Prediction Of Motor Function Recovery In Patients After Hemispheric Ischemic Stroke

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ABSTRACT

Hemispheric ischemic stroke is one of the leading causes of disability among adults, resulting in various motor, cognitive, and emotional impairments. The recovery of motor functions is particularly challenging, as it directly affects patients' quality of life, their ability to perform self-care, and social reintegration. Therefore, predicting motor function recovery after stroke is a highly relevant issue in modern neurology and rehabilitation (1,10).

Ischemic stroke affecting one of the brain hemispheres can lead to various motor disorders, such as paralysis or paresis, which may be temporary or permanent depending on the extent and location of the lesion. It is important to emphasize that the degree of motor function recovery varies among patients, and the key factor in successful rehabilitation is the accurate prediction of these recovery processes (3,5,8).

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RELEVANCE.

Hemispheric ischemic stroke is one of the leading causes of disability among adults, resulting in various motor, cognitive, and emotional impairments. The recovery of motor functions is particularly challenging, as it directly affects patients' quality of life, their ability to perform self-care, and social reintegration. Therefore, predicting motor function recovery after stroke is a highly relevant issue in modern neurology and rehabilitation (1,10).

Ischemic stroke affecting one of the brain hemispheres can lead to various motor disorders, such as paralysis or paresis, which may be temporary or permanent depending on the extent and location of the lesion. It is important to emphasize that the degree of motor function recovery varies among patients, and the key factor in successful rehabilitation is the accurate prediction of these recovery processes (3,5,8).

The prediction of motor function recovery in patients after hemispheric ischemic stroke is based on a multitude of factors, including the patient's age, the severity and location of brain damage, the initial health condition, and the time of rehabilitation initiation. In recent years, new neuroimaging techniques and neuropsychological tests have emerged that can significantly improve the accuracy of prognosis (2,4,6).

Neurologists and rehabilitation specialists are faced with the task of developing accurate predictive models that can help optimize treatment, allocate rehabilitation resources more efficiently, and provide patients with realistic expectations about their recovery potential. This is especially important in the context of an aging population, where stroke is one of the most common causes of long-term disability (9,11).

Thus, the relevance of this article lies in the necessity to develop and improve methods for predicting the recovery of motor impairments following hemispheric ischemic stroke. This would enhance patients' quality of life, accelerate rehabilitation, and reduce the social burden on the healthcare system.

OBJECTIVE.

The objective of the study is to develop and evaluate methods for predicting the recovery of motor impairments in patients after hemispheric ischemic stroke, taking into account factors such as the extent and location of brain damage, the patient's age, initial severity of motor impairment, and the timing of rehabilitation initiation.

MATERIALS AND METHODS

Surviving patients in the hyperacute and acute phases of ischemic stroke (IS) with concomitant type 2 diabetes mellitus (T2DM), *n = 92*, were examined three times: on days 1–3 after the stroke, on days 7–10, and again 12–18 months after the stroke. Based on motor function status at 12–18 months, patients were divided into two groups. Those with positive dynamics in motor recovery were included in the "favorable outcome" group (Group A). Patients whose paresis remained unchanged or worsened were included in the "unfavorable outcome" group (Group B).

Group A included 49 patients with positive hemiparesis dynamics as assessed by the motor deficit scale. This group showed a decrease in NIHSS scores, an increase in Barthel Index scores, and improved HRV (Heart Rate Variability) indicators. Group B included 43 patients with no positive dynamics on NIHSS and Rankin scales, and no improvement in HRV indicators.

The diagnosis of diabetes mellitus (DM) was based on laboratory tests of glucose metabolism. The current criteria for diagnosing DM follow the guidelines of the American Diabetes Association (ADA), 2014.

The level of consciousness in the acute phase of ischemic stroke was assessed using the Glasgow Coma Scale (Easdale G., Jennett B., 1974). The severity of stroke upon admission and the degree of neurological symptoms (assessed at admission, day 3, and day 7) in both groups of patients were evaluated using the NIH Stroke Scale (NIHSS, National Institutes of Health Stroke Scale). The following scales were also used:

SAPS II (Simplified Acute Physiology Score II) – a scale for assessing the severity of patients' conditions in intensive care. Higher scores indicate a more severe condition and an increased risk of a fatal outcome.
SOFA (Sequential Organ Failure Assessment) – a scale for assessing organ and system failure; higher scores reflect the worsening of multiple organ dysfunction.
The obtained data were statistically processed on a Pentium-4 personal computer using programs developed in the EXCEL software package with the application of a statistical function library. The following were calculated: arithmetic mean (M), standard deviation (σ), standard error of the mean (m), relative values (frequency, %), Student's t-test (t), and the probability of error (P). Differences between mean values were considered statistically significant at a significance level of $p < 0.05$.

RESEARCH RESULTS

To determine the rehabilitation potential of patients in the identified groups, an analysis was conducted to identify the most significant indicators—scale scores and the results of clinical and instrumental examinations—that affect the prognosis of motor impairments. The collected data were compiled into a summary table and analyzed.

The table included a substantial number of parameters (approximately 60), covering data on the onset and course of the disease, anamnesis, demographic characteristics, clinical examination findings, instrumental and laboratory investigations, neuropsychological testing, and others. From the wide range of potentially influential factors, it was necessary to isolate those with the most significant impact on stroke outcome.

The aim of the study was to identify criteria or characteristics that determine the patient's potential for motor function recovery. **Table 1** presents summary data on parameters with statistically significant differences between the comparison groups.

Table 1. *Summary data on parameters with statistically significant differences between the comparison groups*

Parameter	Group A (n=49) (Favorable Outcome)	Group B (n=43) (Unfavorable Outcome)	p-value
Male-to-Female Ratio	2.5:1 (35/14)	1:0.6 (22/13)	–
Age > 65 years (%)	38.0%	51.0%	< 0.05
Cardioembolic stroke (%)	22.4%	46.5%	
Lesion size in maximum diameter (mm), Me ± σ	32.5 ± 6.2	36.8 ± 7.1	< 0.05
Stroke complications (points), Me ± σ	2.1 ± 0.5	3.4 ± 0.6	< 0.05
DM complications (points), Me ± σ	3.4 ± 0.7	4.1 ± 0.8	< 0.05
Degree of DM compensation (points), Me ± σ	6.8 ± 1.1	5.5 ± 1.3	< 0.01
Duration of DM (years), Me ± σ	12.3 ± 4.5	14.1 ± 5.2	< 0.05
Glasgow Coma Scale (points), Me ± σ	13.6 ± 1.9	12.1 ± 2.2	< 0.05
NIHSS Scale (points), Me ± σ	6.4 ± 2.3	9.1 ± 2.8	< 0.01
Atrial fibrillation and other arrhythmias (%)	28%	41%	< 0.05
Chronic heart failure (%)	35%	47%	< 0.05
Dyslipidemia (%)	42%	55%	< 0.05

LF/HF ratio	1.81 ± 0.5	1.37 ± 0.3	< 0.01
Barthel Index (points), Me ± σ	68.2 ± 9.3	52.9 ± 8.5	< 0.01
Proximal upper limb paresis (points), Me ± σ	2.8 ± 0.6	3.5 ± 0.9	< 0.05
Distal upper limb paresis (points), Me ± σ	3.1 ± 0.7	3.8 ± 0.8	< 0.05
Early rehabilitation (%)	65.1%	38.8%	< 0.01

As shown in Table 1, the comparison groups differed significantly in all the presented parameters, with the most prominent differences observed in sex distribution and the proportion of patients over the age of 65. These criteria were included in the final mathematical model for predicting ischemic stroke (IS) outcomes in the acute phase of the disease.

Group A exhibited more favorable indicators across most parameters, including smaller lesion size, better compensation of diabetes mellitus (DM), and fewer stroke-related complications. Functional recovery scores, such as those from the NIHSS and Barthel Index, were significantly better in this group, indicating a higher probability of motor function recovery.

In contrast, Group B patients showed more pronounced neurological impairments, reflected in higher NIHSS scores and poorer functional status as measured by the Barthel Index. Additionally, this group had a greater number of cardiovascular complications, including atrial fibrillation and chronic heart failure.

Statistically significant differences were identified between the groups across the majority of parameters, emphasizing the importance of timely rehabilitation and a comprehensive treatment approach for stroke patients with comorbid diabetes mellitus. The selection of the most significant factors reflecting the outcome of ischemic stroke was conducted in several stages. Initially, a universal "broad" set of clinical, instrumental, laboratory, and psychological indicators was created, based on parameters commonly used in clinical practice or scientific research to assess the condition of stroke patients.

To refine this list and identify the most relevant predictive criteria, an analysis was conducted to determine the extent of the differences between patients with favorable and unfavorable outcomes for each parameter. For the neurological scale indicators, logistic regression analysis was performed (Table 2).

The Wald criterion (W) and significance level (p-value) were used to assess whether a given parameter could be included in the binary logistic regression model.

Table 2. ***Logistic regression parameters for neurological scale indicators***

Scale	Coefficient	Standard Error	Wald Criterion	p-value	95% CI (Lower)	95% CI (Upper)
NIHSS	−0.056	0.098	0.332	0.565	−0.249	0.136
SDNN, ms	−0.181	0.390	0.214	0.643	−0.945	0.584
RMSSD, ms	−0.122	0.111	1.200	0.273	−0.339	0.096
LF/HF	0.032	0.026	1.513	0.219	−0.019	0.082
Barthel Index	0.007	0.019	0.125	0.724	−0.030	0.043
Constant	−0.771	3.371	0.052	0.819	−7.377	5.835

A low value of the Wald criterion (W) and a high level of statistical significance (p) served as grounds for excluding factors from the mathematical model. If the *p*-value was less than 0.05, the parameter was considered statistically significant and was retained in the model [7].

As seen in Table 3, the indicators of the neurological scales—NIHSS and Barthel Index—as well as HRV (heart rate variability) indicators proved to be significant for outcome prediction.

An ROC analysis was performed to assess the significance of these parameters (Figure 1). The area under the ROC curve (Receiver Operating Characteristic) was 0.707, indicating a high probability of accurate prediction.

The statistical analysis made it possible to select, from a broad list of potential predictors of ischemic stroke outcomes in patients with type 2 diabetes mellitus (T2DM), those factors that demonstrated the most pronounced statistical differences between the groups with favorable and unfavorable outcomes.

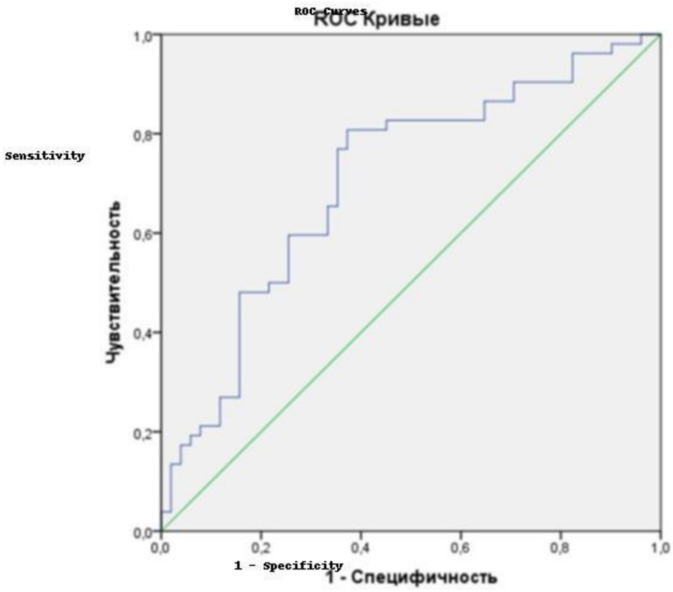

Figure 1. Assessment of the Prognostic Significance of Early Rehabilitation Indicators Using ROC Analysis

Motor function recovery in patients with ischemic stroke (IS) and concomitant type 2 diabetes mellitus (T2DM) is a complex process influenced by multiple factors. To develop a predictive model, key clinical and instrumental indicators with a significant impact on disease outcome were utilized.

Model input parameters. Based on the conducted ROC analysis, the following significant predictors of motor function recovery were identified: NIHSS (National Institutes of Health Stroke Scale), Barthel Index, Glasgow Coma Scale, upper limb paresis (both proximal and distal), and heart rate variability (HRV) dynamics.

Methodology. Logistic regression was employed to construct the prognostic model. The outcome variable was coded as follows: 1 – favorable outcome (motor function recovery), 0 – unfavorable outcome (persistence or worsening of motor impairment). Logistic regression was performed using the predictors found to be statistically significant through preliminary analysis.
The predictive model is represented by the following equation:
$P(\text{recovery}) = 1 / (1 + e^{-(\beta_0 + \beta_1 \cdot \text{NIHSS} + \beta_2 \cdot \text{Fugl-Meyer} + \beta_3 \cdot \text{Barthel Index} + \beta_4 \cdot \text{Glasgow Scale} + \beta_5 \cdot \text{Proximal Paresis} + \beta_6 \cdot \text{Distal Paresis})})$

Where: β_0 is the constant, and β_1 to β_6 are regression coefficients derived from the study data.
Interpretation of results. An increase in NIHSS scores is associated with a worse prognosis. Higher Barthel Index scores indicate a greater likelihood of recovery. Glasgow Coma Scale values also influence recovery probability, especially during the acute phase of IS. The severity of upper limb paresis—both proximal and distal—is a significant predictor of outcome.
Practical application of the model. The developed model allows for the prediction of motor function recovery probability in patients with IS and T2DM. Its application in clinical practice supports a personalized approach to patient rehabilitation, thereby improving treatment outcomes.

The proposed prognostic model can serve as a reliable tool for determining the likelihood of motor function recovery in IS patients with T2DM. It enables the optimization of therapeutic and rehabilitation strategies and enhances outcome prediction. Ischemic stroke in patients with T2DM is characterized by specific pathogenetic features, necessitating an individualized approach to treatment and rehabilitation. Spending on the pathogenetic subtype of the stroke (atherothrombotic, cardioembolic, or hemodynamic), specific patient management strategies are developed.

Management of Patients with Atherothrombotic Stroke and Type 2 Diabetes Mellitus (T2DM)
This subtype develops against the background of significant atherosclerosis of major vessels. Patients are at high risk of recurrent strokes and progression of vascular insufficiency.

1. Acute phase:
- **Intensive antithrombotic therapy (aspirin, clopidogrel)**
- **Glycemic control (target glycemia: 6–10 mmol/L)**
- **Lipid profile monitoring and initiation of statin therapy**
- **Maintenance of arterial blood pressure at <140/90 mmHg**

2. Rehabilitation and secondary prevention:
- **Long-term antiplatelet therapy**
- **Control of arterial hypertension and dyslipidemia**
- **Management of insulin resistance (metformin, SGLT2 inhibitors)**
- **Physical activity and a diet low in saturated fats**

Management of Patients with Cardioembolic Stroke and T2DM
This subtype is often associated with atrial fibrillation, valvular heart disease, or other cardiogenic causes. These patients have a high risk of thromboembolism and recurrent strokes.

1. Acute phase:
- **Anticoagulant therapy (initial heparin administration followed by warfarin or DOACs)**
- **Intensive cardiac rhythm control**
- **Correction of hyperglycemia to minimize cardiovascular complications**
- **Echocardiography to detect intracardiac thrombi**

2. Rehabilitation and secondary prevention:
- **Lifelong anticoagulant therapy if atrial fibrillation is present**
- **Blood pressure and heart failure management**
- **Optimization of antidiabetic therapy considering cardiometabolic profile**
- **Regular cardiology evaluations and adjustment of antiarrhythmic therapy**

Management of Patients with Hemodynamic Stroke and T2DM
This subtype arises from pronounced cerebrovascular insufficiency and is often associated with orthostatic hypotension and chronic cerebral ischemia.

1. Acute phase:
- **Maintenance of adequate blood pressure (avoid sudden fluctuations)**
- **Enhancement of cerebral perfusion (vasoactive and nootropic agents)**
- **Glycemic control with a focus on minimizing hypoglycemic episodes**

2. Rehabilitation and secondary prevention:
- **Treatment of chronic cerebral ischemia (ACE inhibitors, statins, antiplatelet agents)**
- **Improvement of cerebral blood flow (hyperbaric oxygen therapy, physiotherapy)**
- **Diabetes management with an emphasis on agents that do not induce orthostatic hypotension**
- **Cognitive rehabilitation and dementia prevention**

A personalized approach to the management of patients with ischemic stroke (IS) and T2DM allows clinicians to account for the unique pathophysiological mechanisms of each stroke subtype, thereby reducing the risk of recurrence and improving functional outcomes. A comprehensive treatment strategy—including glycemic control, blood pressure management, and prevention of vascular complications—plays a central role in improving patient prognosis

CONCLUSIONS

This study evaluated the impact of type 2 diabetes mellitus (T2DM) on the course and outcomes of ischemic stroke (IS). The analysis was based on the Glasgow Coma Scale, NIHSS, heart rate variability (HRV) parameters, MRI data, as well as assessments of complications and the degree of diabetes compensation.

In the group of patients with T2DM, a more severe course of stroke, larger ischemic lesion sizes, and more frequent complications were observed. Strong correlations were identified between the degree of diabetes compensation, lesion size, and poor stroke outcomes. A longer duration of T2DM was associated with worse clinical results, indicating the detrimental effect of diabetic angiopathy on ischemic processes.

A correlation graph was developed, illustrating interrelationships between parameters (e.g., NIHSS and lesion size correlated at 0.73; disease outcome and lesion size showed a negative correlation of −1.0).

A mathematical model was proposed to predict the probability of an unfavorable outcome in patients with T2DM. Key predictors included the NIHSS score, HRV parameters, lesion size, degree of diabetes compensation, and stroke-related complications. It was found that cardioembolic stroke carries the highest risk of mortality—up to 90% in cases with SAPS II > 40. The prognostic model, built using logistic regression, confirmed the significance of T2DM compensation in predicting stroke outcomes.

Patients were divided into two groups: those with a favorable outcome (n=49) and those with an unfavorable outcome (n=43) regarding motor function recovery. Statistically significant differences were found in NIHSS, Fugl-Meyer, and Barthel Index scores, which formed the basis for a prognostic model developed via ROC analysis. The resulting logistic regression model predicts the probability of motor recovery based on key clinical parameters.

Differentiated management strategies were proposed according to the pathogenetic subtype of stroke:
- Atherothrombotic stroke: Antithrombotic therapy, lipid and glycemic control.
- Cardioembolic stroke: Anticoagulant therapy, rhythm control, and hyperglycemia management.
- Hemodynamic stroke: Maintenance of cerebral perfusion, blood pressure control, and cognitive rehabilitation.

Overall, diabetes control, compensation of its complications, and a personalized stroke management strategy play a critical role in improving patient prognosis.

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