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Status of cognitive frailty in elderly patients with chronic kidney disease and construction of a risk prediction model: a cross-sectional study

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ABSTRACT

Objective To investigate the risk factors of cognitive frailty in elderly patients with chronic kidney disease (CKD), and to establish an artificial neural network (ANN) model.

Design A cross-sectional design.

Setting Two tertiary hospitals in southern China.

Participants 425 elderly patients aged ≥60 years with CKD.

Methods Data were collected via questionnaire investigation, anthropometric measurements, laboratory tests and electronic medical records. The 425 samples were randomly divided into a training set, test set and validation set at a ratio of 5:3:2. Variables were screened by univariate and multivariate logistic regression analyses, then an ANN model was constructed. The accuracy, specificity, sensitivity, receiver operating characteristic (ROC) curve and area under the ROC curve (AUC) were used to evaluate the predictive power of the model.

Results Barthel Index (BI) score, albumin, education level, 15-item Geriatric Depression Scale score and Social Support Rating Scale score were the factors influencing the occurrence of cognitive frailty ($p<0.05$). Among them, BI score was the most important factor determining cognitive frailty, with an importance index of 0.30. The accuracy, specificity and sensitivity of the ANN model were 86.36%, 88.61% and 80.65%, respectively, and the AUC of the constructed ANN model was 0.913.

Conclusion The ANN model constructed in this study has good predictive ability, and can provide a reference tool for clinical nursing staff in the early prediction of cognitive frailty in a high-risk population.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ Cognitive frailty is highly prevalent among elderly patients with chronic kidney disease, and early prediction and intervention can prevent the occurrence or development of cognitive frailty.
- ⇒ Artificial neural networks (ANN) have stronger predictive ability compared with traditional prediction models, the ANN model can provide a new reference tool for clinical practice.
- ⇒ The larger the sample size, the better the prediction power of the model. In the future, it is still necessary to increase the sample size to improve the prediction power of the model.
- ⇒ This study was conducted in only one city of China, which could affect the generalisability of the findings.

INTRODUCTION

The number of people aged 60 years and over is expected to double by 2050, according to a new report released by the WHO, with ageing and super-ageing becoming increasingly serious worldwide.[1] As the most populous country in the world, China has a particularly prominent ageing problem.[2] According to the Social Bulletin of the National Bureau of Statistics in 2019, by the end of 2019, the population over the age of 60 in China had reached 254 million,[3] and it is expected that by 2050, the total elderly population over the age of 60 in China will reach 498 million.[4] Chronic kidney disease (CKD) is a chronic decomposing metabolic disease that has become a major global public health problem among the elderly, with a prevalence of 32%–37% in the elderly population,[5] and increases with age.[6] Ageing is associated with physical frailty and cognitive decline.[7] The incidence of cognitive decline in the elderly in China is 22%, increases with age and is especially high in patients with chronic diseases such as CKD.[8] Cognitive decline can affect the social function and quality of life of the elderly to varying degrees, and even death.[9]

Physical frailty is a geriatric syndrome characterised by a cumulative decline in multisystem physiological functions.[7] The incidence of physical frailty in elderly patients with CKD can be as high as 73%, and is closely related to adverse health outcomes such as prolonged hospital stay, increased risk of falls, cardiovascular events and even death.[10] Several studies have shown a tight and interactive relationship between frailty and cognitive decline due to many common risk factors and mechanisms.[11 12] Elderly patients are considered to have cognitive frailty when having both physical frailty and cognitive decline, excluding dementia, which increases the risk of adverse health outcomes.[13] It has been reported that the incidence of cognitive frailty in communities and hospitals is 1.0%–39.7%.[14 15] Elderly patients with CKD are often at greater risk of cognitive frailty due to anaemia, inflammatory vascular diseases and various metabolic disorders.[16] Several studies have found that the prevalence of cognitive frailty in elderly haemodialysis patients ranges from 4.6% to 25.9%.[17 18] However, there are still few studies and limited evidence on cognitive frailty in elderly patients with CKD, and the reported prevalence varies greatly due to differences in the population studied and the measurement tools used. In addition, the influencing factors of cognitive frailty include physiological, psychological, social and geriatric syndromes. Previous literature has shown that gender, age, education level, income level, physical exercise, disease type, nutrition, sleep and psychological status, creatinine, haemoglobin, albumin and other factors are related to the occurrence of cognitive frailty.[18–21] Moreover, the reversible characteristics of cognitive frailty make it possible to be prevented, delayed or reversed through early prediction and intervention. Therefore, it would be of great significance to construct a prediction model of cognitive frailty for accurate prediction and intervention in high-risk population.

However, at present, prediction models have been mainly based on traditional regression analysis, and less on other machine learning algorithms. An artificial neural network (ANN) is a multilayer complex model with multiple neurons as nodes and synaptic connections.[22] Studies show that, in various systems, compared with traditional rule-based or regression-based models, ANNs have stronger predictive ability and can efficiently identify diseases and high-risk groups.[23–26] Moreover, ANN models have obvious advantages in data processing, identification and data fitting.[27] Therefore, this study constructed an ANN model for early risk prediction of cognitive frailty in elderly patients with CKD, aiming to provide a new reference tool for the early prediction of cognitive frailty in elderly patients with CKD, as well as assist clinical medical workers to quickly identify the risk of cognitive frailty in elderly patients with CKD, and provide a basis for the formulation and implementation of early intervention.

METHODS

Study design and setting

This cross-sectional study was conducted from October 2020 to August 2021 in two tertiary hospitals in Shantou, Guangdong Province, China. Convenience sampling was used to collect data in the Department of Nephrology.

Data collection and ethical considerations

After we contacted and obtained the consent of the two department directors, we invited the department nurses to assist in collecting data. We introduced the purpose of this study to patients in a unified guidance language. After obtaining written informed consent from the patient, a one-to-one survey was conducted by two uniformly trained investigators, and grip strength and body weight were measured by using uniform methods and equipment. The data in this study were obtained from questionnaire investigation, anthropometric measurements, laboratory tests and electronic medical records.

Participants

A total of 430 elderly patients with CKD were recruited from southern China. For selection criteria, subjects were required to have been (1) diagnosed with CKD, (2) at least 60 years of age, (3) without dementia, visual or hearing impairment, and (4) a voluntary participant in the study. Of the 430 participants, five were excluded for complicated malignancies, chronic malnutrition or having acute kidney injury within 3 months. Ultimately, a total of 425 patients were included, with a response rate of 98.84%.

Sample size was calculated according to the sample size estimation method used in epidemiological cross-sectional studies, $n = \frac{Z^2_{1-\partial/2} * P(1-P)}{d^2} * (1+20\%)$, where n is the sample size, Z represents statistic, 1-α/2 represents a two-sided test, P is the disease prevalence and d represents precision. Previous studies found that the prevalence of cognitive frailty in elderly patients with CKD was 25.9%.[18] We assumed a confidence level of 95% with a precision of 5% and adopted a two-sided test, taking into account a 20% non-response rate. Therefore, the minimum sample size required for this study was 295 cases.

Survey instrument

Frailty

Frailty status was assessed by the frailty phenotype defined by Fried *et al*.[28] The scale includes five components: unintentional weight loss, grip strength decline, self-rated exhaustion, low gait speed and physical activity. The total score ranges from 0 to 5, and patients with three or more components were classified as frail, whereas those with fewer than three components were classified as non-frail.

Functional status

The Barthel Index (BI) was used to assess the capacity for daily living.[29] The scale consists of 10 items, for a total score of 100 points, and is graded as severe dependency (score≤40), moderate dependency (41≤score≤60), mild dependency (61≤score≤99) and complete independence. The Cronbach's alpha coefficient of the BI was 0.88, indicating good reliability and validity.[30]

Nutritional status

In the survey, the Mini-Nutritional Assessment-Short Form (MNA-SF) was used to assess nutritional status, and

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was simplified from the MNA by selecting six items to evaluate the risk of malnutrition over the past 3 months.[31] The total score of the MNA-SF ranges from 0 to 14, with a score of less than 11 indicating malnutrition. According to previous research, the scale has good specificity and sensitivity.[32]

Sleep quality

Sleep quality was evaluated by the Pittsburgh Sleep Quality Index (PSQI) in the survey, which was created from Buysse *et al*.[33] The scale is a validated measurement tool to screen for sleep disturbances, and includes 19 self-rated items and five other rated items of which seven components are composed of 18 self-rated items. The seven components are as follows: subjective sleep quality, falling asleep time, sleep duration, sleep efficiency, sleep disturbances, use of sleeping medication and daytime dysfunction. Each component is scored from 0 to 3 points, and the total score ranges from 0 to 21 points by summing the seven component scores. A total score greater than 7 points indicates poor sleep quality. It has been widely used in the Chinese population, and the Cronbach's alpha coefficient for the PSQI was 0.842.[34]

Cognitive status

The Mini-Mental State Examination (MMSE) was used to screen cognitive status in the survey. The MMSE comprised seven dimensions with 30 items, and the total score ranges from 0 to 30, with a higher score indicating higher level of cognitive function.[35] The scale was divided according to the education level of participants: ≤17 points—illiterate; ≤20 points—primary school; ≤24 points—secondary school and above. The Cronbach's alpha coefficient of the MMSE was 0.898.[36]

Depressive symptoms

The 15-item Geriatric Depression Scale (GDS-15) was used to assess depression within the past week, and was simplified from Sheikh and Savage.[37] The total score of the GDS-15 ranges from 0 to 15, with a score of 8 or more indicating the presence of depressive symptoms. The Cronbach's alpha coefficient of GDS-15 was 0.793 in the elderly population of China.[38]

Social function

The Social Support Rating Scale (SSRS) was used to evaluate the level of family social support.[39] The SSRS comprised three dimensions with 10 items, including objective support, subjective support and utilisation of social support, which ranges from 12 to 66 points. The higher the score, the better the family social support; among them, ≤22 is classified as low-level, 23–44 as medium-level and ≥45 as high-level support. The Cronbach's alpha coefficient of the SSRS was 0.825–0.896.

Covariates

The covariates included sociodemographic data, physical indicators, living habits, physical health status and laboratory indices. Sociodemographic data included age, gender, education level, occupation before retirement, monthly income, hospitalisation payment method and mobility aids (yes or no) such as walking stick or wheelchair. Living habits were included, such as smoking, drinking, falling down in the past year (yes or no) and the number of times of exercise per week. Physical health status (CKD stage, dialysis status, comorbidity, polypharmacy) and laboratory indices (C-reactive protein, parathormone, ferritin, albumin, blood urea nitrogen, creatinine, total cholesterol, triglycerides, white cells, haemoglobin, glomerular filtration rate) were obtained from the electronic medical records. Physical indicators (height, body weight, body mass index (BMI), blood pressure, grip strength) were measured by two trained interviewers by using the electronic grip dynamometer (Xiangshan EH101), the electronic sphygmomanometer arm, the scale and the flexible rule.

Statistical analysis

Data were double entered using EpiData V.3.1, and SPSS V.25.0 and SPSS Modeler V.18.0 software were used for statistical analysis and construction of the predictive model. Count data were presented as frequencies and percentages, and the comparison between groups was performed by the χ^2 test. When metrological data conformed to a normal distribution, results were expressed as mean±SD, and the t-test was used for comparison of the groups. Otherwise, median and IQR were used for statistical description, and the comparisons were analysed by the Mann-Whitney U test. Variable screening was conducted by using univariate analysis with an alpha significance level of 0.05. The variables that conformed to colinear diagnosis and were statistically significant ($p<0.05$) were included in the binary logistic regression analysis for inclusion in the final model. Through the binary logistic regression analysis in the study, the results showed that there were five variables with statistical significance ($p<0.05$) and were ultimately included in the prediction model.

Cognitive frailty was considered as a dichotomous dependent variable in the study, and the 425 samples were randomly divided into a training set, test set and validation set at a ratio of 5:3:2 by using a multilayer perceptron ANN. The random number seed was 1 234 567. The training set was used for building the model, the validation set was used to optimise the model parameters, whereas the test set was used for evaluation. Due to the large difference in the samples of target variables (93 cases of cognitive frailty and 332 cases of non-cognitive frailty), in order to avoid the problem that unbalanced data sets lead to the degradation of model prediction power, the balance node in SPSS Modeler was used to conduct random oversampling 3.57 times of cognitive frailty samples in the training set,[40] and the sample size involved a 1:1 ratio of cognitive frailty to non-cognitive frailty cases, after which the ANN model was built. The accuracy, sensitivity, specificity, receiver operating characteristic (ROC) curve and area under the ROC curve

Table 1 Characteristics of the study population

Variables	Total (n=425)	Cognitive frailty (n=93)	Non-cognitive frailty (n=332)	Statistic values	P value
Age, years, M (P_{25}, P_{75})	67 (63, 73)	69 (64, 76.50)	67 (63, 72)	−2.387*	0.017
BMI, mean±SD	22.91±3.53	22.10±3.56	23.14±3.49	2.511†	0.012
Gender, n (%)				3.661‡	0.056
Male	256 (60.2)	64 (68.8)	192 (57.8)		
Female	169 (39.8)	29 (31.2)	140 (42.2)		
Education level, n (%)				32.173‡	<0.001
Primary school and below	250 (58.8)	31 (33.3)	219 (66.0)		
Junior high/high school	144 (33.9)	50 (53.8)	94 (28.3)		
College and above	31 (7.3)	12 (12.9)	19 (5.7)		
Occupation before retirement, n (%)				4.652‡	0.199
Farmer	77 (18.1)	12 (12.9)	65 (19.6)		
Worker	53 (12.5)	8 (8.6)	45 (13.6)		
Intellectual	13 (3.1)	3 (3.2)	10 (3.0)		
Others	282 (66.4)	70 (75.3)	212 (63.9)		
Monthly income (¥), n (%)				4.157‡	0.125
≤3000	185 (43.5)	32 (34.4)	153 (46.1)		
3000–5000	169 (39.8)	44 (47.3)	125 (37.7)		
≥5000	71 (16.7)	17 (18.3)	54 (16.3)		
Mobility aids, n (%)				15.137‡	<0.001
No	377 (88.7)	72 (77.4)	305 (91.9)		
Yes	48 (11.3)	21 (22.6)	27 (8.1)		
Exercise (times/week), n (%)				17.013‡	<0.001
0	328 (77.2)	86 (92.5)	242 (72.9)		
1–2	39 (9.2)	5 (5.4)	34 (10.2)		
≥3	58 (13.6)	2 (2.2)	56 (16.9)		
CKD stage, n (%)				0.191‡	0.662
CKD stages 2–3	27 (6.4)	5 (5.4)	22 (6.6)		
CKD stages 4–5	398 (93.6)	88 (94.6)	310 (93.4)		
Dialysis, n (%)				0.348‡	0.555
No	208 (48.9)	43 (46.2)	165 (49.7)		
Yes	217 (51.1)	50 (53.8)	167 (50.3)		
Heart failure, n (%)				5.010‡	0.025
No	296 (69.6)	56 (60.2)	240 (72.3)		
Yes	129 (30.4)	37 (39.8)	92 (27.7)		
Hyperuricaemia, n (%)				4.947‡	0.026
No	393 (92.5)	91 (97.8)	302 (91.0)		
Yes	92 (7.5)	2 (2.2)	30 (9.0)		
SHPT, n (%)				5.812‡	0.016
No	359 (84.5)	86 (92.5)	273 (82.2)		
Yes	66 (15.5)	7 (7.5)	59 (17.8)		
BI score, M (P_{25}, P_{75})	90 (70, 95)	65 (50, 80)	95 (80, 95)	−8.940*	<0.001
MNA-SF score, M (P_{25}, P_{75})				−6.071*	<0.001
Malnutrition	8 (7, 10)	8 (6, 9)	9 (7, 10)		

Continued

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Table 1 Continued

Variables	Total (n=425)	Cognitive frailty (n=93)	Non-cognitive frailty (n=332)	Statistic values	P value
Eutrophy	12 (11, 13)	12 (11, 13)	12 (11, 13)		
PSQI score, M (P_{25}, P_{75})	8 (5, 12)	10 (6.5, 14.5)	7 (5, 12)	−3.284*	0.001
GDS-15 score, M (P_{25}, P_{75})	6 (3, 9)	9 (6, 11)	4 (2.25, 8)	−7.457*	<0.001
SSRS score, M (P_{25}, P_{75})	38 (34, 43)	36 (32, 38)	39.5 (35, 44)	−5.807*	<0.001
CRP, M (P_{25}, P_{75})	10.9 (3.15, 29.33)	25.3 (6.14, 60.2)	8.46 (2.79, 29.33)	−4.474*	<0.001
Parathormone, M (P_{25}, P_{75})	252.1 (109.95, 412.35)	265.80 (118.75, 358.80)	248.40 (109.53, 425.08)	−0.449*	0.653
Ferritin, M (P_{25}, P_{75})	288.6 (125.25, 408.3)	350.21 (184.55, 500.1)	266.95 (118.7, 397.38)	−2.264*	0.024
Albumin, mean±SD	31.12±5.4	29.80±4.99	31.48±5.47	2.667†	0.008
BUN, M (P_{25}, P_{75})	21.47 (15.43, 29.63)	21.26 (15.22, 29.31)	21.68 (15.50, 29.64)	−0.341*	0.733
Scr, M (P_{25}, P_{75})	641.21 (411.05, 868.28)	616.87 (464.75, 820.42)	645.64 (400.23, 880.75)	−0.406*	0.685
TC, M (P_{25}, P_{75})	4.31 (3.29, 5.31)	3.7 (3.02, 4.92)	4.42 (3.45, 5.41)	−3.141*	0.002
Triglycerides, M (P_{25}, P_{75})	1.29 (0.88, 1.82)	1.17 (0.79, 1.80)	1.30 (0.92, 1.82)	−1.579*	0.114
White cell, M (P_{25}, P_{75})	7.03 (5.67, 8.75)	7.57 (6.11, 9.07)	6.92 (5.61, 8.59)	−2.059*	0.040
Haemoglobin, M (P_{25}, P_{75})	90 (75, 105.5)	87 (72, 102.5)	91 (76, 106)	−1.294*	0.196
GFR, M (P_{25}, P_{75})	6.96 (5.1, 11.51)	7.48 (5.79, 10.41)	6.73 (4.97, 12.08)	−1.050*	0.294

*Z value.
†T value.
‡^{2} value.
.BI, Barthel Index; BMI, body mass index; BUN, blood urea nitrogen; CKD, chronic kidney disease; CRP, C-reactive protein; GDS-15, 15-item Geriatric Depression Scale; GFR, glomerular filtration rate; MNA-SF, Mini-Nutritional Assessment-Short Form; PSQI, Pittsburgh Sleep Quality Index; Scr, serum creatinine; SHPT, secondary hyperparathyroidism; SSRS, Social Support Rating Scale; TC, total cholesterol.

(AUC) were used to evaluate the predictive power of the ANN model.

Patient and public involvement

The patients were not involved in the formulation of the study questions or the design of the study. The results of the study are not intended to be released to the participants, but anthropometric measurements taken during the survey were provided to the participants.

RESULTS

Study sample characteristics

Of the 430 participants enrolled in the study, five were excluded for comorbidity with other severe diseases, and the questionnaire had a 98.8% response rate. The majority of the participants were male (60.2%) and the mean age was 68.5 years. There was a predominance of individuals who were primary school graduates and below (58.8%), and had other occupations (66.4%) before retirement, low monthly income (43.5%), little to no movement (77.2%) and normal BMI (18.5≤BMI<24.9, 64.2%), and moved without mobility aids (88.7%). The prevalence was 21.9% (n=93) for cognitive frailty and 78.1% (n=332) for non-cognitive frailty. Participants with cognitive frailty were more likely to be older, have lower levels of education, move without mobility aids, lack exercise, have comorbidity with other chronic diseases and take three or more medications. The capacity for daily living, nutritional status, sleep quality and social activity were also poor, and depressive symptoms and abnormal laboratory indices were also common (table 1).

Logistic regression analysis of cognitive frailty in elderly patients with CKD

The variables that conformed to colinear diagnosis and were statistically significant (p<0.05) in univariable analysis were included as independent variables, cognitive frailty was included as the dependent variable in the binary logistic regression analysis and variable assignments are shown in table 2. The results of the binary logistic regression analysis showed that education level, BI score, albumin, GDS-15 score and SSRS score were the factors for cognitive frailty (p<0.05) (table 3).

Construction and validation of the cognitive frailty risk prediction model

The neural network prediction model in this study included one input layer, one hidden layer and one output layer. Variables with statistical significance (p<0.05) in the binary logistic regression analysis were considered as the input layer, and included five variables. Whether cognitive frailty was regarded as the output layer, the hidden layer had six neurons, and a hyperbolic tangent function was used for activation. In order to avoid the problem of unbalanced target variables, the samples were randomly divided into training set (311 cases), test set (110 cases) and validation set (104 cases) after random oversampling

Table 2 Assignment of independent variables

Variables	Assignment method
Cognitive frailty	Non-cognitive frailty=0; cognitive frailty=1
Age	Original value entry
BMI	Original value entry
Gender	Female=0; male=1
Education level	Primary school and below=0; junior high/high school=1; college and above=2
Occupation before retirement	Farmer=0; worker=1; intellectual=2; others=3
Monthly income (¥)	≤3000=0; 3000–5000=1; ≥5000=2
Mobility aids	No=0; yes=1
Exercise (times/week)	0=0; 1–2=1; ≥3=2
CKD stage	CKD stages 1–3=0; CKD stages 4–5=1
Dialysis	No=0; yes=1
Heart failure	No=0; yes=1
Hyperuricaemia	No=0; yes=1
SHPT	No=0; yes=1
BI score	Original value entry
MNA-SF score	Malnutrition=0; Eutrophy=1
PSQI score	Original value entry
GDS-15 score	Original value entry
SSRS score	Original value entry
CRP	Original value entry
Parathormone	Original value entry
Ferritin	Original value entry
Albumin	Original value entry
BUN	Original value entry
Creatinine	Original value entry
TC	Original value entry
Triglycerides	Original value entry
White cell	Original value entry
Haemoglobin	Original value entry
GFR	Original value entry

BI, Barthel Index; BMI, body mass index; BUN, blood urea nitrogen; CKD, chronic kidney disease; CRP, C-reactive protein; GDS-15, 15-item Geriatric Depression Scale; GFR, glomerular filtration rate; MNA-SF, Mini-Nutritional Assessment-Short Form; PSQI, Pittsburgh Sleep Quality Index; SHPT, secondary hyperparathyroidism; SSRS, Social Support Rating Scale; TC, total cholesterol.

3.57 times of cognitive frailty samples in the training set. Then, the prediction model of the multilayer perceptron neural network was constructed (see online supplemental file 1). The accuracy, specificity and sensitivity of the ANN model were 86.36%, 88.61% and 80.65%, respectively. The AUC was 0.913, the ROC curve as shown in online supplemental file 2. In order, the normalised importance of the independent variables of the ANN model was as follows: BI score, SSRS score, albumin, GDS-15 score and education level (see online supplemental file 3).

DISCUSSION

Cognitive frailty is a reversible or potentially reversible heterogeneous clinical syndrome that can significantly increase the risk of a series of adverse health outcomes, such as falls, hospitalisation, cardiovascular events and even death in the elderly. In particular, older adults with chronic diseases such as CKD are at greater risk.[16] It is undeniable that early cognitive frailty screening and effective intervention can greatly aid in reversing cognitive frailty. However, the reported prevalence of cognitive frailty varies widely due to differences in study populations and assessment methods. In this study, we found that 21.9% of older patients with CKD have cognitive frailty, which is comparable to a previous study involving cognitive frailty of haemodialysis patients in China,[18] but quite different from a study on the prevalence of cognitive frailty in haemodialysis patients in the USA.[17] In addition, our findings suggest that the main influencing factors for cognitive frailty are BI score, albumin, education level, GDS-15 score and SSRS score.

We found that the capacity for daily living is an independent risk factor for cognitive frailty, indicating that a substantial percentage of elderly patients with CKD are not fully independent of daily living, which is in line with a previous study in the USA.[41] Research has shown that when the capacity for daily living is impaired, the perception of the external environment also can be correspondingly abated, thus reducing brain activity, at the same time, leading to muscle atrophy and strength decline, thereby increasing the patient's physical fatigue, and further leading to increased risk of cognitive frailty.[42] However, impairment of the capacity for daily living is common in elderly patients with CKD, which also highlights the importance of the capacity for daily living assessment. The BI was used to assess the capacity for daily living in our study, which is common in the clinic. It enables nursing staff to identify problems with the living ability of patients early, in order to determine a nursing and intervention plan as soon as possible to improve the patient's quality of life.[43]

In this study, we show that serum albumin is one of the important indexes for evaluating cognitive frailty in patients, and a normal range of serum albumin may reduce the risk of cognitive frailty, which is consistent with other studies.[18 44 45] However, due to the decline of renal function, long-term restriction of protein intake, inflammation, long-term dialysis and other reasons, elderly patients with CKD are prone to protein loss and malnutrition, resulting in sarcopenia, which is also related to cognitive frailty.[16] All in all, medical staff should regularly monitor patient serum albumin, haemoglobin and other nutritional indicators, and take positive treatment

Table 3 Logistic regression analysis for cognitive frailty

Variables	β	SE	Wald χ^2	P value	OR	95% CI
Constant	15.383	5.178	8.826	0.003	–	–
Education level	2.566	0.401	40.896	<0.001	13.009	5.926 to 28.560
BI score	−0.035	0.010	12.908	<0.001	0.965	0.947 to 0.984
Albumin	−0.070	0.033	4.462	0.035	0.932	0.873 to 0.995
GDS-15 score	0.183	0.061	9.053	0.003	1.201	1.066 to 1.354
SSRS score	−0.111	0.033	11.053	0.001	0.895	0.838 to 0.955

BI, Barthel Index; GDS-15, 15-item Geriatric Depression Scale; SSRS, Social Support Rating Scale.

measures for patients with malnutrition and chronic inflammation, so as to maintain the nutritional status of patients and prevent the occurrence of cognitive frailty. In addition, encouraging patients to adhere to a Mediterranean diet may reduce the risk of cognitive decline to some extent.[46]

Previous studies have shown that education level is an independent risk factor for cognitive frailty, and the rate of cognitive frailty is lower among those with high education levels.[47 48] On the one hand, the reason may be related to the fact that the early education training received by patients with a high education level can effectively increase brain reserve and delay brain degeneration.[48] On the other hand, older patients with higher education have a better grasp of disease-related knowledge, which can further improve patient treatment compliance and prevent the occurrence and progression of cognitive frailty.[49] However, the results of this study showed that educational level was positively correlated with cognitive frailty, which may be caused by the imbalance in the proportion of education level among the patients included in this study because most of them were primary school graduates and below. Further verification needs to be conducted by expanding the sample size in the future. Therefore, nursing staff should pay attention to elderly people with different education levels and CKD, formulate corresponding health education content and intervention measures according to the specific needs of each patient and guide patients to be familiar with and master knowledge of the disease, so as to prevent or delay the occurrence and progression of cognitive frailty.

The results of our study also suggest that depression and low social support are risk factors for cognitive frailty, which is consistent with Malek Rivan *et al*'s[20] study. Elderly patients with CKD are prone to anxiety, depression and other adverse emotions due to the long course of the disease and long-term frequent dialysis and hospitalisation, as well as the weakening of social participation and functions.[49] In addition, there is a similar pathological basis between depression and cognitive frailty, which makes the two closely related.[50] Paying attention to a patient's emotional changes, communicating with the patient more, encouraging the patient to participate in social activities and encouraging family members and friends to listen to and accompany the patient can relieve bad mood to a certain extent. Social support is closely related to physical and mental health, and affects individual emotion, thought and behaviour, which plays a key role in the trajectory of cognitive frailty. High levels of social support are a protection factor in cognitive frailty because patients receive emotional and financial support, and obtain access to more health information resources, such as diet or exercise guidance, through the transfer and use of social resources, all of which can effectively improve the patient's physical and mental health.[51]

Through various training algorithms, ANNs can analyse the input variables that affect the dependent variables, and construct a predictive model with higher accuracy than the traditional logistic regression model.[22] In our study, we incorporated physiological, psychological, social and geriatric syndromes and other aspects into an ANN to predict cognitive frailty in elderly patients with CKD. Five variables were ultimately included through univariate and multivariate analyses to construct an ANN model. The accuracy, specificity and sensitivity of the ANN model were 86.36%, 88.61% and 80.65%, respectively, and the AUC of the constructed ANN model was 0.913, indicating that the model has good predictive power for the occurrence of cognitive frailty in elderly patients with CKD. In addition, the results of our study also suggest that the BI score is the most important factor determining cognitive frailty in the analysis of independent variables, with an importance index of 0.30. Therefore, elevating patient capacity for daily living can protect against cognitive frailty in elderly patients. In clinical practice, the probability of cognitive frailty of elderly patients with CKD can be obtained by a neural network algorithm, based on the actual situation of the patients and the corresponding independent variables, with high accuracy and practicability in the clinic.

Two limitations should be mentioned in our study. In terms of the machine learning model, the larger the sample size, the better the prediction power of the model. In the future, it will still be necessary to increase the sample size to improve the prediction power of the model. In addition, the study was conducted in only one city in China, which could affect the generalisability of the findings.

CONCLUSIONS

This cross-sectional study showed a 21.9% prevalence of cognitive frailty among older Chinese patients with CKD. BI score, albumin, education level, GDS-15 score and SSRS score are the main influencing factors for cognitive frailty. An ANN model, based on these factors, has good predictive accuracy, can provide a new reference tool for the early prediction of cognitive frailty in elderly patients with CKD and enables a basis for the implementation of early intervention.

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REFERENCES

1 Who: number of people over 60 years set to double by 2050. *major societal changes required* 2015. [Epub ahead of print: Available at] http://www.who.int/ageing/events/world-report-2015-launch/en/
2 HY D. *Correlation study of elderly frailty and its phenotype with inflammatory response and coagulation function*. Qingdao University., 2019.
3 People's Daily. Statistical bulletin of the People's Republic of China on national economic and social development in 2019 ~([1]). 2020-02-29(005).
4 Zhai ZW, Chen JJ, Li L. Future trends of China's population and aging: 2015~ 2100. *Population Research* 2017;41:60–71.
5 Chen QL. The opinion attaching importance to the effects of frailty on clinical management of elderly with chronic kidney disease. *Chinese Journal of Nephrology, Dialysis & Transplantation* 2019;28:544–5.
6 Walker SR, Wagner M, Tangri N, *et al*. Frailty, and unsuccessful aging: a review. *J Ren Nutr* 2014;24:364–70.
7 Wang LT, CY X, Tang LJ. Cognitive frailty of the elderly and its influencing factors in nursing institutions. *Chinese Journal of Gerontology* 2021;41:3554–7.
8 Wang ZJ, HJ Y, Tang J. Cognitive impairment rate of the elderly in China: a meta-analysis. *Chinese Journal of Evidence-Based Medicine* 2020;20:1295–300.
9 Li J, Zhao JH. Research progress on frailty of the elderly with cognitive impairment. *Journal of Nursing Science* 2021;36:106–10.
10 Lee SJ, Son H, Shin SK. Influence of frailty on health-related quality of life in pre-dialysis patients with chronic kidney disease in Korea: a cross-sectional study. *Health Qual Life Outcomes* 2015;13:70.
11 Kulmala J, Nykänen I, Mänty M, *et al*. Association between frailty and dementia: a population-based study. *Gerontology* 2014;60:16–21.
12 Robertson DA, Savva GM, Kenny RA. Frailty and cognitive impairment--a review of the evidence and causal mechanisms. *Ageing Res Rev* 2013;12:840–51.
13 Dartigues JF, Amieva H. Cognitive frailty: rational and definition from an (i.a. *N.a./i.a.g.g.) international consensus group. J Nutr Health Aging* 2014;18:95.
14 Shimada H, Makizako H, Tsutsumimoto K, *et al*. Cognitive frailty and incidence of dementia in older persons. *J Prev Alzheimers Dis* 2018;5:42–8.
15 Panza F, Seripa D, Solfrizzi V, *et al*. Targeting cognitive frailty: clinical and neurobiological roadmap for a single complex phenotype. *J Alzheimers Dis* 2015;47:793–813.
16 Hou WW, Chang J, Wang YF. Research progress on cognitive frailty in elderly patients with chronic kidney disease. *Chin J Geriatr* 2020;39:1108–12.
17 McAdams-DeMarco MA, Tan J, Salter ML, *et al*. Frailty and cognitive function in incident hemodialysis patients. *Clin J Am Soc Nephrol* 2015;10:2181–9.
18 Jiang TT, Shan Y, LP D. Cognitive frailty in elderly patients with hemodialysis and its relationship with fear of falling. *Chinese Nursing Management* 2020;20:1005–9.
19 Sargent L, Nalls M, Starkweather A, *et al*. Shared biological pathways for frailty and cognitive impairment: a systematic review. *Ageing Res Rev* 2018;47:149–58.
20 Malek Rivan NF, Shahar S, Rajab NF, *et al*. Cognitive frailty among Malaysian older adults: baseline findings from the LRGS TUA cohort study. *Clin Interv Aging* 2019;14:1343–52.
21 Ma L, Zhang L, Zhang Y, *et al*. Cognitive frailty in China: results from China comprehensive geriatric assessment study. *Front Med* 2017;4:174.
22 Zhou D, Yin AC. Application of artificial neural networks in nursing: a literature review. *Journal of Nursing Science* 2020;35:94–7.
23 Ambalavanan N, Carlo WA. Comparison of the prediction of extremely low birth weight neonatal mortality by regression analysis and by neural networks. *Early Hum Dev* 2001;65:123–37.
24 Chen H-L, Yu S-J, Xu Y, *et al*. Artificial neural network: a method for prediction of surgery-related pressure injury in cardiovascular surgical patients. *J Wound Ostomy Continence Nurs* 2018;45:26–30.
25 Nilsson J, Ohlsson M, Thulin L, *et al*. Risk factor identification and mortality prediction in cardiac surgery using artificial neural networks. *J Thorac Cardiovasc Surg* 2006;132:12–19.
26 Imai S, Takekuma Y, Kashiwagi H, *et al*. Validation of the usefulness of artificial neural networks for risk prediction of adverse drug reactions used for individual patients in clinical practice. *PLoS One* 2020;15:e236789.
27 Catley C, Frize M, Walker CR, *et al*. Predicting high-risk preterm birth using artificial neural networks. *IEEE Trans Inf Technol Biomed* 2006;10:540–9.
28 Fried LP, Tangen CM, Walston J, *et al*. Frailty in older adults: evidence for a phenotype. *J Gerontol A Biol Sci Med Sci* 2001;56:M146–56.
29 MAHONEY FI, BARTHEL DW. Functional evaluation: the BARTHEL index. *Md State Med J* 1965;14:61–5.
30 Della Pietra GL, Savio K, Oddone E, *et al*. Validity and reliability of the Barthel index administered by telephone. *Stroke* 2011;42:2077–9.
31 Rubenstein LZ, Harker JO, Salvà A, *et al*. Screening for undernutrition in geriatric practice: developing the short-form mini-nutritional assessment (MNA-SF). *J Gerontol A Biol Sci Med Sci* 2001;56:M366–72.
32 YL H, Jian ZJ. The application and evaluation of the elderly malnutrition assessment methods. *Chin J Geriatr* 2005:37–40.
33 Buysse DJ, Reynolds CF, Monk TH, *et al*. The Pittsburgh sleep quality index: a new instrument for psychiatric practice and research. *Psychiatry Res* 1989;28:193–213.
34 Liu XC, Tang MQ, Hu L. Reliability and validity of the Pittsburgh sleep quality index. *Chi- nese Journal of Psychiatry* 1996:103–7.

35 Katzman R, Zhang M Y O-Y-QMY, Ouang-Ya-Qu, *et al*. A Chinese version of the Mini-Mental state examination; impact of illiteracy in a Shanghai dementia survey. *J Clin Epidemiol* 1988;41:971–8.
36 Zhao QQ. *Frailty screening in the community elders and construction of health intervention model for frailty elders*. Taishan Medical University, 2017.
37 Sheikh J, Savage J Y. Geriatric Depression Scale(GDS):Recent evidence and development of a shorter version. *Clinical Gerontologist* 1986:165–73.
38 Tang D. Application of short form geriatric depression scale(GDS-15) in Chinese elderly. *Chinese Journal of Clinical Psychology* 2013;21:402–5.
39 Xiao SY. Theoretical basis and research application of social support rating scale. *Journal of Clinical Psychiatry* 1994:98–100.
40 Holder LB, Haque MM, Skinner MK. Machine learning for epigenetics and future medical applications. *Epigenetics* 2017;12:505–14.
41 Plantinga LC, Johansen K, Crews DC, *et al*. Association of CKD with disability in the United States. *Am J Kidney Dis* 2011;57:212–27.
42 Chen YY, Zhang ZM, Zuo QQ. Construction and validation of a prediction model for the risk of cognitive frailty among the elderly in a coumunity. *Chin J Nurs* 2022;57:197–203.
43 DD M, YP L. Current status and application value of evaluation of frailty in patients with chronic kidney disease. *Medical Recapitulate* 2021;27:323–8.
44 Khater MS, Abouelezz NF. Nutritional status in older adults with mild cognitive impairment living in elderly homes in Cairo, Egypt. *J Nutr Health Aging* 2011;15:104–8.
45 Sargent L, Nalls M, Amella EJ, *et al*. Shared mechanisms for cognitive impairment and physical frailty: a model for complex systems. *Alzheimers Dement* 2020;6:e12027.
46 Martínez-Lapiscina EH, Clavero P, Toledo E, *et al*. Mediterranean diet improves cognition: the PREDIMED-NAVARRA randomised trial. *J Neurol Neurosurg Psychiatry* 2013;84:1318–25.
47 Feng L, Zin Nyunt MS, Gao Q, *et al*. Cognitive frailty and adverse health outcomes: findings from the Singapore longitudinal ageing studies (SLAS). *J Am Med Dir Assoc* 2017;18:252–8.
48 Ruan Q, Yu Z, Chen M, *et al*. Cognitive frailty, a novel target for the prevention of elderly dependency. *Ageing Res Rev* 2015;20:1–10.
49 Chen GJ, Zhang HL, Yin LX. Analysis on current status and influencing factors of cognitive frailty in maintenance hemodialysis patients. *Chinese Nursing Management* 2021;21:1179–85.
50 Ruan Q, Xiao F, Gong K, *et al*. Prevalence of cognitive frailty phenotypes and associated factors in a community-dwelling elderly population. *J Nutr Health Aging* 2020;24:172–80.
51 Zhao D. *Social support and cognitive frailty among Shandong rural empty-nest older adults: education as a moderator and physical activity as a mediator*. Shandong University, 2021.