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Efficiency of technology for restoring the quality of life of young people with metabolic syndrome and chronic pain using physical therapy

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Abstract.

Purpose: substantiation of criteria for the effectiveness of technology for restoring the quality of life of young people with metabolic syndrome and chronic pain by means of physical therapy.

Material and methods: The study involved 97 young women with metabolic syndrome and chronic pain in the musculoskeletal system. The study used general scientific methods - the method of a systemic approach and systemic analysis, bibliosemantic, content analysis, the method of conceptual modeling and empirical methods - anthropometric, physiological, clinical, sociological, the method of expert assessments, mathematical and statistical research methods. The information base of the study was sources of professional scientific, reference, directive information and the results of our own research, the representativeness and reliability of which are proven by medical and statistical calculations.

Results: Based on the results of factor analysis and taking into account the results of correlation analysis, the criteria for the effectiveness of the proposed technology were developed. In the process of developing the criteria, the machine learning method was used - modeling with multidimensional adaptive regression splines MARSplines. This method made it possible to find mutually agreed indicators and, according to the criterion, select those of them that are more convenient to diagnose.

Conclusions: based on determining the ratio of body length and weight and waist to hip circumference, the dynamics of the BMI index and static back strength, as well as the results of the dynamics of quality of life indicators, it is possible to determine the degree of influence of the means and methods of the author's technology on the quality of life and pain syndrome of women with MS, and also to establish the degree of effect.

Keywords: system for restoring quality of life, technology, physical therapy, metabolic syndrome, chronic pain, efficiency criteria.

Introduction. Metabolic syndrome, or "insulin resistance syndrome", is defined as a pathological condition characterized by the development of abdominal obesity, dyslipidemia, arterial hypertension and carbohydrate metabolism disorders (or the phenomenon of insulin resistance) (Kalmykova, et al., 2024a). The main etiological factors of metabolic syndrome are genetic predisposition, excessive fat consumption and physical inactivity (Kalmykova, et al., 2020; Kalmykova, & Kalmykov, 2023; Kalmykova, et al., 2021a). Recently, it remains almost the most important problem in endocrinology, cardiology, dietetics, internal and family medicine (Kalmykova, 2023a).

An important role in the development of metabolic syndrome is attributed to genetic predisposition, excessive consumption of high-calorie foods and decreased physical activity (Korylchuk, 2019; Kalmykova, et al., 2021b).

According to the WHO, obesity is “an abnormal or excessive accumulation of fat that may have adverse effects on health” (Kalmykova, 2023b). Obesity is an important risk factor for many serious medical problems that lead to a decrease in the quality of life, a significant increase in morbidity and premature death, and disrupts the functioning of the cardiovascular system, which is one of the main manifestations of obesity (Myronyuk, & Dub, 2019).

Obesity is associated with several comorbidities/complications. The most serious endocrine complication is MS (Weiss et al., 2004).

MS is becoming increasingly common among children and adolescents, particularly in obese and overweight populations (Alowfi et al., 2021). Thus, J. Chae et al. examined the prevalence trends of MS and its components among adolescents aged 12 to 18 years in Korea using data from the Korean National Health and Nutrition Examination Survey (KNHANES) for 2007–2018 and analyzed the correlation between each risk factor (Chae et al., 2021). The authors found a significant association between tobacco smoking and higher fasting glucose levels in this study population. Smoking may cause insulin resistance or pancreatic β-cell damage. Other studies have shown that smoking reduces serum glucose levels because nicotine blocks the release of inflammatory cytokines that suppress inflammation associated with insulin resistance and reduce hyperglycemia (Fa-Binefa et al., 2019). Therefore, it is important to emphasize the awareness of adolescents about the importance of quitting smoking, regardless of blood glucose levels.

Obesity and insulin resistance are core components of metabolic syndrome and major risk factors for cardiovascular disease (Kalmykova, et al., 2024b). The positive correlation between obesity and insulin resistance is well established from literature and research (Kalmykova, et al., 2018; Yanushpolska, et al., 2020). However, they have one more common link in the form of hyperleptinemia (Shchurko, et al., 2022).

The problem of MS and type 2 diabetes in Ukraine is quite high and amounts to about 20% in the general population and more than 50% in certain social groups (physical inactivity, fast food lovers, smokers, etc.) (Shved, et al., 2023; Kalmykov & Kalmykova, 2016).

In Ukraine, diabetes is the third most common disease after cardiovascular and

oncological diseases. Over the past ten years, the prevalence of diabetes in Ukraine has increased by one and a half times, and as of January 1, 2015, 1,198,047 patients were registered in the country, which is about 2,9% of the total population. (Yuliya, & Sergey, 2018; Ivanenko, et al., 2020; Turchina, et al., 2022). According to WHO, by 2025 the number of people with diabetes in the world will exceed 330 million people, 85-90% of whom will be type 2 diabetes; according to forecasts, by 2030 the total number of people with diabetes will reach 592 million. The situation is further complicated by the fact that out of 1.1 million registered cases of type 2 diabetes in Ukraine, undiagnosed cases of diabetes are 3-4 times higher than the number of identified patients (Kalmykov, et al., 2021; Kalmykova, 2024c; Turchina, et al., 2024).

Social factors, including lifestyle, type of work, nutrition and physical activity, are preferably considered as factors contributing to the development of MS (Ferguson er al., 2010). The problem of prevalence of MS among representatives of different ethnic groups is of particular importance, which is due to differences in their constitution. At the same time, little is taken into account the fact that the development of MS and its individual components may also depend on natural factors that determine the intensity of energy metabolism in the body and the nature of metabolism. The social significance of the problem of MS is associated with an increase in educational activity among patients, the need to implement the basic principles of primary prevention of obesity, diabetes, especially among children and young people, promoting the principles of healthy eating, increasing the role of physical education and sports, is a significant clinical and epidemiological problem for the population of many industrialized countries (Trybrat, et al., 2017).

Thus, the prevalence of MS tends to increase and depends on many components, which explains the complexity of diagnostics and approaches to the prevention and treatment of this pathology.

One of the main criteria that must be taken into account when developing restorative treatment and prevention of this pathology is metabolic health (van Vliet-Ostaptchouk, et al., 2014).

Purpose of the study is to substantiate the criteria for the effectiveness of technology for restoring the quality of life of young people with metabolic syndrome and chronic pain using physical therapy.

Material and methods of research.

Participants.

The study involved 97 young women with metabolic syndrome and chronic musculoskeletal pain. The studies were conducted in compliance with the principles of biomedical ethics, according to the Helsinki Declaration "Ethical Principles for Medical Research Involving Humans" developed by the World Medical Association, "General Declaration on Bioethics and Human Rights (UNESCO)" (UNESCO. Universal Declaration on Bioethics and Human Rights, 2005; World Medical Association. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects, 2013). In particular, all respondents were aware that the survey was being conducted as part of a scientific study and had the right to refuse the survey at any time.

Material of research. In our study, we used traditional general scientific methods - the method of a systemic approach and systemic analysis, bibliosemantic, content analysis, the method of conceptual modeling and empirical methods - anthropometric, physiological, clinical, sociological, the method of expert assessments, mathematical and statistical research methods. The information base of the study was sources of professional scientific, reference, directive information and the results of our own research, the representativeness and reliability of which are proven by medical and statistical calculations.

The study was carried out in accordance with the priority thematic area “Theoretical and methodological foundations of physical therapy and occupational therapy for organic and functional

disorders of organs and systems of the human body in healthcare practice", 2021-2025. (State registration number 0121U110)

Statistical data analysis

The computer database of the clinical study results was created in the Microsoft Office Excel system. Statistical processing of the study results was performed using parametric methods using the Statistica 10.0 software package.

Standard statistical methods were applied to the analysis of the data set, such as: selective observation with the calculation of statistics characterizing samples by a certain parameter (mean value of the indicator, standard deviation and standard error, Student's t-test), the method of two-sample test for comparing selected indicators in different observation groups, correlation analysis to establish the presence or absence of connections between the studied indicators, the nature and intensity of such a connection. The critical value of the error was set as 5%. In the case when its value was less than 0.05, it was emphasized separately in the work.

When analyzing the variation series, the normality of the distribution was checked. Parametric methods were used for quantitative characteristics with a normal distribution. To assess the probability of the difference in the results obtained in the compared groups, the odd t-criterion (for two groups with a Gaussian distribution); the Mann-Whitney U-criterion (for two groups with a non-Gaussian distribution); the χ^2 (xi-square) criterion when comparing particles were used.

The results obtained are presented as mean values, standard deviations ($\bar{X}\pm S$) and medians (Me). Differences in mean values were considered significant with a probability level of at least 95%. ($p < 0,05$).

The preparatory stage of statistical processing was obtaining descriptive statistics for the groups under study. Then, a correlation analysis of the studied indicators was carried out based on the calculation of paired Spearman correlation coefficients. The paired Spearman correlation coefficient (or linear correlation coefficient) is one of the main indicators of the interdependence of random variables. It characterizes the closeness and direction of the relationship between two correlating features in the presence of a linear dependence between them. We proceeded from the fact that if the pair correlation coefficient is 0, then there is no statistical relationship between the two features, if the pair correlation coefficient by module is 1, then based on the value of the first feature it is possible to accurately reproduce the value of the other feature; if the value of the correlation coefficient by module is less than 0.5, then there is a weak statistical relationship between the two features; if the correlation coefficient by module acquires a value from 0.5 to 0.7, then there is a statistical relationship of medium intensity between the two features; if the correlation coefficient by module takes a value from 0.7 to 0.9, then there is a strong statistical relationship between the two features; if the correlation coefficient acquires a value of more than 0.9 by module, then there is a very strong statistical relationship between the two features. If the value of the correlation coefficient is positive, this indicates the presence of a direct connection between the indicators; if the value of the correlation coefficient is negative, then there is an inversely proportional connection between the indicators. Taking into account the results of the correlation analysis, only those indicators that had strong correlations were included in the mathematical models.

To assess the dynamics of the indicators under the influence of the program, Δ% was calculated individually for each patient, subsequently calculating the average value and the error of the average for Δ% for the sample using descriptive statistics.

Results of the study

Our further research is aimed at substantiating the criteria for the effectiveness of the author's technology. According to the results of the factor analysis and taking into account the

results of the correlation analysis, we developed the criteria for the effectiveness of the proposed technology. In addition, when developing the criteria, the machine learning method was used - modeling with multidimensional adaptive regression splines MARSplines. This method allowed us to find mutually agreed indicators and, according to the criteria, select those of them that are more convenient to diagnose.

As for the pain syndrome, the choice of the efficiency criterion was preceded by the development of predictive models using the MARS multivariate adaptive regression splines method. Since the issue was only about the choice of the criterion, not about predicting the BMI level in women with MS depending on the intensity and localization of the pain syndrome, when developing the models we left the standard settings (21 basis functions and 1 order of interaction were used). The resulting model contains 9 basis functions, one of which has a zero order (stable regression coefficients) and eight basis functions of the first order (Table 1).

Table 1. Coefficients and basis functions of the MARS model determining the relationship between body mass indices and girth measurements of women with MS and pain levels

№	Coefficient α_j			Basic functions of type max(0, independent-knot), or max(0, knot-independent)
	BMI	WC/HC	BL/BW	
β1	29,583	0,750	0,521	
β2	3,906	0,021	0,013	max(0; Lumbar_WP-5,000)
β3	-4,468	-0,053	-0,024	max(0; Lumbar_WP -6,000)
β4	11,206	0,158	0,077	max(0; Cervical-1,500)
β5	-2,588	0,022	-0,006	max(0; 1,500-Cervical)
β6	-6,737	-0,004	-0,046	max(0; Cervical-1,000)
β7	-3,856	-0,097	-0,000	max(0; Knees_WP -1,500)
β8	0,681	-0,010	-0,002	max(0; Chest_ WP -2,000)
β9	2,727	-0,087	-0,017	max(0; 0.500-Chest)

Note: independent – dependent variable; knot – node

According to the table presented, for example, the relationship between body mass indexes and the coverage sizes of women with MS and the level of pain can be presented in this form:

BMI = 29,583 + 3,906*max(0; Lumbar_WP-5,000) - 4,468*max(0; Lumbar_WP-6,000) + 11,206*max(0; Cervical-1,500) - 2,588*max(0; 1,500- Cervical) - 6,737*max(0; Cervical-1,000) - 3,856*max(0; Knees_WP-1,500) + 0,681*max(0; Chest_WP-2,000) + 2,727*max(0; 0,500- Chest)

The generalized cross-validation error after training was 2.255. Moreover, as the analysis of the obtained model showed, the most significant relationship is observed between BMI and pain in the cervical and thoracic regions, as well as in the lumbar and knee regions during the worst periods (Table 2).

Table 2. Regression statistics of the constructed MARS model

Regression statistics	Women's Body Shape Indexes		
	BMI	**WC/HC**	**BL/BW**
Mean (observed)	28,388	0,758	0,508
Standard deviation (observed)	2,732	0,068	0,045
Mean (predicted)	28,388	0,758	0,508
Standard deviation (predicted)	2,433	0,027	0,009
Mean (residual)	0,000	-0,000	0,000
Standard deviation (residual)	1,242	0,062	0,044
R-squared	0,793	0,162	0,043
R-squared adjusted	0,772	0,075	-0,056

As can be seen in the table, the proposed MARS model is 79.3% capable of predicting BMI by the level of pain syndrome in women with MS.

An example of the model's ability to predict body shape indices in women with MS depending on the assessment of lower back pain in the worst period is shown in the figure (Figure 1).

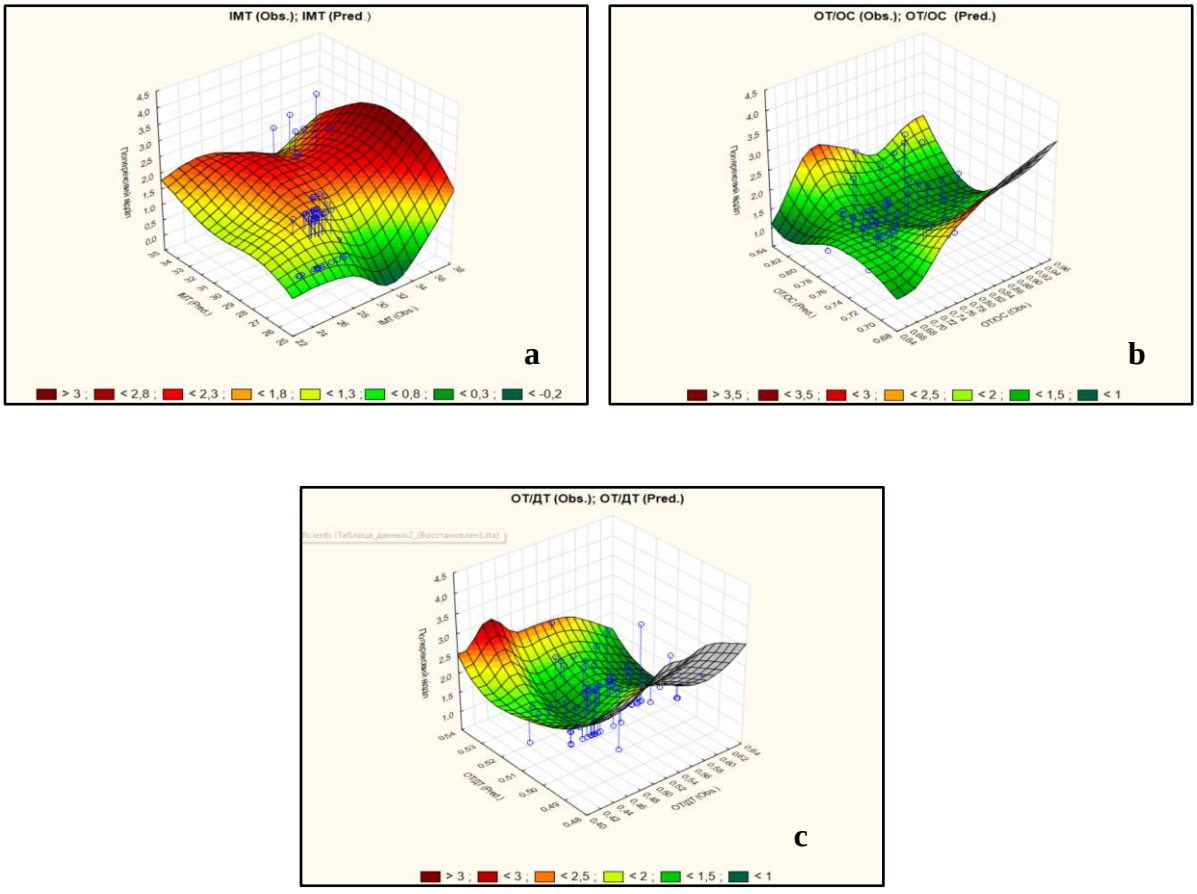

Figure 1. Relationship between body shape indices of women with MS and their assessment of low back pain at worst (n=97), where a) –BMI; b) WC/HC; c) – BL/BW

Consequently, having accepted the BMI efficiency criterion, we can say that with a decrease in BMI, the level of pain in study participants will also decrease.

In order to study the relationship between body shape indices of women with MS and indicators of physical fitness, a study was conducted using multivariate adaptive regression splines MARSplines. Unfortunately, the built models did not demonstrate the expected forecasting accuracy.

Next, an analysis of the relationships between individual indicators of physical fitness and physical performance was conducted. The modeling results showed that there are nonlinear dependencies between the indicators. A satisfactory level of forecasting accuracy (73,7%) was achieved after increasing the maximum number of basic functions to 50 and the number of interaction levels to 3 (Table 3).

Table 3 – Regression statistics of the MARS model

Regression statistics	Model parameters (k1; k2)		
	21/1	**50/2**	**50/3**
Mean (observed)	46,103	46,103	46,103
Standard deviation (observed)	11,726	11,726	11,726
Mean (predicted)	46,103	46,103	46,103
Standard deviation (predicted)	9,433	9,794	10,063
Mean (residual)	-0,000	0,000	-0,000
Standard deviation (residual)	6,965	6,447	6,019
R-squared	0,647	0,698	0,737
R-squared adjusted	0,624	0,674	0,706

Note: k1 – maximum number of basis functions; k2 – number of interactions

The most important variables in constructing the final model were recovery from exercise, the complicated Romberg test, and flexibility.

Among the studied variables, such indicators as the "Flamingo Test" and dynamometry of the weaker arm were not identified as significant by the algorithm. However, it is worth pointing out that when constructing the model, the result of the complicated Romberg test was taken into account, which, like the "Flamingo Test", is used to assess a person's static balance. In addition, in the basis functions there is a reference to the dynamometry of the stronger hand.

Figure 2 demonstrates the relative importance of dependent variables (predictors) according to their relevance.

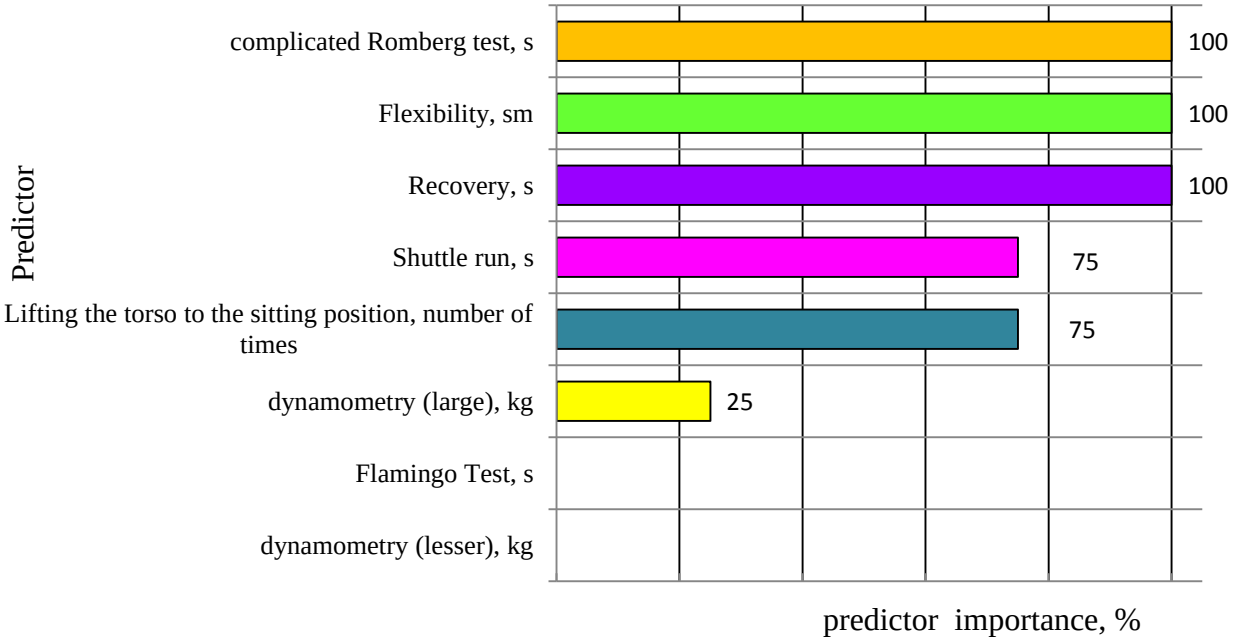

Figure 2. Relative importance of variables in predicting static back endurance in women with MS (n = 97)

The coefficients and basic functions of the MARS model, which determine the relationship between static back endurance and individual indicators of physical fitness and physical performance of women with MS, are given in the table (Table 4).

Table 4. Coefficients and basic functions of the MARS model, which determine the relationship between static back endurance and individual indicators of physical fitness and physical performance of women with MS

№	α_j	Basic functions of type max(0, independent-knot), or max(0, knot-independent)
β1	35,568	
β2	1,999	max(0; 30 Shuttle run)
β3	4,297	max(0; 27-Dynamometry (large))* max(0; Lifting the torso to the sitting position – 16)
β4	2,682	max(0; 11-Flexibility)
β5	-0,153	max(0; 11-Flexibility)* max(0; Romberg test – 7)* max(0; Recovery – 117)
β6	0,337	max(0; 11-Flexibility)* max(0; Romberg Test – 7)* max(0; 117-Recovery)
β7	-0,311	max(0; 11-flexibility)* max(0; 16-Lifting the body into a squat position)
β8	-10,271	max(0; Romberg test – 6)* max(0; 30 Shuttle run)
β9	0,142	max(0; Romberg test – 6)* max(0; 30 Shuttle run)* max(0; Recovery – 50)
β10	0,010	max(0; 160-Recovery)* max(0; 16-Lifting the torso to the sitting position)

Note: independent – dependent variable; knot – node

The following figure shows the ability of the model to predict static back endurance in women with MS based on the variables according to their relative importance (Figure 3).

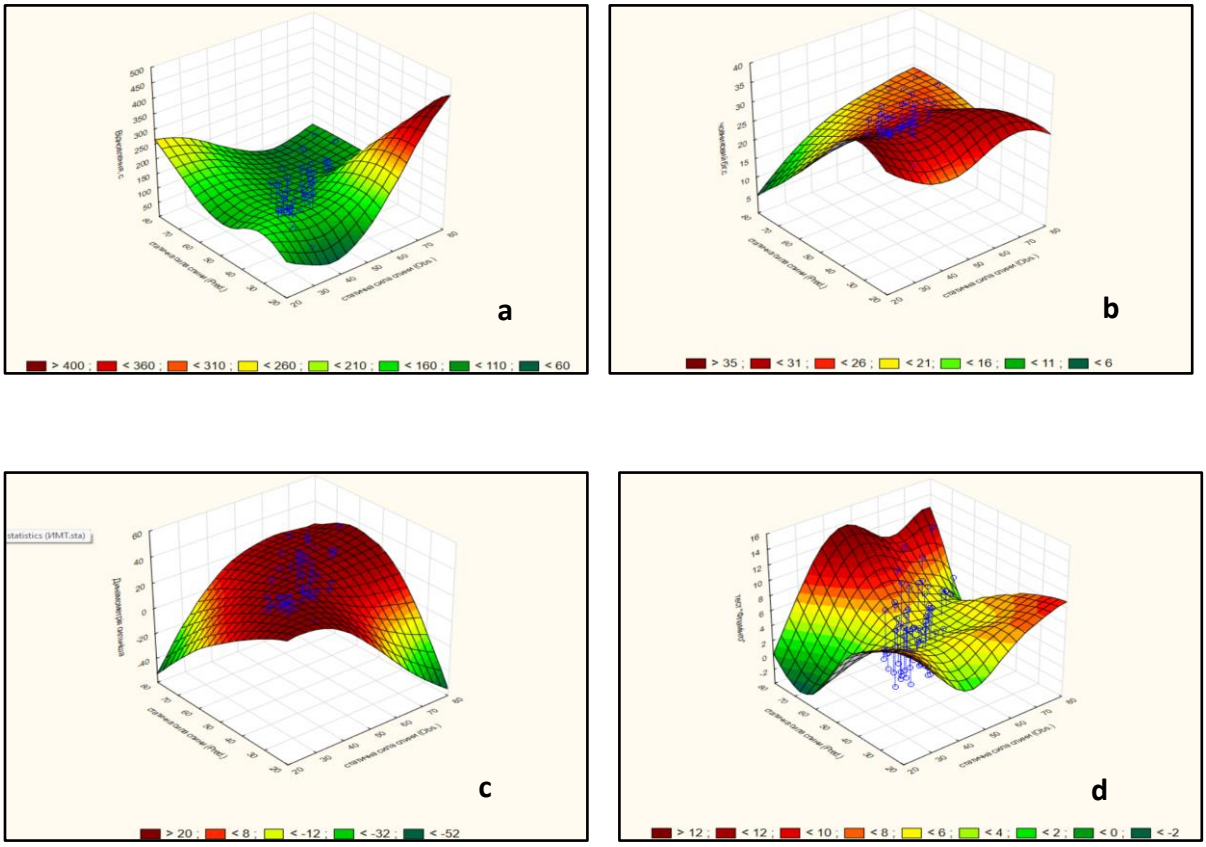

Figure 3. Relationship between static back strength of women with MS and individual indicators of their physical fitness (n=97),

where a) – recovery; b) shuttle run; c) – dynamometry of the stronger hand; c) – Flamingo test

In Figure d) it can be seen that the decrease in the relative variable importance to zero is accompanied by significant deviations in the prediction of static back endurance.

According to the results of the factor and correlation analysis and taking into account the results of modeling by multivariate adaptive regression splines MARSplines and the application of the principal component analysis method, we developed the criteria for the effectiveness of the proposed technology (Table 5).

Table 5. Criteria for the effectiveness of the technology (according to the results of factor and correlation analysis)

№	Name	Content	Justification
1	Physical health	BW	statistically significant (p<0,05) correlation with the assessment of the level of health (ρ=-0,387)
		WC/BL	statistically significant (p<0,05) differences between the indicator depending on the level of health
2	Body composition		statistically significant (p<0.05) correlations with fat mass, % (ρ=0,323), MM, % (ρ=-0,468)
3	Quality of life	PF, RP, BP, GH, VI, MH	stood out in the factor analysis with the exception of SF and RE
4	Cardiometabolic risk	WC/HC	statistically significant (p<0.05) correlations with the Robinson index (ρ=-0,674), BPsyst. (ρ=-0,466), HR (ρ=-0,656), PCI (ρ=0,599), AP (ρ=-0,579)
		muscle strength and body composition	Lifting the torso to the sitting position, WC, MM, FM
5	Functional state of the respiratory system	BMI	statistically significant (p<0.05) with vital index (ρ = -0,434), excursion (ρ = 0,206), saturation (ρ = 0,267)
6	Physical fitness	Static back strength	73,7% of static back strength is determined by balance, agility, flexibility, hand strength and physical performance
7	Pain syndrome	cervical, thoracic, lumbar regions, knee joints	pain in the worst period; median pain rating

Discussion. According to the new concept of clinical medicine, improving the patient's quality of life is a priority or additional goal of treatment. (Pashkevych, et al., 2024). Assessment of QOL is especially important in chronic diseases that require long-term treatment, in particular such as MS (Palykhata, et al., 2017). By determining QOL, it is possible to monitor the effectiveness of treatment and rehabilitation of patients with comorbid chronic diseases. Today, more and more attention is paid to the study of the combined course of MS with chronic pain (CP). The high medical and social significance of both MS and CP is determined by their significant contribution to the deterioration of the health of people of socially active age, significant costs for diagnosis and treatment, a decrease in QOL and disability. That is why the study of QOL in patients with comorbid MS and CP is relevant. Similar evidence of the importance of assessing QOL in comorbid conditions is also found in the works of L.S. Babinets, N.A. Melnyk (Babinets, & Melnyk, 2021).

Recovery programs for MS are based on a differentiated individual approach as one of the priority principles of physical therapy (Tershak, N. M. (2006). An equally important component of the initial examination, according to Yelnikova, should be considered the assessment of rehabilitation potential, since this indicator is the basis for further clinical prognosis - anticipation of the development and consequences of the current disease. When working on drawing up an individual plan and recovery program at various stages of the implementation of rehabilitation intervention, physical therapists should pay attention to subjective factors that affect the initial indicators of the patient's physical, psycho-emotional state, and

therefore can also significantly affect the effectiveness and efficiency of the entire recovery process (Yelnikova, 2016).

The creation of the concept of MS is associated with the identification of a population of patients with high cardiovascular risk. For this group, preventive measures, including lifestyle modification and the use of drugs, can have a significant impact on key health indicators.

Lifestyle changes are one of the key approaches to the treatment of MS, including increased physical activity (PA) and correction of excess body weight. Weight loss usually requires a specially developed multifaceted program, including diet. Experts believe that in order to form a healthy lifestyle, it is necessary to constantly promote healthy eating and proper eating behavior, regular and sufficient PA, quitting bad habits, etc. The results of the studies confirm the relevance of studying the lifestyle of patients with MS (Kalmykova, 2024d).

Increasing the level of physical activity is an important area of work to eliminate the consequences of MS. Modern research by specialists is aimed at studying the impact of physical activity and determining the optimal parameters of physical activity, such as training regimen, static and dynamic work, etc. It has been proven that dynamic training significantly improves the functionality of the circulatory system. Therefore, the use of combined static-dynamic loads is considered optimal. The physiological rationale for the use of physical activity is that oxidative processes in muscles during work occur more effectively than at rest, and therefore the consumption of carbohydrates and fatty acids increases.

Physical activity (PA) is an important strategy for weight loss in obese individuals, but may require time to adopt and commitment from both professionals and patients. Even when weight loss does not occur, PA is associated with many beneficial effects, such as improved cardiovascular function and possible reduction in insulin resistance.

Research substantiates the effectiveness of a comprehensive approach to weight loss, which uses various means, such as kinesitherapy, SPA procedures, correction of eating behavior, motivational training, psychocorrectional exercises, and keeping a health diary. This approach differs from generally accepted physical rehabilitation programs. It has been proven that a comprehensive approach is effective for the rehabilitation of female students with obesity and the risk of developing MS, contributing to the correction of lipid and carbohydrate metabolism.

Conclusion. Thus, based on the determination of the ratios of body length and weight and waist to hip circumference, the dynamics of the BMI index and static back strength, as well as the results of the dynamics of quality of life indicators, it is possible to determine the degree of influence of the technology on the quality of life and pain syndrome of women with MS, and also to establish the degree of effect.

Author's contribution

Conceptualization, YK; methodology, YK and SK; software, OS and SP; check, YK, SK, SP and OS; formal analysis, YK and SK; investigation, YS; resources, YS; data curation, YS; writing - rough preparation, YK, SK, SP and OS; writing - review and editing, YS; visualization, YK, SK, SP and OS; supervision, SK snd SP; project administration, YK. All authors have read and agreed with the published version of the manuscript.

Conflict of interest

The authors declare that there is no conflict of interest.

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