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ORIGINAL RESEARCH

Construction and Validation of a Nomogram for Diagnosis of Female Stress Urinary Incontinence Combined with Anatomic/Intrinsic Urethral Sphincter Deficiency

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Background: In order to improve the diagnostic accuracy of anatomical/intrinsic sphincter deficiency (ISD) in female patients with stress urinary incontinence (SUI) and to provide a reference for surgical approaches, we developed a nomogram model based on urodynamic parameters.

Methods: Clinical data from 1150 women with complicated SUI treated at the Department of Urology, Third Xiangya Hospital, Central South University (01/01/2017–10/30/2023) were retrospectively analyzed. Patients were randomly divided into a training cohort (805 cases, 70%) and a validation cohort (345 cases, 30%). ISD was diagnosed by maximum urethral closure pressure (MUCP <30 cmH_2O) or Valsalva leak point pressure (VLPP ≤60 cmH_2O). Independent predictors of ISD were identified in the training cohort using binary logistic regression to construct the nomogram, validated using the validation cohort.

Results: Multivariate analysis identified abdominal pressure to urinate, IBPM, voiding time, urethral closure pressure, MUCP, and VLPP as independent predictors of ISD. The nomogram demonstrated good discrimination: training cohort AUC = 0.8308 (95% CI: 0.8022–0.8604); validation cohort AUC = 0.8408 (95% CI: 0.7964–0.8844). Decision curve analysis (DCA) indicated significant clinical benefit for both cohorts.

Conclusion: This urodynamic parameter-based nomogram (incorporating abdominal pressure to urinate, IBPM, voiding time, urethral closure pressure, MUCP, and VLPP) provides higher diagnostic accuracy for identifying anatomical/structural differences (ISD) in women with complicated SUI compared to traditional criteria (MUCP <30 cmH_2O or VLPP ≤60 cmH_2O), providing important references for the selection of surgical approaches.

Keywords: stress urinary incontinence, SUI, intrinsic sphincter deficiency, ISD, nomogram

Instruction

Stress urinary incontinence (SUI) is defined as any involuntary leakage of urine, associated with physical activity, such as exercise, sneezing, coughing, laughing, or bending over.[1,2] About 15.7% of adult US women are afflicted with the disease.[3] In Chinese women, the prevalence of SUI is 18.9%,[4] which is one of the important diseases that seriously affect women's socialization and quality of life. Pathophysiologically, SUI is thought to be caused by urethral hypermobility and intrinsic sphincter deficiency (ISD).[5] ISD is mainly associated with injuries to the urethral intrinsic sphincter, including damage, laxity, stiffness, and scarring, which result in incomplete closure of the urethral orifice.[6] Mid-urethral sling surgery (MUS) is the preferred treatment for stress urinary incontinence (SUI), employing either a mid-urethral approach or a transobturator approach. For patients with mild to moderate SUI, the efficacy of MUS is comparable between the two approaches.[7] However, for those with severe SUI or intrinsic sphincter deficiency (ISD), it is

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recommended to use the mid-urethral approach, as it demonstrates significantly higher subjective and objective cure rates compared to the transobturator approach.[8] Based on this, early and accurate diagnosis of intrinsic sphincter deficiency (ISD) is essential for selecting the appropriate surgical approach and improving the effectiveness of the surgery to enhance the quality of life for patients.

Current criteria for judging whether combined with ISD is quantifiable are maximum urethral closure pressure (MUCP < 30 cmH20) or abdominal leak point pressure (VLPP < = 60 cmH20).[9,10] However, classification criteria are still debated,[11–13] and existing criteria do not accurately distinguish ISDs in clinical practice. Therefore, improving the accuracy of judging female SUI with ISD has become an urgent problem to be solved. We hypothesize that, in addition to the Valsalva leak point pressure (VLPP) and maximum urethral closure pressure (MUCP), there may be other quantifiable urodynamic parameters that could help improve the diagnostic accuracy of intrinsic sphincter deficiency (ISD). Over the past six years, we have collected data from 3021 women with stress urinary incontinence (SUI), of whom 1150 underwent preoperative urodynamic studies. Our goal is to enhance the accuracy of identifying the ISD subtype of SUI in women by establishing a nomogram model based on these urodynamic parameters.

Research Materials and Methods

Clinical Data

This study conducted a retrospective analysis by screening the medical records of 3021 patients diagnosed with stress urinary incontinence (SUI) between January 1, 2017, and October 30, 2023. A total of 1150 cases that underwent urodynamic testing prior to surgery were ultimately selected for the analysis.; pressure induction test and bladder neck lifting test were (+). Criteria for diagnosis of ISD: MUCP < 30 cmH20 or VLPP < = 60 cmH20. Exclusion criteria: (1) combined urgency incontinence (2) neurogenic incontinence (3) history of neurological trauma (4) urinary tract infection (5) taking drugs that may affect bladder function. Complicated SUI is classified as SUI after previous incontinence surgery, extensive pelvic surgery including mesh removal surgery, a history of pelvic irradiation, presence of POP, voiding symptoms or significant overactive bladder/urge UI, and neurogenic lower urinary tract dysfunction. Combined urgency incontinence, neurogenic incontinence, history of neurological trauma, urinary tract infection and taking drugs that may affect bladder function will not be tackled in this article.

Urodynamic Examination

Urodynamic equipment was manufactured in 2016 by Medizinische Systeme GmbH, ANDROMEDA, Germany. Model: Ellipse. Product standard: YZB/GER 1948–2013 Urodynamic Analyzer. During the uroflowmetry phase, female patients were seated and catheterization was performed after voiding to determine residual urine volume. Patients were seated during the filling cystometry, urethral pressure tracing, and pressure-flow rate measurement phases. Patients in the abdominal leak point pressure measurement phase were recorded in the Valsalva leak point pressure measurement (VLPP) in the sitting position.

Study Method

A simple randomization method was used to divide the patients into the modeling group 805 (70%) and the validation group 345 (30%) according to the order of enrollment. Based on the criteria for diagnosing intrinsic sphincter deficiency (ISD): MUCP < 30 cmH20 or VLPP ≤ 60 cmH20, variables with a p-value < 0.05 were selected through univariate analysis. Subsequently, independent factors predicting ISD were identified based on group data from multivariate logistic regression analysis. A nomogram model was then constructed and validated using data from a validation set (see Figure 1 for details).

Statistical Methods

Statistical analysis was performed using IBM spss statistics 26.0 and R4.3.2 statistical software. Continuous variables in normally distributed data were presented as X ± SD, and comparisons between groups were performed with independent samples *t*-tests. Continuous variables for non-normally distributed data were expressed as M (Q25, Q75), and

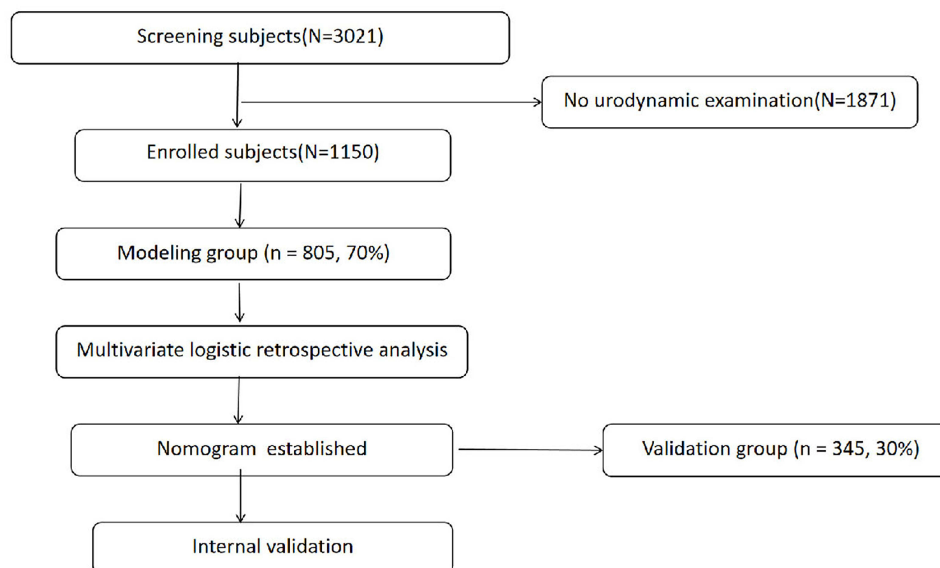

Figure 1 Schematic Diagram.

comparisons between groups were performed using the Wilcoxon test. Missing data were imputed using mean imputation. Qualitative or categorical data were presented as frequencies (percentages) and comparisons between groups were performed using the Chi-square test. Univariate and multivariate binary logistic regression analysis was performed based on the data of the modeling group to select indicators with independent effects on outcome events, and receiver operating characteristic (ROC) curves were selected to analyze the diagnostic efficacy of each independent indicator. Multivariate binary logistic regression analysis was also used to screen indicators that had an independent effect on outcome events to construct nomograms. The model was validated internally and externally to investigate the predictive performance. The discrimination of the model was verified by AUC of the area under the curve of the ROC curve. Hosmer-lemeshow goodness-of-fit was selected to test model calibration. Finally, the net benefit and clinical efficacy of the model were explored by plotting the clinical decision curve analysis (DCA) based on the nomogram model results.

Results

General Information

Of the 1150 SUI patients enrolled, 6 had bladder outlet obstruction, 39 had overactive bladder, 8 had detrusor weakness, 61 had pelvic floor organ prolapse, and 4 had urethral caruncle. Patients were divided into modeling group (n = 805, 70%) and validation group (n = 345, 30%) using a simple randomization method. There were no statistically significant differences in the general data between the modeling group and the validation group ($P > 0.05$, see Table 1 for details). The result indicates that there is no selection bias between the validation group data and the modeling group data, demonstrating high data credibility, which can be used for subsequent data validation analysis.

Comparison Between ISD Group and Non-ISD Group

Among the 1150 patients, based on the criteria for the diagnosis of intrinsic sphincter deficiency (ISD): MUCP < 30 cmH20 or VLPP ≤ 60 cmH20, a total of 510 patients (44%) were clinically classified as having ISD. This included 350 patients (69%) in the model group and 160 patients (31%) in the validation group. Of the 805 patients in the modeling group, 350 were diagnosed as ISD and 455 as non-ISD. There were significant differences in PVR, MCC, IBPM, Pdet-max, urination time, UCP, MUCP, Vesical neck pressure and VLPP values between the two groups ($P < 0.05$). However, there were no statistically significant differences in age, Qmax and VV ($P > 0.05$) (see Table 2 for details). Of the 345 patients in the validation group, 160 were diagnosed with ISD and 185 were non-ISD. There were significant differences in age, urination time, UCP, MUCP, Vesical neck pressure and VLPP values between the two groups ($P < 0.05$). At the

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Table 1 Comparison of Baseline Characteristics Between Training and Validation Cohorts

	Modeling Group (X±SD)(N=805)	Validation Group (X±SD)(N=345)	P
Qmax	17.2 (±8.0)	16.8 (±7.9)	0.392
Vv	201.9 (±127.4)	194.3 (±121)	0.354
PVR	10.1 (±45.3)	8.5 (±47)	0.573
Urination time	28.3 (±25.7)	30.3 (±31)	0.253
MCC	333.8 (±119.3)	333.9 (±126.4)	0.989
IBPM	11.1 (±11.2)	9.8 (±9.7)	0.064
Pdet-max	23.9 (±16.2)	21.4 (±12.9)	0.954
UCP	57.9 (±19.7)	57.7 (±19.4)	0.846
MUCP	49.5 (±22.3)	48.2 (±16.7)	0.308
Vesical neck pressure	25.5 (±7.8)	25.7 (±8.5)	0.684
VLPP	55.9 (±37.6)	59.6 (±39.7)	0.143

Abbreviations: Qmax, Maximum flow rate; Vv, Voided volume; PVR, Post Void Residual; MCC, Maximum cystometric capacity; IBPM, Initial Bladder Pressure during Micturition; Pdet, Detrusor pressure; UCP, Urethral Closure Pressure; MUCP, Maximum urethral closure pressure; VLPP, Valsalva leak point pressure.

Table 2 Comparison of Characteristics Between ISD and Non-ISD Groups (X±SD)

	Modeling Group (N=805)			Validation Group (N=345)		
	ISD Group (350)	Non-ISD Group (455)	P	ISD Group (160)	Non-ISD Group (185)	P
Age	54 (±12)	53 (±9)	0.06	56 (±11)	53 (±10)	0.04
Qmax	17.3 (±8.6)	17.2 (±7.6)	0.988	17.4 (±8.5)	16.3 (±7.4)	0.226
Vv	192.8 (±123.9)	208.8 (±129.8)	0.082	191.4 (±132.0)	196.8 (±111.2)	0.679
PVR	6.5 (±38.3)	12.9 (±49.8)	0.048	6.8 (±36.0)	9.9 (±54.9)	0.547
MCC	317.8 (±127.7)	346.1 (±110.9)	0.001	322.6 (±136.2)	343.7 (±116.8)	0.123
IBPM	9.3 (±10.1)	12.4 (±11.8)	0	9.4 (±8.1)	10 (±10.9)	0.574
Pdet-max	22.4 (±16.4)	25.1 (±15.9)	0.022	20.7 (±12.7)	21.9 (±13.1)	0.392
Urination time	53.6 (±47.3)	61.1 (±51.7)	0.038	52.6 (±44.6)	67.1 (±69.6)	0.027
UCP	50.5 (±18.1)	63.7 (±19.0)	0	50.6 (±19.6)	63.8 (±17.0)	0
MUCP	42.9 (±16.4)	54.6 (±24.8)	0	41.9 (±17.2)	53.6 (±14.2)	0
Vesical neck pressure	23.6 (±7.8)	27 (±7.4)	0	23.4 (±7.5)	27.8 (±8.8)	0
VLPP	39.2 (±24.1)	67.2 (±40.7)	0	40 (±24.3)	74.7 (±42.7)	0

Abbreviations: Qmax, Maximum flow rate; Vv, Voided volume; PVR, Post Void Residual; MCC, Maximum cystometric capacity; IBPM, Initial Bladder Pressure during Micturition; Pdet, Detrusor pressure; UCP, Maximum urethral pressure; MUCP, Maximum urethral closure pressure; VLPP, Valsalva leak point pressure.

same time, there was no significant difference in Qmax, Vv, PVR, MCC and initial bladder pressure during urination ($P > 0.05$) (see Table 2 for details).

Univariate and Multivariate Analysis of SUI Classification in Modeling Group

The results of univariate analysis showed that there were significant differences in MCC, IBPM, Pdet-max, urination time, UCP, MUCP, Vesical neck pressure and VLPP values between the two groups ($P < 0.05$). The results of multivariate analysis showed that abdominal pressure to urinate, IBPM, Urination time, UCP, MUCP, and VLPP were independent factors for ISD in SUI patients ($P < 0.05$) (see Table 3 for details).

Modeling Group ROC Analysis

The ROC curve of multivariate analysis results in the modeling group (Figure 2 and Table 4) showed that VLPP (AUC = 0.753, 95% CI: 0.715–0.789), UCP (AUC = 0.732, 95% CI: 0.695–0.769), MUCP (AUC = 0.728, 95% CI: 0.691–0.766),

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Table 3 Univariable and Multivariable Analyses of SUI Subtypes in the Modeling Cohort

	Univariate Analysis			Multivariate Analysis		
	OR	95% CI	P	OR	95% CI	P
Age	1.013	1.000–1.026	0.057			
MCC	0.998	0.997–0.999	0.001			
IBPM	0.973	0.959–0.987	0.00001	0.95	0.926–0.975	0.0001
Pdet-max	0.989	0.980–0.999	0.023			
Urination time	0.997	0.994–1.000	0.041	0.995	0.991–1.000	0.034
UCP	0.961	0.952–0.969	0.0001	0.962	0.939–0.987	0.002
MUCP	0.957	0.947–0.967	0.001	0.959	0.935–0.983	0.001
Vesical neck pressure	0.94	0.922–0.959	0.0001			
VLPP	0.976	0.971–0.981	0.001	0.972	0.966–0.978	0.0001
Abdominal pressure to urinate	0.645	0.483–0.861	0.003	0.574	0.373–0.883	0.011

Abbreviations: Qmax, Maximum flow rate; Vv, Voided volume; PVR, Post Void Residual; MCC, Maximum cystometric capacity; IBPM, Initial Bladder Pressure during Micturition; Pdet, Detrusor pressure; UCP, Urethral Closure Pressure; MUCP, Maximum urethral closure pressure; VLPP, Valsalva leak point pressure.

IBPM (AUC = 0.622, 95% CI: 0.581–0.662), Urtime (AUC = 0.554, 95% CI: 0.511–0.596), and abdominal pressure to urinate (AUC = 0.550, 95% CI: 0.507–0.592) had decreasing predictive accuracy for ISD in turn.

VLPP (light green) demonstrated significantly higher AUC than other parameters. The AUC of UCP, MUCP, IBPM, Urination time and Abdominal pressure to urinate progressively declined. Abdominal pressure to urinate demonstrated significantly lower AUC than other parameters.

Nomogram Model Building

A nomogram model was constructed according to abdominal pressure to urinate, IBPM, Urination time, UCP, MUCP, VLPP (Figure 3). Illustration: A patient with SUI who underwent a pressure-induced test and bladder neck lift test (+) underwent urodynamic examination showed that no abdominal pressure to urinate scored 5 points, IBPM scored 31 points at 10 cmH_2O, Urination time scored 16 points at 50s, UCP scored 12.5 points at 70 cmH_2O, MUCP scored 92.5 points at 40 cmH_2O, VLPP scored 25 points at 70 cmH_2O, with a total score of 182 points, and 182 points corresponded to a probability of ISD of approximately 43%.

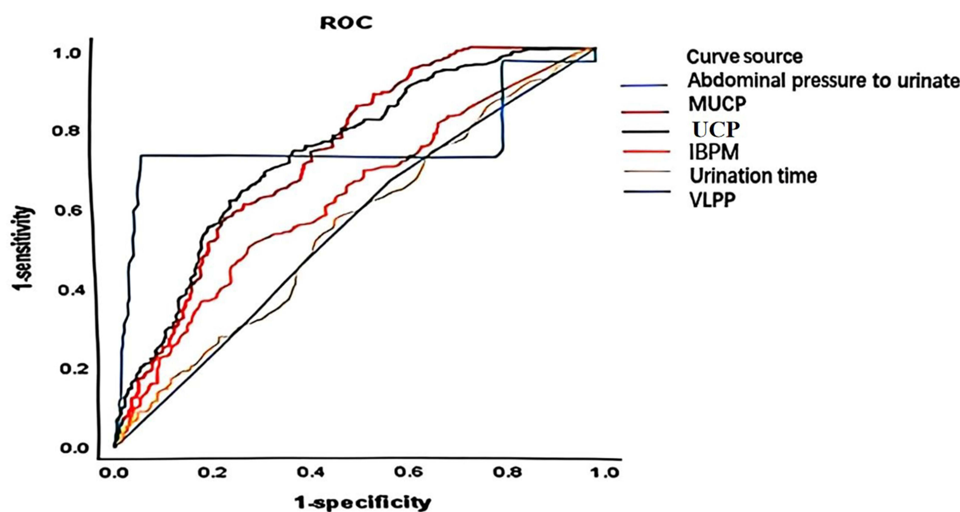

Figure 2 ROC Analysis in the Modeling Cohort.

Table 4 ROC Analysis in the Modeling Cohort

	AUC	95% CI	P
Abdominal pressure to urinate	0.550	0.507–0.592	0.022
IBPM	0.622	0.581–0.662	<0.001
Urination time	0.554	0.511–0.596	0.014
UCP	0.732	0.695–0.769	<0.001
MUCP	0.728	0.691–0.766	<0.001
VLPP	0.752	0.715–0.789	<0.001

Model Validation

The internal data validation results of the modeling group suggested that the AUC of the ROC curve for nomogram prediction of ISD was 0.8308 (95% CI: 0.8022–0. 8604). The external validation results of the validation group showed that the AUC of the ROC curve for nomogram prediction of ISD was 0.8408 (95% CI: 0.7964–0.8844). The calibration curves showed good agreement between the predictions of the nomograms for the modeling and validation groups and the actual measurements. (See Figure 4 for details).

Clinical Decision Curve Analysis

The DCA of the data from the modeling and validation groups (see Figure 5 for details) suggests that the net benefit interval of nomograms in predicting SUI with ISD classification is large and helpful for clinical decision-making.

Discussion

The treatment options for stress urinary incontinence mainly include conservative treatment (eg, pelvic floor muscle training, vaginal pessary), minimally invasive treatment options (eg, urethral bulking agents, CO2 laser, acupuncture, platelet-rich plasma), and invasive surgical treatment.[2] At present, the mainstream surgical approach is MUS. However, in patients with ISD, the efficacy of MUS was significantly worse than that in patients without ISD. For ISD patients, the

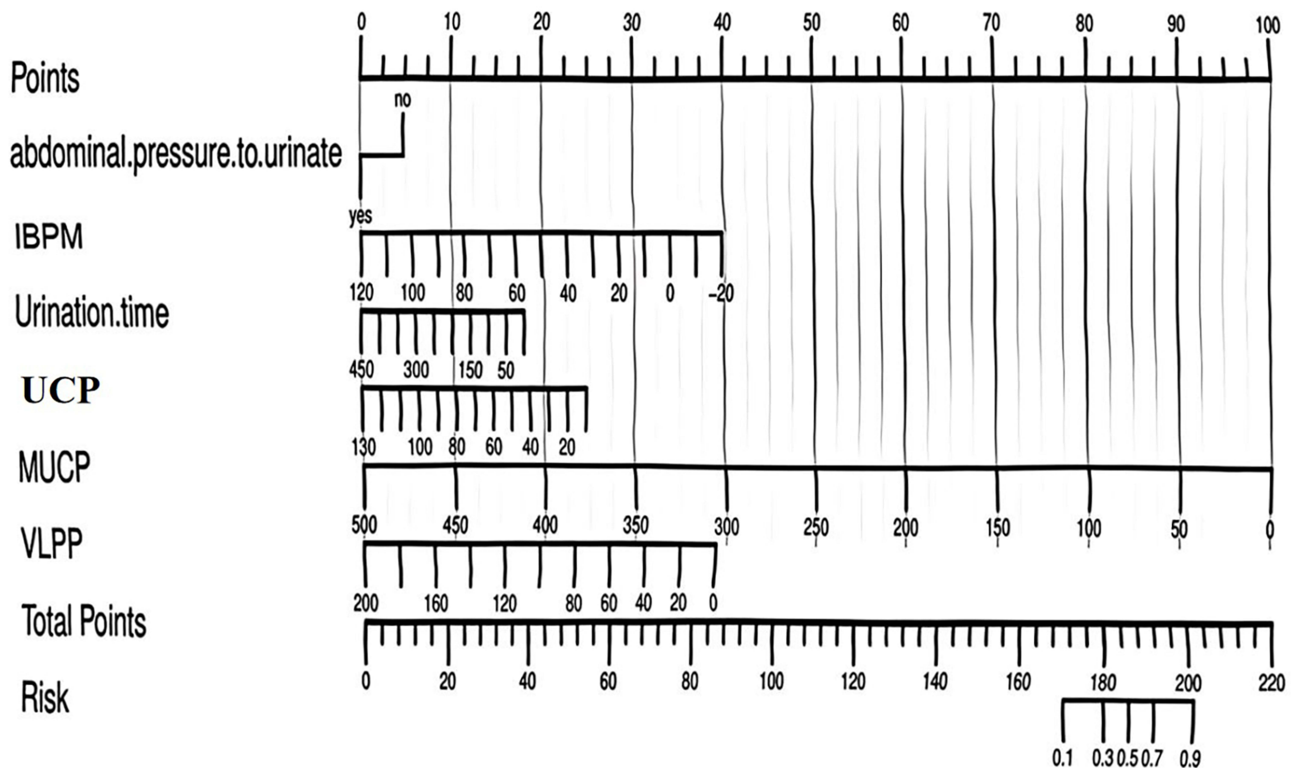

Figure 3 Nomogram Prediction Model.

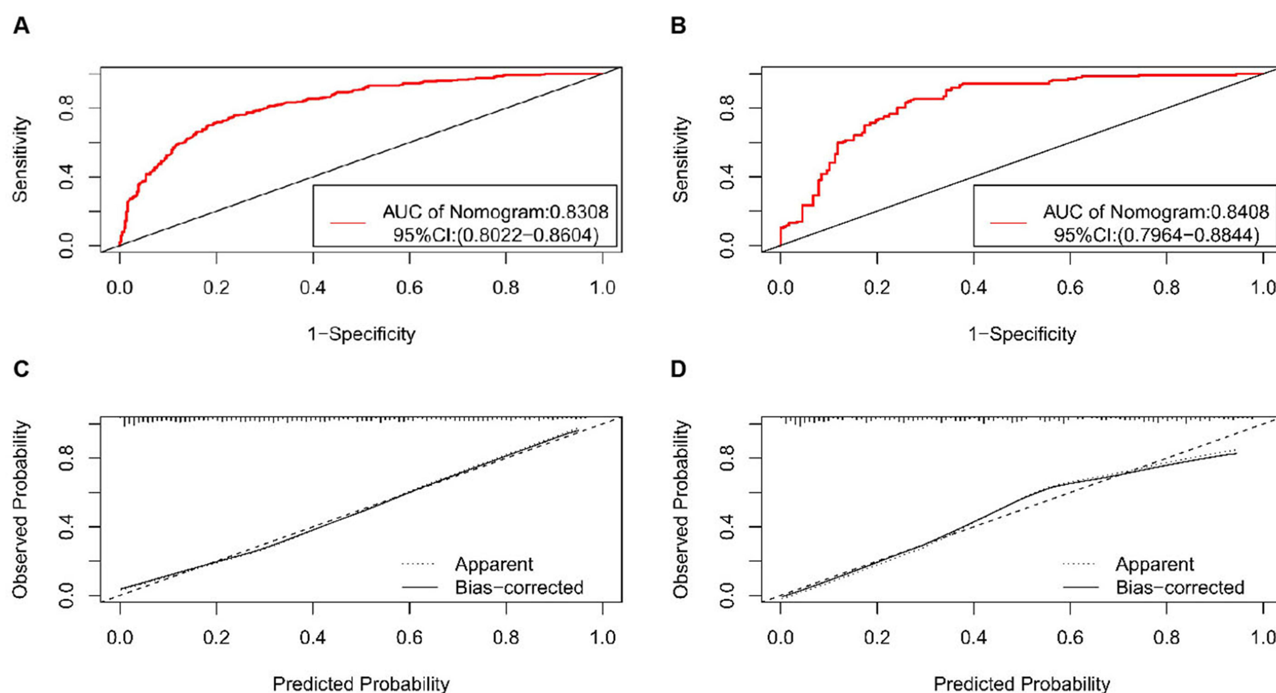

Figure 4 Model Validation Plot. (**A**) Internal validation ROC curve. (**B**) External validation ROC curve. (**C**) Internal validation calibration plot. (**D**) External validation calibration plot.

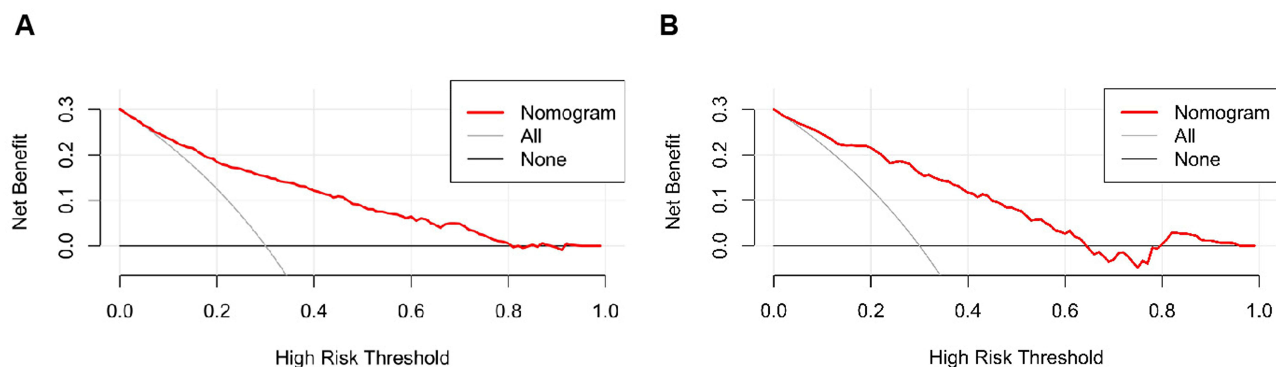

Figure 5 Clinical Decision Curve Analysis. (**A**) Decision curve analysis (DCA) of the modeling cohort. (**B**) DCA of the validation cohort.

long-term cure rate via the retropubic route is better than that via the obturator route.[8] Treatment by increasing the continence function of the urethra by surgery is more inclined.[14]

Therefore, it is very important to accurately separate patients with ISD from SUI. Current discrimination between ISDs is based primarily on MUCP or VLPP values. Because of limited accuracy, there are controversies in clinical practice[12,13,15,16] We found that after ISD grouping according to MUCP < =30 cmH20 or VLPP < = 60 cmH20, there were 80 ISD patients with mean MUCP = 42.9 (± 16.4) cmH20, 80 MUCP < = 30 cmH20, mean VLPP = 39.2 (± 24.1) cmH20, and 320 VLPP < = 60 cmH20 patients in the modeling group. In the validation group, the mean MUCP was 41.9 (± 17.2) cmH20 in ISD patients, 39 in MUCP < = 30 cmH20 patients, 40 (± 24.3) cmH20 in VLPP, and 144 in VLPP < = 60 cmH20 patients. Whether the current cut-off needs to be adjusted to make it more perfect is an issue that deserves the attention of the urologist community. How to improve the ISD judgment has practical value. Urodynamic testing is irreplaceable in identifying lower urinary tract disease, and changes in urodynamics in SUI are mainly VLPP or urethral pressure changes. It is now agreed that preoperative urodynamic testing is recommended for patients with complicated

stress urinary incontinence, or poor response to previous treatment.[10] Of 1150 SUI patients enrolled for urodynamic testing, 510 (44%) were finally clinically classified as ISD. From the modeling group data, ISD patients showed significant changes in voiding time, intravesical pressure changes, and urethral pressure relative to non-ISD patients. Univariate and multivariate logistic analysis revealed that VLPP (AUC = 0.753, 95% CI: 0.715–0.789) and MUCP (AUC = 0.728, 95% CI: 0.691–0.766) had limited predictive effects for the development of ISD. However, if a nomogram was constructed based on the indicators abdominal pressure to urinate, IBPM, Urination time, UCP, MUCP, and VLPP identified by multivariate logistic analysis to form a new model for predicting the occurrence of ISD, the AUC of the ROC curve was 0.8308 (95% CI: 0.8022–0.8604), which can better predict the occurrence of ISD and has better accuracy. The external validation results of the validation group showed that the AUC of the ROC curve for nomogram prediction of ISD was 0.8408 (95% CI: 0.7964–0.8844), which was consistent with the conclusion of the modeling group. Further calibration curve and clinical decision curve analysis showed that the predicted results of this model were in good agreement with the actual measured values and had a large net benefit interval. Our retrospective analysis found that patients who developed ISD were more likely to have concomitant changes in bladder compliance or functional capacity. This may be related to the changes in urethral structure, poor continence function, severe leakage, and long-term inability of the bladder to fully dilate in patients with ISD, which affects the bladder reservoir function. Therefore, early identification of ISD patient groups and early measures can help to protect bladder function and improve the quality of life of patients. This means that nomogram models are not only able to accurately predict ISDs, but also provide valuable references in clinical decision-making. The new predictive model has a superior predictive effect and can provide a more valuable reference for urologists to develop treatment plans for patients.

Our study also has some limitations. All patients were single-center cases. Although the prediction model yielded a high degree of prediction, it failed to form a more specific urologist-applicable scoring scale, and the clinical utility remains limited. In the next step, we will use a multicenter, prospective study to form specific subscales according to the prediction model and further explore the applicability of the model in different populations, combined with other imaging or biomarkers, to improve the accuracy of diagnosis and treatment of SUI and ISD. At the same time, clinicians should combine the specific circumstances of individual patients, comprehensively consider many factors, optimize the diagnosis and treatment strategies, in order to better improve the quality of life of patients.

Ethical Approval Statement

This study was approved by the Ethics Committee of the Third Xiangya Hospital of Central South University (Approval No: Expedited 23928). The study was conducted in accordance with the Declaration of Helsinki, relevant national and institutional guidelines, and ethical standards. Written informed consent was obtained from all patients.

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Disclosure

The authors report no conflicts of interest in this work.

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