Diabetes, Metabolic Syndrome and Obesity

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ORIGINAL RESEARCH

Frailty Prediction Model for Elderly Diabetic Peripheral Neuropathy Patients

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Purpose: Elderly patients with diabetic peripheral neuropathy (DPN) are significantly impacted by frailty, yet frailty prediction models for this population remain underexplored. This study aims to develop and internally validate a frailty prediction model for elderly patients with DPN.

Patients and Methods: A cross-sectional study design was employed, and 400 elderly DPN patients were recruited from a tertiary hospital in Guangdong Province, China, between December 2024 and July 2025. Logistic regression was employed to identify frailty risk factors and develop a prediction model and nomogram for elderly DPN patients. We evaluated the performance of the model using the area under the receiver operating characteristic (ROC) curve, abbreviated as AUC, and was further assessed through the Hosmer-Lemeshow test and calibration curves. The clinical utility of the model was assessed by decision curve analysis (DCA). Internal validation was performed using 1000 bootstrap resamples to reduce the risk of overfitting.

Results: Among the 400 patients, 113 (28.25%) patients had frailty. Six factors were identified as significant predictors: age, marital status, regular exercise, PSQI score, MNA-SF score, and HADS-D score. We constructed a nomogram based on these factors. Internal validation demonstrated good performance in both discrimination and calibration, and DCA confirmed the model's clinical applicability.

Conclusion: The nomogram developed in this study provides an effective tool for the early identification of elderly DPN patients at risk of frailty, thereby informing tailored preventive and intervention strategies. External validation will be conducted in future studies, and future studies will assess the model's generalizability across different regions and healthcare systems. The main predictors identified in this study include age, marital status, regular exercise, PSQI score, MNA-SF score, and HADS-D score, which significantly contribute to frailty risk in elderly DPN patients.

Keywords: diabetic peripheral neuropathy, frailty, nomogram, prediction, risk factors

Introduction

With the global population aging, the prevalence of diabetes continues to rise among the elderly population.[1] Diabetic Peripheral Neuropathy (DPN) is a common chronic complication of diabetes, characterized by symmetrical distal sensory abnormalities, burning pain, tingling, and proprioceptive disturbances.[2] Its incidence can be as high as 50%.[3] DPN significantly impacts quality of life and places a substantial medical burden on elderly diabetic patients.[4,5]

Frailty is a common syndrome in the elderly, characterized by reduced physiological reserves and increased susceptibility to stressors, which makes individuals more vulnerable to adverse health outcomes such as falls, hospitalization, disability, and mortality.[6,7] For elderly patients with DPN, frailty is further compounded by the specific challenges of nerve damage and sensory disturbances, which complicate disease management and increase the risk of

Received: 30 September 2025
Accepted: 13 December 2025
Published: 22 December 2025

additional complications. A study in China involving 203 elderly DPN patients revealed a frailty incidence of 28.57%.[8] DPN is characterized by progressive damage to sensory and motor nerves, which increases the risk of falls and foot ulcers, potentially accelerating physical decline and functional limitation, thereby contributing to frailty.[9,10] Early identification and assessment of frailty risk in elderly DPN patients is crucial for optimizing diabetes management, improving patients' quality of life, and reducing adverse clinical outcomes.

Although studies have shown that diabetes patients are at higher risk of frailty, systematic research on the frailty risk factors in elderly diabetic peripheral neuropathy patients remains scarce.[11,12] Existing frailty models for the elderly often focus solely on physical aspects, overlooking the multifactorial nature of frailty in DPN patients, such as sensory impairments and psychological distress, limiting their predictive accuracy. Accurate prediction of frailty risk is essential for early intervention and better treatment outcomes.

This study aims to develop and validate a frailty prediction model based on clinical data, integrating demographic information, health-related data, psychosocial factors, and laboratory results to enhance the prediction ability of frailty risk in elderly DPN patients. Unlike traditional models that focus solely on physical aspects, this study uses Gobbens' comprehensive frailty model, which integrates physical, psychological, and social domains. This multidimensional approach strengthens the theoretical foundation by capturing the full scope of frailty in elderly DPN patients, offering a more complete and accurate assessment of their health status and risk.[13] The results will be presented through nomograms, which convert traditional complex prediction formulas into intuitive and easily understandable event probability estimates, thereby improving the accuracy of clinical decision-making. The nomogram was selected for its ability to simplify complex prediction formulas and provide intuitive visual representations, which can aid in clinical decision-making. This model will provide an effective early identification tool, thereby improving patient health outcomes.

This study develops a tool designed to help healthcare providers predict frailty in elderly patients with DPN, a condition causing pain and loss of sensation in the legs and feet. Frailty is prevalent in these patients and increases their risk of other health complications. The model integrates physical, mental, and social factors, offering a more comprehensive evaluation of frailty. Early identification of at-risk patients allows for more personalized and effective care.

Methods

Study Design and Population

This cross-sectional study aimed to develop and internally evaluate a frailty prediction model for elderly individuals with DPN in China. The study was conducted at a tertiary hospital in Guangzhou, China, from December 2024 to July 2025. We employed a convenience sampling method to select inpatients diagnosed with DPN, according to the Expert consensus on diagnosis and treatment of diabetic neuropathy (2021 edition).[14] This method was chosen because it provided easier access to a sufficient number of participants from the hospital's inpatient population. Eligible participants were identified based on the inclusion and exclusion criteria, and trained researchers then contacted them, explained the study's purpose and significance, and obtained written informed consent prior to enrollment. The inclusion criteria were as follows: (1) Aged 60 years or older; (2) Clear consciousness and basic communication abilities; (3) Provided written informed consent. Exclusion criteria included: (1) Severe cardiovascular or cerebrovascular diseases, such as arrhythmia, heart failure, or acute stroke; (2) Severe liver or kidney dysfunction, or any malignancy; (3) Severe sensory impairments (visual or auditory) that would hinder participation. Sample size was determined using Events Per Variable (EPV) criterion, which suggests a minimum of 10 participants per candidate predictor variable.[15] According to related literature, the prevalence of frailty among older DPN patients is 28.57%.[8] Planning for 10 EPV with up to 10 parameters and allowing a 10% invalid-questionnaire rate, we set the target enrollment at ≈389. However, to ensure adequate statistical power and account for potential missing data, we included 400 participants in the final analysis. The study adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for reporting observational research.

Measures

Data were collected by trained researchers using paper-based questionnaires that were validated in similar populations. Their reliability and cultural appropriateness for the Chinese population were confirmed through expert review and

Cronbach's α values. The general information questionnaire consisted of three sections: sociodemographic characteristics, clinical and health-behavior variables, and laboratory measurements. Sociodemographic data included age, gender, marital status, education level, and other relevant characteristics. Clinical and behavioral variables included diabetes duration, diabetes-related complications, polypharmacy (use of ≥5 medications), comorbidities (≥2 chronic diseases), body mass index, regular exercise, tobacco use, and other relevant factors. Laboratory measurements included glycated hemoglobin, serum albumin, hemoglobin, and other relevant parameters.

The Chinese version of the Tilburg Frailty Indicator (TFI) was used to assess frailty across three domains: physical, psychological, and social.[16] The version used in this study consists of 15 items, with 8 physical, 4 psychological, and 3 social items. Each item is scored on a binary scale, yielding a total score ranging from 0 to 15. A score of ≥5 indicates frailty, with higher scores reflecting greater frailty. The internal consistency was acceptable, with a Cronbach's α of 0.710.[17]

The Pittsburgh Sleep Quality Index (PSQI) was applied to assess subjective sleep quality over the preceding month.[18] It consists of 19 self-rated items grouped into seven components: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medications, and daytime dysfunction. The total score ranges from 0 to 21, with higher scores indicating poorer sleep quality. A score greater than 7 was defined as poor sleep quality, while scores of 7 or below indicated good sleep quality. The Chinese version of the PSQI demonstrated a Cronbach's α of 0.842, confirming its reliability.[19]

The Mini Nutritional Assessment-Short Form (MNA-SF) was employed to assess nutritional status in older adults.[20] It includes six items that assess factors such as food intake, weight loss, mobility, psychological stress, neuropsychological problems, and BMI. The total score ranges from 0 to 14, with scores between 12 and 14 indicating normal nutritional status, scores from 8 to 11 indicating a risk of malnutrition, and scores from 0 to 7 indicating malnutrition.

The Hospital Anxiety and Depression Scale (HADS) was utilized to screen for anxiety and depression in hospital settings.[21] It consists of two subscales: Anxiety (HADS-A) and Depression (HADS-D), each with seven items. Each item is scored on a 4-point Likert scale, ranging from 0 to 3. In this study, a subscale score of 10 or more was considered indicative of anxiety or depression. The Chinese versions of the HADS demonstrated Cronbach's α values of 0.869 for the anxiety subscale and 0.807 for the depression subscale, indicating good internal consistency.[22]

The Summary of Diabetes Self-Care Activities (SDSCA) was adopted to assess self-management behaviors in individuals with diabetes.[23] The overall Cronbach's α of the scale is 0.62, with test-retest reliability of 0.83. The scale consists of five dimensions: diet (4 items), exercise (2 items), blood glucose monitoring (2 items), foot care (2 items), and medication (1 item), totaling 11 items. Of these, 10 items are scored positively, and 1 item is scored negatively. The scale uses an 8-point Likert scale, with each item scored from 0 to 7. The total score ranges from 0 to 77, with higher scores indicating better self-management. The Chinese version of the SDSCA demonstrated adequate reliability with a Cronbach's α of 0.62.[24]

Finally, the Social Support Rating Scale (SSRS) was used to assess social support levels across three dimensions: objective support, subjective support, and utilization of social support.[25] The total score is categorized as follows: ≤22 indicates low support, 23~44 indicates moderate support, and ≥45 indicates high support. The Chinese version of the SSRS demonstrated good reliability, with Cronbach's α values ranging from 0.825 to 0.896.[26]

All questionnaires were verified and collected on-site, with a two-person verification process conducted prior to data entry to ensure accuracy and eliminate invalid responses, thereby maintaining data integrity.

Statistical Analysis

Data entry and verification were performed using Excel 2021 by two independent operators. Data analysis was conducted using R version 4.2.3. Continuous variables with normal distribution were expressed as mean ± standard deviation (SD), and comparisons between groups were made using independent-sample t-tests. Effect sizes were calculated using Cohen's d to assess the magnitude of group differences. For non-normally distributed continuous variables, the median (interquartile range) [M(P25, P75)] was used, with group comparisons performed using the Mann–Whitney *U*-test. Categorical variables were presented as frequencies and percentages (%) and analyzed using the Pearson's Chi-squared test or Fisher's exact test. To identify independent risk factors for frailty, variables with $P < 0.05$ in univariate analysis were entered into a multivariate logistic regression model for variable selection. Effect sizes for logistic regression were

reported as odds ratios (ORs).The nomogram was developed using the "rms" package in R. The discriminatory ability of the model was assessed using the area under the receiver operating characteristic (ROC) curve (AUC). Internal validation was performed using 1000 bootstrap resamples, and a calibration curve was drawn to evaluate the model's calibration. Additionally, decision curve analysis (DCA) was conducted to assess the clinical utility of the prediction model.[27] All statistical tests were two-sided, with $P < 0.05$ considered statistically significant.

Results

Study Population Characteristics

A total of 425 elderly patients with DPN were initially recruited, of whom 15 patients declined participation. Consequently, 410 participants were included in the study. At the outset of the survey, four participants withdrew due to the lengthy questionnaire, and among the remaining 406, six questionnaires were deemed invalid. Three questionnaires were excluded due to short completion times (less than 5 minutes), and the other three were excluded due to clear response patterns (nearly identical answers for all items). Ultimately, 400 elderly DPN patients were included in the final analysis (Figure 1), yielding an effective response rate of 97.56%. The sample comprised 183 males and 217 females, with a mean age of 70.9 ± 7.9 years. Among the 400 participants, 113 (28.25%) were classified as frail, with a frailty score of 6.10 ± 1.37. The physical frailty score was 2.86 ± 1.22, the psychological frailty score was 1.98 ± 0.88, and the social frailty score was 1.26 ± 0.44. All scores in the frail group were significantly higher than those in the non-frail group (all $P < 0.001$). Effect sizes for physical, psychological, and social frailty were large (Cohen's d = 1.80, 1.58, and 0.96, respectively), indicating substantial differences between the frail and non-frail groups. Other baseline characteristics and inter-group differences are shown in Table 1.

Multivariable Logistic Regression Analysis

With frailty as the dependent variable, variables that showed statistical significance ($P < 0.05$) in univariate analysis were selected for multivariable logistic regression analysis. The variable assignments are shown in Table 2. The results revealed that age (OR = 1.062, 95% CI: 1.018−1.11), marital status (OR = 5.953, 95% CI: 3.131−11.797), regular exercise (OR = 0.243, 95% CI: 0.130−0.448), PSQI score (OR = 1.117, 95% CI: 1.052−1.189), MNA-SF score (OR = 0.710, 95% CI: 0.619−0.807), and HADS-D score (OR = 1.084, 95% CI: 1.011−1.163) were independently associated with frailty ($P < 0.05$), as shown in Table 3. Multicollinearity diagnostics were performed for these six variables, and the variance inflation factor (VIF) for ranged from 1.026 to 1.240, all below the prespecified VIF < 5 threshold, indicating no multicollinearity among the variables.

Frailty Risk Prediction Model and Nomogram Construction

Based on the results of logistic regression analysis, the final frailty risk prediction model for elderly DPN patients was constructed as follows: Logit (P) =ln[P/(1−P)]=−3.66+0.061×Age+1.784×Marital Status-1.415×Regular Exercise +0.111×PSQI score-0.343×MNA-SF score+0.081×HADS-D score. A nomogram was developed based on the prediction model, with the values of each predictor converted into scores along the "Points" axis. These scores were then summed to provide a "Total Points," which was mapped to the probability of the event (Figure 2). For example, a patient who is 70 years old (score = 42), married (score = 0), does not engage in regular exercise (score = 65), has a PSQI score of 16 (score = 80), an MNA-SF score of 8 (score = 86), and an HADS-D score of 12 (score = 42) would have a total score of 42 + 0 + 65 + 80 + 86 + 42 = 312. According to the nomogram, the corresponding probability of frailty for this patient would be approximately 0.76.

Evaluation of the Frailty Risk Prediction Model

ROC analysis revealed an AUC of 0.889 (95% CI 0.854–0.924), indicating good discriminatory ability of the model (Figure 3). The Hosmer-Lemeshow test yielded $\chi^2 = 7.434$, P = 0.491, consistent with adequate fit. The optimal cutoff value was determined to be 0.313 based on the Youden index, at which point the sensitivity was 84.3%, specificity was 82.3%, and the Youden index was 0.67. This threshold provides a practical decision point for identifying elderly DPN patients at high

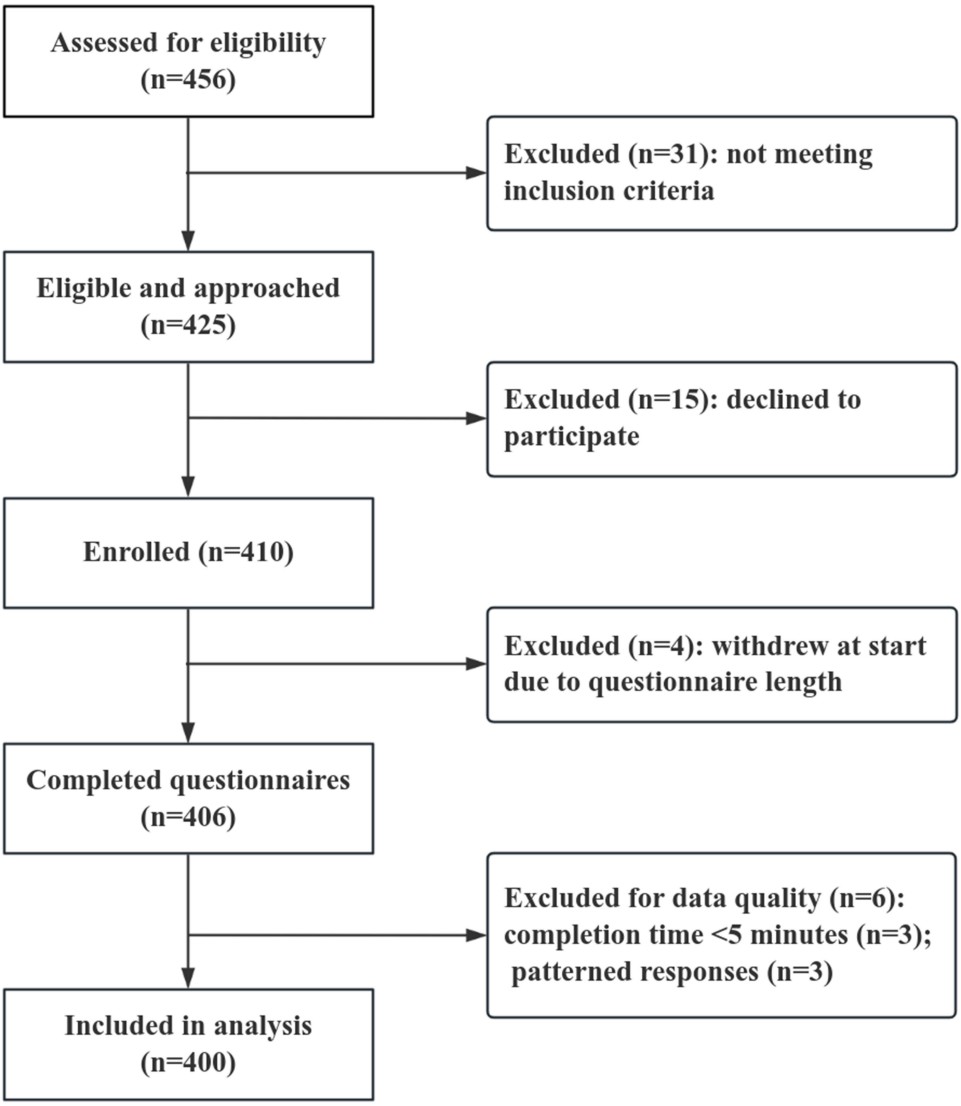

Figure 1 The diagram of process to screen participants.

risk of frailty, allowing healthcare providers to prioritize interventions for those at greater risk. Internal validation with 1000 bootstrap resamples produced an optimism-corrected C-index similar to the apparent AUC (Figure 4). The intercept was 0, the slope was 1, and the Brier score was 0.115. The calibration curve (Figure 5) demonstrated a high degree of agreement between the predicted and observed values, indicating good predictive performance of the model. DCA demonstrated higher

Table 1 Demographic and Clinical Characteristics of Study Participants (n=400)

Variables	Non-Frailty (n=287)	Frailty (n=113)	Total (n=400)	$Z/t/\chi^2$	*P* value
Age (years)	70 (65, 74)	75 (70, 80)	71 (66, 76)	−5.751	<0.001
Gender				15.564	<0.001
Male	149 (51.9%)	34 (30.1%)	183 (45.8%)		
Female	138 (48.1%)	79 (69.9%)	217 (54.2%)		

(*Continued*)

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Table 1 (Continued).

Variables	Non-Frailty (n=287)	Frailty (n=113)	Total (n=400)	Z/t/χ^2	*P* value
Marital Status				69.754	<0.001
Married	207 (72.1%)	30 (26.5%)	237 (59.2%)		
Unmarried/Divorced/Widowed	80 (27.9%)	83 (73.5%)	163 (40.8%)		
Education				19.885	<0.001
Primary school or below	76 (26.5%)	52 (46%)	128 (32%)		
Junior high school	79 (27.5%)	34 (30.1%)	113 (28.2%)		
Senior high school/ Technical Secondary school	99 (34.5%)	21 (18.6%)	120 (30%)		
University or above	33 (11.5%)	6 (5.3%)	39 (9.8%)		
Living arrangement				0.153	0.696
Living with others	136 (47.4%)	56 (49.6%)	192 (48%)		
Living alone	151 (52.6%)	57 (50.4%)	208 (52%)		
Payment for Medical Expenses					0.769
Self-paid	13 (4.5%)	7 (6.2%)	20 (5%)	0.525	
Medical insurance	246 (85.7%)	96 (85%)	342 (85.5%)		
Other	28 (9.8%)	10 (8.8%)	38 (9.5%)		
Regular Exercise				81.54	<0.001
No	52 (18.1%)	73 (64.6%)	125 (31.2%)		
Yes	235 (81.9%)	40 (35.4%)	275 (68.8%)		
History of falls				5.276	0.022
No	250 (87.1%)	88 (77.9%)	338 (84.5%)		
Yes	37 (12.9%)	25 (22.1%)	62 (15.5%)		
Tobacco use				6.801	0.033
Never	174 (60.6%)	83 (73.5%)	257 (64.2%)		
Current	58 (20.2%)	12 (10.6%)	70 (17.5%)		
Former	55 (19.2%)	18 (15.9%)	73 (18.2%)		
Alcohol use				1.47	0.480
Never	200 (69.7%)	85 (75.2%)	285 (71.2%)		
Current	36 (12.5%)	10 (8.8%)	46 (11.5%)		
Former	51 (17.8%)	18 (15.9%)	69 (17.2%)		
Duration of Diabetes				17.463	<0.001
<1 year	26 (9.1%)	4 (3.5%)	30 (7.5%)		
1~10 years	95 (33.1%)	22 (19.5%)	117 (29.2%)		
10~20 years	96 (33.4%)	39 (34.5%)	135 (33.8%)		
≥ 20 years	70 (24.4%)	48 (42.5%)	118 (29.5%)		
Number of Diabetic Complications				3.861	0.049
1~2 complications	143 (49.8%)	44 (38.9%)	187 (46.8%)		
≥ 3 complications	144 (50.2%)	69 (61.1%)	213 (53.2%)		
Comorbidities				13.563	<0.001
No	73 (25.4%)	10 (8.8%)	83 (20.8%)		
Yes	214 (74.6%)	103 (91.2%)	317 (79.2%)		

(*Continued*)

Table 1 (Continued).

Variables	Non-Frailty (n=287)	Frailty (n=113)	Total (n=400)	Z/t/χ^2	*P* value
Polypharmacy				0.526	0.468
No	118 (41.1%)	42 (37.2%)	160 (40%)		
Yes	169 (58.9%)	71 (62.8%)	240 (60%)		
Diabetes treatment regimen				—	0.198
None	3 (1%)	2 (1.8%)	5 (1.2%)		
Oral	114 (39.7%)	39 (34.5%)	153 (38.2%)		
Insulin	7 (2.4%)	0 (0%)	7 (1.8%)		
Oral+Insulin	163 (56.8%)	72 (63.7%)	235 (58.8%)		
BMI (kg/m^2)	23.5 (21.7,26.2)	23.2 (20.5, 26)	23.5(21.5, 26.1)	0.921	0.357
Waist circumference (cm)	89 (82, 95)	88 (81, 94)	88 (82, 94.3)	1.222	0.221
Hypoglycemia frequency within 1 year	0 (0, 1)	0 (0, 1)	0 (0, 1)	−0.167	0.832
PSQI score	7 (4, 12)	12 (8, 16)	9 (5, 14)	−6.153	<0.001
MNA-SF score	13 (11, 14)	11 (9, 12)	13 (10, 14)	6.648	<0.001
HADS-A score	5 (3, 5)	5 (3, 5)	5 (3, 5)	0.54	0.582
HADS-D score	2 (1, 6)	6 (4, 9)	3 (1, 8)	−7.742	<0.001
SDSCA score	46 (40, 52)	44 (40, 49)	46 (40, 51)	2.23	0.026
SSRS score	30 (26.5, 35)	28 (24, 32)	30 (26, 34)	3.225	0.001
Laboratory values					
HbA1c (%)	8.4 (7.2, 10.5)	8.3 (6.7, 9.9)	8.4 (7.2, 10.3)	1.588	0.112
TC (mmol/L)	4.1 (3.3, 4.9)	4 (3.0, 4.8)	4.1 (3.2, 4.9)	1.296	0.195
HDL-C (mmol/L)	1.1 (1.0, 1.3)	1.2 (1.0, 1.4)	1.1 (1.0 1.4)	−0.825	0.410
LDL-C (mmol/L)	2.4 (1.8, 3.2)	2.3 (1.5, 3.0)	2.4 (1.7, 3.1)	1.348	0.178
Scr (umol/L)	74 (60.5, 90)	75 (62, 105)	74 (61, 94)	−1.099	0.272
ALB (g/L)	41.9 (39.4, 44.1)	40 (37.7, 41.9)	41.4 (38.8, 43.6)	4.738	<0.001
Hb (g/L)	130 (119, 139)	123 (108, 135)	127 (116, 138)	3.528	<0.001
FPG (mmol/L)	7.4 (6.2, 9.2)	6.8 (5.8, 9.1)	7.2 (6, 9.1)	1.769	0.077

Abbreviations: BM, Body Mass Index; PSQI, Pittsburgh Sleep Quality Index; MNA-SF, Mini Nutritional Assessment-Short Form; HADS-A, Hospital Anxiety and Depression Scale-Anxiety; HADS-D, Hospital Anxiety and Depression Scale-Depression; SDSCA, Summary of Diabetes Self-Care Activities; SSRS, Social Support Rating Scale; HbA1c, glycated hemoglobin A1c; TC, Total cholesterol; HDL-C, high density lipoprotein cholesterol; LDL-C, low density lipoprotein cholesterol; Scr, serum creatinine; ALB, albumin; Hb, Hemoglobin; FPG, fasting plasma glucose.

Table 2 Assignment of Independent Variables

Variables	Assignment Method
Gender	Male=1; Female=2
Marital Status	Married=1; Unmarried/ Divorced/ Widowed=2
Education	Primary school or below=1; Junior high school=2; Senior high school/Technical secondary school=3; University or above=4
Regular Exercise	No=0; Yes=1
History of falls	No=0; Yes=1

(*Continued*)

Table 2 (Continued).

Variables	Assignment Method
Tobacco use	Never=1; Current=2; Former=3
Duration of Diabetes	<1 year=1; 1~10 years=2; 10~20 years=3; ≥ 20 years=4
Number of Diabetic Complications	1~2 complications=1; ≥3 complications=2
Comorbidities	No=0; Yes=1

Table 3 Results of Multivariable Logistic Regression Analysis of Frailty

Variables	*β*	*SE*	*Wald* χ^2	*P*	*OR (95% CI)*
Constant	−3.66	1.89	3.749	0.053	0.026 (0.001–1.021)
Age	0.061	0.022	7.543	0.006	1.062 (1.018–1.11)
Marital Status Married Unmarried/Divorced/Widowed	 1.784	 0.337	 28.051	 <0.001	 Reference 5.953 (3.131–11.797)
Regular Exercise No Yes	 −1.415	 0.315	 20.168	 <0.001	 Reference 0.243 (0.13–0.448)
PSQI score	0.111	0.031	12.534	<0.001	1.117 (1.052–1.189)
MNA-SF score	−0.343	0.068	25.739	<0.001	0.71 (0.619–0.807)
HADS-D score	0.081	0.036	5.197	0.023	1.084 (1.011–1.163)

net benefit than "treat-all" and "treat-none" over clinically relevant thresholds (Figure 6), supporting clinical utility. These results further confirm the excellent performance of the nomogram we developed.

Discussion

Current research on frailty primarily focuses on common chronic disease populations, and there is a lack of frailty risk prediction tools for DPN patients. In this study, the frailty prevalence in elderly DPN patients was observed to be 28.25%, which is lower than the level reported by Ye et al in another hospitalized population.[8] The difference may be related to the different assessment tools used. While previous studies often employed the Fried frailty phenotype, which primarily assesses physical dimensions, the TFI used in this study includes physical, psychological, and social dimensions. This makes it potentially more suitable for elderly DPN patients, who frequently experience emotional distress and social isolation in addition to physical symptoms. Furthermore, the physical frailty score (2.86 ± 1.22) was higher than the psychological (1.98 ± 0.88) and social frailty scores (1.26 ± 0.44), indirectly confirming the amplifying effects of DPN-related factors such as nerve damage, muscle strength decline, balance dysfunction, and chronic pain on physiological frailty. These results support the use of multidimensional assessment tools like TFI in clinical screening to capture a broader spectrum of frailty, including psychological and social factors.

Despite the growing global awareness of frailty, research on frailty management and physical therapy interventions remains limited in many low- and middle-income countries (LMICs). Literature indicates that in these countries, physiotherapy is generally concentrated in urban centers, while rural areas struggle to access these services due to limited healthcare resources, a shortage of professionals, and inadequate infrastructure.[28] In Tanzania, for example,

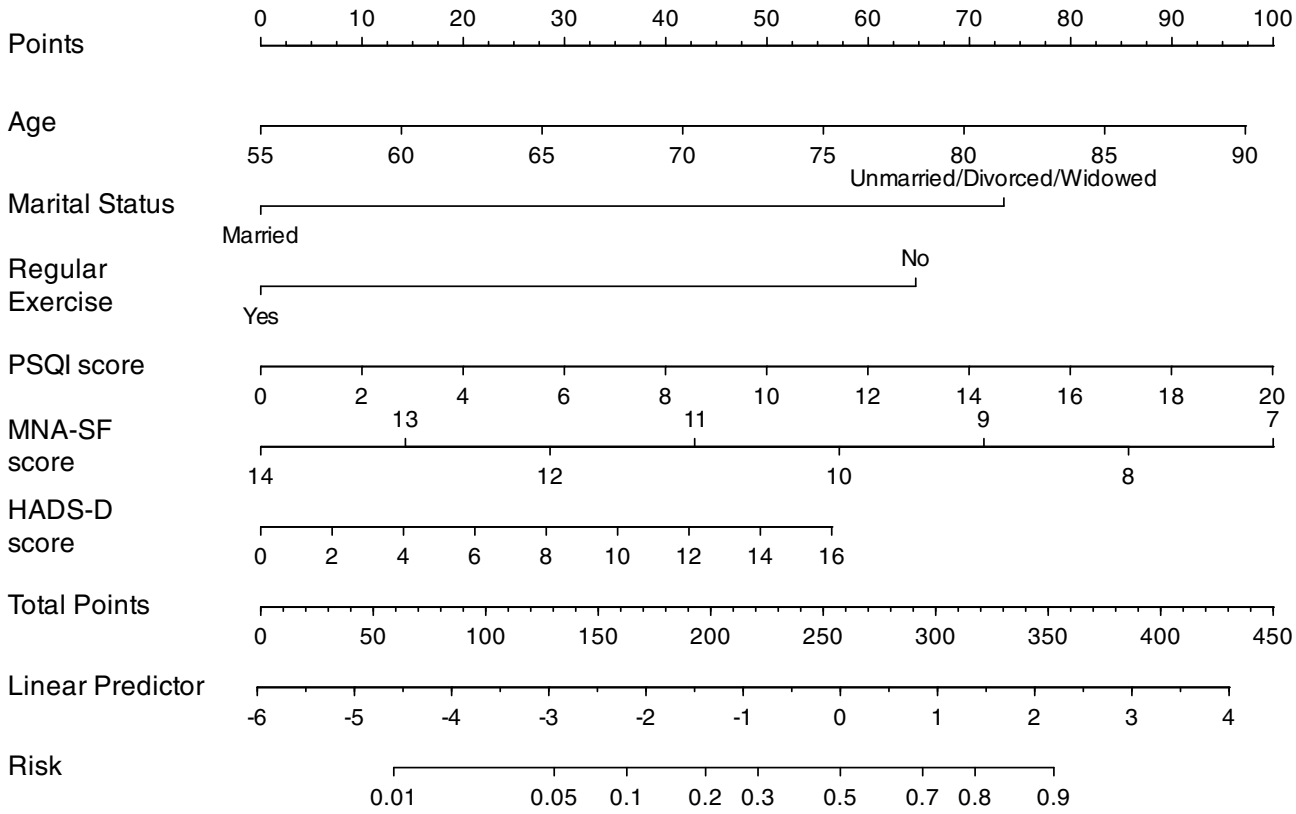

Figure 2 Nomogram for predicting frailty in elderly patients with DPN.

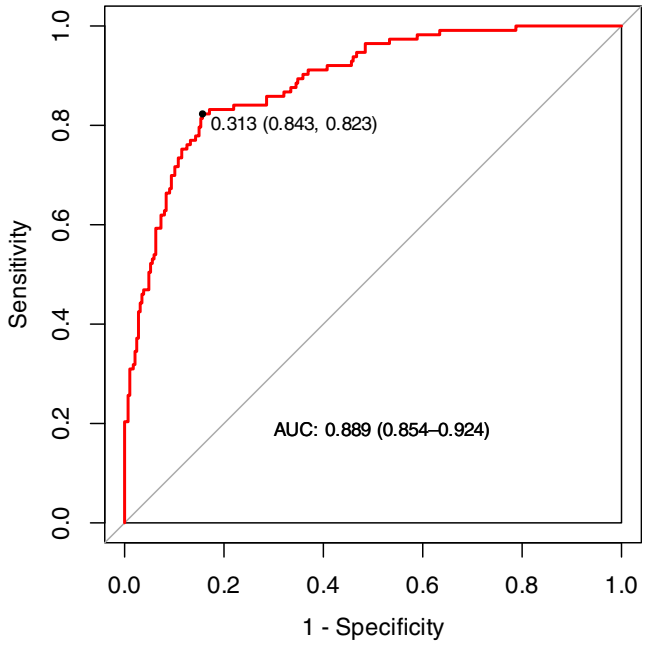

Figure 3 ROC curve of the prediction model.

despite the high prevalence of frailty among hospitalized elderly patients, resources for geriatrics and frailty management are extremely limited.[29] Similarly, In Nepal, although the importance of frailty is recognized, the lack of resources, medical facilities, and appropriate service models has resulted in a very limited number of frailty clinics based on

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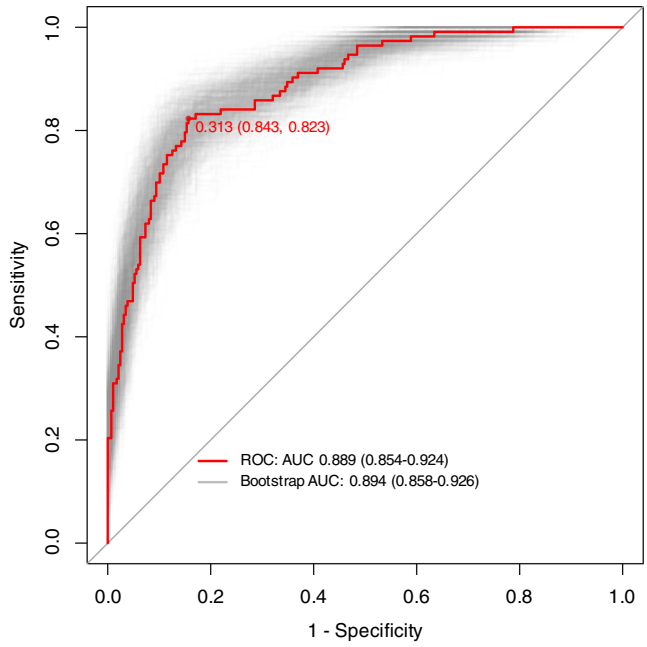

Figure 4 ROC Curve for internal validation of the prediction model.

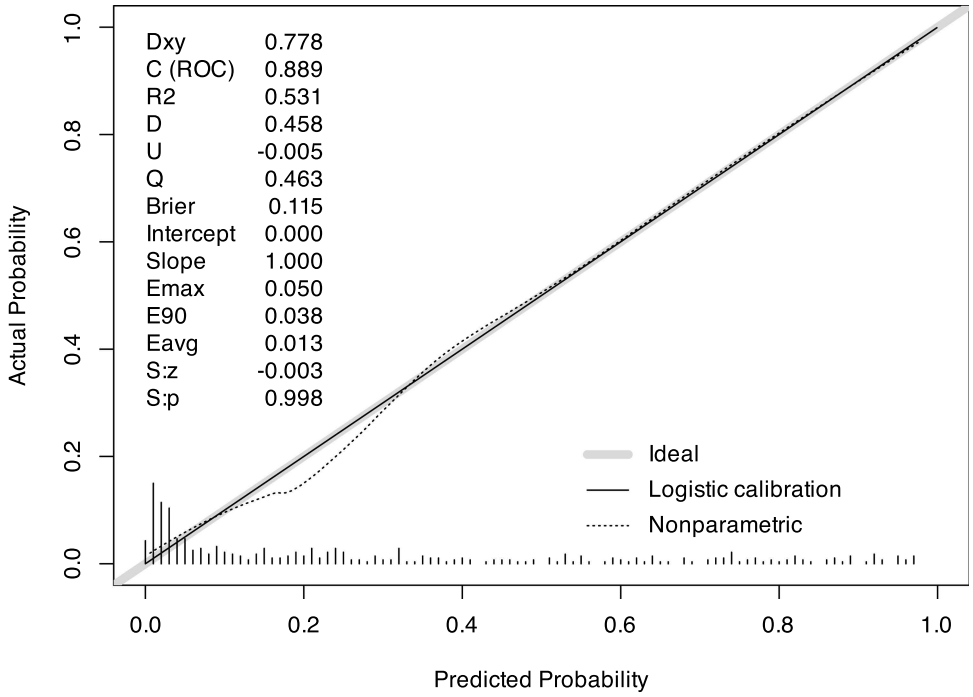

Figure 5 Calibration curve for the nomogram.

comprehensive geriatric assessment (CGA), making frailty management and screening difficult to implement.[30] These studies suggest that LMICs face similar challenges in frailty management and physiotherapy, where shortages in economic and healthcare infrastructure, along with inadequate social support systems, hinder the effective implementation of these interventions.

In this study, diabetes duration was significantly associated with frailty in the univariate analysis ($p < 0.001$), while HbA1c was not ($p = 0.112$). The lack of association between HbA1c and frailty may be attributed to its role as a marker

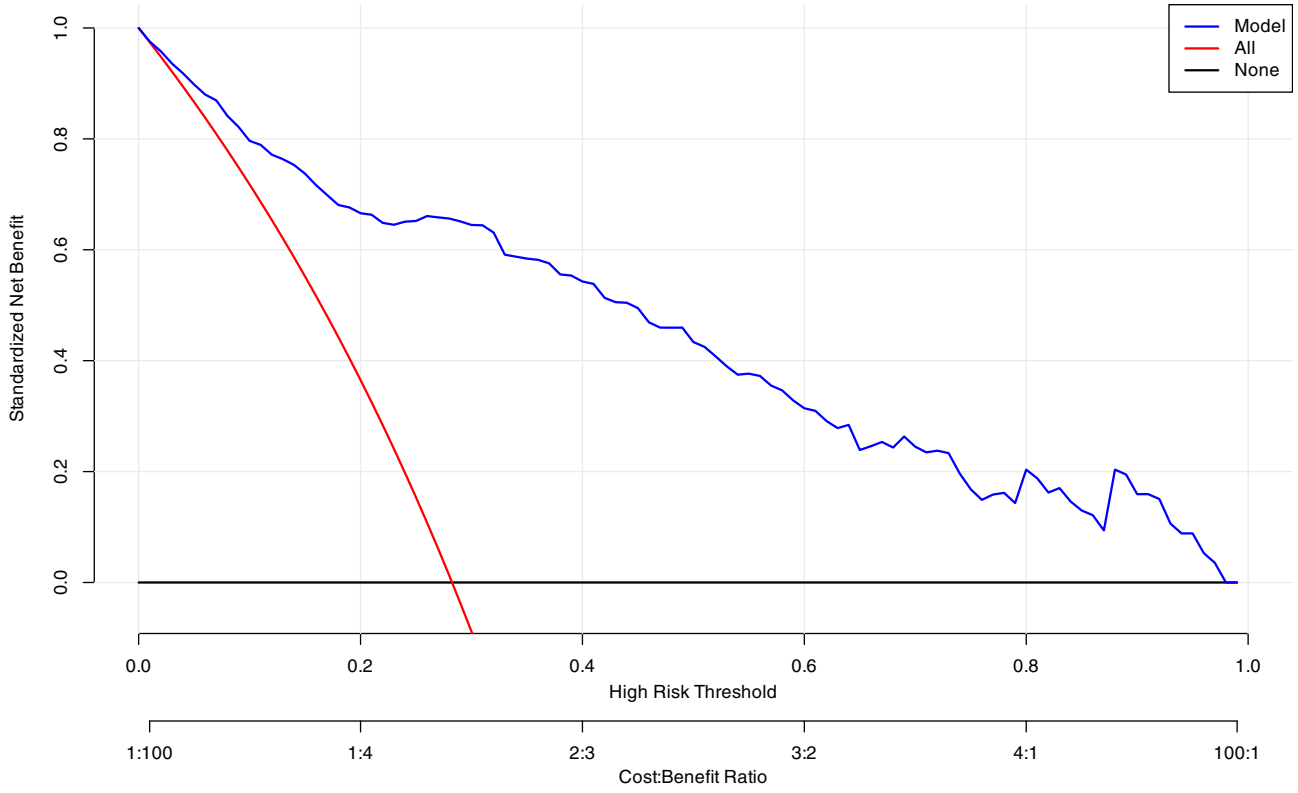

Figure 6 DCA curve for the nomogram.

of long-term average blood glucose levels, which may not fully account for the effects of glycemic variability or acute hyperglycemia that can influence frailty.[31] In contrast, the duration of diabetes and its associated complications are known to contribute to frailty in older adults, suggesting that disease duration may reflect the cumulative burden of chronic hyperglycemia.[32]

In multivariate logistic regression, we observed that age, marital status, regular exercise, PSQI score, MNA-SF score, and HADS-D score were independent factors associated with frailty in elderly DPN patients. Age was positively correlated with frailty risk (OR = 1.06, 95% CI 1.02–1.11), consistent with previous studies.[8] As age increases, degenerative changes in various organs may lead to a decline in individual reserve capacity, weakening muscle strength and deteriorating nerve function, thereby potentially increasing frailty risk.[33] Although age is irreversible, early screening and comprehensive management may help delay the progression of frailty. Clinically, frailty screening and follow-up should be routinely conducted for elderly DPN individuals.

Compared to married individuals, those who were unmarried, divorced, or widowed had a significantly higher risk of frailty (OR = 5.95, 95% CI 3.13–11.80), which is consistent with the study by Bu.[34] Spousal and family support may buffer psychological stress, promote healthy behaviors, and reduce negative emotions,which may be associated with a lower risk of frailty.[35] Clinically, elderly DPN patients without a spouse or primary caregiver should be given special attention, with community and family resources integrated to provide emotional support and daily assistance through volunteer teams, compensating for insufficient social support.

This study shows that compared to individuals with no regular exercise, those who engaged in regular exercise had a lower frailty risk (OR = 0.24, 95% CI 0.13–0.45), consistent with findings in community-based elderly populations.[36] Moderate-to-vigorous physical activity (MVPA) and daily walking steps were negatively correlated with frailty.[37] Research suggests that implementing segmented MVPA (≥70 minutes/week) or walking approximately 4000 steps daily may be more effective in enhancing the protective effects than merely reducing sedentary time. Given the sensory impairments and motor function decline associated with DPN, regular exercise may improve gait coordination, balance

https://doi.org/10.2147/DMSO.S570083

ability, muscle strength, and peripheral circulation, helping to slow the frailty progression.[38] Clinically, individualized exercise plans should be developed based on age, disease duration, comorbidities, and pain tolerance, specifying the type, frequency, intensity, and precautions of exercise, to optimize exercise combinations that enhance strength, improve endurance, and reduce frailty-related risks.

We found that for each additional point in the PSQI score, the risk of frailty was associated with an increase (OR = 1.12, 95% CI 1.05–1.19), consistent with the study by Fu et al.[39] The mechanism may involve DPN-related neuropathic pain and autonomic dysfunction, which contribute to fragmented sleep and circadian rhythm disturbances, leading to impaired growth hormone secretion, reduced muscle protein synthesis, and accelerated muscle catabolism, thus exacerbating frailty.[40,41] Clinically, the PSQI scale can be routinely used for screening, and interventions such as daytime aerobic exercise, bedtime music intervention, and cognitive behavioral therapy may be implemented for high-risk populations. Wearable devices can be used to objectively assess sleep when necessary, aiming to improve sleep quality and potentially reduce frailty-related risks.

The MNA-SF score was negatively correlated with frailty (OR = 0.71, 95% CI 0.62–0.81), meaning the higher the score, the lower the risk of frailty, which is consistent with existing research.[42] Malnutrition is associated with various physiological impairments, such as immune suppression, delayed wound healing, and reduced therapeutic response.[43] In the elderly DPN population, malnutrition may be associated with decreased muscle mass/strength and limited functional recovery, which may be associated with the risk of frailty. Previous studies have shown that low MNA-SF scores are significantly associated with poor clinical outcomes in elderly hospitalized patients, including increased mortality and readmission rates.[44] These findings suggest that timely nutrition and frailty assessments have potential clinical value. The MNA-SF, as a tool for assessing nutritional status, has been validated in multiple studies and has predictive power for frailty in the elderly.[45] Some studies suggest that dietary/nutritional interventions can improve nutritional status and may reduce frailty-related risks and improve function.[46] Clinically, routine nutritional screening could be conducted, and individualized dietary guidance and necessary nutritional support may be provided for those at risk, in conjunction with exercise and blood glucose management, to reduce frailty-related risks.

The HADS-D score was independently associated with frailty (OR = 1.08, 95% CI 1.01–1.16), consistent with previous studies.[34] A Mendelian randomization study suggested a bidirectional association between depression and frailty.[47] Depressive symptoms have been linked to the development and progression of frailty.[48] Depression and frailty share similar pathological mechanisms, which explains their close relationship.[49] Persistent depressive moods may reduce the patient's interest in diet, exercise, and social interaction, increasing the risk of malnutrition, reducing social participation, and decreasing physical activity, ultimately potentially exacerbating functional decline and contributing to frailty. In DPN patients, chronic neuropathic pain and foot complications may further worsen emotional distress and reduce quality of life.[50] Clinically, emotional issues should be routinely identified and managed to reduce the negative impact of depression on function and frailty risk. Emotional follow-ups, health education, and moderate social participation can help alleviate negative emotions and improve overall quality of life.

In conclusion, the nomogram developed in this study provides a comprehensive and personalized tool for predicting frailty risk in elderly DPN patients. Unlike existing frailty models, which often focus on individual factors, this nomogram integrates key physical, psychological, and social factors, offering a more holistic and individualized approach to frailty risk prediction. By inputting relevant patient data, clinicians can generate a frailty risk score that guides personalized management plans, including exercise, nutritional support, and psychological care. Integrating the nomogram into routine clinical practice provides a proactive approach to frailty prevention and management, enabling healthcare providers to tailor interventions to individual patient needs. Future studies should validate this nomog1ram in diverse populations and assess its ability to predict long-term clinical outcomes, such as hospital readmissions and mortality.

Limitations

The nomogram prediction model developed in this study demonstrates strong practicality and accuracy in assessing frailty in elderly DPN patients. However, several limitations should be acknowledged. Firstly, the study is based on a single-center design with a limited sample size, which may restrict the generalizability of the findings. Secondly, the lack of external validation of the model limits the model's applicability across different regions and healthcare systems.

Additionally, the cross-sectional design of the study prevents the establishment of causal relationships. The use of a convenience sampling method may have also introduced selection bias, limiting the generalizability of the findings to the broader population of elderly DPN patients. Future research should aim to expand the sample size, incorporate multi-center data, and perform external validation across diverse settings to enhance the model's reliability and broader applicability. In addition, employing randomized sampling techniques would help minimize bias and improve the external validity of the results.

Conclusion

The findings of this study indicate that age, regular physical activity, PSQI scores, MNA-SF scores, HADS-D scores, and marital status are independent factors influencing frailty in elderly patients with DPN. The predictive model developed demonstrates good predictive performance and, through the use of a nomogram, provides a simple and efficient tool for clinicians to identify high-risk elderly DPN patients at an early stage. This model is designed for risk stratification, allowing healthcare providers to categorize patients based on their risk of frailty and implement individualized preventive measures to reduce the occurrence and progression of frailty. Future multi-center prospective studies are needed for external validation to assess the model's effectiveness across diverse populations. Additionally, integrating this nomogram into clinical practice and routine screening is crucial for early frailty detection and intervention in elderly DPN patients, enabling informed decision-making and personalized care.

Data Sharing Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethical Approval

This study has been approved by the Ethics Committee of the Third Affiliated Hospital of Guangzhou Medical University (approval No. LCYJ-2024-068) and has been conducted in full compliance with ethical standards. All procedures were performed in accordance with the principles outlined in the Declaration of Helsinki.

Informed Consent

All enrolled patients were fully informed about the study and provided written informed consent to participate.

Acknowledgments

We would like to express our sincere gratitude to all the patients who participated in this study. Their valuable contributions made this research possible.

Author Contributions

Xiaoqiao Xie, and Yixin Huang contributed equally to this work. Conceptualization: Xiaoqiao Xie, Yixin Huang, Xiaofang Zou. Data curation: Yaru Wang, Wanping Chen, Xuli Liang, Chen Xiong. Formal analysis: Yaru Wang, Chen Xiong. Funding acquisition: Xiaofang Zou. Investigation: Xiaoqiao Xie, Yixin Huang, Wanping Chen, Xuli Liang. Methodology: Xiaoqiao Xie, Yixin Huang, Xiaofang Zou. Project administration: Yaru Wang, Xiaofang Zou. Resources: Wanping Chen, Xuli Liang, Xiaofang Zou. Software: Yaru Wang, Wanping Chen. Supervision: Xiaoqiao Xie, Yixin Huang, Xiaofang Zou. Validation: Xuli Liang, Chen Xiong. Visualization: Xiaoqiao Xie, Yixin Huang. Writing-original draft: Xiaoqiao Xie, Yixin Huang. Writing-review & editing: Xiaofang Zou. All authors took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

There is no funding to report.

Disclosure

The authors declare that they have no conflicts of interest in this work.

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