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Original Article

Development and validation of nomogram models for predicting urinary incontinence following radical prostatectomy in high-risk prostate cancer patients

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Abstract: Objective: To develop a risk stratification model for predicting urinary incontinence following radical prostatectomy (RP) in high-risk prostate cancer patients based on their clinicopathological characteristics. Methods: A retrospective analysis was conducted on 520 prostate cancer patients who underwent RP between January 2016 and January 2024. Baseline characteristics, pathological data, laboratory parameters, and surgery-related factors were collected. Urinary continence status at 1, 3, and 6 months postoperatively was assessed. Multivariate logistic regression analyses were performed to identify independent risk factors, and nomograms were constructed to predict urinary incontinence risk at each time point. Results: Urinary incontinence rates at 1, 3, and 6 months postoperatively were 92.88%, 69.62%, and 23.65%, respectively. At 1 month, a higher Gleason score (OR=2.178, P=0.003) was a risk factor, while robot-assisted surgery was protective (OR=0.289, P=0.003). At 3 months, higher Gleason score (OR=1.565, P=0.004) increased risk, whereas lower BMI (<25 kg/m^2) (OR=0.448, P=0.005) and longer preoperative membranous urethral length (≥14 mm) (OR=2.368, P<0.001) were protective. At 6 months, shorter membranous urethral length (<14 mm) (OR=3.622, P<0.001), neoadjuvant hormone therapy (OR=5.783, P<0.001), and higher Gleason score (OR=2.824, P<0.001) were risk factors, while lower BMI (OR=0.317, P<0.001), smaller prostate volume (<40 mL) (OR=0.591, P=0.044), and lower CONUT score (<4) (OR=0.372, P<0.001) were protective. The nomograms showed good predictive performance, with AUCs of 0.679 at 3 months and 0.818 at 6 months. Conclusions: The developed nomograms effectively stratify the risk of urinary incontinence following RP in high-risk patients, facilitating individualized perioperative management and rehabilitation strategies.

Keywords: Prostate cancer, radical prostatectomy, urinary incontinence, risk factors, nomogram, prediction model, risk stratification

Introduction

Prostate cancer is among the most common malignancies in men, with its incidence steadily rising worldwide, particularly in Western countries. In China, the prevalence is also increasing due to lifestyle changes, an aging population, and advancements in diagnostic methods such as prostate-specific antigen (PSA) screening, posing a significant public health challenge [1-3]. For patients with localized prostate cancer, radical prostatectomy (RP) remains a widely accepted treatment aimed at achieving oncological cure through complete removal of the prostate gland [4]. Although RP improves long-term survival, it is frequently associated with postoperative complications, particularly urinary incontinence, which significantly impairs patients' quality of life [5, 6].

Urinary incontinence is a common and distressing complication after RP, resulting from damage to the urethral sphincter, pelvic floor structures, and neurovascular bundles during surgery [7]. Stress urinary incontinence, characterized by involuntary leakage during activities that increase abdominal pressure such as coughing or sneezing, is particularly prevalent [8]. This condition not only causes physical discomfort but also leads to psychological dis-

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tress, with studies reporting elevated rates of anxiety, depression, and social withdrawal among affected patients [9, 10]. For some, chronic incontinence may persist long-term, severely affecting both physical and mental health, and often necessitating interventions such as artificial urinary sphincter implantation [11, 12]. While continence typically improves over time in many patients, a subset continues to experience long-term incontinence, highlighting the need for early prediction and targeted intervention.

Previous studies have identified various risk factors for post-RP urinary incontinence, including baseline patient characteristics (e.g. age, BMI), tumor-related factors (e.g. PSA level, Gleason score), and surgical factors (e.g. surgical approach, membranous urethral length, prostate volume, nerve-sparing techniques, and neoadjuvant hormone therapy) [13, 14]. Intraoperative blood loss has also been associated with delayed continence recovery, potentially reflecting increased surgical complexity and trauma [15]. Furthermore, technical details such as bladder neck size may influence postoperative continence, underscoring the importance of surgical precision [16]. However, existing predictive models typically focus on continence outcomes at a single postoperative time point, overlooking the dynamic recovery process that unfolds over several months.

This study aimed to retrospectively analyze data from prostate cancer patients undergoing RP to identify independent risk factors for urinary incontinence at 1, 3, and 6 months postoperatively. We further sought to develop and internally validate nomogram models to predict urinary incontinence risk at these key time points. Nomograms provide an intuitive, user-friendly tool that integrates complex risk factors into a graphical format, facilitating rapid risk assessment and personalized management of high-risk patients.

Methods and materials

Sample size calculation

To determine the required number of participants, we referenced a study by Rajih et al. [17], which reported a six-month urinary incontinence rate of 71.1%. The sample size was calculated using the formula: $N = Z^2 \times [P \times (1 - P)]/E^2$, where the margin of error (E) was set to 0.05, the Z-score to 1.96, and the expected proportion (P) to 0.711. This yielded a required sample size of 316 cases. After accounting for a potential 10% attrition rate, the final target sample size was adjusted to 351 cases.

General information

This retrospective study analyzed baseline data from 520 prostate cancer patients who underwent radical prostatectomy at the *Beilun People's Hospital and The First Affiliated Hospital, Zhejiang University School of Medicine*, between January 2016 and January 2024. Ethical approval was obtained from the Medical Ethics Committee of Beilun People's Hospital.

Inclusion and exclusion criteria

Patients were included if they met the following criteria: pathological diagnosis of prostate cancer confirmed by preoperative biopsy [18]; treatment with laparoscopic or robot-assisted radical prostatectomy; no evidence of distant metastasis on preoperative MRI, CT, and bone scans; no history of urinary incontinence prior to surgery; and no prior endocrine therapy or radiotherapy before preoperative assessment.

Exclusion criteria were: incomplete clinical records; preoperative neurogenic bladder or other bladder dysfunction; preoperative urinary incontinence unrelated to prostate cancer; conversion to open surgery; distant metastasis; or history of prior pelvic surgery.

Definition of urinary continence

Urinary continence status was defined based on postoperative pad usage. Patients using zero to one pad per day were considered continent, while those using more than one pad per day were classified as incontinent [6].

Urinary continence status was assessed at 1, 3, and 6 months postoperatively, and patients were categorized into continence (0-1 pad/day) and incontinence (>1 pad/day) groups accordingly.

Clinical data collection

Data were collected retrospectively through systematic review of electronic medical records and paper archives, covering:

Baseline data: age, BMI, comorbidities (hypertension, diabetes).

Preoperative imaging: pelvic MRI assessments of membranous urethral length (MUL) and documentation of preoperative neoadjuvant hormone therapy (NHT).

Laboratory indicators: preoperative PSA levels and Controlling Nutritional Status (CONUT) score, derived from serum albumin, lymphocyte count, and cholesterol levels.

Surgical details: surgical approach (laparoscopic or robot-assisted), prostate volume, operative duration, intraoperative blood loss, and neurovascular bundle (NVB) preservation status.

Postoperative pathology: Gleason score and tumor stage according to AJCC classification.

Follow-up: urinary continence status at 1, 3, and 6 months postoperatively, assessed during scheduled follow-up visits or standardized telephone interviews. Data collection was performed by uniformly trained researchers to ensure consistency.

Outcome measures

The primary outcome was urinary continence status at 1, 3, and 6 months postoperatively.

Secondary outcomes included identification of independent risk factors for urinary incontinence at each time point, evaluation of nomogram predictive performance, and analysis of dynamic transitions between risk groups from 3 to 6 months post-surgery.

Statistical analysis

Statistical analyses were performed using SPSS version 27.0 (IBM Corp., Armonk, NY, USA) and R version 4.3.2 (R Foundation for Statistical Computing, Vienna, Austria). Categorical variables were presented as frequencies and percentages, with intergroup comparisons via chi-square test or continuity-corrected chi-square test as appropriate. Continuous data were tested for normality using the Kolmogorov-Smirnov test. Normally distributed data were reported as mean ± standard deviation and compared using independent samples t-tests, while non-normally distributed data were presented as median (interquartile range) and compared using the Mann-Whitney U test or Kruskal-Wallis H test.

Binary logistic regression analyses identified independent risk factors for urinary incontinence at each time point. Variables with $P<0.05$ in univariable analyses, along with other clinically relevant variables, were entered into the multivariable models. Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated.

Nomograms were constructed in R using the rms package. Model performance was assessed via ROC curves and AUC values (pROC or ROCR packages), calibration curves (rms package), and Hosmer-Lemeshow test or Brier score. Decision curve analysis (DCA) was performed using the rmda package. The ggalluvial package was used to generate Sankey diagrams illustrating dynamic risk group transitions. A two-sided *P*-value <0.05 was considered statistically significant.

Results

Postoperative status distribution between continence and incontinence groups

At 1 month postoperatively, 7.12% (37 cases) of patients were continent, while 92.88% (483 cases) experienced urinary incontinence. At 3 months, continence was achieved in 30.38% (158 cases), with 69.62% (362 cases) remaining incontinent. By 6 months, continence rates increased to 76.35% (397 cases), and 23.65% (123 cases) remained incontinent (**Figure 1**).

Baseline factors affecting urinary continence status at 1 month postoperatively

Univariable analysis comparing baseline data between continent and incontinent groups at 1 month post-RP identified BMI ($P=0.025$), surgical approach ($P=0.004$), NVB preservation ($P=0.044$), and Gleason score ($P<0.001$) as significant factors. No significant differences were observed for age, hypertension, diabetes mellitus, preoperative MUL, prostate volume, operative time, intraoperative blood loss, preoperative NHT, preoperative PSA level, pathological stage, or CONUT score (all $P>0.05$; **Table 1**).

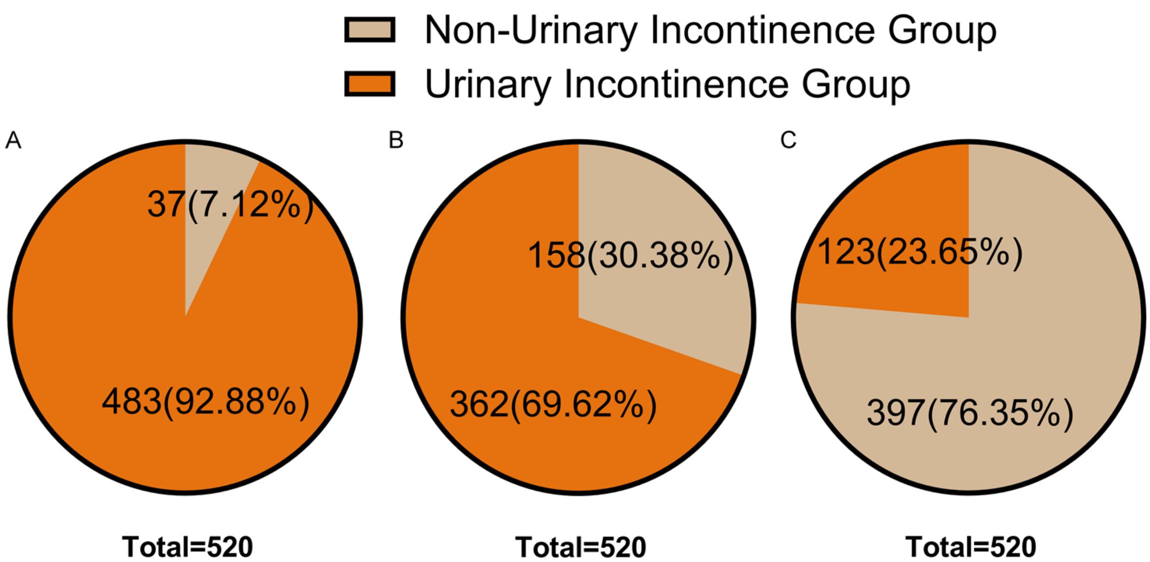

Figure 1. Urinary continence status of patients at 1, 3, and 6 months. A. Distribution of patient urinary continence status at 1 month postoperatively. B. Distribution of patient urinary continence status at 3 months postoperatively. C. Distribution of patient urinary continence status at 6 months postoperatively.

Table 1. Comparison of baseline data between continence and incontinence groups at 1 month postoperatively

Factor	Continence Group (n=37)	Incontinence Group (n=483)	χ^2	*P*-value
Age				
≥65 years	4 (10.81%)	78 (16.15%)	0.737	0.391
<65 years	33 (89.19%)	405 (83.85%)		
BMI (kg/m^2)				
≥25	2 (5.41%)	99 (20.50%)	5.001	0.025
<25	35 (94.59%)	384 (79.50%)		
History of hypertension				
Yes	7 (18.92%)	71 (14.70%)	0.480	0.489
No	30 (81.08%)	412 (85.30%)		
History of diabetes mellitus				
Yes	7 (18.92%)	59 (12.22%)	0.854	0.355
No	30 (81.08%)	424 (87.78%)		
Surgical approach				
Laparoscopic	27 (72.97%)	434 (89.86%)	8.132	0.004
Robot-assisted	10 (27.03%)	49 (10.14%)		
PREOPERATIVE MUL (mm)				
≥14	19 (51.35%)	177 (36.65%)	3.164	0.075
<14	18 (48.65%)	306 (63.35%)		
Prostate volume (mL)				
≥40	25 (67.57%)	325 (67.29%)	0.001	0.972
<40	12 (32.43%)	158 (32.71%)		
Operative time (min)				
≥180	25 (67.57%)	321 (66.46%)	0.019	0.891
<180	12 (32.43%)	162 (33.54%)		
Intraoperative blood loss (mL)				
≥400	18 (48.65%)	277 (57.35%)	1.060	0.303
<400	19 (51.35%)	206 (42.65%)		

Preoperative NHT				
Yes	6 (16.22%)	54 (11.18%)	0.432	0.511
No	31 (83.78%)	429 (88.82%)		
NVB preservation				
Yes	13 (35.14%)	101 (20.91%)	4.062	0.044
No	24 (64.86%)	382 (79.09%)		
Preoperative PSA (ng/mL)				
<10	20 (54.05%)	311 (64.39%)	1.587	0.208
10-20	17 (45.95%)	172 (35.61%)		
>20				
Gleason score	7 (18.92%)	75 (15.53%)	0.584	0.747
≤6	7 (18.92%)	114 (23.60%)		
7	23 (62.16%)	294 (60.87%)		
≥8				
Pathological stage	8 (21.62%)	25 (5.18%)	16.625	<0.001
T2	14 (37.84%)	175 (36.23%)		
T3a	15 (40.54%)	283 (58.59%)		
T3b				
CONUT score	12 (32.43%)	165 (34.16%)	1.419	0.492
≥4	14 (37.84%)	140 (28.99%)		
<4	11 (29.73%)	178 (36.85%)		

Note: BMI: Body Mass Index, MUL: Membranous Urethral Length, NHT: Neoadjuvant Hormone Therapy, NVB: Neurovascular Bundle, PSA: Prostate-Specific Antigen, CONUT: Controlling Nutritional Status.

Independent risk factors for urinary incontinence at 1 month postoperatively

Univariable logistic regression showed that lower BMI (<25 kg/m^2; OR=0.222, P=0.041) and robot-assisted surgery (vs. laparoscopic; OR=0.305, P=0.003) were protective factors, while preoperative NHT (OR=2.049, P=0.048) and higher Gleason score (OR=2.230, P=0.001) were risk factors. Other variables were not significant (all P>0.05). Multivariable logistic regression confirmed robot-assisted surgery (OR=0.289, P=0.003) as an independent protective factor and higher Gleason score (OR=2.178, P=0.003) as an independent risk factor. BMI and preoperative NHT were not significant in the multivariable model (both P>0.05; **Table 2**).

Baseline factors affecting urinary continence status at 3 months postoperatively

At 3 months, BMI (P=0.002), preoperative MUL (P<0.001), and pathological stage (P<0.001) were significant factors. Patients with lower BMI (<25 kg/m^2), longer preoperative MUL (≥14 mm), and earlier pathological stage (T2) had higher continence rates. Other variables, including age, hypertension, diabetes mellitus, surgical approach, prostate volume, operative time, intraoperative blood loss, preoperative NHT, NVB preservation, preoperative PSA level, Gleason score, and CONUT score were not significant (all P>0.05; **Table 3**).

Independent risk factors for urinary incontinence at 3 months postoperatively

Univariable logistic regression identified lower BMI (<25 kg/m^2; OR=0.432, P=0.003) and longer preoperative MUL (≥14 mm; OR=2.439, P<0.001) as protective factors, while higher Gleason score (OR=1.655, P<0.001) was a risk factor. Other variables were not significant (all P>0.05). Multivariable logistic regression confirmed lower BMI (<25 kg/m^2; OR=0.448, P=0.005) and longer preoperative MUL (≥14 mm; OR=2.368, P<0.001) as independent protective factors, and higher Gleason score (OR=1.565, P=0.004) as an independent risk factor (**Table 4**).

Baseline factors affecting urinary continence status at 6 months postoperatively

At 6 months, BMI (P<0.001), preoperative MUL (P<0.001), prostate volume (P=0.043),

Table 2. Independent risk factors for urinary incontinence at 1 month postoperatively by logistic regression analysis

Variable	Univariable			Multivariable		
	OR value	*P*-value	95% CI	OR value	*P*-value	95% CI
Age	0.629	0.394	0.184-1.638			
BMI (kg/m^2)	0.222	0.041	0.036-0.744	0.249	0.061	0.040-0.850
History of hypertension	1.354	0.490	0.530-3.038			
History of diabetes mellitus	1.677	0.242	0.653-3.790			
Surgical approach	0.305	0.003	0.143-0.695	0.289	0.003	0.131-0.677
Preoperative MUL	1.825	0.079	0.930-3.593			
Prostate volume (mL)	1.013	0.972	0.506-2.137			
Operative time	1.051	0.891	0.525-2.218			
Intraoperative blood loss (mL)	0.705	0.305	0.358-1.380			
Preoperative NHT	2.049	0.048	0.981-4.106	1.788	0.123	0.833-3.681
NVB preservation	0.651	0.211	0.332-1.288			
Preoperative PSA	1.038	0.870	0.653-1.587			
Gleason score	2.230	0.001	1.358-3.650	2.178	0.003	1.295-3.658
Pathological stage	1.080	0.706	0.724-1.615			
CONUT score	0.697	0.380	0.291-1.494			

Note: OR: Odds Ratio, CI: Confidence Interval, BMI: Body Mass Index, MUL: Membranous Urethral Length, NHT: Neoadjuvant Hormone Therapy, NVB: Neurovascular Bundle, PSA: Prostate-Specific Antigen, CONUT: Controlling Nutritional Status.

Table 3. Comparison of baseline data between continence and incontinence groups at 3 months postoperatively

Factor	Continence Group (n=158)	Incontinence Group (n=362)	χ^2	*P*-value
Age				
≥65 years	26 (16.46%)	56 (15.47%)	0.081	0.777
<65 years	132 (83.54%)	306 (84.53%)		
BMI (kg/m^2)				
≥25	18 (11.39%)	83 (22.93%)	9.352	0.002
<25	140 (88.61%)	279 (77.07%)		
History of hypertension				
Yes	23 (14.56%)	55 (15.19%)	0.035	0.852
No	135 (85.44%)	307 (84.81%)		
History of diabetes mellitus				
Yes	15 (9.49%)	51 (14.09%)	2.096	0.148
No	143 (90.51%)	311 (85.91%)		
Surgical approach				
Laparoscopic	135 (85.44%)	326 (90.06%)	2.326	0.127
Robot-assisted	23 (14.56%)	36 (9.94%)		
Preoperative MUL (mm)				
≥14	83 (52.53%)	113 (31.22%)	21.281	<0.001
<14	75 (47.47%)	249 (68.78%)		
Prostate volume (mL)				
≥40	106 (67.09%)	244 (67.40%)	0.005	0.944
<40	52 (32.91%)	118 (32.60%)		
Operative time (min)				
≥180	110 (69.62%)	236 (65.19%)	0.968	0.325
<180	48 (30.38%)	126 (34.81%)		

Intraoperative blood loss (mL)				
≥400	93 (58.86%)	202 (55.80%)	0.419	0.517
<400	65 (41.14%)	160 (44.20%)		
Preoperative NHT				
Yes	24 (15.19%)	36 (9.94%)	2.965	0.085
No	134 (84.81%)	326 (90.06%)		
NVB preservation				
Yes	42 (26.58%)	72 (19.89%)	2.878	0.090
No	116 (73.42%)	290 (80.11%)		
Preoperative PSA (ng/mL)				
<10	102 (64.56%)	229 (63.26%)	0.080	0.777
10-20	56 (35.44%)	133 (36.74%)		
>20				
Gleason score	21 (13.29%)	61 (16.85%)	1.121	0.571
≤6	39 (24.68%)	82 (22.65%)		
7	98 (62.03%)	219 (60.50%)		
≥8				
Pathological stage	12 (7.59%)	21 (5.80%)	14.343	<0.001
T2	75 (47.47%)	114 (31.49%)		
T3a	71 (44.94%)	227 (62.71%)		
T3b				
CONUT score	56 (35.44%)	121 (33.43%)	2.071	0.355
≥4	40 (25.32%)	114 (31.49%)		
<4	62 (39.24%)	127 (35.08%)		

Note: BMI: Body Mass Index, MUL: Membranous Urethral Length, NHT: Neoadjuvant Hormone Therapy, NVB: Neurovascular Bundle, PSA: Prostate-Specific Antigen, CONUT: Controlling Nutritional Status.

Table 4. Independent risk factors for urinary incontinence at 3 months postoperatively by logistic regression analysis

Variable	Univariable			Multivariable		
	OR value	*P*-value	95% CI	OR value	*P*-value	95% CI
Age	1.076	0.777	0.640-1.773			
BMI (kg/m^2)	0.432	0.003	0.243-0.732	0.448	0.005	0.249-0.770
History of hypertension	0.951	0.852	0.553-1.593			
History of diabetes mellitus	0.64	0.150	0.337-1.149			
Surgical approach	0.648	0.129	0.372-1.148			
Preoperative MUL	2.439	<0.001	1.664-3.585	2.368	<0.001	1.604-3.506
Prostate volume (mL)	0.986	0.944	0.664-1.474			
Operative time	1.224	0.326	0.822-1.839			
Intraoperative blood loss (mL)	1.133	0.517	0.777-1.659			
Preoperative NHT	1.458	0.091	0.937-2.251			
NVB preservation	1.058	0.777	0.718-1.568			
Preoperative PSA	0.912	0.477	0.706-1.171			
Gleason score	1.655	<0.001	1.228-2.234	1.565	0.004	1.151-2.129
Pathological stage	0.97	0.789	0.776-1.212			
CONUT score	0.91	0.662	0.594-1.379			

Note: BMI: Body Mass Index, MUL: Membranous Urethral Length, NHT: Neoadjuvant Hormone Therapy, NVB: Neurovascular Bundle, PSA: Prostate-Specific Antigen, CONUT: Controlling Nutritional Status.

Table 5. Comparison of baseline data between continence and incontinence groups at 6 months postoperatively

Factor	Continence Group (n=397)	Incontinence Group (n=123)	χ^2	*P*-value
Age				
≥65 years	60 (15.11%)	22 (17.89%)	0.544	0.461
<65 years	337 (84.89%)	101 (82.11%)		
BMI (kg/m²)				
≥25	60 (15.11%)	41 (33.33%)	19.919	<0.001
<25	337 (84.89%)	82 (66.67%)		
History of hypertension				
Yes	56 (14.11%)	22 (17.89%)	1.053	0.305
No	341 (85.89%)	101 (82.11%)		
History of diabetes mellitus				
Yes	48 (12.09%)	18 (14.63%)	0.548	0.459
No	349 (87.91%)	105 (85.37%)		
Surgical approach				
Laparoscopic	349 (87.91%)	112 (91.06%)	0.925	0.336
Robot-assisted	48 (12.09%)	11 (8.94%)		
Preoperative MUL (mm)				
≥14	175 (44.08%)	21 (17.07%)	29.165	<0.001
<14	222 (55.92%)	102 (82.93%)		
Prostate volume (mL)				
≥40	258 (64.99%)	92 (74.80%)	4.106	0.043
<40	139 (35.01%)	31 (25.20%)		
Operative time (min)				
≥180	270 (68.01%)	76 (61.79%)	1.633	0.201
<180	127 (31.99%)	47 (38.21%)		
Intraoperative blood loss (mL)				
≥400	230 (57.93%)	65 (52.85%)	0.991	0.320
<400	167 (42.07%)	58 (47.15%)		
Preoperative NHT				
Yes	48 (12.09%)	12 (9.76%)	0.501	0.479
No	349 (87.91%)	111 (90.24%)		
NVB preservation				
Yes	107 (26.95%)	7 (5.69%)	24.799	<0.001
No	290 (73.05%)	116 (94.31%)		
Preoperative PSA (ng/mL)				
<10	250 (62.97%)	81 (65.85%)	0.337	0.562
10-20	147 (37.03%)	42 (34.15%)		
>20				
Gleason score	60 (15.11%)	22 (17.89%)	2.895	0.235
≤6	87 (21.91%)	34 (27.64%)		
7	250 (62.97%)	67 (54.47%)		
≥8				
Pathological stage	27 (6.80%)	6 (4.88%)	36.549	<0.001
T2	171 (43.07%)	18 (14.63%)		
T3a	199 (50.13%)	99 (80.49%)		
T3b				
CONUT score	127 (31.99%)	50 (40.65%)	3.343	0.188
≥4	123 (30.98%)	31 (25.20%)		
<4	147 (37.03%)	42 (34.15%)		

Note: BMI: Body Mass Index, MUL: Membranous Urethral Length, NHT: Neoadjuvant Hormone Therapy, NVB: Neurovascular Bundle, PSA: Prostate-Specific Antigen, CONUT: Controlling Nutritional Status.

Table 6. Independent risk factors for urinary incontinence at 6 months postoperatively by logistic regression analysis

Variable	Univariable			Multivariable		
	OR value	*P*-value	95% CI	OR value	*P*-value	95% CI
Age	0.817	0.461	0.484-1.422			
BMI (kg/m^2)	0.356	<0.001	0.224-0.568	0.317	<0.001	0.186-0.538
History of hypertension	0.754	0.306	0.444-1.316			
History of diabetes mellitus	0.802	0.460	0.454-1.470			
Surgical approach	0.714	0.338	0.342-1.374			
Preoperative MUL	3.829	<0.001	2.342-6.522	3.622	<0.001	2.123-6.426
Prostate volume (mL)	0.625	0.044	0.392-0.978	0.591	0.044	0.351-0.978
Operative time	1.315	0.202	0.860-1.997			
Intraoperative blood loss (mL)	1.229	0.320	0.818-1.845			
Preoperative NHT	6.114	<0.001	2.959-14.837	5.783	<0.001	2.652-14.645
NVB preservation	0.882	0.562	0.573-1.343			
Preoperative PSA	0.824	0.146	0.635-1.074			
Gleason score	2.866	<0.001	1.914-4.440	2.824	<0.001	1.821-4.544
Pathological stage	0.848	0.183	0.665-1.080			
CONUT score	0.459	<0.001	0.300-0.706	0.372	<0.001	0.227-0.606

Note: BMI: Body Mass Index, MUL: Membranous Urethral Length, NHT: Neoadjuvant Hormone Therapy, NVB: Neurovascular Bundle, PSA: Prostate-Specific Antigen, CONUT: Controlling Nutritional Status.

NVB preservation (P<0.001), and pathological stage (P<0.001) were significant factors. Patients with lower BMI (<25 kg/m^2), longer preoperative MUL (≥14 mm), smaller prostate volume (<40 mL), NVB preservation, and earlier pathological stage (T2) had higher continence rates. Other factors, including age, hypertension, diabetes mellitus, surgical approach, operative time, intraoperative blood loss, preoperative NHT, preoperative PSA level, Gleason score, and CONUT score showed no significant differences (all P>0.05; **Table 5**).

Independent risk factors for urinary incontinence at 6 months postoperatively

Univariable logistic regression identified lower BMI (<25 kg/m^2; OR=0.356, P<0.001), smaller prostate volume (<40 mL; OR=0.625, P=0.044), and lower CONUT score (<4; OR=0.459, P<0.001) as protective factors. Shorter preoperative MUL (<14 mm; OR=3.829, P<0.001), preoperative NHT (OR=6.114, P<0.001), and higher Gleason score (OR=2.866, P<0.001) were risk factors. Other variables were not significant (all P>0.05). Multivariable logistic regression confirmed lower BMI (<25 kg/m^2; OR=0.317, P<0.001), smaller prostate volume (<40 mL; OR=0.591, P=0.044), and lower CONUT score (<4; OR=0.372, P<0.001) as independent protective factors, and shorter preoperative MUL (<14 mm; OR=3.622, P<0.001), preoperative NHT (OR=5.783, P<0.001), and higher Gleason score (OR=2.824, P<0.001) as independent risk factors (**Table 6**).

Construction of nomograms for predicting urinary continence at 3 and 6 months

Nomograms were developed to predict urinary continence at 3 and 6 months postoperatively based on independent risk factors identified in multivariable analyses. The 3-month nomogram included BMI, preoperative MUL, and Gleason score, with the risk model: Risk Score = -0.8026 × BMI + 0.8621 × preoperative MUL + 0.4477 × Gleason score, indicating strong correlations with continence outcomes (**Figure 2A**).

The 6-month nomogram incorporated BMI, preoperative MUL, prostate volume, preoperative NHT, Gleason score, and CONUT score, with the risk model: Risk Score = -1.1489 × BMI + 1.2869 × preoperative MUL - 0.5255 × prostate volume + 1.7550 × preoperative NHT + 1.0383 × Gleason score - 0.9895 × CONUT score.

Preoperative NHT and Gleason score showed strong correlations; BMI, preoperative MUL, and CONUT score showed moderate correla-

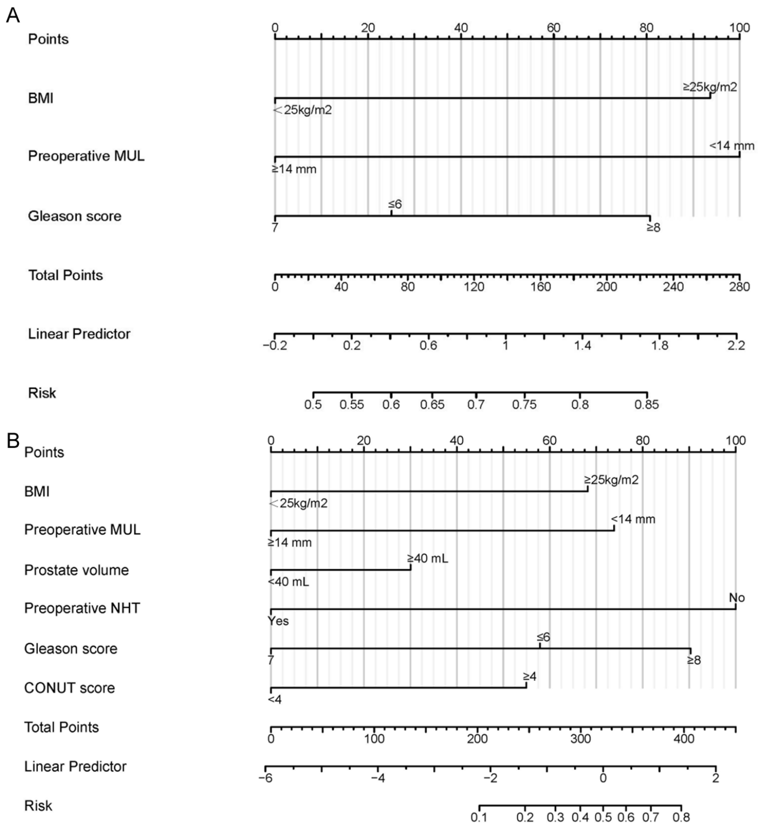

Figure 2. Nomograms for predicting urinary continence in patients at 3 and 6 months. A. Nomogram for predicting urinary continence in patients at 3 months postoperatively. B. Nomogram for predicting urinary continence in patients at 6 months postoperatively. Note: BMI: Body Mass Index, MUL: Membranous Urethral Length, NHT: Neoadjuvant Hormone Therapy, CONUT: Controlling Nutritional Status.

tions; prostate volume showed a weak correlation with continence (**Figure 2B**).

Validation and clinical utility assessment of 3- and 6-month nomogram models

For the 3-month model, ROC analysis yielded an AUC of 0.679, indicating moderate discriminative ability (**Figure 3A**). Calibration curve analysis demonstrated good agreement between predicted and observed probabilities (Brier score: 0.1967, corrected slope: 1.0181, Emax: 0.0069; **Figure 3B**). DCA indicated net clinical benefit for threshold probabilities between 0% and 54%, with a maximum net benefit of 30.38% (**Figure 3C**).

For the 6-month model, ROC analysis showed an AUC of 0.818, indicating good discriminative ability (**Figure 3D**). Calibration curve analysis confirmed excellent calibration (Brier score: 0.1359, corrected slope: 1.0047, Emax: 0.0028; **Figure 3E**). DCA indicated net benefit for threshold probabilities between 0% and 85%, with a maximum net benefit of 23.65% (**Figure 3F**).

Comparison of low-, medium-, and high-risk groups at 3 and 6 months postoperatively

Patients were stratified into low-, medium-, and high-risk groups based on the 3rd percentile method. Significant differences in incontinence scores were observed across groups at both time points (P<0.001). The high-risk group consistently had the highest incontinence scores, followed by the medium- and low-risk groups, with greater separation observed at 6 months (**Figure 4**).

Risk stratification and clinical characteristics analysis at 3 months postoperatively

Based on 3-month nomogram scores, significant differences in continence status were observed (P<0.001), with the high-risk group exhibiting the highest incontinence rates, followed by the medium- and low-risk groups. Baseline characteristics differed significantly by BMI (P<0.001), preoperative MUL (P<0.001), and pathological stage (P<0.001). The high-risk group had a higher proportion of patients with BMI ≥25 kg/m^2, preoperative MUL <14 mm (nearly all high-risk patients), and pathological stage T3b. The low-risk group had a higher proportion with MUL ≥14 mm. No significant differences were observed for age, hypertension, diabetes mellitus, surgical approach, prostate volume, operative time, intraoperative blood loss, preoperative NHT, NVB preservation, preoperative PSA level, Gleason score, or CONUT score (all P>0.05; **Table 7**).

Risk stratification and clinical characteristics analysis at 6 months postoperatively

Based on 6-month nomogram scores, significant differences in continence status were

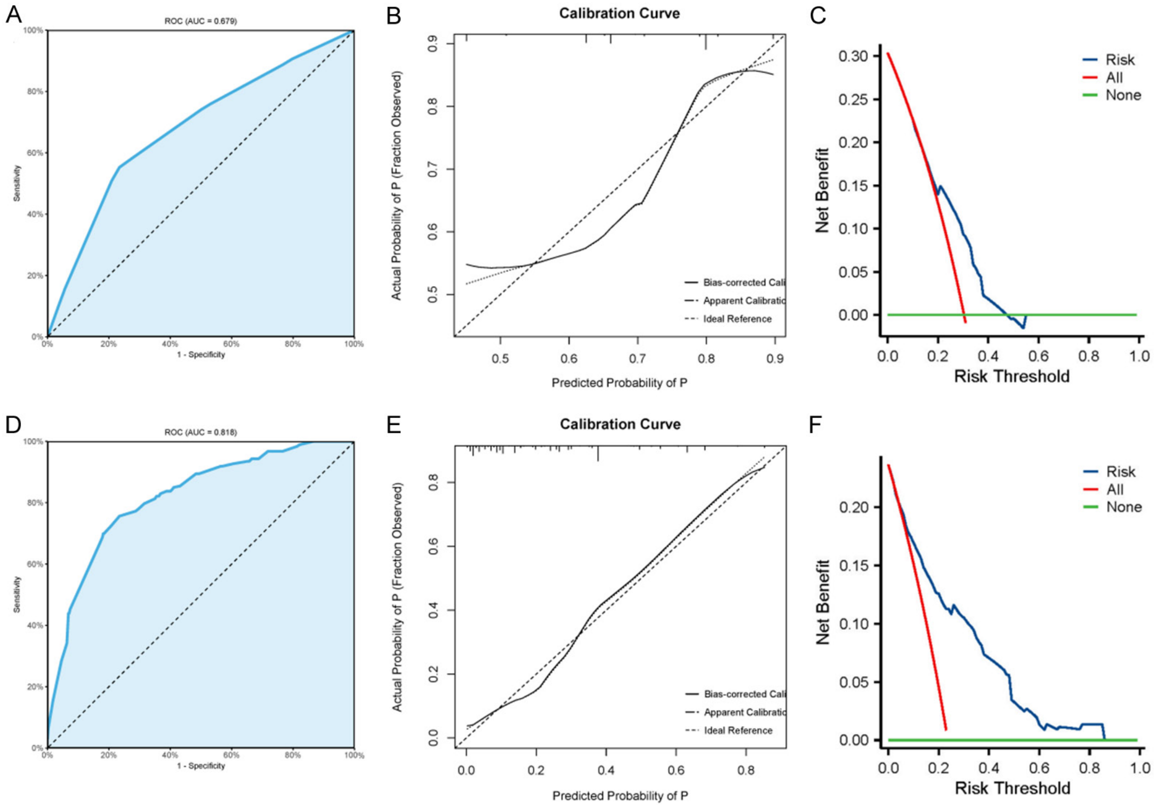

Figure 3. Internal validation of nomograms for predicting urinary continence in patients at 3 and 6 months. A. ROC curve for the 3-month postoperative urinary incontinence risk prediction model. B. Calibration curve for the 3-month postoperative urinary incontinence risk prediction model. C. DCA curve for the 3-month postoperative urinary incontinence risk prediction model. D. ROC curve for the 6-month postoperative urinary incontinence risk prediction model. E. Calibration curve for the 6-month postoperative urinary incontinence risk prediction model. F. DCA curve for the 6-month postoperative urinary incontinence risk prediction model. Note: ROC: Receiver Operating Characteristic, AUC: Area Under the Curve, DCA: Decision Curve Analysis.

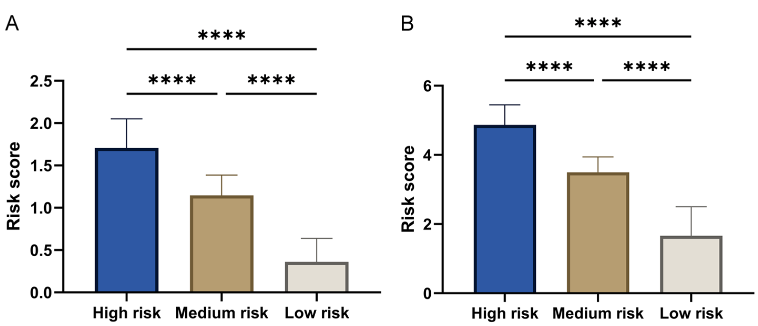

Figure 4. Distribution of low, medium, and high urinary incontinence risk scores at 3 and 6 months postoperatively. A. Distribution of low, medium, and high urinary incontinence risk scores at 3 months postoperatively. B. Distribution of low, medium, and high urinary incontinence risk scores at 6 months postoperatively. Note: ****P<0.0001.

observed (P<0.001). Interestingly, the score-defined low-risk group showed the highest incontinence rates, followed by the medium- and high-risk groups, suggesting that a "high-risk" designation corresponded to better continence outcomes in this model. Baseline characteristics differed significantly by BMI (P<0.001), preoperative MUL (P<0.001), prostate volume (P<0.001), NVB preservation (P<0.001), and pathological stage (P<0.001). The score-defined low-risk group (with high actual incontinence rates) had higher proportions of patients with BMI ≥25 kg/m^2, preoperative MUL <14 mm (nearly all), prostate volume ≥40 mL, no NVB preservation, and pathological stage T3b. No significant differences were observed for age, hypertension, diabetes mellitus, surgical approach, operative time, intraoperative blood loss, preoperative NHT, preoperative PSA level, Gleason score, or CONUT score (all P>0.05; **Table 8**).

Table 7. Comparison of baseline data and clinical outcomes among high, medium, and low-risk groups (defined by 3-month risk score)

Group	Low Risk (n=173)	Medium Risk (n=173)	High Risk (n=174)	χ^2	*P*-value
Urinary continence status					
Incontinence group	94 (54.34%)	127 (73.41%)	141 (81.03%)	31.000	<0.001
Continence Group	79 (45.66%)	46 (26.59%)	33 (18.97%)		
Age					
≥65 years	26 (15.03%)	32 (18.50%)	24 (13.79%)	1.552	0.460
<65 years	147 (84.97%)	141 (81.50%)	150 (86.21%)		
BMI (kg/m²)					
≥25	3 (1.73%)	33 (19.08%)	65 (37.36%)	70.356	<0.001
<25	170 (98.27%)	140 (80.92%)	109 (62.64%)		
History of hypertension					
Yes	24 (13.87%)	25 (14.45%)	29 (16.67%)	0.592	0.744
No	149 (86.13%)	148 (85.55%)	145 (83.33%)		
History of diabetes mellitus					
Yes	24 (13.87%)	21 (12.14%)	21 (12.07%)	0.326	0.849
No	149 (86.13%)	152 (87.86%)	153 (87.93%)		
Surgical approach					
Laparoscopic	153 (88.44%)	157 (90.75%)	151 (86.78%)	1.371	0.504
Robot-assisted	20 (11.56%)	16 (9.25%)	23 (13.22%)		
Preoperative MUL (mm)					
≥14	156 (90.17%)	40 (23.12%)	0 (0.00%)	323.787	<0.001
<14	17 (9.83%)	133 (76.88%)	174 (100.00%)		
Prostate volume (mL)					
≥40	110 (63.58%)	118 (68.21%)	122 (70.11%)	1.777	0.411
<40	63 (36.42%)	55 (31.79%)	52 (29.89%)		
Operative time (min)					
≥180	119 (68.79%)	107 (61.85%)	120 (68.97%)	2.561	0.278
<180	54 (31.21%)	66 (38.15%)	54 (31.03%)		
Intraoperative blood loss (mL)					
≥400	92 (53.18%)	106 (61.27%)	97 (55.75%)	2.411	0.300
<400	81 (46.82%)	67 (38.73%)	77 (44.25%)		
Preoperative NHT					
Yes	21 (12.14%)	21 (12.14%)	18 (10.34%)	0.365	0.833
No	152 (87.86%)	152 (87.86%)	156 (89.66%)		
NVB preservation					
Yes	47 (27.17%)	36 (20.81%)	31 (17.82%)	4.620	0.099
No	126 (72.83%)	137 (79.19%)	143 (82.18%)		
Preoperative PSA (ng/mL)					
<10	104 (60.12%)	110 (63.58%)	117 (67.24%)	1.904	0.386
10-20	69 (39.88%)	63 (36.42%)	57 (32.76%)		
>20					
Gleason score	26 (15.03%)	27 (15.61%)	29 (16.67%)	4.986	0.289
≤6	40 (23.12%)	49 (28.32%)	32 (18.39%)		
7	107 (61.85%)	97 (56.07%)	113 (64.94%)		
≥8					
Pathological stage	32 (18.50%)	1 (0.58%)	0 (0.00%)	155.990	<0.001
T2	66 (38.15%)	102 (58.96%)	21 (12.07%)		
T3a	75 (43.35%)	70 (40.46%)	153 (87.93%)		
T3b					

CONUT score	59 (34.10%)	58 (33.53%)	60 (34.48%)	3.232	0.520
≥4	51 (29.48%)	45 (26.01%)	58 (33.33%)		
<4	63 (36.42%)	70 (40.46%)	56 (32.18%)		

Note: BMI: Body Mass Index, MUL: Membranous Urethral Length, NHT: Neoadjuvant Hormone Therapy, NVB: Neurovascular Bundle, PSA: Prostate-Specific Antigen, CONUT: Controlling Nutritional Status.

Dynamic transition of urinary incontinence risk groups from 3 to 6 months postoperatively

A Sankey diagram (**Figure 5**) illustrated the dynamic transitions in urinary incontinence risk groupings from 3 to 6 months postoperatively. Patients' classifications at 3 months (left) and 6 months (right) showed significant changes. Some patients transitioned from high-risk to medium- or low-risk groups, indicating marked improvement in continence recovery. Others remained in the same risk group, suggesting stable recovery status. A few transitioned from medium- or low-risk to high-risk groups, reflecting worsening or persistent incontinence. These dynamic transitions highlight the individual variability in continence recovery, emphasizing that recovery trajectories are often nonlinear.

Discussion

RP remains a cornerstone therapy for localized prostate cancer. However, urinary incontinence is a frequent postoperative complication that can profoundly diminish patients' quality of life [19]. This study retrospectively evaluated the clinicopathological data of high-risk patients undergoing RP, with the primary aim of identifying independent risk factors for urinary incontinence at one, three, and six months postoperatively. Additionally, we constructed nomogram models to predict incontinence risk at three and six months, providing a scientific foundation for early identification of high-risk patients and implementation of personalized intervention strategies.

This investigation focused on the dynamic recovery of urinary continence after RP. Gradual restoration was observed, with continence rates of 7.12%, 30.38%, and 76.35% at one, three, and six months, respectively. This trajectory aligns with both clinical experience and published findings. For example, Lardas et al. [20] reported a strong correlation between urinary incontinence at three months and factors such as age, MUL, prostate volume, and the Charlson Comorbidity Index (CCI), noting a recovery pattern from three to twelve months consistent with our results. Furthermore, existing literature indicates that non-nerve-sparing surgical techniques may limit long-term continence recovery [21]. The notably low continence rate at one month is attributable to surgical trauma, pelvic floor injury, and inflammatory edema. The significant improvement observed thereafter underscores the efficacy of postoperative rehabilitation and pelvic floor muscle training, suggesting that most patients can achieve effective urinary control in the medium to long term. Nevertheless, addressing factors that impede recovery at one month remains crucial for enhancing immediate postoperative quality of life.

At one month, multivariable logistic regression identified a higher Gleason score as an independent risk factor for urinary incontinence, while robot-assisted surgery was protective compared with laparoscopic surgery. The Gleason score, as an indicator of tumor malignancy, likely correlates with increased surgical invasiveness, adversely affecting continence recovery. This finding is supported by Kohada et al. [22], who reported that age and biochemical recurrence predicted urinary incontinence 60 months after robot-assisted prostatectomy. Additionally, other studies have confirmed that a higher Gleason score is an independent risk factor for stress urinary incontinence, likely due to impaired periurethral tissues [23]. The protective benefit of robot-assisted surgery stems from its superior preservation of the urethra and neurovascular bundles. Supporting this, Püllen et al. [24] observed declining urinary incontinence rates following robot-assisted prostatectomy with technological advancements.

We did not develop a predictive nomogram for one-month urinary incontinence due to the extremely low continence rate (7.12%) in this cohort, resulting in a small sample size for the

Table 8. Comparison of baseline data and clinical outcomes among high, medium, and low-risk groups (defined by 6-month risk score)

Group	Low Risk (n=173)	Medium Risk (n=173)	High Risk (n=174)	χ^2	*P*-value
Urinary continence status					
Incontinence group	10 (5.78%)	29 (16.76%)	84 (48.28%)	93.565	<0.001
Continence Group	163 (94.22%)	144 (83.24%)	90 (51.72%)		
Age					
≥65 years	28 (16.18%)	22 (12.72%)	32 (18.39%)	2.136	0.344
<65 years	145 (83.82%)	151 (87.28%)	142 (81.61%)		
BMI (kg/m^2)					
≥25	10 (5.78%)	33 (19.08%)	58 (33.33%)	42.100	<0.001
<25	163 (94.22%)	140 (80.92%)	116 (66.67%)		
History of hypertension					
Yes	26 (15.03%)	27 (15.61%)	25 (14.37%)	0.105	0.949
No	147 (84.97%)	146 (84.39%)	149 (85.63%)		
History of diabetes mellitus					
Yes	27 (15.61%)	21 (12.14%)	18 (10.34%)	2.239	0.326
No	146 (84.39%)	152 (87.86%)	156 (89.66%)		
Surgical approach					
Laparoscopic	157 (90.75%)	152 (87.86%)	152 (87.36%)	1.156	0.561
Robot-assisted	16 (9.25%)	21 (12.14%)	22 (12.64%)		
Preoperative MUL (mm)					
≥14	118 (68.21%)	75 (43.35%)	3 (1.72%)	166.806	<0.001
<14	55 (31.79%)	98 (56.65%)	171 (98.28%)		
Prostate volume (mL)					
≥40	102 (58.96%)	102 (58.96%)	146 (83.91%)	32.749	<0.001
<40	71 (41.04%)	71 (41.04%)	28 (16.09%)		
Operative time (min)					
≥180	109 (63.01%)	118 (68.21%)	119 (68.39%)	1.454	0.483
<180	64 (36.99%)	55 (31.79%)	55 (31.61%)		
Intraoperative blood loss (mL)					
≥400	92 (53.18%)	100 (57.80%)	103 (59.20%)	1.401	0.496
<400	81 (46.82%)	73 (42.20%)	71 (40.80%)		
Preoperative NHT					
Yes	20 (11.56%)	19 (10.98%)	21 (12.07%)	0.100	0.951
No	153 (88.44%)	154 (89.02%)	153 (87.93%)		
NVB preservation					
Yes	98 (56.65%)	15 (8.67%)	1 (0.57%)	185.948	<0.001
No	75 (43.35%)	158 (91.33%)	173 (99.43%)		
Preoperative PSA (ng/mL)					
<10	110 (63.58%)	109 (63.01%)	112 (64.37%)	0.070	0.966
10-20	63 (36.42%)	64 (36.99%)	62 (35.63%)		
>20					
Gleason score	23 (13.29%)	28 (16.18%)	31 (17.82%)	2.387	0.665
≤6	37 (21.39%)	42 (24.28%)	42 (24.14%)		
7	113 (65.32%)	103 (59.54%)	101 (58.05%)		
≥8					
Pathological stage	28 (16.18%)	5 (2.89%)	0 (0.00%)	102.092	<0.001
T2	86 (49.71%)	72 (41.62%)	31 (17.82%)		
T3a	59 (34.10%)	96 (55.49%)	143 (82.18%)		
T3b					

CONUT score	50 (28.90%)	61 (35.26%)	66 (37.93%)	4.407	0.354
≥4	51 (29.48%)	51 (29.48%)	52 (29.89%)		
<4	72 (41.62%)	61 (35.26%)	56 (32.18%)		

Note: BMI: Body Mass Index, MUL: Membranous Urethral Length, NHT: Neoadjuvant Hormone Therapy, NVB: Neurovascular Bundle, PSA: Prostate-Specific Antigen, CONUT: Controlling Nutritional Status.

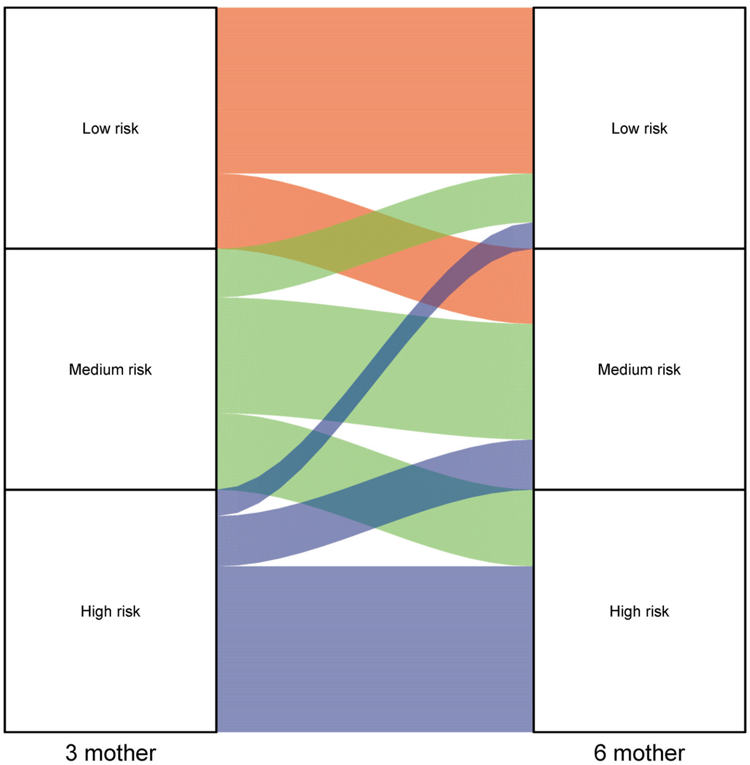

Figure 5. Sankey diagram illustrating the dynamic transition of patient risk groupings from 3 to 6 months postoperatively.

continent group. Building a model under these conditions would carry a substantial risk of statistical bias and overfitting, compromising its predictive accuracy. Although the incidence of incontinence at one month was high (92.88%), the scarcity of continent patients precluded reliable model development. Therefore, modeling efforts focused on the three- and six-month milestones, which are more critical for assessing sustained continence recovery.

By three months, the factors influencing urinary incontinence had evolved. While a higher Gleason score persisted as an independent risk factor, multivariable analysis also identified a low BMI (<25 kg/m^2) and longer preoperative MUL (≥14 mm) as significant protective factors. The continued influence of Gleason score highlights the tumor's biological impact on recovery trajectories. A lower BMI is advantageous as it reduces intra-abdominal pressure, lessening the burden on pelvic floor structures. Additionally, a longer preoperative MUL facilitates sphincteric preservation, promoting continence recovery. Fonseca et al. [25], in their study of Retzius-sparing prostatectomy, found that MUL was associated with continence recovery at twelve months, a relationship evident by three months in our cohort. This aligns with other reports suggesting that longer preoperative MUL predicts earlier continence restoration [26].

The three-month nomogram developed based on these factors achieved an AUC of 0.679, indicating moderate discriminative power. Notably, literature suggests that preoperative models incorporating MRI parameters can yield higher AUC values, indicating potential avenues for improving predictive accuracy [27]. Despite its moderate AUC, the calibration curves and DCA confirmed the clinical utility of our model for preoperative risk evaluation.

At six months post-surgery, the factors influencing urinary incontinence became more complex. Independent risk factors included shorter preoperative MUL (<14 mm), preoperative NHT, and higher Gleason score. Protective factors were lower BMI (<25 kg/m^2), smaller prostate volume (<40 mL), and lower CONUT score (<4). The sustained significance of MUL and Gleason score was thus reaffirmed. The detrimental effect of NHT may relate to its adverse impacts on pelvic floor musculature and nerve function. A smaller prostate volume likely simplifies surgical procedures, facilitating the preservation of critical functional structures. Additionally, a low CONUT score, reflecting better nutritional status, supports postoperative tissue repair and overall recovery. Consistent with this, Xiong et al. [28] correlated higher CONUT scores with increased urinary incontinence rates, underscoring nutrition's role in continence restoration. Similarly, literature indicates that lower BMI promotes recovery through favorable metabolic effects [29].

The six-month nomogram model, integrating these multifactorial risk factors, demonstrated high predictive efficacy with an AUC of 0.818. Calibration curves and DCA further confirmed its strong clinical utility. These results align with findings by Pinkhasov et al. [30], who also developed six-month incontinence risk models, while other studies suggest incorporating functional parameters, such as urethral pressure profiles, could further optimize predictive accuracy [31].

Risk stratification based on the nomograms revealed significant disparities in urinary incontinence rates among high-, medium-, and low-risk groups at three months postoperatively. The primary differentiators were BMI, preoperative MUL, and pathological stage, consistent with Collette et al. [32], who demonstrated similar predictive value using PROMs. Notably, at six months, the "high-risk group" exhibited the best urinary continence outcomes. This apparent paradox likely reflects a misinterpretation of the scoring mechanism: in this model, a "high-risk score" corresponds to a higher probability of achieving continence rather than remaining incontinent. This distinction is critical for correct clinical application. Supporting this, Amparore et al. [33] have demonstrated that machine learning algorithms can enhance predictive accuracy for urinary incontinence following robot-assisted prostatectomy.

To further elucidate recovery trajectories, this study employed a Sankey diagram to visually depict dynamic transitions in risk categories from three to six months postoperatively. This visualization effectively captured individual variability and non-linear recovery patterns, showing that while some patients improved and moved to lower-risk groups, others remained unchanged or worsened. Literature emphasizes the importance of such dynamic tracking, as early predictors like age and MUL remain significant throughout recovery [34]. Yu et al. [35] also highlighted the value of preoperative pelvic floor EMG in early incontinence prediction, reinforcing the need for continuous, personalized follow-up and intervention strategies tailored to each patient's recovery path.

However, certain limitations must be acknowledged. The retrospective design introduces potential selection and information biases, and as a single-center study, generalizability may be limited. Additionally, continence definitions were not based on quality-of-life questionnaires, and both nomogram models require external validation. The predictive efficacy of the three-month model, in particular, could be improved. Future research should prioritize multicenter prospective studies, incorporate a broader range of influencing factors, and explore machine learning approaches to optimize predictive models.

In summary, this study identified independent risk factors for urinary incontinence at various postoperative time points following RP and developed nomogram models with good predictive performance and clinical utility. These models serve as valuable tools for preoperative identification of high-risk patients, enabling the formulation of individualized intervention strategies to improve postoperative urinary continence recovery and overall quality of life.

Disclosure of conflict of interest

None.

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