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Development and validation of a nomogram for urinary tract infection in geriatric patients with hip fracture: a retrospective study

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Abstract. – OBJECTIVE: This study aims to develop and validate a risk nomogram for urinary tract infections (UTIs) in geriatric patients with hip fractures.

PATIENTS AND METHODS: A total of 900 geriatric patients who underwent hip fracture surgery at Dandong Central Hospital between June 2017 and June 2023 were systematically collected. The cohort was randomly divided into a training set (70%, n=632) and a validation set (30%, n=268) for model development and validation, respectively. Univariate and multivariate logistic regression analyses were conducted to identify the independent risk factors associated with UTIs. Based on the results of the multivariate analysis, a UTI nomogram prediction model was developed and evaluated in the training and validation sets using the C-index, ROC curve, calibration curve, and decision curve analysis to assess discrimination, calibration, and clinical utility, respectively.

RESULTS: Out of the 900 participants, 24.6% were diagnosed with UTIs. The nomogram was developed based on 9 predictors that were found to be independently associated with UTI. The area under the curve (AUC) for predicting UTI in geriatric patients with hip fractures was 0.829 in the training set and 0.803 in the validation set. Following internal verification, the modified C-index remained at 0.829. Furthermore, the nomogram's calibration plot and decision curve analysis demonstrated good performance in both the training and validation sets.

CONCLUSIONS: The established and validated nomogram provides a reliable and convenient tool for predicting UTI risk in geriatric patients with hip fractures. This model facilitates the early identification of high-risk patients and offers guidance for implementing targeted preventive interventions.

Key Words:
Hip fracture, urinary tract infection, Geriatric, Prediction model, Nomogram.

Abbreviations

UTI: urinary tract infection; ROC: Receiver operating characteristic curve; DCA: Decision curve analysis; STROCS: Strengthening the Reporting of Cohort Studies in Surgery; IQR: Interquartile range; AUC: area under the curve; VIFs: variance inflation factors; OR: Odds ratios; CI: Confidence intervals; SE: standard error; CT: Computed Tomography; MRI: Magnetic Resonance Imaging; NA: Not available.

Introduction

Urinary tract infection (UTI) is a frequently underestimated but common complication among geriatric patients with hip fractures, with reported incidences ranging from 8% to 52% during hospitalization[1-4]. However, the considerable adverse impact of UTIs on clinical outcomes in this vulnerable population is frequently underestimated. UTI occurrence esca-

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lates the risks of delirium, mortality, and other postoperative complications[3,5,6]. It also hampers rehabilitation progress and functional recovery[7]. Moreover, UTI significantly prolongs hospital stays and increases medical costs[2,4,8]. Thus, in recent years, there has been an increased clinical focus on the prevention, early diagnosis, and management of UTI in elderly patients with hip fractures.

While prior studies have focused on analyzing the incidence, risk factors, and preventive measures for UTIs in various populations, few have specifically examined the development of predictive models for UTIs in geriatric hip fracture patients[2,7]. Despite urinary catheterization being a significant risk factor, the Centers for Disease Control and Prevention reported that 25% of hospital-acquired UTIs are not catheter-associated[9,10]. Moreover, recent studies[3,11-13] have identified various valuable predictors for UTI risk in geriatric patients with hip fractures, including advanced age, female gender, diabetes, and low serum albumin level. Nevertheless, there is currently no predictive model specifically tailored for UTIs in this specific patient population. Consequently, there is an unmet need for individualized risk assessment and prevention approaches to effectively decrease the occurrence of UTIs.

This study aims to develop and validate a personalized nomogram model that accurately predicts the risk of UTI in geriatric patients with hip fractures. By identifying high-risk individuals and implementing timely preventive interventions, the incidence of UTIs could be significantly reduced, resulting in improved rehabilitation and clinical outcomes. This predictive nomogram, specifically tailored for UTI risk assessment in elderly patients with hip fractures, presents an innovative precision medicine approach with substantial clinical utility.

Patients and Methods

Patients

This study adhered to the STROCS guideline and complied with the tenets of the 1964 Helsinki Declaration and its subsequent amendments. Approval was obtained from the Institutional Review Board of Dandong Central Hospital, and written informed consent was obtained from the patients or their legal guardians.

We retrospectively collected clinical data from a total of 1,210 elderly patients diagnosed with hip fractures at the Affiliated Dandong Central Hospital of China Medical University between June 2017 and June 2023. The inclusion criteria for this study were: (1) age ≥60 years; (2) radiographic confirmation of hip fracture through X-ray or CT imaging; (3) surgical confirmation of hip fracture. The following exclusion criteria were applied: (1) patients who did not receive surgical treatment; (2) patients with incomplete clinical data; (3) patients with multiple fractures; (4) patients with pathological hip fractures; (5) patients with old fractures; (6) patients with a recent (within 3 months) history of antibiotic use, urinary catheterization, or recurrent urinary tract infection (UTI). Based on these exclusion criteria, a total of 310 patients were excluded, resulting in a final retrospective cohort study involving 900 patients. The screening process and participant flow are illustrated in the flow diagram (Figure 1a).

Diagnosis of UTI

Patients were diagnosed with urinary tract infections (UTIs) based on the guidelines provided by the Centers for Disease Control and Prevention[14]. The diagnostic criteria required the presence of at least one clinical symptom of UTI, including a fever exceeding 38°C, dysuria, increased urinary frequency, urgency, or suprapubic pain. Additionally, a positive urine culture (bacterial count > 105 CFU/mL) or a positive urine analysis (leukocyte esterase and nitrites detected in a midstream urine specimen) were considered. Two experienced urologists determined the final UTI diagnoses by evaluating the clinical manifestations and urine culture results. To develop a robust predictive model, we assembled a multidisciplinary team comprising physicians, biostatisticians and researchers with expertise in data analysis.

Data Collection

We collected data on 39 potential risk factors for urinary tract infections (UTIs) by reviewing relevant literature and clinical records from our institution[3,4]. Demographic factors included age, gender, smoking, alcohol use, history of urinary stones, bladder/ureteral diseases, urological surgery, and chronic steroid use. Comorbidities considered were hypertension, diabetes, COPD, cardiovascular disease, stroke, dementia, chronic liver disease, malignancy, and hospital

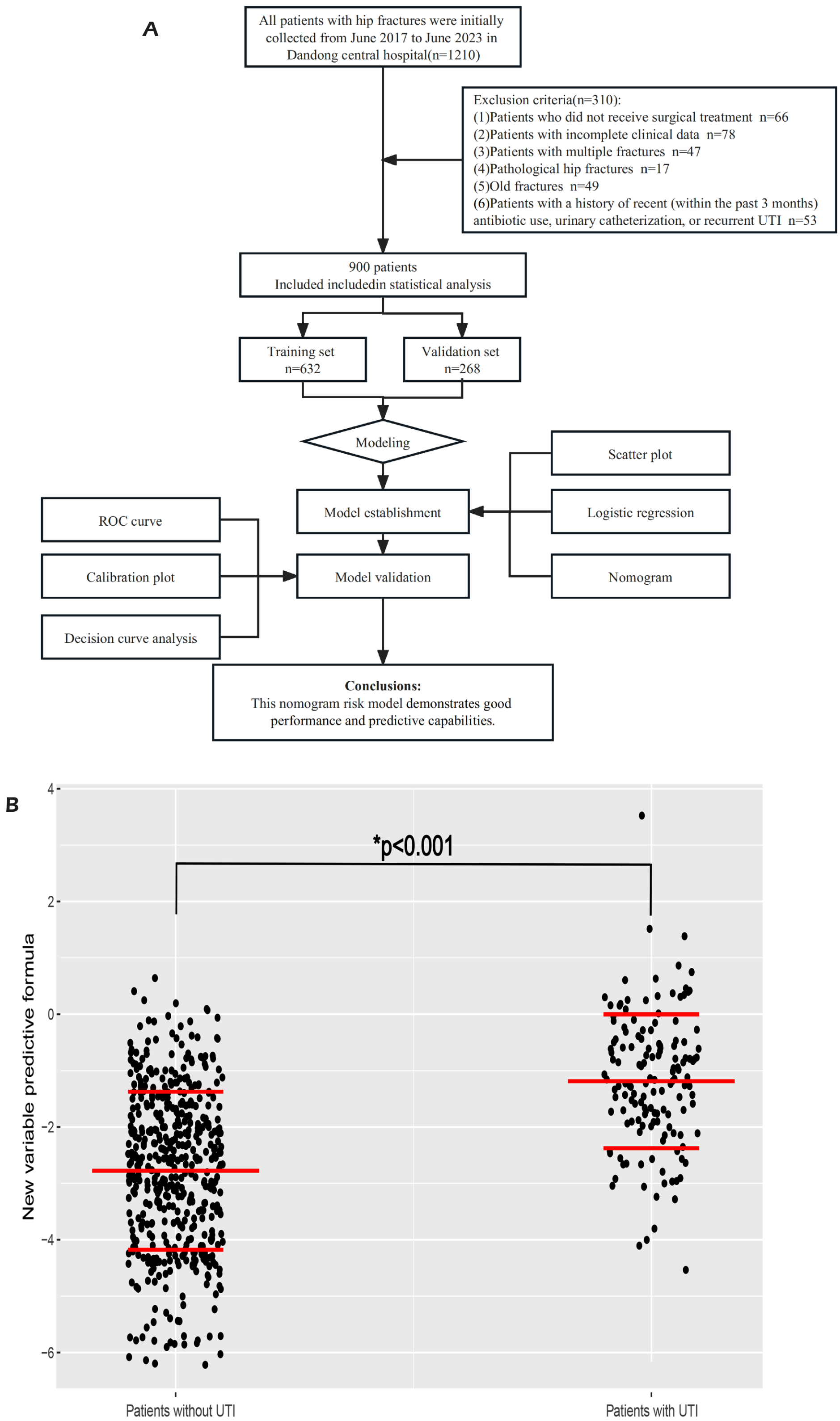

Figure 1. A, Flow diagram of study design. **B,** Scatter plot of the predicted values of the UTI group and the non-UTI group.

readmission. Injury variables encompassed fracture type, surgery type, admission time (from injury to admission), bedridden time (from admission to surgery), intraoperative blood loss, transfusion requirement, surgery duration, and postoperative ICU stay. Laboratory parameters, obtained within 24 hours of admission, included white blood cell count, neutrophil count, lymphocyte count, platelet count, D-dimer level, and blood glucose. Data retrieval from electronic medical records of orthopedic patients at Dandong Central Hospital was performed by three researchers (WYT, WY, QML), who were specifically trained in data collection.

Statistical Analysis

Categorical variables were presented as numbers and percentages (%) and compared using Chi-square tests. Continuous variables were assessed for normal distribution using the Shapiro-Wilk test. Normally distributed continuous data were expressed as mean ± standard deviation and analyzed using independent sample *t*-tests. Non-normally distributed continuous data were reported as median (interquartile range) and compared using the Mann-Whitney U test.

Univariate logistic regression analyses were performed to assess the association between each potential risk factor and UTI. Variables with a significance level of $p<0.05$ in the univariate analysis were included in the multivariate logistic regression analysis to identify possible predictors. Multicollinearity in the multivariate model was evaluated using variance inflation factors (VIFs). Based on the multivariate analysis, a predictive nomogram for UTI risk was developed using R software in the training set.

To evaluate the performance of the predictive model, we plotted the receiver operating characteristic (ROC) curve and calculated the area under the curve (AUC) to measure sensitivity and specificity. Calibration plots were also generated to examine the accuracy of the model's predictions. To determine if the predictive model improves forecasted net income, we assessed its clinical utility using decision curve analysis (DCA). Data analysis was conducted using SPSS version 26.0 (IBM Corp., Armonk, NY, USA) for statistical analysis and R version 4.0.3 (R Foundation for Statistical Computing, Vienna, Austria) for nomogram construction.

Results

Baseline Clinical and Demographic Characteristics of Patients

A total of 900 geriatric patients with hip fractures were enrolled in this study, with 261 males and 639 females. Among all the patients, 221 individuals (24.56%) experienced urinary tract infections (UTIs). The patients were randomly allocated using a 7:3 ratio, with 632 patients assigned to the training set and 268 patients assigned to the validation set. The baseline clinical and demographic characteristics of both sets were comparable, as shown in Table I. Furthermore, Table II provides the baseline characteristics of the UTI and non-UTI groups.

Independent Risk Factors in the Training Set

Univariate and multivariate logistic regression analyses revealed several independent risk factors for urinary tract infection (UTI) among geriatric patients with hip fractures. These factors included age ≥80 years, female gender, diabetes, fracture type, surgery type, bedridden time, blood glucose >6.10 mmol/L, albumin <35 g/L, and indwelling urinary catheter duration (Table III). The outcomes of the multivariate logistic regression analysis, including the intercept, β coefficient, and odds ratio, are presented in Table IV. The diagnosis for collinearity indicated that the variance inflation factors for these risk factors ranged from 1.125 to 1.227, signifying the absence of multicollinearity.

Nomogram Model Establishment

Based on a multivariate logistic regression analysis, we developed an individualized nomogram model to predict urinary tract infection (UTI) risk in elderly hip fracture patients. The nomogram model consists of 9 independent UTI risk factors, which are depicted in Figure 2a and 2b. Each factor in the nomogram is assigned a corresponding score, and the total score reflects the predicted UTI risk. For example, a 70-year-old female patient (24 points), without diabetes (8 points), with an albumin level of 30 g/L (17 points), normal admission blood glucose (14 points), a urinary catheter for 15 hours (35 points), bedridden for over 7 days (15 points), a femoral neck fracture (6 points), and underwent intramedullary nailing (9 points) would have a total score of 128 points, corresponding to a predicted UTI risk of 74%. Furthermore, a predictive

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

Variables	UTI Primary cohort (n = 632)	UTI Validation cohort (n = 268)	*p*-value
Demographic			
Age ≥ 80 (n, %)	249 (39.4)	93 (34.7)	0.184
Male gender (n, %)	230 (36.4)	101 (37.7)	0.713
Smoking (n, %)	101 (16.0)	47 (17.5)	0.565
Alcohol (n, %)	65 (10.3)	36 (13.4)	0.171
Hypertension (n, %)	349 (55.2)	166 (61.9)	0.062
Diabetes (n, %)	159 (25.2)	70 (26.1)	0.762
COPD (n, %)	76 (12.0)	29 (10.8)	0.607
Cardiovascular disease (n, %)	183 (29.0)	91 (34.0)	0.136
Stroke (n, %)	162 (25.6)	75 (28.0)	0.464
Dementia (n, %)	19 (3.0)	6 (2.2)	0.522
Chronic liver disease (n, %)	34 (5.4)	16 (6.0)	0.724
Tumor (n, %)	53 (8.4)	26 (9.7)	0.524
Chronic steroid use (n, %)	4 (0.6)	2 (0.7)	0.848
Readmission (n, %)	219 (34.7)	98 (36.6)	0.582
Type of fracture			
Femoral neck fracture (n, %)	330 (52.2)	131 (48.9)	0.123
Intertrochanteric fracture (n, %)	277 (43.8)	118 (44.0)	
Subtrochanteric fracture (n, %)	25 (4.0)	19 (7.1)	
Type of surgery			
Total hip arthroplasty (n, %)	89 (14.1)	41 (15.3)	0.339
Hemiarthroplasty (n, %)	166 (26.3)	61 (22.8)	
Intramedullary nail (n, %)	265 (41.9)	111 (41.4)	
Plate/screw (n, %)	35 (5.5)	24 (9.0)	
Multiple screws (n, %)	77 (12.2)	31 (11.6)	
Operation surgery			
Admission time			
< 6 hours (n, %)	320 (50.9)	150 (56.0)	0.099
6-24 hours (n, %)	108 (17.1)	31 (11.5)	
> 24 hours (n, %)	202 (32.0)	87 (32.5)	
Bedridden time			
< 4 days (n, %)	180 (28.5)	59 (22.0)	0.084
4-7 days (n, %)	342 (54.1)	56.3 (56.3)	
> 7 days (n, %)	110 (17.4)	58 (21.6)	
Blood lost during surgery, ×ml [median (IQR)]	120.00 (111.75)	120.00 (114.75)	0.088
Transfusion (n, %)	100 (15.8)	53 (19.8)	0.149
Surgery time, ×hour [median (IQR)]	1.42 (0.66)	1.50 (0.83)	0.062
Postoperative ICU (n, %)	12 (1.9)	7 (2.6)	0.496
ASA			
III-V (n, %)	384 (60.8)	163 (60.8)	0.986
I-II (n, %)	248 (39.2)	105 (39.2)	
Laboratory findings			
WBC level, ×10^9/L [median (IQR)]	8.50 (3.50)	8.60 (3.78)	0.572
LYM count, ×10^9/L [median (IQR)]	1.20 (0.70)	1.20 (0.60)	0.276
PLT count, ×10^9/L [median (IQR)]	194.00 (86.75)	193.50 (85.50)	0.982
HGB level, ×g/L [median (IQR)]	121.00 (25.00)	121.00 (28.75)	0.901
Cr , ×µmol/L [median (IQR)]	61.00 (25.75)	61.00 (23.75)	0.729
BUN/Cr, [median (IQR)]	0.11 (0.06)	0.10 (0.05)	0.140
UA,× mmol/L [median (IQR)]	285.00 (132.75)	278.50 (134.25)	0.249
Cholesterol,× mmol/L [median (IQR)]	4.56 (1.50)	4.46 (1.55)	0.400
ALB < 35 g/L (n, %)	123 (19.5)	57 (21.3)	0.536
Blood glucose > 6.10 mmol/L (n, %)	307 (48.6)	140 (52.2)	0.315
Urinary system			
Chronic kidney disease (n, %)	38 (6.0)	15 (5.6)	0.809
History of urinary tract stones (n, %)	12 (1.9)	5 (1.9)	0.973
History of bladder ureteral disease (n, %)	31 (4.9)	13 (4.9)	0.972
History of urological surgery (n, %)	27 (4.3)	8 (3.0)	0.361
Indwelling urinary catheter (n, %)	319 (50.5)	137 (51.1)	0.860
Urinary catheter indwelling time,× hour [median (IQR)]	0 (2)	2 (6)	0.577

The *p*-value indicates whether the difference between two sets of data for a certain indicator is statistically significant. Abbreviations: UTI, urinary tract infection; IQR, Interquartile Range; COPD, Chronic Obstructive Pulmonary Disease; ICU, Intensive Care Unit; ASA, American Society of Anesthesiologists physical status classification; WBC, White blood cell; LYM: Lymphocyte; PLT, Platelet; HGB, Hemoglobin; Cr, Creatinine; BUN/Cr: Blood Urea Nitrogen to Creatinine ratio; UA: Uric Acid; ALB: Albumin.

Table II. Baseline clinical and demographic characteristics of the training set in patients without and with UTI.

Variables	UTI		*p*-value
	Patients without UTI (n = 486)	Patients with UTI (n = 146)	
Demographic			
Age ≥ 80 (n, %)	165 (34.0)	84.00 (57.5)	< 0.001
Male gender (n, %)	202 (41.6)	28 (19.2)	< 0.001
Smoking (n, %)	85 (17.5)	16 (11.0)	0.059
Alcohol (n, %)	56 (11.5)	9 (6.2)	0.062
Hypertension (n, %)	251 (51.6)	98 (67.1)	0.001
Diabetes (n, %)	94 (19.3)	65 (44.5)	< 0.001
COPD (n, %)	52 (10.7)	24 (16.4)	0.062
Cardiovascular disease (n, %)	126 (25.9)	57 (39.0)	0.002
Stroke (n, %)	112 (23.0)	50 (34.2)	0.007
Dementia (n, %)	14 (2.9)	5 (3.4)	0.736
Chronic liver disease (n, %)	24 (4.9)	10 (6.8)	0.369
Tumor (n, %)	45 (9.3)	8 (5.5)	0.148
Chronic steroid use (n, %)	4 (0.8)	0 (0)	0.271
Readmission (n, %)	162 (33.3)	57 (39.0)	0.204
Type of fracture			
Femoral neck fracture (n, %)	269 (55.3)	61 (41.8)	0.010
Intertrochanteric fracture (n, %)	197 (40.5)	80 (54.8)	
Subtrochanteric fracture (n, %)	20 (4.1)	5 (3.4)	
Type of surgery			
Total hip arthroplasty (n, %)	67 (13.8)	22 (15.1)	< 0.001
Hemiarthroplasty (n, %)	130 (26.7)	36 (24.7)	
Intramedullary nail (n, %)	187 (38.5)	78 (53.4)	
Plate/screw (n, %)	28 (5.8)	7 (4.8)	
Multiple screws (n, %)	74 (15.2)	3 (2.1)	
Operation surgery			
Admission time			
< 6 hours (n, %)	247 (50.8)	75 (51.4)	0.649
6-24 hours (n, %)	80 (16.5)	28 (19.2)	
> 24 hours (n, %)	159 (32.7)	43 (29.5)	
Bedridden time			
< 4 days (n, %)	155 (31.9)	25 (17.1)	< 0.001
4-7 days (n, %)	261 (53.7)	81 (55.5)	
> 7 days (n, %)	70 (14.4)	40 (27.4)	
Blood lost during surgery, ×ml [median (IQR)]	113.00 (124.00)	120.00 (100.00)	0.026
Transfusion (n, %)	65 (13.4)	35 (24.0)	0.002
Surgery time, ×hour [median (IQR)]	1.42 (0.69)	1.42 (0.80)	0.365
Postoperative ICU (n, %)	3 (0.6)	9 (6.2)	< 0.001
ASA			
III-V (n, %)	283 (58.2)	101 (69.2)	0.018
I-II (n, %)	203 (41.8)	45 (30.8)	
Laboratory findings			
WBC level, $\times 10^9$/L [median (IQR)]	8.40 (3.53)	8.85 (3.53)	0.029
LYM count, $\times 10^9$/L [median (IQR)]	1.20 (0.70)	1.10 (0.70)	0.010
PLT count, $\times 10^9$L [median (IQR)]	196.50 (88.00)	191.50 (83.25)	0.689
HGB level, ×g/L [median (IQR)]	121.00 (24.00)	117.00 (25.50)	0.001
Cr, ×µmol/L [median (IQR)]	61.00 (23.25)	61 (37.00)	0.622
BUN/Cr, [median (IQR)]	0.11 (0.05)	0.12 (0.06)	0.001
UA,× mmol/L [median (IQR)]	284.50 (126.00)	288.00 (146.00)	0.605
Cholesterol, ×mmol/L [median (IQR)]	4.57 (1.49)	4.50 (1.51)	0.777
ALB < 35 g/L (n, %)	81 (16.7)	42 (28.8)	0.001
Blood glucose > 6.10 mmol/L (n,%)	198 (40.7)	109 (74.7)	< 0.001
Urinary system			
Chronic kidney disease (n, %)	21 (4.3)	17 (11.6)	0.001
History of urinary tract stones (n, %)	5 (1.0)	7 (4.8)	0.003
History of bladder ureteral disease (n, %)	16 (3.3)	15 (10.3)	0.001
History of urological surgery (n, %)	18 (3.7)	9 (6.2)	0.197
Indwelling urinary catheter (n, %)	219 (45.1)	100 (68.5)	< 0.001
Urinary catheter indwelling time, ×hour [median (IQR)]	0 (2.00)	2.00 (6.00)	< 0.001

The *p*-value indicates whether the difference between two sets of data for a certain indicator is statistically significant. Abbreviations: UTI, urinary tract infection; IQR, Interquartile Range; COPD, Chronic Obstructive Pulmonary Disease; ICU, Intensive Care Unit; ASA, American Society of Anesthesiologists physical status classification; WBC, White blood cell; LYM: Lymphocyte; PLT, Platelet; HGB, Hemoglobin; Cr, Creatinine; BUN/Cr: Blood Urea Nitrogen to Creatinine ratio; UA: Uric Acid; ALB: Albumin.

Table III. Univariate and Multivariate analysis of UTI in the training set.

Characteristics	Univariate			Multivariate		
	OR	95% CI	*p*-value	OR	95% CI	*p*-value
Age ≥ 80	2.64	1.81-3.85	< 0.001	1.88	1.14-3.10	0.013
Male gender	0.33	0.21-0.52	< 0.001	0.23	0.12-0.43	< 0.001
Smoking	0.58	0.33-1.03	0.061	1.84	0.74-4.60	0.189
Alcohol	0.50	0.24-1.05	0.066	1.16	0.37-3.64	0.799
Hypertension	1.91	1.30-2.82	0.001	0.90	0.55-1.49	0.684
Diabetes	3.35	2.25-4.98	< 0.001	2.24	1.35-3.69	0.020
COPD	1.64	0.97-2.77	0.064	0.97	0.49-1.91	0.928
Cardiovascular disease	1.83	1.24-2.70	0.002	1.22	0.74-2.02	0.429
Stroke	1.74	1.16-2.60	0.007	1.33	0.80-2.20	0.274
Dementia	1.20	0.42-3.38	0.736	NA	NA	NA
Chronic liver disease	1.42	0.66-3.03	0.372	NA	NA	NA
Tumor	0.57	0.26-1.23	0.153	NA	NA	NA
Chronic steroid use	0.00	0.00-NA	0.999	NA	NA	NA
Readmission	1.28	0.87-1.88	0.204	NA	NA	NA
Type of fracture	0.68	0.50-0.94	0.018	0.44	0.25-0.79	0.005
Type of surgery	0.80	0.68-0.95	0.010	0.64	0.46-0.91	0.012
Admission time	0.95	0.77-1.17	0.65	NA	NA	NA
Bedridden time	1.88	1.41-2.50	< 0.001	1.42	1.02-2.02	0.049
Blood lost during surgery, ×ml	1.00	1.00-1.00	0.314	NA	NA	NA
Transfusion	2.04	1.29-3.24	0.002	0.90	0.49-1.68	0.748
Surgery time, ×hour	1.13	0.86-1.47	0.392	NA	NA	NA
Postoperative ICU	10.57	2.82-39.60	< 0.001	4.08	0.84-19.80	0.081
ASA	1.61	1.09-2.39	0.018	0.70	0.42-1.17	0.174
WBC count, $\times 10^9$/L	1.09	1.02-1.16	0.010	1.03	0.95-1.12	0.477
LYM count , $\times 10^9$/L	0.61	0.42-0.89	0.010	0.77	0.49-1.21	0.255
PLT count, $\times 10^9$/L	1.00	0.99-1.00	0.858	NA	NA	NA
HGB count, ×g/L	0.98	0.98-0.99	0.001	1.00	0.99-1.01	0.831
Cr, ×μmol/L	1.00	1.00-1.00	0.591	NA	NA	NA
BUN/Cr	5.55	0.49-63.04	0.167	NA	NA	NA
UA, × mmol/L	1.00	1.00-1.00	0.179	NA	NA	NA
Cholesterol, × mmol/L	1.02	0.87-1.20	0.824	NA	NA	NA
ALB < 35 g/L	2.02	1.31-3.11	0.001	2.02	1.16-3.52	0.013
Blood glucose > 6.10 mmol/L	4.29	2.83-6.49	< 0.001	2.83	1.68-4.77	< 0.001
Chronic kidney disease	2.92	1.50-5.70	0.002	2.20	0.91-5.32	0.079
History of urinary tract stones	4.85	1.51-15.50	0.008	1.52	0.29-7.94	0.623
History of bladder ureteral disease	3.36	1.62-6.98	0.001	1.36	0.45-4.05	0.585
History of urological surgery	1.71	0.75-3.89	0.202	NA	NA	NA
Indwelling urinary catheter	2.65	1.79-3.92	< 0.001	1.49	0.83-2.67	0.185
Urinary catheter indwelling time, ×hour	1.22	1.15-1.29	< 0.001	1.13	1.04-1.23	0.003

Univariate analysis *p*-value: Indicates whether the correlation between each variable and UTI is statistically significant. $p < 0.10$ suggests the variable is a potential risk factor for UTI. Multivariate analysis p-value: In the multivariate logistic regression model, *p*-value determines whether the relationship between each independent variable and UTI is statistically significant after controlling for other variables. $p < 0.05$ indicates the variable is independently associated with UTI.

formula was created based on regression coefficients and constants: logit(p) = -0.924 + 0.631 * age – 1.462 * gender + 0.805 * diabetes – 0.813 * fracture type – 0.441 * surgery type + 0.353 * bedridden time + 1.041 * blood glucose + 0.703 * albumin + 0.123 * urinary catheter time. The input of original data produced the scatter plot shown in Figure 1b. Predicted values significantly differed between the UTI (-1.19 ± 1.19) and non-UTI groups (-2.77 ± 1.40) ($p<0.001$).

Nomogram Model Validation

The AUC of the nomogram was 0.829 and 0.803 in the training and validation sets, respectively, as shown in Figure 3a and 3b. Furthermore, the nomogram ROC curve exhibited higher values compared to individual risk factors, as displayed in Figure 3c. The nomogram demonstrated greater net benefit compared to non-intervention across threshold probabilities ranging from 2% to 80% in the training

Table IV. Multivariate Analysis of UTI in Geriatric Patients with Hip Fractures in the training set.

Risk factor	β	SE	Wald	OR	95% CI	*p*-value
Age ≥ 80	0.631	0.255	6.134	1.88	1.14-3.10	0.013
Male gender	-1.462	0.318	21.144	0.23	0.12-0.43	< 0.001
Diabetes	0.805	0.256	9.865	2.24	1.35-3.69	0.020
Type of fracture	-0.813	0.293	7.712	0.44	0.25-0.79	0.005
Type of surgery	-0.441	0.176	6.246	0.64	0.46-0.91	0.012
Bedridden time	0.353	0.179	3.888	1.42	1.02-2.02	0.049
Blood glucose > 6.10 mmol/L	1.041	0.266	15.271	2.83	1.68-4.77	< 0.001
ALB < 35 g/L	0.703	0.283	6.176	2.02	1.16-3.52	0.013
Urinary catheter indwelling time	0.123	0.042	8.824	1.13	1.04-1.23	0.003

β, beta; SE, standard error; Wald: Wald statistic; OR, odds ratio; CI, confidence interval; UTI, urinary tract infection; ALB: Albumin; The p-value is used to determine whether the relationship between each independent variable and UTI is statistically significant.

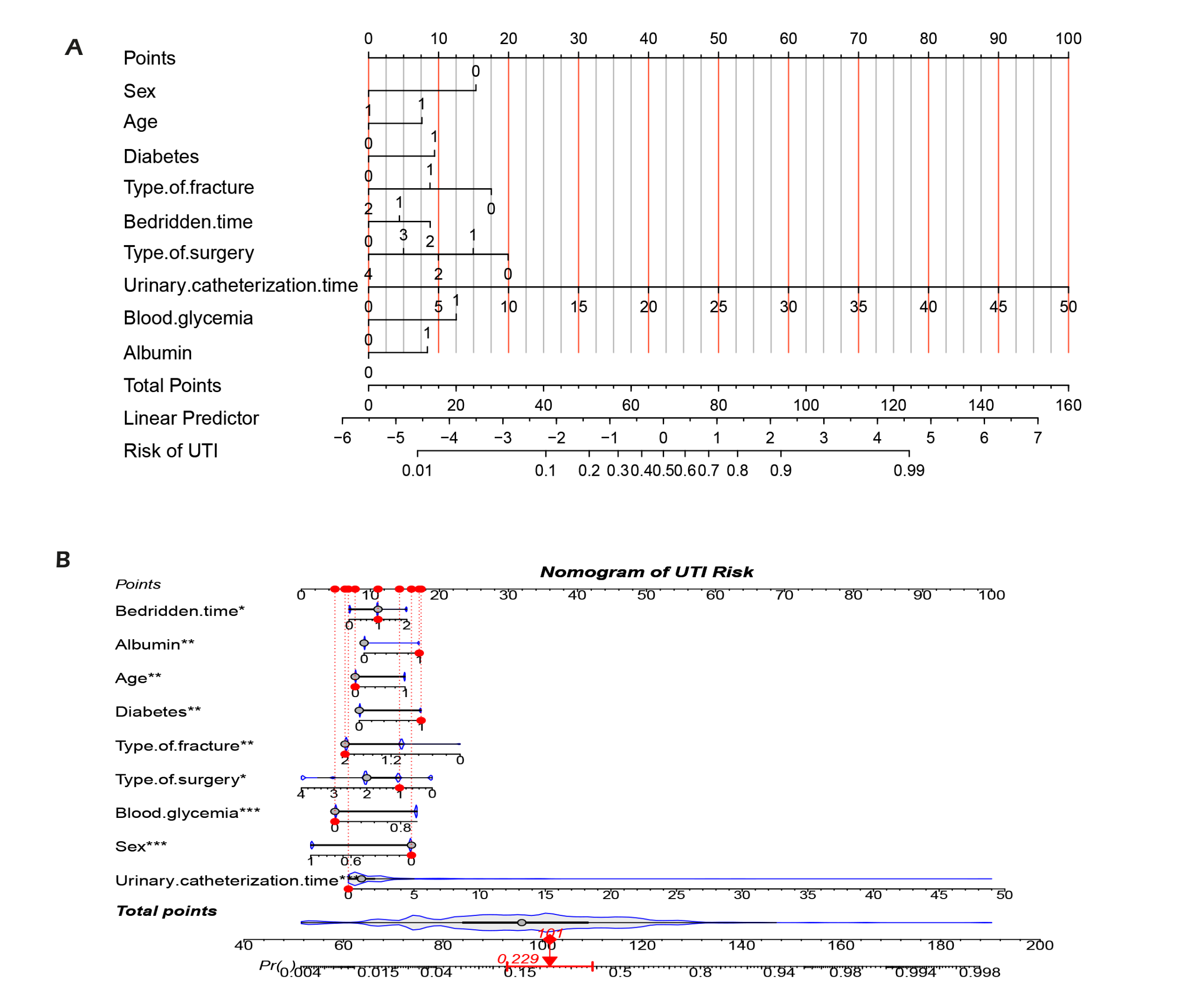

Figure 2. Nomogram for predicting UTI in geriatric patients with hip fracture. **A**, Nine variables were included in the nomogram prediction model, namely: age ≥80 years, female gender, diabetes, fracture type, surgery type, prolonged bedrest, hyperglycemia, hypoalbuminemia, and Urinary catheter indwelling time. **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.

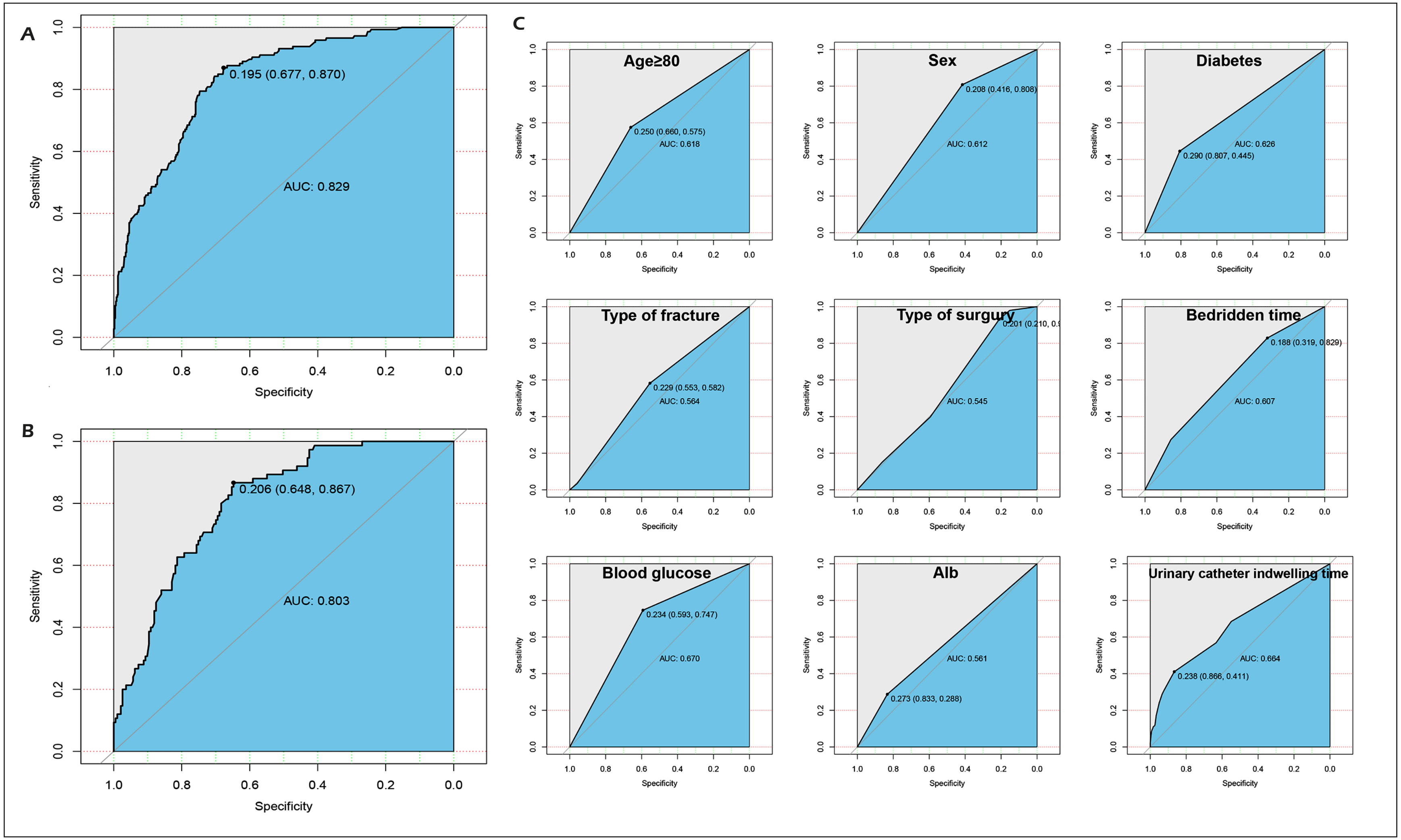

Figure 3. Receiver operating characteristic curves of the training set (**A**) and validation set (**B**). The area under the csurve (AUC) was positively correlated with the predictive accuracy of the nomogram. **C,** The ROC curve of nine independent risks factors.

set and from 2% to 76% in the validation set. The decision curve analysis illustrates that the nomogram consistently offered a superior net benefit in comparison to no assessment across a broad range of threshold probabilities, as depicted in Figure 4a and 4c. The calibration plots (Figure 4b and 4d) exhibited a strong agreement between the predicted and observed probabilities. The Hosmer-Lemeshow test (χ^2=13.243, df=8, p=0.1038) indicated no significant difference between the predicted and observed values, thereby suggesting good predictive efficacy and model fitness. The nomogram's C-index was 0.829 (95% CI, 0.758-0.900), indicating excellent discriminatory ability. Taken together, these metrics validate the nomogram's accurate prediction of UTI risk in elderly hip fracture patients. The nomogram demonstrates robust discriminatory power and predictive performance. This highlights its dependability as a useful clinical tool.

Discussion

Urinary tract infection (UTI) is a frequent complication in elderly patients with hip fractures and can greatly impact their rehabilitation and prognosis[7]. The occurrence of UTIs is influenced by several factors. Firstly, invasive procedures, such as catheterization during surgery increase the risk of UTI[15]. Secondly, urinary obstruction and retention facilitate bacterial colonization and proliferation, leading to infection[8]. Additionally, the elderly population has weakened immunity and often presents with comorbidities, making them more susceptible to infections[16]. Therefore, timely identification and intervention for UTIs are critically important in managing these patients.

To investigate the prediction of UTI risk, we conducted a retrospective study involving a large number of elderly hip fracture patients. Using the collected clinical data, we developed a nomogram that incorporates multiple clinical

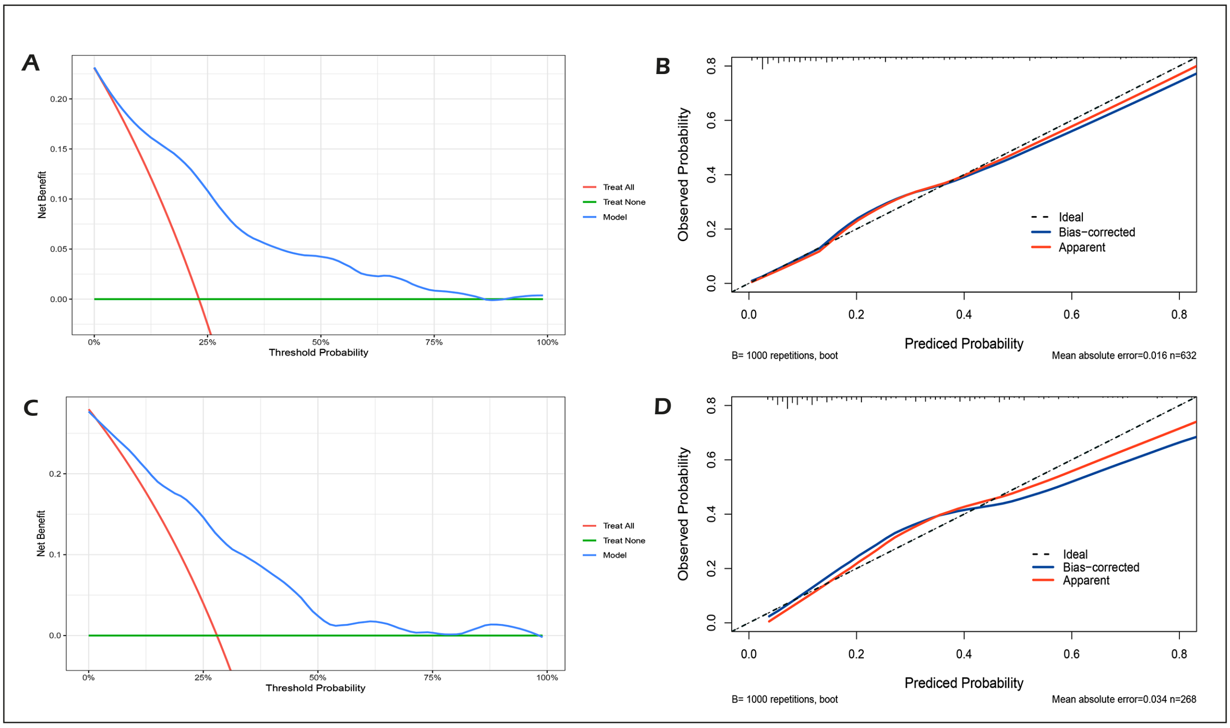

Figure 4. Decision curve analysis of the nomogram in the training set (**A**) and validation set (**C**). The blue line displays the net benefit of our model. The red line assumes that all patients develop UTIs. The green line assumes that no patients develop UTI. Calibration plot of the nomogram in the training (**B**) 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.

and laboratory parameters reflecting the key factors in UTI pathogenesis. Through statistical analysis and multivariate logistic regression, we determined weighted coefficients for nine variables: age ≥80, sex, diabetes, fracture type, surgery type, bedridden time, blood glucose >6.10 mmol/L, albumin <35 g/L, and catheter indwelling time. By incorporating these variables and coefficients, we created a simplified and intuitive nomogram-based risk assessment tool. Internal and external validation of the nomogram demonstrated its good accuracy and stability in predicting UTIs. Furthermore, when compared to conventional approaches, the nomogram showed superior discrimination in identifying individuals at high risk.

Age and Sex

Our study identified advanced age (≥80 years) and female sex as significant risk factors for UTIs in geriatric patients with hip fractures. As individuals age, their immune function declines, making them more vulnerable to infections[16]. Additionally, age-related changes in bladder capacity, incomplete voiding, and urinary stasis can promote bacterial colonization and the development of UTIs[17].

Furthermore, our analysis revealed that female sex is a prominent risk factor for UTIs within this cohort. Female patients faced a significantly higher risk of UTIs compared to males. This observation aligns with established anatomical differences between sexes, as the shorter urethral length in females enables easier bacterial entry and increases susceptibility to UTIs[18]. Moreover, hormonal fluctuations unique to females may also contribute to the elevated risk of UTIs[19]. Numerous studies have reported that sex and age are independent risk factors for UTIs, with Lin et al[3] specifically noting a significantly increased risk in female and geriatric patients.

In summary, advanced age and female sex are major risk factors for UTIs in geriatric patients with hip fractures. As the population ages, the incidence of hip fractures rises, imposing an increased risk for UTIs in elderly female patients. Taking appropriate preventive measures in this population is crucial to effectively reduce the incidence of UTIs and improve prognosis.

Diabetes

Diabetes mellitus (DM) increases susceptibility to UTIs through multiple mechanisms. This association can be attributed to chronic hyperglycemia, which induces microvascular complications leading to ischemic bladder and urethral damage. Consequently, voiding function and urinary clearance are impaired[20]. In addition, the presence of glycosuria in DM creates a favorable growth environment for uropathogens in the urinary tract[21]. Moreover, hyperglycemia hampers leukocyte function and weakens the immune defenses against bacteria. The development of diabetic cystopathy further elevates UTI risk as it results in incomplete bladder emptying, urinary stasis, and residuals[22].

Numerous studies have demonstrated a higher prevalence of UTIs in patients with DM. For example, Aswani et al[23] reported a high greater incidence of UTIs in diabetic women compared to non-diabetic women. Nitzan et al[24] observed an increased risk of UTIs in both type 1 and type 2 DM[25]. Additionally, Nanayakkara et al[26] found that a longer duration of DM was associated with a higher susceptibility to UTIs. Collectively, these studies provide strong epidemiological evidence to support DM as a significant independent risk factor for UTIs.

Type of Fracture

Our study revealed significant variations in the risk of developing UTIs among different types of hip fractures. Particularly, our findings indicated that femoral neck fractures had a considerably lower incidence of UTIs after surgery compared to proximal femoral fractures. This observation is consistent with a study by Fischer et al[27], who also noted lower UTI rates in patients with femoral neck fractures compared to those with proximal femoral fractures. Several factors may contribute to these differences. Firstly, cervical fractures are relatively closed fractures with smaller surgical incisions and therefore, have a lower risk of infection. Furthermore, the use of screw fixation in cervical fractures causes less trauma, enabling early mobilization and aiding in the recovery of bladder function. In contrast, proximal femoral fractures require extensive soft tissue dissection, which delays mobilization and increases the risk of UTIs. Additionally, the implants used for proximal femoral fractures also elevate the risk of infection[28].

Type of Surgery

Different surgical approaches are associated with varying probabilities of UTIs in this study. Specifically, total hip replacement (THR) is significantly linked to a higher UTI risk compared to intramedullary (IM) nailing. There are several reasons for this disparity. Firstly, THR necessitates more extensive tissue dissection and causes greater surgical trauma. Additionally, prolonged bed rest following THR can delay mobilization and hinder bladder emptying. The use of hip implants further increases the risk of implant-associated infections, and the use of cement during THR can contribute to inflammation. In addition, Basile et al[29] found that the occurrence of prosthetic joint infections is due to bacteria adhering to the prosthetic surface through mechanisms, such as biofilm formation, coupled with the characteristics of the prosthetic material itself, as well as patients' existing immunodeficiency, diabetes, obesity, chronic renal insufficiency and other systemic diseases that can reduce the host's resistance, and the complex interplay of factors, such as surgical contamination. In contrast, the minimal invasiveness of IM nailing enables early mobilization and facilitates bladder recovery, ultimately reducing the risk of UTIs[30,31]. In line with prior research, a study conducted by Rodrigue et al[32] also found that patients undergoing THR had a significantly higher incidence of UTIs compared to those treated with IM nailing. The consistency between our findings and previous research bolsters the reliability of our study's results.

Bedridden Time

In multivariable analysis, prolonged bedridden time (>7 days) emerged as an independent risk factor for UTIs, particularly among elderly patients with hip fractures. Extended bedridden periods can result in urinary stasis, incomplete bladder emptying, and urinary retention in these individuals. Multiple factors contribute to this, including decreased bladder tone, alterations in urinary flow, and impaired mobility. Furthermore, recumbency amplifies mechanical compression of the urinary tract and compromises hygiene, creating an environment conducive to bacterial colonization, growth, and subsequent UTIs. Our findings align with previous studies[33-35] conducted on orthopedic surgery patients, highlighting an increased UTI risk associated with prolonged bedridden time. However, the specific association between bedridden time and UTIs in hip fracture patients has not been extensively evaluated. Our study provides evidence that limiting immobilization could effectively reduce the risk of UTIs in this vulnerable population. Consequently, implementing early mobilization protocols and rehabilitation interventions may be justified for hip fracture patients.

Blood Glucose >6.10 mmol/L

This study has identified hyperglycemia (>6.10 mmol/L) as an independent risk factor for UTIs in geriatric patients with hip fractures. The multivariable analysis demonstrated significantly higher odds of UTIs in the presence of hyperglycemia. Several mechanisms may contribute to this association in this susceptible population. Hyperglycemia induces osmotic diuresis, resulting in increased urine output and frequency. This can lead to urinary stasis and incomplete emptying, creating an environment conducive to bacterial proliferation in residual urine[36]. Hyperglycemia also impairs neutrophil function, negatively affecting the immune response against urinary pathogens[22]. Furthermore, the acidic environment of the urine promotes bacterial growth. At the cellular level, hyperglycemia disrupts the glycosaminoglycan layer, which possesses antibacterial properties[37].

Previous studies have demonstrated that poor glycemic control increases the risk of postoperative infections, including UTIs, in diabetic patients undergoing orthopedic procedures[11]. Our findings extend this evidence specifically to elderly patients with hip fractures. Therefore, strict glycemic management during the perioperative period may be necessary to reduce the risk of UTIs in this vulnerable population. Nonetheless, larger prospective studies are needed to establish optimal glycemic targets for preventing UTIs in geriatric patients with hip fractures.

Albumin <35 g/L

Our study has identified hypoalbuminemia as an independent predictor of UTIs in geriatric patients with hip fractures. Hypoalbuminemia serves as an indicator of poorer health and compromises the immune system, making individuals more susceptible to infections. Albumin plays a vital role in exerting antioxidative effects and binding pathogens and toxins, thereby reducing humoral defenses against UTIs. Additionally, albumin helps maintain proper oncotic pressure, preventing fluid extravasation that could impede urine flow and heighten the risk of UTIs[38]. Furthermore, albumin is involved in drug transport and metabolism, and hypoalbuminemia may increase the free fraction of antibiotics, thereby reducing their efficacy against urinary pathogens[39].

While previous studies have recognized the association between hypoalbuminemia and surgical infections, as well as sepsis, few have specifically investigated its impact on UTIs[40]. Our study yields preliminary evidence suggesting that low albumin levels may increase susceptibility to UTIs in frail geriatric patients with hip fractures through multiple mechanisms. However, prospective studies are necessary to validate our findings and assess whether albumin supplementation could potentially reduce the incidence of UTIs in this vulnerable population.

Urinary Catheter Indwelling Time

This study has revealed that the duration of indwelling urinary catheterization is a significant predictor of UTIs. Catheterization compromises the host's natural defenses and provides a direct pathway for bacteria to enter the bladder. The surface of the catheter promotes the formation of biofilms, which protect the organisms from antibiotics and immune responses[41]. Prolonged catheter retention leads to urine stasis, causing bladder distension and mucosal irritation[42]. Additionally, the catheter itself can cause mechanical trauma to the urethra. These effects disrupt the bladder's mucosal integrity and increase vulnerability to UTIs[15].

Previous research consistently supports urinary catheterization as the primary risk factor for nosocomial UTIs[9,15]. However, the optimal catheterization duration and related UTI risk in elderly hip fracture patients remain unclear. Our findings indicate that a reduction in the duration of indwelling catheters may result in a lower incidence of UTIs in this specific population. Moreover, exploring alternatives, such as intermittent catheterization should be considered.

Limitations

Nomograms are increasingly utilized as novel noninvasive visualization tools for clinical prediction modeling. In this study, we have developed and validated a nomogram specifically designed for individualized prediction of urinary tract infection (UTI) risk in geriatric patients with hip fractures, using readily available admission variables. The nomogram was derived from a training cohort and demonstrated favorable discrimination and calibration when validated in an independent cohort. Unlike traditional models focused on laboratory parameters, this nomogram incorporates routine clinical data that can be easily obtained upon presentation. By providing a quantitative estimation of UTI risk, it enables clinicians to stratify patients at the time of admission and guide targeted preventive interventions for individuals at high risk. Consequently, this model serves as an effective clinical decision aid to facilitate precision prevention of UTIs within this vulnerable population.

However, it is important to acknowledge the limitations of this study. Firstly, it was conducted at a single center, potentially limiting the generalizability of our findings to other populations and healthcare settings. Secondly, the retrospective design introduces a potential for bias and restricts the ability to establish causal relationships between the identified risk factors and the occurrence of UTIs. Thirdly, although the nomogram model displayed good discrimination and predictive performance, it was solely validated within the derivation cohort utilized for its development. Consequently, external validation using independent datasets is necessary to confirm the generalizability of the model. Fourthly, the decision curve analysis suggests that the logistic regression model for predicting UTIs may be beneficial for patients. However, the actual clinical utility in improving treatment decisions and patient outcomes requires further evaluation.

Conclusions

In this study, we have created and validated a nomogram tailored to predict the risk of urinary tract infection (UTI) in geriatric patients with hip fractures on an individual basis. The nomogram exhibited strong discrimination and calibration, underscoring its reliability in risk prediction. This tool facilitates the early identification of high-risk patients, enabling targeted preventive interventions. By utilizing this nomogram, we can effectively decrease both the occurrence of UTIs and the associated complications.

Conflict of Interest

The authors declare that they have no conflict of interests.

Authors' Contribution

Study concept: RJH and DWB. Study design: All authors. Acquisition, analysis, or interpretation of data: WW, QML, and WY. urinary tract infection diagnosis: JXY and XPD. Statistical analysis: WYT. Drafting of the manuscript: WYT and WW. Critical revision of the manuscript for important intellectual content: All authors.

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None.

Ethics Approval

The Institutional Review Board of Dandong Central Hospital approved the study (No. DDZX-202304030), which followed the principles of the Declaration of Helsinki of 1964 and its later amendments.

Availability of Data and Materials

All data can be obtained from the corresponding author by reasonable request.

Informed Consent

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

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