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Development of a Frailty Prediction Model Among Older Adults in China: A Cross-Sectional Analysis Using the Chinese Longitudinal Healthy Longevity Survey

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ABSTRACT

Aims: To identify the risk factors associated with frailty among older adults in China and develop a predictive model for assessing their frailty risk.

Design: Secondary cross-sectional analysis.

Methods: The 2018 Chinese Longitudinal Healthy Longevity Survey (CLHLS) provided data for this study. A total of 9006 participants were included in the analysis. Their general demographic, socioeconomic status and health behaviour risk factors were collected in the CLHLS. Frailty was assessed using the Frailty Index. A visual nomogram model was constructed based on independent predictors identified using multivariate analysis. The nomogram's discrimination and calibration capabilities were evaluated using the C-statistics and calibration curves. A 1000-times resampling enhanced bootstrap method was performed for internal validation of the nomogram.

Results: The results showed that living in rural settings, having a primary education level, having a spouse, having basic living security, smoking, drinking, exercising and social activities were protective factors against frailty. Increasing age, being underweight or obese, adverse self-assessed economic status and poor sleep quality were risk factors of frailty. The AUC values of the internal validation set were 0.830. The calibration curve was close to ideal. The Brier score was 0.122. The above results showed that the nomogram model had a good predictive performance.

Conclusions: A simple and fast frailty risk prediction model was developed in this study to help healthcare professionals screen older adults at high risk of frailty in China.

Impact: The frailty risk prediction model will assist healthcare professionals in risk management and decision-making and provide targeted frailty prevention interventions. Screening high-risk older adults and early intervention can reduce the risk of adverse outcomes and save medical expenses for older adults and society, thereby realising cost-effective planning of health resources and healthy ageing.

Xianping Tang and Dongdong Shen are co-first authors of this article.

Patient or Public Contribution: No patient or public contribution. This study was a cross-sectional, secondary analysis of the CLHLS data.

1 | Introduction

Based on the World Population Prospects 2022 by the United Nations, the number and proportion of older adults worldwide are expected to increase significantly (United Nations Department of Economic and Social Affairs PD 2022). The report predicts that by 2050, older adults will constitute approximately 20% of the world's population. The prevalence of frailty is projected to increase with the global population ageing trend. Frailty is a clinical syndrome characterised by reduced physiological reserve and dysfunction of multiple systems, resulting in increased vulnerability and reduced resistance to stress in older adults (Clegg et al. 2013). Frailty in older adults can lead to a series of adverse outcomes, including functional decline, falls, reduced mobility, disability, increased risk of hospitalisation and even death (Fried et al. 2001; Hoogendijk et al. 2019). It also incurs increased medical expenditure and significant care burden to families (Hoogendijk et al. 2019; Bock et al. 2016).

2 | Background

As global aging continues to intensify, population aging in China has become a public health issue. According to the most recent report from the National Bureau of Statistics of China, as of the end of 2022, the population of older adults in China has surpassed 280 million, representing approximately 19.8% of the country's total population. This demographic means China is swiftly approaching the stage of moderate aging. According to previous studies, the prevalence of frailty in China varied between 5.9% and 17.4% (He et al. 2019). Early signs of frailty tend to be subtle and may go unnoticed by older adults. Compounded by a lack of awareness and misconceptions about frailty among both older adults and healthcare professionals, diagnosis is frequently delayed, resulting in significant adverse outcomes (Seino et al. 2020). Additionally, research indicates that healthcare costs over a three-month period for frail older adults, approximately $4000, are approximately five times higher than those for non-frail counterparts (Dent et al. 2017). This undoubtedly exacerbates financial strains on older adults and the healthcare system. Therefore, frailty has become a formidable challenge for China (Qin, Hao, et al. 2022).

Frailty is a clinically dynamic condition. Early detection and proactive intervention can play a pivotal role in decelerating or even reversing the progression of frailty (Hoogendijk et al. 2019; Gill et al. 2006). Developing a frailty prediction model to identify high-risk older adults and reduce their risk of adverse outcomes is immensely significant. Frailty models have evolved from single-factor approaches to multi-factorial ones, from targeting the entire population to focusing on specific demographic groups. For example, Doba developed a frailty prediction model in older adults, using increased pulse pressure, slowed gait, cognitive impairment and hearing impairment combined to predict frailty (Doba et al. 2012). In another study, researchers established the electronic Frailty Index (eFI), integrating the frailty prediction model into the medical assessment system (Clegg et al. 2016). This innovation was utilised to inform clinical practices, resulting in enhanced clinical outcomes for patients within primary care settings. Frailty prediction models vary widely by older adults' socio-demographics, health behaviours and social environment across countries. Risk prediction models in developed countries are constructed relatively early. The predictors are relatively simple and easy to obtain but often lack external validation (Gao et al. 2022). Currently, research on frailty prediction models in China is minimal. Dong et al. developed a frailty risk prediction model for community-dwelling older adults, focusing on demographics and lifestyle factors (Dong, Gu, et al. 2021). However, certain confounding factors, such as economic status and behavioural factors, were not taken into account in their analysis. Furthermore, this study used the Fried frailty phenotype to measure frailty, and the results cannot be generalised to older adults with impaired physical function or cognitive impairment. The same was true in another study, and the model could only be applied to community-dwelling people with diabetes (Bu et al. 2023). The widespread adoption of frailty prediction models in China faces challenges due to insufficient support from large populations and multi-centre research studies. By reviewing the literature, we found only one such study. Li et al. developed a frailty risk prediction model using 30 predictive variables with an AUC value of 0.881 and good prediction performance (Li et al. 2022). Model development typically entails trade-offs between accuracy, complexity and interpretability. While incorporating more predictive variables or objective data may enhance accuracy, it can also complicate model calculations, diminishing the model's clinical practicality. In real-world clinical practice, healthcare professionals often prefer simpler tools (Park et al. 2021).

Identifying risk factors for frailty is the first step to building a prediction model. The onset of frailty involves multiple organ systems, such as the cardiovascular system, the skeletal muscle, the respiratory system, the immune system, the brain and the endocrine system (Clegg et al. 2013; Fan et al. 2020). Based on previous literature reports (Qin, Hao, et al. 2022; Wang, Hu, and Wu 2022; Mailliez et al. 2020; Ocampo-Chaparro et al. 2019), frailty encompasses a myriad of risk factors, including socio-demographic factors such as sex, age, education and living status; health factors such as polypharmacy, comorbidities and cognitive function; behavioural factors such as smoking, drinking, nutritional status and exercise; psychological factors such as depression; and biological factors such as albumin and vitamin D levels. Given its multifaceted nature, frailty is a complex syndrome that cannot be accurately predicted by a single factor or dimension alone. Indeed, certain factors contributing to frailty, such as comorbid conditions, may be challenging to control. Additionally, some factors may necessitate instrumental measurement or evaluation by medical professionals. Given the essential characteristics of older adults, establishing a predictive model based on multiple dimensional factors that are easily provided and under the control of older adults themselves may enhance the generalisability and feasibility of the model.

Therefore, we used the Chinese Longitudinal Healthy Longevity Survey data to select conveniently accessible demographic, socioeconomic status and health behaviour risk factors to construct a frailty risk prediction model tailored to older adults in China. That will allow healthcare professionals to screen high-risk groups and propose tailored intervention programmes timely.

3 | The Study

3.1 | Aim and Objective

This study aimed to describe the current status of frailty and related risk factors among older adults in China and construct a frailty risk prediction model for this population.

4 | Methods

4.1 | Design and Participants

This cross-sectional study is a secondary analysis of existing data. The data came from the eighth wave of the Chinese Longitudinal Healthy Longevity Survey (CLHLS) published by the Peking University Healthy Aging and Development Research Centre in 2020.

The CLHLS database is China's longest-tracked ageing health survey and the most extensive scientific survey involving older adults worldwide. The project began in 1998 and was conducted by the Peking University Healthy Aging and Development Research Centre. Follow-up surveys were conducted every 3 to 4 years. Adopting a targeted random sampling method, professional investigators collected comprehensive information on physical and mental health, cognitive function, socioeconomic status, lifestyle, diet, nutrition and home care needs of older adults aged 65 and above through face-to-face interviews. The survey covers 23 provinces, municipalities and autonomous regions in China, with 67.40% of the participants aged 80 years and older. By providing high-quality microdata, CLHLS aimed to explore factors conducive to a long and healthy life, improve quality of life in later years and prolong survival for older adults.

This study selected the latest CLHLS data for the 2017–2018 wave, including 15,874 participants. After excluding participants with missing data, a total of 9006 participants were included in the analysis.

4.2 | Measures

4.2.1 | Frailty

The Frailty Index is a frailty assessment tool developed by Rockwood based on the cumulative deficit model and includes many variables such as signs, symptoms, functional impairment and laboratory indicators (Mitnitski, Mogilner, and Rockwood 2001). Because the variable selection criteria were inconsistent, they were freely constructed following standard operating procedures (Searle et al. 2008).

Based on previous research (Yang and Gu 2016), a total of 38 variables (39 defects) were selected for the Frailty Index, including activities of daily living (ADL), instrumental activities of daily living (IADL), functional limitations, cognitive function, self-rated health status, symptom of psychological distress, hearing and visual impairment, chronic disease conditions and severe illness status in the past 2 years. Each variable was operated as a binary variable, with 0 (no) and 1 (yes) representing the existence of health deficits. For example, a self-rated loneliness score was as follows: Yes = 1, No = 0. However, two points were awarded if a person has had more than one serious illness in the past 2 years. The calculation of the Frailty Index is a sum of items with health defects divided by the total number of items. The Frailty Index value ranges from 0 to 1, with the higher value indicating more health deficiency and, thus, more severe frailty. A Frailty Index score ≥ 0.25 indicated frailty, while a score < 0.25 was considered non-frail. More details on the Frailty Index can be found in Table S1.

4.2.2 | Predictors of Frailty

Under the consideration of maximising the clinical practicability of the prediction model, the study opted to utilise demographic, socioeconomic and health behaviour variables from the CLHLS dataset as independent variables. These variables were selected based on their relevance and ease of access for older adults. The demographic variables comprised seven factors: sex (male or female), age group (65–79 years, 80–94 years, or 95–115 years), residence (urban or rural), living arrangement (with family, alone or in a nursing home), education level (illiteracy, primary school, or middle school and above), number of children (0, 1–2, or ≥ 3) and marital status (having a spouse or not). Socioeconomic variables included three factors: receipt of basic living security (yes or no), enrolment in pension insurance (yes or no) and self-assessed economic status (categorised as good or poor based on respondents' perception of their economic status compared to others in their local area). Health behaviour variables encompassed six factors: smoking status (yes or no), alcohol consumption (yes or no), engagement in social activities (yes or no), participation in regular exercise (yes or no), body mass index (categorised as underweight, normal weight, overweight or obese) (Chen et al. 2004) and sleep quality (categorised as good or poor based on respondents' subjective assessment of their sleep quality).

4.3 | Ethical Considerations

The CLHLS study was approved by the Research Ethics Committee of Peking University. All CLHLS participants voluntarily signed written informed consent, which included an agreement to use the data in future research. This study was conducted in strict compliance with ethical guidelines and approved by the Institutional Review Board Committee to which the author belongs (IRB number: XZMU-2022-ZK001).

4.4 | Statistical Analysis

For descriptive statistics, categorical variables were expressed as frequencies and percentages. The Chi-square tests for univariate analysis were used to compare categorical variables. Variables with a significant univariate relationship ($p < 0.05$) were entered into the multivariate binary logistic regression model. Variables were then selected using stepwise regression to identify independent predictors of frailty. The predictors were used to construct the nomogram model. The C-index and Area under the ROC curve (AUC) were used to assess the model's discrimination ability. The value of the C-index ranged from 0.5 to 1.0, and a C-index value > 0.7 indicated that the constructed nomogram model had excellent discriminating ability. The calibration capability of the nomogram was evaluated with a calibration curve and the Hosmer-Lemeshow test (p-value > 0.05 indicates good calibration). The Brier score was a comprehensive indicator of the discrimination and calibration of the model. The model was considered to perform well when the Brier score ≤ 0.25. A bootstrap resampling procedure was used to validate the internal performance of the model. All statistical analyses were conducted using IBM SPSS 25.0 and R version V4.2.0. A two-sided p-value < 0.05 indicated statistical significance.

5 | Results

5.1 | Characteristics of the Participants

Among the 9006 participants (mean age 83.2, range 65 to 115), 4527 were males (50.3%). In terms of demographic and socioeconomic characteristics, most participants were urban residents (56.8%), lived with family members (81.0%), illiterate and primary school level (78.9%), had a spouse (52.5%), had three or more children (74.9%), had normal BMI (51.9%), had basic living security (87.4%), had no pension insurance (71.7%) and had poor self-assessed economic status (91.1%) accounted for the majority. In terms of health behaviours, most participants did not drink alcohol (83.2%), smoke (82.8%), exercise (64.0%) and participate in social activities (90.1%). Additionally, a substantial portion of participants reported good sleep quality (85.9%). Table 1 shows the descriptive characteristics of the participants in this study.

The participants were categorised as non-frail and frail. The mean of FI was 0.15, and the range of FI was between 0 and 0.82. Of the 9006 older adults, 1857 (20.6%) were identified as frail, and 7149 (79.4%) were non-frail. For the univariate analysis, age, sex, residence, living status, education level, marital status, number of children, basic living security, self-assessed economic status, body mass index (BMI), sleep quality, smoking status, drinking status, physical exercise and social activities were found to be significantly correlated with frailty ($p < 0.001$). However, there was no significant correlation between pension insurance and frailty ($p = 0.113$).

5.2 | Factors Associated With Frailty

With frailty as the dependent variable, 15 variables with statistical significance in the univariate analysis were used as the independent variables, and the binary stepwise classification logistic regression analysis was introduced, with the inclusion criteria $\alpha = 0.05$ and exclusion criteria $\beta = 0.10$. Table 2 describes the assignment of independent variables and dependent variables. Table 3 shows that older adults aged 80–84 years exhibited a higher risk of frailty compared to those aged 65–79 years (OR = 4.581, 95% CI: 3.875, 5.415). Furthermore, individuals aged 95–115 years had a substantially elevated risk of frailty compared to the 65–79 years age group (OR = 14.228, 95% CI: 11.549, 17.529). Compared with those living with their families, participants living in nursing homes (OR = 3.066, 95% CI: 2.254, 4.171) had about 3.1 times higher risk of frailty, and those living alone (OR = 0.581, 95% CI: 0.490, 0.689) had a lower risk of frailty. Participants who were underweight (OR = 1.189, 95% CI: 1.005, 1.407) or obese (OR = 1.392, 95% CI: 1.112, 1.742) had a higher risk of frailty than those with a normal BMI. Participants with poor sleep quality (OR = 2.071, 95% CI: 1.767, 2.428) had a higher risk of frailty than those with good sleep quality. Participants with poor self-assessed economic status (OR = 1.413, 95% CI: 1.132, 1.763) had a higher risk of frailty than those with good self-assessed economic status. In addition, having a spouse (OR = 0.650, 95% CI: 0.560, 0.754), a primary education level (OR = 0.801, 95% CI: 0.698, 0.918), living in a rural setting (OR = 0.634, 95% CI: 0.559, 0.719), having basic living security (OR = 0.711, 95% CI: 0.585, 0.865), smoking (OR = 0.758, 95% CI: 0.626, 0.919), drinking (OR = 0.602, 95% CI: 0.493, 0.736), exercise (OR = 0.328, 95% CI: 0.283, 0.381) and social activities (OR = 0.623, 95% CI: 0.476, 0.816) were protective factors against frailty.

5.3 | Nomogram Construction

Based on the 13 independent predictors screened by the logistic regression, we established a nomogram of the risk of frailty among older adults in China (Figure 1). The nomogram is implemented through R language. According to the contribution of each predictor in the model to the outcome, line segments with scales are plotted on the same plane at a certain proportion. It is a visual display of complex mathematical formulas that is easy to understand and use. To use the nomogram, we first determined the position of each variable on the corresponding axis. To determine the point value of each variable, we drew a vertical line from the position on the variable axis to the point axis. Subsequently, all variable point values were summed and positioned on the Total points axis. Finally, a vertical line from the values corresponding to the Total points axis was drawn downward to the Risk axis to determine the risk of frailty. For example, a community-dwelling older adult is 85 years old (57 points), lives alone (0 points) in a rural area (0 points), is illiterate (9 points), has no spouse (17 points) and has basic living security (0 points), poor self-assessed economic status (14 points), obesity (13 points), poor sleep quality (28 points), no smoking (12 points), no drinking (20 points), no physical exercise (42 points) and social activity participation (0 points). The total point of the nomogram model will be 212, and the corresponding risk of frailty is 0.41.

TABLE 1 | Basic characteristics of the participants ($n = 9006$).

Variable	N (%)	Non-frail	Frail	x^2	p
Sex				98.424	< 0.001
Male	4527 (50.3)	3784 (83.6)	743 (16.4)		
Female	4479 (49.7)	3365 (75.1)	1114 (24.9)		
Age				1575.670	< 0.001
65~79	4235 (47.0)	3976 (93.9)	259 (6.1)		
80~94	3573 (39.7)	2660 (74.4)	913 (25.6)		
95~115	1198 (13.3)	513 (42.8)	685 (57.2)		
Residence				47.953	< 0.001
Urban	5118 (56.8)	3931 (76.8)	1187 (23.2)		
Rural	3888 (43.2)	3218 (82.8)	670 (17.2)		
Living status				137.030	< 0.001
With family	7295 (81.0)	5829 (79.9)	1466 (20.1)		
Alone	1463 (16.2)	1196 (81.7)	267 (18.3)		
In a nursing home	248 (2.8)	124 (50.0)	124 (50.0)		
Education level				258.512	< 0.001
Illiterate	2842 (31.6)	1971 (69.4)	871 (30.6)		
Primary School	4263 (47.3)	3554 (83.4)	709 (16.6)		
Middle school or above	1901 (21.1)	1624 (85.4)	277 (14.6)		
Marital status				559.536	< 0.001
No spouse	4275 (47.5)	2940 (68.8)	1335 (31.2)		
Having a spouse	4731 (52.5)	4209 (89.0)	522 (11.0)		
Number of children				50.860	< 0.001
0	124 (1.4)	87 (70.2)	37 (29.8)		
1~2	2135 (23.7)	1806 (84,6)	329 (15.4)		
≥ 3	6747 (74.9)	5256 (77.9)	1491 (22.1)		
Body mass index				141.024	< 0.001
Underweight	1099 (12.2)	744 (67.7)	355 (32.3)		
Normal	4674 (51.9)	3688 (78.9)	986 (21.1)		
Overweight	2449 (27.2)	2082 (85.0)	367 (15.0)		
Obese	784 (8.7)	635 (81.0)	149 (19.0)		
Basic living security				22.381	< 0.001
No	1138 (12.6)	843 (74.1)	295 (25.9)		
Yes	7868 (87.4)	6306 (80.1)	1562 (19.9)		
Pension insurance				2.511	0.113
No	6453 (71.7)	5095 (79.0)	1358 (21.0)		
Yes	2553 (28.3)	2054 (80.5)	499 (19.5)		
Economic situation				25.006	< 0.001
Good	806 (8.9)	585 (72.6)	221 (27.4)		
Poor	8200 (91.1)	6564 (80.0)	1636 (20.0)		

(Continues)

TABLE 1 | (Continued)

Variable	N (%)	Non-frail	Frail	x^2	p
Sleep quality				74.234	< 0.001
Good	7736 (85.9)	6256 (80.9)	1480 (19.1)		
Poor	1270 (14.1)	893 (70.3)	377 (29.7)		
Smoking				76.522	< 0.001
No	7455 (82.8)	5791 (77.7)	1664 (22.3)		
Yes	1551 (17.2)	1358 (87.6)	193 (12.4)		
Drinking				105.792	< 0.001
No	7495 (83.2)	5802 (77.4)	1693 (22.6)		
Yes	1511 (16.8)	1347 (89.1)	164 (10.9)		
Exercise				413.727	< 0.001
No	5762 (64.0)	4199 (72.9)	1563 (27.1)		
Yes	3244 (36.0)	2950 (90.9)	294 (9.1)		
Social activities				81.135	< 0.001
No	8111 (90.1)	6341 (78.1)	1777 (21.9)		
Yes	888 (9.9)	808 (91.0)	80 (9.0)		

Note: All numbers mean frequency (percentage). $p < 0.05$ indicates statistical significance.

TABLE 2 | Description of variable assignment.

Classification of variables	Variables	Assignments
Independent	Sex	Male = 1; Female = 2
	Age	65~79 = 1; 80~94 = 2; 95~115 = 3
	Residence	Urban = 1; Rural = 2
	Living status	With family = 1; Alone = 2; In a nursing home = 3
	Education level	Illiterate = 1; Primary school = 2; Middle school or above = 3
	Marital status	No spouse = 0; Having a spouse = 1
	Number of children	0 = 0; 1~2 = 1; ≥ 3 = 2
	Body mass index	Normal = 1; Underweight = 2; Overweight = 3; Obese = 4
	Basic living security	No = 0; Yes = 1
	Economic situation	Good = 0; Poor = 1
	Sleep quality	Good = 0; Poor = 1
	Smoking	No = 0; Yes = 1
	Drinking	No = 0; Yes = 1
	Exercise	No = 0; Yes = 1
	Social activities	No = 0; Yes = 1
Dependent	Frailty	No = 0; Yes = 1

TABLE 3 | Logistic regression on factors associated with frailty among the participants.

Variable	Beta	Wald	*p*	OR	95% CI
Age					
65~79 years	Reference				
80~94 years	1.522	317.838	< 0.001	4.581	3.875, 5.415
95~115 years	2.655	622.271	< 0.001	14.228	11.549, 17.529
Residence					
Urban	Reference				
Rural	−0.455	50.235	< 0.001	0.634	0.559, 0.719
Living status					
With family	Reference				
Alone	−0.543	39.087	< 0.001	0.581	0.490, 0.689
In a nursing home	1.120	50.879	< 0.001	3.066	2.254, 4.171
Education level					
Illiterate	Reference				
Primary school	−0.222	10.074	0.002	0.801	0.698, 0.918
Middle school or above	0.043	0.182	0.670	1.044	0.856, 1.274
Marital status					
No spouse	Reference				
Having a spouse	−0.431	32.306	< 0.001	0.650	0.560, 0.754
Body mass index					
Normal	Reference				
Underweight	0.173	4.051	0.044	1.189	1.005, 1.407
Overweight	0.051	0.433	0.511	1.053	0.904, 1.226
Obese	0.331	8.343	0.004	1.392	1.112, 1.742
Basic living security					
No	Reference				
Yes	−0.341	11.584	0.001	0.711	0.585, 0.865
Economic situation					
Good	Reference				
Poor	0.345	9.327	0.002	1.413	1.132, 1.763
Sleep quality					
Good	Reference				
Poor	0.728	80.748	< 0.001	2.071	1.767, 2.428
Smoking					
No	Reference				
Yes	−0.277	7.993	0.005	0.758	0.626, 0.919
Drinking					
No	Reference				
Yes	−0.507	24.738	< 0.001	0.602	0.493, 0.736

(Continues)

TABLE 3 | (Continued)

Variable	Beta	Wald	p	OR	95% CI
Exercise					
No	Reference				
Yes	−1.114	213.274	< 0.001	0.328	0.283, 0.381
Social activities					
No	Reference				
Yes	−0.473	11.840	0.001	0.623	0.476, 0.816

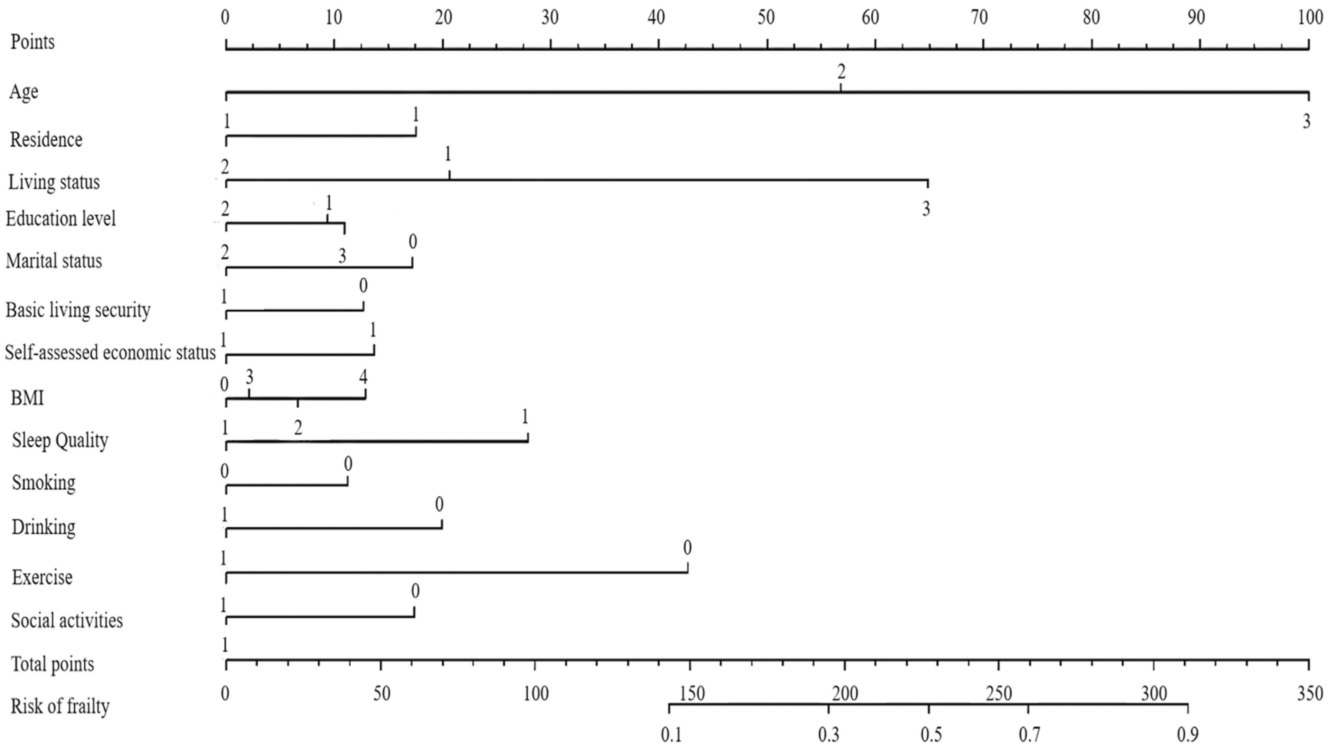

FIGURE 1 | A nomogram to predict frailty risk among older adults in China.

5.4 | Nomogram Performance

We calculated the AUC as 0.831 (95% CI: 0.823, 0.839). By calculating the Youden index, we got this model's optimal cutoff value of 0.192, with corresponding sensitivity and specificity of 79.6% and 72.7%, respectively. We internally validated the frailty risk prediction model for older adults using the bootstrap method with 1000 repetitions and obtained a reliable C-index of 0.830 (95% CI: 0.820, 0.840). The C-index and AUC values were more significant than 0.7, indicating the model had excellent discriminative ability. Hosmer-Lemeshow test and calibration curve were usually used to evaluate the goodness-of-fit of the constructed model. The chi-square value of the Hosmer-Lemeshow test was 12.658 ($p=0.124$), and a calibration chart (Figure 2) showed that the calibration curve almost coincided with the ideal curve, indicating that the model was well-calibrated. The Brier score of the model was 0.122, showing a good overall predictive performance.

6 | Discussion

Due to differences in frailty assessment tools and geographic regions, the prevalence of frailty in different countries varied from 3.9% to 51.4% (Siriwardhana et al. 2018). The results of this study showed that the prevalence of frailty in older adults in China was 20.6%, consistent with several previous studies (Li et al. 2022; O'Caoimh et al. 2021). Frailty is an essential risk factor for a range of adverse health outcomes (Fried et al. 2001), and identifying high-risk individuals is critical to preventing frailty and its associated adverse outcomes, especially in its early stages.

Increasing age was an independent risk factor for frailty. Age-stratified analysis showed that compared with older adults aged 65–79, the prevalence of frailty in older adults aged 80–94 and 95–115 increased by 4.581 times and 14.228 times, respectively, and the increase in prevalence was significantly higher than in

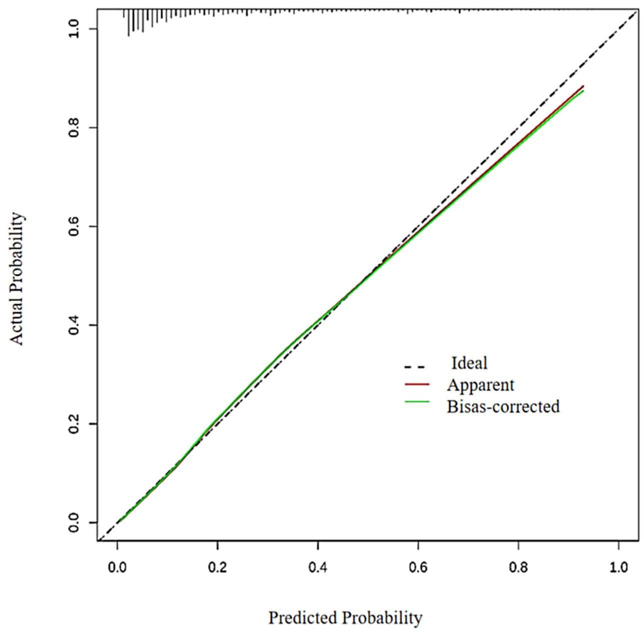

FIGURE 2 | Internal verification calibration diagram of the model.

other studies (He et al. 2019). In this study, the advanced age population accounted for 53%, and the prevalence of frailty among the advanced age population may be overestimated. Ageing is associated with progressive homeostatic dysregulation of multiple physiological systems and impairs the body's reserves, resilience and intrinsic capabilities, thereby increasing the risk of frailty (Clegg et al. 2013). Our study showed that the prevalence of frailty among older adults in rural areas was lower than that in urban settings, a conclusion contrary to that of Zeng et al. (Zeng et al. 2023) Compared with rural older adults, urban older adults are more concerned about their physical health and are more likely to receive frailty screening. Advances in medical conditions and technology can prolong life and delay death, but they do not necessarily improve quality of life. Especially in urban areas, advanced level of medical technology may also lead to over-medicalisation, resulting in physical injuries, increased expenses for examination and treatment, and psychological burdens, which are more likely to escalate frailty in older adults. The demographic characteristics showed that most older adults lived with their families (81%), which aligned with the traditional Chinese 'family pension' model. However, due to changes in China's family structure, many non-traditional families have emerged, such as single-living families, and the family pension cannot undertake new functions (Su, Hu, and Peng 2017). In this article, it was observed that older adults who lived alone exhibited a reduced risk of frailty compared to those living with their families. This phenomenon can be elucidated by considering that older adults living alone tend to retain similar psychological and social needs as younger individuals. They actively resist social withdrawal by engaging in social or recreational activities, thereby enhancing their self-adaptability and fostering social integration (Qin, Liu, et al. 2022). Social participation not only diminishes the risk of frailty but also indirectly ameliorates adverse outcomes associated with frailty (Abe et al. 2023; Kim et al. 2020). To a certain extent, nursing homes can effectively alleviate the weakening family pension function and burden of care for older adults (Liu et al. 2022). This study revealed that the prevalence of frailty among older adults residing in nursing homes was approximately 50%, which aligns roughly with previous research findings (Liu et al. 2020). Notably, older adults in nursing homes are predominantly characterised by disability, advanced age and multimorbidity, rendering them incapable of receiving adequate care at home and indicative of more severe health issues (Liu et al. 2020). Moreover, the geographical remoteness of many nursing homes, coupled with the upheaval in lifestyle and the fear of the unfamiliar, may contribute to feelings of loneliness, anxiety and loss of appetite among residents, thus predisposing them to frailty (Zhao et al. 2019; Rudzińska et al. 2023). Additionally, older adults with spouses exhibited a lower risk of frailty compared to their single counterparts. Single older adults tend to have lower levels of activities of daily living and are more susceptible to frailty (Xu et al. 2020). Furthermore, another study highlighted that frail individuals may exhibit a correlation with poor health in both themselves and their spouses, sharing the risk factors, and were more likely to experience the loss of a spouse (Kojima et al. 2020).

From a socioeconomic standpoint, maintaining a favourable self-assessed economic status and ensuring basic living security emerge as pivotal factors in mitigating frailty among older adults. Recent research findings corroborate this assertion (Li et al. 2022). Financial assistance provided by the government and society serves as a form of robust social support, which plays a crucial role in enhancing the overall well-being of older adults. Social support is integral to the life satisfaction of older individuals. Those who benefit from substantial support experience reduced life pressures and harbour a more positive outlook on life. Furthermore, older adults with improved economic circumstances often report higher levels of life satisfaction. Life satisfaction represents the subjective evaluation of an individual's living conditions and overall quality of life, encapsulating their perceptions of fulfilment and contentment (Pahlevan Sharif et al. 2021). Therefore, by fostering a supportive environment and ensuring economic stability, policymakers and community stakeholders can contribute significantly to enhancing older adults' well-being and life satisfaction. An investigation involving 7070 community-dwelling older adults in China revealed a noteworthy negative correlation between frailty and life satisfaction (Qin et al. 2020). Consequently, tailored interventions can be developed to enhance the well-being of older adults based on their economic circumstances. For older adults with improved financial means, the provision of diverse services and various social activities can be beneficial. These activities could encompass opportunities for social engagement, leisure pursuits and access to cultural events, all aimed at enriching their lives and fostering a sense of fulfilment. Conversely, for older adults facing economic challenges, it is essential to allocate additional funds and material support. Such targeted assistance aims to ensure a more equitable distribution of resources, enabling individuals with limited financial resources to access necessary support services and amenities. This approach to 'precise assistance' can effectively enhance the overall life satisfaction of older adults, irrespective of their economic status. By addressing their specific needs and circumstances, these interventions contribute to promoting a higher quality of life among older adults across diverse economic backgrounds.

Compared with those with normal BMI, the odds of frailty were 1.189 and 1.392 times higher in older adults with underweight and obesity, respectively, and there was no significant difference between those with overweight ($p = 0.511$). Similar to the U-shaped relationship between BMI and frailty risk observed in a previous meta-analysis, the lowest risk point appeared when the BMI was 18.5–29.9 kg/m^2 (Yuan, Chang, and Wang 2021). Being underweight and obese can lead to sarcopenia (Crovetto Mattassi, Henríquez Mella, and Pérez 2022; Miura et al. 2021), a central element of physical frailty. Daily exercise is an essential factor in preventing frailty. However, our study found that more than half of older adults were reluctant to participate in exercise, possibly because they were fearful of falling. As frailty increases, so does the tendency not to exercise, creating a vicious cycle (Qin et al. 2021). Previous studies have found that a 9-month multicomponent physical exercise intervention significantly decreased falls and frailty risk and is cost-effective (Han et al. 2020). Our study has found that board games, square dancing, travel and other organised social activities can effectively reduce the risk of frailty. Huang et al. found in a 2-year cohort study that irregular participation in social activities can prevent frailty and that frequent social activities (almost every day) were not associated with frailty (Huang et al. 2021). Another cross-sectional study also showed that social activities at a frequency of once a week were associated with a lower risk of frailty (Kim et al. 2020). Frequency of participation is important, but other aspects should also be focused on, such as satisfaction and type of participation (Ye et al. 2020). In addition, rigorous randomised controlled trials are necessary to validate the effectiveness of these social activity programmes in preventing frailty. Compared with those with good sleep quality, older adults with poor sleep quality had a higher incidence of frailty. Several studies have also shown that sleep is significantly negatively related to multiple dimensions of frailty in terms of physiology, psychology and society, and the correlation has been verified through multiple frailty assessment tools simultaneously (Balomenos et al. 2021; Fan et al. 2022).

Different from the conclusions of most previous studies (Wang, Hu, and Wu 2022; Franse et al. 2017; Etman et al. 2015), our study found that primary education level, smoking and drinking were protective factors against frailty. Based on a comprehensive community survey, Franse et al. identified a correlation wherein older adults with primary and secondary education were more susceptible to frailty than those with tertiary education (Franse et al. 2017). However, our findings do not align with this conclusion. This discrepancy may stem from the fact that the educational attainment of participants in our study is predominantly low, with nearly 80% possessing primary school education or below. Individuals with primary school education often exhibit cultural awareness and a strong focus on health, thereby prioritising the cultivation of healthy behaviours and lifestyles. Moreover, individuals with some level of education tend to have broader interests and engage more actively in social interactions, which may mitigate the risk of frailty. However, our study indicates an ambiguous relationship between middle school education and above and frailty, potentially due to the limited representation of this demographic within our sample. This situation could be attributed to the socio-historical context of the participants. China entered a turbulent period marked by social upheaval, economic instability and scarcity of resources during the 20th century, significantly impeding educational opportunities for many. The majority of our study participants experienced these challenges during their formative years, resulting in a generally low level of educational attainment (Dong, Du, et al. 2021). Interestingly, smoking and drinking were protective factors for the development of frailty in older adults. One possible explanation for this phenomenon could stem from a bias known as the 'sick quitter' effect, a notion consistent with findings from two other studies utilising data from the Chinese Longitudinal Healthy Longevity Survey (CLHLS) (Li et al. 2022; Lv et al. 2023). Owing to their declining health, many older adults may opt actively or passively be advised to cease smoking and drinking. To mitigate this bias, it is advisable to categorise individuals who smoke or drink as either never smokers/drinkers or non-smokers (drinkers). Furthermore, our study solely examined current smoking and alcohol consumption status without considering the frequency or quantity of these habits. Consequently, our understanding of smoking and drinking behaviours remains incomplete. Thus, further investigation is warranted to elucidate the association between smoking or alcohol consumption and frailty among older adults.

6.1 | Strengths and Limitations

The strengths of this study can be summarised in the following points. First, the CLHLS data provided a large, nationally representative sample of older adults, and our results could be widely generalisable to older adults in China. Secondly, we analysed the risk factors of frailty from the three dimensions of demographic, socioeconomic and health behaviour and provided a theoretical basis for frailty prevention and intervention guidance. Finally, all predictors of the model were highly accessible, non-invasive and economical, allowing healthcare professionals to make clinical diagnoses quickly. In addition to the above advantages, this study has some limitations. First, no conclusion on causality was made since this was a cross-sectional study. Second, although we have conducted internal validation of the model, the lack of external validation limits the model's generalisation performance. Future research efforts should focus on conducting external validation of the predictive ability of the model across multiple centres, different time periods and various clinical scenarios. Additionally, it is important to consider incorporating multiple potential predictors, such as biomarkers and polypharmacy, which were not included in the current study due to limitations in the CLHLS design. Integrating these factors into future research endeavours can enhance the accuracy and robustness of predictive models in this field.

6.2 | Implications for Practice

Currently, there are a few reports on frailty prediction models for older adults in China based on national surveys. The nomogram quantifies and visualises the predictors' risk ratio in the logistic regression model, and the probability of the target event can be obtained through a simple calculation. As a simple and efficient early warning tool, our predictive model may apply more to community older adults' health care than other predictive models. On the one hand, our nomogram is applicable and accessible. The predictive indicators of the model obtained through consultation or from residents' health records are all convenient and accessible items in community diagnosis and treatment services, which not only avoids the waste of medical resources but also increases the compliance of older adults. On the other hand, community healthcare professionals can identify risk factors before the appearance of frailty-related symptoms in each older adult, understand the size of the risk and provide personalised interventions and care measures for older adults. Finally, the dynamic monitoring of older adults through the model can also help understand the frailty risk factors.

7 | Conclusion

In this study, a nomogram model was developed and validated to predict frailty among older adults in China. The model integrated demographic, socioeconomic and health behavioural factors and had been internally validated and proven to be a useful risk assessment tool. This predictive model will be valuable for screening older adults in China at high risk for frailty. It also provided intervention target information for frail older adults to improve their quality of life and life expectancy.

Author Contributions

X.T. and D.S. developed the study idea and design, collected data, conducted data analysis and drafted the manuscript. T.Z. helped collect data, conducted data analysis and searched literature. S.G. contributed to the manuscript revision. X.W. and A.W. provided critical feedback on the manuscript. Y.X. and M.L. helped with the study design and manuscript revision. All authors critically reviewed the manuscript and approved the final version.

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Ethics Statement

This study was approved by the Ethics Committee of Xuzhou Medical University (IRB number: XZMU-2022-ZK001).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are openly available on the CLHLS website and can be accessed at https://doi.org/10.18170/DVN/WBO7LK.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.