the overall patterns are likely to be similar.

**CONCLUSIONS**

Because most high-risk patients may be only briefly high-risk for hospitalization, nonrandomized evaluations of interventions that identify patients based on a single risk score may appear to have positive effects on patient health due to naturally decreasing risk over time in the majority of patients. Identified predictors of patients remaining persistently high-risk could inform efforts to

tailor the intensity and type of interventions to improve health for veterans with the most sustained needs. ■

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**Authorship Information:** Concept and design (ETC, ESW, AMR, SDF, JY); acquisition of data (ETC, RP); analysis and interpretation of data (ETC, RP, ESW, AMR, SV, JY); drafting of the manuscript (ETC, RP, SDF); critical revision of the manuscript for important intellectual content (ETC, RP, ESW, AMR, SDF, SV, JY); statistical analysis (ETC, RP, ESW, SV); provision of patients or study materials (ETC); obtaining funding (ETC); administrative, technical, or logistic support (ETC); and supervision (ETC).

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**eAppendix Table 1.** Care Assessment Needs (CAN) 2.0 Model Coefficients, Odds Ratios, and Associated 95% Confidence Intervals for Hospitalization 90-day Model

	Model Coefficient Hospitalization in 90 days			Odds Ratio Hospitalization in 90 days		
	Estimate	95% CI		Estimate	95% CI	
<b>Demographics</b>						
Age < 55 vs Age >= 85	-0.150	-0.176	-0.124	0.861	0.838	0.883
Age 55-64 vs Age >= 85	-0.047	-0.071	-0.024	0.954	0.932	0.976
Age 65-74 vs Age >= 85	-0.123	-0.145	-0.101	0.884	0.865	0.904
Age 75-84 vs Age >= 85	-0.120	-0.144	-0.097	0.887	0.866	0.908
Not Married vs Married	0.229	0.217	0.242	1.258	1.243	1.273
Vet Priority level 0 vs 5	-0.232	-0.259	-0.204	0.793	0.772	0.815
Vet Priority level 1 vs 5	-0.075	-0.103	-0.046	0.928	0.902	0.955
Vet Priority level 2 vs 5	-0.241	-0.271	-0.212	0.785	0.763	0.809
Vet Priority level 4 vs 5	0.042	0.000	0.085	1.043	1.000	1.088
Enlisted/Unknown vs Officer	0.370	0.311	0.429	1.448	1.365	1.535
SES Index Decile 1 vs Default/No SES Index Calculated	0.015	-0.006	0.036	1.015	0.994	1.037
SES Index Decile 2 vs Default/No SES Index Calculated	-0.039	-0.062	-0.017	0.962	0.940	0.984
SES Index Decile 3 vs Default/No SES Index Calculated	-0.043	-0.067	-0.020	0.957	0.936	0.980
SES Index Decile 4 vs Default/No SES Index Calculated	-0.082	-0.106	-0.058	0.921	0.899	0.943
SES Index Decile 5 vs Default/No SES Index Calculated	-0.107	-0.131	-0.082	0.899	0.877	0.921
SES Index Decile 6 vs Default/No SES Index Calculated	-0.106	-0.131	-0.081	0.900	0.878	0.922
SES Index Decile 7 vs Default/No SES Index Calculated	-0.140	-0.166	-0.115	0.869	0.847	0.891
SES Index Decile 8 vs Default/No SES Index Calculated	-0.119	-0.145	-0.094	0.888	0.865	0.910
SES Index Decile 9 vs Default/No SES Index Calculated	-0.154	-0.180	-0.127	0.858	0.835	0.880
SES Index Decile 10 vs Default/No SES Index Calculated	-0.181	-0.208	-0.154	0.835	0.812	0.858
<b>Vital Signs</b>						
Body Mass Index: 0/Unknown vs > 40	0.420	0.353	0.487	1.522	1.423	1.627
Body Mass Index: 16 <= BMI <= 40 vs > 40	0.040	0.016	0.064	1.040	1.016	1.066
Coefficient of Variation for Weight: <= 4 vs > 4	-0.133	-0.145	-0.120	0.876	0.865	0.887
Most Recent Pulse Vital Measurement prior 1 year: < 60 vs >= 90	-0.286	-0.309	-0.263	0.751	0.734	0.769
Most Recent Pulse Vital Measurement prior 1 year: 60 <= pulse < 90 or Unknown vs >= 90	-0.212	-0.227	-0.197	0.809	0.797	0.821
Most Recent Systolic Blood Pressure Measurement prior 1 year: < 110 vs >= 160	-0.152	-0.181	-0.123	0.859	0.834	0.884
Most Recent Systolic Blood Pressure Measurement prior 1 year: 110 <= syst < 140 or Unknown vs >= 160	-0.255	-0.279	-0.231	0.775	0.756	0.794
Most Recent Systolic Blood Pressure Measurement prior 1 year: 140 <= syst < 160 vs >= 160	-0.153	-0.180	-0.127	0.858	0.835	0.881

	Model Coefficient			Odds Ratio		
	Estimate	Hospitalization in 90 days 95% CI		Estimate	Hospitalization in 90 days 95% CI	
<b>Medical and Psychiatric Comorbidities</b>						
Charlson-Deyo Mortality Score: 0 vs > 4	-0.390	-0.413	-0.367	0.677	0.661	0.693
Charlson-Deyo Mortality Score: 1 vs > 4	-0.311	-0.333	-0.289	0.733	0.717	0.749
Charlson-Deyo Mortality Score: 2 vs > 4	-0.190	-0.213	-0.167	0.827	0.809	0.846
Charlson-Deyo Mortality Score: 3-4 vs > 4	-0.137	-0.158	-0.117	0.872	0.854	0.890
No Mental Disorder Dx & No PTSD Dx vs Mental Disorder Dx or PTSD Dx prior 1 year	-0.111	-0.126	-0.097	0.895	0.882	0.908
Mental Disorder Dx & PTSD Dx vs Mental Disorder Dx or PTSD Dx prior 1 year	-0.065	-0.082	-0.047	0.937	0.921	0.954
Alcohol Dxs prior 2 years: 0-1 vs > 1	-0.281	-0.299	-0.263	0.755	0.742	0.768
Chronic Airway Obstruction Dxs prior 2 years: 0 vs > 0	-0.144	-0.159	-0.129	0.866	0.853	0.879
No Dementia Dx vs Dementia Dx prior 1 year	-0.143	-0.166	-0.121	0.867	0.847	0.886
<b>Medications</b>						
No Antipsychotic Medication Filled prior 1 year vs Antipsychotic Med Filled	-0.167	-0.186	-0.148	0.846	0.830	0.862
No BetaBlocker Medication Filled prior 1 year vs BetaBlocker Med Filled	-0.171	-0.185	-0.158	0.842	0.831	0.854
No Furosemide Medication Filled prior 1 year vs Furosemide Med Filled	-0.203	-0.220	-0.186	0.816	0.802	0.830
No Hydroxymethylglutarly-CoenzymeA Medication Filled prior 1 year vs HMGOA Med Filled	0.092	0.079	0.105	1.097	1.083	1.111
<b>Laboratory and Radiology Measures</b>						
Most Recent Albumin Lab result prior 1 year: > 3.4 vs No Albumin Lab	-0.110	-0.126	-0.094	0.896	0.882	0.910
Most Recent Albumin Lab result prior 1 year: 0-3.4 vs No Albumin Lab	0.137	0.114	0.160	1.147	1.121	1.173
Low Red Blood Count Labs prior 2 years: 0 vs > 9	-0.216	-0.239	-0.193	0.806	0.787	0.825
Low Red Blood Count Labs prior 2 years: 1-9 vs > 9	-0.077	-0.098	-0.055	0.926	0.906	0.946
Low Sodium Labs prior 2 years: 0 vs > 9	-0.095	-0.130	-0.060	0.909	0.878	0.941
Low Sodium Labs prior 2 years: 1 vs > 9	-0.007	-0.044	0.030	0.993	0.957	1.030
Low Sodium Labs prior 2 years: 2-4 vs > 9	-0.002	-0.039	0.034	0.998	0.962	1.035
Low Sodium Labs prior 2 years: 5-9 vs > 9	0.018	-0.023	0.058	1.018	0.978	1.060
High White Blood Cell Labs prior 2 years: 0 vs > 1	-0.146	-0.162	-0.131	0.864	0.851	0.877
High White Blood Cell Labs prior 2 years: 1 vs > 1	-0.013	-0.035	0.008	0.987	0.966	1.008
Chest Xray CPTs prior 90 days: 0 vs > 2	-0.468	-0.510	-0.426	0.626	0.601	0.653
Chest Xray CPTs prior 90 days: 1-2 vs > 2	-0.047	-0.089	-0.004	0.954	0.915	0.996
<b>Inpatient and Outpatient Utilization Measures</b>						
Hosp Stays & Bed Days of Care prior 1 year: level 0 vs 4	0.689	0.638	0.740	1.991	1.892	2.096
Hosp Stays & Bed Days of Care prior 1 year: level 1 vs 4	0.292	0.243	0.341	1.339	1.275	1.407
Hosp Stays & Bed Days of Care prior 1 year: level 2 vs 4	0.064	-0.004	0.132	1.066	0.996	1.141
Hosp Stays & Bed Days of Care prior 1 year: level 3 vs 4	0.117	0.080	0.154	1.124	1.083	1.167
All Hospital Admissions prior 1 year: 0 vs > 2	-1.238	-1.283	-1.192	0.290	0.277	0.304
All Hospital Admissions prior 1 year: 1 vs > 2	-0.613	-0.656	-0.570	0.542	0.519	0.566
All Hospital Admissions prior 1 year: 2 vs > 2	-0.360	-0.392	-0.328	0.698	0.676	0.720

	Model Coefficient			Odds Ratio		
	Hospitalization in 90 days			Hospitalization in 90 days		
	Estimate	95% CI		Estimate	95% CI	
Emergency Room Stop Code Visits prior 1 year: 0 vs > 2	-0.479	-0.498	-0.460	0.619	0.608	0.631
Emergency Room Stop Code Visits prior 1 year: 1-2 vs > 2	-0.124	-0.142	-0.106	0.883	0.868	0.899
Established Office Visit CPTs prior 90 days: 0 vs > 4	-0.434	-0.455	-0.412	0.648	0.635	0.662
Established Office Visit CPTs prior 90 days: 1-4 vs > 4	-0.210	-0.227	-0.193	0.810	0.797	0.824
Phone CPTs 21to30 mins prior 2 years: 0 vs > 1	-0.173	-0.190	-0.155	0.841	0.827	0.856
Phone CPTs 21to30 mins prior 2 years: 1 vs > 1	-0.053	-0.074	-0.032	0.949	0.929	0.968
Other Non-Face Stop Code Visits prior 1 year: 0 vs > 15	-1.121	-1.172	-1.070	0.326	0.310	0.343
Other Non-Face Stop Code Visits prior 1 year: 1-2 vs > 15	-0.704	-0.737	-0.671	0.495	0.478	0.511
Other Non-Face Stop Code Visits prior 1 year: 3-4 vs > 15	-0.464	-0.492	-0.435	0.629	0.611	0.647
Other Non-Face Stop Code Visits prior 1 year: 5-9 vs > 15	-0.196	-0.217	-0.176	0.822	0.805	0.839
Other Non-Face Stop Code Visits prior 1 year: 10-15 vs > 15	-0.029	-0.046	-0.011	0.972	0.955	0.989
Primary Care Stop Code Visits prior 1 year: 0 vs > 6	0.252	0.218	0.286	1.286	1.243	1.330
Primary Care Stop Code Visits prior 1 year: 1 vs > 6	-0.051	-0.075	-0.026	0.951	0.927	0.974
Primary Care Stop Code Visits prior 1 year: 2 vs > 6	-0.044	-0.065	-0.023	0.957	0.937	0.977
Primary Care Stop Code Visits prior 1 year: 3-4 vs > 6	-0.007	-0.024	0.009	0.993	0.977	1.009
Primary Care Stop Code Visits prior 1 year: 5-6 vs > 6	0.000	-0.017	0.018	1.000	0.983	1.018
Phone Stop Code Visits prior 1 year: 0 vs > 3	-0.096	-0.118	-0.073	0.909	0.889	0.929
Phone Stop Code Visits prior 1 year: 1-3 vs > 3	-0.038	-0.062	-0.013	0.963	0.940	0.987
CT Primary Stop Code Visits prior 1 year: 0 vs > 3	-0.256	-0.279	-0.233	0.774	0.757	0.792
CT Primary Stop Code Visits prior 1 year: 1-3 vs > 3	-0.055	-0.078	-0.032	0.947	0.925	0.968
Cardiology Stop Code Visits prior 1 month: 0 vs > 0	-0.391	-0.420	-0.363	0.676	0.657	0.696
TIU Consent Notes prior 1 year: 0 vs > 4	-0.146	-0.172	-0.119	0.865	0.842	0.888
TIU Consent Notes prior 1 year: 1 vs > 4	-0.037	-0.064	-0.010	0.964	0.938	0.990
TIU Consent Notes prior 1 year: 2-4 vs > 4	-0.022	-0.048	0.003	0.978	0.953	1.003
TIU Telephone Notes prior 2 years: 0 vs > 9	-0.218	-0.243	-0.193	0.804	0.784	0.825
TIU Telephone Notes prior 2 years: 1-4 vs > 9	-0.038	-0.054	-0.021	0.963	0.947	0.979
TIU Telephone Notes prior 2 years: 5-9 vs > 9	0.014	-0.002	0.030	1.014	0.998	1.031
Outpatient Visits prior 3 years: 0-90 vs > 180	-0.494	-0.516	-0.472	0.610	0.597	0.623
Outpatient Visits prior 3 years: 91-180 vs > 180	-0.172	-0.188	-0.155	0.842	0.828	0.857
Intercept	-1.399					

Model Calibration	AUC
90 – Day Event	0.81
1 – Year Event	0.79
90 – Day Hospitalization	0.83

1 – Year Hospitalization	0.81
90 – Day Mortality	0.87
1 – Year Mortality	0.86

**eAppendix Table 2.** ICD-9 codes for selected medical and behavioral conditions

ICD 9 Description	ICD-9 CM Code
Hypertension	401.0, 401.1, 401.9, 402.10, 402.90, 402.xx, 404.10, 404.90, 404, 405.11, 405.19, 405.91, 405.99
Diabetes	250.xx
Depression	293.83, 296.2, 296.3, 296.82, 296.90, 296.99, 300.4, 311.xx
Anxiety	300.00, 300.01, 300.02, 300.09, 300.23, 300.20, 300.21, 300.22
Bipolar	296.0, 296.1, 296.4, 296.5, 296.6, 296.7, 296.80, 296.81, 296.89
Asthma or COPD	493.xx, 494.xx, 496.xx, 491.0, 491.1, 491.2, 491.8, 491.9, 492.0, 492.8
Congestive Heart Failure	402.01, 402.11, 402.91, 404.01, 404.03, 404.11, 404.13, 404.91, 404.93, 428.xx, 425.xx
Coronary Artery Disease	411.xx, 414.xx
Arthritis	710.0, 710.1, 712.xx, 713.xx, 714.xx, 715.xx, 719.3, 720.xx, 721.xx, 716.5-716.9, 719.4-719.6, 719.8, 719.9
Chronic Kidney Disease	403.01, 403.11, 403.91, 404.02, 404.03, 404.12, 404.13, 404.92, 404.93, 585.5, 585.6 all stage V or End Stage, all V45.1 and V56 dialysis, E879.1
Alcohol Abuse	303.01, 303.90, 303.91, 303.92, 305.00, 305.01, 305.02
Dementia	331.0-331.2, 290.xx, 291.2, 292.82, 294.1, 294.2, 331.82
Chronic Pain	338.21, 338.22, 338.28, 338.29
Vision problem	369.xx
Hearing problem	388.xx, 389.xx, V41.2
Homeless	V60.0
Nonadherence	V15.81
Neck and Back Pain	720.xx, 721.xx, 722.xx, 723.xx, 724.xx, 846.xx, 805.xx, 806.xx, 756.10, 756.11, 756.12, 756.13, 756.19, 839.42, 839.1, 839.2, 847.0, 847.1, 847.2, 847.3, 847.9, 996.4
Headache	346.xx, 339.xx, 307.81, 784.0
Schizophrenia	295.xx
Tumor	172.xx, 140.xx, 174.xx – 208.xx, 209.0, 209.1, 209.2, 209.3
Tobacco use disorder	305.10



**eAppendix Table 3.** Generalized logistic regression model<sup>a</sup> comparing: 1) Persistently high risk vs Intermittently & Initially high risk;  
2) Persistently high & Intermittently high vs Initially high risk

	Persistently High CAN (n=35,770)		Intermittently High CAN (n=51,354)		Persistently Low CAN (n=107,473)		High vs. Intermittent+Low			High+Intermittent vs. Low		
	N		N		N		Odds Ratio Estimate	Lower 95%	Upper95%	Odds Ratio Estimate	Lower 95%	Upper 95%
<b>Demographics</b>												
Age < 45 years old	1,051	2.94%	1,952	3.80%	6,785	6.31%	REF	REF	REF	REF	REF	REF
Age 45-65 years old	17,521	48.98%	23,560	45.88%	49,116	45.70%	2.004	1.877	2.142	1.890	1.807	1.977
Age > 65 years old	17,199	48.08%	25,842	50.32%	51,569	47.98%	1.847	1.730	1.974	1.886	1.803	1.972
Female	2,079	5.81%	3,278	6.38%	7,517	6.99%	REF	REF	REF	REF	REF	REF
Male	33,692	94.19%	48,076	93.62%	99,954	93.01%	1.155	1.116	1.196	1.155	1.116	1.196
Married	10,364	28.97%	17,426	33.93%	38,438	35.77%	REF	REF	REF	REF	REF	REF
Unmarried	25,407	71.03%	33,928	66.07%	69,033	64.23%	1.330	1.297	1.364	1.189	1.167	1.212
Hispanic	2,140	6.51%	2,930	6.18%	6,102	6.18%	1.123	1.069	1.180	1.071	1.030	1.114
Other	1,427	4.34%	1,852	3.90%	3,786	3.84%	1.200	1.130	1.274	1.117	1.064	1.172
Black, non-Hispanic	8,668	26.36%	11,508	24.26%	22,008	22.30%	1.226	1.192	1.261	1.182	1.156	1.209
White, non-Hispanic	20,653	62.80%	31,139	65.65%	66,776	67.67%	REF	REF	REF	REF	REF	REF
Rural/Highly Rural	8,976	25.13%	14,695	28.65%	33,201	31.21%	0.769	0.749	0.789	0.824	0.807	0.840
Urban	26,743	74.87%	36,585	71.34%	73,153	68.78%	REF	REF	REF	REF	REF	REF
<b>Medical and behavioral comorbidities</b>												
Hypertension	31,161	87.11%	42,959	83.65%	80,919	75.49%	1.857	1.816	1.9	1.857	1.816	1.9
Diabetes	20,813	58.18%	26,796	52.18%	45,853	42.67%	1.627	1.599	1.655	1.627	1.599	1.655
Depression	21,207	59.29%	26,772	52.13%	48,014	44.79%	1.631	1.593	1.669	1.511	1.484	1.538
Anxiety	10,529	29.75%	12,437	24.49%	22,508	21.23%	1.477	1.440	1.516	1.348	1.320	1.377
Bipolar	4,292	12.00%	5,116	9.96%	8,799	8.21%	1.417	1.367	1.470	1.354	1.313	1.396
Asthma or COPD	19,611	54.82%	23,396	45.56%	33,064	30.84%	2.188	2.15	2.227	2.188	2.15	2.227
Congestive Heart Failure	15,299	42.77%	15,888	30.94%	19,136	17.81%	2.642	2.579	2.706	2.574	2.520	2.628
Coronary Artery Disease	16,499	46.12%	20,916	40.73%	32,192	30.03%	1.700	1.661	1.740	1.754	1.721	1.787
Arthritis	24,921	69.67%	33,517	65.27%	60,818	56.73%	1.556	1.528	1.584	1.556	1.528	1.584

	Persistently High CAN (n=35,770)		Intermittently High CAN (n=51,354)		Persistently Low CAN (n=107,473)		High vs. Intermittent+Low			High+Intermittent vs. Low		
	N		N		N		Odds Ratio Estimate	Lower 95%	Upper95%	Odds Ratio Estimate	Lower 95%	Upper 95%
Chronic Kidney Disease	3,656	10.22%	3,196	6.22%	3,636	3.38%	2.484	2.394	2.575	2.484	2.394	2.575
Alcohol Abuse	10,856	30.35%	12,878	25.08%	20,633	19.25%	1.626	1.585	1.668	1.571	1.538	1.605
Dementia	5,963	16.67%	6,236	12.14%	8,357	7.78%	1.949	1.897	2.002	1.949	1.897	2.002
Chronic Pain	4,280	11.96%	4,258	8.29%	6,116	5.71%	1.941	1.869	2.016	1.796	1.735	1.858
Vision problem	2,882	8.06%	3,390	6.60%	5,209	4.86%	1.522	1.469	1.577	1.522	1.469	1.577
Hearing problem	10,637	29.74%	14,383	28.01%	25,387	23.68%	1.264	1.232	1.296	1.298	1.272	1.325
Neck and Back Pain	22,171	61.98%	29,712	57.86%	53,453	49.86%	1.480	1.454	1.506	1.480	1.454	1.506
Headache	6,719	18.78%	7,918	15.42%	12,837	11.98%	1.535	1.490	1.583	1.484	1.447	1.523
Schizophrenia	3,758	10.51%	3,891	7.58%	6,253	5.83%	1.717	1.651	1.786	1.554	1.501	1.609
Tumor	10,262	28.69%	13,150	25.61%	21,646	20.19%	1.446	1.417	1.475	1.446	1.417	1.475
Nicotine Dependence	15,096	42.20%	19,574	38.12%	35,121	32.76%	1.386	1.354	1.419	1.356	1.331	1.382
<b>Utilization</b>												
Any VHA emergency department visits in 2 years	33,216	92.86%	44,260	86.19%	61,310	57.05%	6.558	6.292	6.838	6.045	5.900	6.195
Any VHA hospitalizations in 2 years	31,959	89.34%	38,522	75.01%	44,117	41.05%	7.729	7.464	8.006	6.081	5.956	6.209
<b>Markers of social instability</b>												
Homeless	4,519	12.63%	5,354	10.43%	8,911	8.29%	1.465	1.414	1.518	1.414	1.372	1.457
Nonadherence	4,541	12.69%	3,931	7.65%	4,737	4.42%	2.514	2.421	2.611	2.330	2.246	2.417
	<b>Mean (SD)</b>		<b>Mean (SD)</b>		<b>Mean (SD)</b>							
Number of ZIP code changes in 2 years	1.76 (1.25)		1.63 (1.11)		1.47 (0.93)		1.21	1.20	1.22	1.21	1.20	1.22
	<b>%</b>		<b>%</b>		<b>%</b>							
% of outpatient visits as no-shows, median	13.81%		12.12%		12.03%		1.476	1.363	1.597	0.877	0.826	0.931
Zero no-shows in 2 years	1.56%		4.15%		10.28%		0.174	0.159	0.189	0.275	0.264	0.287

<sup>a</sup>We used the Brant test of parallel regression assumption for the independent variables. For the variables that fail the assumption, we present two odds ratios comparing 1) high risk vs intermittent & low (combined); 2) high risk & intermittent (combined) vs low risk. For the variables that do not violate the assumption, the odds ratio is the same for both sets of comparisons.

**eAppendix Table 4.** Multinomial logit model comparing persistently high risk to intermittently high risk and persistently high risk to initially high risk

<b>Parameter</b>	<b>Persistently High Risk relative to Intermittently High Risk Odds Ratio Estimate</b>	<b>Lower 95% CI</b>	<b>Upper 95% CI</b>	<b>Persistently High Risk relative to Initially High Risk Odds Ratio Estimate</b>	<b>Lower 95% CI</b>	<b>Upper 95% CI</b>
Coronary Artery Disease	1.140 <sup>b</sup>	1.083	1.201	1.488 <sup>b</sup>	1.415	1.564
Congestive Heart Failure	1.779 <sup>b</sup>	1.688	1.877	3.633 <sup>b</sup>	3.478	3.862
Chronic Kidney Disease	1.718 <sup>b</sup>	1.577	1.875	3.165 <sup>b</sup>	2.892	3.460
Hypertension	1.135 <sup>b</sup>	1.057	1.218	1.553 <sup>b</sup>	1.454	1.658
Diabetes	1.238 <sup>b</sup>	1.179	1.300	1.647 <sup>b</sup>	1.571	1.726
Chronic Pain	1.406 <sup>b</sup>	1.302	1.521	1.880 <sup>b</sup>	1.738	2.031
Back and Neck Pain	1.072 <sup>a</sup>	1.020	1.127	1.300 <sup>b</sup>	1.241	1.364
Headache	1.255 <sup>b</sup>	1.177	1.337	1.672 <sup>b</sup>	1.570	1.779
Arthritis	1.159 <sup>b</sup>	1.101	1.219	1.458 <sup>b</sup>	1.389	1.531
Nonadherence	1.497 <sup>b</sup>	1.384	1.617	2.188 <sup>b</sup>	2.021	2.37
Tumor	1.383 <sup>b</sup>	1.310	1.458	2.203 <sup>b</sup>	2.089	2.319
Tobacco use disorder	1.208 <sup>b</sup>	1.149	1.271	1.718 <sup>b</sup>	1.637	1.804
Visual Impairment	1.160 <sup>b</sup>	1.063	1.265	1.477 <sup>b</sup>	1.354	1.610
Hearing impairment	1.054 <sup>a</sup>	1.001	1.11	1.147 <sup>b</sup>	1.091	1.206
Reside in urban area	1.163 <sup>b</sup>	1.103	1.227	1.284 <sup>b</sup>	1.220	1.352
Homeless	0.930	0.853	1.014	0.881 <sup>a</sup>	0.810	0.958
Number of discharges against medical advice <sup>c</sup>	4.854 <sup>b</sup>	3.622	6.508	71.429 <sup>b</sup>	51.238	103.672
Number of palliative care encounters <sup>c</sup>	2.825 <sup>b</sup>	2.388	3.354	21.277 <sup>b</sup>	16.820	27.001
Number of visits to mental health <sup>c</sup>	1.439 <sup>b</sup>	1.385	1.496	2.132 <sup>b</sup>	2.053	2.211
Number of zip code changes <sup>c</sup>	1.490 <sup>b</sup>	1.243	1.788	4.098 <sup>b</sup>	3.429	4.904
Age	1.006 <sup>b</sup>	1.003	1.008	1.019 <sup>b</sup>	1.017	1.021
Gender (Male vs Female)	1.114	0.982	1.266	1.109	0.985	1.251
White, non-Hispanic (vs Hispanic)	0.875 <sup>a</sup>	0.795	0.963	0.833 <sup>b</sup>	0.761	0.913
Black, non-Hispanic (vs Hispanic)	0.912	0.824	1.011	0.896	0.814	0.988

<b>Parameter</b>	<b>Persistently High Risk relative to Intermittently High Risk Odds Ratio Estimate</b>	<b>Lower 95% CI</b>	<b>Upper 95% CI</b>	<b>Persistently High Risk relative to Initially High Risk Odds Ratio Estimate</b>	<b>Lower 95% CI</b>	<b>Upper 95% CI</b>
Other race (vs Hispanic)	0.963	0.834	1.113	0.912	0.795	1.047

<sup>a</sup>p<0.05; <sup>b</sup>p<0.001

<sup>c</sup> Due to the LOG(10) transformation of the independent variable, a 10-fold increase in the independent variable is needed to produce the OR effect.



**eAppendix Table 5.** Risk status during two-year study period among patients in the top 5% of risk for hospitalization in the next 90 days, stratified by age < 65 (n=109,283) and ≥ 65yo (n=149,476)

Study month <sup>a</sup>	Death (n)	VHA hospitalization (n)	Dropped out of VHA care (n)	Persistently high risk (n)	Intermittently high risk (n)	Initially high risk (n)
<b>Age &lt; 65 (n=109,283)</b>						
1	80	1236	295	105581	1412	679
2	615	4538	904	91589	7715	3922
3	1211	4908	1273	80804	13970	7117
4	1723	5024	1385	72110	19099	9942
5	2310	5929	1674	64496	22642	12232
6	2769	5062	1759	59979	25435	14279
7	3292	5663	2016	54567	27304	16441
8	3779	4993	2233	50576	29135	18567
9	4244	4859	2252	46835	30539	20554
10	4791	5590	2569	42274	31325	22734
11	5210	4888	2502	39159	32535	24989
12	5659	4829	2690	36046	33170	26889
13	6152	5129	2840	32682	33505	28975
14	6636	4422	2658	30861	34035	30671
15	7200	5230	3070	28255	33605	31923
16	7635	4671	3104	26734	33852	33287
17	8047	4719	3102	25323	33452	34640
18	8428	4586	3221	23872	33087	36089
19	8833	5054	3623	22237	31867	37669
20	9196	4411	3756	21310	31163	39447
21	9564	4252	3963	20288	30155	41061
22	9947	5046	4232	18775	28201	43082
23	10275	4400	4207	18071	26772	45558
24	10646	4869	4681	16898	24398	47791
25	10914	3614	4548	16716	22958	50533
<b>Age ≥ 65yo (n=149,476)</b>						
1	374	1887	386	143933	2106	790
2	2254	6266	1185	123818	11401	4552
3	4304	6752	1626	108659	20117	8018
4	6104	6612	1670	96720	27313	11057

Study month <sup>a</sup>	Death (n)	VHA hospitalization (n)	Dropped out of VHA care (n)	Persistently high risk (n)	Intermittently high risk (n)	Initially high risk (n)
5	8112	7524	2054	85916	32244	13626
6	9869	6244	2125	79343	36010	15885
7	11630	7186	2602	71420	38357	18281
8	13127	5933	2695	66006	40929	20786
9	14532	5760	2623	60820	42668	23073
10	16115	6720	3210	54526	43472	25433
11	17438	5607	3148	50253	44981	28049
12	18842	5539	3236	46071	45595	30193
13	20389	6178	3377	41378	45573	32581
14	21732	5382	3219	38587	46204	34352
15	23452	6144	3661	34979	45355	35885
16	24795	5450	3756	32710	45261	37504
17	26093	5373	3899	30553	44488	39070
18	27281	5184	4040	28878	43646	40447
19	28544	5902	4542	26543	41703	42242
20	29612	5205	4870	25142	40455	44192
21	30698	4920	5165	23875	38621	46197
22	31849	5657	5565	21992	36056	48357
23	32826	4882	5610	21004	34171	50983
24	34079	5635	6257	19458	30431	53616
25	34891	4113	6082	19054	28396	56940

<sup>a</sup> Each study month constituted the calendar month from November 23, 2012 – November 22, 2014. The first and last month had partial weekly CAN probabilities.

**eAppendix Table 6.** Risk status during two-year study period among patients in the top 5% of risk for hospitalization in the next 90 days (n=258,759)

Study month <sup>a</sup>	Death (n)	VHA hospitalization (n)	Dropped out of VHA care (n)	Persistently high risk (n)	Intermittently high risk (n)	Initially high risk (n)
1	454	3,123	681	249,514	3,518	1,469
2	2,869	10,804	2,089	215,407	19,116	8,474
3	5,515	11,660	2,899	189,463	34,087	15,135
4	7,827	11,636	3,055	168,830	46,412	20,999
5	10,422	13,453	3,728	150,412	54,886	25,858
6	12,638	11,306	3,884	139,322	61,445	30,164
7	14,922	12,849	4,618	125,987	65,661	34,722
8	16,906	10,926	4,928	116,582	70,064	39,353
9	18,776	10,619	4,875	107,655	73,207	43,627
10	20,906	12,310	5,779	96,800	74,797	48,167
11	22,648	10,495	5,650	89,412	77,516	53,038
12	24,501	10,368	5,926	82,117	78,765	57,082
13	26,541	11,307	6,217	74,060	79,078	61,556
14	28,368	9,804	5,877	69,448	80,239	65,023
15	30,652	11,374	6,731	63,234	78,960	67,808
16	32,430	10,121	6,860	59,444	79,113	70,791
17	34,140	10,092	7,001	55,876	77,940	73,710
18	35,709	9,770	7,261	52,750	76,733	76,536
19	37,377	10,956	8,165	48,780	73,570	79,911
20	38,808	9,616	8,626	46,452	71,618	83,639
21	40,262	9,172	9,128	44,163	68,776	87,258
22	41,796	10,703	9,797	40,767	64,257	91,439
23	43,101	9,282	9,817	39,075	60,943	96,541
24	44,725	10,504	10,938	36,356	54,829	101,407
25	45,805	7,727	10,630	35,770	51,354	107,473

<sup>a</sup> Each study month constituted the calendar month from November 23, 2012 – November 22, 2014. The first and last month had partial weekly CAN probabilities.