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Development and validation of a nomogram for 30-day readmission after hip fracture surgery in geriatric patients

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Abstract. – OBJECTIVE: 30-day readmission after hip fracture surgery in the elderly is common and costly. A predictive tool to identify high-risk patients could significantly improve outcomes. This study aims to develop and validate a risk nomogram for 30-day readmission after hip fracture surgery in geriatric patients.

PATIENTS AND METHODS: We retrospectively analyzed 1,249 geriatric hip fracture patients (≥60 years) undergoing surgery at Dandong Central Hospital from October 2011 to October 2023. Using a 7:3 ratio, patients were randomly divided into training (n=877) and validation (n=372) sets. Independent risk factors for 30-day readmission were identified using LASSO regression and logistic regression in the training set. A nomogram was constructed using the identified predictors. Finally, the C-index, ROC curve, calibration curve, and decision curve analysis were used to validate the model in the training and validation sets respectively.

RESULTS: The nomogram was developed based on the 8 predictors of age, prior stroke, chronic liver disease, treatment, uric acid (UA), total protein (TP), albumin (ALB), and pneumonia that were found to be independently associated with 30-day readmission. The nomogram showed good discrimination with a C-index of 0.88 in the training set and 0.84 in the validation set. Calibration curves exhibited good agreement between predicted and observed outcomes. Decision curve analysis demonstrated clinical utility.

CONCLUSIONS: We developed and validated a nomogram incorporating eight clinical variables to accurately predict the individualized risk of 30-day readmission after hip fracture surgery in elderly patients. The model demonstrated favorable discrimination, calibration, and clinical utility. It can help to identify high-risk patients needing additional interventions to prevent avoidable hospital readmissions.

Key Words:
Hip fracture, Readmission, Geriatric, Prediction model, Nomogram.

Introduction

Hip fractures are a major health issue among the geriatric population over 65 years old, often leading to disability, reduced quality of life, and higher mortality[1,2]. The incidence of hip fractures is expected[3-5] to rise with the aging population, from approximately 1.7 million cases in 1990 to over 4.5 million by 2050.

Sarcopenia, the age-related decline in muscle mass and function, plays a crucial role in hip fractures among the elderly population[6]. This condition compromises strength, balance, and mobility, thereby amplifying the risk of falls and fractures[7,8]. Moreover, a substantial proportion of elderly hip fracture patients experience neuropathic pain postoperatively, further exacerbating their likelihood of readmission[9,10]. Unmanaged neuropathic pain can also hinder mobility, potentially impeding participation in post-surgical rehabilitation programs[11,12].

The rate of unplanned 30-day readmission after hip fracture surgery in elderly patients is estimated to be between 4% and 30%[13,14]. These readmissions negatively impact outcomes, costs, and quality of care[15,16]. Identifying high-risk individuals is crucial for implementing preventive measures to avoid readmissions.

Current tools have limitations for predicting readmission after hip fracture surgery. For exam-

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ple, while the Charlson Comorbidity Index (CCI) accurately predicts mortality risk, its ability to forecast readmission likelihood and duration of hospitalization for elderly hip fracture patients is limited[17]. Therefore, there is a need for a more reliable model to guide interventions and discharge planning.

This study develops and validates a nomogram to predict 30-day readmission risk after hip fracture surgery in older adults. By analyzing a large cohort of geriatric hip fracture patients, we identified preoperative and perioperative factors associated with readmission. This nomogram represents a major advance toward precision medicine for hip fracture patients. Once externally validated, it could become an invaluable bedside tool guiding clinical decision-making and discharge planning. By identifying high-risk individuals, this model enables tailored interventions during care transitions to reduce preventable readmissions and improve outcomes.

Patients and Methods

Patients

We collected clinical data from 1,249 patients diagnosed with hip fractures at Dandong Central Hospital between October 2011 and October 2023. This study followed the STROCS guidelines and adhered to the ethical principles outlined in the 1964 Helsinki Declaration and its subsequent amendments. The study protocol was approved by the Ethics Committee at our hospital, and written informed consent was obtained from all study participants or their legal guardians.

The following inclusion criteria were applied: (1) age ≥60 years; (2) radiographic confirmation of hip fracture (femoral neck, intertrochanteric, or subtrochanteric fracture) by X-ray or CT imaging; (3) surgical verification of hip fracture. The exclusion criteria for this study were: (1) Patients aged <60 years; (2) Patients with pathologic fractures; (3) Patients with multiple fractures; (4) Patients without surgical treatment; (5) Patients who died within 30 days after surgery; (6) Patients with incomplete hospitalization records. Based on the exclusion criteria, 1,063 patients were excluded, resulting in a retrospective cohort study of 1,249 patients. The screening process and participant flow are shown in a flow diagram in Figure 1A.

Definition of 30-Day Readmission

The primary outcome was 30-day hospital readmission after hip fracture surgery in geriatric patients. Readmission was defined as hospital admission within 30 days of discharge following initial hip fracture surgery. Two orthopedic surgeons independently reviewed the medical charts to determine readmission events, with any disagreement resolved by consensus discussion after re-reviewing the relevant records.

Data Collection

A total of 55 potential risk factors for 30-day readmission were identified through a literature review and examination of patient records at our hospital. Data collected included demographics, comorbidities, fracture type, treatment, surgical details, laboratory findings, and postoperative complications in elderly hip fracture patients. Demographics included age, gender, smoking, and alcohol use. Comorbidities were hypertension, diabetes, COPD, cardiovascular disease, prior stroke, dementia, intracerebral hemorrhage, chronic liver disease, chronic kidney disease, and chronic steroid use. Fracture types were femoral neck, intertrochanteric, and subtrochanteric. Treatments included total hip arthroplasty, hemiarthroplasty, intramedullary nailing, plate/screw fixation, and multiple screw fixation. Surgical details included blood loss, transfusion needs, ICU monitoring, admission/bedrest time, surgery duration, and ASA grade. Complications were deep vein thrombosis, urinary tract infection, and pneumonia. Laboratory parameters were obtained within 24 hours of admission. After specialized training in data collection, three researchers (WY, WW, QML) extracted data from orthopedic patients' electronic medical records at Dandong Central Hospital.

Statistical Analysis

Descriptive statistics were used to summarize the data. Categorical variables were reported as percentages (%) and compared using Chi-square tests. Continuous variables were presented as mean ± standard deviation and analyzed using independent sample *t*-tests.

In the training set, LASSO regression was used for variable selection, followed by univariate and multivariate logistic regression to identify independent risk factors for 30-day readmission. Variables with $p<0.05$ in univariate analysis were included in the multivariate logistic regression analysis to identify potential predictors. A nomo-

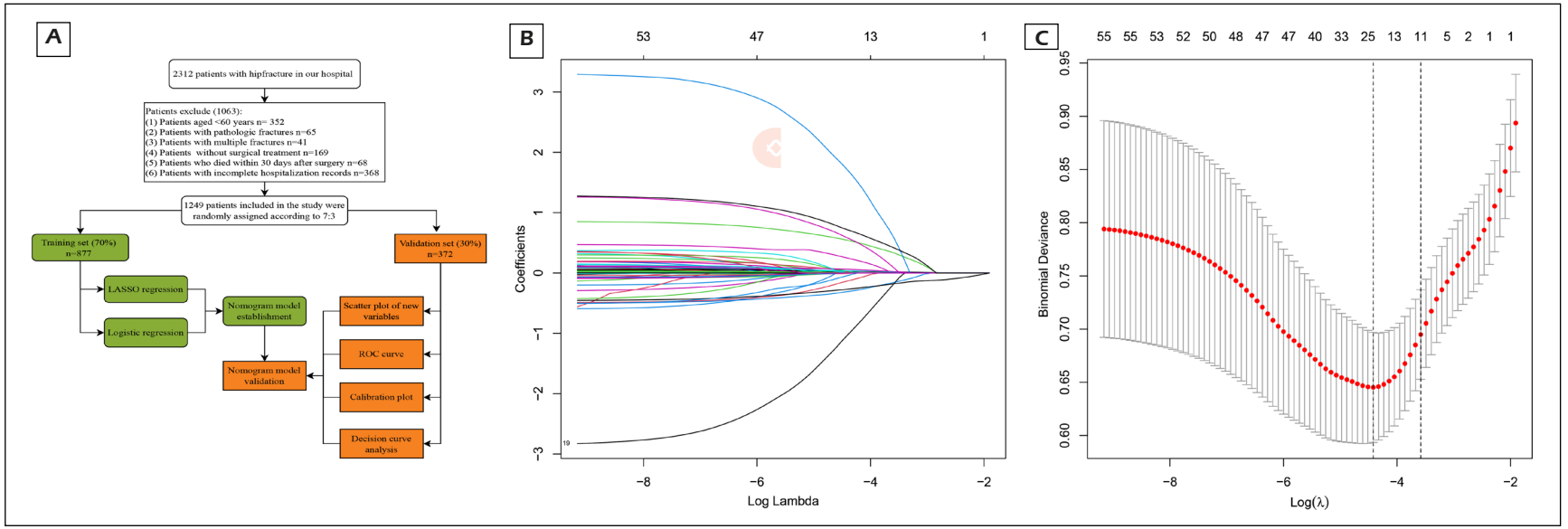

Figure 1. A, Flow diagram of study design. **B,** LASSO coefficient profiles of the 55 features. A coefficient profile plot was produced against the log (lambda) sequence. **C,** The partial likelihood deviance (binomial deviance) curve was plotted *vs.* log (lambda). Dotted vertical lines were drawn at the optimal values by using the minimum criteria and the 1 SE of the minimum criteria (the 1-SE criteria). LASSO performs shrinkage and selection on coefficients using the regularization parameter lambda.

gram to predict 30-day hospital readmission risk was developed using R software (The R Foundation for Statistical Computing, Vienna, Austria), incorporating variables from the multivariate logistic regression model derived from the training dataset.

Scatterplots of predicted probabilities for the 30-day readmission and non-readmission groups showed distinct, non-overlapping distributions, calculating the discrimination ability of the predictive model. The predictive nomogram's performance was assessed by generating a receiver operating characteristic (ROC) curve and calculating the area under the curve (AUC) to evaluate sensitivity and specificity. Optimal cutoff values were determined by the Youden index. Variance inflation factors (VIFs) were calculated for the multivariate model to assess multicollinearity. Calibration plots were evaluated by the Hosmer-Lemeshow test to inspect the nomogram's accuracy. Decision curve analysis (DCA) determined if the predictive model enhances net benefit predictions, evaluating its clinical utility. To comprehensively evaluate model performance, ROC analysis, calibration plots, and decision curve analysis were applied in both the training set and validation set. Statistical analysis was performed using SPSS 26.0 (IBM Corp., Armonk, NY, USA) and R 4.0.3 (The R Foundation for Statistical Computing, Vienna, Austria) for nomogram building.

Results

Baseline Clinical and Demographic Characteristics of Patients

After applying exclusion criteria, the final study population was composed of 1,249 geriatric hip fracture patients, including 493 males and 756 females. A total of 199 patients (15.93%) experienced a 30-day readmission. Using a 7:3 ratio, patients were randomly divided into a training set (n=877) and a validation set (n=372). The training set was used to develop the predictive model. As shown in Table I, the baseline clinical and demographic characteristics were similar between the two sets. Table II further compares the baseline features between groups with and without 30-day readmission.

Independent Risk Factors in the Training Set

In the training set, LASSO regression first selected 22 potential risk factors from the 55 candidates. These factors were further evaluated by univariate and multivariate logistic regression analysis (Figure 1B and 1C). Variables with $p<0.05$ in univariate analysis were included in the multivariate model to identify independent predictors. Finally, 8 factors were identified as independent risk factors for a 30-day readmission after multivariate adjustment: age (OR=1.03, 95% CI: 1.01-1.06, $p=0.035$), prior stroke (OR=2.02, 95% CI: 1.28-3.18, $p=0.002$), chronic liver disease (OR=2.85, 95% CI: 1.16-7.01, $p=0.023$), treatment (OR=0.60, 95% CI: 0.47-0.75, $p<0.001$), uric acid (UA) (OR=1.01, 95% CI: 1.00-1.02, $p=0.011$), total protein (TP) (OR=1.13, 95% CI: 1.08-1.18, $p<0.001$), albumin (ALB) (OR=0.73, 95% CI: 0.69-0.78, $p<0.001$), and pneumonia (OR=2.22, 95% CI: 1.19-4.14, $p=0.012$) (Table III and Table IV). Table IV presents the multivariate logistic regression results, including the intercept, β coefficient, and odds ratio. A new predictive formula was developed using the regression coefficients and constants:

Logit(p) = -1.049 + 0.030*Age + 0.703*Prior stroke + 1.047*Chronic liver disease - 0.517*Treatment + 0.002*UA + 0.123*TP - 0.313*ALB + 0.797*Pneumonia.

Nomogram Model Establishment

A nomogram model was constructed using multivariate logistic regression to estimate individualized 30-day readmission risk in geriatric hip fracture patients. As shown in Figures 2A and 2B, the nomogram incorporates 8 independent risk factors for a 30-day readmission. Each factor is allotted a score, and the total score corresponds to the predicted readmission risk. For example, a 90-year-old female patient (41 points), with a prior stroke (42 points), without chronic liver disease (36 points), with total hip arthroplasty (46 points), with UA = 400 mmol/L (39 points), with TP =70 g/L (42 points), with ALB = 35 g/L (47 points), and without pneumonia (36 points) would have a total score of 329 points, corresponding to a predicted 30-day readmission risk of 76%.

Nomogram Model Validation

The scatterplots of the new variable for the 30-day readmission and non-readmission groups showed well-separated, non-overlapping distributions in both the training set (-0.85 ± 1.45 *vs.* -3.34 ± 1.61, $p<0.001$) and validation set (-1.28 ± 1.42 *vs.* -3.19 ± 1.61, $p<0.001$). This indicates the nomogram has good discrimination ability (Figures 3A and 3B).

Table I. Baseline clinical and demographic characteristics of the training and validation set.

Variables	Training set (n = 877)	Validation set (n = 372)	*p*-value
Demographic			
Age, × year [Mean (SD)]	74.93 (9.67)	74.92 (9.86)	0.985
Male gender (n, %)	358 (40.8)	135 (36.3)	0.134
Smoking (n, %)	165 (18.8)	49 (13.2)	0.016
Alcohol (n, %)	106 (12.1)	37 (9.9)	0.277
Comorbidities			
Hypertension (n, %)	442 (50.4)	184 (49.5)	0.762
Diabetes (n, %)	215 (24.5)	75 (12.6)	0.096
COPD (n, %)	104 (11.9)	47 (12.6)	0.701
Cardiovascular disease (n, %)	263 (30.0)	116 (31.2)	0.675
Prior stroke (n, %)	226 (25.8)	93 (25.0)	0.775
Dementia (n, %)	25 (2.9)	18 (4.8)	0.078
Intracerebral hemorrhage (n, %)	38 (4.3)	26 (7.0)	0.052
Chronic liver disease (n, %)	39 (4.4)	17 (4.6)	0.924
Chronic kidney disease (n, %)	43 (4.9)	19 (5.1)	0.879
Chronic steroid use (n, %)	7 (0.8)	1 (0.3)	0.284
Type of fracture			
Femoral neck fracture (n, %)	466 (53.1)	209 (56.2)	0.591
Intertrochanteric fracture (n, %)	357 (40.7)	143 (38.4)	
Subtrochanteric fracture (n, %)	54 (6.2)	20 (5.4)	
Treatment			
Total hip arthroplasty (n, %)	113 (12.9)	48 (12.9)	0.798
Hemiarthroplasty (n, %)	211 (24.1)	100 (26.9)	
Intramedullary nail (n, %)	282 (33.3)	121 (32.5)	
Plate/screw (n, %)	116 (13.2)	42 (11.3)	
Multiple screws (n, %)	145 (16.5)	61 (16.4)	
Surgical blood loss, × ml [Mean (SD)]	173.32 (156.25)	175.49 (142.62)	0.818
Transfusion (n, %)	136 (15.5)	65 (17.5)	0.387
Postoperative ICU (n, %)	36 (4.1)	22 (5.9)	0.165
Admission time			
< 6 hours (n, %)	472 (53.8)	188 (50.5)	0.495
6-24 hours (n, %)	132 (15.1)	56 (15.1)	
> 24 hours (n, %)	273 (31.1)	128 (34.4)	
Bedridden time, × day [Mean (SD)]	5.88 (3.69)	5.85 (4.66)	0.918
Surgery time, × hour [Mean (SD)]	1.65 (0.76)	1.68 (0.89)	0.643
ASA			
III-IV (n, %)	491 (56.0)	203 (54.6)	0.645
I-II (n, %)	386 (44.0)	169 (45.4)	
Laboratory findings			
RBC level, × 10^9/L [Mean (SD)]	3.93 (0.69)	3.93 (0.64)	0.928
WBC level, × 10^9/L [Mean (SD)]	8.89 (2.89)	8.71 (2.75)	0.303
NEU level, × 10^9/L [Mean (SD)]	6.81 (2.81)	6.70 (2.66)	0.521
LYM count, × 10^9/L [Mean (SD)]	1.35 (0.72)	1.31 (0.55)	0.328
PLT count, × 10^9/L [Mean (SD)]	207.60 (84.42)	206.56 (77.41)	0.828
HGB level, × g/L [Mean (SD)]	120.04 (20.82)	119.87 (119.58)	0.893
MPV, × fL [Mean (SD)]	8.59 (1.19)	8.50 (1.02)	0.212
RDW , % [Mean (SD)]	13.84 (1.54)	13.76 (1.36)	0.356
K, × mmol/L [Mean (SD)]	4.01 (0.47)	3.99 (0.47)	0.560
Na, × mmol/L [Mean (SD)]	139.74 (4.99)	139.32 (4.28)	0.154
Ca, × mmol/L [Mean (SD)]	2.20 (0.15)	2.19 (0.15)	0.132
Blood glucose, × mmol/L [Mean (SD)]	6.91 (2.85)	6.70 (2.38)	0.193
BUN, × mmol/L [Mean (SD)]	7.57 (5.27)	7.01 (3.58)	0.062
Cr , × µmol/L [Mean (SD)]	75.11 (72.46)	66.44 (41.38)	0.031
BUN/Cr, [Mean (SD)]	0.11 (0.08)	0.14(0.39)	0.127
UA, × mmol/L [Mean (SD)]	293.07 (108.21)	280.40 (96.28)	0.051
ALT, × U/L [Mean (SD)]	20.41 (39.57)	23.86 (54.72)	0.211
AST, × U/L [Mean (SD)]	23.42 (21.92)	25.32 (32.28)	0.170
TP, × g/L [Mean (SD)]	65.48 (6.66)	65.57 (6.78)	0.831

Continued

Table I *(Continued)*. Baseline clinical and demographic characteristics of the training and validation set.

Variables	Training set (n = 877)	Validation set (n = 372)	*p*-value
ALB, × g/L [Mean (SD)]	38.53 (5.08)	38.48 (4.82)	0.869
CHOL, × mmol/L [Mean (SD)]	4.56 (1.12)	4.58 (1.12)	0.685
LDL, × mmol/L [Mean (SD)]	2.80 (0.95)	2.85 (0.99)	0.444
HDL, × mmol/L [Mean (SD)]	1.26 (0.41)	1.26 (0.44)	0.832
TG, × mmol/L [Mean (SD)]	1.34 (0.74)	1.36 (0.96)	0.674
FIB, × g/L [Mean (SD)]	3.69 (1.00)	3.57 (1.18)	0.103
APTT, × s [Mean (SD)]	30.91 (5.51)	31.26 (5.92)	0.306
PT, × s [Mean (SD)]	12.77 (2.76)	12.84 (2.18)	0.680
TT, × s [Mean (SD)]	14.96 (4.44)	15.15 (2.80)	0.449
D-Dimer, × mg/L [Mean (SD)]	4.95 (5.15)	4.91 (5.03)	0.892
Complication			
DVT (n, %)	121 (13.8)	43 (11.6)	0.284
UTI (n, %)	187 (21.3)	97 (26.1)	0.079
POP (n, %)	81 (9.2)	33 (8.9)	0.838

$p < 0.05$: statistically significant difference. SD, standard deviation; COPD, chronic obstructive pulmonary disease; ASA, American Society of Anesthesiologists physical status classification; RBC, red blood cell count; WBC, white blood cell count; NEU, neutrophil; LYM, lymphocyte; PLT, platelet count; HGB, hemoglobin; MPV, mean platelet volume; RDW, red cell distribution width; K, potassium; Na, sodium; Ca, calcium; Blood glucose, blood glucose level; BUN, blood urea nitrogen; Cr, creatinine; BUN/Cr, blood urea nitrogen/creatinine ratio; UA, uric acid; ALT, alanine aminotransferase; AST, aspartate aminotransferase; TP, total protein; ALB, albumin; CHOL, cholesterol; LDL, low-density lipoprotein; HDL, high-density lipoprotein; FIB, fibrinogen; APTT, activated partial thromboplastin time; PT, prothrombin time; TT, thrombin time; DVT, deep vein thrombosis; UTI, urinary tract infection; POP, post-operative pneumonia.

The nomogram achieved high AUCs of 0.881 and 0.840 in the training and validation sets, respectively (Figures 3C and 3D). With a C-index of 0.881 (95% CI: 0.859-0.903), the nomogram demonstrated excellent discrimination.

The variance inflation factors (VIFs) ranging from 1.027 to 2.071 for the 8 risk factors indicated no multicollinearity. Calibration plots showed strong agreement between predicted and observed probabilities (Figures 4A and 4B). The Hosmer-Lemeshow goodness-of-fit test showed no evidence of poor fit for the multivariate logistic regression models in both the training set (χ^2= 5.892, df=8, p=0.659) and validation set (χ^2= 6.362, df=8, p=0.607), indicating that the models were well-calibrated.

Decision curve analysis illustrates the nomogram consistently offered superior net benefit compared to no assessment across a broad range of threshold probabilities (1-79% training set, 2-81% validation set) (Figures 4C and 4D).

The nomogram demonstrated robust discrimination and prediction of the 30-day readmission risk, as evidenced by the validation metrics. These findings support it as a reliable and clinically useful tool for individualized readmission risk estimation.

Discussion

Hip fracture is a leading cause of hospitalization among geriatric patients, with incidence projected[4,5] to exceed 4.5 million by 2050 as the elderly population grows. These patients often have electrolyte disturbances and comorbidities that complicate recovery after surgery. As a result, readmission rates may rise as well[18]. Identifying major risk factors for early readmission and establishing patient-centered postoperative management can help to reduce unintended hospitalizations and associated costs. Prior studies[14,19] found 30-day readmission rates after discharge of 4-30%. The 30-day readmission rate in our cohort was 15.9%, consistent with previous literature.

To investigate the 30-day readmission risk prediction after hip fracture, we conducted a large retrospective study of elderly patients. Using collected clinical data, we developed a nomogram incorporating multiple clinical and laboratory parameters representing key factors implicated in readmission pathogenesis. Through statistical analysis and multivariate logistic regression, we assigned weighted coefficients to eight variables: age, prior stroke, chronic liver disease, treatment type, uric acid level, total protein, albumin, and

Table II. Baseline clinical and demographic characteristics of patients without and with 30-day readmission in the training and validation set.

Variables	Training set (n = 877)			Validation set (n = 372)		
	Validation set (n = 372)	30-day readmission (n=144)	p	Without 30-day readmission (n = 317)	30-day readmission (n = 55)	p
Demographic						
Age, × year [Mean (SD)]	73.74 (9.56)	80.96 (7.85)	< 0.001	73.75 (9.49)	81.64 (9.36)	< 0.001
Male gender (n, %)	304 (41.5)	54 (37.5)	0.375	117 (36.9)	18 (32.7)	0.552
Smoking (n, %)	138 (18.8)	27 (18.8)	0.983	41 (12.9)	8 (14.5)	0.774
Alcohol (n, %)	92 (12.6)	14 (9.7)	0.341	35 (11.0)	2 (3.6)	0.090
Comorbidities						
Hypertension (n, %)	352 (48.0)	80 (62.5)	0.001	150 (47.3)	34 (61.8)	0.047
Diabetes (n, %)	165 (22.5)	50 (34.7)	0.002	57 (18.0)	18 (32.7)	0.012
COPD (n, %)	74 (10.1)	30 (20.8)	< 0.001	34 (10.7)	13 (23.6)	0.008
Cardiovascular disease (n, %)	204 (27.8)	59 (41.0)	0.002	91 (28.7)	25 (45.5)	0.013
Stroke (n, %)	159 (21.7)	67 (46.5)	< 0.001	76 (24.0)	17 (30.9)	0.273
Dementia (n, %)	22 (3.0)	3 (2.1)	0.545	11 (3.5)	7 (12.7)	0.003
Intracerebral hemorrhage (n, %)	31 (4.2)	7 (4.9)	0.733	21 (6.6)	5 (9.1)	0.508
Chronic liver disease (n, %)	24 (3.3)	15 (10.4)	< 0.001	15 (4.7)	2 (3.6)	0.719
Chronic kidney disease (n, %)	28 (3.8)	15 (10.4)	0.001	17 (5.4)	2 (3.6)	0.591
Chronic steroid use (n, %)	4 (4.5)	3 (2.1)	0.058	0 (0)	1 (1.8)	0.016
Type of fracture						
Femoral neck fracture (n, %)	380 (51.8)	86 (59.7)	0.024	171 (53.9)	38 (69.1)	0.086
Intertrochanteric fracture (n, %)	312 (42.6)	45 (31.3)		127 (40.1)	16 (29.1)	
Subtrochanteric fracture (n, %)	42 (5.6)	13 (9.0)		19 (6.0)	1 (1.8)	
Treatment						
Total hip arthroplasty (n, %)	90 (12.3)	23 (16.0)	< 0.001	37 (11.7)	11 (20.0)	0.001
Hemiarthroplasty (n, %)	157 (21.4)	54 (37.5)		76 (24.0)	24 (43.6)	
Intramedullary nail (n, %)	245 (33.4)	47 (32.6)		105 (33.1)	16 (29.1)	
Plate/screw (n, %)	106 (14.5)	10 (6.9)		41 (12.9)	1 (1.8)	
Multiple screws (n, %)	135 (18.4)	10 (6.9)		58 (18.3)	3 (5.5)	
Surgical blood loss, × ml [Mean (SD)]	172 (157.54)	176.19 (150.02)	0.810	176.17 (148.54)	171.56 (103.02)	0.825
Transfusion (n, %)	113 (15.4)	23 (16.0)	0.866	56 (17.7)	9 (16.4)	0.814
Postoperative ICU (n, %)	33 (4.5)	3 (2.1)	0.181	20 (6.3)	2 (3.6)	0.438
Admission time						
< 6 hours (n, %)	397 (54.2)	75 (52.1)	0.892	164 (51.7)	24 (43.6)	0.530
6-24 hours (n, %)	110 (15.0)	22 (15.3)		47 (14.8)	9 (16.4)	
> 24 hours (n, %)	226 (30.8)	47 (32.6)		106 (33.4)	22 (44.0)	
Bedridden time, × day [Mean (SD)]	5.78 (3.64)	6.38 (3.89)	0.078	5.95 (4.94)	5.33 (2.82)	0.364
Surgery time, × hour [Mean (SD)]	1.67 (0.77)	1.58 (0.64)	0.168	1.70 (0.93)	1.54 (0.65)	0.207
ASA						
III-V (n, %)	381 (52.0)	110 (76.4)	< 0.001	156 (49.2)	47 (58.5)	< 0.001
I-II (n, %)	352 (48.0)	34 (23.6)		161 (50.8)	8 (14.5)	
Laboratory findings						
RBC level, × 10^9/L [Mean (SD)]	3.95 (0.69)	3.83 (0.67)	0.053	3.94 (0.66)	3.86 (0.51)	0.403
WBC level, × 10^9/L [Mean (SD)]	8.87 (2.92)	9.01 (2.72)	0.586	8.61 (2.80)	9.29 (2.36)	0.091
NEU level, × 10^9/L [Mean (SD)]	6.77 (2.85)	7.01 (2.63)	0.349	2.73 (0.15)	2.21 (0.30)	0.145
LYM count, × 10^9/L [Mean (SD)]	1.37 (0.75)	1.22 (0.51)	0.025	1.30 (0.55)	1.34 (0.55)	0.594
PLT count, × 10^9/L [Mean (SD)]	206.96 (84.29)	210.88 (85.35)	0.611	201.97 (72.63)	233.00 (97.29)	0.006
HGB level, × g/L [Mean (SD)]	120.87 (21.00)	115.85 (19.40)	0.008	120.08 (20.14)	118.69 (16.13)	0.628
MPV, × fL [Mean (SD)]	8.59 (1.23)	8.63 (0.94)	0.716	8.55 (1.03)	8.28 (0.99)	0.072
RDW , % [Mean (SD)]	13.75 (1.46)	14.34 (1.86)	< 0.001	13.77 (1.42)	13.72 (0.86)	0.811
K, × mmol/L [Mean (SD)]	4.00 (0.46)	4.06 (25.500.53)	0.186	4.00 (0.47)	3.82 (0.43)	0.226
Na, × mmol/L [Mean (SD)]	139.74 (3.40)	139.73 (9.66)	0.977	139.50 (3.97)	138.25 (5.68)	0.123
Ca, × mmol/L [Mean (SD)]	2.20 (0.15)	2.18 (0.15)	0.611	2.18 (0.15)	2.21 (0.16)	0.074

Continued

Table II *(Continued)*. Baseline clinical and demographic characteristics of patients without and with 30-day readmission in the training and validation set.

Variables	Training set (n = 877)			Validation set (n = 372)		
	Validation set (n = 372)	30-day readmission (n=144)	*p*	Without 30-day readmission (n = 317)	30-day readmission (n = 55)	*p*
Blood glucose, × mmol/L [Mean (SD)]	6.74 (2.73)	7.82 (3.26)	< 0.001	6.56 (2.32)	7.47 (2.49)	0.009
BUN, × mmol/L [Mean (SD)]	7.29 (5.11)	8.99 (5.87)	< 0.001	6.90 (3.58)	7.62 (3.57)	0.166
Cr , × μmol/L [Mean (SD)]	71.44 (61.05)	93.78 (112.54)	0.001	65.54 (41.81)	71.64 (38.76)	0.314
BUN/Cr, [Mean (SD)]	0.11 (0.08)	0.11 (0.05)	0.804	0.15 (0.41)	0.12 (0.04)	0.546
UA, × mmol/L [Mean (SD)]	288.05 (103.47)	318.67 (127.06)	0.002	280.14 (94.07)	281.93 (109.10)	0.899
ALT, × U/L [Mean (SD)]	21.05 (42.77)	17.15 (14.54)	0.280	23.73 (55.07)	24.64 (53.12)	0.909
AST, × U/L [Mean (SD)]	23.70 (23.30)	22.02 (12.71)	0.402	25.61 (23.16)	23.64 (24.1)	0.563
TP, × g/L [Mean (SD)]	65.70 (6.70)	64.36 (6.34)	0.027	65.62 (6.69)	65.30 (7.36)	0.746
ALB, × g/L [Mean (SD)]	39.43 (4.75)	33.93 (4.17)	< 0.001	39.04 (4.73)	35.20 (3.93)	< 0.001
CHOL, × mmol/L [Mean (SD)]	4.60 (1.12)	4.34 (1.10)	0.014	4.59 (1.12)	4.56 (1.08)	0.846
LDL, × mmol/L [Mean (SD)]	2.83 (0.96)	2.68 (0.90)	0.084	2.86 (0.93)	2.77 (0.87)	0.511
HDL, × mmol/L [Mean (SD)]	1.28 (0.43)	1.17 (0.33)	0.005	1.27 (0.45)	1.23 (0.33)	0.570
TG, × mmol/L [Mean (SD)]	1.33 (0.76)	1.38 (0.62)	0.455	1.37 (1.01)	1.30 (0.68)	0.600
FIB, × g/L [Mean (SD)]	3.65 (1.09)	3.88 (1.13)	0.018	3.56 (1.20)	3.66 (1.07)	0.565
APTT, × s [Mean (SD)]	30.83 (5.05)	31.31 (7.42)	0.334	31.21 (6.16)	31.58 (4.38)	0.673
PT, × s [Mean (SD)]	12.72 (2.72)	13.01 (2.99)	0.255	12.78 (2.00)	13.18 (3.02)	0.212
TT, × s [Mean (SD)]	14.85 (4.49)	15.54 (4.15)	0.086	15.08 (2.45)	15.57 (4.30)	0.228
D-Dimer, ×mg/L [Mean (SD)]	4.95 (5.19)	4.98 (4.95)	0.945	5.07 (5.20)	3.98 (3.83)	0.070
Complication						
DVT (n, %)	89 (12.1)	32 (22.2)	0.001	38 (12.0)	5 (9.1)	0.535
UTI (n, %)	137 (18.7)	50 (34.7)	< 0.001	79 (24.9)	18 (32.7)	0.224
POP (n, %)	48 (6.5)	33 (22.9)	< 0.001	23 (7.3)	10 (18.2)	0.009

$p < 0.05$: statistically significant difference. 30-day readmission, urinary tract infection; IQR, Interquartile Range; COPD, chronic obstructive pulmonary disease; ASA, American Society of Anesthesiologists physical status classification; RBC, red blood cell count; WBC, white blood cell count; NEU, neutrophil; LYM, lymphocyte; PLT, platelet count; HGB, hemoglobin; MPV, mean platelet volume; RDW, red cell distribution width; K, potassium; Na, sodium; Ca, calcium; Blood glucose, blood glucose level; Cr, creatinine; BUN/Cr, blood urea nitrogen/creatinine ratio; UA, uric acid; ALT, alanine aminotransferase; AST, aspartate aminotransferase; TP, total protein; ALB, albumin; CHOL, cholesterol; LDL, low-density lipoprotein; HDL, high-density lipoprotein; FIB, fibrinogen; APTT, activated partial thromboplastin time; PT, prothrombin time; TT, thrombin time; DVT, deep vein thrombosis; UTI, urinary tract infection; POP, post-operative pneumonia.

pneumonia. To our knowledge, this is the first nomogram evaluating predictors of the 30-day hospital readmission specifically for hip fractures. The nomogram provides an intuitive, point-based risk assessment tool using these variables and coefficients. Both internal and external validation demonstrated good accuracy and stability of the nomogram for predicting 30-day readmission. Moreover, compared to conventional approaches, the nomogram showed superior discrimination in identifying high-risk individuals.

Age

This study found that advanced age is an independent risk factor (OR=1.03, 95% CI: 1.01-1.06, p=0.035) for the 30-day hospital readmission after surgical repair of hip fracture. This is consistent with previous studies[20-23] that have identified older age as a risk factor for readmission following hip fracture surgery. Kates et al[20] observed an increasing readmission rate with age, rising from 4.7% in those 60-69 years old to 16.3% in those over 90 years old. Age over 85 independently predicted readmission (OR=1.52, p=0.03). Jou et al[21] found patients aged over 50 years had high rates of rehospitalization and in-hospital mortality among Taiwanese women with hip fractures. Khan et al[22] identified age as an independent predictor of readmission (OR=1.06, p=0.003). Toson et al[23] identified ad-

Table III. Univariate and multivariate analysis of 30-day readmission in the training set.

Characteristics	Univariate			Multivariate		
	OR	95% CI	*p*-value	OR	95% CI	*p*-value
Age	1.09	1.07-1.11	< 0.001	1.03	1.01-1.06	0.035
Diabetes	1.83	1.25-2.69	0.002	1.14	0.66-1.98	0.644
Prior stroke	3.14	1.76-6.73	< 0.001	2.02	1.28-3.18	0.002
Chronic liver disease	3.44	0.24-1.05	< 0.001	2.85	1.16-7.01	0.023
Type of fracture	1.13	0.84-1.52	0.424	NA	NA	NA
Treatment	0.69	0.59-0.81	< 0.001	0.60	0.47-0.75	< 0.001
Postoperative ICU	0.45	0.14-1.49	0.192	NA	NA	NA
Admission time	1.05	0.86-1.28	0.633	NA	NA	NA
ASA	2.99	1.98-4.51	< 0.001	1.29	0.78-2.12	0.326
RBC	0.78	0.60-1.00	0.054	NA	NA	NA
K	1.28	0.89-1.86	0.186	NA	NA	NA
NA	1.00	0.96-1.04	0.977	NA	NA	NA
CA	0.52	0.15-1.77	0.297	NA	NA	NA
BG	1.12	1.06-1.18	< 0.001	1.07	0.99-1.15	0.094
Cr	1.00	1.00-1.01	0.003	1.00	1.00-1.00	0.629
UA	1.01	1.01-1.02	0.002	1.01	1.00-1.02	0.011
TP	0.97	0.94-1.00	0.027	1.13	1.08-1.18	< 0.001
ALB	0.80	0.76-0.83	< 0.001	0.73	0.69-78	< 0.001.
HDL	0.48	0.29-0.80	0.005	0.74	0.43-1.27	0.271
PT	1.03	0.98-1.09	0.281	NA	NA	NA
TT	1.03	0.99-1.06	0.163	NA	NA	NA
Pneumonia	4.24	2.61-6.90	< 0.001	2.22	1.19-4.14	0.012

vanced age as a significant risk factor for rehospitalization within 30 days in a study of 47,698 geriatric hip fracture patients.

Advanced age is an independent risk factor for hospital 30-day readmission in elderly patients with hip fractures. This may be attributed to several pathological and physiological changes associated with aging. First, osteoporosis becomes more severe with advanced age, leading to poorer fracture healing[24,25]. Second, the prevalence of chronic diseases like cardiovascular disease and diabetes increases with age, negatively impacting fracture recovery[26]. Third, age-related muscle wasting results in poorer mobility and a higher risk of subsequent falls and fractures after discharge[27]. Finally, poorer adaptation to new environments after hospitalization may lead to non-compliance with medical advice and an increased risk of re-injury[28]. In summary, these age-related declines in bone quality, health status, mobility, immunity, and cognition contribute to the higher readmission rates seen in elderly hip

Table IV. Multivariate analysis of 30-day readmission in geriatric patients with hip fractures in the training set.

Risk factor	β	SE	Wald	OR	95% CI	*p*-value
Age	0.030	0.014	4.464	1.03	1.01-1.06	0.035
Prior stroke	0.703	0.232	9.199	2.02	1.28-3.18	0.002
Chronic liver disease	1.047	0.459	5.198	2.85	1.16-7.01	0.023
Treatment	-0.517	0.117	19.399	0.60	0.47-0.75	< 0.001
UA	0.002	0.001	6.408	1.01	1.00-1.02	0.011
TP	0.123	0.022	32.124	1.13	1.08-1.18	< 0.001
ALB	-0.313	0.033	87.686	0.73	0.69-78	< 0.001.
Pneumonia	0.797	0.319	6.259	2.22	1.19-4.14	0.012

β, beta; SE, standard error; Wald: Wald statistic; OR, odds ratio; CI, confidence interval; UA, uric acid; TP, total protein; ALB: Albumin; The p-value is used to determine whether the relationship between each independent variable and 30-day readmission is statistically significant. Logit(p) = -1.049 + 0.030*Age + 0.703*Prior stroke + 1.047*Chronic liver disease - 0.517*Treatment + 0.002*UA + 0.123*TP - 0.313*ALB + 0.797*Pneumonia.

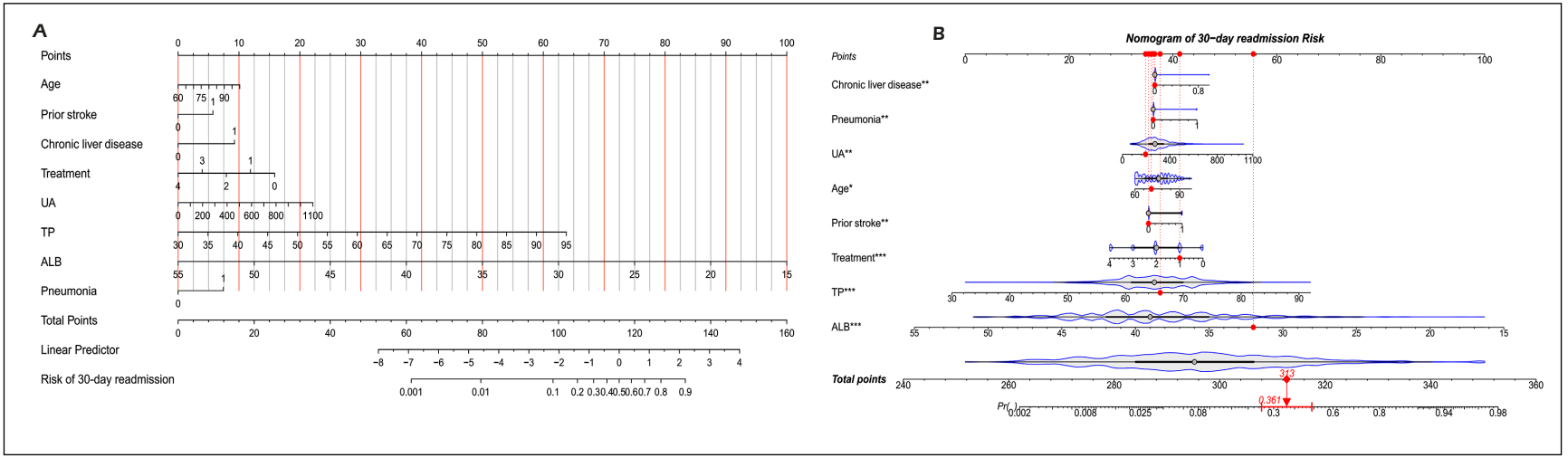

Figure 2. Nomogram for predicting 30-day readmission in geriatric patients with hip fracture. **A,** Eight variables were included in the nomogram prediction model, namely: age, prior stroke, chronic liver disease, treatment, UA, TP, ALB, and pneumonia. **B,** Dynamic nomogram as an example. The significance of the asterisks beside each variable in part b represents the importance of all the risk factors. A simple example analysis: For example, a 90-year-old female patient (41 points), with a prior stroke (42 points), without chronic liver disease (36 points), with total hip arthroplasty (46 points), with UA = 400 mmol/L (39 points), with TP = 70 g/L (42 points), with ALB = 35 g/L (47 points), and without pneumonia (36 points) would have a total score of 329 points, corresponding to a predicted 30-day readmission risk of 76%.

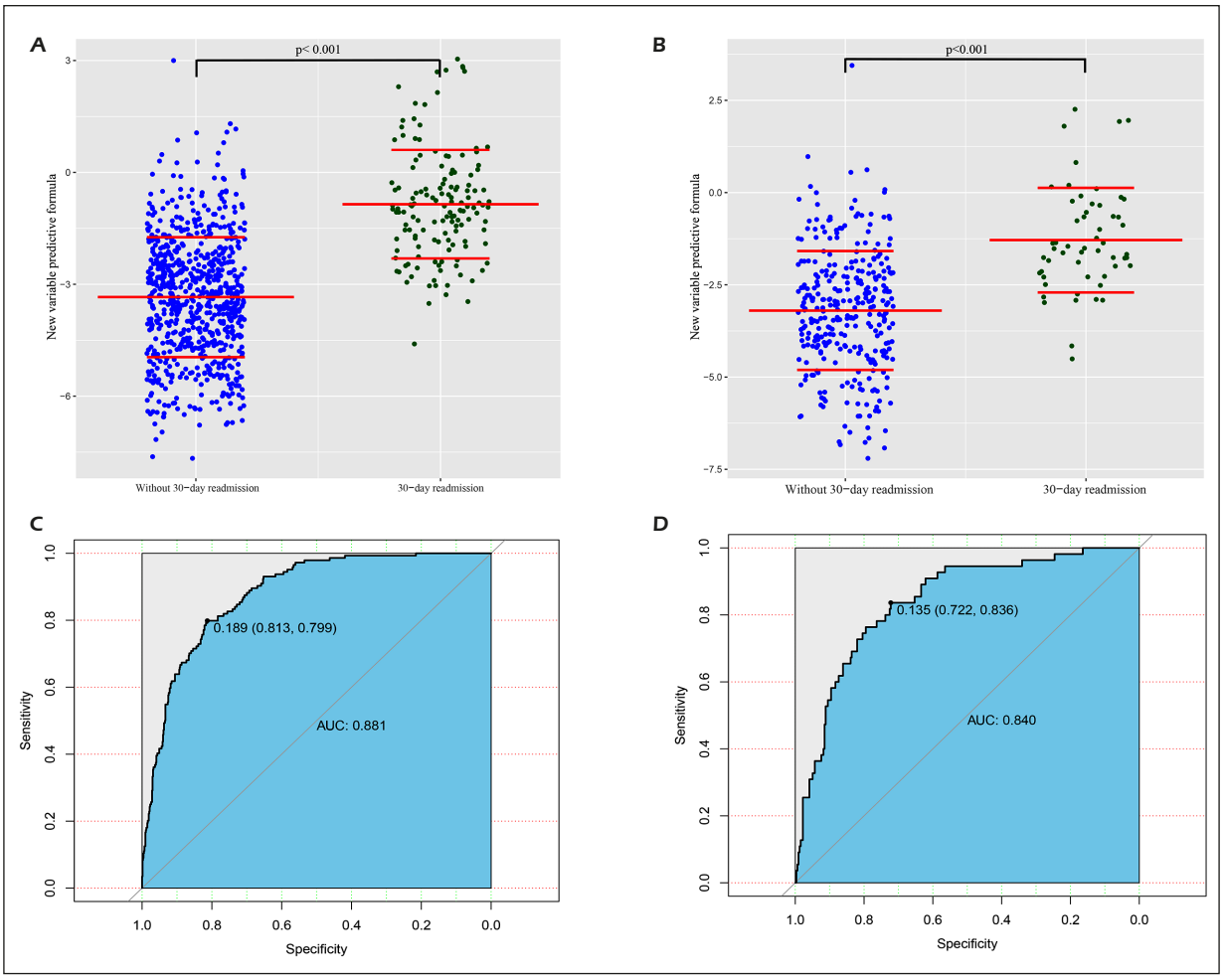

Figure 3. Scatter plot of the new variable of the without 30-day readmission patients and the 30-day readmission patients in the training set (**A**) and validation set (**B**). New variable predictive formula: Logit(p) = -1.049 + 0.030*Age + 0.703*Prior stroke + 1.047*Chronic liver disease - 0.517*Treatment + 0.002*UA + 0.123*TP - 0.313*ALB + 0.797*Pneumonia. Receiver operating characteristic curves (ROC) of the training set (**C**) and validation set (**D**).

fracture patients. Targeting these factors through comprehensive geriatric assessment and multidisciplinary interventions may help reduce readmissions in this high-risk population.

Prior Stroke

Our analysis identified prior stroke as an independent risk factor for 30-day readmission in elderly hip fracture patients (OR=2.02, 95% CI: 1.28-3.18, p=0.002). This finding aligns with several previous studies in literature. For example, Martin et al[29] found an increased risk of 30-day readmission among hip fracture patients with a history of stroke compared to those without prior stroke.

There are several potential reasons why prior stroke may increase the risk of 30-day readmission in elderly patients undergoing hip fracture surgery. Firstly, stroke can cause motor impairment and cognitive dysfunction, which can hinder rehabilitation training and adherence to treatment plans. This, in turn, increases the risk of postoperative complications like infections and re-injury[30]. Secondly, stroke patients often have other comorbidities, such as hypertension, diabetes, and reduced immunity. These comorbid conditions increase the risk of postoperative complications and readmission[31]. Thirdly, some post-stroke sequelae, like swallowing disorders, are more likely to cause pneumonia, which is a major cause of hospital readmission after hip fracture surgery[32]. Fourthly, reduced cognitive and coordination abilities after a stroke make it difficult for patients to comply with postopera-

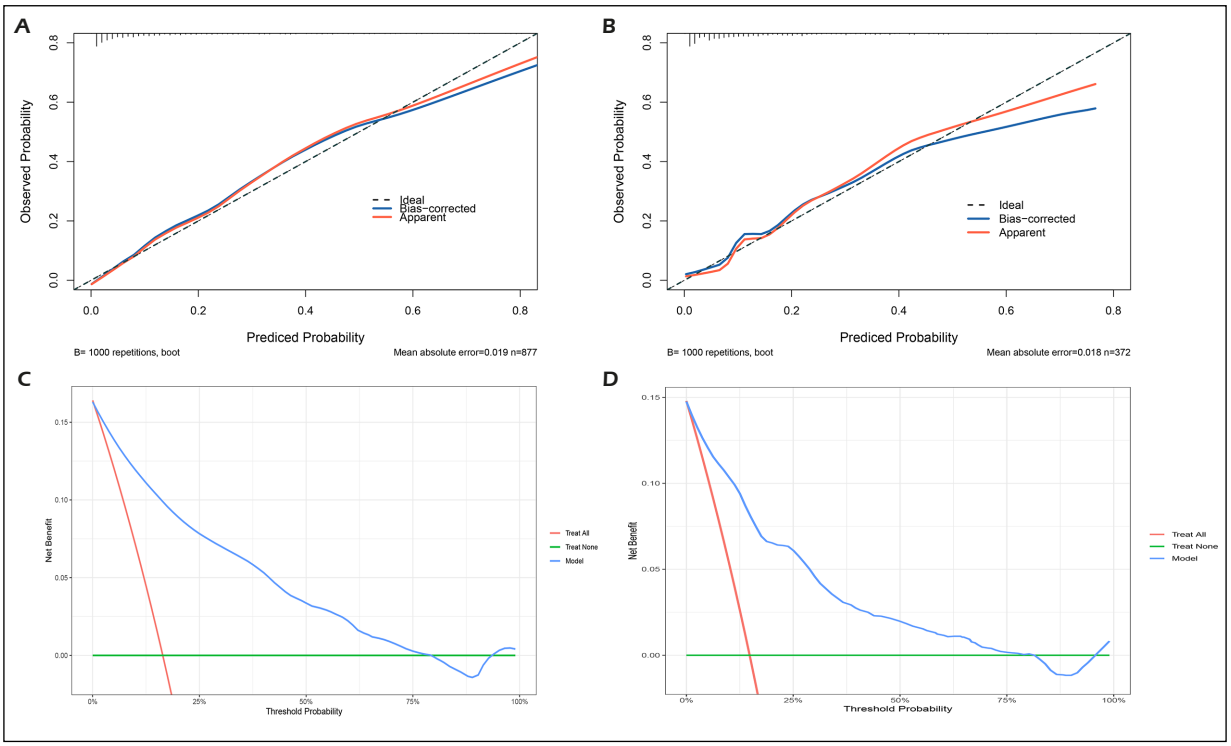

Figure 4. Decision curve analysis of the nomogram in the training set (**A**) and validation set (**B**). The blue line displays the net benefit of our model. The red line assumes that all patients develop 30-day readmission. The green line assumes that no patients develop 30-day readmission. Calibration plot of the nomogram in the training (**C**) and validation (**D**) set. Predictions generated from the model are plotted against actual patient outcomes. The dotted line represents the perfect model calibration. The red line (apparent) indicates calibration when the model is applied to each set, and the green line (bias-corrected) indicates calibration when the model is applied to the bootstrap set.

tive instructions, elevating the risks of re-injury and infection[33]. In summary, the disabilities and comorbidities associated with prior stroke appear to increase the risk of post-surgical complications and readmissions after hip fracture repair in elderly patients. Further research is needed to explore if customized rehabilitation programs and strict comorbidity control can help reduce readmissions in this high-risk population.

Chronic Liver Disease

In our analysis, patients with chronic liver diseases exhibited a substantially higher risk of 30-day readmission compared to those without liver diseases (OR=2.85, 95% CI: 1.16-7.01, p=0.023). This increased readmission risk persisted after adjusting for demographics, comorbidities, and postoperative complications. Our findings align with several previous studies[34,35] demonstrating increased readmission rates among hip fracture patients with chronic liver disease. For example, Montomoli et al[34] found that patients with liver disease, especially cirrhosis, had increased 30-day mortality following hip fracture surgery compared to patients without liver disease. Additionally, Tseng et al[35] found that chronic liver disease, particularly cirrhosis, was associated with a higher risk of complications and rehospitalization in geriatric hip fracture patients undergoing surgical repair (adjusted OR=1.295, 95% CI: 1.143-1.467).

There are several potential explanations for the increased risk of 30-day readmission in hip fracture patients with liver disease. Firstly, liver disease can cause coagulation dysfunction and bleeding disorders, leading to increased surgical complications that require readmission[36]. Furthermore, liver disease is associated with malnutrition and muscle wasting, which impairs healing, rehabilitation, and immunity after hip fracture surgery. This increases the risk of postoperative falls, re-fracture, and infection that may necessitate readmission[37]. Additionally, liver dysfunction alters medication metabolism used during and

after hip surgery. This can lead to side effects and complications requiring readmission[38]. Finally, liver disease is also associated with other conditions like osteoporosis that negatively impact fracture healing[39]. The combination of these factors contributes to the increased readmissions.

Treatment

Our analysis found that surgical treatment type was an independent predictor of 30-day readmission risk in elderly hip fracture patients (OR=0.60, 95% CI: 0.47-0.75, $p<0.001$). Specifically, patients who underwent total hip arthroplasty had a significantly higher readmission rate compared to those who received other surgical procedures such as hemiarthroplasty, intramedullary nailing, plate/screw fixation, or multiple screw fixation[40].

Several factors may explain the higher readmission rates with total hip arthroplasty in our cohort. Firstly, arthroplasty is a more invasive procedure with higher perioperative complications including infections, dislocations, and surgical site issues that are key drivers of readmission[41,42]. Comparatively, other fixation procedures have lower failure and infection rates. Secondly, total hip arthroplasty requires extensive rehabilitation and has activity restrictions that can delay recovery in frail elderly patients. In contrast, other procedures allow earlier mobilization[43]. Thirdly, our cohort undergoing total hip arthroplasty may have greater comorbidities and complications that inherently increase their readmission likelihood[44]. The underlying patient characteristics likely contribute to the treatment effects to some degree.

Overall, our findings indicate elderly hip fracture patients undergoing total hip arthroplasty may benefit from closer monitoring and preventive efforts to avoid readmission. Further studies are needed to definitively compare readmission rates between total hip arthroplasty and other treatment procedures for this population. The treatment choice should balance rehospitalization risk against the functional benefits of arthroplasty in the frail elderly.

Uric Acid (UA)

Our analysis revealed elevated serum uric acid levels as an independent risk factor for a 30-day readmission in geriatric hip fracture patients (OR=1.01, 95% CI: 1.00-1.02, $p=0.011$). Several other studies[45-47] have similarly demonstrated increased readmissions among patients with high uric acid. For instance, a large-scale prospective cohort study[45] of elderly adults with hip fractures found that hyperuricemia (UA >420 μmol/L) significantly increased the risk of unplanned 30-day readmission by 32% after adjusting for potential confounders, particularly in men. Furthermore, a retrospective study[46] of patients undergoing heart failure patients found that elevated uric acid levels were an independent predictor of 30-day hospital readmission. According to another study[47], patients with hyperuricemia or gout or patients with high levels of serum uric acid may face poor outcomes of hip fractures.

Some potential mechanisms may explain this relationship. Firstly, high uric acid induces endothelial dysfunction, limiting tissue perfusion and delaying post-surgical recovery[48]. Secondly, hyperuricemia is associated[49] with insulin resistance, hypertension, and kidney disease - comorbidities increasing readmission likelihood. Thirdly, elevated uric acid causes immune dysfunction and impairs neutrophil function, which may increase postoperative infections, necessitating rehospitalization[50]. Finally, as an antioxidant, hyperuricemia may reflect increased oxidative stress, which can impair healing after hip fracture surgery[47]. Overall, monitoring and controlling uric acid levels through treatment may help reduce avoidable readmissions in this susceptible population.

Total Protein (TP)

Our study found that higher total serum protein levels were independently associated with an increased 30-day readmission risk following hip fracture surgery in the elderly (OR=1.13, 95% CI: 1.08-1.18, $p<0.001$).

Some potential mechanisms may contribute to this relationship. Firstly, elevated protein levels may reflect an acute inflammatory response to trauma, surgery, or infection[51]. This inflammatory state can impair healing and increase complications, necessitating readmission. Secondly, high protein levels may be a marker of dehydration in some patients. Dehydration increases the risk of acute kidney injury, electrolyte abnormalities, and other issues requiring rehospitalization. Thirdly, abnormal protein metabolism may indicate underlying diseases like cancer or autoimmune conditions associated with poorer prognosis and outcomes after hip fracture surgery[52]. Finally, elevated protein levels may be caused by intravenous albumin given to treat hypoproteinemia[53]. This may reflect underlying malnutrition and frailty in a subset of patients.

Our study identified high total protein levels as an independent predictor of 30-day readmission. The underlying etiology likely varies between individuals but may serve as a useful clinical marker to identify high-risk patients needing more intensive post-discharge care and follow-up to prevent unintended hospital return.

Albumin (ALB)

Our analysis determined that hypoalbuminemia is also an independent risk factor for 30-day readmission among elderly hip fracture patients (OR=0.73, 95% CI 0.69-0.78, $p<0.001$). This aligns with the majority of previous findings. For instance, a study[54] conducted on patients with ankle fractures found that an albumin level <3.5 g/dL was an independent risk factor for complications and readmission n (RR: 1.54; 95% CI: 1.13-2.08; $p=0.006$). Another study[55] conducted on patients with lower extremity trauma found that hypoalbuminemia patients had higher rates of postoperative complications, including increased rates of mortality, sepsis, reintubation, reoperation, and readmission (11.4% *vs.* 4.1%; RR: 2.53). A study[56] conducted on patients undergoing surgical decompression of spinal metastases found that hypoalbuminemia was associated with a lower rate of unplanned 30-day readmissions (adjusted OR=0.18; 95% CI: 0.05-0.63; $p=0.007$).

Several mechanisms could underpin this relationship in this susceptible group. Firstly, hypoalbuminemia impairs immune cell function and antibody production, increasing the risk of infection. Infections are a common cause of readmission in hypoalbuminemia patients[57]. Secondly, albumin helps maintain oncotic pressure, which keeps fluid in the bloodstream[58]. Low oncotic pressure causes fluid to leak out of the blood vessels into tissues, leading to oedema. This can impair organ function and require readmission. Thirdly, albumin is essential for collagen formation and tissue repair. Hypoalbuminemia impairs wound healing, leading to dehiscence, infections, and the need for readmission[59]. Lastly, albumin transports vitamins, minerals, and trace elements in the blood[60]. Hypoalbuminemia can cause deficiencies in these nutrients, impacting organ function and leading to complications necessitating readmission.

Pneumonia

This study has consistently shown that pneumonia is another independent risk factor for rehospitalization within 30 days after hip fracture surgery (OR=2.22, 95% CI: 1.19-4.14, $p=0.012$)[61], significantly increasing the likelihood of readmission in these patients, which is consistent with most prior research[62-64] results. For example, a large cohort study[62] found a markedly increased 30-day readmission rate for those with pneumonia *vs.* those without (OR=2.42, 95% CI: 1.82-3.24). Additionally, a systematic review[63] synthesizing 5 studies concluded that pneumonia increases the risk of 30-day readmission after hip fracture surgery in elderly patients. Furthermore, Salarbaks et al[64] identified pneumonia as an independent predictor of 30-day rehospitalization after hip fracture surgery. Taken together, there is strong evidence that pneumonia significantly increases the likelihood of readmission within 30 days in patients after surgery for hip fracture.

Firstly, pneumonia occurring early after hip fracture surgery can impair rehabilitation efforts and lead to deconditioning, muscle weakness, and reduced mobility, further impairing lung function and increasing the likelihood of readmission[65]. Additionally, pneumonia patients commonly belong to high-risk groups such as the elderly, males, or those with chronic comorbidities like chronic obstructive pulmonary disease (COPD) and diabetes. Patients in these high-risk groups often have poorer underlying health, weaker immune systems, and decreased lung function[66]. The presence of multiple health issues in this population makes them more prone to developing severe, complicated pneumonia that requires hospitalization when infected.

Limitations

Nomograms are emerging as new noninvasive visualization tools for clinical prediction models. In this study, we developed and validated a nomogram to individually predict 30-day readmission risk in elderly hip fracture patients, using readily obtainable admission factors. Derived in a training cohort, the nomogram showed favorable discrimination and calibration when validated in an independent cohort. Quantitatively estimating readmission risk facilitates the stratification of patients on admission and guides preventive interventions for high-risk individuals. Thus, this model serves as an effective clinical decision aid to enable targeted prevention of 30-day readmission in this vulnerable population.

However, several limitations should be considered when interpreting the results. First, the retrospective design introduces potential bias and

precludes establishing causal relationships between identified risk factors and readmission. Second, as a single-center study, generalizability to other settings is unclear. Third, while decision curve analysis indicates potential utility, further assessment is needed to determine the actual clinical impact on treatment decisions and outcomes. Fourth, as a statistical model, it cannot replace clinical judgment in individualized decision-making. Finally, the model was limited to available data. Other potentially important predictors, such as frailty, nutrition, and social support, were not included.

Conclusions

In this study, we developed and validated a novel nomogram for predicting 30-day readmission after hip fracture surgery in geriatric patients. With good discrimination, calibration and clinical utility, this nomogram can facilitate the identification of high-risk patients for timely interventions to reduce avoidable readmissions. Further external validation is required before clinical application.

Conflict of Interest
The authors declare that they have no conflict of interests.

Authors' Contribution
Study concept: RJH. Study design: All authors. Acquisition, analysis, or interpretation of data: WYT, WY, WW, and QML. Statistical analysis: WBD, WYT, WY and YHL. Drafting of the manuscript: WYT. Critical revision of the manuscript for important intellectual content: All authors.

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Availability of Data and Materials
All data can be obtained from the corresponding author by reasonable request.

Ethics Approval
The Institutional Review Board of Dandong Central Hospital approved the study (No. DDZX-202308011), which followed the principles of the Declaration of Helsinki of 1964 and its later amendments.

Informed Consent
Written informed consent was obtained from all participants in this study.

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References

1) Amarilladonoso FJ, Lópezespuela F, Ronceromartín R, Lealhernandez O, Puertoparejo LM, Aliagavera I, Toribiofelipe R, Lavadogarcía JM. Quality of life in elderly people after a hip fracture: a prospective study. Health Qual Life Outcomes 2020; 18: 15-25.
2) Stubbs B, Perara G, Koyanagi A, Veronese N, Vancampfort D, Firth J, Sheehan K, De Hert M, Stewart R, Mueller C. Risk of Hospitalized Falls and Hip Fractures in 22,103 Older Adults Receiving Mental Health Care vs 161,603 Controls: A Large Cohort Study. J Am Med Dir Assoc 2020; 21: 1893-1899.
3) Kannus P, Parkkari J, Sievänen H, Heinonen A, Vuori I, Järvinen M. Epidemiology of hip fractures. Bone 1996; 18: 57-63.
4) Dhanwal DK, Dennison EM, Harvey NC, Cooper C. Epidemiology of hip fracture: Worldwide geographic variation. Indian J Orthop 2011; 45: 15-22.
5) Veronese N, Maggi S. Epidemiology and social costs of hip fracture. Injury 2018; 49: 1458-1460.
6) Steihaug OM, Gjesdal CG, Bogen B, Kristoffersen MH, Lien G, Ranhoff AH. Sarcopenia in patients with hip fracture: A multicenter cross-sectional study. PLoS One 2017; 12: 780-719.
7) Yeung SSY, Reijnierse EM, Pham VK, Trappenburg MC, Lim WK, Meskers CGM, Maier AB. Sarcopenia and its association with falls and fractures in older adults: A systematic review and meta-analysis. J Cachexia Sarcopenia Muscle 2019; 10: 485-500.
8) Landi F, Liperoti R, Russo A, Giovannini S, Tosato M, Capoluongo E, Bernabei R, Onder G. Sarcopenia as a risk factor for falls in elderly individuals: Results from the ilSIRENTE study. Clin Nutr 2012; 31: 652-658.
9) Zolio L, Lim KY, Mckenzie JE, Yan MK, Estee M, Hussain SM, Cicuttini F, Wluka A. Systematic review and meta-analysis of the prevalence of neuropathic-like pain and/or pain sensitization in people with knee and hip osteoarthritis. Osteoarthritis Cartilage 2021; 29: 1096-1116.
10) Giovannini S, Coraci D, Brau F, Galluzzo V, Loreti C, Caliandro P, Padua L, Maccauro G, Biscot-

ti L, Bernabei R. Neuropathic Pain in the Elderly. Diagnostics 2021; 11: 613-618.

11) Bates D, Schultheis BC, Hanes MC, Jolly SM, Chakravarthy KV, Deer TR, Levy RM, Hunter CW. A Comprehensive Algorithm for Management of Neuropathic Pain. Pain Med 2019; 20: 2-12.

12) Colloca L, Ludman T, Bouhassira D, Baron R, Dickenson AH, Yarnitsky D, Freeman R, Truini A, Attal N, Finnerup NB, Eccleston C, Kalso E, Bennett DL, Dworkin RH, Raja SN. Neuropathic pain. Nature Reviews Disease Primers 2017; 3: 251-265.

13) Kates SL, Behrend C, Mendelson DA, Cram P, Friedman SM. Hospital readmission after hip fracture. Arch Orthop Trauma Surg 2015; 135: 329-337.

14) Gentil L, Grenier G, Fleury MJ. Factors Related to 30-day Readmission following Hospitalization for Any Medical Reason among Patients with Mental Disorders: Facteurs liés à la réhospitalisation à 30 jours suivant une hospitalisation pour une raison médicale chez des patients souffrant de troubles mentaux. Can J Psychiatry 2021; 66: 43-55.

15) Gupta S, Zengul FD, Davlyatov GK, Weechmaldonado R. Reduction in Hospitals' Readmission Rates: Role of Hospital-Based Skilled Nursing Facilities. Inquiry 2019; 56: 994-1001.

16) Rajamaki B, Koponen M, Hartikainen S, Tolppanen AM. Length of hospital stay after hip fracture and readmission rates of persons with and without Alzheimer's disease: a matched cohort study. BMC Geriatr 2015; 6: 25-41.

17) Miettinen SSA, Savolainen S, Kröger H. Charlson comorbidity index predicts the 10-year survivorship of the operatively treated hip fracture patients. Eur J Orthop Surg Traumatol 2023; 33: 1141-1148.

18) Mull HJ, Graham LA, Morris MS, Rosen AK, Richman JS, Whittle J, Burns E, Wagner TH, Copeland LA, Wahl T, Jones C, Hollis RH, Itani KMF, Hawn MT. Association of Postoperative Readmissions With Surgical Quality Using a Delphi Consensus Process to Identify Relevant Diagnosis Codes. JAMA Surgery 2018; 153: 728-740.

19) Pereira F, Verloo H, Zhivko T, Di Giovanni S, Meyermassetti C, Von Gunten A, Martins MM, Wernli B. Risk of 30-day hospital readmission associated with medical conditions and drug regimens of polymedicated, older inpatients discharged home: a registry-based cohort study. BMJ open 2021; 11: 755-764.

20) Kates SL, Behrend C, Mendelson DA, Cram P, Friedman SM. Hospital readmission after hip fracture. Arch Orthop Trauma Surg 2014; 135: 329-337.

21) Jou HJ, Siao RY, Tsai YS, Chen YT, Li CY, Chen CC. Postdischarge rehospitalization and in-hospital mortality among Taiwanese women with hip fracture. Taiwan J Obstet Gynecol 2014; 53: 43-47.

22) Khan MA, Hossain FS, Dashti Z, Muthukumar N. Causes and predictors of early re-admission after surgery for a fracture of the hip. J Bone Joint Surg Br 2012; 94-B: 690-697.

23) Toson B, Harvey LA, Close JCT. The ICD-10 Charlson Comorbidity Index predicted mortality but not resource utilization following hip fracture. J Clin Epidemiol 2015; 68: 44-51.

24) Osipov B, Emami AJ, Christiansen BA. Systemic Bone Loss After Fracture. Clin Rev Bone Miner Metab 2018; 16: 116-130.

25) Clark D, Nakamura M, Miclau T, Marcucio R. Effects of Aging on Fracture Healing. Curr Osteoporos Rep 2017; 15: 601-608.

26) Zhao Y, Zhang H, Li N, Li J, Zhang L. Chronic Pain after Bone Fracture: Current Insights into Molecular Mechanisms and Therapeutic Strategies. Brain Sciences 2022; 12: 1056-1072.

27) Ferrucci L, Baroni M, Ranchelli A, Lauretani F, Maggio M, Mecocci P, Ruggiero C. Interaction Between Bone and Muscle in Older Persons with Mobility Limitations. Curr Pharm Des 2014; 20: 3178-3197.

28) Bernheim SM, Ross JS. Hospital Discharge and the Transition Home for Poor Patients: "I Knew I Couldn't Do What They Were Asking Me". J Gen Intern Med 2014; 29: 269-270.

29) Martin CT, Gao Y, Pugely AJ. Incidence And Risk Factors For 30-Day Readmissions After Hip Fracture Surgery. Iowa Orthop J 2016; 36: 155-160.

30) Mcdonald MW, Black SE, Copland DA, Corbett D, Dijkhuizen RM, Farr TD, Jeffers MS, Kalaria RN, Karayanidis F, Leff AP, Nithianantharajah J, Pendlebury S, Quinn TJ, Clarkson AN, Osullivan MJ. Cognition in stroke rehabilitation and recovery research: Consensus-based core recommendations from the second Stroke Recovery and Rehabilitation Roundtable. Int J Stroke 2019; 14: 774-782.

31) Samuel AM, Diazcollado PJ, Szolomayer LK, Nelson SJ, Webb ML, Lukasiewicz AM, Grauer JN. Incidence of and Risk Factors for Inpatient Stroke After Hip Fractures in the Elderly. Orthopedics 2018; 41: 25-38.

32) Ang SH, Hwong WY, Bots ML, Sivasampu S, Abdul Aziz AF, Hoo FK, Vaartjes I. Risk of 28-day readmissions among stroke patients in Malaysia (2008-2015): Trends, causes and its associated factors. PLoS One 2021; 16: 448-460.

33) Elkind MSV, Boehme AK, Smith CJ, Meisel A, Buckwalter MS. Infection as a Stroke Risk Factor and Determinant of Outcome After Stroke. Stroke 2020; 51: 3156-3168.

34) Montomoli J, Erichsen R, Gammelager H, Becic Pedersen A. Liver disease and mortality among patients with hip fracture: a population-based cohort study. Clin Epidemiol 2018; 10: 991-1000.

35) Tseng FJ, Gou GH, Wang SH, Shyu JF, Pan RY. Chronic liver disease and cirrhosis in-

crease morbidity in geriatric patients treated surgically for hip fractures: analysis of the US Nationwide Inpatient Sample. BMC Geriatr 2022; 22: 28-41.

36) Periyalwar P, Dasarathy S. Malnutrition in cirrhosis: contribution and consequences of sarcopenia on metabolic and clinical responses. Clin Liver Dis 2012; 16: 95-131.

37) Dasarathy S. Cause and management of muscle wasting in chronic liver disease. Curr Opin Gastroenterol 2016; 32: 1-12.

38) Verbeeck RK, Horsmans Y. Effect of hepatic insufficiency on pharmacokinetics and drug dosing. Pharm World Sci 1998; 20: 183-192.

39) Nakchbandi IA. Osteoporosis and fractures in liver disease: relevance, pathogenesis and therapeutic implications. World J Gastroenterol 2014; 20: 9427-9438.

40) Zafar SN, Shah AA, Nembhard C, Wilson LL, Habermann EB, Raoof M, Wasif N. Readmissions After Complex Cancer Surgery: Analysis of the Nationwide Readmissions Database. J Oncol Pract 2018; 14: 335-345.

41) Parker MJ, Gurusamy KS. Internal fixation versus arthroplasty for intracapsular proximal femoral fractures in adults. Cochrane Database Syst Rev 2006; 2006: 25-32.

42) Parker MJ, Handoll HHG. Replacement arthroplasty versus internal fixation for extracapsular hip fractures in adults. Cochrane Database Syst Rev 2006; 6: 86-101.

43) Tian Y, Liu Z, Liu S, Jing W, Li L, Ma W, Han Y. Efficacy of bed exercise in elderly patients after total hip arthroplasty: A retrospective study of 539 patients. Medicine 2022; 101: 31779-31786.

44) Lan P, Chen X, Fang Z, Zhang J, Liu S, Liu Y. Effects of Comorbidities on Pain and Function After Total Hip Arthroplasty. Front Surg 2022; 9: 21-29.

45) Preyer O, Concin H, Nagel G, Zitt E, Ulmer H, Brozek W. Serum uric acid is associated with incident hip fractures in women and men - Results from a large Austrian population-based cohort study. Maturitas 2021; 148: 46-53.

46) Naderi N, Chenaghlou M, Mirtajaddini M, Norouzi Z, Mohammadi N, Amin A, Taghavi S, Pasha H, Golpira R. Predictors of readmission in hospitalized heart failure patients. J Cardiovasc Thorac Res 2022; 14: 11-17.

47) Liu M, Chu Q, Yang C, Wang J, Fu M, Zhang Z, Sun G. The paradoxical relation between serum uric acid and outcomes of hip fracture in older patients after surgery: A 1-year follow-up study. Surgery 2022; 172: 1576-1583.

48) Borgi L, Mcmullan C, Wohlhueter A, Curhan GC, Fisher ND, Forman JP. Effect of Uric Acid-Lowering Agents on Endothelial Function. Hypertension 2017; 69: 243-248.

49) Karis E, Crittenden DB, Pillinger MH. Hyperuricemia, Gout, and Related Comorbidities: Cause and Effect on a Two-Way Street. South Med J 2014; 107: 235-241.

50) Zhao J, Wei K, Jiang P, Chang C, Xu L, Xu L, Shi Y, Guo S, Xue Y, He D. Inflammatory Response to Regulated Cell Death in Gout and Its Functional Implications. Front Immunol 2022; 13: 0267-1379.

51) Jain S, Gautam V, Naseem S. Acute-phase proteins: As diagnostic tool. J Pharm Bioallied Sci 2011; 3: 118-120.

52) Hedström M, Ljungqvist O, Cederholm T. Metabolism and catabolism in hip fracture patients: Nutritional and anabolic intervention—a review. Acta Orthop 2006; 77: 741-747.

53) Yu YT, Liu J, Hu B, Wang RL, Yang XH, Shang XL, Wang G, Wang CS, Li BL, Gong Y, Zhang S, Li X, Wang L, Shao M, Meng M, Zhu F, Shang Y, Xu QH, Wu ZX, Chen DC. Expert consensus on the use of human serum albumin in critically ill patients. Chin Med J 2021; 134: 1639-1654.

54) Wilson JM, Kukowski NR, Staley CA, Bariteau JT. Role of Hypoalbuminemia as an Independent Predictor of 30-Day Postoperative Complications Following Surgical Fixation of Ankle Fractures. Foot Ankle Int 2020; 41: 303-312.

55) Wilson JM, Lunati MP, Grabel ZJ, Staley CA, Schwartz AM, Schenker ML. Hypoalbuminemia Is an Independent Risk Factor for 30-Day Mortality, Postoperative Complications, Readmission, and Reoperation in the Operative Lower Extremity Orthopaedic Trauma Patient. J Orthop Trauma 2019; 33: 284-291.

56) Hussain AK, Cheung ZB, Vig KS, Phan K, Lima MC, Kim JS, Di Capua J, Kaji DA, Arvind V, Cho SK. Hypoalbuminemia as an Independent Risk Factor for Perioperative Complications Following Surgical Decompression of Spinal Metastases. Global Spine J 2018; 9: 321-330.

57) Li P, Yin YL, Li D, Woo Kim S, Wu G. Amino acids and immune function. Br J Nutr 2007; 98: 237-252.

58) Diskin CJ, Stokes TJ, Dansby LM, Carter TB, Radcliff L, Thomas SG. Towards an understanding of oedema. BMJ 1999; 318: 1610-1613.

59) Shoulders MD, Raines RT. Collagen Structure and Stability. Annu Rev Biochem 2009; 78: 929-958.

60) Bhattacharya PT, Misra SR, Hussain M. Nutritional Aspects of Essential Trace Elements in Oral Health and Disease: An Extensive Review. Scientifica 2016; 2016: 1-12.

61) Bohl DD, Sershon RA, Saltzman BM, Darrith B, Della Valle CJ. Incidence, Risk Factors, and Clinical Implications of Pneumonia After Surgery for Geriatric Hip Fracture. J Arthroplasty 2018; 33: 1552-1556.

62) Lee SH, Kim KU. Risk Factors for Postoperative Pneumonia in the Elderly Following Hip Fracture Surgery: A Systematic Review and Meta-Analysis. Geriatr Orthop Surg Rehabil 2022; 13: 838-850.

63) Ali AM, Gibbons CER. Predictors of 30-day hospital readmission after hip fracture: a systematic review. Injury 2017; 48: 243-252.

64) Salarbaks AM, Lindeboom R, Nijmeijer W. Pneumonia in hospitalized elderly hip fracture patients: the effects on length of hospital-stay, in-hospital and thirty-day mortality and a search for potential predictors. Injury 2020; 51: 1846-1850.

65) Chang SC, Lai JI, Lu MC, Lin KH, Wang WS, Lo SS, Lai YC. Reduction in the incidence of pneumonia in elderly patients after hip fracture surgery: An inpatient pulmonary rehabilitation program. Medicine 2018; 97: 11845-11852.

66) Han SB, Kim SB, Shin KH. Risk factors for postoperative pneumonia in patients undergoing hip fracture surgery: a systematic review and meta-analysis. BMC Musculoskelet Disord 2022; 23: 12-21.