Predicting Risk of Potentially Preventable Hospitalization in Older Adults with Dementia

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OBJECTIVES: Reducing potentially preventable hospitalization (PPH) among older adults with dementia is a goal of *Healthy People 2020*, yet no tools specifically identify patients with dementia at highest risk. The objective was to develop a risk prediction model to identify older adults with dementia at high imminent risk of PPH.

DESIGN: A 30-day risk prediction model was developed using multivariable logistic regression. Patients from fiscal years (FY) 2009 to 2011 were split into development and validation cohorts; FY2012 was used for prediction.

SETTING: Community-dwelling older adults (≥65 years of age) with dementia who received care through the Veterans Health Administration.

PARTICIPANTS: There were 1 793 783 participants.

MEASUREMENTS: Characteristics associated with hospitalization risk were (1) age and other demographic factors; (2) outpatient, emergency department, and inpatient utilization; (3) medical and psychiatric diagnoses; and (4) prescribed medication use including changes to psychotropic medications (eg, initiation or dosage increase). Model discrimination was determined by the C statistic for each of the three cohorts. Finally, to determine whether predicted 30-day risk strata were stable over time, the observed PPH rate was calculated out to 1 year.

RESULTS: In the development cohort, .6% of patients experienced PPH within 30 days. The C statistic for the development cohort was .83 (95% confidence interval [CI] = .83-.84) and .83 in the prediction cohort (95% CI = .82-.84). Patients in the top 10% of predicted 30-day PPH risk accounted for more than 50% of 30-day PPH admissions in all three cohorts. In addition, those predicted to be at elevated 30-day risk remained at higher risk throughout a year of follow-up.

CONCLUSION: It is possible to identify older adults with dementia at high risk of imminent PPH, and their risk remains elevated for an entire year. Given the negative outcomes associated with acute hospitalization for those with dementia, healthcare systems and providers may be able to engage these high-risk patients proactively to avoid unnecessary hospitalization. **J Am Geriatr Soc 67:2077-2084, 2019.**

Key words: dementia; potentially preventable hospitalization; risk prediction

Patients with dementia have an all-cause hospitalization rate approximately 1.4 times higher than other older adults, and potentially preventable hospitalization (PPH) is nearly 1.8-times higher.[1] PPH captures admission for ambulatory care-sensitive conditions such as congestive heart failure (CHF) or pneumonia, that, with optimal outpatient access and management, are potentially unnecessary. Reduction of PPH specifically in older adults with dementia is a goal of *Healthy People 2020*.[2,3] Their elevated hospitalization risk is worrying because, although all older adults are at increased risk of hospitalization-associated delirium, iatrogenic complications, and cognitive and functional decline,[4-6] the consequences are greater for patients with dementia,[7,8] for whom cognitive or functional decline are risk factors for institutionalization.[9,10]

As the population with dementia nearly triples by 2050,[11] even small reductions in the rate of PPH could have a large impact. Unfortunately, no controlled dementia care intervention trials have demonstrated a reduction in hospitalization.[12,13] One possible reason is the trials were not specifically designed to target patients at the highest risk of hospitalization. Given the potential adverse consequences of hospitalization for older adults with dementia, identifying

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those at high risk before they need to be hospitalized, especially admissions for conditions that could potentially be treated in an outpatient setting, is critical.

Approaches to risk-stratify patients with dementia that do not rely on overburdened primary care clinicians[14] is key to appropriately targeting supports that may benefit these older adults and their caregivers.[15] For this analysis, we used national data from the US Veterans Health Administration (VHA) electronic health record (EHR) to develop a multivariable logistic regression model to predict PPH admission within 30 days (developmental cohort). We then used the model to identify risk tiers among a different cohort of older adults with dementia (validation cohort) and determine whether the model could accurately predict risk among the new set of patients (prediction cohort).

METHODS

Study Sample and Outcome

The study sample (n = 1 793 783) was drawn from older adults treated in the VHA from October 1, 2008, through September 30, 2012 (fiscal years [FY] 2009-2012). The first index date was October 1, 2008 (ie, the start of FY2009), with a cohort including patients who met these four inclusion criteria: (1) 65 years of age or older; (2) at least one inpatient or outpatient encounter within the previous 12 months to establish use of VHA services; (3) dementia diagnosis before index date (based on one or more encounter with one of the following *International Classification of Diseases, Ninth Revision, Clinical Modification* (*ICD-9-CM)* codes, as used in previous work[16-18]: 046.1, 046.3, 290.0, 290.1x, 290.2x, 290.3, 290.4x, 291.2, 294.10, 294.11, 331.0, 331.1, and 331.82); and (4) not in a VHA inpatient or long-term care setting on the index date.

Then we expanded the cohort by moving the index date ahead at 2-month intervals from December 1, 2008; February 1, 2009; and so on, through August 1, 2012. All patients who met the four inclusion criteria at the index date of each 2-month interval (eg, on December 1, 2008) were considered at risk for PPH and included in the cohort. Therefore, a single patient could contribute multiple at-risk intervals to the final cohort.

The event of interest was PPH admission within 30 days of entering the cohort (ie, the index date). We defined PPH using the primary *ICD-9-CM* discharge diagnosis (Table S1) for the inpatient admission, applying the Agency for Healthcare Research and Quality (AHRQ) prevention quality indicators[19] that include conditions both acute (eg, dehydration, bacterial pneumonia, kidney or urinary tract infection) and chronic (diabetes, asthma, chronic obstructive pulmonary disease, hypertension, CHF exacerbation, angina). To be consistent with prior studies,[1,3,20] we also included cellulitis, gastric/duodenal/peptic ulcer, ear/nose/throat infection, gastroenteritis, hypoglycemia, hypokalemia, influenza, malnutrition, and seizure disorder. The total cohort from the first 3 years (FY2009-2011) was randomly split into halves to develop and validate the prediction model (n = 664 355 and 664 357, respectively); the final year (FY2012; n = 465 071) was used as a prediction cohort to apply the model.

Measures

Candidate model variables were chosen based on prior work examining predictors of hospitalization in older adults.[21-23] Demographic variables included age, sex, race (white, black, other race, unknown race), Hispanic ethnicity, marital status (married, single/never married, divorced, widowed, unknown), and urbanicity (urban, rural, highly rural as defined by VHA using US Census designations). Clinical characteristics included length of time since the first dementia diagnosis (a proxy for dementia severity, ascertained from records going back 10 y), number of unique prescription medications as of the index date, and presence of the following conditions based on clinical encounters in the preceding 12 months (Table S1): diagnoses used to derive the Charlson Comorbidity Index; each PPH condition; delirium (or other transient mental status change); and individual psychiatric conditions including depression, bipolar disorder, and anxiety disorders.

Service utilization characteristics included the number of outpatient, inpatient, and emergency department visits for specific pre-index intervals: 1, 2, 3, 6, 9, and 12 months.

Behavioral and psychological symptoms of dementia may be associated with hospitalization risk,[24,25] and the use of psychotropic medications suggests these symptoms are present,[26] so we used indicators of psychotropic (eg, antipsychotic, antidepressant, sedative/hypnotic, mood stabilizer) and antidementia (eg, cholinesterase inhibitors and memantine) medication prescribing: prevalent use, incident use, and dosage escalation. Each psychotropic indicator was determined for 1, 2, 3, 6, 9, and 12 months pre-index, as well as on the index date.

Analysis

Our goal was to develop a model predicting 30-day PPH risk; we followed an analytic plan similar to one used to develop and validate a suicide risk prediction model among VHA patients using the VHA EHR.[27] To develop a model to predict 30-day PPH, we used the development cohort and fit multivariable logistic regression. Generalized estimation equation with independence was used to adjust for potential correlation from repeated inclusion of the same patients.

Because the medication and service utilization measures were collected for several prespecified time intervals that were potentially correlated (eg, antipsychotic use 1, 2, 3, 6, 9, and 12 months pre-index), we screened each set of measures separately to determine which were most predictive. Based on the magnitude and significance of the parameter estimates, 1 month pre-index was most predictive of PPH, so the final model only included medication and service utilization indicators from the month pre-index. Longer pre-index intervals (eg, 3 or 6 months pre-index) did not further add to model predictiveness, with parameter estimates close to zero.

To allow for effect modification of diagnoses and utilization measures by patient age, we also considered variable-by-age interaction terms, but they were neither significant nor improved the model fit so were not retained. For continuous or count measures (age, number of outpatient visits, etc), we included linear and square terms after centering the measures to allow nonlinear relationships. We did not use any additional variable reduction approaches and retained all variables in the model regardless of statistical significance

because our focus was on overall prediction of risk rather than causal inferences related to specific characteristics and the associated PPH risk.

We present the distribution of select patient sociodemographic and clinical characteristics in the development cohort overall and among those with a PPH admission within 30 days or 1 year. Patient characteristics are described for those at risk of PPH at all intervals; if a patient is at risk of PPH in more than one interval, that person's contribution to the patient characteristics is considered as if from a different patent for each interval. Therefore, the values of the predictors corresponding to each time interval are all accounted for separately.

Model discrimination was assessed by calculating the C statistic in each of the three cohorts: development (half 1 of FY2009-2011), validation (half 2 of FY2009-2011), and prediction (FY2012). In each study cohort, based on the ranked predicted probability of PPH admission within 30 days, we set risk cut points starting with those patients with the top .1% predicted probability down through lower, more inclusive tiers of risk (eg, top .5%, 1.0%, 5.0%, etc). We examined risk concentration for each cut point by determining the number of observed PPH admissions for patients in the risk tier divided by the number of expected PPH admissions based on the overall cohort PPH rate. We used the validation cohort to display calibration graphically by deciles of predicted risk and also used the Hosmer-Lemeshow test for goodness of fit.

To appreciate the impact of applying the model to a new set of patients, performance characteristics (sensitivity, specificity, positive predictive value, and negative predictive value) were determined in the prediction cohort using the prespecified risk cut points.

Finally, to determine whether those at high imminent (ie, 30-day) risk of PPH remained at high risk throughout an entire year, we applied the 30-day PPH risk cut points to the prediction cohort to determine each tier's risk concentration 1, 3, 6, and 12 months post-index. Statistical analyses were done using SAS v.9.4 (SAS Institute, Cary, NC).

RESULTS

Select demographic and clinical characteristics of the development cohort are presented in Table 1 (all characteristics are listed in Table S2) that included 664 355 adults with dementia. The 30-day PPH rate was 69.7 per 1000 person-years; 1-year PPH rate was 57.6 per 1000 person-years. The PPH rate of black patients was nearly double that of white patients. Those patients who experienced PPH within 30 days had more use of each type of inpatient and outpatient service, as well as more of every category of psychotropic medication use including dose increases in the pre-index month.

The development model had very good discrimination,[28] with a C statistic = .834 (95% confidence interval [CI] = .827-.840); model coefficients are presented in Table S3. When the model was applied to the validation and prediction cohorts, there was only a slight loss of discrimination, with C statistics of .832 (95% CI = .825-.838) and .829 (95% CI = .821-.838), respectively. Figure 1 plots the expected (predicted) and observed PPH admission rates by decile of predicted risk for the validation cohort. The predicted rate was close to the observed rate across deciles, although the model slightly overestimated events in the lower deciles and slightly underestimated among the highest risk groups. Although the Hosmer-Lemeshow statistic was significant (χ^2 = 159.8; df = 8; P < .001), this is likely a function of the large sample size.

In each of the three cohorts of patients with dementia (Table 2), among the top 1.0% of patients by predicted 30-day PPH probability, the observed PPH rate ranged from 13.4 to 14.1 times higher than the crude rates (ie, risk concentration). Little overfitting was indicated as seen by the consistent risk concentration across all three cohorts for each predicted probability cut point. Of note, patients in the top 10% of predicted 30-day PPH risk accounted for 52.9% to 53.9% of 30-day PPH admissions in each cohort. Performance characteristics for various cut points of predicted risk are presented in Table 3.

Finally, we applied our predicted 30-day probability cut points to the prediction cohort to examine the trajectory of risk (ie, observed PPH number, rate, and risk concentration) over 1 year (Figure 2 and Table S4). Older adults predicted to be at high 30-day risk of PPH had an elevated risk of admission for the entire year. For example, the top 1% had 13.4-times higher 30-day PPH risk than patients with dementia overall during the first month, but over the following year their 12-month PPH risk was still 7.7-times higher than the 12-month risk for patients with dementia overall.

DISCUSSION

Using data from more than 660 000 adults with dementia, we developed a model that showed high discrimination for predicting 30-day risk of PPH using information available in the EHR. The model also had very good discrimination in the validation cohort (C statistic = .83), indicating little overfitting. Discrimination of the prediction model in the prediction cohort was also high (C statistic = .83), and prediction cohort patients at high 30-day risk remained at elevated risk during 1 year of follow-up. Although this model needs to be tested in other health systems to determine generalizability, our findings suggest this EHR-based approach may be feasible.

We found a PPH risk gradient among older adults with dementia: within the top .1%, 30-day risk of PPH was nearly 20 times higher than among patients overall. Expanding the definition of high risk to the top 10%, a fivefold higher risk of 30-day PPH remained. Although risk concentration did decrease over 12 months, those at high 30-day risk maintained persistently elevated risk. A variety of dementia care management and caregiver support programs decreased caregiver burden, patient behavioral symptoms of dementia, or time to nursing home placement,[29-32] but intervention trials typically did not reduce hospitalization.[33] Null findings from randomized intervention trials may suggest these interventions do not reduce hospitalization; an alternative explanation is that participants were not risk-stratified to maximize hospitalization impact. The GRACE intervention trial, which provided care management for low-income older adults (with or without dementia), demonstrated this: there was no impact on hospitalization overall, but admissions were reduced in those who screened at high risk of hospitalization at baseline.[34] Given the growing

Table 1. Select Demographic and Clinical Characteristics and 30-day and 1-year Rates of Potentially Preventable Hospitalization among the Development Cohort

Characteristic[a]	N (%)		Patients with PPH within 30 d, N (%)		Patients with PPH within 1 y, N (%)		30-d PPH rate per 1000 person-years[b]	1-y PPH rate per 1000 person-years[b]
All	664 355		3745	(.6)	31 962	(4.8)	69.7	57.6
Age, y								
65-74	113 964	(17.2)	659	(17.6)	5732	(17.9)	71.5	58.9
75-84	322 642	(48.6)	1688	(45.1)	14 639	(45.8)	64.6	53.6
≥85	227 749	(34.3)	1398	(37.3)	11 591	(36.3)	76.1	63.0
Sex								
Male	647 274	(97.4)	3646	(97.4)	31 088	(97.3)	69.7	57.6
Race								
White	482 594	(72.6)	2743	(73.2)	23 214	(72.6)	70.3	57.5
Black	67 907	(10.2)	694	(18.5)	5971	(18.7)	127.1	109.6
Other races	15 463	(2.3)	100	(2.7)	943	(3.0)	80.0	73.4
Unknown or missing	98 391	(14.8)	208	(5.6)	1834	(5.7)	26.1	22.0
Hispanic ethnicity								
Yes	17 794	(2.7)	156	(4.2)	1236	(3.9)	108.8	85.1
No	575 614	(86.6)	3421	(91.4)	29 277	(91.6)	73.5	60.9
Unknown or missing	70 947	(10.7)	168	(4.5)	1449	(4.5)	29.3	24.5
Marital status								
Married	429 644	(64.7)	1903	(50.8)	16 399	(51.3)	54.7	45.0
Single/never married	35 670	(5.4)	294	(7.9)	2586	(8.1)	102.6	90.0
Divorced	79 610	(12.0)	651	(17.4)	5440	(17.0)	101.5	84.0
Widowed	116 469	(17.5)	889	(23.7)	7465	(23.4)	94.7	79.4
Unknown or missing	2962	(.4)	8	(.2)	72	(.2)	33.4	29.2
Residence								
Urban	432 406	(65.1)	2670	(71.3)	22 558	(70.6)	76.4	62.9
Rural	224 684	(33.8)	1048	(28.0)	9159	(28.7)	57.6	48.2
Highly rural	7265	(1.1)	27	(.7)	245	(.8)	45.9	39.8
Diagnoses present in past 12 mo								
Myocardial infarction	20 181	(3.0)	337	(9.0)	2182	(6.8)	210.0	144.1
Cerebrovascular disease	125 495	(18.9)	1256	(33.5)	10 227	(32.0)	124.7	102.9
Delirium or other transient mental status change	280 286	(42.2)	2100	(56.1)	16 953	(53.0)	93.0	74.5
Depression	167 864	(25.3)	1249	(33.4)	10 508	(32.9)	92.2	76.3
Posttraumatic stress disorder	40 426	(6.1)	309	(8.3)	2545	(8.0)	94.7	76.3
Other anxiety disorders	48 414	(7.3)	413	(11.0)	3295	(10.3)	105.9	83.2
Duration of dementia, y								
<1	165 081	(24.8)	1035	(27.6)	7811	(24.4)	77.7	56.8
1-3	292 349	(44.0)	1510	(40.3)	13 327	(41.7)	63.8	54.4
4-6	141 122	(21.2)	709	(18.9)	6645	(20.8)	62.1	56.3
≥7	65 803	(9.9)	491	(13.1)	4179	(13.1)	92.4	77.1
Type of dementia								
Alzheimer's disease	545 775	(82.2)	2794	(74.6)	24 050	(75.2)	63.3	52.6
Vascular dementia	175 687	(26.4)	1429	(38.2)	12 212	(38.2)	101.0	85.8
Lewy body dementia	32 098	(4.8)	236	(6.3)	1762	(5.5)	91.6	69.9
Progressive multifocal leukoencephalopathy	256	(<.1)	2	(.1)	11	(<.1)	97.2	52.3
Jakob-Creutzfeldt disease	236	(<.1)	3	(.1)	21	(.1)	157.9	109.4
Alcoholic dementia	20 558	(3.1)	167	(4.5)	1419	(4.4)	101.0	85.4
Pick's dementia	9980	(1.5)	59	(1.6)	533	(1.7)	73.1	64.4
Utilization in past month								
Medical/surgical outpatient visits, n								
0	336 372	(50.6)	732	(19.6)	7846	(24.5)	26.8	27.1
1	147 262	(22.2)	687	(18.3)	6753	(21.1)	57.5	54.1
2	77 930	(11.7)	564	(15.1)	5037	(15.8)	89.6	78.4
≥3	102 791	(15.5)	1762	(47.1)	12 326	(38.6)	216.1	162.1

Table 1 (Contd.)

Characteristic[a]	N (%)		Patients with PPH within 30 d, N (%)		Patients with PPH within 1 y, N (%)		30-d PPH rate per 1000 person-years[b]	1-y PPH rate per 1000 person-years[b]
Acute inpatient hospitalizations, n								
0	655 674	(98.7)	3314	(88.5)	29 992	(93.8)	62.4	54.5
1	8313	(1.3)	396	(10.6)	1851	(5.8)	640.5	403.9
≥2	368	(.1)	35	(.9)	119	(.4)	1412.7	824.0
Medications on index date, n								
0	139 929	(21.1)	517	(13.8)	4178	(13.1)	45.9	36.8
1-2	93 255	(14.0)	265	(7.1)	2675	(8.4)	35.0	33.4
3-4	114 498	(17.2)	348	(9.3)	3678	(11.5)	37.4	37.1
5-6	109 603	(16.5)	537	(14.3)	4548	(14.2)	60.4	48.4
≥7	207 070	(31.2)	2078	(55.5)	16 883	(52.8)	124.6	100.6
Class of psychotropic use on index date								
Antipsychotic	64 358	(9.7)	530	(14.2)	4378	(13.7)	102.4	86.0
Antidepressant	175 836	(26.5)	1295	(34.6)	10 918	(34.2)	91.1	75.0
Sedative/Hypnotic	49 248	(7.4)	369	(9.9)	3172	(9.9)	92.8	78.6
Mood stabilizer	48 743	(7.3)	453	(12.1)	3808	(11.9)	115.4	96.2
Psychotropic dose increase in prior month								
Antipsychotic	19 709	(3.0)	178	(4.8)	1430	(4.5)	112.4	92.6
Antidepressant	51 758	(7.8)	411	(11.0)	3439	(10.8)	98.4	80.7
Sedative/Hypnotic	13 970	(2.1)	121	(3.2)	952	(3.0)	107.4	83.6
Mood stabilizer	13 526	(2.0)	137	(3.7)	1108	(3.5)	125.8	101.6

Abbreviation: PPH, potentially preventable hospitalization.

[a]For the complete list of characteristics included in the predictive model and model coefficients, see Table S2 and Table S3, respectively.

[b]Calculated as number of patients with PPH divided by the at-risk days where person-days are counted until the earliest date of PPH, non-PPH admission, death, or end of follow-up period (30 d for 30-d rate and 12 mo for 12-mo rate) and expressed as per 1000 person-years. Participants who were at risk in multiple intervals are counted multiple times. In the development cohort, 16 396 (13%) patients were included only once, 15 042 (12%) patients twice,14 049 (11.2%) patients 3 times, 12 868 (10.2%) patients 4 times, 11 567 (9.2%) patients 5 times, 10 921 (8.7%) patients 6 times, 10 714 (8,5%) 7 times, 10 066 (8%) 8 times, 8921 (7.1%) patients 9 times, 6693 (5.3%) 10 times, 4434 (3.5%) 11 times, 2386 (1.9%) patients 12 times, 1092 (.8%) patients 13 times, 358 (.3%) patients 14 times, 84 (.07%) patients 15 times, 14 (.01%) patients 16 times, 2 patients 17 times, and 1 patient 18 times.

population of older adults with dementia, limited resources call for risk stratification strategies to help target interventions appropriately, rather than attempting to deliver a given intervention to all.

Analyses based on claims or administrative data of older adults can be subject to unobserved confounding by factors such as frailty or functional status that are associated with health outcomes but not routinely available in administrative data.[35,36] Yet our model had excellent predictive ability derived entirely from structured information in the EHR, without any additional information from the patient or caregiver. In contrast, the Probability of Repeated Admission Instrument, used in the GRACE trial to identify the high-risk patients at baseline, has to be completed by the older adult and includes items on self-rated health and the presence of an informal caregiver.[37] Given the enormous demands on primary care providers' time,[14] harnessing the EHR may be a feasible means to risk-stratify these patients without requiring any additional input from providers, patients, or caregivers.

The ability of our model to identify high-risk patients is notable given that the overall cohort, older adults with dementia, is, at baseline, at a significantly elevated risk of admission compared with the general adult population. The predictive ability of our model is comparable with a separately developed PPH predictive model for VA patients of all ages,[23] but our model discriminates slightly better than other risk models specifically developed for older adults.[22,38-41] A review of risk stratification applied six different models: Adjusted Clinical Groups, Hierarchical Condition Categories, Elder Risk Assessment, Chronic Comorbidity Count, Charlson Comorbidity Index, and Minnesota Health Care Home Tiering to more than 80 000 primary care patients seen in a large academic health system. Across the six models, the C statistic for 1-year hospitalization prediction was .67 to .73.[39]

One specific model feature that may have facilitated identifying high-risk patients was the inclusion of psychotropic medications as predictors, specifically new medication starts and dosage increases. Changes to psychotropic medications may herald the presence or worsening of symptoms such as agitation or psychosis.[26,42] Such behavioral and psychological symptoms of dementia may dominate the clinical presentation of patients with dementia, and the related caregiver distress is associated with increased hospitalization and costs for patients.[25] Alternatively, such medication changes may be to treat delirium or other transient changes in mental status that were recorded for more than 40% of cohort patients in the prior 12 months. Although information about behavioral symptoms is typically not available in the EHR or delirium may not be reliably recorded, incorporating information about psychotropic medication changes, which would be in the EHR, may help identify patients whose behavioral problems either reflect a worsening medical problem or are part of the constellation of symptoms that led to hospital admission.[42] Regardless of the clinical rationale for such medication changes, this information can be useful to identify high-risk older adults.

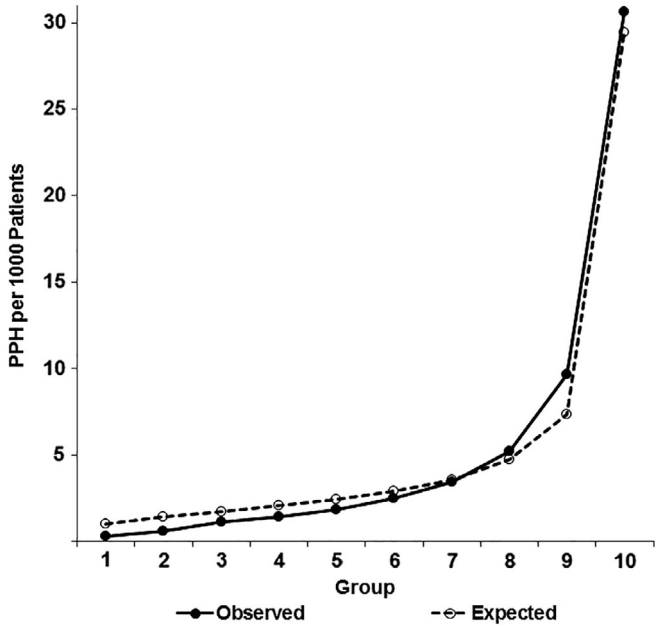

Figure 1. Calibration curve for the predicted 30-day potentially preventable hospitalization (PPH) risk model applied to the validation cohort. The figure compares observed and expected (predicted) PPH admissions across deciles of risk among older adults with dementia in the Veterans Health Administration. Expected events closely follow observed events, although given the large sample size, prediction does vary across deciles, slightly overpredicting risk in the bottom deciles and slightly underpredicting risk in the top deciles (Hosmer-Lemeshow statistic: $\chi^2 = 159.8$; df = 8; $P < .001$).

The 12-month PPH admission rate among our population—57.6 admissions per 1000 person-years in the development sample—is, as expected for patients with dementia, higher than for adults overall in the VHA[43] and older adults in the general population.[44] However, the rate is lower than in an analysis of Medicare beneficiaries with dementia.[20] This discrepancy between VHA and Medicare PPH rates is partially because most older VHA patients have Medicare, so some PPH admissions occur at community facilities. Although this analysis was not designed to identify particular characteristics associated with PPH, it is notable that black patients experienced much higher PPH rates than other patients, in a system designed for equal access to care regardless of socioeconomic or insurance status.

A limitation of our analysis is that it only includes data from the VHA. Although this limits generalizability, it suggests feasibility for other healthcare systems to develop and implement their own internal risk prediction models. The model only captures PPH risk among patients identified with a dementia diagnosis that likely represents the subset

Table 3. Performance Characteristics by Cut Point of Predicted 30-day PPH Risk in the Prediction Cohort

Predicted probability cut point[a], %	Sensitivity, %	Specificity, %	PPV, %	NPV, %
Top .1	1.9	99.9	9.9	99.5
Top .5	7.7	99.5	8.1	99.5
Top 1.0	13.4	99.1	7.1	99.5
Top 5.0	37.4	95.2	3.9	99.7
Top 10.0	52.9	90.2	2.8	99.7
Top 20.0	69.3	80.3	1.8	99.8
Top 50.0	90.3	50.2	1.0	99.9
100.0	100.0	.0	.5	NA

Abbreviations: NA, due to 0 denominator; NPV, negative predictive value; PPH, potentially preventable hospitalization; PPV, positive predictive value.
[a]Performance characteristics are calculated when those patients whose predicted 30-day PPH risk probability is at or exceeds the row cut point are considered positive for PPH and the remaining patients are considered negative for PPH.

Table 2. The 30-day PPH Risk Concentration and Admission Rate by Cut Point of Predicted 30-day PPH Probability across the Three Cohorts

	Development[a] (n = 664 355)			Validation[b] (n = 664 357)			Prediction[c] (n = 465 071)		
Predicted probability cut point, %	Patients with PPH,%[d]	Risk concentration[e]	PPH rate per 1000 person-year[f]	Patients with PPH,%	Risk concentration	PPH rate per 1000 person-year	Patients with PPH,%	Risk concentration	PPH rate per 1000 person-year
Top .1	2.4	24.3	1956.9	2.0	20.4	1635.2	1.9	18.8	1389.0
Top .5	8.4	16.9	1317.0	7.7	15.4	1207.8	7.7	15.4	1113.3
Top 1.0	13.6	13.6	1034.5	14.1	14.1	1092.7	13.4	13.4	953.2
Top 5.0	38.4	7.7	564.6	38.5	7.7	571.8	37.4	7.5	512.0
Top 10.0	53.9	5.4	389.6	53.8	5.4	393.1	52.9	5.3	357.0
Top 20.0	70.3	3.5	250.6	69.5	3.5	250.3	69.3	3.5	230.5
Top 50.0	91.0	1.8	127.8	90.1	1.8	127.8	90.3	1.8	118.4
100.0	100.0	1.0	69.7	100.0	1.0	70.4	100.0	1.0	65.1

Abbreviation: PPH, potentially preventable hospitalization.
[a]C statistic = .83; 95%CI = .82-.84.
[b]C statistic = .83; 95%CI = .82-.83.
[c]C statistic = .82; 95%CI = .82-.83.
[d]The percentage of overall cohort PPH admissions accounted for by the patients within a given risk tier.
[e]Risk concentration = (observed no. of PPHs in risk tier)/(expected no. of PPHs based on rate among older adults with dementia overall).
[f]Calculated as the number of patients with PPH for each cut point divided by the at-risk days where person-days are counted until the earliest date of PPH, non-PPH admission, death, or end of follow-up period (30 d) and expressed as per 1000 person-years.

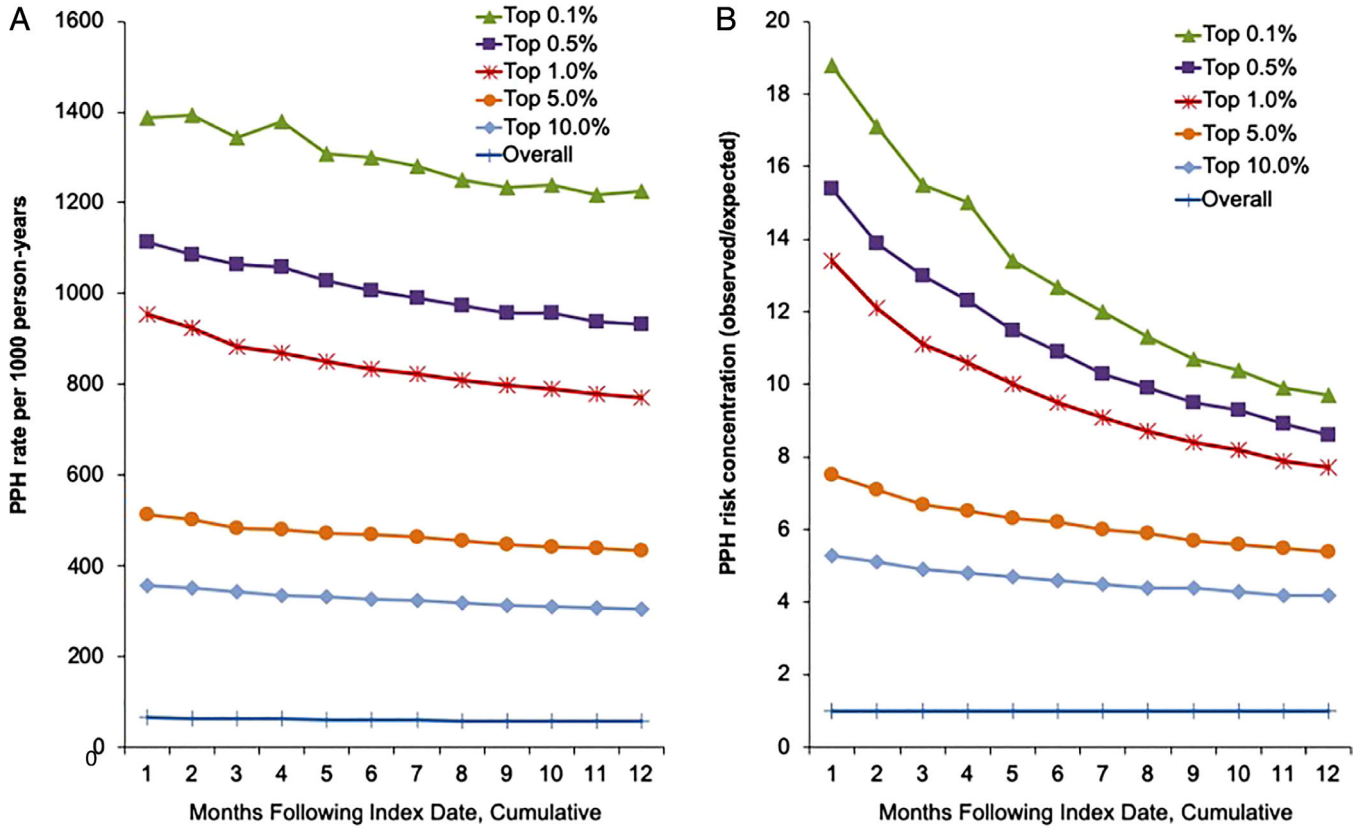

Figure 2. Cumulative potentially preventable hospitalization (PPH) rate and risk concentration over 1 year by cut point of 30-day predicted PPH risk in the prediction cohort. This figure demonstrates the change in A, PPH rate, and B, PPH risk concentration (observed PPH admissions in risk tier)/(predicted PPH admissions based on the rate among older adults with dementia overall) over 12 months based on the tier of predicted risk in the prediction cohort. Although the rate and risk concentration decline over time, the risk tiers maintain their relative positions at all time points, and those at elevated 30-day risk continue to experience PPH admissions at higher rates all year.

of patients with more advanced illness. In addition, the prediction data set is drawn from 2012 that is now more than 6 years old. In 2012, the VA introduced the Strategic Analytics for Improvement and Learning Value Model that includes PPH as a quality indicator. Heightened attention to PPH and other systemwide delivery changes mean a model developed with more recent data may perform differently. There is controversy over the utility of the PPH construct; a 2016 study found that, of AHRQ-designated preventable admissions, reviewing clinicians considered less than half preventable.[45] However, Hodgson and colleagues suggest the PPH construct is still potentially useful, provided it is used to understand the underlying mechanisms increasing admission and not just to examine factors associated with admission.[46] In this case, although risk prediction may help identify patients who could benefit from intervention, it cannot suggest the type of intervention that would be effective.

In conclusion, the acute inpatient hospital is a challenging environment for older adults with cognitive impairment, stressful to both patients and their caregivers. It is critical to address healthcare issues proactively before a crisis occurs and patients with dementia require hospitalization, particularly as the number of older adults with dementia grows. This analysis demonstrates that it is possible for healthcare systems to accurately identify older adults with dementia at high risk of imminent PPH.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article.

Table S1: *ICD-9-CM* diagnoses used to define potentially preventable hospitalization (PPH) and non-Charlson medical and psychiatric conditions

Table S2: Complete demographic and clinical characteristics and 30-day and 1-year rates of PPH among the development cohort

Table S3: Coefficients of all variables in the final model in the development cohort

Table S4: Cumulative PPH rate and risk concentration from 1 month to 1 year by cut point of 30-day predicted PPH risk in the prediction cohort

Supplementary Material S1: Variable-defining *ICD-9-CM* codes, characteristics, and model coefficients of the development cohort and PPH risk decay over 1 year.