

Construction and verification of a model for predicting fall risk in patients with maintenance hemodialysis[†]



Original article

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Received: 9 October 2023; Accepted: 4 August 2024; Published: 20 December 2024

Abstract: **Objective:** To construct a risk prediction model for fall in patients with maintenance hemodialysis (MHD) and to verify the prediction effect of the model.

Methods: From June 2020 to December 2020, 307 patients who underwent MHD in a tertiary hospital in Chengdu were divided into a fall group (32 cases) and a non-fall group (275 cases). Logistic regression analysis model was used to establish the influencing factors of the subjects. Hosmer–Lemeshow and receiver operating characteristic (ROC) curve were used to test the goodness of fit and predictive effect of the model, and 104 patients were again included in the application research of the model.

Results: The risk factors for fall were history of falls in the past year (OR = 3.951), dialysis-related hypotension (OR = 6.949), time up and go (TUG) test (OR = 4.630), serum albumin (OR = 0.661), frailty (OR = 7.770), and fasting blood glucose (OR = 1.141). Hosmer–Lemeshow test was $P = 0.475$; the area under the ROC curve was 0.907; the Youden index was 0.642; the sensitivity was 0.843; and the specificity was 0.799.

Conclusions: The risk prediction model constructed in this study has a good effect and can provide references for clinical screening of fall risks in patients with MHD.

Keywords: construction • fall • maintenance hemodialysis • risk prediction model • verification

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1. Introduction

Fall prevention is an important part of nursing safety management. The Joint Committee on Institutional Safety in the United States clearly stated that falls are a core as well as sensitive indicator of caring quality. Patients with maintenance hemodialysis (MHD) have disease and dialysis-related unique factors, which have

become a high-risk population for falls. Plantinga et al.¹ conducted a study on severe fall injuries in elderly patients with end-stage renal disease in the United States before and after hemodialysis, including 81,653 patients aged 67–100 years, and a total of 12,757 severe fall injuries occurred during the peridialysis

[†]This project was supported by Health Commission of Sichuan Province (No. 19PJ194).

How to cite this article: Liu Y, Zeng YL, Zhang S, Meng L, He XH, Tang Q. Construction and verification of a model for predicting fall risk in patients with maintenance hemodialysis. *Front Nurs.* 2024;4:387–394.

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period. Desmet et al.² conducted an 8-week prospective study on 389 patients with Hemodialysis (HD) in 8 Belgian dialysis centers, and the incidence rate was 12.7%, which is equivalent to an average of 1.18 times/ (person-year).³ Cook and Tomlinson conducted a cross-sectional survey of 135 patients with HD in Toronto, 27% of patients had a fall in the past 12 months, and 16% had a fall in the previous 12 months or earlier. Falls in patients with HD are likely to cause adverse outcomes.⁴ Mild cases can cause pain, soft tissue damage, and dislocation; severe cases can cause fractures, brain damage, and loss of independence, seriously affecting the quality of life and survival of patients and increasing the risk of death.⁵ According to statistics, patients with HD with a fall have a 60% higher risk of death 1 year after than those without a fall. Therefore, it is particularly important to identify MHD high-risk groups of falls effectively and predict the risk of falls in patients with MHD accurately, which is a prerequisite for implementing intervention strategies of MHD high-risk fall groups and an important means to prevent falls in patients with MHD.^{6,7} Literature search found that, currently, there are only two foreign studies on fall-specific assessment tools for patients with MHD, and both lack of effective external validation. Next, due to differences in race, region, diet, and social culture, the application of foreign scales to Chinese populations often has certain limitations. There are few fall risk prediction tools based on the patients with MHD in China at present. It can be seen that the fall risk prediction tools for localized MHD population in China need to be established and evaluated urgently.

Based on the above-mentioned background, this study intended to construct and verify the fall risk prediction model of patients with MHD through univariate analysis and logistic variable screening results, aiming to provide a reference for clinical nurses to screen patients at high risk of fall with MHD.

2. Methods

2.1. Subjects

The convenience sampling method was adopted to select patients who underwent MHD in a tertiary hospital in Chengdu from July 2020 to December 2020. Inclusion criteria were as follows: (1) the patient underwent hemodialysis treatment for more than 3 months; (2) patients with an average weekly hemodialysis frequency greater than or equal to 3 times; and (3) having normal intelligence and be able to communicate normally and complete assessment tests. Exclusion criteria were as follows: (1) patients

with hemodialysis undergoing hospitalization; (2) patients who are participating in clinical research on other drug applications or device interventions; and (3) some traumas and diseases significantly affect postural control. Rejection criteria were as follows: patient lost to follow-up or deceased. All patients signed informed consent forms and were willing to be investigated.

Predictors of falls in patients with MHD were screened by literature search and expert opinion. According to the Kendall working criterion, the sample size should be calculated at least 5–10 times than the number of variables. The study totally consists of 16 items including 2 general data, 7 health status surveys, 5 laboratory indicators, and 2 physical function assessments. Besides, considering the incidence of falls in patients with hemodialysis about 27% and the loss as well as invalid samples 5%–10%, the sample size required for the modeling population in this study was determined to be $16 \times 5 \times (1 + 0.1) \div 0.27 = 326$ cases. In the end, 326 cases were enrolled, and 307 cases were valid.⁸ The minimum sample size required for external validation of the model was 100 cases. Considering the 10% loss to follow-up rate, 110 cases were finally enrolled, and 104 cases were valid.

2.2. Methods

2.2.1. Instrument

Comprehensively using literature research method, expert discussion method, etc., patients with self-compiled MHD fall questionnaire included the following 4 parts. (1) General information of patients: age and gender; (2) health status investigation: dialysis period (months), whether it is complicated with cardiovascular disease, whether hearing or vision is reduced, whether assistive devices are used, whether there is a fall in the past 1 year, whether it is weak (using the⁹ Fatigue, Resistance, Ambulation, Illness, Loss of Weight (FRAIL) weakness scale), and whether there is dialysis-related hypotension; (3) laboratory indicators (before the latest dialysis at enrollment): hemoglobin, serum albumin, serum phosphorus, serum calcium, and fasting blood glucose; and (4) physical function assessment: grip strength test¹⁰ and time up and go (TUG) test.

2.2.2. Diagnosis of Intradialytic Hypotension (IDH)

Systolic blood pressure decreased by ≥ 20 mmHg (or mean arterial pressure decreased by ≥ 10 mmHg) during dialysis, symptoms of hypotension were existed, or

intervention was needed.¹¹ It was defined as IDH of the patient whose blood pressure was collected after each hemodialysis if the incidence of IDH was $\geq 1/10$ during this study.

2.2.3. Grip strength test

The subject's legs should be naturally separated into an upright posture, and the arms are naturally drooping. It is necessary to take the maximum value from 2 times holding the grip dynamometer with full force. The grip dynamometer adopted Xiangshan EH101 grip dynamometer.

2.2.4. Criteria for determining falls

The criteria were as follows: sudden involuntary changes in position, causing any part of the body other than the feet to touch the ground accidentally, and excluding falls caused by disability, onset of disease, external violence, or environmental factors.

2.3. Data collection

The data were collected from the blood purification information system or medical records by the nurses of the hemodialysis department who had undergone unified training after obtaining informed consent from the patient. Incomplete information was recorded by asking the patient. Besides, the FRAIL weakness scale and physical function assessment were tested by the nurse on the spot. Blinded follow-up was conducted when the patient visited the hospital for dialysis treatment each time until 6 months after who received the baseline survey. Anonymous and double entry of questionnaires were conducted via EpiData 3.0.

2.4. Statistical analysis

SPSS 25.0 performs statistical analysis. Non-normally distributed metric data were represented by median (quartile P25, Quartile p75), and rank sum tests were used for between-group comparisons. The counting data were expressed using examples and percentages, and the χ^2 test was used for comparison between groups. Logistic regression was used to construct a predictive model, and the calibration and discrimination of the model were evaluated by Hosmer–Lemeshow and receiver operating characteristic (ROC) curve. The application performance of the model was verified by sensitivity and specificity. $P < 0.05$ was statistically significant.

3. Results

3.1. General information on the subject of the study

A total of 307 patients were participated in this study, including 174 males (56.68%) and 133 females (43.32%) who aged 29–86 (60.52 ± 13.25) years. Falls occurred in 32 patients, with an incidence of 10.4%.

3.2. Univariate analysis of falls in patients with MHD

A total of 307 patients with MHD were divided into fall and non-fall groups, 32 of who had falls. Univariate analysis of falls in patients with MHD is shown in Table 1.

3.3. Establishment of a model for predicting fall risk in patients with MHD

Nine statistically significant factors (i.e., age, hearing or vision loss, use of assistive devices, a history of falls in the past year, frailty, dialysis-related hypotension, TUG test, serum albumin, and fasting blood glucose) were performed by binary logistic regression analysis whose values are assigned in Table 2. The results showed that a history of falls in the past year, dialysis-related hypotension, TUG test, frailty, serum albumin, and fasting blood glucose were the influencing factors of falls ($P < 0.05$), as shown in Table 3. The final formula was given as $P = 1 / \{1 + \exp[-(1.374 \times \text{history of falls in the past year} + 1.939 \times \text{dialysis-related hypotension} + 1.533 \times \text{TUG test} + 2.050 \times \text{frailty} - 0.414 \times \text{serum albumin} + 0.131 \times \text{fasting blood glucose} + 9.588)]\}$.

3.4. Fitting and prediction effect analysis of fall risk prediction model for patients with MHD

The Hosmer–Lemeshow test for predictive models was $P = 0.475$. Besides, the area under the ROC curve of this model was 0.907 (95% CI [0.879–0.935], $P < 0.001$), as seen in Figure 1. Moreover, the Jordon index maximum value of the model was 0.642, whose sensitivity was 0.843 and specificity was 0.799.

3.5. Validation of fall risk prediction model for patients with MHD

A total of 104 patients with MHD who met the inclusion criteria were selected as the research subjects for the model to be applied for clinical validation from March

Variable	Fall group, cases (%)	Non-fall group, cases (%)	Z/ χ^2 value	P value
Age, (years, M [P25, P75])	72 (67.25, 76.75)	59 (49.00, 69.00)	-5.077	0
Dialysis period (months, M [P25, P75])	72 (34.25, 135.00)	62 (30.00, 135.00)	-0.734	0.463
Gender			0.184	0.668
Male	17 (53.1)	157 (57.1)		
Female	15 (46.9)	118 (42.9)		
Cardiovascular disease			0.139	0.710
Yes	31 (96.9)	257 (93.5)		
No	1 (3.1)	18 (6.5)		
Hearing or vision loss			9.525	0.002
Yes	8 (25.0)	148 (53.8)		
No	24 (75.0)	127 (46.2)		
Use of assistive devices			38.603	0
Yes	14 (43.8)	18 (6.5)		
No	18 (56.3)	257 (93.5)		
A history of falls in the past year			36.544	0
Yes	16 (50.0)	26 (9.5)		
No	16 (50.0)	249 (90.5)		
Frailty			30.790	0
Yes	22 (68.8)	62 (22.5)		
No	10 (31.3)	213 (77.5)		
Dialysis-related hypotension			39.347	0
Yes	19 (59.4)	38 (13.8)		
No	13 (40.6)	237 (86.2)		
TUG test, seconds (s)			39.157	0
<13.5	11 (34.4)	228 (82.9)		
≥13.5	21 (65.6)	47 (60.9)		
Grip strength test (KG, M [P25, P75])	22.15 (13.95, 27.50)	23.90 (18.30, 27.80)	-1.498	0.134
Hemoglobin (g/L, M [P25, P75])	109.0 (99.00, 122.00)	112.5 (106.00, 126.00)	-1.010	0.312
Serum albumin (g/L, M [P25, P75])	32.75 (29.68, 36.40)	40.10 (38.40, 42.00)	-6.719	0
Serum phosphorus (mmol/L, M [P25, P75])	1.71 (1.49, 1.93)	1.88 (1.46, 2.25)	-1.420	0.155
Serum calcium (mmol/L, M [P25, P75])	2.36 (2.13, 2.52)	2.27 (2.13, 2.47)	-0.367	0.713
Fasting blood glucose (mmol/L, M [P25, P75])	9.1 (5.07, 12.88)	5.68 (4.82, 7.52)	-3.788	0

Note: TUG, time up and go; KG, kilogram.

Table 1. Univariate analysis of falls in patients with hemodialysis in the modeling group.

Variable	Assignment mode
Age (years)	Plug in the original
Hearing or vision loss	No = 0, yes = 1
Use of assistive devices	No = 0, yes = 1
A history of falls in the past year	No = 0, yes = 1
Frailty	No = 0, yes = 1
Dialysis-related hypotension	No = 0, yes = 1
TUG test	<13.5 s = 0, ≥13.5 s = 1
Serum albumin (g/L)	Plug in the original
Fasting blood glucose (mmol/L)	Plug in the original

Note: TUG, time up and go.

Table 2. Assignment table of independent variables.

2021 to August 2021. Notably, 56 (53.85%) males and 48 (46.15%) females were among the participants who were aged 33–85 (60.81 ± 13.604) years. In total, 12 actual falls occurred, so that the incidence rate was 11.54%. The model judged 9 cases of falls, 3 cases of which were false judgment, so that the sensitivity was 0.750. Besides, the model judged 77 cases of non-falls when 92 cases of actual non-falls occurred, so that the specificity was 0.837 because of the 15 cases of misjudgment. Hosmer–Lemeshow test was $P = 0.317$, the area under ROC curve was 0.855[95% CI (0.750–0.960), $P < 0.001$], and the maximum value of the Jordon index was 0.587.

Variable	B value	Standard error	Wald value	P value	OR value	95% CI
A history of falls in the past year	1.374	0.642	4.575	0.032	3.951	1.122–13.913
Dialysis-related hypotension	1.939	0.686	7.981	0.005	6.949	1.811–26.672
TUG test	1.533	0.684	5.027	0.025	4.630	1.213–17.678
Serum albumin	−0.414	0.085	23.978	0.000	0.661	0.560–0.780
Frailty	2.050	0.655	9.801	0.002	7.770	2.153–28.046
Fasting blood glucose	0.131	0.057	5.341	0.021	1.141	1.020–1.275
Constant	9.588	3.054	9.858	0.002		

Note: TUG, time up and go; OR, odds ratio; CI, confidence level.

Table 3. Logistic regression analysis of fall-related factors in patients with hemodialysis.

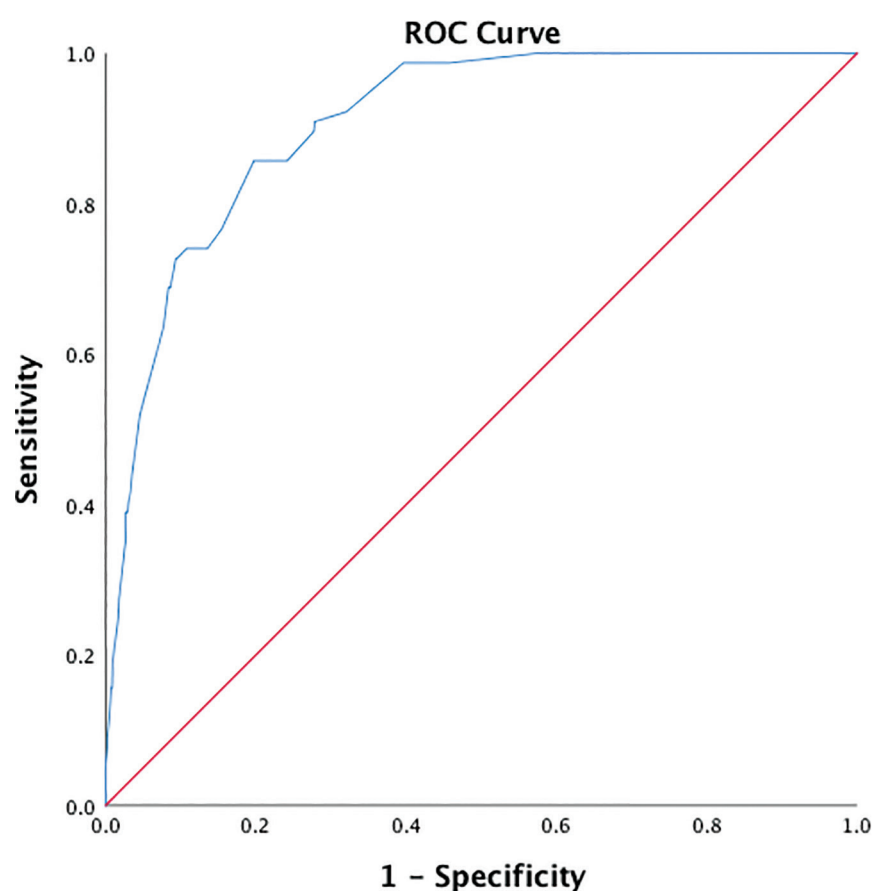


Figure 1. ROC curve of the model predicting falls in patients with hemodialysis. ROC, receiver operating characteristic.

4. Discussion

4.1. The established fall risk prediction model for patients with MHD is scientific and practical

The risk prediction model established by statistical analysis in this study can quantify the effect of various risk factors on the occurrence of falls in patients with MHD,

so as to obtain the predicted risk value of fall occurrence corresponding to the patients with MHD, making the fall risk assessment of patients with MHD more structured and systematic. At the same time, the quality of the model in this study was mainly evaluated from the differentiation and calibration degree, respectively, testing the ability of the model to distinguish patients who fall and non-fall, as well as the consistency between the prediction probability and the actual fall probability,

which improved the scientificity of the model. The prediction model showed that the areas under ROC curves in the modeling group and the verification group were 0.907 and 0.855, respectively, both greater than 0.75, indicating that the prediction model had a strong ability to identify potential falls in patients with MHD, with good differentiation. Next, the *P* values were 0.475 and 0.317, respectively, in the Hosmer–Lemeshow test, both greater than 0.05, indicating that the probability of patients with MHD falling predicted by the model was close to the actual incidence rate, with good calibration.

4.2. Analysis of fall-related risk factors in patients with MHD

4.2.1. *Patients with FRAIL are more likely to fall*

Frailty referred to a syndrome with increased vulnerability caused mainly by physical weakness, body degeneration, and a variety of chronic diseases.¹² FRAIL scale was adopted in this study to evaluate the frailty of the patients. Mcadams-Demarco et al.¹³ found that weakness combined with patients with MHD is an independent risk factor for falls. It was the same as this study that showed that weakness combined with patients with MHD is positively correlated with falls in patients with MHD whose OR value (OR = 7.770) was higher than other influencing factors, indicating that weakness was the most important influencing factor for falls in patients with MHD. The main reason may be that FRAIL indicators in the FRAIL scale, such as fatigue, sense of resistance¹⁴, and low activity, could reflect patients' impaired energy and physical strength, which could directly increase patients' risk of falling.¹⁵ Liang¹⁵ found that frailty of patients with MHD was associated with no exercise and low pre-protein, which suggested that when formulating fall prevention measures for patients with MHD, nurses could arrange patients with MHD to enhance moderate impedance exercise and aerobic endurance exercise, routinely screen patients with MHD for frailty, and conduct health education on the prevention as well as treatment of frailty.

4.2.2. *TUG test ≥ 13.5 s, a history of falls in the past year can increase the incidence of falls*

Gait instability had been recognized as a relatively stable risk factor for falls.¹⁰ The decline of the body's function from patients with MHD due to the combined effects of their own diseases, drugs, and dialysis treatment led to the decline of gait stability and balance ability. St. Thomas Risk Assessment Tool in Falling Elderly Inpatients (Stratify), TUG, Berg Balance Scale (BBS), Short Physical Performance Battery (SPPB),

etc. were commonly used for clinical gait and balance screening methods. Considering risk prediction tools requiring to be as simple and efficient as possible, this study chose the simplest and the most efficient TUG test among them. This study showed that the TUG test was associated with falls in patients with MHD, namely, the incidence of falls in patients with MHD was higher when the TUG test was ≥ 13.5 s than when the TUG test was < 13.5 s,¹⁶ which were consistent with previous systematic reviews. The TUG test had good clinical efficacy in distinguishing between low- and high-fall risks, which was an ideal tool for evaluating gait and balance.

The results of this study showed that the risk of falling in patients with MHD who had fallen in the past year was 3.951 times than who had not fallen in the past year,⁶ which was basically consistent with previous studies. Fall history could be regarded as one of the high-risk factors for falling. However,² some experts believed that fall history was retrospective information, which may cause bias. Therefore, when collecting the fall history, nurses could conduct real-time inquiry weekly to record whether patients with MHD have fallen or not. On the one hand, the accuracy of information collection could be ensured; on the other hand, early detection and intervention could be realized to avoid patients with MHD from falling again and improve the life quality of the patients.

4.2.3. *Hypoproteinemia, fasting hyperglycemia, and orthostatic hypotension were prone to falls*

This study found that the serum albumin level was one of the independent factors affecting patients' falls,¹⁷ which was basically consistent with Liu Anping's study because serum albumin was an endogenous nutrient synthesized by the liver, whose level could reflect the nutritional status of the patient. When the serum albumin level was low, it meant that the patient's nutritional intake is insufficient. Reservoir muscles would accelerate their own breakdown and consumption, leading to a decrease in muscle mass and limb function of patients, which would increase the risk of falls. Therefore, for patients with MHD with low serum albumin levels, nursing staff could pay attention to daily diet guidance for patients and suggest them to take more high-protein foods, such as beef, fish, eggs, milk, soybean, etc. Protein powder could be supplemented appropriately. For some patients who cannot eat, enteral and parenteral nutrition could also be implemented to improve the serum albumin level of patients.

This study showed that patients with MHD with higher fasting blood glucose concentrations had a

higher risk of falls. Blood glucose concentration was an important indicator for judging whether patients had diabetes mellitus.^{2,18} Previous studies believed that diabetes mellitus was a risk factor for falls in patients with MHD, which were similar as the results of this study. Diabetic patients often have microvascular and macrovascular complications, such as cardiovascular and cerebrovascular diseases, autonomic neuropathy, peripheral neuropathy, retinopathy, and vision loss. Besides, the persistent high blood sugar toxicity could cause arterial occlusion of the lower extremities, which reduced the motor function of the legs, leading to increase the risk of falls. Therefore, nurses needed to strengthen health education for patients with hyperglycemic MHD, guide them to avoid eating too much high-sugar and high-carbohydrate diet, and at the same time, conduct moderate aerobic exercises, such as Tai Chi, brisk walking, etc., so as to actively control blood sugar and delay diabetes progression of retinal and neuropathy to avoid the falls.

Roberts et al.¹⁹ found that orthostatic hypotension is a predictor of falls in patients with MHD, which is consistent with the results of this study. Orthostatic hypotension is one of the acute complications of patients with MHD, mainly due to the fact that the intravascular blood volume of patients with hemodialysis needed to be transferred to the outside of the body through ultrafiltration, and then, the fluid in the interstitial space was likely to be insufficiently compensated, resulting in insufficient effective circulating blood volume of the body and ischemia of important organs, such as insufficient blood supply to the brain. The attack was often accompanied with sweating, dizziness, vertigo, yawning, and desire to defecate or incontinence, and those with a significant drop in blood pressure might also have symptoms, such as angina, arrhythmia, vomiting, and lethargy, which

often led to falls. Therefore, on the one hand,²⁰ medical staff could choose the appropriate hemodialysis method to avoid excessive dialysis; on the other hand, body position management and safety guidance should be conducted for patients with MHD with orthostatic hypotension, such as informing patients of the correct way to get up, avoiding standing up suddenly and standing for a long time, defecating hard, avoiding high temperature environment, etc.

5. Conclusions

In summary, the fall risk prediction model constructed in this study had a good effect, which could provide reference for clinical assessment of fall risk in patients with MHD. This study only collected the most recent laboratory test at the time of patient enrollment, which might cause bias in results due to the clinical routine laboratory test being once every 3 months, and the time span of this study was 6 months. Serum C-reactive protein and 25-hydroxyvitamin D were not included in this study due to funding constraints. In the future, the risk prediction model can be further improved, and the clinical application effect of the model can be further explored through spatial verification and domain validation.

Ethical approval

Ethical issues are not involved in this article. The rural left-behind elderly who voluntarily participated was informed about the purpose of the study, and this study would not have any negative impact on them.

Conflicts of interest

All contributing authors declare no conflicts of interest.

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