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Development and validation of a nomogram for predicting the risk of nursing home-acquired pneumonia

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Abstract. – OBJECTIVE: Nursing home-acquired pneumonia (NHAP) is one of the most frequent infections in nursing homes, with a difficult diagnosis, poor prognosis, and high mortality. The present study was performed to develop and validate a nomogram to predict the risk of NHAP in nursing homes.

MATERIALS AND METHODS: Based on a literature review and clinician's recommendations, we identified and collected the possible factors affecting the occurrence of NHAP. Based on the above factors, a retrospective observational study of 620 nursing home residents' medical records was performed from September 2016 to September 2021. Significant risk factors for NHAP were identified by univariate and multivariate analysis successively. A nomogram was constructed based on the binary logistic regression models to visualize the prediction model. The model's performance was determined by the concordance index (C-index), and the prediction accuracy was evaluated using a calibration curve. Clinical effectiveness was evaluated by decision curve analysis (DCA).

RESULTS: Finally, 12 independent risk factors were identified and assembled into the nomogram. The nomogram had a C-index of 0.958 (95% confidence interval: 0.943-0.972). The area under the receiver operating characteristic curve (AUC-ROC) value of the nomogram was 0.958 ($p<0.05$), and the calibration plot showed good goodness of fit. The decision curve analysis and clinical impact curve showed good clinical usefulness of the nomogram.

CONCLUSIONS: A nomogram for the early prediction of NHAP, which is easy for nurses to perform in nursing homes, was successfully constructed and validated, and it had a good predictive performance.

Key Words:
Risk factor, Prediction model, Nomogram, Nursing home-acquired pneumonia.

Introduction

Nursing home acquired pneumonia (NHAP) is one of the most common infections among nursing home residents[1] and accounts for more than 40% of the total infection rate[2]. Most of the residents in nursing homes are older people with comorbidities[3] and usually with multidrug resistance (MDR)[4]. The mortality rate of NHAP is as high as 46.6%[5,6], and it is the leading cause of death among nursing home residents[5,7]. Considering the high prevalence and high mortality of NHAP among nursing homes, early assessment and diagnosis might be crucial for preventing the occurrence of NHAP. However, due to the atypical clinical manifestations of NHAP[8,9] and the weak specificity of evaluation tools[10] and biological markers[11], there is no clear diagnostic standard for NHAP worldwide[5]. Conditions vary from region to region, thus not all nursing homes have imaging and laboratory examination[12], and some of the older people in the nursing home are bedridden for a long time and their activities are limited, so it is inconvenient to transfer them to the hospital for examination, which further increases the difficulty of diagnosis. Due to the difficulty of early diagnosis of NHAP, empirical antibiotic treatment is preferred in most cases before diagnosis[13], but cannot effectively control the progression of NHAP[14]. Therefore, identifying and effectively applying objective and easily obtainable indicators in a nursing home environment to predict NHAP is essential. Based on these indicators, a prediction model for NHAP should be established to primarily screen out residents with high NAHP risk and locate their specific problems, which would be critical for early targeting of each resident's specific risk factors for NHAP to develop effective preventive strategies.

Early studies identified several risk factors for the occurrence of NHAP, such as advanced age[15], male sex[16], bedridden status[17], malnutrition[5], oral hygiene[18], dysphagia[19], aspiration[20], tube feeding[21], consciousness[19], polypharmacy [22], etc. NHAP patients are characterized by poor

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body function and comorbidities[5], such as asthma, immunosuppression, lung disease, diabetes, dementia, or stroke, which are closely related to NHAP[23]. The use of some drugs, such as antipsychotics, histamine receptor blockers and proton pump inhibitors, sedatives, and steroids, is also associated with a high risk of NHAP[2,11]. However, there is a lack of comprehensive research, and the independent risk factors for NHAP were equivocal. None of the studies integrated the risk factors for NHAP to establish a prediction model.

Nomograms are well-established statistical tools to individualize risk assessment[24]. By integrating different determinant variables, nomograms can generate the individual probability of clinical events, visualize the prediction model and quantify the risk[25]. Nomograms meet our needs for clinically integrated models and fulfilled our drive toward personalized medicine. Compared with other tools, nomograms are more convenient and suitable for the special environment of nursing homes. The purpose of this study was to identify independent risk factors for the occurrence of NHAP in nursing home residents and develop and verify a visual NHAP individual risk prediction model.

Patients and Methods

Study Design and Participants

This retrospective observational study included patients who resided in a nursing home in Northeast China between September 2016 and September 2021. The inclusion criteria of patients were as follows: a. no pneumonia presented within 48 hours of admission; b. complete medical records. c. the diagnosis of NHAP was signed and confirmed by the clinician and recorded in the medical record. The diagnostic criteria of NHAP are based on the following: (1) have at least two of the following typical clinical manifestations: cough, expectoration, fever, chest pain, general weakness and loss of appetite. Wet rales can be heard during lung auscultation. When the lung is solid, there are signs such as percussion dullness, enhanced speech fibrillation and bronchial respiratory sound; (2) interpretation of a chest radiograph as demonstrating pneumonia, probable pneumonia, or the presence of an infiltrate; (3) the same pathogen was isolated from blood or sputum culture for two consecutive times. This study included 27 variables that were potentially associated with the occurrence of NHAP. According to the principle that each variable in regression analysis has at least ten outcome events[26], the minimum sample size required 270 NHAP samples. The final sample size is estimated to be approximately 540. This study followed the guidelines of the Declaration of Helsinki. Due to the retrospective and non-interventionist design, this study waived written informed consent.

Predictor Variables and Data Collection

Based on a literature review and clinician recommendations from the nursing home, we identified possible factors affecting the occurrence of NHAP and collected data on these variables from medical records. Data from the NHAP patients were collected from admission to diagnosis of NHAP. The data collection of non-NHAP residents included all medical record information throughout their hospitalization in nursing homes, and the specific indicators were subject to the latest data. NHAP-related variables included age, gender (male, female), body mass index (BMI), weight loss (no, slight, sustained), nutritional status (poor, average, good), oral hygiene (poor, inadequate, good), dependence of oral care (independent, partially dependent, totally dependent), type of diet (general diet, semiliquid, all-liquid), consciousness (clear-headed state, somnolence/confusion/stupor), time of bedridden (no, within one year, more than one year), Barthel index values (independent, mild dependent, moderate dependent, severe dependent), Kubota's Water Swallow Test score, bucking (no, occasionally, often), aspiration (no, yes), gastroesophageal reflux (no, occasionally, often), comorbidities (no, yes), tracheotomy (no, yes), smoking (no, yes), drinking (no, yes), number of drug types, steroid (China Resources Sanjiu Medical & Pharmaceutical Co., Ltd., Shenzhen, Guangdong Province, China) therapy (no, yes), antacid drug (hunanfangsheng pharmaceutical co., ltd., Changsha, Hunan Provence, China) use (no, yes), sedative-hypnotic drug (Shanghai Pharmaceuticals Holding Co., Ltd., Shanghai, China) use (no, yes), suction (no, occasionally, often), oral care frequency (0, 1, ≥ 2 times/day), nasal feeding tube (no, yes), frequency of turning over and backslap (no, occasionally, every 2 hrs during daytime, every 2 hrs all day). The cut-off values for continuous variables were defined according to the threshold of clinical significance by the ROC curve as follows: age (86 years), BMI (20 kg/m^2), number of drug types (4) and Water Swallow Test Score (2 points). To avoid potential bias, all variables were clearly defined as

exposure before the study, and details are noted in Table I. Data collection and recording were conducted simultaneously by two clinical nurses and one clinician, all of whom received standardized training. They are not involved in data analysis or verifying the statistical significance of the conclusion and are not responsible for it.

Statistical Analysis

Data were entered using Microsoft Excel 2019 for Windows (Microsoft, Redmond, WA, USA). MedCalc software 19.0.4 for Windows (MedCalc Software Ltd, Ostend, Belgium) was used to draw the receiver operating characteristic (ROC) curve. The variables were analyzed by IBM SPSS Statistics 25.0 for Windows (IBM Corp., Armonk, NY, USA). R software for Windows (version 3.5.1; http://www.R-project.org) was used to construct a nomogram and verify the model. $p<0.05$ was considered as statistically significant for all the analyses in this study.

Data were presented as frequencies and percentages for categorical variables. To optimize the discrimination ability and simplify the application, each continuous variable was converted into binary categorical variables by the receiver operating characteristic (ROC) curve (realized by MedCalc software) to judge the threshold value. Variables were analyzed by IBM SPSS Statistics 25.0 for Windows. All variables were compared using the x^2 test for single factor analysis. Then, variables associated with the occurrence of NHAP were included in the binary logistic regression analysis to identify independent risk factors. A nomogram (realized by the rms package of R software) was constructed based on the results of the binary logistic regression model to establish the prediction scoring system of NHAP. The basic principle of the nomogram was to assign scores based on the weight of each influencing factor in the binary logistic regression model and finally calculate the predicted value of NHAP through the functional transformation relationship between the total score and the occurrence probability of NHAP.

In the model verification phase, we used the bootstrap method for internal verification (complete after sampling the original data 1000 times) and the concordance index (C-index) with 95% confidence interval (CI) to measure the discrimination of the prediction model. The area under the receiver operating characteristic (ROC) curve was used to test the prediction ability of the model. In general, an area under the ROC curve (AUC) > 0.75 indicated that the model had sufficient discrimination. Furthermore, the calibration curve was used to verify the accuracy of the model. Decision curve analysis (DCA) was used to investigate the net benefit of patients and compare it with the net benefit of patients predicted by separate factors to prove its clinical applicability. Finally, a clinical impact curve (CIC) was plotted to evaluate the applicability net benefits of the model with the best diagnostic value.

Results

Characteristics of Included Residents

In total, 620 residents in the nursing homes were included in this study, with a median age of 88 years (IQR: 83-92 years), and 276 patients (44.5%) were male. Among them, 336 (54.2%) residents had NHAP and 284 (45.8%) residents did not suffer from NHAP. The characteristics of NHAP patients and non-NHAP patients are shown in Table I. There was no significant difference in sex ($p=0.187$), gastroesophageal reflux ($p=0.156$), or tracheotomy ($p=0.868$) between the non-NHAP group and the NHAP group by single factor analysis. Factors with $p<0.05$ in the NHAP rate screened above were further analyzed by binary logistic regression, and twelve independent risk factors were identified, including age, weight loss, oral hygiene, water swallow test score, aspiration, comorbidities, smoking, steroid (China Resources Sanjiu Medical & Pharmaceutical Co., Ltd., Shenzhen, Guangdong Province, China) therapy, sedative-hypnotic drug (Shanghai Pharmaceuticals Holding Co., Ltd., Shanghai, China) use, suction, oral care frequency and frequency of turning over and backslap. The detailed analysis results are presented in Table II, and the results are reported as odds ratios (95% CIs). The forest map of influencing factors is shown in Figure 1a.

Development of the NHAP Prediction Model

Based on binary logistic regression, we constructed a nomogram (Figure 1 b) to visualize the NHAP risk prediction model. Coefficients of the variables were scaled to scores within the range of 0 to 100, reflecting their contribution to the occurrence of NHAP. The scoring system of the nomogram is shown in Table III. The scores of each variable were added together to obtain the total score of the patient. In this NHAP prediction

Table I. Univariate analysis of possible risk factors affecting the occurrence of NHAP.

Variable	Non-NHAP n=284(%)	NHAP n=337(%)	c^2	*p*-value
Baseline characteristics				
Age (years old)				
≤86	227 (66.2)	116 (33.8)	45.619	<0.001*
>86	108 (39)	169 (61)		
Gender				
Male	141(51.1)	135 (48.9)	1.737	0.187
Female	194 (56.4)	150 (43.6)		
Body mass index (kg/m^2)				
>20	194 (68.3)	90 (31.7)	43.011	<0.001*
≤20	141 (42)	195 (58)		
Weight loss †				
No weight loss	178 (73.6)	64 (26.4)	138.028	<0.001*
Slight weight loss	153 (55)	125 (45)		
Sustained weight loss	4 (4)	96 (96)		
Nutritional status ‡				
Poor	143 (69.4)	63 (30.6)	72.465	<0.001*
Average	173 (55.6)	138 (44.4)		
Good	19 (18.4)	84 (81.6)		
Oral hygiene §				
Poor	180 (78.3)	50 (21.7)	115.914	<0.001*
Inadequate	152 (45.2)	184 (54.8)		
Good	3 (5.6)	51 (94.4)		
Dependence of oral care				
Independent	109 (80.1)	27 (19.9)	94.344	<0.001*
Partially dependent	165 (60.2)	109 (39.8)		
Totally dependence	61 (29)	149 (71)		
Type of diet				
General diet	222 (69.8)	96 (30.2)	90.307	<0.001*
Semiliquid	64 (55.7)	51 (44.3)		
All-liquid	49 (26.2)	138 (73.8)		
Consciousness ‖				
Clear-headed state	294 (64.2)	164 (35.8)	72.847	<0.001*
Somnolence/Confusion/Stupor	41 (25.3)	121 (74.7)		
Time of bedridden				
No	103 (75.7)	33 (24.3)	94.725	<0.001*
Within 1 year	130 (70.7)	54 (29.3)		
More than 1 year	102 (34)	198 (66)		
Barthel index values ¶				
Independent	63 (84)	12 (16)	52.918	<0.001*
Mild dependent	34 (65.4)	18 (34.6)		
Moderate dependent	74 (64.9)	40 (35.1)		
Severe dependent	164 (43.3)	215 (56.7)		
Water Swallow Test (score) ††				
≤2	248 (76.3)	77 (23.7)	136.458	<0.001*
>2	87 (29.5)	208 (70.5)		
Bucking				
No	264 (61.3)	167 (38.7)	30.157	<0.001*
Occasionally	58 (36.5)	101 (63.5)		
Often	13 (43.3)	17 (56.7)		
Aspiration				
No	326 (57.3)	243 (42.7)	29.621	<0.001*
Yes	9 (17.6)	42 (82.4)		
Gastroesophageal reflux				
No	276 (56)	217 (44.0)	3.718	0.156
Occasionally	45 (46.9)	51 (53.1)		
Often	14 (45.2)	17 (54.8)		

Continued

Table I. Univariate analysis of possible risk factors affecting the occurrence of NHAP.

Variable	Non-NHAP n=284(%)	NHAP n=337(%)	χ^2	*p*-value
Comorbidities				
No	212 (82.8)	44 (17.2)	145.416	<0.001*
Yes	123 (33.8)	241 (66.2)		
Tracheotomy				
No	331 (54)	282 (46)	0.028	0.868
Yes	4 (57.1)	3 (42.9)		
Smoking				
No	325 (56.5)	250 (43.5)	19.768	<0.001*
Yes	10 (22.2)	35 (77.8)		
Drinking				
No	329 (56.4)	254 (43.6)	22.655	<0.001*
Yes	6 (16.2)	31 (83.8)		
Treatment/nursing status				
Number of drug types				
>4	225 (69.9)	97 (30.1)	67.706	<0.001*
≤4	110 (36.9)	188 (63.1)		
Steroid therapy				
No	302 (61.9)	186 (38.1)	56.912	<0.001*
Yes	33 (25)	99 (75)		
Antacid drug use				
No	284 (58.6)	201 (41.4)	18.358	<0.001*
Yes	51 (37.8)	84 (62.2)		
Sedative-hypnotic drug use				
No	246 (63.9)	139 (36.1)	39.790	<0.001*
Yes	89 (37.9)	146 (62.1)		
Suction				
No	291 (70.3)	123 (29.7)	133.265	<0.001*
Occasionally	37 (22.8)	125 (77.2)		
Often	7 (15.9)	37 (84.1)		
Oral care frequency(times/day)				
0	215 (72.1)	83 (27.9)	81.966	<0.001*
1	77 (43.5)	100 (56.5)		
≥2	43 (29.7)	102 (70.3)		
Nasal feeding tube				
No	297 (66)	153 (34)	94.640	<0.001*
Yes	38 (22.4)	132 (77.6)		
Frequency of turning over and backslap				
No	62 (56.4)	48 (43.6)	31.121	<0.001*
Occasionally	122 (49.4)	125 (50.6)		
Every 2 hrs during daytime	73 (44.8)	90 (55.2)		
Every 2 hrs all day	78 (78)	22 (22)		

NHAP=nursing home acquired pneumonia; q2h=every 2 hrs. *p<0.05, indicates statistically significant. †The degree of weight loss as no weight loss, slight weight loss (recent weight loss < 5%) or sustained weight loss (continuous weight loss > 3 months and ≥ 5%). ‡Nutritional status was graded Through the Subjective Global Assessment (SGA)[44]. §Oral hygiene was assessed according to Oral Assessment Guide (OAG)[45]. ‖The state of consciousness was divided into four levels according to Glasgow Coma Scale (GCS): clear-headed state, somnolence, confusion, stupor, and according to the number of people at each level, we combined the last three items during data analysis. **Barthel index values was used to evaluate the self-care ability of patients. The total score is 100, 61-99 is mild dependent, 41-60 is moderate dependence, and ≤40 is severe dependence. ††Kubota's Water Swallow Test was a method to evaluate the swallowing function of patients.

Table II. Multivariate analysis of independent risk factors affecting the occurrence of NHAP. *(Continued)*

Variables	Coefficients	SE	*p*-value	OR (95% CI)
Age (years old)				
>86	1.61	0.326	<0.001*	5.002 (2.64-9.475)
≤86	0			1
Body mass index (kg/m²)				
≤20	0.038	0.435	0.931	1.038 (0.442-2.437)
>20	0			1
Weight loss			0.002*	
Sustained weight loss	3.49	0.976	<0.001	32.790 (4.843-221.993)
Slight weight loss	0.685	0.439	0.118	1.984 (0.840-4.688)
No weight loss	0			1
Nutritional status			0.091	
Poor	-0.682	0.888	0.443	0.506 (0.089-2.885)
Average	-1.19	0.6	0.047	0.304 (0.094-0.985)
Good	0			1
Oral hygiene			<0.001*	
Poor	4.158	1.041	<0.001	63.965 (8.317-491.922)
Inadequate	1.053	0.411	0.01	2.867 (1.281-6.418)
Good	0			1
Dependence of oral care			0.052	
Totally dependence	1.779	0.808	0.028	5.924 (1.215-28.875)
Partially dependent	1.428	0.616	0.02	4.172 (1.247-13.961)
Independent	0			1
Type of diet			0.492	
Semiliquid	0.174	0.479	0.716	1.190(0.466-3.040)
All-liquid	-1.521	1.52	0.317	0.219 (0.011-4.296)
General diet	0			1
Consciousness				
Somnolence/Confusion/Stupor	0.32	0.467	0.493	1.377 (0.552-3.438)
Clear-headed state	0			1
Time of bedridden			0.445	
More than 1 year	0.408	0.461	0.377	1.503 (0.609-3.709)
Within 1 year	-0.07	0.487	0.886	0.932 (0.359-2.421)
No	0			1
Barthel index values			0.081	
Mild dependent	-0.259	0.757	0.733	0.772 (0.175-3.405)
Moderate dependent	-0.38	0.681	0.576	0.684 (0.180-2.595)
Severe dependent	-1.529	0.765	0.046	0.217 (0.048-0.971)
Independent	0			1
Water Swallow Test (score)				
>2	1.251	0.507	0.014*	3.492 (1.294-9.425)
≤2	0			1
Bucking			0.082	
Often	-0.836	0.952	0.38	0.434 (0.067-2.802)
Occasionally	-1.022	0.458	0.026	0.360 (0.147-0.884)
No	0			1
Aspiration				
Yes	2.345	0.971	0.016*	10.437 (1.556-70.02)
No	0			1
Comorbidities				
Yes	2.996	0.46	<0.001*	20.005 (8.113-49.330)
No	0			1

Continued

Table II. Multivariate analysis of independent risk factors affecting the occurrence of NHAP. *(Continued)*

Variables	Coefficients	SE	*p*-value	OR (95% CI)
Smoking				
Yes	2.914	0.781	<0.001*	18.439 (3.986-85.301)
No	0			1
Drinking				
Yes	1.834	0.987	0.063	6.262 (0.905-43.317)
No	0			1
Number of drug types				
>4	-0.429	0.368	0.244	0.651 (0.317-1.340)
≤4	0			1
Steroid therapy				
Yes	0.959	0.424	0.024*	2.608 (1.137-5.985)
No	0			1
Antacid drug use				
Yes	-0.272	0.414	0.511	0.762 (0.338-1.714)
No	0			1
Sedative-hypnotic drug use				
Yes	0.83	0.336	0.013*	2.293 (1.187-4.430)
No	0			1
Suction			<0.001*	
Occasionally	2.027	0.48	<0.001	7.589 (2.96-19.455)
Often	1.858	0.924	0.044	6.411 (1.047-39.248)
No	0			1
Oral care frequency (times/day)			<0.001*	
≥2	1.786	0.467	<0.001	5.965 (2.389-14.894)
1	0.04	0.493	0.936	1.041 (0.396-2.737)
0	0			1
Nasal feeding tube				
Yes	1.186	1.444	0.412	3.273 (0.193-55.443)
No	0			1
Frequency of turning over and backslap			<0.001*	
No	3.787	0.741	<0.001	44.113 (10.324-188.493)
Occasionally	1.657	0.654	0.011	5.245 (1.454-18.914)
q2h during daytime	2.255	0.67	0.001	9.533 (2.566-35.417)
q2h all day	0			1
Constant	-8.083	0.952	<0.001	<0.001

SE=Standard error; OR=odds ratio; CI= confidence interval; q2h=every 2 hrs. *p<0.05, indicates statistically significant.

model, the distribution of scores generated by the nomogram ranged from 0 to 330 with a median of 207 (interquartile range: 178-237), and the risk of the occurrence of NHAP increased with the score. We selected 50% as the cut-off score point. In other words, if the patient's score is greater than the cut-off score point of 207, the patient has a high probability of NHAP.

Validation and Assessment of the NHAP Prediction Model

In this NHAP prediction model, the C-index was 0.958 (95% CI: 0.943-0.972), which was used to show the predictive accuracy. This result indicated that our nomogram had a good level of discriminative ability. The ROC curve of the NHAP prediction model is shown in Figure 2a, and the AUC was 0.958 (p<0.05). In the calibration chart (Figure 2b), the calibration curve almost coincides with the reference line. This means that the predicted values of the nomogram were in good agreement with the actual observed values. Decision curve analysis (DCA) (Figure 2c) showed that using the nomogram to predict the occurrence of NHAP had the best net benefit. In the clinical impact curve

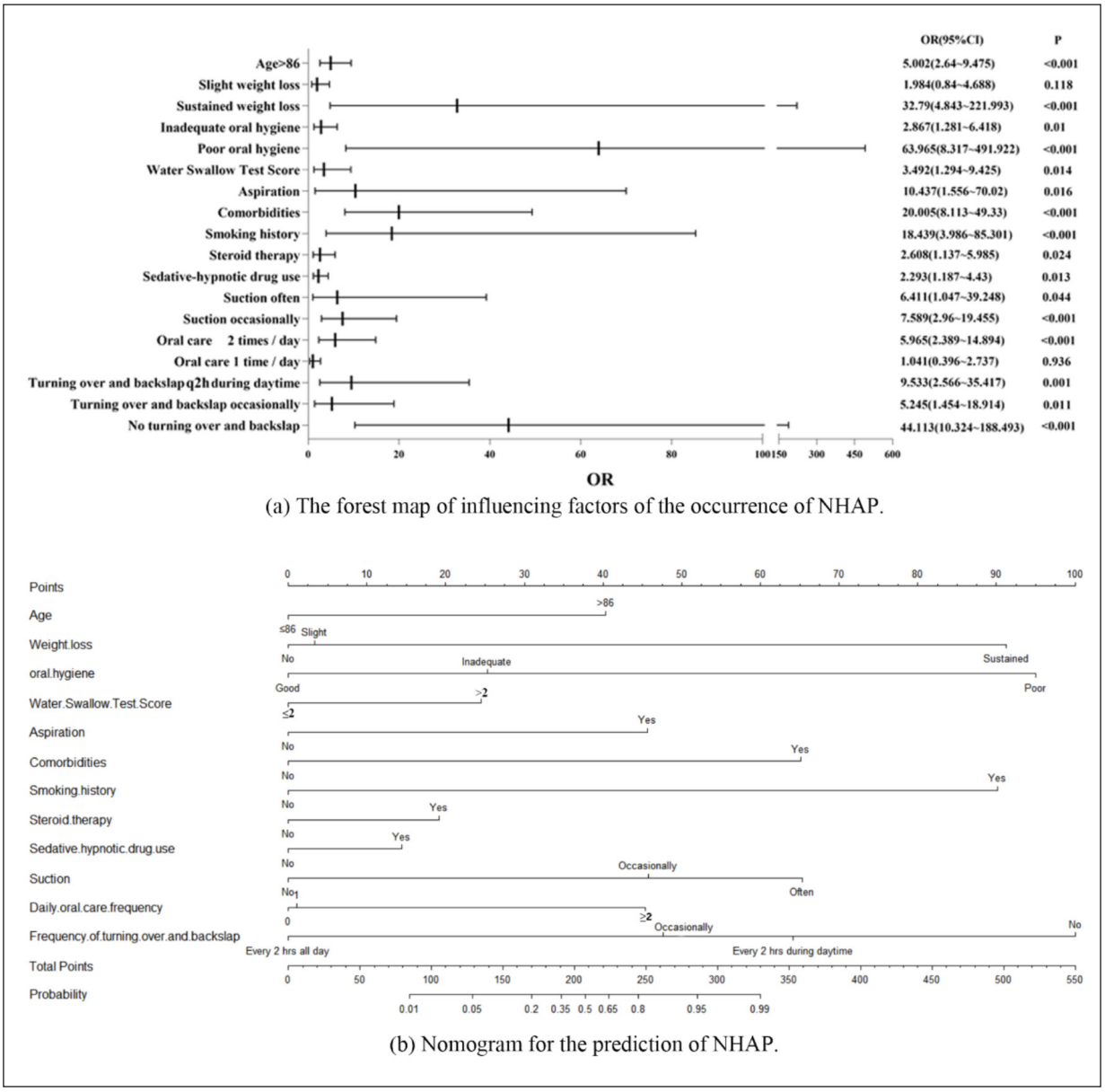

Figure 1. The forest map of influencing factors and nomogram for the prediction of NHAP. (**a**) The forest map showed the coefficients and 95% confidence intervals of binary logistic regression analysis and the p value of significance test. (**b**) Nomogram visualized the risk prediction of NHAP. Coefficients of the variables were scaled to scores within the range of 0 to 100. In this NHAP prediction model, the distribution of scores generated by the nomogram ranged from 0 to 330 with a median of 207 (interquartile range: 178-237).

(CIC) (Figure 2d), when the threshold probability is more than 60%, the predicted number of patients is basically consistent with the actual number of patients. The overall prediction performance of this prediction model was excellent, and it can preferably predict the risk of NHAP individually according to the distinct conditions of different patients.

Discussion

NHAP is a major killer in nursing homes. Identifying predictors and high-risk patients is very important to prevent the occurrence and development of NHAP. The present study developed and verified a simple and convenient nomogram which can effectively achieve the individualized risk prediction of NHAP.

Table III. Scoring system of the NHAP prediction model. The scoring system of the nomogram was shown in Table III. The scores of each variable are added together to obtain the total score of the patient.

Variables	Rank	Score	Variables	Rank	Score
Age	>86	40	Smoking	Yes	90
	≤86	0		No	0
Weight loss	Sustained	91	Steroid therapy	Yes	19
	Slight	3		No	0
	No	0	Sedative-hypnotic drug	Yes	14
Oral hygiene	Poor	95		No	0
	Inadequate	25	Water Swallow Test score	>2	24
	Good	0		≤2	0
Aspiration	Yes	46	Oral care frequency (times/day)	≥2	45
	No	0		1	1
Comorbidities	Yes	65		0	0
	No	0	Frequency of turning over and backslap	No	100
Suction	Often	65		Occasionally	48
	Occasionally	46		q2h* during daytime	64
	No	0		q2h all day	0

q2h: every 2 hrs.

In our study, the nomogram incorporated 12 independent risk factors from 27 variables based on binary logistic regression. Although most of them have been recognized as patient characteristics of NHAP in previous studies, independent predictors for NHAP vary greatly in different reports. Many studies suggest that advanced age is a major risk factor for NHAP[20,27]. However, in a prospective cohort study, advanced age did not increase the incidence rate of NHAP, and only over 90 years old did the incidence rate of NHAP increase significantly[21]. In our study, we found that advanced age was an independent risk factor for NHAP, which was consistent with the previous literature. Moreover, the cut-off value of age divided by the ROC curve was 86. The final results showed that the prevalence of NHAP in patients > 86 years old was significantly higher than that in patients ≤ 86 years old. In addition to advanced age, it was also considered to be a significant feature of NHAP that the majority of patients were male[16,28]. However, in the univariate analysis of our study, male sex was not a significant factor for NHAP (p=0.187). This discrepancy may be caused by regional differences and different demographic characteristics of the study populations.

Most of the residents in the nursing home had comorbid diseases[3]. Coupled with prolonged bed rest[17], their functional status was poor[29]. Therefore, they are more likely to suffer from pneumonia than their counterparts living in the community[30]. We included the characteristics of nursing home residents in the analysis and found that comorbidity, weight loss, dysphagia and other factors were independent influencing factors of NHAP. However, bedridden status, nutritional status and Barthel index were not included in the final NHAP prediction model. They were not independent risk factors for the occurrence of NHAP. This may be because pneumonia in nursing homes was mostly caused by inhalation factors[31]. In older adults, the nervous system response and sensitivity decline, the ability to swallow and cough decreases, and sputum deposition, vomiting or asphyxia often makes it easy for the microorganism to stay and breed, which is the main reason for the high incidence rate of NHAP[32]. As previous studies have shown, nursing home residents with dysphagia have a higher risk of pneumonia[19,33]. In this study, the dysphagia of patients was reflected by Kubota's Water Swallow Test score, and the lower the score, the worse the swallowing ability. We also found that aspiration and the use of sedative-hypnotics were independent risk factors for NHAP, which was consistent with the results of a prospective case-control study[34]. This illustrates that inhalation factors should be taken into account seriously when formulating NHAP prevention plans in the future.

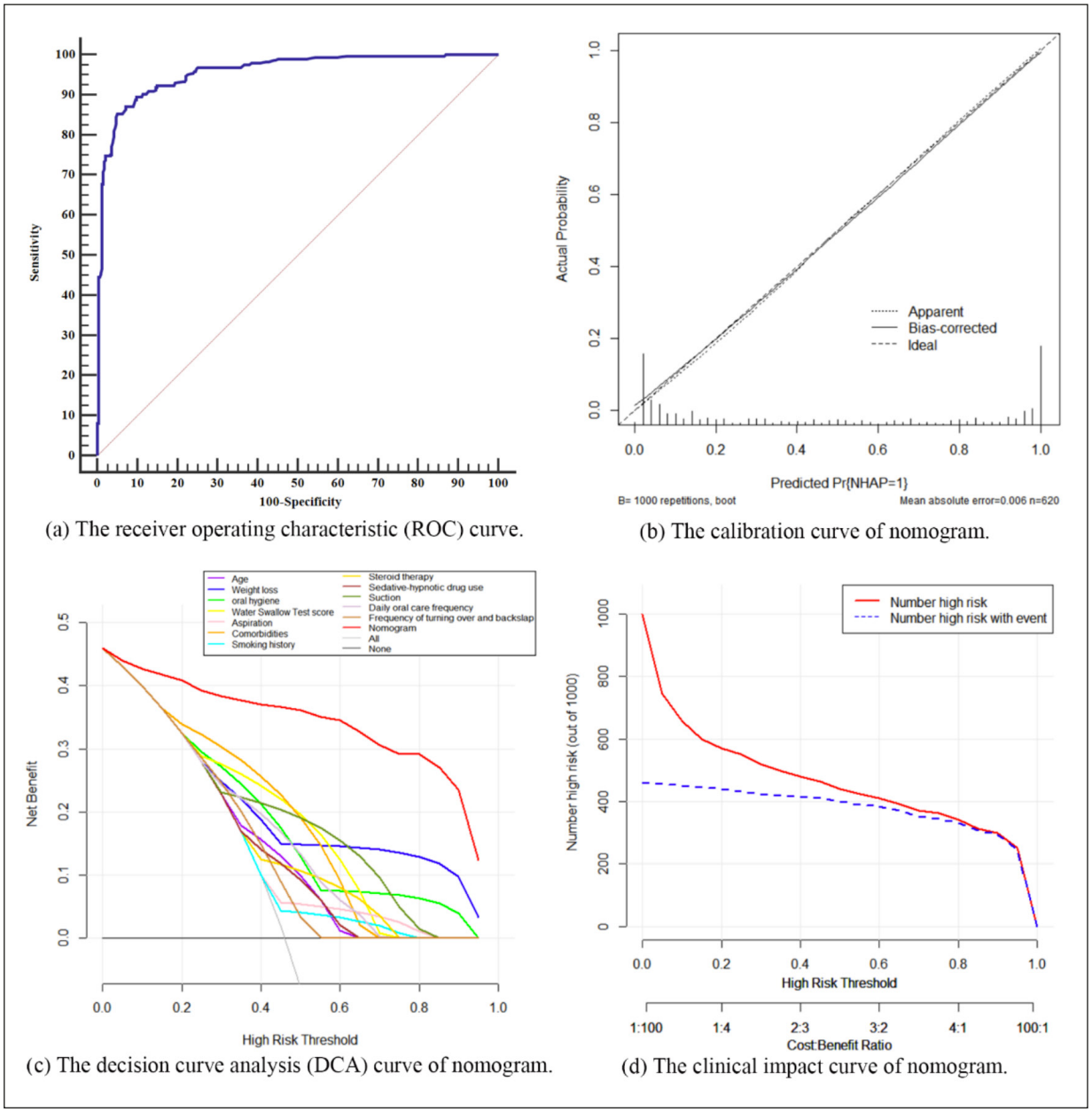

Figure 2. Verification results of Nomo diagram. (**a**) The area under the receiver operating characteristic (ROC) curve was used to test the prediction ability of the model. (**b**) The calibration curve was used to verify the accuracy of the model. (**c**) Decision curve analysis (DCA) was used to investigate the net benefit of patients and compare it with the net benefit of patients predicted by separate indicators to prove its clinical applicability. (***d***) Clinical impact curve (CIC) was plotted to evaluate applicability net benefits of the model with the best diagnostic value.

This study included the treatment and nursing status of patients in the construction of the NHAP prediction model. Research has shown that steroid therapy, sedative-hypnotic drugs, oral care frequency and frequency of turning over and backslap have a significant impact on NHAP, which proves the importance of implementing preventive measures. Interestingly, in this study, the increased frequency of oral care was a risk factor rather than a protective factor. The reason for this result was that the index employed in this study is the frequency of nurses' oral care for patients, who often had poor oral states and strong dependence on oral care. Many residents who could clean their mouths by themselves were not included in the case,

and such residents often had good oral health. Therefore, the high frequency of oral care did not mean that residents had good oral hygiene and health. For those who cannot clean their mouth by themselves, due to their poor self-care ability, oral cavity care may also lead to the risk of accidental aspiration and increase the risk of NHAP[35]. In this study, another oral health factor we included was oral hygiene, which was also identified as an independent influencing factor. This proved that patients with poor oral hygiene had a high risk of NHAP. A study showed that professional oral care could reduce the incidence of pneumonia in nursing homes[36]. Improving oral hygiene and reducing the concentration of oral pathogenic microorganisms can reduce the risk of dental plaque accumulation and bacterial pneumonia[37]. Due to the particularity of the population in nursing homes, the frequency of oral care had not been recognized as a protective factor for NHAP, but good oral hygiene was a stable protective factor for NHAP. Therefore, we suggest that we actively take a variety of appropriate measures to promote oral health and reduce the risk of NHAP in the process of oral care.

Compared with the common manifestations of pneumonia, NHAP patients often show atypical symptoms and often have more nonspecific reactions[38,39]. One study found that nursing home residents are less likely to experience chills, pleuritic chest pain, headache, myalgia, and productive cough than similarly aged patients with CAP[8]. In addition, nursing homes are usually equipped with only basic medical facilities and do not have the conditions for laboratory examination[20] and imaging examination[12]. Therefore, we did not include related factors in the binary logistic analysis as candidate variables. Considering the universal applicability of the model, we included as many of the factors that could be obtained easily in the nursing home environment as possible. Some preventive measures have been introduced in recent years, such as oral care measures[40], swallowing assessment and improved feeding patterns[41], and advance care planning (ACP) [42,43]. However, it may be not appropriate to apply these measures to all patients without selection because some are time-consuming, laborious and expensive. The nomogram developed in this study can identify the high-risk groups of NHAP and their potential risk factors. Appropriate interventions and preventive measures for these populations based on risk factors may bring significant clinical benefits.

Limitations

There were still some limitations in this study. The data of this study were from one nursing home in Northeast China, so the results may be affected by regional factors. The applicability of this model in other regions and nursing homes still needs external verification. Moreover, a prospective study is required to further confirm the reliability of the nomogram.

Conclusions

The present study developed and validated an NHAP prediction model with 12 independent risk factors. And the NHAP prediction scoring system is established through a nomogram to visualize the NHAP prediction risk. The variables of this NHAP prediction model are easy to obtain, the risk index is easy to calculate, the prediction result is reliable, and it has good clinical applicability. Medical staff in nursing homes can use this NHAP prediction model to systematically analyze patients and disease characteristics to form targeted prevention strategies. Moreover, this NHAP prediction model can continuously and dynamically assess the changing trend of an individual's NHAP risk and make a judgment on the effectiveness of preventive interventions.

Conflict of Interests

The authors declare that they have no conflict of interest to declare.

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Authors' Contributions

Study concept and design: Bolun Zhao, Peiya Tan; Acquisition of data: Miao Huo, Xiaohua Zhou; Analysis and interpretation of data: Peiya Tan, Xiaohua Zhou, Bolun Zhao; Drafting of the manuscript: Peiya Tan, Xiaohua Zhou, Miao Huo; Critical revision of the manuscript for important intellectual content: Bolun Zhao.

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Availability of Data and Material

The datasets generated during and analyzed during the current study are available from the corresponding author on reasonable request.

Ethics Approval

Not required as this manuscript does not include details, images or videos related to the participants.

Informed Consent

Due to the retrospective and non-interventionist design, this study waived written informed consent.

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