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The authors declare no conflict of interest.

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PROGNOSTIC MODELING OF FUNCTIONAL STATUS IN PATIENTS WITH NEUROGENIC BLADDER BASED ON CLINICAL AND URODYNAMIC PREDICTORS

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Neurogenic bladder is associated with complex lower urinary tract dysfunction that may lead to functional limitations and impaired quality of life. Considerable interindividual variability in clinical outcomes highlights the need for personalized prediction of rehabilitation results. The aim of the study was to develop prognostic models of functional limitations and quality of life in patients with neurogenic bladder at 3 months. The study included 40 patients with neurogenic urinary tract dysfunction. Demographic, clinical, and urodynamic characteristics were assessed, together with lower urinary tract symptoms using the ICIQ-OAB questionnaire, functional status using WHODAS 2.0, and quality of life using WHOQOL-BREF. Prognostic models were developed using multiple linear regression analysis based on eight predefined predictors. Five statistically significant prognostic models were developed. The WHODAS 2.0 model explained 64.9% of the variance (adjusted $R^2=0.559$; $p<0.001$), while the four WHOQOL-BREF domain models explained 60.0–64.5% of the variance (adjusted $R^2=0.496–0.553$; $p<0.001$). The ICIQ-OAB score was the most consistent independent predictor, while urinary tract infection made a statistically significant contribution to all models. The developed prognostic equations enable quantitative estimation of expected functional limitations and quality-of-life outcomes at 3 months and may provide a basis for personalized rehabilitation planning. Further prospective validation of the models is required.

Key words: neurogenic bladder, urodynamic study, prognostic model, functional limitations, quality of life, rehabilitation management.

Connection of the publication with planned research work.

The study was conducted in accordance with the consolidated research plan of the research topic “Medical, physiotherapeutic and occupational therapy support of sports, health-promoting and rehabilitation training” (state registration number 0121U114435) of the Department of Physical Rehabilitation, Sports Medicine and Vasculariology, Dnipro State Medical University.

Introduction.

Neurogenic lower urinary tract dysfunction is one of the most common and complex manifestations of neu-

rological diseases and injuries of the nervous system [1]. It accompanies a wide range of pathological conditions, including spinal cord injury, multiple sclerosis, spina bifida, Parkinson's disease, stroke, and other disorders of the central and peripheral nervous systems [2]. According to current studies and clinical guidelines, symptoms of neurogenic urinary dysfunction occur in more than 70–90% of patients after spinal cord injury, in 50–90% of patients with multiple sclerosis, and in a substantial proportion of individuals with cerebrovascular and neurodegenerative diseases [3–7].

Neurogenic bladder results from impaired complex neurophysiological interactions between the central and peripheral nervous systems that coordinate the storage and emptying phases of the urinary bladder. The localization and nature of the neurological lesion determine the development of different types of lower urinary tract dysfunction, including neurogenic detrusor overactivity, detrusor areflexia, detrusor-sphincter dyssynergia, and sphincteric insufficiency, each characterized by distinct clinical manifestations and risks of urological complications.

Impaired bladder storage and emptying not only cause clinical symptoms such as urinary incontinence, urgency, urinary retention, or the need for catheterization, but also substantially increase the risk of urinary tract infections, vesicoureteral reflux, upper urinary tract damage, urolithiasis, and chronic renal failure [8–10]. At the same time, these disorders considerably affect patients' daily functioning, social activity, psychological well-being, and quality of life, making neurogenic bladder an important problem in contemporary rehabilitation medicine [11–13].

Despite substantial advances in the diagnosis and treatment of neurogenic lower urinary tract dysfunction, current clinical decisions are predominantly based on individual clinical or urodynamic parameters and do not account for their combined effects on patient functioning [14]. Rehabilitation outcomes, however, are determined by multiple factors, including demographic characteristics, disease duration, clinical manifestations of urinary dysfunction, urodynamic parameters, and patients' subjective assessment of symptoms [15]. Comprehensive quantitative assessment of the contribution of these predictors to functional limitations and reduced quality of life remains insufficiently studied.

Therefore, the application of mathematical modeling and multivariable statistical methods represents a promising approach for developing prognostic models capable of comprehensively quantifying the contribution of clinical, functional, and urodynamic factors to functional limitations and quality of life. Such an approach may provide a basis for personalized prediction of rehabilitation outcomes and individualization of rehabilitation management.

The aim of the study.

To develop and statistically substantiate a prognostic model of the level of disability and quality of life in patients with neurogenic bladder during the long-term rehabilitation period by determining the quantitative contribution of clinical, functional, and urodynamic predictors using multiple regression analysis.

Object and research methods.

The study was conducted in accordance with the principles of the Declaration of Helsinki of the World Medical Association, "Ethical Principles for Medical Research Involving Human Subjects" (revised in October 2013), and was approved by the Biomedical Ethics Committee of Dnipro State Medical University (Protocol No. 12 dated October 25, 2023). The study was performed in accordance with the principles of evidence-based medicine as a single-center observational retrospective-prospective analytical study. All patients provided written informed consent to participate in the study and to publication of the study results.

A total of 40 patients with symptoms of neurogenic bladder were examined. Participants were selected using purposive sampling among individuals undergoing rehabilitation and follow-up in specialized departments and at the Rehabilitation Center of the University Hospital of Dnipro State Medical University.

The inclusion criteria were: age ≥ 18 years; male or female sex; symptoms of neurogenic urinary dysfunction associated with spinal cord injury or chronic spinal cord diseases, including conditions related to structural spinal disorders; multiple sclerosis; spina bifida; Parkinson's disease; sequelae of acute cerebrovascular disorders and/or traumatic brain injury; ability to complete the questionnaires independently or with assistance from a trusted person; and written informed consent to participate in the study and publication of the results.

The exclusion criteria were: absence of documented results of comprehensive urodynamic testing required for analysis; urological diseases, including benign prostatic hyperplasia in men, chronic non-neurogenic incontinence, congenital abnormalities and/or consequences of traumatic injuries of the genitourinary system; and performance of percutaneous transcatheter tibial electrical stimulation of the urinary bladder between assessments T0 and T1.

For each participant, medical history was collected, including review of medical records, to identify exclusion criteria, followed by comprehensive assessment using clinical, functional, and questionnaire-based methods.

For development of the prognostic model, all potential predictors were initially grouped into three thematic blocks according to their clinical significance: demographic characteristics, clinical indicators and urological complications, and urodynamic parameters (**table 1**).

Body mass index (BMI) was calculated as body weight (kg) divided by height squared (m^2), in accordance with World Health Organization recommendations [16]. BMI was analyzed as a continuous variable (kg/m^2) in the statistical analysis, whereas WHO classification was used when describing the clinical characteristics of the sample.

Table 1 – Predictor system of the prognostic model

Predictor block	Variables
Demographic	Age (years); Body mass index (kg/m^2); Sex
Urological	Disease duration (years); Total ICIQ-UI SF score; Total ICIQ-OAB score; Urinary tract calculi (yes/no); Vesicoureteral reflux (yes/no); Urinary tract infection (yes/no); Urinary leakage during increased intra-abdominal pressure (yes/no)
Urodynamic	Maximum cystometric capacity (mL); Detrusor compliance index, $\Delta V/\Delta P_{det}$; Bladder outlet obstruction index (BOOI); Bladder Contractility Index (BCI); Bladder Voiding Efficiency (BVE, %)

Validated Ukrainian-language versions of the ICIQ-UI SF [17] and ICIQ-OAB [18] questionnaires were used to assess the severity of urinary symptoms.

Urodynamic testing was performed in accordance with standardized principles for the performance and interpretation of urodynamic studies established by the International Continence Society (ICS), with assessment of bladder storage and emptying function parameters [19].

Objective assessment of lower urinary tract function was provided by comprehensive urodynamic testing, which enabled quantitative assessment of bladder reservoir and evacuation functions, detrusor contractility, infravesical obstruction, compliance, and emptying efficiency. Urodynamic testing was performed using the Solar Blue modular wireless urodynamic system (Laborie, the Netherlands; formerly Medical Measurement Systems, MMS).

For comprehensive assessment of quality of life and disability at 3 months after the initial assessment, standardized instruments were used: the WHODAS 2.0 (36-item version) (World Health Organization Disability Assessment Schedule 2.0) [20–22] to assess overall functioning and social functioning, and the WHOQOL-BREF (Ukrainian version) [23, 24] to assess subjective health-related quality of life.

The 3-month follow-up period was selected as a clinically meaningful prognostic horizon sufficient to assess early functional changes and changes in quality of life in patients with neurogenic bladder. In accordance with the contemporary principles of prognostic model development and the TRIPOD framework, all predictors were assessed at the time of the initial examination (T0), whereas outcome measures were assessed after 3 months (T1), ensuring temporal ordering between predictors and predicted outcomes [25].

Statistical analysis was performed using STATISTICA 6.1 (StatSoft Inc., USA; license No. AGAR909E415822FA). Quantitative variables were described using the arithmetic mean (M), standard deviation (SD), median (Me), lower and upper quartiles (Q25; Q75), and minimum and maximum values. Qualitative variables were presented as absolute frequencies (n) and percentages (%).

At the initial analysis stage, correlation analysis was performed to assess the strength and direction of associations between potential predictors and functional and quality-of-life outcomes. Pearson's correlation coefficient was used for quantitative and binary-coded variables; binary predictors were coded as 0/1.

Multiple linear regression analysis was used to develop the prognostic models. The dependent variables assessed 3 months after the initial examination were, sequentially, the overall level of disability according to WHODAS 2.0 and the four quality-of-life domains according to WHOQOL-BREF: physical health, psychological well-being, social relationships, and environment. The same predefined set of eight predictors was used in all models: age, sex, body mass index, disease duration, ICIQ-OAB score, presence of urinary tract calculi, presence of urinary tract infection, and Bladder Contractility Index (BCI). The performance of the models was assessed using the multiple correlation coefficient (R), coefficient of determination (R^2), adjusted coefficient of determination, and significance of the F-test. The independent contribution of individual predictors was assessed using standardized regression coefficients (β), unstandardized regression coefficients (B), and corresponding levels of statistical significance. Multicollinearity was assessed using predictor tolerance values. Regression model diagnostics included analysis of standardized residuals, normal probability plots of residuals, plots of residuals against predicted values, as well as Mahalanobis distance and Cook's distance to identify potentially influ-

ential observations [26, 27]. Statistical significance was defined as $p < 0.05$.

Research results and their discussion.

The study included 40 patients with neurogenic bladder. The mean age of the participants was 44.6 ± 11.84 years. The mean body mass index was 27.6 ± 4.92 kg/m². The mean disease duration was 9.7 ± 6.03 years.

Bladder calculi were detected in 23 (57.5%) patients, urinary tract infection in 22 (55.0%), and vesicoureteral reflux in 16 (40.0%). Urinary leakage during increased intra-abdominal pressure during urodynamic testing was recorded in 22 (55.0%) patients.

The mean ICIQ-UI SF score was 7.08 ± 2.53 points, while the mean ICIQ-OAB score was 7.35 ± 2.66 points. Among the urodynamic parameters assessed, mean bladder compliance was 21.38 ± 16.39 mL/cm H₂O, maximum cystometric capacity was 358.0 ± 196.48 mL, BOOI was 28.25 ± 15.88 , BCI was 134.55 ± 60.24 , and Bladder Voiding Efficiency was $37.1 \pm 13.10\%$.

At the functional assessment stage, the mean overall level of disability according to WHODAS 2.0 was $48.3 \pm 13.60\%$. The mean WHOQOL-BREF domain scores were 12.29 ± 2.27 for physical health, 13.19 ± 2.29 for psychological well-being, 13.66 ± 2.31 for social relationships, and 14.34 ± 2.39 for environment.

Initial correlation analysis and selection of predictors. To identify potential predictors of functional limitations and quality of life, correlation analysis was performed between baseline clinical, demographic, and urodynamic characteristics and the WHODAS 2.0 and WHOQOL-BREF outcomes. The analysis included 40 observations; associations were considered statistically significant at $p < 0.05$.

Age was not significantly associated with either the level of disability according to WHODAS 2.0 or any WHOQOL-BREF domain ($p > 0.65$). Similarly, sex was not significantly associated with the studied functional or quality-of-life outcomes ($p > 0.14$).

Body mass index demonstrated a moderate positive association with the level of disability according to WHODAS 2.0 ($r = 0.490$; $p = 0.001$). At the same time, higher BMI was associated with lower quality-of-life scores across all four WHOQOL-BREF domains: physical health ($r = -0.462$; $p = 0.003$), psychological well-being ($r = -0.449$; $p = 0.004$), social relationships ($r = -0.423$; $p = 0.007$), and environment ($r = -0.479$; $p = 0.002$).

Disease duration was also significantly associated with functional status. Longer disease duration was associated with a higher level of disability according to WHODAS 2.0 ($r = 0.445$; $p = 0.004$), whereas scores in all four WHOQOL-BREF domains decreased ($r = -0.422$ to -0.488 ; $p = 0.001$ – 0.007).

The strongest associations among the clinical characteristics were observed for symptom burden assessed using ICIQ-UI SF and ICIQ-OAB. The ICIQ-OAB score demonstrated a positive association with the level of disability according to WHODAS 2.0 ($r = 0.629$; $p < 0.001$) and negative associations with all four WHOQOL-BREF domains: physical health ($r = -0.613$; $p < 0.001$), psychological well-being ($r = -0.603$; $p < 0.001$), social relationships ($r = -0.603$; $p < 0.001$), and environment ($r = -0.620$; $p < 0.001$).

The presence of urinary tract calculi was associated with a higher level of disability according to WHODAS 2.0 ($r = 0.343$; $p = 0.030$) and lower scores in the physi-

Table 2 – Initial analysis of the associations between potential predictors and functional outcomes at 3 months

Potential predictor	WHODAS 2.0, %	WHOQOL-BREF: Physical Health	WHOQOL-BREF: Psychological Well-being	WHOQOL-BREF: Social Relationships	WHOQOL-BREF: Environment
Age, years	-0,014 (0,932)	0,033 (0,838)	-0,021 (0,900)	0,061 (0,708)	0,074 (0,652)
Sex	-0,226 (0,162)	0,233 (0,148)	0,223 (0,167)	0,195 (0,228)	0,224 (0,165)
Body mass index	0,490 (0,001)	-0,462 (0,003)	-0,449 (0,004)	-0,423 (0,007)	-0,479 (0,002)
Disease duration, years	0,445 (0,004)	-0,436 (0,005)	-0,488 (0,001)	-0,423 (0,007)	-0,433 (0,005)
ICIQ-UI SF	0,560 (<0,001)	-0,556 (<0,001)	-0,544 (<0,001)	-0,549 (<0,001)	-0,548 (<0,001)
ICIQ-OAB	0,629 (<0,001)	-0,613 (<0,001)	-0,603 (<0,001)	-0,603 (<0,001)	-0,620 (<0,001)
Presence of urinary tract calculi	0,343 (0,030)	-0,341 (0,031)	-0,329 (0,038)	-0,258 (0,107)	-0,384 (0,014)
Urinary tract infection	0,421 (0,007)	-0,418 (0,007)	-0,451 (0,003)	-0,425 (0,006)	-0,377 (0,017)
Vesicoureteral reflux	0,198 (0,220)	-0,181 (0,264)	-0,176 (0,278)	-0,152 (0,348)	-0,215 (0,183)
Bladder compliance, $\Delta V/\Delta P_{det}$	-0,087 (0,595)	0,110 (0,500)	0,122 (0,454)	0,064 (0,696)	0,097 (0,552)
Urinary leakage during increased intra-abdominal pressure	0,073 (0,656)	-0,078 (0,634)	-0,041 (0,804)	-0,037 (0,821)	-0,044 (0,786)
Maximum cystometric capacity, mL	-0,089 (0,585)	0,112 (0,491)	0,123 (0,450)	0,068 (0,678)	0,099 (0,543)
BOOI	0,148 (0,364)	-0,169 (0,297)	-0,174 (0,284)	-0,118 (0,467)	-0,157 (0,334)
BCI	0,105 (0,521)	-0,128 (0,430)	-0,136 (0,402)	-0,084 (0,608)	-0,114 (0,485)
Bladder Voiding Efficiency, %	-0,248 (0,122)	0,232 (0,150)	0,204 (0,208)	0,217 (0,178)	0,248 (0,123)

Notes: Pearson correlation coefficients (r) and corresponding p values are presented; n=40. For binary variables coded as 0/1, the Pearson correlation coefficient is equivalent to the point-biserial correlation.

cal health ($r=-0.341$; $p=0.031$), psychological well-being ($r=-0.329$; $p=0.038$), and environment ($r=-0.384$; $p=0.014$) domains of WHOQOL-BREF. The association with the social relationships domain was not statistically significant ($r=-0.258$; $p=0.107$).

Urinary tract infection was significantly associated with a higher level of disability according to WHODAS 2.0 ($r=0.421$; $p=0.007$) and lower scores across all four WHOQOL-BREF domains: physical health ($r=-0.418$; $p=0.007$), psychological well-being ($r=-0.451$; $p=0.003$), social relationships ($r=-0.425$; $p=0.006$), and environment ($r=-0.377$; $p=0.017$).

In contrast, vesicoureteral reflux was not significantly associated with the studied outcomes: WHODAS 2.0 ($r=0.198$; $p=0.220$), physical health ($r=-0.181$; $p=0.264$), psychological well-being ($r=-0.176$; $p=0.278$), social relationships ($r=-0.152$; $p=0.348$), or environment ($r=-0.215$; $p=0.183$).

Unlike clinical symptoms, most of the urodynamic parameters examined did not demonstrate statistically significant simple correlations with measures of functional status and quality of life (table 2).

Urodynamic parameters did not demonstrate statistically significant simple correlations with the studied outcomes. Specifically, bladder compliance, maximum cystometric capacity, BOOI, BCI, and Bladder Voiding Efficiency had $p>0.05$ across all analyzed outcomes. Likewise, urinary leakage during increased intra-abdominal pressure was not significantly associated with WHODAS

2.0 ($r=0.073$; $p=0.656$) or any WHOQOL-BREF domain ($p=0.634-0.821$).

The absence of statistically significant simple correlations was not considered sufficient grounds for automatically excluding urodynamic parameters from the prognostic analysis, because their potential independent

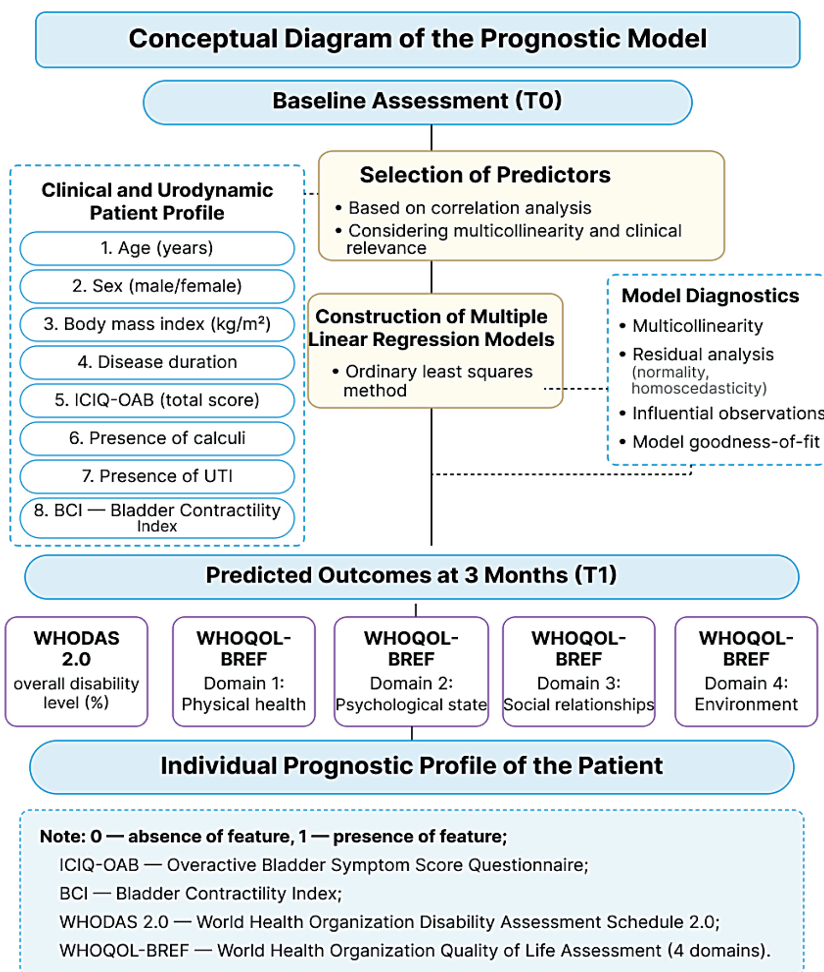


Figure 1 – Conceptual structure of the system of prognostic models for the patient's functional profile at 3 months.

Table 3 – Overall characteristics of the prognostic models for functional outcomes at 3 months

Model	Multiple R	R ²	Adjusted R ²	F	p
WHODAS 2.0	0,806	0,649	0,559	7,17	<0,001
WHOQOL-BREF Domain 1: Physical Health	0,796	0,634	0,539	6,7	<0,001
WHOQOL-BREF Domain 2: Psychological Well-being	0,801	0,642	0,5	6,96	<0,001
WHOQOL-BREF Domain 3: Social Relationships	0,774	0,6	0,496	5,8	<0,001
WHOQOL-BREF Domain 4: Environment	0,803	0,645	0,553	7,04	<0,001

Notes: Multiple R – multiple correlation coefficient characterizing the strength of the overall association between the included predictors and the predicted outcome; R² – coefficient of determination representing the proportion of variance in the dependent variable explained by the combined predictors; adjusted R² – coefficient of determination adjusted for the number of predictors; F – Fisher's statistic for assessing the overall statistical significance of the regression model; p – statistical significance level of the model.

contribution may become apparent only after accounting for the combined effects of clinical and other patient characteristics.

Based on the results of the initial correlation analysis, assessment of multicollinearity, and clinical relevance of the studied variables, a unified set of potential predictors was established and subsequently used to develop all five prognostic models. The set included age, sex, body mass index, disease duration, total ICIQ-OAB score, presence of urinary tract calculi, presence of urinary tract infection, and Bladder Contractility Index (BCI).

ICIQ-OAB was selected as the only symptom-specific questionnaire to avoid duplication of information, because a very strong correlation was observed between ICIQ-OAB and ICIQ-UI SF in the study sample ($r=0.94$), which could result in predictor redundancy and complicate interpretation of the regression model. Among the urodynamic parameters, BCI was selected as a clinically informative integrated measure of detrusor contractility. Bladder compliance, maximum cystometric capacity, and BOOI were not included in the same model with BCI because of pronounced multicollinearity among the urodynamic parameters ($|r|=0.96-0.99$), which could result in unstable regression coefficients. Bladder Voiding Efficiency was also not included in the final predictor set because, in the presence of BCI, it did not provide an

additional clinically necessary component for characterizing lower urinary tract function. Thus, an identical set of eight potential predictors was used for all five outcomes, ensuring comparability of the developed models.

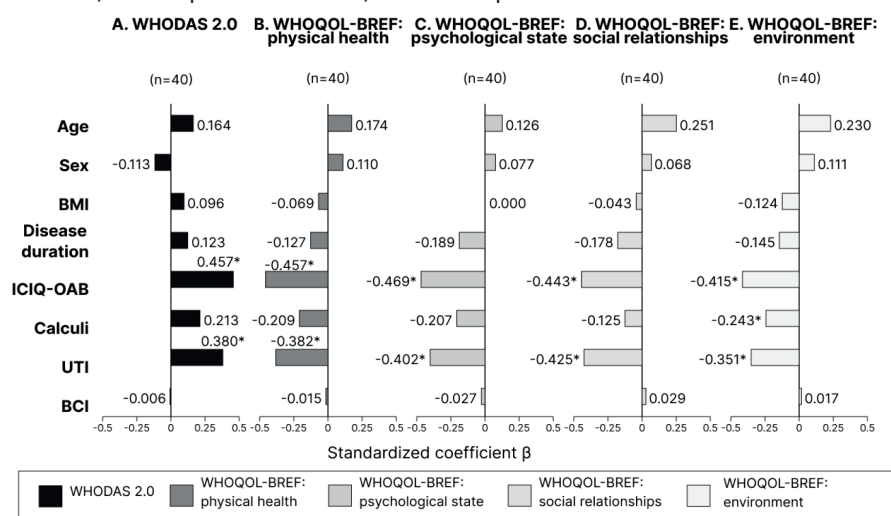
The unified set of predictors served as the input block for constructing a system of five interconnected prognostic models, each predicting a distinct functional outcome at 3 months (figure 1).

The multiple linear regression analysis resulted in five prognostic models. The WHODAS 2.0 model was statistically significant and demonstrated a strong multiple correlation between the observed outcome and the combined set of predictors (Multiple R=0.806). The coefficient of determination was R²=0.649, indicating that the included predictors explained 64.9% of the variance in the WHODAS 2.0 score. After adjustment for the number of predictors, the adjusted R² was 0.559, indicating that 55.9% of the variance remained explained after accounting for model complexity. The overall regression model was statistically significant ($F(8,31)=7.17$; $p<0.001$).

Analysis of the independent contribution of individual predictors showed that ICIQ-OAB was statistically significant ($\beta=0.457$; $B=2.340$; $p=0.011$), as was the presence of urinary tract infection ($\beta=0.380$; $B=10.254$; $p=0.003$). The presence of urinary tract calculi demonstrated a positive trend toward an independent association with the level of disability ($\beta=0.213$; $B=5.787$; $p=0.077$), but did not reach statistical significance. Age, sex, body mass index, disease duration, and BCI did not demonstrate statistically significant independent contributions to the model ($p>0.05$).

The four WHOQOL-BREF models were also statistically significant. The model for the Physical Health domain demonstrated Multiple R=0.796, R²=0.634, and adjusted R²=0.539 ($F=6.70$; $p<0.001$). The Psychological Well-being model showed Multiple R=0.801, R²=0.642, and adjusted R²=0.550 ($F=6.96$; $p<0.001$). The Social Relationships model demonstrated Multiple R=0.774, R²=0.600, and adjusted R²=0.496 ($F=5.80$; $p<0.001$). The Environment model showed Multiple R=0.803, R²=0.645, and adjusted R²=0.553 ($F=7.04$; $p<0.001$). Thus, the models explained 60.0–64.5% of the variance in the corresponding WHOQOL-BREF domains, while adjusted R² ranged from 49.6% to 55.3%.

Across the four WHOQOL-BREF models, the ICIQ-OAB score demonstrated a statistically significant inde-



Note. Standardized regression coefficients (β) are presented for five prognostic models.

Positive β values indicate a direct association, negative values indicate an inverse independent association of the predictor with the outcome.

* – statistically significant independent predictor ($p < 0.05$).

Figure 2 – Independent contribution of predictors to the prognostic models of functional outcomes at 3 months.

pendent negative association with the predicted quality-of-life scores. The presence of urinary tract infection was also independently associated with lower scores in all four domains. The presence of urinary tract calculi demonstrated a statistically significant independent contribution specifically to the Environment domain. The remaining predictors—age, sex, body mass index, disease duration, and BCI—did not demonstrate statistically significant independent contributions in any of the four models ($p > 0.05$). The general characteristics of the developed prognostic models are presented in **table 3**.

For a clear comparison of the independent contributions of the included predictors across the five prognostic models, the standardized regression coefficients (β) were presented graphically (**figure 2**).

The most pronounced and consistent independent contributions across all models were demonstrated by the ICIQ-OAB score and the presence of urinary tract infection. For ICIQ-OAB, the standardized regression coefficient β was 0.457 in the WHODAS 2.0 model and ranged from -0.415 to -0.469 in the WHOQOL-BREF models. For urinary tract infection, the corresponding values were 0.380 and -0.351 to -0.425 , respectively. The contributions of the other predictors were less pronounced, while the BCI coefficients remained close to zero across all models.

The analysis resulted in five mathematical prognostic models presented as multiple linear regression equations. These equations allow calculation of the predicted WHODAS 2.0 score and individual WHOQOL-BREF domain scores at 3 months based on individual predictor values.

Prognostic equations:

- $WHODAS\ 2.0_{3mo} = 11.870 - 0.205 \times Age - 3.175 \times Sex + 0.644 \times BMI + 0.551 \times Disease\ duration + 2.340 \times ICIQ-OAB + 5.787 \times Calculi + 10.254 \times UTI - 0.00134 \times BCI$

- $WHOQOL-PH_{3mo} = 17.582 + 0.036 \times Age + 0.518 \times Sex - 0.078 \times BMI - 0.095 \times Disease\ duration - 0.393 \times ICIQ-OAB - 0.950 \times Calculi - 1.728 \times UTI - 0.00058 \times BCI$

- $WHOQOL-PWB_{3mo} = 17.298 + 0.027 \times Age + 0.363 \times Sex + 0.001 \times BMI - 0.142 \times Disease\ duration - 0.405 \times ICIQ-OAB - 0.949 \times Calculi - 1.831 \times UTI - 0.00104 \times BCI$

- $WHOQOL-SR_{3mo} = 17.379 + 0.053 \times Age + 0.327 \times Sex - 0.049 \times BMI - 0.135 \times Disease\ duration - 0.384 \times ICIQ-OAB - 0.575 \times Calculi - 1.946 \times UTI + 0.00110 \times BCI$

- $WHOQOL-E_{3mo} = 20.812 + 0.051 \times Age + 0.550 \times Sex - 0.146 \times BMI - 0.114 \times Disease\ duration - 0.373 \times ICIQ-OAB - 1.569 \times Calculi - 1.665 \times UTI + 0.00067 \times BCI$

Where: WHODAS 2.0_{3mo} – predicted overall level of disability according to WHODAS 2.0 at 3 months, %; WHOQOL-BREF_{3mo} – predicted score for the respective WHOQOL-BREF domain at 3 months; Age – patient age, years; Sex – binary-coded predictor: 0/1; BMI – body mass index, kg/m²; Disease duration – disease duration, years; ICIQ-OAB – total ICIQ-OAB questionnaire score; Calculi – presence of urinary tract calculi, binary-coded predictor: 0/1; UTI – presence of urinary tract infection, binary-coded predictor: 0/1; BCI – Bladder Contractility Index.

Diagnostic assessment of the regression models did not reveal substantial violations of the main assumptions of multiple linear regression. For the WHODAS 2.0 model, standardized residuals ranged from -1.67 to 1.97 , the maximum Cook's distance was 0.26, and the

maximum Mahalanobis distance was 17.04. The corresponding observation did not simultaneously demonstrate an elevated standardized residual or excessive influence on the model; therefore, there were no grounds for its exclusion.

For the four WHOQOL-BREF models, standardized residuals ranged from -2.15 to 2.15 , and maximum Cook's distance values did not exceed 0.41. Tolerance values were identical across all models and ranged from 0.391 to 0.835, indicating no critical multicollinearity. Graphical assessment using normal probability plots and plots of residuals against predicted values revealed no pronounced deviations from normality of residuals or systematic changes in residual variance. Thus, all five models met the principal diagnostic criteria for multiple linear regression and were considered suitable for subsequent use in predicting functional outcomes at 3 months.

Conclusions.

A prognostic modeling framework for patients with neurogenic bladder was developed based on a unified set of demographic, clinical, and urodynamic predictors. Five multiple linear regression models were developed to predict the overall level of disability according to WHODAS 2.0 and four WHOQOL-BREF quality-of-life domains at 3 months.

The developed models demonstrated statistically significant overall performance and explained 64.9% of the variance in WHODAS 2.0 scores and 60.0–64.5% of the variance in the four WHOQOL-BREF domains. The ICIQ-OAB score was the most consistent independent predictor across all five models, while urinary tract infection demonstrated a statistically significant independent contribution to both functional disability and all four quality-of-life domains. The presence of urinary tract calculi additionally contributed to the prediction of the Environment domain of WHOQOL-BREF.

The proposed prognostic equations enable quantitative estimation of expected functional limitations and quality-of-life outcomes at 3 months based on individual patient characteristics. The findings provide a methodological basis for personalized rehabilitation planning and may contribute to the development of individualized rehabilitation management strategies for patients with neurogenic bladder. Further prospective studies in larger patient cohorts are required to externally validate the developed models and assess their clinical applicability.

Prospects for further research.

Further research should focus on prospective validation of the developed prognostic models in larger and clinically heterogeneous patient populations. External validation, assessment of calibration and predictive accuracy, and evaluation of the clinical utility of the models will be required before their implementation in routine rehabilitation practice. Future studies may also investigate whether the incorporation of additional neurological, functional, and patient-reported characteristics can improve the predictive performance and generalizability of the models.

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ПРОГНОСТИЧНЕ МОДЕЛЮВАННЯ ФУНКЦІОНАЛЬНОГО СТАНУ ПАЦІЄНТІВ ІЗ НЕЙРОГЕННИМ СЕЧОВИМ МІХУРОМ НА ОСНОВІ КЛІНІЧНИХ ТА УРОДИНАМІЧНИХ ПРЕДИКТОРІВ

Васильченко В. С., Соміло О. В.

Резюме. Нейрогенний сечовий міхур супроводжується комплексними порушеннями функції нижніх сечових шляхів, які можуть призводити до значних обмежень повсякденної діяльності та погіршення якості життя. Поєднання клінічних, функціональних та уродинамічних чинників зумовлює значну індивідуальну варіабельність наслідків захворювання, що обґрунтовує необхідність персоналізованого прогнозування реабілітаційних результатів. Метою дослідження було розроблення прогностичних моделей функціональних обмежень та якості життя пацієнтів із нейрогенним сечовим міхуром через 3 місяці. Обстежено 40 пацієнтів із нейрогенним порушенням функції сечовидільної системи. Оцінювали демографічні, клінічні та уродинамічні характеристики, симптоми дисфункції нижніх сечових шляхів за стандартизованим опитувальником ICIQ-OAB, а також функціональний стан і якість життя за опитувальниками WHODAS 2.0 та WHOQOL-BREF відповідно. Прогностичні моделі розробляли методом множинного лінійного регресійного аналізу для прогнозування загального рівня порушення діяльності за WHODAS 2.0 та чотирьох сфер якості життя за WHOQOL-BREF через 3 місяці. Для побудови моделей використовували уніфікований набір із восьми предикторів: вік, стать, індекс маси тіла, тривалість захворювання, показник ICIQ-OAB, наявність конкрементів сечових шляхів, інфекція сечовидільної системи та індекс скоротливості детрузора (BCI).

Модель WHODAS 2.0 була статистично значущою ($R=0,806$; $R^2=0,649$; скоригований $R^2=0,559$; $F(8,31)=7,17$; $p<0,001$), при цьому найбільший незалежний внесок мали показник ICIQ-OAB та наявність інфекції сечовидільної системи. Моделі для чотирьох сфер WHOQOL-BREF також були статистично значущими та пояснювали 60,0–64,5% варіабельності відповідних показників, при цьому скоригований R^2 становив 49,6–55,3%. Показник ICIQ-OAB був найбільш стабільним незалежним предиктором у всіх моделях; інфекція сечовидільної системи також мала статистично значущий внесок у прогнозування WHODAS 2.0 та всіх чотирьох сфер WHOQOL-BREF. Для сфери «Довкілля» наявність конкрементів сечових шляхів була додатковим статистично значущим предиктором. Розроблені рівняння дають змогу кількісно прогнозувати функціональні обмеження та окремі компоненти якості життя через 3 місяці на основі індивідуальних характеристик пацієнта. Отримані результати створюють підґрунтя для персоналізованого планування реабілітації пацієнтів із нейрогенним сечовим міхуром та потребують подальшої проспективної валідації.

Ключові слова: нейрогенний сечовий міхур, дисфункція нижніх сечових шляхів, прогностична модель, функціональні обмеження, якість життя, уродинамічне дослідження, реабілітаційний менеджмент.

PROGNOSTIC MODELING OF FUNCTIONAL STATUS IN PATIENTS WITH NEUROGENIC BLADDER BASED ON CLINICAL AND URODYNAMIC PREDICTORS

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Abstract. Neurogenic bladder is associated with complex lower urinary tract dysfunction that may lead to substantial limitations in daily activities and impaired quality of life. The combination of clinical, functional, and urodynamic factors contributes to considerable interindividual variability in disease outcomes, highlighting the need for personalized prediction of rehabilitation outcomes. The aim of the study was to develop prognostic models of functional limitations and quality of life in patients with neurogenic bladder at 3 months. The study included 40 patients with neurogenic urinary tract dysfunction. Demographic, clinical, and urodynamic characteristics were assessed, together with lower urinary tract dysfunction symptoms using the standardized ICIQ-OAB questionnaire and functional status and quality of life using the WHODAS 2.0 and WHOQOL-BREF questionnaires, respectively. Prognostic models were developed using multiple linear regression analysis to predict the overall level of disability according to WHODAS 2.0 and four domains of quality of life according to WHOQOL-BREF at 3 months. A unified set of eight predictors was used for model development: age, sex, body mass index, disease duration, ICIQ-OAB score, presence of urinary tract calculi, urinary tract infection, and detrusor contractility index (BCI).

The WHODAS 2.0 model was statistically significant ($R=0.806$; $R^2=0.649$; adjusted $R^2=0.559$; $F(8,31)=7.17$; $p<0.001$), with ICIQ-OAB score and urinary tract infection demonstrating the greatest independent contributions. The models for the four WHOQOL-BREF domains were also statistically significant and explained 60.0–64.5% of the variance in the respective outcomes, with adjusted R^2 ranging from 49.6% to 55.3%. The ICIQ-OAB score was the most consistent independent predictor across all models; urinary tract infection also made a statistically significant contribution to the prediction of WHODAS 2.0 and all four WHOQOL-BREF domains. For the Environmental domain, the presence of urinary tract calculi was an additional statistically significant predictor. The developed equations enable quantitative prediction of functional limitations and individual components of quality of life at 3 months based on individual patient characteristics. The findings provide a basis for personalized rehabilitation planning in patients with neurogenic bladder and require further prospective validation.

Key words: neurogenic bladder, urodynamic study, prognostic model, functional limitations, quality of life, rehabilitation management.

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The authors declare no conflict of interest.

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A – Work concept and design, B – Data collection and analysis, C – Responsibility for statistical analysis, D – Writing the article, E – Critical review, F – Final approval of the article.

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