Predicting Mortality in Nursing Home Residents With Lower Respiratory Tract Infection

The Missouri LRI Study

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Context Lower respiratory tract infection (LRI) is a leading cause of mortality and hospitalization in nursing home residents. Treatment decisions may be aided by a clinical prediction rule that identifies residents at low and high risk of mortality.

Objective To identify patient characteristics predictive of 30-day mortality in nursing home residents with an LRI.

Design, Setting, and Patients Prospective cohort study of 1406 episodes of LRI in 1044 residents of 36 nursing homes in central Missouri and the St Louis, Mo, area between August 15, 1995, and September 30, 1998.

Main Outcome Measure Thirty-day all-cause mortality.

Results Thirty-day mortality was 14.7% (n = 207). In a logistic analysis, using generalized estimating equations to adjust for clustering, we developed an 8-variable model to predict 30-day mortality, including serum urea nitrogen, white blood cell count, body mass index, pulse rate, activities of daily living status, absolute lymphocyte count of less than 800/μL (0.8×10^9/L), male sex, and deterioration in mood over 90 days. In validation testing, the model exhibited reasonable discrimination (c = .76) and calibration (nonsignificant Hosmer-Lemeshow goodness-of-fit statistic, P = .54). A point score based on this model's variables fit to the entire data set closely matched observed mortality. Fifty-two percent of residents had low (score of 0-4) or relatively low (score of 5-6) predicted 30-day mortality, with 2.2% and 6.2% actual mortality, respectively.

Conclusions Our model distinguishes nursing home residents at relatively low risk for mortality due to LRI. If independently validated, our findings could help physicians identify nursing home residents in need of different therapeutic approaches for LRI.

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PNEUMONIA AND THE SOMEwhat broader category of lower respiratory tract infection (LRI), which includes pneumonia, bronchitis, and tracheobronchitis, are the leading causes of mortality and hospitalization among nursing home residents.[1-4] In recent outcome studies, 30-day mortality from pneumonia or LRI ranged between 11.4% and 30%.[5-9] Clinical findings consistently associated with mortality have included functional dependence (defined by activities of daily living [ADLs]) and elevated respiratory rate.[5,7,10,11]

Because many nursing home residents are chronically ill and near the end of life, the first step in making treatment decisions should be determining appropriate therapeutic measures (eg, aggressive care, limited curative treatment, or strictly palliative care). For strictly palliative care, maximizing comfort should guide treatment. Otherwise, clinicians need to determine illness severity to decide on specific treatment and whether residents should be treated in the nursing home or hospital. Residents at low risk for mortality may be excellent candidates for nursing home management, which may prevent complications from hospitalization.[12,13] For community-acquired pneumonia, the validated Pneumonia Severity Index (PSI) provides guidance.[14] However, because of its broad scope, most nursing home residents would be classified in its 2 highest-risk categories.

In a large prospective sample of nursing home residents with LRI, we derived and validated a new predictive model to better distinguish residents at low risk of dying. We chose 30-day mortality as the most useful outcome for considering treatment decisions, which is consistent with the approach of other researchers.[14]

See also Patient Page.

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Box 1. Lower Respiratory Tract Infection (LRI) Definition*

An LRI was defined to include either pneumonia or other LRI.
Both of the following criteria were required for pneumonia:

- Interpretation of a chest radiograph as demonstrating pneumonia or probable pneumonia. If a previous radiograph exists for comparison, the infiltrate should be new.
- At least 2 of the LRI symptoms and signs below are present.

All 3 of the following criteria were required for other LRI (bronchitis, tracheobronchitis):

- Pneumonia as defined above is absent or no chest radiograph is available.
- At least 3 of the LRI signs and symptoms below are present.
- In the presence of chronic obstructive pulmonary disease or congestive heart failure, additionally, the resident must have a temperature of ≥38°C for the illness to qualify as an LRI.

LRI symptoms and signs used in the definition:

- New or increased cough
- New or increased sputum production
- Fever (≥38°C)
- Pleuritic chest pain
- New or increased physical findings on chest examination (rales, rhonchi, wheezes, bronchial breathing)
- One of the following indications of change in status or breathing difficulty: new/increased shortness of breath, or respiratory rate greater than 25/min, or worsening mental or functional status (significant deterioration in the resident's cognitive status or in the resident's ability to carry out the activities of daily living, respectively).

*Based on the statement of a consensus development conference concerning infection-surveillance definitions for long-term care facilities.[16] We modified the definition to explicitly exclude residents with chronic obstructive pulmonary disease or congestive heart failure who lacked either a fever or probable pneumonia on chest radiograph to avoid including congestive heart failure or chronic obstructive pulmonary disease exacerbations as an LRI.

METHODS

We identified participants from 36 nursing homes in central Missouri and the St Louis, Mo, area. Facility characteristics were similar to 1997 national averages.[15] For example, 64% were for profit vs 67% nationally. Forty-seven percent of the facilities had fewer than 100 beds, 44% had between 100 and 199, and 8% had 200 or more, whereas facilities nationwide had 50%, 42%, and 8%, respectively. Thirty-one percent of the facilities were in nonmetropolitan areas vs 38% nationally.

Definition of LRI

We chose to study mortality from LRI rather than pneumonia to make our findings most relevant to nursing home practice. Physicians caring for nursing home patients frequently do not obtain chest radiographs, and the clinical distinction between bronchitis or tracheobronchitis and pneumonia is difficult, even though the conditions are pathologically distinct. Thus, LRI includes pneumonia and other LRI (BOX 1). The definition is a modification of a surveillance definition for long-term care facilities.[16]

Patient Identification and Evaluation

Project nurses called or visited facilities at least 6 days per week to identify residents who had respiratory (eg, cough, sputum production) or nonspecific (eg, fever, acute confusion) symptoms compatible with an LRI. The nurses were also available by pager, and facility staff and physicians were encouraged to report ill residents at other times. Under a physician-authorized protocol, residents with such symptoms received a focused history and physical examination by a trained project nurse within 24 hours and usually on the same day. Most evaluations included a chest radiograph, complete blood count, and a chemistry panel. Project nurses predominantly had advanced-practice education or extensive clinical experience and training in physical assessment. Since evaluations were authorized by attending physicians, who also received clinical information regarding each case, they were considered part of appropriate care. Therefore, institutional review boards at each institution approved a simplified consent process using a simple acceptance or refusal of the evaluation as part of medical care. Potential cases were identified from August 15, 1995, through September 30, 1998. However, all facilities were not involved until December 1997. Additional details of resident identification and evaluation are described elsewhere.[17]

Of the 4959 illness episodes reported by nursing homes, project nurses performed 2592 evaluations to determine whether to include the episode in the study. We did not evaluate (hereafter excluded) residents who accounted for a total of 1191 episodes because they did not have lower respiratory or systemic symptoms or signs except for cough (FIGURE). We also excluded 1176 episodes in which residents were (1) ineligible because they were younger than 60 years old, not in the facility at least 14 days, or had taken an antibiotic in the last 7 days for a previous LRI; (2) not appropriate for an outcomes study because they had a "no antibiotics" order, were not expected to live more than 30 days, were enrolled in hospice, or had acquired immunodeficiency syndrome; (3) cared for by a physician not participating in the protocol or the resident, family, or physician declined a specific evaluation; or (4) identified too late for a

timely evaluation (>48 hours after treatment was initiated). Some episodes were excluded for more than 1 reason. We compared age and vital signs between the 2592 evaluations and the 724 episodes that would have qualified for an evaluation but were excluded because of lack of permission for evaluation or because of late notification (categories 3 and 4 above). Age, pulse, and respiratory rate were not significantly different, but average temperature was slightly higher in those not evaluated (37.4°C vs 37.2°C; $P = .002$).

Data Collection and Measures

Clinical evaluations of nursing home residents were recorded on standardized forms and placed in the medical record. When an LRI seemed likely, project nurses collected additional data using the nursing home Minimum Data Set (MDS),[18,19] which is a reliable instrument when used by trained nurse assessors.[20] From hospital (for residents who were hospitalized) and nursing home records, we obtained the following: active diagnoses and studies pertaining to diagnosis (for example, urinalysis and cultures of blood, urine, or sputum); oxygen therapy; immunization information; medications, including antibiotics, psychotropic drugs, and respiratory drugs; prior diagnoses; and prior hospital use. In 9.2% of evaluations, the resident was transferred to the hospital before project nurses could complete a physical assessment. In these instances, we obtained vital sign and clinical examination data from hospital records. Vital sign data used in the analysis were those obtained by the project nurse or, if not available, those first obtained at the hospital (usually the emergency department record). We chose the first available laboratory data after the resident qualified for evaluation.

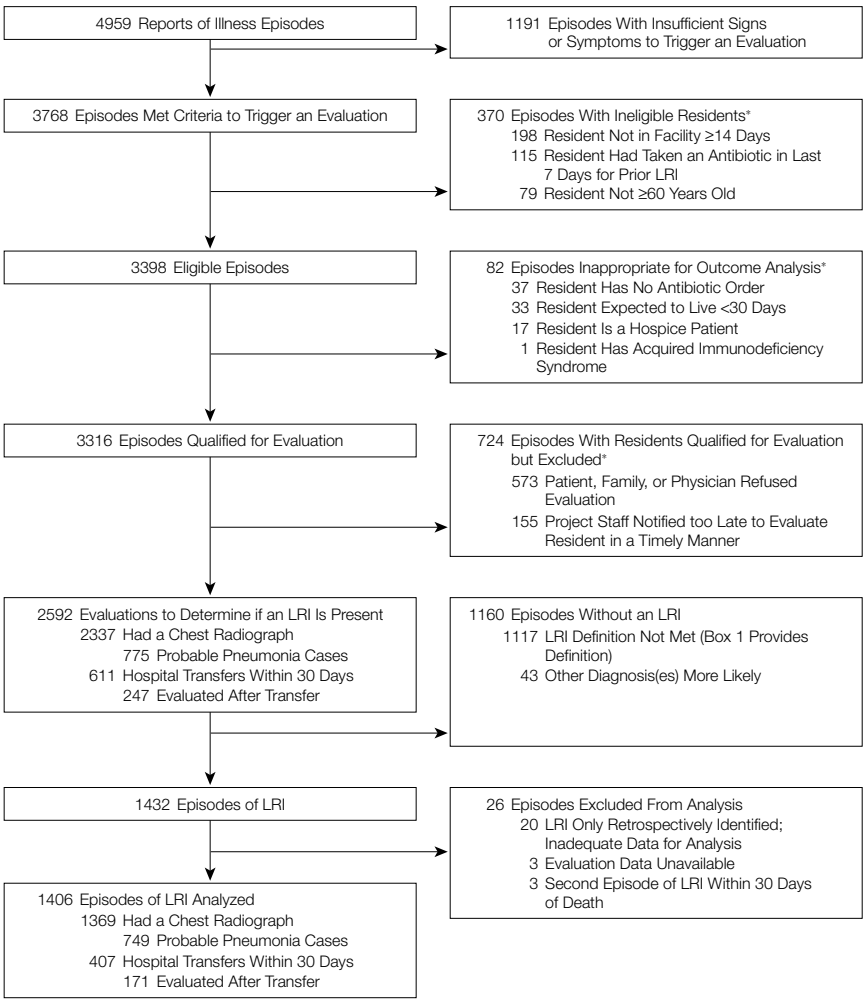
From the MDS, we obtained data on depression and delirium; height and weight; other diagnoses and conditions (including pressure ulcers); use of devices, such as restraints; and the Cognitive Performance Scale (CPS),[21] which measures cognitive impairment. We measured ADL dependency, by summing self-performance scores for 4 ADL items (grooming, using the toilet, locomotion, and eating) from the MDS (MDS ADL [Short Form], scale range of 0-16).[22] In the final multivariable analyses, we simplified this to a 0 to 4 scale by counting the number of these 4 ADL items in which the individual was rated as either dependent or required extensive assistance. Consistent with MDS instructions, we evaluated ADL and cognitive status for the week prior to evaluation; delirium symptoms (MDS section B5)[19] include an indication of new onset or worsening.

We ascertained survival or mortality from all causes at 30 days for all residents. Project nurses returned to nursing homes at 30 days to reassess functional status in living residents. In the few instances in which residents had moved, we followed up on their status at their new location. In the 3 instances in which this was not possible, we performed a death certificate search.

Radiographic Classification and Case Review

Chest radiographs were obtained in 2337 of the 2592 evaluations. We chose to evaluate radiology reports rather than

Figure. Exclusion Criteria and Pathway to Study Sample



LRI indicates lower respiratory tract infection. Asterisk indicates some episodes were excluded for more than 1 reason so the sum exceeds the total number shown.

reviewing all radiographs because only the report is typically available to clinicians. Based on defined criteria, 2 clinicians independently classified radiology reports into 3 categories: negative, possible, or probable (this group includes definite pneumonia). For example, according to these criteria, a report describing "new left lower lobe infiltrate suggestive of pneumonia" is probable pneumonia, while a report indicating "possible infiltrate" or "infiltrate suggestive of pneumonia or congestive heart failure" is possible pneumonia. In St Louis, 2 clinicians evaluated the reports, and in central Missouri 2 of 4 clinicians considered each report. When disagreement occurred, all 6 raters at the 2 sites independently reviewed the reports and attempted to reach consensus. In 11.7% of cases, consensus either could not be achieved, or was for possible pneumonia when only probable pneumonia would have qualified the episode for inclusion as an LRI under the study definition. In those instances, an additional radiologist independently interpreted the actual radiographs.

Following abstraction of all clinical information and final radiographic classification, project geriatricians (D.R.M., E.F.B., and S.C.Z.) reviewed clinical information from all evaluations to make a final determination of whether an episode met our case definition. In addition to 1117 episodes that did not meet the LRI definition (Figure), we found an additional 43 that technically met our definition but were not included as LRI cases because another illness or combination of illnesses was more likely (including 36 in which there was a documented urinary tract infection).

An additional 26 episodes were dropped from our analytic sample; in 23 there were inadequate data on predictor variables and 3 residents had 2 episodes of LRI in a 30-day interval during which they died. Since death should only be attributed to 1 episode, we excluded the second episode in these 3 instances.

Statistical Analyses

Data imputation was used for missing data since in developing multivariable models, data imputation is recommended as less biased than dropping cases.[23] In this study, imputing mean values for missing continuous data and the largest category value for missing dichotomous variables was as efficient as more complicated procedures for imputation. Episodes were then randomly assigned to a 70% development (n = 975) and 30% validation (n = 431) sample. Selecting candidate variables and model building were restricted to the development data until a final variable reduction step.

The initial step in variable selection was based on the literature and clinical relevance, as judged by the 3 geriatrician investigators. A list of 25 categories of variables that might be related to mortality was constructed, including demographic factors (age, sex, race), vital signs (pulse, respiratory rate, temperature, blood pressure), findings of delirium (eg, acute confusion, decreased alertness), cognitive status, nutritional status (weight, body mass index [BMI], total lymphocyte count), physical function (ADL status and other mobility indicators), indicators of depression, comorbid conditions (eg, congestive heart failure, chronic obstructive pulmonary disease, stroke), and other laboratory findings (eg, white blood cell count, serum urea nitrogen, serum sodium).

We then considered descriptive and bivariable statistics describing the relationship of specific symptoms and examination findings to 30-day mortality. Using S-Plus software,[24] continuous variables were examined with smoothed plots showing the shape of the relationship between the variable and mortality. Based on clinical relevance and statistical considerations, we then took the best representatives from these 25 categories of variables for consideration in building our multivariable model.[25] We excluded 2 indicators of nutritional status, albumin and cholesterol, because of excessive missing data (35% and 48%, respectively). Changes in Medicare regulations during the study precluded physicians from ordering a comprehensive chemistry panel in nursing home residents with a possible LRI. Consistent with contemporary standards of care, most subjects did not receive an arterial blood gas or pulse oximetry.

We used forward and backward stepwise logistic regression to consider combinations of variables for inclusion in our final model (using $P = .10$ as an initial criterion for statistical significance). We used generalized estimating equations to adjust logistic regression estimates for 2 kinds of correlation within our data: individuals nested within facilities and participants represented by more than 1 episode.[26] As few individuals had more than 4 episodes of LRI, we restricted the generalized estimating equations analysis to 4 or fewer episodes to avoid unstable estimates.

In testing continuous variables in these models, we considered the shape of the variable's relationship to mortality. For example, temperature exhibits a minimum mortality with a slight elevation of temperature and higher mortality with both high and low temperatures. Therefore, we tested linear and quadratic terms as well as using dummy variables to represent low, mid-range, and high temperatures. We also limited the range of continuous variables to avoid undue influence of outliers. For example, serum urea nitrogen was set to 10 if less than 10 and to 80 if more than 80. In making final decisions on model inclusion, we considered clinical meaningfulness and the gain in discrimination by including a variable as measured by the *c* statistic and the Aikake Information Criterion (both available through SAS statistical software).[27] We also reconsidered key variables based on the literature, such as age and respiratory rate, which had not been retained in stepwise selection procedures.

The result of these analyses was an 11-variable model. Because this was an excessive number of variables for the size of our validation data set, prior to the final model validation, we drew 5 other random samples from the entire data set. Three of the 11 variables originally fit to the development sample (low temperature, congestive heart failure on

chest radiograph, and bilateral infiltrate on chest radiograph) improved discrimination in only half of the 6 samples, so they were dropped from the model.

We then used coefficients for the 8-variable model, as estimated in the development sample, to test the model's discrimination and calibration in the original validation sample.[28] To assess discrimination, we primarily used the *c* statistic, which evaluates among all possible pairs of individuals whether those with higher predictive risk are more likely to die. The *c* statistic is also equal to the area under the receiver operating characteristic curve. The Hosmer-Lemeshow goodness-of-fit statistic was used to measure calibration by assessing agreement between predicted and observed risk by decile of predicted risk.[29]

Finally, the 8-variable model was fit to the entire data set and used to create an approximation in the form of a simple scoring system for clinicians. The predicted probability of mortality associated with each point total was computed by averaging predicted probability from this logistic model for all episodes with a given point total. Statistical analyses were performed with S-Plus[24] and SAS statistical software.[27]

Table 1. Characteristics of Nursing Home Residents With 1406 Episodes of Lower Respiratory Tract Infections*

Characteristic	Development Sample With 975 Episodes	Validation Sample With 431 Episodes
Sex		
Female	654 (67.1)	294 (68.2)
Male	321 (32.9)	137 (31.8)
Race		
Black	79 (8.1)	36 (8.4)
White	896 (91.9)	395 (91.6)
Age, y		
60-69	52 (5.3)	19 (4.4)
70-79	203 (20.8)	76 (17.6)
80-89	413 (42.4)	200 (46.4)
≥90	307 (31.5)	136 (31.6)
Activities of daily living score†		
0-3	154 (15.8)	74 (17.2)
4-7	197 (20.2)	83 (19.3)
8-11	222 (22.8)	90 (20.9)
12-15	214 (21.9)	77 (17.9)
16	183 (18.8)	101 (23.4)
Comorbid conditions		
Congestive heart failure	308 (31.6)	136 (31.6)
Chronic obstructive pulmonary disease	197 (20.2)	81 (18.8)
Cerebrovascular accident	289 (29.6)	153 (35.5)
Dementia (minimum data set or hospital discharge)	614 (63.0)	262 (60.8)
Depression	384 (37.4)	155 (36.0)
Diabetes	192 (19.7)	91 (21.1)
Pressure ulcers (last 7 days)	147 (15.1)	59 (13.7)

*Values are expressed as number (percentage).
†Activities of daily living (short form)[22] from minimum data set: sum of self-performance scores for grooming, using the toilet, locomotion, and eating completed at the time of evaluation (scores of 8 were converted to 4).

RESULTS

Project nurses evaluated residents in 2592 episodes with symptoms or signs suggesting an LRI. From these evaluations, we identified 1406 episodes in 1044 individuals for inclusion in our outcome analysis. The Figure shows how we derived our sample. Most residents (n = 794) had a single episode, 176 had 2 episodes, 48 had 3 episodes, 18 had 4 episodes, and 8 had more than 4 episodes. In all but 37 of the 1406 episodes, chest radiographs were available. Based on the assessments of radiographic reports, 186 (13.2%) had possible pneumonia and 748 (53.2%) had probable pneumonia. There were 207 deaths (14.7%) from all causes within 30 days, with 143 in the nursing home, 62 in the hospital, and 2 in an extended care unit following hospitalization. Nineteen percent were hospitalized within 48 hours and 27% were hospitalized within 30 days.

TABLE 1 shows selected characteristics of the development and validation samples at the onset of the LRI episode. Of note, 75% of episodes occurred in subjects who were older than 80 years. TABLE 2 and TABLE 3 show the bivariable relationship of selected variables to 30-day mortality in our entire sample. A large number of variables are associated with 30-day mortality, including most factors seen in previous studies.

Multivariable Analysis

Based on clinical and statistical considerations, we selected an 8-variable model of 30-day LRI mortality, including serum urea nitrogen, white blood cell count, BMI, pulse rate, ADL score, low total lymphocyte count (<800/μL [0.8×10^9/L]), male sex, and decline in mood over 90 days. TABLE 4 shows estimates derived using generalized estimating equations for the entire data set. As shown in TABLE 5, the model fit to the developmental sample showed good discrimination ($c = 0.82$) and calibration (Hosmer-Lemeshow goodness-of-fit statistic $P = .85$ with nonsignificant values indicating acceptable calibration). When the coefficients from the developmental sample were applied to the validation sample, discrimination declined ($c = 0.76$) but calibration remained acceptable ($P = .54$). The validation sample estimate is more likely to be representative of the model's discriminating ability in an independent sample. Another useful measure of discrimination is the ratio of mortality in the highest-risk and lowest-risk quintiles as predicted by the model. In the

development set this ratio was 17.2, and in the validation set it was 13.8. In contrast to these findings, testing of the 11-variable model showed that although it performed well in the development data (c=0.83 and Hosmer-Lemeshow statistic P=0.35), it did not perform as well in the validation set (c=0.74 and P=.001, which indicates poor calibration).

Table 2. Bivariable Relationship of Selected Signs and Symptoms With 30-Day Mortality in the Entire Data Set*

	No. Missing	No. of Residents With Condition	Mortality	
			No. (%)	RR (95% CI)
Demographics				
Age, y	0			
60-69		71	4 (5.6)	0.40 (0.15-1.09)
70-79		279	39 (14.0)	Reference
80-89		613	94 (15.3)	1.10 (0.78-1.55)
≥90		443	70 (15.8)	1.13 (0.79-1.62)
Race	0			
Black		115	17 (14.8)	1.00 (0.63-1.59)
White		1291	190 (14.7)	Reference
Sex	0			
Male		458	89 (19.4)	1.56 (1.21-2.01)
Female		948	118 (12.4)	Reference
Functional status				
Acute decline in function	0	589	103 (17.5)	1.37 (1.07-1.76)
Activities of daily living score†	11			
0-3		228	18 (7.9)	Reference
4-7		280	27 (9.6)	1.22 (0.69-2.16)
8-11		312	38 (12.2)	1.54 (0.90-2.63)
12-15		291	54 (18.6)	2.35 (1.42-3.89)
16		284	65 (22.9)	2.90 (1.77-4.74)
Deterioration in mood in last 90 days	51	115	28 (24.4)	1.81 (1.27-2.57)
Cognitive Performance Scale	11			
0-2		442	39 (8.8)	Reference
3-5		693	109 (15.7)	1.78 (1.26-2.52)
6		260	54 (20.8)	2.35 (1.61-3.45)
Vital signs				
Pulse ≥100/min	26	347	80 (23.1)	1.91 (1.48-2.45)
Respiratory rate ≥30/min	31	405	86 (21.2)	1.72 (1.33-2.21)
Temperature, °C	27			
36.1-38.2		1031	140 (13.6)	Reference
≥38.3		288	51 (17.7)	1.30 (0.97-1.75)
<36.1		60	14 (23.3)	1.72 (1.06-2.79)
Systolic blood pressure <95 mm Hg	53	112	38 (33.9)	2.58 (1.92-3.47)
Diagnosis via chest radiograph				
Possible/probable congestive heart failure	37	295	58 (19.7)	1.51 (1.14-1.99)
Possible/probable pneumonia	37	934	159 (17.0)	1.90 (1.36-2.64)
Laboratory findings				
Absolute lymphocyte count <800/μL (0.8 × 10^9/L)	197	265	64 (24.2)	1.95 (1.48-2.56)
Albumin ≤2.8 g/dL	492	125	46 (36.8)	3.02 (2.25-4.07)
Serum urea nitrogen ≥30 mg/dL (10.7 mmol/L)	221	401	105 (26.2)	2.89 (2.19-3.81)
Cholesterol ≤200 mg/dL (5.18 mmol/L)	680	560	86 (15.4)	2.32 (1.27-4.24)
Hematocrit ≤30%	152	116	26 (22.4)	1.58 (1.10-2.29)
Oxygen saturation <90%	1020	151	47 (31.1)	1.56 (1.10-2.21)
Sodium ≥140 mEq/L	215	589	115 (19.5)	1.90 (1.42-2.53)
White blood cell count ≥15 × 10^3/μL	166	207	50 (24.2)	1.85 (1.38-2.46)

*There were a total of 1406 episodes. Cut points chosen for continuous variables are for illustration only and do not represent the only form in which they were considered in multivariable modeling. RR indicates relative risk; CI, confidence interval.
†Based on minimum data set.

Simplified Clinical Prediction Rule

We used the logistic model based on the entire data set to develop a simplified risk score, which approximates our logistic model, and can be more easily applied by clinicians (TABLE 6 and BOX 2). TABLE 7 shows how individual scores correspond to average predicted probabilities (from the logistic model) and observed mortality. The left portion of the table shows the risk score applied to the entire data set. Table 7 also shows how a similar score based on the logistic model from the development set performs in the development and validation sets.

COMMENT

We developed a new risk-prediction model for LRI in nursing home residents. In a large sample, our simplified scoring system identified 52% of residents with a low (score of 0-4) or relatively low (score of 5-6) 30-day mortality risk. Although many of these residents are likely candidates for nursing home management, 30% of those hospitalized within 48 hours in our study had scores of 0 to 6. Hospitalization rates for nursing home residents with infection and other acute illnesses vary substantially among nursing homes,[30-33] and some of such hospitalizations may be unnecessary.[34] If confirmed in other settings, our model could be helpful in assessing the need for hospitalization. For higher-risk residents, decisions about treatment location will depend on individualized treatment goals and weighing the hazards of hospitalization against the nursing home's capability to provide adequate care.

For patients with community-acquired pneumonia, the current standard for estimating risk is the PSI.[14] It uses age, sex, nursing home residence, altered mental status, vital signs, serum urea nitrogen, glucose, pH, serum sodium, oxygen saturation, presence of pleural effusion, and selected

comorbid diseases to classify individuals into 5 risk groups. However, its structure (adding points for each year of age and for nursing home residence) places most nursing home residents in high-risk categories. In a retrospective study, the PSI predicted mortality reasonably well in 158 episodes of nursing home–acquired pneumonia[9]; however, 85% were classified in the highest-risk categories (classes IV and V). Although we studied the broader category of LRI and not just pneumonia, the PSI classifies 87% of our subjects in risk classes IV and V. While the PSI remains an important tool in the more general context for which it was developed, our model better distinguishes lower-risk episodes of LRI in the nursing home setting.

Our predictors bear some similarities but also notable differences to those in the PSI. Common variables to both predictive models include pulse, serum urea nitrogen, and male sex. Age, a key determinant of the PSI, dropped out early in our modeling process and is not statistically significant if added to our final model. This likely reflects the old age of our sample and the nursing home population in general. Among such individuals, functional measures, such as ADL status, provide more useful prognostic information than chronological age.

As with our model, ADL dependency has been repeatedly associated with LRI or pneumonia mortality in nursing home samples.[5-7,10,11,35] Poor nutritional status has been linked to a variety of poor outcomes.[36] Low BMI and low total lymphocyte count,[37] which are 2 markers of poor nutritional status, were strongly associated with mortality from LRI in our model. It is possible that other nutritional variables might be superior, but both of these are readily available.

Our final 2 risk factors were elevated white blood cell count and decline in mood over the previous 90 days. While elevated white blood cell count has not been a significant predictor in previous multivariable models of mortality from pneumonia in nursing home settings, it was in 2 hospital-based studies of pneumonia outcomes[38,39]; one of these included just elderly patients.[39] Major depression[40] and comorbid depression[41-43] have been associated with mortality in nursing home residents, but not specifically from LRI. In our study, mood decline was a better predictor than summary depression scores, so it is not clear if this reflects depression or is a marker for general decline.

Several variables do not appear in our model. Rapid respiratory rate predicts mortality not only in the PSI, but also in 3 previous nursing home studies using multivariable analyses, including our pilot study.[5,7,35] In the current study, pulse rate was highly correlated with

Table 3. Bivariable Relationship of Conditions With 30-Day Mortality in the Entire Data Set*

	No. Missing	No. of Residents With Condition	Mortality	
			No. (%)	RR (95% CI)
Conditions				
Body mass index, kg/m^2	11			
<18.80		280	69 (24.6)	Reference
18.80-21.39		278	43 (15.5)	0.63 (0.44-0.88)
21.40-23.59		269	33 (12.3)	0.50 (0.34-0.73)
23.60-26.69		270	32 (11.8)	0.48 (0.33-0.71)
≥26.70		298	24 (8.05)	0.33 (0.21-0.50)
Cough	0	1182	151 (12.8)	0.51 (0.39-0.67)
Decubitus ulcers	0	206	49 (23.8)	1.81 (1.36-2.40)
Feeding tube	0	132	23 (17.4)	1.21 (0.81-1.79)
Foley catheter	7	90	16 (17.8)	1.23 (0.77-1.96)
No influenza vaccine within year	266	183	25 (13.7)	1.04 (0.70-1.55)
No pneumonia vaccine on chart	3	888	140 (15.8)	1.21 (0.92-1.59)
Somnolent or comatose or restless	0	313	79 (25.2)	2.16 (1.68-2.77)
Weight loss	41	186	39 (21.0)	1.58 (1.16-2.17)
Comorbid conditions				
Chronic obstructive pulmonary disease	0	278	32 (11.5)	0.74 (0.52-1.06)
Congestive heart failure	0	444	88 (19.8)	1.60 (1.25-2.06)
Diabetes	0	283	32 (11.3)	0.73 (0.51-1.03)
Stroke	0	442	67 (15.2)	1.04 (0.80-1.37)

*There was a total of 1406 episodes. Cut points chosen for continuous variables are for illustration only and do not represent the only form in which they were considered in multivariable modeling. RR indicates relative risk; CI, confidence interval.

Table 4. Predictors of 30-Day Mortality in Residents With 4 or Fewer Episodes: Generalized Estimating Equations Analysis*

Variable	Coefficient	OR (95% CI)
Intercept	–4.53	
Serum urea nitrogen, mg/dL†	0.046	1.58 (1.42-1.76)‡
White blood cell count, × 10^3/μL	0.052	1.69 (1.23-2.32)‡
Absolute lymphocyte count <800/μL§	0.613	1.85 (1.27-2.69)
Pulse	0.017	1.19 (1.08-1.30)‡
Men§	0.555	1.74 (1.24-2.44)
Activites of daily living (0-4 scale)	0.310	1.36 (1.21-1.53)
Body mass index‖	–0.089	0.41 (0.28-0.61)‡
Deterioration in mood in past 90 days§	0.970	2.64 (1.58-4.39)

*There was a total of 1394 episodes. Values represent the model to fit the entire data set as follows: serum urea nitrogen less than 10 mg/dL was set to 10 and greater than 80 mg/dL to 80; white blood cell counts less than 5 × 10^3/μL were set to 5 and greater than 30 × 10^3/μL to 30; pulse less than 60/min was set to 60 and greater than 140/min to 140; body mass index less than 12 kg/m^2 to 12 and greater than 35 kg/m^2 to 35. OR indicates odds ratio; CI, confidence interval.
†To convert to mmol/L, multiply by 0.357.
‡Odds ratio is shown for a 10-unit change.
§For dichotomous variables, 1 equaled yes or present; zero, no or not present.
‖If calculated using pounds and inches, convert to kg/m^2 by multiplying by 693.6.

Table 5. Measures of Calibration and Discrimination for Generalized Estimating Equations Analysis of 30-Day Mortality in Development and Validation Data Sets and All Data Combined*

Data Set	Quintile of Mortality Risk, %†					*c*	*P* Value‡
	1	2	3	4	5		
Entire (1394 episodes)§						.80	.82
Predicted	2.3	5.5	9.5	16.7	40.3		
Observed	2.5	3.9	9.0	17.6	40.5		
Developmental (970 episodes)‖						.82	.84
Predicted	1.8	4.8	8.9	16.2	42.0		
Observed	2.6	3.1	8.8	15.5	43.3		
Validation (431 episodes)						.76	.54
Predicted	1.8	4.6	9.1	17.6	46.4		
Observed	2.3	7.0	8.1	23.3	33.7		

*All analyses were restricted to a maximum of 4 episodes per individual.
†One is the lowest and 5 is the highest level of risk.
‡Hosmer-Lemeshow goodness-of-fit test. Calculated using deciles, but quintiles are presented for simplicity. Nonsignificant values indicate good fit.
§The model fit to the entire data set is not the same as the one fit to the developmental data alone. The coefficients of the model for the entire data set are shown in Table 4.
‖The coefficients for the model fit to developmental data only are: intercept, −4.800; serum urea nitrogen, 0.051; white blood cell count, 0.047; absolute lymphocytes less than 800/μL, 0.743; pulse, 0.017; men, 0.618; body mass index, −0.094; activities of daily living, 0.372; and deterioration in mood, 1.290. Units for all variables are the same as those in Table 3.

Table 6. Scoring System for Estimating 30-Day Mortality From Lower Respiratory Tract Infection*

Variable and Value	Points Assigned
Serum urea nitrogen, mg/dL†	
≤16	0
16.1-27	1
27.1-38	2
38.1-49	3
49.1-60	4
60.1-71	5
>71	6
White blood cell count	
≤14	0
14.1-24	1
>24	2
Absolute lymphocyte count	
>800/μL (0.8×10^9/L)	0
≤800/μL (0.8×10^9/L)	1
Pulse, beats/min	
≤72	0
73-102	1
103-132	2
>132	3
Sex	
Female	0
Male	1
Body mass index, kg/m^2	
>31	0
25.1-31	1
19.1-25	2
13.1-19	3
≤13	4
Activities of daily living‡	
0	0
1-2	1
3-4	2
Mood deterioration over last 90 days	
No	0
Yes	2

*Select the appropriate number of points for each variable. To derive risk score, sum the assigned points.
†To convert to mmol/L, multiply by 0.357.
‡Based on grooming, using the toilet, locomotion, and eating. Each is assigned a zero if the resident is independent, requires supervision, or requires limited assistance; 1, if the resident requires extensive assistance or is totally dependent. The 4 scores are summed to derive a score of zero to 4, which is assigned points as shown.

respiratory rate and was a better predictor than respiratory rate. Nonetheless, absence of respiratory rate as a variable is a potential weakness of our risk prediction score, and it will be an important variable to assess in future studies evaluating our prediction rule. Oxygen saturation is also an important variable in the PSI, but such measurements were relatively uncommon in nursing homes during our study. For the 27% of subjects who had such data, adding oxygen saturation did not improve our prediction rule. Oxygen saturation data may play an important role in assessing treatment decisions in the future. Although fever, low temperature, and bilateral infiltrates have clinical appeal, and on a bivariable level are strongly related to mortality, they did not improve our model. In fact, low temperature and abnormal radiographic findings were included in our penultimate model (the 11-variable model) but were removed because they weakened the model in other random samples. Finally, several comorbid conditions, such as congestive heart failure, are important indicators in the PSI. None were significant in our multivariable modeling. Their lack of importance in our models may reflect their high prevalence and the high degree of disability among nursing home residents (Table 1).

Limitations

Our findings are subject to several limitations. A key issue is generalizability to other settings. All study facilities were in central or eastern Missouri. While they were similar in size and ownership to facilities nationally,[15] factors affecting mortality could differ in other states or countries. More importantly, predictive models often perform less well in independently derived samples. Internal validation samples help avoid overfitting models to the peculiarities of a particular data set, but that is not sufficient to determine the ultimate utility of a prediction rule. Our model and its associated scoring system should be validated in other studies of nursing home residents to confirm their usefulness.

Second, important data may have been missing or misclassified. Although we identified subjects prospectively, some examination information had to be obtained from hospital records in 9.2% of evaluations. Hospital record data may not have been as detailed as project nurse assessments. Further, though all project nurses had strong assessment skills and additional training for this project, they might have missed some important findings. However, among variables ultimately included in our model, biases are unlikely. Most represented objective findings with high reliability, including pulse, sex, and the 3 laboratory results. Weight and height to compute BMI may be unreliable in nursing home records, but it is unlikely that they would be systematically biased across the study. Patient ADL status and information on mood decline were obtained from interviews with nursing home staff familiar with the resident.

Box 2. Numerical Example of the Missouri Lower Respiratory Tract Infection (LRI) Project Risk Score

Consider a hypothetical male nursing home resident with an LRI who exhibits the following: serum urea nitrogen of 20 mg/dL (7.14 mmol/L); white blood cell count of 8000/μL (8.0×10^9/L) with 15% lymphocytes; pulse of 80/min; requires extensive assistance in hygiene and locomotion, limited assistance in using the toilet, and supervision in eating; weight, 66 kg (145 lb); height, 170.3 cm (5' 8"); and has not had a recent decline in mood.

To calculate absolute lymphocyte count, multiply white blood cell count by percentage of lymphocytes: (8000/μL) × .15 = 1200/μL. To convert height to meters, recall that there are 2.54 cm per inch. Therefore, body mass index equals 66 divided by $(68 \times .0254)^2 = 22.1$.

The Missouri LRI Project risk score is calculated as follows:

(1 point for serum urea nitrogen) + (0 points for white blood cell count) + (0 points for absolute lymphocyte count <800/μL) + (1 point for pulse) + (1 point for sex) + (1 point for activities of daily living) + (2 points for body mass index) + (0 points for mood change) = 6 total points.

Table 7 shows that individuals with a score between 5 and 6 have a predicted 30-day mortality risk of 6.9%. Alternatively, using the logistic model in Table 4, a 6.7% mortality risk would be obtained as follows:

$$\text{sum} = (-4.53 + [0.046 \times 20] + [0.052 \times 8] + [0.613 \times 0] + [0.017 \times 80] + [0.555 \times 1] + [0.31 \times 2] - [0.089 \times 22.1] + [0.97 \times 0]) = -2.63$$

$$\text{predicted mortality} = e^{\text{sum}}/(1 + e^{\text{sum}}) = 0.067 \text{ or } 6.7\%$$

Table 7. Observed and Predicted Mortality From Lower Respiratory Tract Infection Associated With Level of Risk Score*

Data Set	Mortality Risk Score 1-4 (Low)	5-6 (Relatively Low)	7-8 (Moderate)	9-10 (High)	11-17 (Very High)
Entire (1394 episodes)					
No. of episodes	276	451	418	184	65
Predicted mortality, %	2.4	6.9	15.6	34.5	61.6
Observed mortality, %	2.2	6.2	15.8	35.9	60.0
Developmental (970 episodes)†					
No. of episodes	164	253	297	162	94
Predicted mortality, %	1.7	5.0	11.8	26.6	52.8
Observed mortality, %	1.8	5.1	10.8	27.2	53.2
Validation (431 episodes)					
No. of episodes	75	111	115	79	51
Predicted mortality, %	2.7	7.2	15.7	22.8	35.3
Observed mortality, %	1.8	5.0	11.6	25.0	54.2

*All analyses were restricted to a maximum of 4 episodes per individual. Predicted values represent the average predicted probability from the generalized estimating equations model for all episodes with specified point totals. Observed mortality is the actual mortality for those with specified point totals. We recommend values for the entire data set as the most likely to be generalizable.

†The points assigned for the model fit to developmental data only are: serum urea nitrogen (mg/dL, 14 or less = zero, 14.1 to 24 = 1, 24.1 to 34 = 2, 34.1 to 44 = 3, 44.1 to 54 = 4, 54.1 to 64 = 5, 64.1 to 74 = 6, 74 or more = 7; white blood cell count ($\times 10^3$/μL), 14 or less = zero, 14.1 to 24 = 1, 24.1 or more = 2; absolute lymphocyte count 800/μL or less = 1, greater than 800/μL = zero; pulse 74/min or less = zero, 75 to 104 = 1, 105 to 134 = 2, 135 or more = 3; sex, male = 1, female = zero; body mass index (kg/m^2), 14 or less = 4, 14.1 to 19 = 3, 19.1 to 25 = 2, 25.1 to 30 = 1, 30.1 or more = zero; activities of daily living (scale of 0-4), 0 = zero, 1 to 2 = 1, 3 = 2, 4 = 3; and deterioration in mood yes = 3, no = zero. Units for all variables are the same as those in Table 3. Conversion factors for international units are shown in Table 3.

Finally, we combined pneumonia and other LRIs in our analysis because clinically distinguishing between the 2 is often difficult, particularly in the nursing home setting, where physicians, advanced-practice nurses, or physician assistants are frequently unavailable to assess acutely ill residents. Portable radiographs obtained in nursing homes are of variable quality and require cautious interpretation. Although we made special efforts to ensure consistency in classifying radiology reports as possible, probable, or negative for pneumonia, we reviewed reports rather than radiographs in most cases. We may have misclassified some subjects as to whether their radiograph suggested pneumonia. We chose to review reports since reports and not radiographs are usually available to physicians caring for nursing home residents. Furthermore, because of our broader definition of LRI, a chest radiograph positive for pneumonia was not essential for study inclusion. However, pneumonia on chest radiograph was not a significant predictor of mortality in our multivariable model. These choices were intended to make our findings optimally useful to physicians making treatment decisions for ill nursing home residents with LRIs.

Conclusion

We identified a new predictive model for 30-day mortality risk in nursing home residents with LRIs. Our results are notable for identifying relatively low-risk residents. Our prediction rule could aid clinicians and researchers in optimizing care for nursing home residents with LRIs. As with all prediction rules, it should be validated in other settings.

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