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CONTENT

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Prediction of quality of life parameters among university students for the optimization of health-enhancing recreational programs

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Abstract

Purpose. The present study sought to construct and empirically test predictive models of health-related quality of life (HRQoL) in a cohort of Ukrainian university students. The models incorporated behavioural patterns, psychosocial factors, and safety-related perceptions as key determinants. By doing so, the research aimed to generate evidence-based insights that could inform the development of more effective, context-sensitive recreational and health-promotion programs tailored to the challenges of studying and living under wartime conditions.

Material & Methods. The study involved 172 students (48.8% male, 51.2% female; aged 18–25 years) enrolled in Ukrainian higher education institutions. Data collection included standardized questionnaires: the SF-36 Health Survey (Physical Component Summary (PCS) and Mental Component Summary (MCS)), the International Physical Activity Questionnaire – Short Form (IPAQ-SF), the Satisfaction With Life Scale (SWLS), and the Service Quality Assessment Scale (SQAS) adapted to wartime conditions. Factor analysis identified two main domains («Motivation» and «Constraints»), and additional variables such as time and financial limitations were analysed separately. Predictive modelling was conducted using Gradient Boosting Trees (GBT) and Random Forest (RF) methods. Model performance was evaluated with MAE, RMSE, and MAPE metrics.

Results. The models demonstrated distinct predictive capacities for physical and mental components of HRQoL. PCS was effectively predicted using a simple GBT structure with high accuracy (MAE=5.53, RMSE=45.70, MAPE=0.102), while MCS required more complex modelling (130 trees). RF outperformed GBT for MCS prediction (RMSE=83.96 vs. 98.02; MAPE=0.180 vs. 0.198). Variable importance analysis revealed that safety was the strongest predictor of PCS, while life satisfaction (SWLS) and physical activity (IPAQ) were the most influential for MCS. In both models, sex and training frequency were the least significant predictors.

Conclusions. Machine learning approaches provide valuable tools for predicting HRQoL among students in challenging contexts. The findings confirm that physical well-being is strongly influenced by environmental safety, whereas mental well-being depends more on subjective life satisfaction and physical activity. These results highlight the need for integrated health-enhancing recreational programs combining physical activity with psychosocial support and safety measures in Ukrainian universities during wartime.

Keywords: physical activity, machine learning, quality of life, students, model, safety, Ukraine.

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Introduction

Quality of Life (QoL) is defined by the WHO as an individual's perception of their position in life in the context of the culture, and value systems in which they live and in relation to their goals, expectations, standards and concerns (WHO, 2020). For students who are in a critical period of socialisation and professional competence development, QoL is particularly important. Numerous studies confirm that low levels of physical activity and high levels of academic stress are associated with a deterioration in students' physical and mental well-being, while regular physical activity and adequate physical fitness contribute to an increase in QoL indicators (Kljajević et al., 2022). In particular, health-enhancing recreational physical activity (team sports, outdoor activities, structured physical activities) has been shown to have a positive impact on the mental health, socialisation, and overall well-being of young people (Obray et al., 2024; Rhodes et al., 2025; Rodríguez-Bravo et al., 2020).

Furthermore, recent studies emphasise that students' QoL is determined not only by their level of physical activity, but also by a complex of socio-psychological and educational factors (Schramlová et al., 2024). A heavy academic workload, limited access to recreational resources, and insufficient attention to psycho-emotional support have a negative impact on QoL, which justifies the need for targeted health-enhancing recreational programmes in higher education institutions.

The last decade has been characterised by growing interest in the use of machine learning (ML) methods in predicting health and well-being indicators (Abegaz et al., 2025). Tree-based ensemble algorithms, particularly Gradient Boosting Trees and Random Forest, demonstrate greater predictive accuracy than classical statistical models, particularly when dealing with nonlinear and multifactorial relationships (Oparina et al., 2025). ML models that integrate social determinants of health, behavioural indicators, and mental metrics are successfully used to predict HRQoL at the individual level, although they are accompanied by the methodological challenge of finding a balance between accuracy and interpretability of results (Raoof, 2025).

In the Ukrainian context, the relevance of the problem takes on an additional dimension. War significantly affects students' mental health and QoL, causing anxiety, depression and loneliness (Andrieieva et al., 2023; Byshevets et al., 2023). The safety of the educational environment becomes not only a prerequisite for the learning process, but also a basic predictor of students' emotional stability and viability (Stelter et al., 2025). That is why the integration of safety indicators (infrastructure, warning systems, and organisational regulations) into QoL predictive models is conceptually and empirically justified.

Despite this, Ukraine lacks comprehensive models for predicting students' QoL that combine behavioural metrics (e.g., IPAQ physical activity level), mental health indicators (SWLS life satisfaction) and specific wartime factors (educational environment safety index). This approach opens up prospects for the personalised design of health-enhancing recreational programmes aimed at identifying risk groups and targeting key components of QoL such as physical activity, mental resilience, and social support. Therefore, the creation and validation of predictive ML models of the physical and mental components of students' QoL, taking into account complex determinants (behavioural, mental, social, and security) is an urgent scientific problem. The results of such models can form the basis for improving the structure and content of health-enhancing recreational programmes in higher education institutions in Ukraine during wartime.

Material and methods

Participants

The study involved 172 university students aged 18 to 25 (M=20; SD=20-21) representing various courses and educational programmes at higher education institutions in Ukraine. The sample was balanced in terms of sex and included 84 young men (48.8%) and 88 young women (51.2%), which made it possible to identify sex-related differences in the level of physical activity and QoL indicators. The criteria for inclusion in the study were: active student status (bachelor's degree); no medical contraindications to physical activity; regular attendance at the university's sports and recreation centre (SRC); and voluntary consent. All participants confirmed their informed consent to participate in the study. For safety and ethical reasons, the conditions of studying under martial law were taken into account: students were involved only in cases where the educational process took place in a safe environment. Thus, the sample was a representative group of Ukrainian students who were in a period of high academic workload and adaptation to changes in the social and educational environment, which allowed us to investigate the relationship between physical activity, quality of life, and safety factors.

Research organization

In this study, several internationally validated instruments were employed to ensure the methodological robustness of data collection and interpretation. To evaluate perceptions of service quality in the sphere of sports and health-related activities, the Sports and Health Service Quality Assessment Scale (SQAS) was applied. The instrument, originally developed for assessing the quality of sports services (Lam et al., 2005), was contextually adapted to the realities of wartime Ukraine. The modified version included 42 items, structured into seven analytical dimensions. Reliability diagnostics confirmed an exceptionally high level of internal consistency (Cronbach's α=0.991) and stability of responses (split-half reliability = 0.994).

Assessment of health-related quality of life (HRQoL) was carried out using the Short Form-36 Health Survey (SF-36), one of the most widely implemented generic tools in clinical and health research. The instrument consists of 36 items, grouped into eight domains that collectively generate two composite indices: the Physical Component Summary (PCS) and the Mental Component Summary (MCS). Scores for each domain were calculated on a 0–100 scale, where higher values reflect better perceived health status. The psychometric evaluation in our sample confirmed satisfactory internal reliability (Cronbach's α=0.753) and good test stability (split-half reliability = 0.810).

The International Physical Activity Questionnaire – Short Form (IPAQ-SF), adjusted to the Ukrainian sociocultural and environmental context, was used to obtain a quantitative estimate of physical activity. The short version of the IPAQ comprises seven questions covering vigorous and moderate physical activity, walking, and sedentary behavior during the previous week. Energy expenditure was calculated in metabolic equivalent minutes per week (MET-min/week) and categorized into three levels: low (<600), moderate (600–3000), and high (>3000). The reliability assessment demonstrated acceptable consistency for this cohort (test–retest correlation r=0.79).

Statistical analysis

Machine learning methods were used to predict the physical (PCS) and mental (MCS) components of QoL. The main model used was Gradient Boosting Trees (GBT) with the following parameters: 200 trees, maximum depth – 10, learning rate – 0.1. To verify the results, Random Forest (RF) models (40 trees, depth – 10) were additionally constructed.

In each case, the data was randomly divided into training (70%) and test (30%) samples. Cross-validation was used to avoid overfitting. The performance of the models was evaluated using the following standard metrics: MAE (Mean Absolute Error), RMSE (Root Mean Squared Error), and MAPE (Mean Absolute Percentage Error). The calculations were performed in STATISTICA 14.0 (StatSoft, USA).

Since the results of the factor analysis revealed two significant factors explaining 76.6% of the total variance (Factor 1 includes all motives for visiting SRC, and Factor 2 includes all limiting factors, except for lack of time and finances, four variables were created from the 19 available for further analysis: «Motivation» (average value of all motives), «Limitations» (average value of Factor 2 components), «Lack of time», and «Lack of finances». The decision to treat the factors «Lack of time» and «Lack of finances» as separate variables was justified by their unique influence and lack of correlation with other limiting factors.

Thus, the data set used for analysis included the following dependent variables: physical component (PCS) and mental component (MCS) of QoL, as well as independent variables: satisfaction with life (SWLS) assessed on a scale from 5 to 35 points; satisfaction with sports and health services (SQAS) consisted of seven factors (SQAS1 – staff, SQAS2 – locker room, SQAS3 – programm, etc.) assessed on a Likert scale from 1 to 7 points; level of physical activity (IPAQ) assessed on a scale from 0 to 35 points; motivation to visit the SRC, average value for all motives was assessed on a Likert scale from 1 to 7 points; limiting factors, average value for all limiting factors, except for «lack of time» and «lack of finances», was assessed on a Likert scale from 1 to 7 points; lack of time assessed on a Likert scale from 1 to 7 points; and lack of finances scored on a Likert scale from 1 to 7 points. Categorical variables included sex: 1 – male, 0 – female; and group of respondents by frequency of visits to the SRC: 1 – 3 or more times a week, 2 – 1-2 times a week.

Results

To assess the relationship between independent variables and the physical component of QoL, the programme constructed a single tree. To predict PCS, there was a simple linear relationship that can be adequately described by a single tree, i.e. a simple set of rules (Fig. 1a). To predict the mental component of QoL based on the data studied, 130 trees were needed. As can be seen (Fig. 1b), the prediction error of the training data steadily decreases as more and more additive terms (trees) are added to the model. However, after 130 trees, the performance for the test data of independently taken samples actually begins to deteriorate, clearly indicating the point at which the model begins to overfit the data. The Boosted Trees algorithm automatically determines this point and calculates the predicted values (and generates deployment code to calculate the predicted values using rapid model deployment) for the corresponding number of trees.

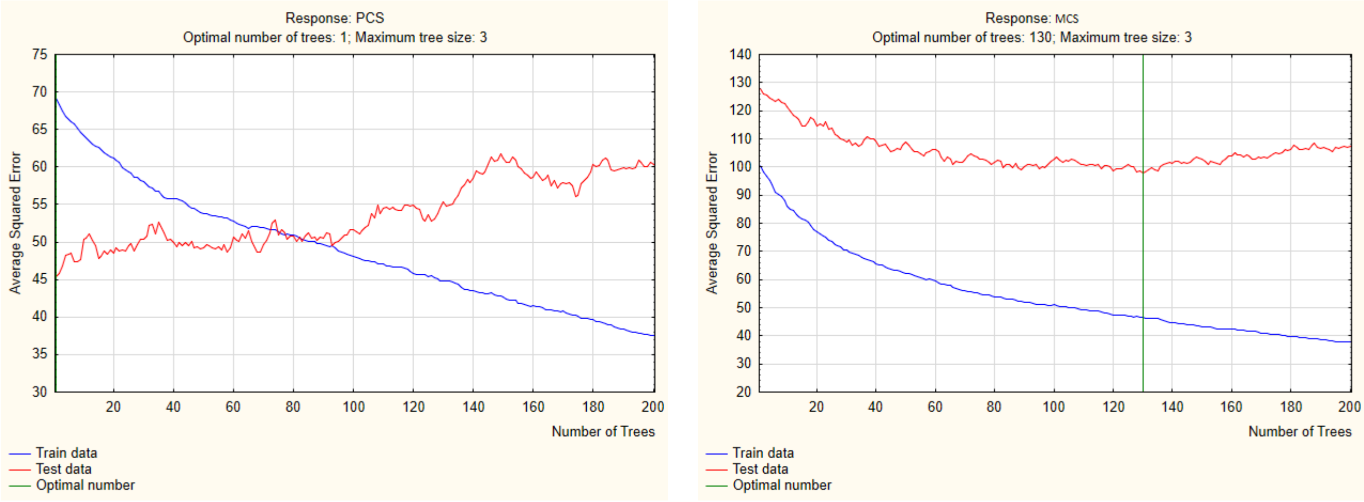

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Figure 1. **Summary of Boosted Trees.**

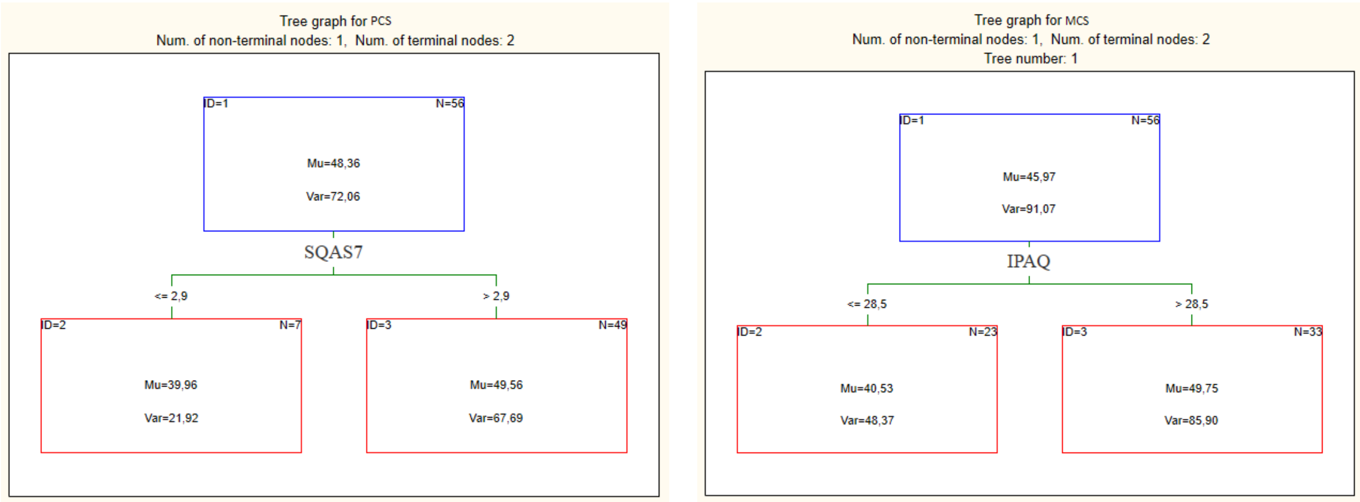

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Figure 2. **Examples of trees for the physical and mental components of students' quality of life.**

This indicates that the relationship between independent variables and MCS is much more complex than the relationship between them and PCS. For MCS models, more trees were needed to reveal these complex relationships and make accurate predictions.

Figure 2 illustrates the trees obtained for the physical (a) and mental (b) components (Fig. 2).

The average PCS value for the root node is 48.36±8.49 (where 8.49 is the standard deviation calculated as the square root of the variance Var). This means that the PCS values in the root node deviate from 48.36 by an average of 8.49 units.

If the SQAS7 'Safety' score exceeds 2.9 points (average and above), the average PCS value increases to 49.56±8.23. In a node where the SQAS7 score is below 2.9, the average PCS value is 39.96±4.68. Thus, when the SQAS7 score exceeds 2.9 points, the average PCS value increases by approximately 9.6 units (49.56-39.96), which is 24% of the average PCS value in a node with a lower SQAS7 score (39.96) (Fig. 3a). To predict MCS, 130 trees were constructed using the Gradient Boosting Trees algorithm. Each tree in this algorithm sequentially corrects the errors of the previous ones, and the final prediction is the sum of the predictions of all 130 trees. As an example, let us consider one of the trees in this model. If the physical activity score (IPAQ) exceeds 28.5 points, the average MCS value increases by approximately 9.22 units (49.75-40.53). This represents 22.7% of the average MCS value in the node where the IPAQ score is below 28.5 points (40.53) (Fig. 3b).

Model 1 determines the relative importance of factors influencing the physical and mental components of QoL. With regard to PCS, it should be noted that safety (availability of shelters, timely air raid warnings, safety during air raids and resumption of classes after them, general safety) has the greatest weight (1.0), especially during

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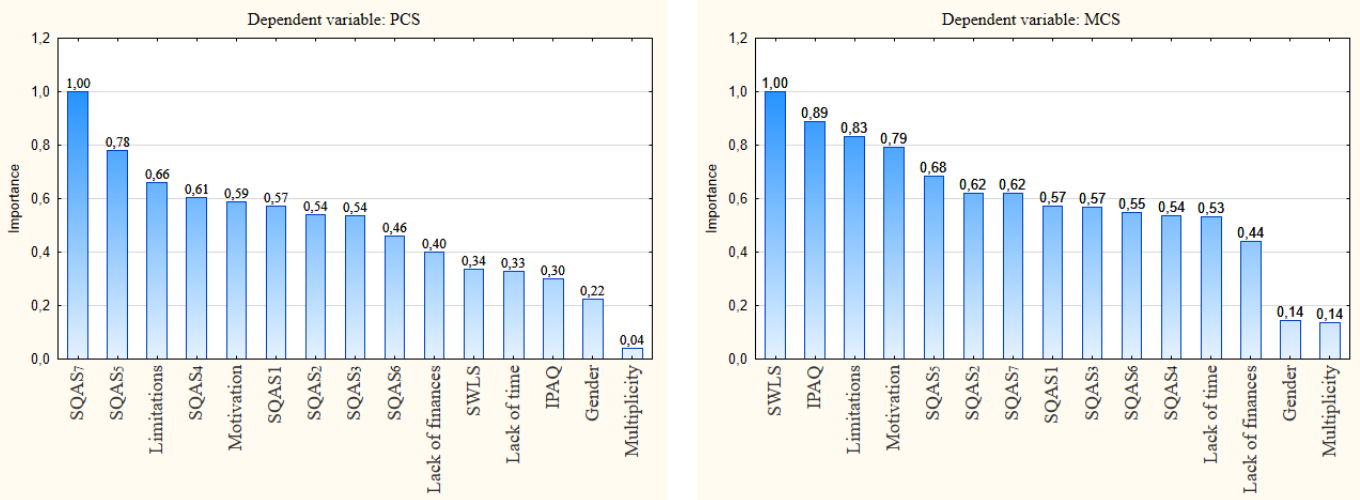

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Figure 3. **Relative importance of variables for predicting physical and mental components of QoL (Model 1)**

wartime. This indicates that safety is a primary factor affecting students' physical well-being and emphasises the importance of creating a safe environment for physical education and sports in wartime. The high weight of the predictor «Events» (0.782), which includes the frequency of events, their informational support and quality, suggests that the quality and organisation of events play an important role in the physical component of QoL. In addition, the factors «Limitations» (lack of motivation, poor health, fear or shyness, lack of support, inaccessibility of sports infrastructure, lack of interesting programmes) and «Training facilities» (comfort of the hall/pool, modern equipment, adequacy of signage, variety and accessibility of equipment, overall service) also have a significant impact (0.652 and 0.606, respectively). This indicates that the limitations faced by students and the quality of training facilities play an important role in their physical well-being (Fig. 3a). The mental component of QoL (MCS) includes the following most significant factors. Among them is SWLS (Satisfaction with Life), which, as expected, has the greatest weight (1.0). This confirms that mental well-being is closely related to overall life satisfaction. The next most important factor is IPAQ (Physical Activity), whose high weight (0.886) emphasises its importance for mental well-being. This confirms that physical activity not only improves physical health but also has a positive effect on mental health. Factors such as «Constraints», «Motivation» (improving physical health and mental well-being, socialisation and communication, achieving sporting goals, obtaining pleasure, relieving stress and tension, increasing productivity, development of useful habits, the opportunity for self-expression) and «Activities» also have a significant impact (0.833, 0.792 and 0.685, respectively), indicating that students' mental well-being depends on various factors, including limitations, motivation, and activities. In addition, «Programmes» and «Safety» have a weight of more than 0.6, indicating that training programmes and safety are of significant importance (Fig. 3b).

When building Random Forest models, we found that about 10 trees are needed in an ensemble to predict PCS, and about 15 trees are needed for MCS (see Fig. 4a and 4b).

An analysis of significant factors influencing the physical component of QoL (PCS), obtained using the Random Forest model, revealed that satisfaction with life (SWLS) is the most significant predictor (weight 1.00). The following factors also have a significant impact (weight 0.98–0.99): Staff (possession of the necessary knowledge/skills, neatness and clothing, willingness to help, sociability, response to complaints, etc.); Adaptability (convenient schedule and format of classes, student support, inclusiveness); Locker room (general service, cleanliness of showers, accessibility, safety). As for the significant factors influencing the mental component of QoL (MCS), the priority factor was «Safety» (SQAS7) (weight 1.00). The next most significant factors, satisfaction with life (SWLS) and locker room, have significantly lower weights: 0.782 and 0.715, respectively (Fig. 5). Irrespective of the predictive approach applied (Gradient Boosting Trees or Random Forest), the variables «Sex» and «Frequency of classes» demonstrated minimal explanatory power in relation to both the physical and mental domains of students' quality of life. By contrast, under wartime conditions, the «Safety» factor emerged as a critical determinant, consistently showing strong predictive weight across both modeling strategies for the physical and mental components of QoL. To evaluate the relative per-

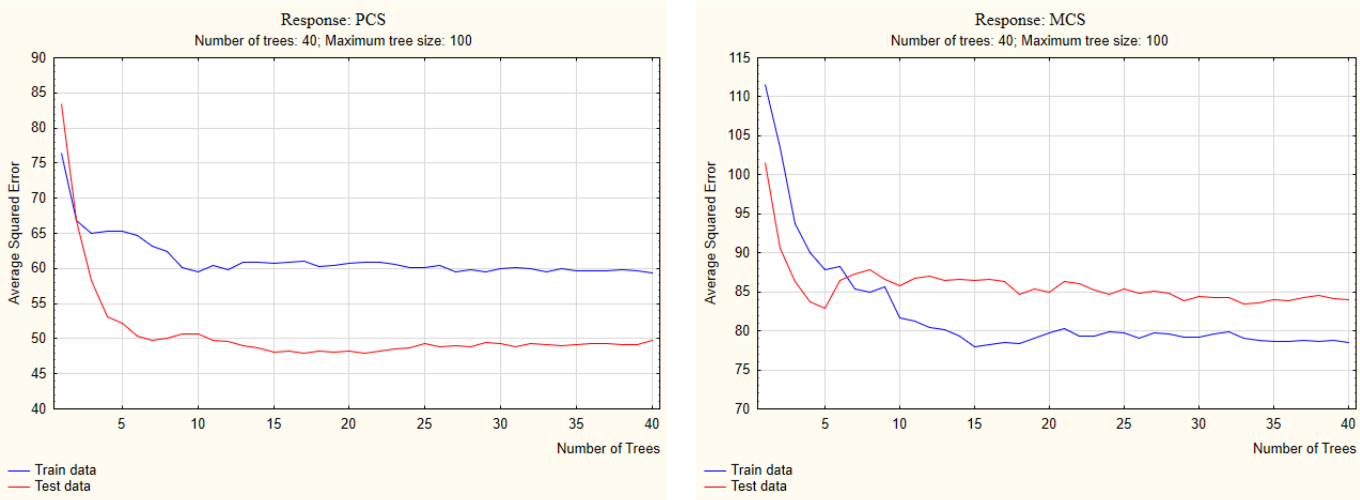

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Figure 4. Summary of Random Forest

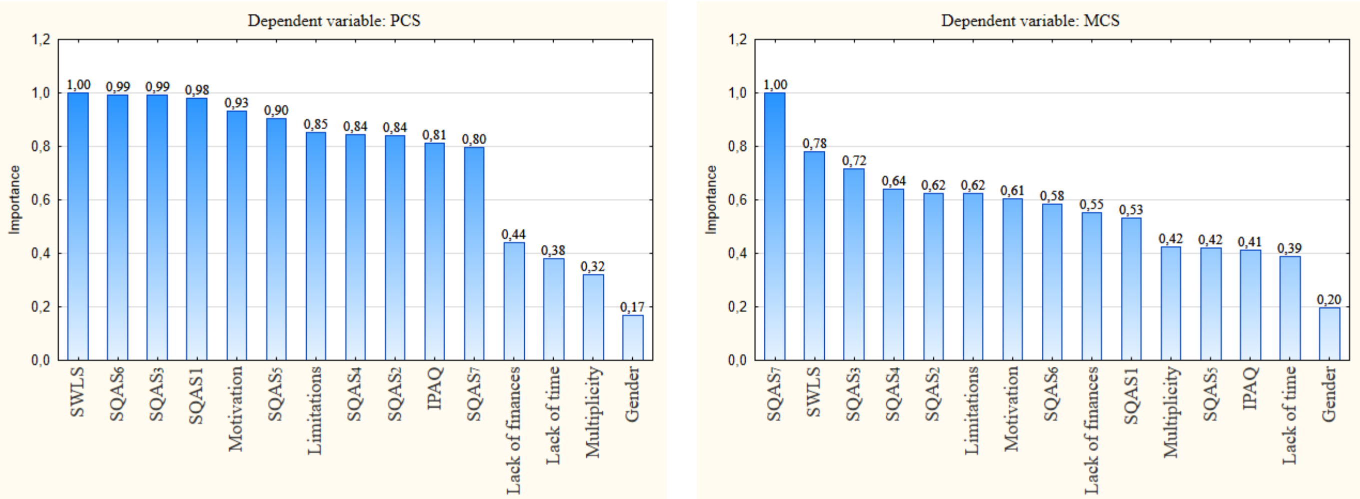

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Figure 5. Relative importance of variables for predicting physical and mental components of QoL (Model 2)

formance of the two algorithms in forecasting the Physical Component Summary (PCS) and Mental Component Summary (MCS), a residual analysis was conducted.

For the PCS, the residuals exhibited a normal distribution, as confirmed by the Shapiro-Wilk W test, thereby allowing the application of Student's t-test for independent samples. The comparison revealed no statistically significant differences between Gradient Boosting Trees and Random Forest models ($t=1.793$; $df=99$; $p=0.0868$). In contrast, the residuals for the MCS demonstrated deviations from normality in the Gradient Boosting Trees model ($W=0.911$; $p=0.0009$). Consequently, a non-parametric Mann-Whitney U test was employed to compare model performance for this component. This approach allowed for a more robust comparison of the predictive accuracy between the two methods when distributional assumptions were not met. The analysis did not reveal any statistically significant differences between the MCS models either ($U=1220.0$; $Z=-0.855$; $p=0.3926$). This indicates that both models perform equally well on the data. On the other hand, the findings of a comparative analysis of model quality metrics demonstrated that Gradient Boosting Trees exhibited the following outcomes in predicting physical (PCS) and mental (MCS) components of QoL (Table 1).

The results showed that the Gradient Boosting Trees model demonstrates higher prediction quality, as evidenced by lower metric values: MAE (5.53 vs. 5.70), RMSE (45.70 vs. 49.76) and MAPE (0.102 vs. 0.119). In addition, the simplicity of the Gradient Boosting Trees model, which performs effectively with a single tree, is an additional advantage over Random Forest, which requires an ensemble of about 10 trees for stabilisation. Unlike PCS prediction, the Random Forest model showed better results for MCS. The RMSE

Table 1. Model quality assessment based on test samples

Model	PCS			MCS		
	MAE	RMSE	MAPE	MAE	RMSE	MAPE
Gradient Boosting Trees						
1	5.53	45.70	0.102	7.46	98.02	0.198
Random Forest						
2	5.70	49.76	0.119	7.69	83.96	0.180

(83.96) and MAPE (0.180) metrics for Random Forest are lower than those for Gradient Boosting Trees (98.02 and 0.198, respectively). This indicates that Random Forest provides more accurate MCS predictions. In both cases, the models showed better results for predicting the physical component (PCS) than for the mental component (MCS). The result obtained is important for understanding the peculiarities of modelling subjective assessments of the physical and mental components of QoL. It shows that the physical component of QoL is more predictable than the mental component, which is more complex and variable.

Discussion

The results confirm that the level of safety is a determining predictor of both the physical and mental components of the QoL among higher education students. This conclusion is consistent with the findings of previous studies of Ukrainian researchers, which have emphasised the critical role of socio-psychological factors in maintaining the well-being of students under conditions of increased stress, particularly during wartime (Andrieieva et al., 2022, 2025; Maltsev et al., 2022; Petrachkov et al., 2023). A sense of security can be seen as a basic condition for the implementation of adaptive mechanisms that ensure the preservation of physical and mental health.

The identified impact of physical activity and life satisfaction on the indicators of QoL is consistent with reported data. Ramón-Arbués et al. (2022) demonstrated that regular physical activity among students is closely correlated with higher QoL indicators. Similar results were obtained by researchers, emphasising the integral importance of physical culture for maintaining vitality and psycho-emotional stability (Hakman et al., 2020; Steinacker et al., 2023).

Intelligent data analysis revealed that machine learning models are capable of accurately predicting the physical and mental components of QoL taking into account the multifactorial nature of the phenomenon. This is in line with current scientific trends, where machine learning algorithms are used to model individual trajectories of mental and physical health (Zhang et al., 2023). Similar approaches have already demonstrated their effectiveness in identifying hidden patterns of correlation between physical fitness levels and psychological indicators in students (Pang & Wang, 2022).

The results of the study reinforce the current understanding of quality of life as a multidimensional construct, where physical, psychological, and social factors are intertwined (WHOQOL Group, 2020). Under conditions of war and social instability, when traditional sources of well-being are limited, the importance of safety, physical activity, and life satisfaction increases significantly. This highlights the need to integrate QoL prediction methods into the practice of educational institutions, which will allow for the timely identification of at-risk groups of students and the development of targeted health-enhancing recreational programmes.

The results of the study confirm the effectiveness of using intelligent data analysis methods, in particular stochastic gradient boosting trees (GBDT) and random forest, in predicting the physical and mental components of QoL. The results are consistent with previous studies, which indicate the high accuracy of machine learning algorithms in modelling multifactorial processes related to health and physical activity.

A comparison of the models used revealed that GBDT demonstrates higher predictive power than Random Forest, which may be due to its ability to take into account complex relationships between variables and optimise the learning process through adaptive tree weight updating. However, it should be noted that the use of GBDT requires careful tuning of hyperparameters to achieve maximum performance, which may be a limitation in its application for real-time analysis of large data sets.

An analysis of the factors that most influence the predicted components of QoL showed that physical activity level, subjective perception of one's own health, and stress level play a key role. These findings are consistent with studies that emphasise the importance of a healthy lifestyle and psycho-emotional state in shaping a person's overall well-being. At the same time, the interaction between individual factors indicates the need for a comprehensive approach to predicting QoL.

Despite the positive results, this study has certain limitations. First, the study sample was relatively limited, which may affect the generalisability of the conclusions. Second, only quantitative indicators were taken into account without a detailed analysis of individual socio-economic factors, which may also have a significant impact on QoL. Further studies should include larger samples and consider additional social and psychological aspects to improve the accuracy of the models.

Practical Implications

The outcomes of this research extend beyond theoretical considerations and hold direct applicability for the organization of student support systems in higher education. The pronounced influence of safety-related perceptions on both physical and mental quality-of-life domains demonstrates that the creation of secure educational and living environments should be regarded as a strategic priority, particularly in conflict-affected regions. Such measures may include not only infrastructural improvements but also the expansion of psychological counseling services and stress-management initiatives.

Equally important is the role of physical activity, which emerged as a consistent determinant of quality of life across both physical and mental dimensions. This finding provides a strong rationale for the integration of structured physical education, recreational programs, and individualized exercise interventions into the daily routines of students. In doing so, universities may counterbalance the adverse health consequences of reduced mobility and sedentary behaviors that are often exacerbated in crisis conditions.

The study also highlights the contribution of life satisfaction, motivational factors, and activity-related limitations to students' well-being. These insights suggest that effective health-promotion strategies should adopt a multifaceted approach, combining physical training with psychological resilience-building, motivational support, and opportunities for social participation.

Finally, the demonstrated effectiveness of machine learning methods (GBT and RF) in predicting quality of life supports their application as innovative tools for data-driven monitoring and personalized intervention design. Embedding such models into institutional health frameworks could facilitate early identification of at-risk groups and inform tailored interventions aimed at sustaining both physical and mental health outcomes.

Conclusions

The application of the Gradient Boosted Trees (GBT) method revealed notable differences in the complexity of relationships between independent variables and the QoL components. For the physical component, the model generated a single tree, while for the mental component, 130 trees were required, indicating a substantially more intricate interplay between predictors and students' psychological well-being in wartime conditions.

Both the GBT and RF models consistently identified "Safety" (SQAS7) as a critical determinant, highlighting its priority for students under conditions of armed conflict. Regular physical activity (IPAQ) was also a significant contributor to both physical (RF; 0.821) and mental (GBT; 0.886) domains of quality of life. Additional influential factors included overall life satisfaction (SWLS), functional limitations, motivation, and engagement in daily activities. Conversely, variables such as "Sex" and "Frequency of classes" showed no significant effect on students' quality of life. The findings emphasize the importance of incorporating the war-related context into quality-of-life research.

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Supplementary Information

Author's contribution

Olena Andrieieva: Conceptualization, Methodology, Check, Formal Analysis, Investigation, Resources, Writing – Rough Preparation, Writing – Review and Editing, Visualization, Supervision, Project Administration; **Nataliia Byshevets:** Conceptualization, Methodology, Software, Formal Analysis, Investigation, Resources, Data Curation, Writing – Rough Preparation, Visualization; **Andriy Vindyk:** Conceptualization, Methodology, Investigation, Resources, Writing – Review And Editing; **Vadym Stepanuk:** Methodology, Software, Investigation, Resources, Writing – Review And Editing; **Inna Khrypko**: Investigation, Resources. All authors have read and agreed with the published version of the manuscript.

Declarations

Conflict of Interest
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Efficacy of Blood Flow Restriction Training (BFRT) in Alleviating Chronic Wrist Pain and Enhancing Forearm Function among Badminton Players: A Pilot Study

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Abstract

Purpose. Wrist pain is a prevalent concern among badminton players often resulting from monotonous physical stress and overuse, which can lead to functional limitations and compromised performance. Blood flow restriction training (BFRT) has emerged as promising intervention in musculoskeletal rehabilitation therapy, offering muscular benefits at low intensities. However, its efficacy in upper limb conditions, particularly chronic wrist pain in athletes, remains underexplored. To assess the success of BFRT in dropping wrist pain, enhancing range of motion (ROM), and promoting muscle hypertrophy among badminton players with chronic wrist discomfort

Material & Methods. A descriptive and quantitative case series was conducted with 10 badminton players (6 males, 4 females; mean age: 27.2 ± 1.81 years) experiencing chronic wrist pain for over three months. Participants underwent a four-week BFRT intervention involving low-intensity biceps and wrist curls, performed three times a week. Cuff pressure was standardised at 50% of limb occlusion pressure (LOP), and the exercises were conducted at 20% of one repetition (max). Pain (VAS), ROM, and forearm girth were assessed pre- and post-intervention.

Results. The mean VAS score reduced from 6.9 ± 1.10 at baseline to 0 post-intervention, indicating a 100% reduction in perceived pain. Forearm girth increased from a mean of 6.68 ± 1.2 inches to 6.88 ± 1.3 inches, reflecting hypertrophy. Participants reported an improvement in their ability to use their hands functionally and a reduction in pain during daily activities. Statistically significant pain reduction was observed earlier in female participants compared to males.

Conclusions. BFRT significantly alleviated wrist pain, improved muscular adaptations, and enhanced functionality in badminton players, demonstrating its potential as a low-risk and cost-effective alternative technique as compared to traditional high-load resistance training. These preliminary findings suggest that it could be used for upper limb rehabilitation, but further large-scale controlled trials are needed to establish its general applicability.

Keywords: Blood Flow Restriction, Wrist Pain, ROM, Badminton Players.

Introduction

BFRT-Training sets an exceptional workout technique, which requires utilizing a magnified cuff to moderately restrict blood flow to a specific extremity throughout the low-concentration confrontation exercise (Patterson et al., 2019). This trend has gained considerable attention in recent years due to its potential benefits for muscle development and rehabilitation (Loenneke et al., 2012). Certain pneumatic cuffs are applied by BFRT, and they partially compress a specific limb's blood flow. In layman's terms, BFRT is what you might term a blood pressure cuff-like pressure bandage put on your arm or leg and done during periods of muscular training (Branco Ferraz et al., 2018). A cuff is usually put on the inner thigh or middle arm and inflated to a specific pressure, typically 40% to 60% of the person's systolic blood pressure (Bryk et al., 2016). This degree of occlusion cuts off most of their blood circulation, but some arterial flow is still maintained even at such low levels (Burton & McCormack, 2022).

BFRT training works by moderately occluding, preserving arterial influx while venous return, thereby making the environment hypoxic inside the target muscle. This physiological condition accelerates the build-up of metabolites, including lactate and hydrogen ions. These metabolites then stimulate muscle protein synthesis through activation of the mTOR pathway and increased recruitment of fibres responsible for rapid twitching (Pearson & Hussain, 2015). Metabolic stress generated by low-load resistance training triggers hormonal responses, including increased growth hormone secretion. This enhances muscle hypertrophy and vascular adaptation, even with minimal mechanical strain.

In addition to its muscular benefits, BFRT has demonstrated significant analgesic effects. These are attributed to two mechanisms: exercise-induced hypoalgesia (EIH) and the initiation of endogenous opioid pathways. Studies suggest that these mechanisms contribute to both short-term and sustained pain relief (Hughes & Patterson, 2020). Consequently, BFRT presents a dual advantage of reducing pain and improving function, making it highly applicable in rehabilitation contexts where high-load exercises are contraindicated. Despite the growing body of literature supporting BFRT in lower limb and postoperative rehabilitation, its application in upper limb conditions, particularly in wrist joint dysfunctions, remains relatively underexplored.

Most existing studies have focused on knee osteoarthritis, ACL recovery, or post-fracture rehabilitation, with limited attention to chronic wrist pain in badminton athletes. There is also a lack of trials examining BFRT's effects on sport-specific upper limb injuries, such as those sustained by badminton players who frequently engage in repetitive wrist movements. Furthermore, many published trials focus on strength outcomes without evaluating functional or patient-reported measures such as pain scales, the activities of daily living (ADL), and range of motion. Additionally, variations in BFRT protocols (e.g., cuff pressure, limb occlusion percentage, exercise intensity) contribute to inconsistencies in reported outcomes. Thus, there is a need for standardised protocols and evidence on real-world clinical applications of BFRT in upper limb pain management. This study aimed to evaluate the effectiveness of Blood Flow Restriction Training (BFRT) in reducing chronic wrist pain and enhancing forearm function among badminton players. Specifically, it assessed changes in pain levels, range of motion, and muscle hypertrophy following a four-week low-intensity BFRT intervention, and gender differences.

Material and Methods

Study Design

A quantitative and descriptive approach was employed in the process. Focusing on specific symptoms and providing a detailed description of them is the goal of a descriptive technique.

Participants

The sample included ten badminton players, both male and female, from the Physiotherapy Department at Golgotia University. Their average age was 27.2±1.81 years, their average height was 168.42±10.80 cm, their average weight was 60.1±7.72 kg, and their BMI was 20.66±1.44 kg/m².

Sampling

A strategy of stratified random sampling was employed. On the provided form, all participants agreed to the study's terms in writing. The participants all stated that they were OK. The researcher provided technical explanations to the participants before the test on the implementation methods.

Sample Selection

The sample selection for the study was conducted using G*Power software, which recommended a sample size of 10 (West Attica, 2023).

*Calculation on G*Power for Sample Selection*

t tests – Means: Difference between two dependent means.

Analysis: A priori: Compute required sample size.

Input: Tail(s) = 2
Effect size = 1.0
α = 0.05
Power = 0.80

Output:
Critical t = 2.2621572
Df = 9
Total sample size = 10

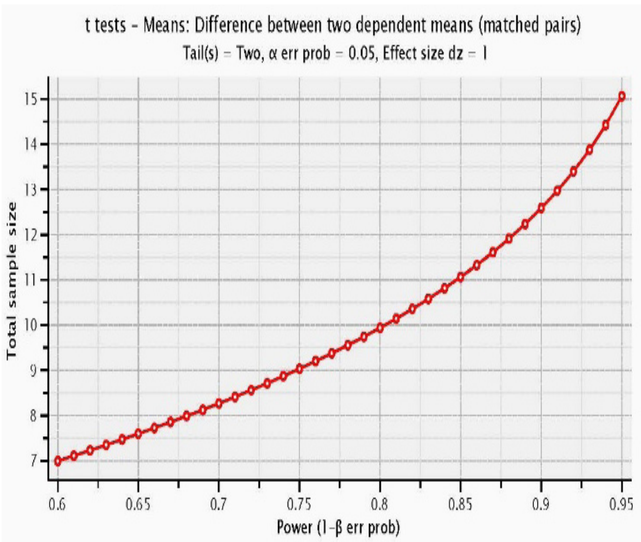

Figure 1. **Showing the Sample Size Graph.**

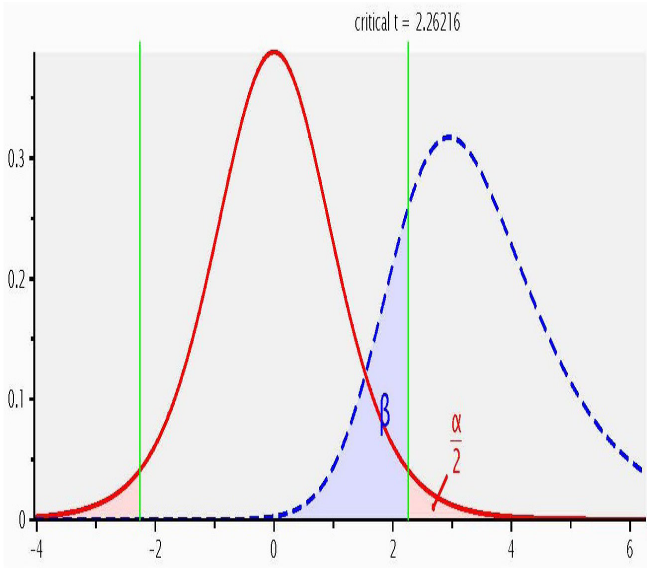

Figure 2. **Showing the Sample Critical t value**

Procedures

This study employed a quantitative and descriptive approach to evaluate the effects of blood flow restriction training (BFRT) on chronic wrist pain in badminton players. The procedure consisted of the following steps:

Participant Recruitment and Baseline Assessment

- Participants: Ten badminton players (both male and female) with chronic wrist pain (≥3 months) were included.
- Exclusion Criteria: Acute injuries or contraindications to BFRT.

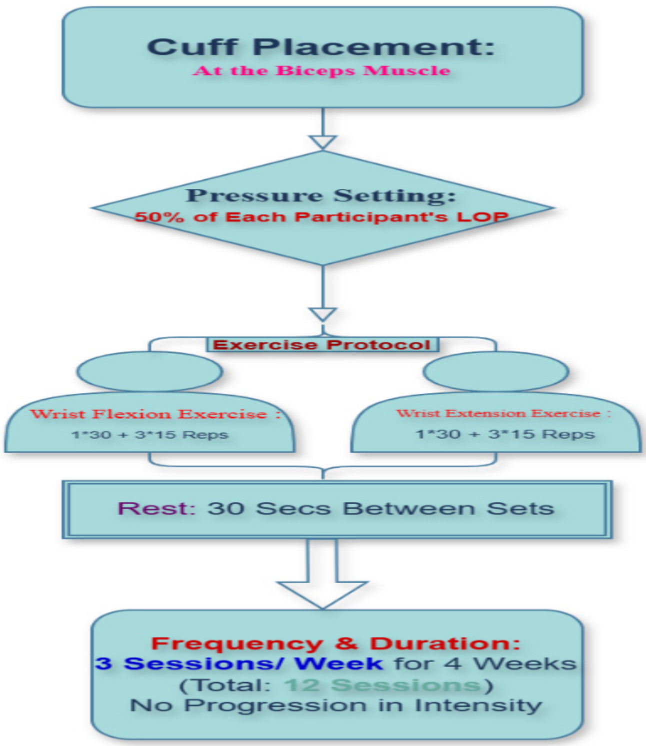

Figure 3. **BFRT Intervention Protocol.**

- Baseline Measurements:
  - Demographic data: (age, gender, height, weight).
  - Pain assessment: Visual Analog Scale (VAS).
  - Wrist range of motion (ROM): Goniometer.
  - Limb Occlusion Pressure (LOP): Handheld Doppler Device.
  - BFRT used on the Upper Limb

Monitoring and Safety

Participants were monitored for pain, numbness, or discomfort during sessions. Any adverse effects resulted in the cuff pressure being released immediately.

Post-Intervention Assessment

- Pain (VAS): Re-evaluated after 4 weeks.
- Forearm Girth: Measured to assess muscle hypertrophy.
- ROM: Reassessed using a goniometer.

Instruments used

Visual Analogue Scale (VAS)

A psychometric tool was used to measure subjective characteristics like pain intensity among the participants. Patients were asked to rate their level of discomfort on a 10-centimeter-long line that went from "no pain" to "worst imagined pain."

Goniometer

It was used to measure the angle of joint movement. It helped to assess the range of motion (ROM) in joints such as the wrist.

Limb Occlusion Pressure (via Doppler)

The minimal pressure needed to block blood flow in a limb was determined by its use. Using a Doppler, a researcher determined the pressure by detecting when the arterial pulse disappears under a cuff. LOP ensured safe and individualised pressure settings under BFRT.

Blood Flow Restriction (BFRT)

In this study, a pneumatic blood flow restriction (BFRT) machine was used, featuring adjustable pressure cuffs applied to the upper arm. Limb Occlusion Pressure (LOP) was measured using a handheld Doppler device, and cuff pressure was standardised to 50% of LOP for safe and effective training during low-intensity resistance exercises.

All 10 individuals were informed about the purpose, methods, potential benefits and risks of the intervention before participating in the trial. The methodology, assessment methods, and expected results were carefully explained. Participants were informed that their contribution was voluntary and that they could leave at any time without penalty. Before making a decision, all six participants were given adequate time to ask questions and address concerns, and they signed a formal agreement. They were informed that their personal and medical information would only be used for research purposes.

Data Analysis

Descriptive statistical analysis was used to provide results as mean and standard deviation values for pain (VAS), range of motion (ROM), and forearm girth before and after the intervention. To evaluate the statistical significance of changes in VAS scores, a paired samples t-test was conducted (α=0.05).

Results

All 10 participants in this study reported persistent pain, functional limitations, and difficulty in performing daily activities due to their wrist pain. The primary complaint across all cases was pain around the wrist joint, which was aggravated by grasping, pinching, or repetitive wrist movements. The excruciating pain varied but was notable enough to interfere with basic activities. Ranges are recorded as decreased (Table 1).

Table 1. Demographic Details of Participants

Participant	Gender	Age	History of Pain
1	Male	28	3 months
2	Female	27	3 months 20 days
3	Male	28	3 months 15 days
4	Male	30	4 months
5	Female	25	3 months
6	Female	26	4 months
7	Male	25	3 Months 10 Days
8	Female	26	2 Months 25 Days
9	Male	27	4 months
10	Female	30	3 months

Table 2. Characteristics of Participants (Age, Weight, Height, BMI, LOP)

	LI+BFR_L [N=6(M)+4(F)]	p-value
	Mean (SD)	
Age (years)	27.2(1.81)	.143
Weight (kg)	60.10 (7.78)	.915
Height (m)	168.42(10.80)	.665
BMI (kg/m²)	20.66(1.44)	.896
LOP (mmHg)	188.50 (14.72)	.516

LI+BFR_L=Low-intensity exercise with blood flow restriction “Low”, M= Male, F=Female,

The characteristics of participants (Table 2) in the LI+BFR_L group (N=10) are presented as mean (SD). Statistical comparisons, as indicated by the p-values, revealed no significant differences between groups for any demographic or baseline variable. Specifically, age (p=.143), weight (p=.915), height (p=.665), BMI (p=.896), and limb occlusion pressure (LOP, p=.516) were all statistically comparable, confirming successful group equivalence at the outset of the study.

Analysis of Table 3 reveals a consistent pattern of restricted wrist range of motion across all ten participants. Measured values for flexion (2°-4°), extension (15°-25°), ulnar deviation (9°-12°), and radial deviation (6°-8°) were substantially diminished compared to established normative values. This uniform reduction indicates a significant functional impairment within the cohort, confirming a marked deficit in all primary planes of wrist movement before the intervention.

Pre-test evaluation (Table 4) revealed uniformly high pain and positive clinical signs. The mean VAS score was 6.9 (±1.10), indicating severe baseline pain. Provocative tests were predominantly positive for intense (IP) or unbearable pain (UP), with the distal radioulnar joint test positive in all participants (9 IP, 1 UP). Similarly, the scaphoid shift and ballottement tests were positive in the majority (8 IP/2 UP and 9 IP/1 UP, respectively), confirming significant wrist pathology across the cohort before intervention.

The selection of bicep curls and wrist curls was based on their ability to target key muscle groups affected by wrist dysfunction and pain. Biceps curls ensure proximal upper limb activation, while wrist curls specifically address forearm and wrist flexors/extensors, which are critical for functional grip and daily activities. Incorporating these movements within the BFRT protocol allows for hypertrophy and strength gains without applying high loads that could exacerbate pain.

Pain Reduction (VAS Scores)

The mean (SD) pre-intervention VAS score was 6.9±1.10. At the culmination of the 4 weeks, all participants reported a VAS score of 0, indicating complete pain resolution. The mean (SD) reduction in VAS score was 0±0, reflecting a 100% decrease from the baseline for all cases.

Forearm Girth (Hypertrophy Effect)

The mean (SD) in forearm girth in the pretest

Table 3. Range of motion of the wrist joint

	Patient’s ID									
Motion	P-1	P-2	P-3	P-4	P-5	P-6	P-7	P-8	P-9	P-10
Wrist Flexion (°)	3	4	2	2	3	4	3	2	2	3
Wrist Extension (°)	20	18	25	15	18	22	18	22	20	24
Ulnar deviation (°)	10	12	11	9	10	11	11	12	12	10
Radial deviation (°)	6	7	7	6	7	8	7	6	8	8

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Table 4. Pre-test Evaluation Participants

	Patient's ID										
Outcome Measurement	P-1	P-2	P-3	P-4	P-5	P-6	P-7	P-8	P-9	P-10	Mean (SD)
VAS	7	8	6	9	6	6	6	7	6	8	6.9 (1.10)
Distal Radioulnar Joint Test	IP	IP	IP	UP	IP	UP	IP	IP	IP	IP	
Scaphoid Shift Test	IP	IP	UP	IP	IP	IP	IP	IP	UP	IP	
Ballottement Test	IP	UP	IP	IP	IP	IP	IP	IP	IP	IP	

No Pain: NP, Mild Pain: MP, Moderate Pain: MoP, Intense Pain: IP, Unspeakable Pain: UP.

Table 5. The BFRT protocol was applied to all participants

Component	Description
Cuff Placement	At the Biceps Muscle
LOP Determination	Measured with a handheld Doppler; BFRT applied at 50% of LOP.
Exercise 1	Wrist Flexion Exercise (20% 1RM)
Reps & Sets (Biceps)	a) 1×30 reps; b) 3×15 reps; c) 30 sec rest amid sets
Exercise 2	Wrist Extension Exercise (20% 1RM)
Reps & Sets (Wrist)	Same as the biceps protocol
Rest Between Sets	30 seconds
Session Frequency	Per week – 3 sessions
Duration of Treatment	4 weeks – 12 sessions
Monitoring	Observation for pain, numbness, and tightness during each session
Progression	No progression; standardised protocol used throughout the intervention period

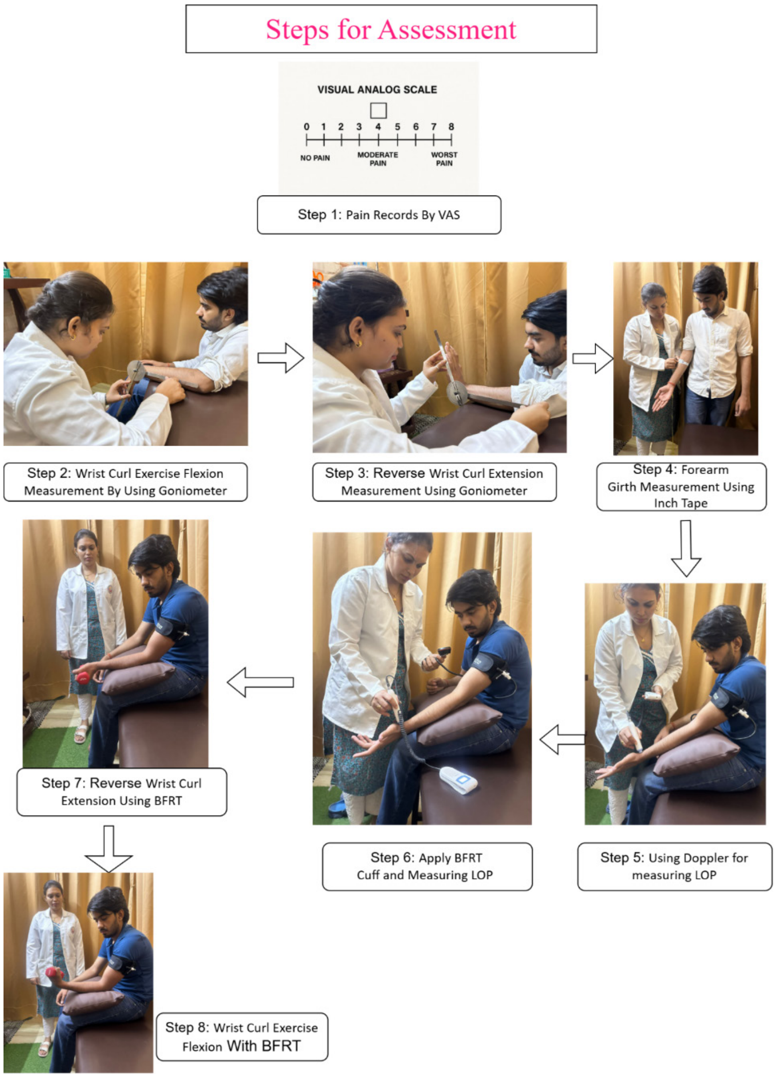

Figure 4. Steps followed for documenting assessment.

was 6.68±1.2 inches. The mean increase in forearm girth post-intervention was 6.88±1.3 inches. All 10 participants exhibited measurable increases in muscle girth, supporting the hypertrophic effect of BFRT when used in low-load resistance protocols.

Table 6. LOP (mmHg) of participants

Participants	Limb Occlusion Pressure [LOP]
1	210
2	160
3	180
4	180
5	200
6	190
7	180
8	185
9	195
10	205
Mean (SD)	188.5(14.72)

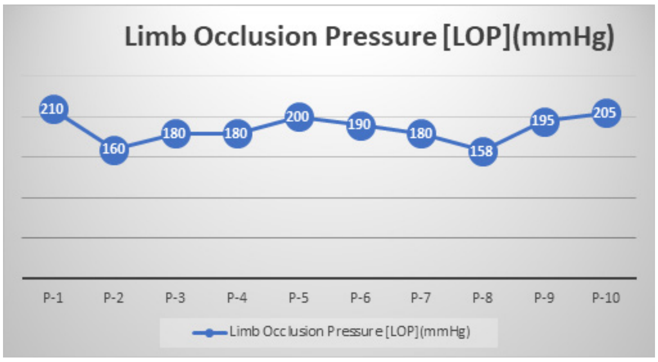

Figure 5. LOP (mmHg) Flow Chart of participants.

A 100% pain reduction over 4 weeks with minimal equipment and load makes BFRT an efficient and scalable intervention for wrist pain in sports rehabilitation. The muscle girth increase, although modest, reflects physiological adaptation and functional improvement (Table 6 & Figure 5).

Table 7. VAS Record of Participants (Pre and Post Score)

Participants	Pre-VAS	Post-VAS after 1st week	Post-VAS after 2nd week	Post-VAS after 3rd week	Post-VAS after 4th week
1	7	5	3.5	1	0
2	8	4.5	4	3	0
3	6	4	3	2.5	0
4	9	3.5	2	1	0
5	6	5	3.5	1	0
6	6	4.5	4	3	0
7	6	4	3	2.5	0
8	7	3.5	2	1	0
9	6	3	2	1	0
10	8	3.5	2.5	1.5	0
Mean	6.9	4.05	2.95	1.75	0
SD	1.100505	0.68516016	0.797565741	0.889756521	0

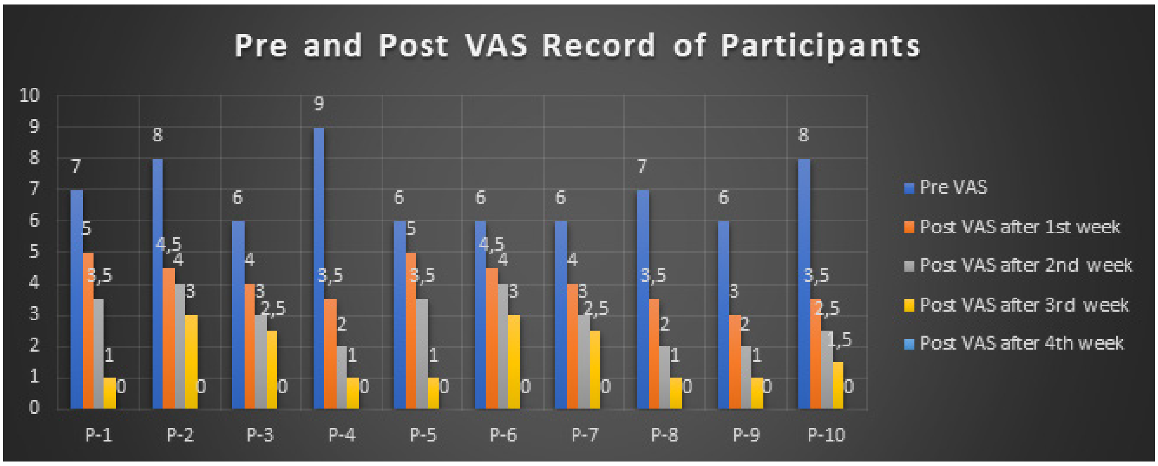

Figure 6. VAS Record of Participants in Pre- and Post-Period

The mean (SD) pre-intervention VAS score was 6.9±1.10. At the culmination of the 4 weeks, all participants reported a VAS score of 0, indicating complete pain resolution. The mean (SD) reduction in VAS score was 0±0, reflecting a 100% decrease from the baseline for all cases (Table 7 & Figure 6)

Table 8. **Forearm Girth (inch) Record of Participants (Pre and Post)**

Participants	Pre-forearm Girth (inch)	Post-forearm Girth after 4 weeks (inches)
P-1	7.1	7.3
P-2	5.2	5.6
P-3	8.5	8.8
P-4	5.6	5.1
P-5	5.2	5.7
P-6	7.5	7.11
P-6	6.8	7.2
P-7	8	8.7
P-8	6.3	6.7
P-9	5.2	5.9
P-10	7.1	7.3
Mean (SD)	6.68(1.2)	6.88(1.3)

The mean (SD) in forearm girth in the pre-test was 6.68±1.2 inches. The mean increase in forearm girth post-intervention was 6.88±1.3 inches. All 10 participants exhibited measurable increases in muscle girth, supporting the hypertrophic effect of BFRT when used in low-load resistance protocols (Table 8 & Figure 7).

The results in Table 9 indicate that there was no significant difference in baseline pain levels between male and female participants before the BFRT intervention. However, from the first week post-intervention onwards, females consistently reported significantly lower VAS scores, reflecting greater pain reduction compared to males. The difference became statistically significant from the first week ($p<.05$) and was highly significant by the third week ($p=.002$). By the fourth week, both groups reported zero pain, indicating the overall effectiveness of BFRT. However, the more rapid and consistent improvement in females suggests possible gender-based variation in treatment response.

The participants were diagnosed with wrist pain and had challenges in their ADLs, professional site, and quality of life because of pain,

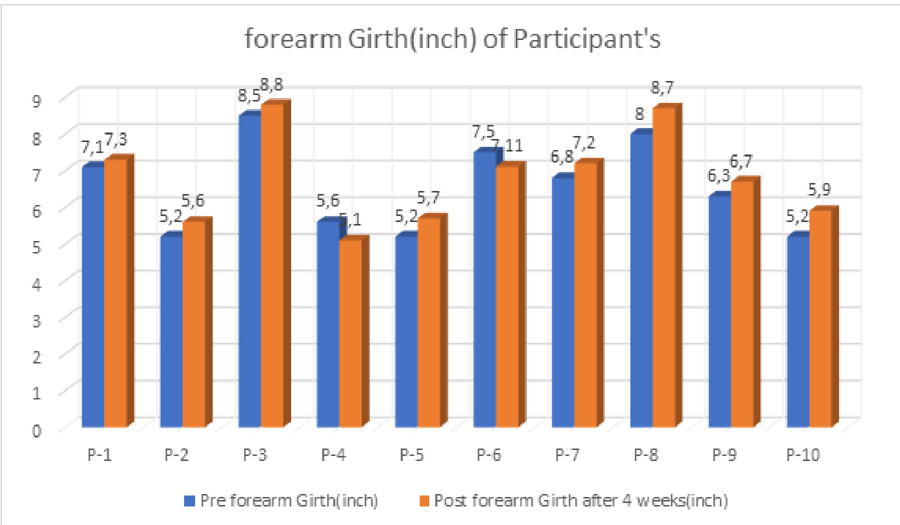

Figure 7. **Change in Forearm Girth (inch) of Participants**

Table 9. **Result showing the Impact of BFRT on Gender in Pre- and Post-Session**

VAS	Gender	N	Mean	Standard Deviation	Sig. (2-tailed)	p<.05	Result
Pre	Male	6	6.6667	.81650	0.444	**Not Sig.**	No significant difference in initial pain between genders
	Female	4	7.2500	1.50000	0.515		
Post 1st Week	Male	6	4.3333	.60553	0.032	**Sig.**	Significant difference—females had significantly lower pain levels than males.
	Female	4	3.6250	.62915	0.024		
Post 2nd Week	Male	6	3.1667	.68313	0.020	**Sig.**	The difference continues to be statistically significant—females improved more.
	Female	4	2.6250	.94648	0.019		
Post 3rd Week	Male	6	1.8333	.93095	0.009	**Sig.**	Highly significant difference—females experienced even greater pain relief.
	Female	4	1.6250	.94648	0.002		
Post 4th Week	Male	6	.0000	.00000	0	**0**	Standard deviations are 0 → all participants reported zero pain
	Female	4	.0000	.00000	0		

weakness, and reduced hand grip. Some of the participants disclosed difficulty while gripping, lifting objects, & performing repetitive wrist movements. Pain with VAS scores between 5 and 9 leads to discomfort even in a resting position. The functional limitations related to the condition reflect frustration, with some participants expressing anxiety about their inability to perform daily activities. After applying the intervention, most of the participants disclosed a notable pain reduction, improved wrist ranges, increased hand functionality, and reported more confidence while using their hands, experiencing less disturbance while performing ADLs, and recapturing some independence in their daily lives.

Discussion

The present study investigated the efficacy of a 4-week low-intensity blood flow restriction training (BFRT) protocol in a cohort of ten young adults suffering from chronic wrist pain and significant functional limitations. The results demonstrate a profound and consistent therapeutic effect, culminating in complete pain resolution, marked improvements in functional wrist range of motion (ROM), and measurable muscular hypertrophy in all participants. These findings align with and extend the growing body of evidence supporting BFRT as a potent rehabilitation modality, particularly for populations where high-load training is contraindicated or poorly tolerated.

The most striking outcome was the complete abolition of pain, with Visual Analog Scale (VAS) scores reducing from a severe mean of 6.9 (±1.10) to 0 in all participants after four weeks. This rapid and total pain relief surpasses the outcomes typically reported in standard low-load training without BFR(Centner et al., 2019). The mechanism behind this pronounced analgesic effect may be multifaceted. (Hughes & Patterson, 2020) provided compelling evidence that high-pressure BFR resistance exercise induces a significantly greater and longer-lasting exercise-induced hypoalgesia (EIH) in the exercising limb compared to both low- and high-load training without BFR. They attributed this effect partly to the elevated production of beta-endorphin, an endogenous opioid, observed during BFR exercise. The protocol employed in our study, utilizing BFR at 50% of Limb Occlusion Pressure (LOP), likely engendered a similar neurophysiological response, effectively modulating pain perception both locally and systemically. This is highly relevant for clinical practice, as it suggests BFRT can break the cycle of pain and disuse without relying on pharmaceutical interventions.

Furthermore, the results indicated a potential gender disparity in the rate of pain reduction, with female participants reporting significantly lower VAS scores from the first post-intervention week onward. While both genders achieved a pain-free state by week four, the accelerated response in females suggests a possible sex-based difference in pain modulation mechanisms activated by BFRT. This observation warrants further investigation in larger, controlled trials to elucidate the underlying physiological or hormonal factors and to optimize personalized treatment protocols.

Concurrently with pain resolution, participants exhibited significant improvements in active wrist ROM. Pre-intervention measurements revealed severe restrictions in flexion, extension, ulnar deviation, and radial deviation, values far below the normative functional ranges established by (Palmer et al., 1985). The restoration of movement towards these normative values is a critical indicator of regained functional capacity. The observed improvements can be attributed to two primary factors facilitated by the BFRT protocol: reduced pain allowing for greater movement and increased strength and stability of the periarticular musculature. The exercises targeted the wrist flexors and extensors, which are fundamental for dynamic joint stability and controlled movement (Fernandes et al., 2020). By enhancing the strength and endurance of these muscles with low mechanical stress, BFRT likely improved arthrokinematics and motor control, thereby facilitating greater voluntary ROM.

The significant increase in mean forearm girth from 6.68 (±1.2) inches to 6.88 (±1.3) inches provides tangible evidence of muscle hypertrophy, a central adaptation sought in rehabilitation to counteract atrophy and improve function. This finding is consistent with the meta-analysis by Lixandrão et al., 2015, which concluded that low-load BFR training promotes hypertrophic adaptations similar to those achieved with conventional high-load resistance training. The physiological premise for this is that BFR creates a potent metabolic environment (e.g., hypoxia, metabolite accumulation) that stimulates fast-twitch fiber recruitment and anabolic signaling pathways, leading to muscle growth despite the use of loads as low as 20-30% of 1RM (Pearson & Hussain, 2015) more recently, the use of low-intensity resistance exercise with blood-flow restriction (BFR. The application of this principle to the forearm musculature, as demonstrated here and by Fernandes et al., 2020 confirms that smaller muscle groups respond robustly to BFRT. This hypertrophic response is clinically invaluable, as increased muscle cross-sectional area directly contributes to strength gains and functional resilience.

The safety and practicality of the implemented protocol are paramount to its clinical translation. The use of a standardized pressure (50% of LOP), measured objectively via handheld Doppler, ensures a patient-specific yet reproducible stimulus, mitigating risks associated with arbitrary absolute pressures(Hughes et al., 2017). The absence of any adverse events, such as exacerbation of pain, numbness, or concerns regarding vascular safety (as measured by D-dimer levels in studies like Fan et al., 2023, reinforces the findings of other case reports and clinical trials that BFRT is a safe adjunct in musculoskeletal rehabilitation, even in post-surgical contexts(Ponce-Fuentes et al., 2025). The protocol's low-load nature (20% 1RM) makes it uniquely suitable for painful conditions, allowing for therapeutic exercise during acute or subacute phases where traditional training would be impractical or harmful.

This finding is consistent with previous studies indicating that BFRT is beneficial for the rehabilitation of the musculoskeletal system. For example, Loenneke et al. (2012) and Hughes et al. (2017) reported that BFRT can significantly improve muscle strength and functional capacity while reducing excessive pain, even at low resistance loads. Furthermore, Fan et al. (2023) found that incorporating BFRT into the recovery of patients after wrist surgery was more beneficial than previous methods. Our observations coincide with these studies, which also support the successful application of BFRT in arm rehabilitation. The reduction in pain that exercise can achieve is due to exercise-induced hypoalgesia. In this state, performing physical tasks temporarily decreases people's sensitivity to certain types of pain. This effect is thought to be caused by endorphins in the body, conditioned pain modulation and increased β-endorphin secretion (Hughes & Patterson, 2020). Increased forearm girth after BFRT use can be explained by mechanical and metabolic stimuli. This fires off mTOR signals, leading to muscle hypertrophy, and activates satellite cells in a low-load environment (Pearson & Hussain, 2015)., as well as activate satellite cells in a low-load environment (Pearson & Hussain, 2015)more recently, the use of low-intensity resistance exercise with blood-flow restriction (BFR.

In conclusion, the results of this study strongly support the integration of low-intensity BFRT into the rehabilitation framework for individuals with chronic wrist pain and functional impairment. The intervention produced a rapid and complete resolution of pain, likely mediated by enhanced endogenous opioid activity and EIH; significantly improved functional wrist ROM; and induced measurable muscle hypertrophy. These outcomes occurred without adverse events, highlighting the protocol's safety and efficacy. While the dramatic results are promising, the limitations of an uncontrolled case series design must be acknowledged. Therefore, these findings should be considered preliminary yet highly compelling. They warrant further investigation through randomized controlled trials comparing BFRT to standard care and other active interventions. Future research should seek to determine the optimal dosing parameters (pressure, load and volume) for different patient groups, and investigate the reasons for the observed gender differences in pain modulation. Ultimately, BFRT represents a paradigm shift in rehabilitation, as it enables clinicians to utilise the physiological adaptations of high-intensity training via a low-intensity, pain-free and clinically viable approach.

Possible Mechanisms

The reduction in pain that exercise can achieve is due to exercise-induced hypoalgesia. In this state, carrying out physical activities temporarily reduces people's sensitivity to certain types of pain. It is thought that this effect is caused by endorphins in the body, conditioned pain modulation and increased β-endorphin secretion (Hughes & Patterson, 2020). Increased forearm girth after BFRT use can be explained by mechanical and metabolic stimuli. This fires off mTOR signals, leading to muscle hypertrophy, and activates satellite cells in a low-load environment (Pearson & Hussain, 2015).

Clinical Relevance

It has been suggested that BFRT could be used as an alternative to high-load resistance training for patients recovering from wrist injuries, as it is a viable, low-risk and cost-effective option. Badminton players, for instance, typically rely heavily on grip power and wrist movements. This method provides them with an evidence-based way to increase strength and function while alleviating pain during rehabilitation.

Limitations

- The small sample size (n=10) limits generalizability.
- There was no control group, making it difficult to rule out placebo effects or natural retrieval as suppliers to experiential outcomes.
- The short follow-up duration (4 weeks) does not account for the long-term sustainability of gains.
- No blinding or randomization was employed, which may introduce assessment bias.

Future Directions

- Conduct randomized controlled trials (RCTs) with larger sample sizes to validate these findings.
- Include long-term follow-up to evaluate the sustainability of pain relief and functional improvement.
- Investigate the dose-response relationship of BFRT (e.g., varying LOP, duration, and resistance levels).
- Explore neurophysiological assessments to quantify the analgesic mechanisms underlying BFRT, such as functional MRI or nociceptive threshold testing.

Conclusion

This study provides preliminary evidence that BFRT can effectively reduce wrist pain, enhance range of motion, and promote muscle hypertrophy in athletes. Further controlled studies with larger samples are warranted to establish generalizability.

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Supplementary Information

Author's contribution

Taruna Verma: Conceptualization, Methodology, Formal Analysis, Investigation, Data Curation, Writing – Rough Preparation, Writing – Review and Editing, Visualization; **Sajjad Alam:** Conceptualization, Software, Check, Formal Analysis, Supervision, Project Administration; **Shagun Agarwal:** Check, Resources, Writing – Review and Editing, Supervision. All authors have read and agreed with the published version of the manuscript.

Declarations

Ethical Approval
The ethical approval was received from the Departmental Ethics Committee, Department of Physiotherapy, Galgotias University.

Conflict of Interest
The authors declare no conflicts of interest.

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Effectiveness of individualized occupational therapy interventions without the use of prosthetics for military servicemen with unilateral upper extremity amputations

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Abstract

Purpose. This paper presents the results of an experimental study investigating the effectiveness of individualized occupational therapy interventions for people with upper limb amputations without the use of prosthetic devices. This study is relevant because the number of people in Ukraine who have had a limb amputated as a result of the ongoing war is increasing, as is the need for effective rehabilitation methods to improve quality of life.

Material & Methods. The study employed a pre-test–post-test experimental design, allowing for the evaluation of changes in participants' functional status and occupational performance following a structured occupational therapy intervention without prosthetic devices. Occupational therapy sessions were aimed at client education and teaching the clients new skills to use modified and compensatory strategies for task performance, adaptive equipment, as well as making adaptation of the environment for increased functional independence. Participants included 10 male military servicemen between the ages of 20 and 45 years old with upper extremity amputations who participated in occupational therapy interventions for two months. The assessment was carried out using the Canadian Occupational Performance Measure (COPM), Disabilities of Arm, Shoulder and Hand (DASH) questionnaire and Visual Analogue Scale (VAS). Statistical data were analyzed using descriptive statistics and paired samples t-test.

Results. As a result of the occupational therapy interventions, the study participants demonstrated a statistically significant decrease in disability levels according to the DASH, as evidenced by an average score decrease from 80.5 prior to intervention to 44.2 post-intervention ($p<.001$). Similarly, the COPM assessment revealed clinically significant improvements (≥2-point change) in the performance of personal hygiene tasks, dressing, and cooking, as well as in satisfaction with performing personal hygiene, cooking, and driving tasks. The decrease in pain levels reported by the participants was also statistically significant with an average of 5,5 pre-test and 3,4 post-test on VAS ($p<.001$).

Conclusions. The comparative analysis of disability levels, pain levels, as well as performance of meaningful occupations before and after interventions indicates a significant improvement in functional independence and life satisfaction of military servicemen with amputations following an individualized occupational therapy program. Results presented in the paper demonstrate a positive correlation between COPM and DASH. The study indicates that occupational therapy services aimed at teaching compensatory strategies of task performance, environmental education and patient education are beneficial for clients with upper extremity amputations even without the use of prosthetic devices. Additionally, the results of the study support the effectiveness of occupational therapy for military servicemen.

Keywords: occupational therapy, military servicemen, upper extremity amputations, COPM, DASH, quality of life.

Introduction

Upper extremity loss, often resulting from trauma related to burns, violence, occupational accidents, or combat injuries (Orr et al., 2018), profoundly affects an individual's ability to engage in meaningful occupations. It has been reported that compared to lower limb loss, individuals with upper limb amputations experience more severe impairments in occupational performance and report a higher disability rating as well as increased susceptibility to post-traumatic stress disorder (PTSD) (Fitzgibbons & Medvedev, 2015). The number of military and civilian clients with upper extremity amputations has dramatically increased since the full-scale invasion of Ukraine in 2022, although official statistics have not been made public.

Occupational therapy (OT) plays a pivotal role in addressing the complex needs of this population across the rehabilitation continuum. Occupational therapists are well trained to serve this population due to their holistic approach that includes both physical rehabilitation and psychosocial support (AOTA, 2021). Pre-prosthetic OT care includes wound and edema management, desensitization, range of motion, and functional training, all essential for preparing the residual limb for prosthetic use. In addition, occupational therapists collaborate with clients to determine the most appropriate prosthetic device based on their lifestyle needs and functional goals, helping manage expectations regarding device capabilities and limitations (Atkins, 2016; Hermansson & Turner, 2017; Klarich & Brueckner, 2014). Once a device is selected, OT provides training for prosthetic controls to ensure functional integration into meaningful daily activities, improving functional independence and quality of life and facilitating communication with the prosthetist regarding potential concerns (Atkins, 2016; Hermansson & Turner, 2017).

Beyond physical rehabilitation, OT also addresses the psychosocial implications of limb loss. Practitioners support emotional adjustment, facilitate community reintegration, and help clients re-engage in roles such as worker, caregiver, or student (Smurr et al., 2008; Swanson Johnson & Mansfield, 2014). Therapy interventions may include coping strategy development, goal setting, and self-efficacy enhancement. Those who received OT services demonstrated improved psychosocial outcomes, including better adjustment to limb loss, greater ease in discussing their condition, improved work-related confidence, and increased acceptance of both the amputation and the prosthetic device (Laurie & Mandacina, 2018).

Importantly, OT also serves individuals who either elect not to use a prosthetic device or are awaiting one. Biddis & Chau (2007) reported that adult clients show rejection rates of 26% for body-powered prostheses and 23% for electric ones, with an overall non-wear rate of 20%. A systematic review of 123 studies by Smail et al. (2020) revealed that, over time, the primary reasons for prosthetic abandonment consistently aligned with two main categories: comfort and function. Among the most frequently reported and enduring comfort-related issues were prosthesis weight, heat buildup, and excessive perspiration. In such cases, OT focused on one-handed techniques, environmental adaptations, and task modification to support continued engagement in daily life (Biddiss & Chau, 2007; AOTA, 2021). This comprehensive approach underscores the essential role of OT in maximizing function, participation, and quality of life for individuals with upper limb loss regardless the use of prosthetic devices. The purpose of this study was to investigate the effectiveness of an OT treatment program without the use of prosthetics for military servicemen with upper extremity amputations in Ukraine.

Material and methods

Participants

The study used a convenience sample of 10 military servicemen receiving occupational therapy services in an outpatient rehabilitation clinic in Kyiv. All participants were males between ages 20 and 45, with an average age of 32). Inclusion criteria encompassed: age over 18, unilateral upper limb amputation, cognitive ability sufficient to participate in an interview and complete self-ratings. Exclusion criteria included: age under 18, civilian trauma, bilateral amputations. This research project was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. Study participants signed informed consent and were notified of their right to withdraw from participation from the study at any time without any consequences. The study was approved by the Ethics Committee of the National University of Ukraine on Physical Education and Sport (Protocol №10 from 19.09.2024).

Methods

The study utilized a pre- and post-intervention design, with data collected at two distinct time points to evaluate changes resulting from the occupational therapy intervention. Occupational therapy services were provided for two months with an average duration of sessions lasting on average 60 minutes, 3 times per week.

To collect and compare data related to patient outcomes, we utilized three valid assessment tools: the Visual Analogue Scale (VAS), the Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire, and the Canadian Occupational

Performance Measure (COPM). The VAS is a simple, unidimensional tool used to measure subjective pain intensity by asking individuals to report their pain level on a 10-point scale ranging from "no pain" to "worst pain imaginable" (Hawker et al., 2011). It is widely used due to its ease of use, responsiveness, and minimal burden on participants with various health conditions.

The DASH is a 30-item self-report questionnaire that assesses symptoms and function of clients with musculoskeletal disorders of the upper limbs (Østlie et al., 2011). It provides a quantitative score representing the patient's perceived disability, allowing for detailed functional evaluation. The shortened version of this instrument, QuickDASH, has been proven to be reliable and valid in people with upper limb amputations. A recent study confirms the successful use of the DASH with individuals with upper extremity amputations (Pyörny et al., 2024).

The COPM is a client-centered outcome measure that identifies issues in occupational performance through a semi-structured interview process (Larsen & Law, 2025). It enables patients to self-rate their performance and satisfaction in priority areas, facilitating individualized goal-setting and tracking of meaningful change over time.

Procedure

Initial assessment was conducted using the VAS, the DASH and the COPM and was supplemented with data collected through observation and occupational profile. Interventions aimed at training basic activities of daily living (ADLs) with the goal of restoration of function and independence through task adaptation, use of assistive technology, and environmental modification. First, adaptation of methods for task completion involved teaching individuals to use their residual limb, contralateral limb, or other body parts (such as the mouth, thighs, or torso) to stabilize or manipulate objects during ADLs. Techniques included compensatory strategies such as one-handed dressing methods (e.g., anchoring clothing against a surface while inserting the arm), using friction or gravity to assist with tasks, and sequencing activities to optimize efficiency and reduce frustration (Atkins et al., 1996; Resnik & Borgia, 2015). Second, adaptive equipment and clothing played a critical role in compensating for the loss of limb function. Common aids included built-up or curved utensils for easier grasp, non-slip mats and suction holders to stabilize dishes or grooming tools, and adaptive clothing with Velcro, magnetic closures, or larger zipper pulls to reduce the fine motor demands of dressing (Burger & Marincek, 2007; Østlie et al., 2012). These devices supported autonomy and reduced reliance on caregivers. Third, reorganizing the environment was essential to enhance safety and efficiency during daily routines. Strategies include using non-slip mats and stable surfaces for grooming or cooking, positioning key items within accessible reach, and optimizing room layouts to minimize trip hazards and promote single-limb balance during mobility tasks, all of which are crucial for fall prevention and energy conservation (Stark et al., 2021). Collectively, these evidence-based interventions aligned with occupational therapy principles of maximizing participation, promoting independence, and facilitating functional adaptation in daily living contexts.

For military servicemen, return to independent driving is a significant marker of restoration of functional independence. Occupational therapy interventions addressed both the physical and psychosocial aspects of this complex task. Psychosocial interventions, including counseling and cognitive-behavioral strategies, were used to reduce driving-related anxiety and build confidence, especially in veterans with post-traumatic stress disorder (PTSD) or who associate driving with traumatic events (Classen et al., 2014). Educational sessions provided essential knowledge about the legal process for obtaining adaptation for vehicles, funding support for vehicle modification, helping veterans navigate bureaucratic systems advocating for their needs (Miller et al., 2021). Training also focused on the use of vehicle adaptations such as spinner knobs, left-side gear shifters, electronic hand controls, and remote mirror adjusters, all of which enable one-handed or compensatory driving techniques (Burger and Marincek, 2013).

Clients were taught methods of one-handed driving that emphasize control, safety, and biomechanical efficiency, often using simulated driving to practice skills. Functional components of driving, such as entering and exiting the vehicle, seatbelt fastening, mirror adjustments, and ignition use, were addressed through task-specific training that breaks down each activity into manageable steps and encouraged practice with adaptive tools. Following a two-month intervention, the clients were assessed using the abovementioned outcome measures: the VAS, the DASH, and the COPM.

Statistical analysis

Statistical analysis used in the study included: descriptive statistics, tests of normality and the Paired samples t-test.

Results

As a result of individualized client-centered and occupation-focused interventions, clients demonstrated substantial improvements across multiple outcome measures (Table 1).

Table 1. Descriptive statistics of pre- and post-test assessment using the DASH and VAS (n=10)

	Range	Min	Max	Mean	SE	SD
DASH pre-test	14.1	74.2	88.3	80.530	1.3832	4.3742
DASH post-test	9.1	39.4	48.5	44.160	1.0406	3.2908
VAS pre-test	3.00	4.00	7.00	5.5000	.26874	.84984
VAS post-test	2.00	2.00	4.00	3.4000	.26667	.84327

Table 2. Test of normality for pre- and post-test assessment using the DASH and the VAS

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DASH pre-test	.128	10	.200	.977	10	.950
DASH post-test	.171	10	.200	.936	10	.514
VAS pre-test	.222	10	.178	.906	10	.258
VAS post-test	.362	10	<.001	.717	10	.001

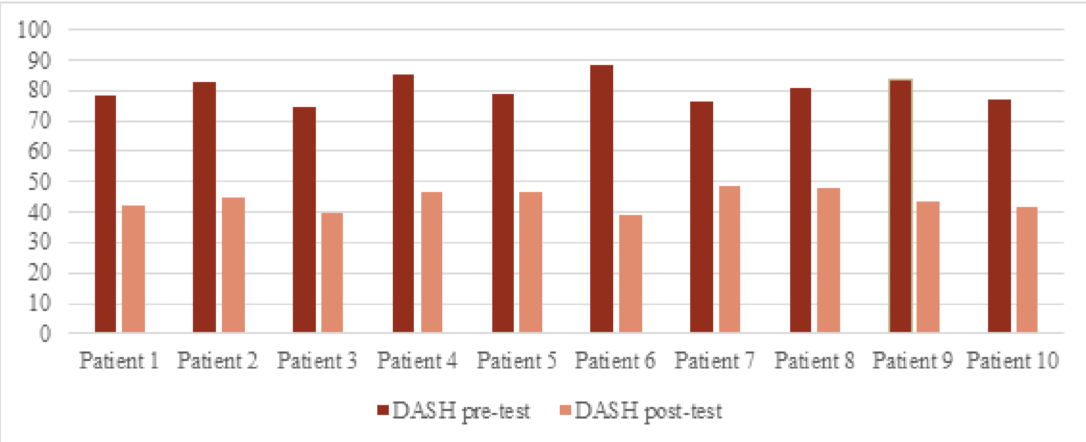

Figure 1. Changes in DASH scores pre- and post-intervention.

Table 3. Paired Samples T-test analysis of pre-and post-tests on the DASH and VAS

	Paired Differences					t	df	Significance	
	Mean	SD	SE	95% CI Lower	95% CI Upper			One-Sided p	Two- Sided p
Differences in DASH scores	36.37	5.65	1.79	32.33	40.41	20.36	9	<.001*	<.001*
Differences in VAS scores	2.10	.875	.28	1.47	2.73	7.58	9	<.001*	<.001*

*Note: * - represents statistically significant difference at p<0,01.*

Based on the results of Kolmogorov-Smirnov and Shapiro-Wilk tests, we concluded that most data were normally distributed except for post-test testing on VAS as evident from Table 2. Therefore, we used the parametric paired t-test to determine whether there was a statistically significant difference between client outcomes as measured before and after occupational therapy intervention.

According to the DASH questionnaire, there was a notable reduction in perceived disability, with average scores decreasing from 80.5 pre-intervention to 44.2 post-intervention as illustrated on Fig. 1. This change represents a clinically meaningful improvement in upper limb function and suggests enhanced ability to perform daily tasks with less difficulty.

Additionally, participants experienced a considerable reduction in pain levels, with Visual Analogue Scale (VAS) scores dropping from an average of 5.5 before the intervention to 3.4 afterward, indicating improved pain management and comfort during daily activities.

The results of Paired samples t-test suggest that the improvements in both the DASH and the VAS scores after the intervention were statistically significant (Table 3). The effect size analysis for the paired samples indicates a very large and clinically meaningful effect with Cohen's d=6.44 with a 95% CI of 3.45 to 9.42., Hedges' g=6.17

Table 4. Changes in performance and satisfaction as a result of the COPM interview

Occupational performance issues	Performance 1	Satisfaction 1	Performance 2	Satisfaction 2	Change in performance	Change in satisfaction
Personal hygiene	2.8	2.0	4.8	4.0	+2.0*	+2.0*
Dressing	2.6	1.8	4.6	3.6	+2.0*	+1.8
Cooking	2.0	2.0	4.8	4.8	+2.8*	+2.8*
Leisure (physical exercises)	1.2	1.0	2.8	2.2	+1.6	+1.2
Driving	1.8	1.2	3.2	3.2	+1.4	+2.0*

*Note: * - represents minimal clinically significant difference.*

for the DASH, and Cohen's d=2.40 with a 95% CI of 1.13 to 3.64, Hedges' g=2.30 for VAS.

Similarly, performance and satisfaction with the performance of identified occupations assessed using the COPM revealed a ≥2-point change in most areas of daily activities. Specifically, participants reported marked gains in their ability to perform personal hygiene tasks, dressing, and cooking, as well as increased satisfaction in performing personal hygiene, cooking, and driving. The changes in pre- and post-ratings of key activities as reported by the COPM are presented in Table 4.

Discussion

The results of our study indicate that the individualized OT interventions developed for clients with unilateral upper extremity amputations without the use of prosthetic devices is effective in restoring functional independence across key life domains such as self-care, leisure activities, and driving. Data collected using the COPM and DASH outcome measures confirmed this as average scores for performance and satisfaction (COPM) improved, while levels of functional disability (DASH) significantly decreased. Perceived disability ratings per DASH reported by our study participants (44.2) after occupational therapy interventions are consistent with those reported by American veterans with unilateral upper limb amputations (49.5) (Resnik et al., 2019). These outcomes reflect both an objective enhancement of daily functioning and an improvement in patients' subjective perception of their activity and independence. Therefore, our results complement the clinical commentary of Rich and colleagues (2025) who concluded that occupational therapy plays an essential role in rehabilitation of clients with lower extremity amputations and highlighted its effectiveness in supporting the client's cognitive and mental health, activity, accessibility through training and interventions targeting pain reduction.

While specific protocols and guidelines for occupational therapy interventions targeting prosthetic use have been developed and successfully integrated into practice a long time ago (Smurr et al., 2008; Resnik et al., 2019), interventions that exclude prosthetic training are also essential for rehabilitation of clients with upper extremity amputations regardless of their stage of recovery. Previous research indicated that despite many years of training individuals with amputations still have problems with activities of daily living, particularly in relation to independent functioning (Kejlaa, 1993). A national study of veterans with upper limb loss conducted in the United States in 2019 found that 52% of veterans with upper extremity amputations wore their prosthetic device less than 8 hours per day, with almost a third of the overall number of participants reporting wearing prostheses less than 4 hours per day (Resnik et al., 2019). These findings suggest that clients with amputations spend most of their time without the prosthetic device, even if they have it, which substantiates the need for interventions focusing on prosthetic-free functional independence.

Our findings highlighting the positive impact of occupational therapy intervention in reducing pain are particularly significant given the high prevalence of phantom and residual limb pain among individuals with amputations. A recent systematic review and meta-analysis revealed that residual limb pain in individuals with upper limb amputation was 58% (95% CI: 46 to 68) (List et al., 2025). Both phantom and residual pain can persist for years after amputations, making occupational therapy interventions targeting participation and pain reduction especially useful for functional recovery, psychological well-being, and quality of life.

The interventions used in our study were structured around gradual engagement in therapy, beginning with basic self-care tasks and advancing to more complex activities such as exercise routines and driving. This progressive, occupation-focused and client-centered approach aligns with contemporary research emphasizing the importance of personalized therapy for individuals with limb loss (AOTA, 2021). Literature also supports the notion that occupational therapy programs are most effective when tailored to patients' personal goals and life context, a principle that was central to the design of this study. A recent study carried out by Stevens and colleagues suggested that activity and participation was the strongest predictor of well-being in individuals with upper limb amputation (Stevens et al., 2023), which highlights the significance of our findings.

Occupational therapy interventions for driving are critically important, as the interruption in driving represents a significant disruption in daily life and occupational participation (Bassingthwaighte et al., 2024). In a study on occupational performance needs of young veterans in the US (Plach & Sells, 2013), driving was identified as one of the key needs for reintegration into the community. A positive impact on occupational therapy for driving rehabilitation of combat veterans has been reported (Classen et al., 2014a, Classen et al., 2014b). Using occupational therapy-based task-specific training for imitation or simulated driving training reinforced procedural memory and improved performance before real-world testing. Therefore, the results of our study support and enhance previous research. Interventions included in our study offered a comprehensive, individualized approach that supported the clients' safe and confident return to driving.

Lastly, our results point to a positive correlation between the decreasing scores on the DASH and improved performance and participation on the COPM. Therefore, our study adds to the existing literature comparing outcome measures like the COPM and DASH. Similarly to findings of Lauritzson and colleagues (2023), our study revealed a weak correlation between the DASH and the COPM. This may be attributed to the fact that each tool captures distinct aspects of functional ability, with the COPM offering a more personalized, client-centered, and flexible approach to evaluating occupational performance and the DASH providing a general measure of perceived disability.

Conclusion

Our study validates the effectiveness of occupational therapy interventions without the use of prosthetics for clients with unilateral upper extremity amputations as evident from a clinically significant change in scores on the DASH and VAS before and after intervention. Additionally, study participants experienced a clinically significant improvement (≥2 points of change) in performance of personal hygiene tasks, dressing and cooking, and in satisfaction with performing personal hygiene, cooking and driving. These outcomes support the recommendation for broader clinical implementation of similar programs, with a focus on individualized care, occupation-focused and client-centered approaches, we all we active client involvement to meet rehabilitation goals. Additionally, the results presented in the paper demonstrate a positive correlation between COPM and DASH. The study indicates that occupational therapy services aimed at teaching compensatory strategies of task performance, environmental education and patient education are beneficial for clients with upper extremity amputations even without the use of prosthetic devices.

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Supplementary Information

Author's contribution

Anna Postonogova: Conceptualization, Methodology, Investigation, Data Curation, Writing – Rough Preparation, Visualization, Project Administration; **Oleksandra Kalinkina:** Check, Resources, Writing – Rough Preparation; **Kostiantyn Kalinkin:** Check, Visualization; **Iryna Zharova:** Check, Formal Analysis, Resources, Writing – Review And Editing, Supervision; **Olexii Nikanorov:** Methodology, Software, Writing – Review And Editing. All authors have read and agreed with the published version of the manuscript.

Declarations

Conflict of Interest
Authors declare no conflict of interest to disclose.

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Functional overstrain during long-term rehabilitation of military personnel with musculoskeletal Injuries of the limbs

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Abstract

Purpose. To study the main causes of functional overstrain in military personnel with musculoskeletal injuries of the limbs during long-term rehabilitation while applying standard physical therapy protocols.

Material & Methods. 56 military personnel who had sustained musculoskeletal injuries of the limbs 16 months earlier as a result of mine-explosive and gunshot wounds were examined. During the previous 10 months of long-term rehabilitation, standard physical therapy protocols were used according to the specific nosology. The participants were divided into groups and subgroups according to their nosology and type of heart rhythm regulation. Test load 1 was developed for servicemen with upper limb injuries, and test load 2 – for military personnel with lower limb injuries. To assess the adaptive and compensatory responses of the participants to the test loads, indicators of heart rate spectral analysis and blood biomarkers (creatine phosphokinase, lactate dehydrogenase, testosterone, and cortisol) were used. Monitoring of possible adaptive changes was carried out before and after 15 days of using physical therapy protocols under the supervision of rehabilitation specialists.

Results. At the beginning of the study, regardless of the nosology, a shift in autonomic balance was simultaneously observed toward both sympathetic and parasympathetic activity. In 50% of the examined participants, an enhancement of the central contour of sinus rhythm regulation was observed along with decreased cortisol concentration and increased LDH activity in the blood. Such adaptive-compensatory responses to a stress stimulus indicate low muscle glycogen reserves and an insufficient level of resistance, reflecting a state of non-functional overstrain and a risk of adaptive failure. Other study participants had a decrease in the influence of the central contour, accompanied by opposite changes in the LF/HF ratio. CPK levels increased significantly, and blood cortisol concentration almost reached the upper limit of normal, indicating a state of functional overstrain. The results obtained after 15 days of using the prescribed physical therapy protocols under the supervision of rehabilitation specialists showed almost identical changes in HRV indicators and blood biomarkers as those observed at the beginning of the study. Such prolonged changes in biomarkers indicate a continuously progressing depletion of adaptive reserves due to compensatory reactions triggered by excessive stress stimuli.

Conclusions. Using inpatient rehabilitation services by military personnel over the previous 10 months led to the development of a state of non-functional overstrain in 50% of the examined individuals. A re-examination conducted over 15 days in inpatient conditions, concerning the influence of physical therapy protocols recommended by physical rehabilitation specialists on the neuromuscular system readaptation, confirmed the previous results. The study results allowed for a clear identification of the main problems causing the FOR and NFOR state development in military personnel with these nosologies, and the necessity of using a wide range of biomarkers to assess their adaptive and compensatory responses to physical load.

Keywords: servicemen, musculoskeletal injuries of the limbs, functional overstrain, long-term rehabilitation, readaptation, biomarkers.

Introduction

In the modern rehabilitation system, improving physical therapy protocols through the development of individualized load models combined with unique sets of exercises of various types is one of the most complex challenges (Gray et al., 2025; Gregg et al., 2025). This issue is particularly acute for military personnel with musculoskeletal injuries of the limbs resulting from mine-explosive and gunshot wounds.

Due to this context and the importance of practical implementation, a considerable number of researchers are actively focusing on developing effective mechanisms for the neuromuscular system readaptation (Salonen et al., 2019; Chernozub et al., 2025). One of the most difficult aspects, especially during the long-term rehabilitation of military personnel with such nosologies, is the correspondence between the loads used in standard physical therapy protocols and the functional reserves of the body (Lodhi et al., 2025; Whitehurst et al., 2025).

The absence of a scientifically grounded concept for developing an integrated system to monitor the readaptation processes of the body's systems during long-term physical rehabilitation, using a wide range of physiological and biochemical biomarkers, further complicates this issue (Cadegiani et al., 2019; Busso et al., 2025).

One of the important and relevant issues that arises during physical rehabilitation of servicemen with musculoskeletal limb injuries resulting from wounds, especially after a prolonged period (over 2–3 months) of hypodynamia, is the initial level of resistance (Chernozub et al., 2024; Maqsood et al., 2025). In other words, it is the ability of the body's systems (for example, the neuromuscular, humoral, energy, and other systems) to adequately counteract an external stress stimulus through mechanisms of short-term adaptation (Stephenson et al., 2021; Chernozub et al., 2023).

Studies of the readaptation of the neuromuscular system in military personnel and in athletes showed that negative manifestations of functional (FOR) and non-functional (NFOR) overstrain occurred as hypokinesia developed (Fiala et al., 2025; Watanabe et al., 2025). These conditions can have symptoms of adaptive failure due to the mismatch between load parameters and the initial functional reserves or resistance levels, or disadaptation (Olkhovyi et al., 2025, Uphill et al., 2025).

Studying this issue, researchers have encountered a new problem of identifying the most informative biomarkers for assessing adaptive and compensatory reactions during muscular activity in rehabilitation (Cadegiani et al., 2019; Grandou et al., 2021). A comprehensive review of the fundamental research in this field reveals the absence of a well-defined classification system for determining the optimal combination and application of assessment methods, including heart rate variability analysis, biochemical testing of blood or tissues, and electromyography.

Purpose of the Study. To study the main causes of functional overstrain in military personnel with musculoskeletal injuries of the limbs during long-term rehabilitation while applying standard physical therapy protocols.

Material and Methods

Participants

The study involved 56 military personnel (men) who had sustained musculoskeletal injuries of the limbs 16 months earlier as a result of mine-explosive and gunshot wounds. The mean age of the participants was 35±9.3 years. During the previous 10 months of long-term rehabilitation, standard physical therapy protocols were used in training sessions, taking into account the specific nosology.

Rehabilitation was carried out in inpatient settings (21 days) and on an outpatient basis (15 days), with rest intervals of 45-60 days. The participants were divided into two groups (28 individuals in each) depending on the characteristics of their injuries. Group 1 included servicemen who had sustained musculoskeletal injuries of the upper limbs, while Group 2 consisted of those with lower limb injuries.

The study was conducted in rehabilitation centers and hospital departments in Mykolaiv and Odesa, and at the research centers of modern kinesiology "KINEZUS" located in these cities. The study design was approved by the Bioethics Committee of Lesya Ukrainka Volyn National University, Lutsk. All participants signed a written informed consent form after receiving comprehensive information about the study's risks and benefits, in compliance with the ethical standards of the Declaration of Helsinki.

Measurements

Heart Rate Variability (HRV) Assessment

To determine HRV indicators (in the time and frequency domains), a Polar V800 heart rate monitor (Finland) was used. RR intervals were recorded using an H10 sensor (Polar Electro Oy, Finland). Data were processed using Polar Flow software and the Kubios HRV Standard 3.5.0 program (University of Eastern Finland). The study primarily assessed the basal (at rest) level and the pattern of changes in heart rate spectral analysis parameters in response to test loads, taking into account the specific characteristics of the participants' musculoskeletal limb injuries.

When analyzing the spectral characteristics of HRV, the following indicators were evaluated: VLF – very low-frequency spectrum of cardio intervals, LF – sympathetic activity, HF – parasympathetic tone, and LF/HF – balance between vagal and sympathetic tone mechanisms. RR interval signal recordings were taken from participants in a seated position at rest, before and after acute physical load. According to HRV research standards, a 5-minute recording period of RR intervals was considered optimal (Korobeinikova et al., 2024).

Blood Biomarkers

The activities of lactate dehydrogenase (LDH) and creatine phosphokinase (CPK) in the serum of the servicemen were measured using a kinetic method on equipment from High Technology Inc. (USA) with the PRESTIGE 24i LQ LDH reagent kit (Poland). Serum concentrations of the steroid hormones testosterone and cortisol in the participants were measured using an enzyme-linked immunosorbent assay (ELISA) with the Steroid-IFA-testosterone reagent kit on equipment from Alkor Bio. Reference values for the biochemical parameters in the participants' serum were as follows: creatine phosphokinase (CPK), 40-270 U/L; lactate dehydrogenase (LDH), 195-462 U/L; cortisol, 150-660 nmol/L; and testosterone, 8.64-29.01 nmol/L. Blood sampling was performed by medical personnel in accordance with internationally accepted standards for biomedical research. Monitoring involved evaluating the basal (at rest, pre-load) concentrations of the investigated blood biomarkers and characterizing their responses to the applied test loads.

Research Design

The study was conducted in several stages throughout 2025.

At the first stage, the medical records of the examined military personnel were analyzed to determine the specifics of their nosological conditions and the characteristic changes in the neuromuscular system of the affected limbs during long-term rehabilitation (10-12 months). The features of the physical therapy protocols used for each nosology in the post-acute and early long-term periods, as well as their impact on readaptation, were evaluated. Based on the analyzed data, test loads were designed to assess the participants' functional reserves.

Test load 1 was developed for Group 1 military personnel with neuromuscular injuries of the upper limbs. The participant performed a *body-weight squat exercise* for 60 seconds with variations in kinematic technique characteristics, without fixation or relaxation phases at peak points. Participants assumed a seated starting position with the knee angle roughly 90°. During the concentric phase of the movement, primarily recruiting muscle groups of the legs and trunk (agonists, synergists, and stabilizers), the controlled angle between the thigh and lower leg should increase by no more than 45°. The duration of the eccentric phase was 5 seconds, and the concentric phase was 3 seconds.

Test load 2 was developed for Group 2 military personnel with neuromuscular injuries of the lower limbs. The participant performed a forward trunk bend from a seated position for 60 seconds, with hands placed on the shoulders using a partial range of motion (80-85°) without fixation or relaxation phases at the peak points. The duration of the eccentric phase was 5 seconds, and the concentric phase was 3 seconds. Considering the kinematic characteristics of this exercise, the maximum load was applied primarily to the back-muscle groups. Both test loads primarily relied on anaerobic glycolysis to supply energy for intense muscular activity lasting over 60 seconds.

At the second stage, the initial functional state of the examined military personnel was assessed, based on the analysis of HRV indicators and laboratory results of serum biomarkers at rest (basal level). Based on the spectral HRV parameters and considering autonomic balance, participants in each group were divided into two subgroups: sympathotonic (LF/HF>1.5) and normotonic (LF/HF<1.5). Thus, participants in subgroups 1^S and 2^S were classified as sympathotonic, while military personnel in subgroups 1^N and 2^N were classified as normotonic.

The adaptive and compensatory responses of the participants' body systems to the assigned test loads were also assessed using HRV indicators and blood biomarkers. Analysis of the responses to the acute stress stimulus indicated that the formation of additional subgroups reflecting effective short-term adaptation mechanisms was not required (1^{Sa}, 1^{Na}, 2^{Sa}, 2^{Na}). Subgroups (1^{Sc}, 1^{Nc}, 2^{Sc}, 2^{Nc}) were formed in which compensatory mechanisms were evident in response to test loads that imposed excessive stress on the body.

At the third stage, the effectiveness of standard physical therapy protocols in the long-term rehabilitation of military personnel with musculoskeletal limb injuries was evaluated. Monitoring of possible adaptive changes or manifestations of different types of functional overstrain was conducted both in inpatient settings and on an outpatient basis over 15 working days.

At the beginning and end of the rehabilitation period, a comparative analysis was conducted to assess changes in the basal levels of spectral heart rate parameters and blood biomarkers, as well as the participants' responses to an acute test load. The obtained results were subsequently processed and analyzed.

Statistical Analysis

A statistical analysis of the study results was performed using the IBM *SPSS* Statistics 26 software package (StatSoft Inc., USA). The G*Power 3.1.96 program (Germany) was used to determine the minimum sample size for the study (statistical power calculation). Non-parametric statistical analysis methods were applied to calculate the median (Me) and interquartile range (IQR). The Kruskal-Wallis test was used to compare baseline parameters across the four groups of examined military personnel. The Wilcoxon signed-rank test was applied to compare two dependent samples.

Results

Table 1 illustrates changes in spectral heart rate parameters in response to acute test loads among the examined military personnel, before 15 days of inpatient or outpatient physical therapy during long-term rehabilitation.

The data obtained at the beginning of the study indicate that the basal levels of spectral analysis parameters differ depending on the nosology of the examined military personnel and the type of their heart rhythm regulation. The results show that in the examined subgroups with a high initial level of tension in heart rhythm regulation systems (subgroups 1^S and 2^S), VLF parameters were almost twice as high as in participants with lower values (minimum 3.5-fold) of autonomic balance (subgroups 1^N and 2^N).

Analysis of the responses to test load 1 in Group 1 participants indicates a simultaneous shift in autonomic balance toward both sympathetic and parasympathetic activity among the normotonic participants. Among the sympathotonic subgroups, only a decrease in the tension of heart rhythm regulation systems was observed.

Subgroup 1^{Sc} participants in response to the stimulus had a significant ($p<0.05$) decrease in the LF/HF ratio (−64.2%), simultaneously with an increase in the central regulation of sinus rhythm (VLF +30.5%). Subgroup 1^{Nc} participants showed an increase in VLF power (+38.6%) accompanied

Table 1. Results of spectral heart rate analysis parameters in military personnel at rest and in response to acute test loads before the next rehabilitation (Me, IQR), n=56

Groups of military personnel with musculoskeletal limb injuries			HRV parameters			
			VLF, %	LF, %	HF, %	LF/HF
Basal level (at rest, pre-load)						
1	1^S		38.71 (2.18)	52.22 (3.19)	9.07 (0.65)	5.75 (0.36)
	1^N		19.69 (1.59)	46.55 (2.98)	33.76 (2.12)	1.37 (0.11)
2	2^S		32.45 (2.71)	54.52 (3.19)	13.03 (0.65)	4.18 (0.32)
	2^N		17.22 (1.46)	44.86 (3.03)	37.92 (2.52)	1.18 (0.08)
After test load 1						
1	1^S	1^{Sa}	3.26 (0.25)*	67.21 (4.13)*	29.53 (2.25)*	2.27 (0.19)*
		1^{Sc}	69.23 (4.81)*	20.74 (2.22)*	10.03 (1.01)	2.06 (0.18)*
	1^N	1^{Na}	5.19 (0.43)*	68.73 (3.79)*	26.08 (1.89)*	2.63 (0.29)*
		1^{Nc}	58.33 (4.01)*	37.56 (2.77)*	4.11 (0.35)*	9.14 (0.72)*
After test load 2						
2	2^S	2^{Sa}	11.86 (0.99)*	75.81 (4.29)*	12.33 (1.01)	6.14 (0.41)*
		2^{Sc}	62.17 (4.74)*	33.24 (2.41)*	4.59 (0.28)*	7.24 (0.55)*
	2^N	2^{Na}	33.78 (2.45)*	35.49 (2.76)*	30.73 (2.14)*	1.15 (0.08)
		2^{Nc}	4.89 (0.33)*	65.72 (4.53)*	29.39 (2.22)	2.23 (0.12)*

*Notes: Group 1 – with upper limb injuries; Group 2 – with lower limb injuries; Subgroups 1^S and 2^S – sympathotonic; Subgroups 1^N and 2^N – normotonic; Sa-Na – manifestation of short-term adaptation mechanisms; Sc-Nc – manifestation of compensatory mechanisms in response to an excessive stress stimulus for the body; * – p<.05 – compared with pre-load (at rest) values.*

by a shift of autonomic balance toward sympathetic regulation (LF/HF increased 6.6-fold) under similar conditions. These results indicate pronounced manifestations of functional overstrain (1^{Sc} and 1^{Nc}) and that the test loads represented an excessive stress stimulus for their bodies.

Sympathotonic military personnel of Group 2 increased the tension of heart rhythm regulation systems in response to test load 2. In subgroup 2^{Sa}, these changes occurred along with an increased sympathetic tone (LF +21.3%) and decreased VLF power (−20.5%). In subgroup 2^{Nc}, VLF increased (+29.7%) while both sympathetic (LF −19.0%) and parasympathetic (HF −8.4%) tone decreased.

Table 2 presents the changes in blood biomarkers (CPK, LDH, testosterone, and cortisol) in the examined military personnel at rest and in response to acute test loads before the next rehabilitation.

The results of the laboratory tests indicate that the baseline levels of the monitored blood biomarkers in the examined military personnel, regardless of their nosology or type of heart rhythm regulation, were within the reference values.

Test load 1 caused an increase in all blood biomarker parameters in 50% of military personnel with musculoskeletal injuries of the upper limbs (1^{Sa} and 1^{Na}), regardless of the type of heart rhythm regulation. The most significant ($p<0.05$) changes in the studied blood biomarkers were observed in participants of subgroup 1^{Na} (CPK +62.2%; testosterone +9.9%; cortisol +46.5%) in response to this stress stimulus. However, participants of the other two subgroups had a notable decrease in blood cortisol (1^{Sc} −34.7%; 1^{Nc} −19.5%) along with an increase in LDH activity (1^{Sc} +29.1%; 1^{Nc} −17.0%).

Military personnel with musculoskeletal injuries of the lower limbs exhibited similar adaptive and compensatory responses to test load 2 to those observed in Group 1. In half of the participants (subgroups 2^{Sc} and 2^{Nc}), the stimulus caused a significant decrease in cortisol, accompanied by an increase in blood lactate dehydrogenase activity, with values exceeding the reference range.

Table 3 shows changes in spectral heart rate parameters in response to acute test loads among the examined military personnel after 15 days of using inpatient or outpatient physical therapy protocols during long-term rehabilitation.

A comparative analysis of the baseline levels of spectral HRV parameters throughout the study showed a significant decrease in the tension of heart rhythm regulation systems only in study participants with musculoskeletal injuries of the upper limbs (subgroup 1^{S}). These participants demonstrated an almost identical pattern of HRV changes as observed at the beginning of the study in response to acute test loads after 15 days of using inpatient or outpatient physical therapy protocols provided by specialists. At both stages of monitoring, there was no consistent pattern in the direction or magnitude of spectral heart rate

Table 2. **Changes in blood biomarkers of the examined military personnel at rest and in response to acute test loads before the start of the next rehabilitation (Me, IQR), n=56**

Groups of military personnel with musculoskeletal limb injuries			CPK, U/L	LDH, U/L	Testosterone, nmol/L	Cortisol, nmol/L
Basal level (at rest, pre-load)						
1	1^{S}		53.28 (3.28)	378.35 (19.76)	9.12 (0.63)	526.12 (23.48)
	1^{N}		47.66 (2.57)	418.15 (21.78)	8.95 (0.56)	429.34 (27.19)
2	2^{S}		42.31 (3.02)	456.22 (19.21)	8.78 (0.71)	440.15 (19.76)
	2^{N}		50.73 (3.89)	396.75 (22.03)	9.38 (0.73)	493.73 (22.63)
After test load 1						
1	1^{S}	1^{Sa}	76.28 (4.42)*	428.32 (24.13)*	9.89 (0.78)*	625.45 (28.06)*
		1^{Sc}	46.17 (3.11)*	488.56 (22.91)*	9.03 (0.65)	343.27 (21.24)*
	1^{N}	1^{Na}	77.31 (5.58)*	427.66 (25.32)	9.84 (0.67)*	629.05 (30.37)*
		1^{Nc}	46.09 (3.73)	489.44 (23.76)*	9.06 (0.78)	345.51 (23.41)*
After test load 2						
2	2^{S}	2^{Sa}	62.79 (4.82)*	476.39 (22.14)*	8.82 (0.62)	598.38 (25.74)*
		2^{Sc}	52.18 (3.44)	520.08 (28.51)*	9.14 (0.77)*	312.12 (18.07)*
	2^{N}	2^{Na}	63.03 (5.04)*	477.41 (20.68)*	8.97 (0.55)*	632.81 (31.98)*
		2^{Nc}	52.01 (4.23)	521.68 (29.11)*	9.43 (0.69)	328.34 (17.56)*

*Notes: Group 1 – with upper limb injuries; Group 2 – with lower limb injuries; Subgroups 1^{S} and 2^{S} – sympathotonic; Subgroups 1^{N} and 2^{N} – normotonic; Sa-Na – manifestation of short-term adaptation mechanisms; Sc-Nc – manifestation of compensatory mechanisms in response to an excessive stress stimulus for the body; * – p<.05 – compared with pre-load (at rest) values.*

Table 3. **Changes in spectral heart rate parameters of the examined military personnel in response to acute test loads after 15 days of using physical therapy protocols during long-term rehabilitation (Me, IQR), n=56**

Groups of military personnel with musculoskeletal limb injuries			HRV parameters			
			VLF, %	LF, %	HF, %	LF/HF
Basal level (at rest, pre-load)						
1		1^S	29.88 (2.03)	56.87 (3.27)	13.25 (1.05)	4.29 (0.31)
		1^N	14.32 (1.12)	49.93 (3.02)	35.75 (2.48)	1.39 (0.12)
2		2^S	27.02 (2.25)	59.29 (3.77)	13.69 (1.18)	4.33 (0.35)
		2^N	12.72 (1.17)	48.34 (3.69)	38.94 (3.01)	1.24 (0.11)
After test load 1						
1	1^S	1^{Sa}	4.31 (0.31)*	68,03 (3,93)*	27,66 (2,11)*	2,45 (0,17)*
		1^{Sc}	63.37 (5.27)*	31.04 (2.48)*	5.59 (1.23)*	5.55 (0.35)*
	1^N	1^{Na}	6.29 (0.37)*	71.88 (3.56)*	21.83 (1.67)*	3.29 (0.24)*
		1^{Nc}	54.78 (4.27)*	24.11 (1,43)*	21.11 (1.35)*	1.14 (0.08)*
After test load 2						
2	2^S	2^{Sa}	9.25 (0.73)*	61.73 (4.84)	29.02 (1.81)*	2.13 (0.17)*
		2^{Sc}	65.37 (4.28)*	30.09 (2.05)*	4.54 (0.31)*	6.62 (0.51)*
	2^N	2^{Na}	34.65 (2.81)*	35.77 (2.54)*	29.58 (2.32)*	1.21 (0.09)
		2^{Nc}	4.38 (0.31)*	72.63 (5.13)*	22.99 (1.96)*	3.15 (0.19)*

*Notes: Group 1 – with upper limb injuries; Group 2 – with lower limb injuries; Subgroups 1^S and 2^S – sympathotonic; Subgroups 1^N and 2^N – normotonic; Sa-Na – manifestation of short-term adaptation mechanisms; Sc-Nc – manifestation of compensatory mechanisms in response to an excessive stress stimulus for the body; * – p<.05 – compared with pre-load (at rest) values.*

Table 4. **Changes in blood biomarkers of the examined military personnel in response to acute test loads after 15 days of using physical therapy protocols during long-term rehabilitation (Me, IQR), n=56**

Groups of military personnel with musculoskeletal limb injuries			Blood biomarkers			
			CPK, U/L	LDH, U/L	Testosterone, nmol/L	Cortisol, nmol/L
Basal level (at rest, pre-load)						
1		1^S	54.15 (3.42)	402.23 (21.33)	10.16 (0.79)	497.82 (22.78)
		1^N	46.98 (3.07)	398.85 (20.59)	9.51 (0.86)	397.98 (26.49)
2		2^S	43.58 (3.62)	407.72 (24.29)	9.38 (0.77)	467.55 (28.37)
		2^N	52.07 (4.12)	373.74 (22.73)	10.23 (0.89)	473.44 (27.39)
After test load 1						
1	1^S	1^{Sa}	85.31 (5.12)*	431.95 (27.43)*	11.83 (0.97)*	643.05 (34.16)*
		1^{Sc}	52.23 (3.45)	512.12 (31.14)*	9.93 (0.75)	387.87 (20.94)*
	1^N	1^{Na}	61.59 (4.38)*	418.32 (27.62)*	10.14 (0.77)*	523.95 (31.07)*
		1^{Nc}	47.05 (3.89)	475.41 (25.87)*	10.23 (0.68)*	215.45 (17.44)*
After test load 2						
2	2^S	2^{Sa}	61.53 (4.82)*	458.73 (20.84)*	10.57 (0.83)*	625.19 (31.68)*
		2^{Sc}	44.98 (2.17)	489.31 (26.21)*	9.29 (0.69)	369.67 (23.67)*
	2^N	2^{Na}	57.23 (3.12)*	453.83 (24.18)*	11.07 (0.85)*	672.14 (38.28)*
		2^{Nc}	48.13 (2.93)*	509.66 (27.81)*	10.16 (0.69)	366.36 (23.76)*

*Notes: Group 1 – with upper limb injuries; Group 2 – with lower limb injuries; Subgroups 1^S and 2^S – sympathotonic; Subgroups 1^N and 2^N – normotonic; Sa-Na – manifestation of short-term adaptation mechanisms; Sc-Nc – manifestation of compensatory mechanisms in response to an excessive stress stimulus for the body; * – p<.05 – compared with pre-load (at rest) values.*

analysis parameters depending on the type of nosology, heart rhythm regulation, or baseline HRV values.

Table 4 illustrates changes in blood biomarkers of the examined military personnel in response to acute test loads after 15 days of using inpatient or outpatient physical therapy protocols during long-term rehabilitation.

The results of laboratory analyses indicate that the baseline levels of the monitored blood biomarkers in the examined military personnel fall within the reference values, regardless of their injury type or heart rate regulation pattern. However, only the baseline testosterone concentration in blood serum shows a statistically significant positive change (on average +8.7%) among participants with musculoskeletal injuries of both upper and lower limbs.

After 15 days of implementing physical therapy protocols designed to enhance functional reserves under the supervision of rehabilitation specialists, the expected long-term adaptive effects were not observed. In response to the test loads, 50% of the participants continued to demonstrate a marked decrease in cortisol concentration accompanied by an increase in LDH activity above the upper reference limit. These changes were observed irrespective of the nature of the musculoskeletal injuries or the participants' baseline resistance levels. Additionally, participants in subgroups 1^{Sa}, 2^{Sa}, and 2^{Na} exhibited persistently high blood cortisol levels in response to the applied stressor, similar to those observed at the beginning of the study.

Analysis of HRV and blood biomarkers across all study phases allowed for the assessment of adaptive and compensatory responses to the applied stress stimulus. The findings suggest that some military personnel experienced functional overstrain (FOR), while others showed characteristics of non-functional overstrain (NFOR).

Discussion

This study presents the results of an investigation aimed at evaluating the effectiveness of contemporary physical therapy protocols during long-term rehabilitation of military personnel with musculoskeletal injuries of the limbs caused by mine-explosive or gunshot wounds. Based on the analysis of adaptive and compensatory responses of body systems to various loads, the mechanisms for addressing functional (FOR) and non-functional (NFOR) overstrain during rehabilitation of the military personnel with these nosologies (Gray et al., 2025; Watanabe et al., 2025).

A system was developed to assess short-term and long-term adaptation and compensatory mechanisms during rehabilitation interventions, using HRV spectral analysis and blood biomarkers. The obtained results complement existing scientific data (Chernozub et al., 2025; Maqsood et al., 2025, Olkhovyi et al., 2025), indicating that baseline parameters, both in HRV indices and blood biomarkers, do not allow for a clear determination of the organism's resistance level, particularly during long-term rehabilitation.

The insufficient number of fundamental studies dedicated to developing scientifically grounded test loads using diverse methods, considering the specifics of servicemen's nosologies, further complicates the assessment of functional reserves (Olkhovyi et al. 2025, Uphill et al., 2025). Consequently, the lack of effective practical solutions negatively affects the development of optimal mechanisms for adjusting physical therapy protocols (Mallardo et al., 2024; Whitehurst et al., 2025).

The results indicate that military personnel exhibit highly variable responses to acute loads during long-term rehabilitation, regardless of their nosology or even the type of heart rate regulation. Identical manifestations of short-term adaptation mechanisms and compensatory reactions were observed both before the start of rehabilitation interventions and after 15 days of applying standard physical therapy protocols.

The selection of an appropriate set of biomarkers capable of accurately reflecting the efficiency of functional reserve readaptation mechanisms in servicemen with musculoskeletal limb injuries represents an ongoing scientific challenge. Addressing this issue is essential for distinguishing between functional overreaching (FOR) and non-functional overreaching (NFOR) during long-term rehabilitation processes (Grandou et al., 2021; Fiala et al., 2025).

The findings indicate that ten months of using physical therapy protocols, delivered in both inpatient and outpatient settings under the guidance of rehabilitation specialists, produced notable changes in baseline HRV parameters. These parameters varied significantly depending on the servicemen's nosological classification. The higher the initial level of stress on the heart rhythm regulation systems, the greater the VLF parameters of the participants, regardless of the specifics of their injury.

In response to test loads, both participants with musculoskeletal upper and lower limb injuries exhibited shifts in autonomic balance toward either sympathetic or parasympathetic dominance. However, 50% of the participants increased their central control of sinus rhythm regardless of the direction of these shifts in autonomic balance. In most cases, these HRV spectral changes after load occurred alongside a decrease in cortisol concentration and an increase in blood LDH activity.

The characteristic features of adaptive and compensatory responses to the stress stimulus indicate low muscle glycogen reserves and insufficient resistance levels, reflecting a state of non-functional overstrain and a risk of adaptation failure (Busso et al., 2025; Chernozub et al., 2025). The analysis revealed that several subgroups demonstrated a diminished central control over the sinoatrial node after the applied load, regardless of the type of heart rate regulation or underlying nosology. This reduction was associated with opposing dynamics in LF/HF indices. At the same time, notable biochemical changes were recorded. These included a marked increase in CPK activity and a pronounced rise in blood cortisol concentration, reaching values close to the upper limit of the normal range.

The observed changes in HRV spectral analysis and blood biomarkers indicate a state of functional overstrain in this category of participants (Gancitano et al., 2021; Miyatsu et al., 2023). These results highlight the need for a fundamental adjustment of loading regimes and exercise complexes with this nosology during the rehabilitation of military personnel. Sports physiology researchers studying the re-adaptation of the neuromuscular system note that after 8-10 weeks of an appropriate load regime, resistance levels increase, and the body ceases to respond positively to the stimulus (Fiala et al., 2025; Watanabe et al., 2025).

The results observed after 15 days of using the prescribed physical therapy protocols under the supervision of rehabilitation specialists demonstrated almost identical changes in HRV parameters and blood biomarkers as those recorded at the beginning of the study. Some participants had a significant decrease in cortisol concentration and an increase in blood LDH activity beyond normal limits in response to the load, accompanied by an enhancement of the central control of sinus rhythm. These sustained changes in biomarker profiles indicate a gradual and ongoing depletion of adaptive reserves. This process appears to stem from compensatory mechanisms activated by a very strong stress stimulus (Salonen et al., 2019; Uphill et al., 2025).

Considering these physiological changes in the body during neuromuscular re-adaptation against a backdrop of persistent deficits in energy reserves necessary for muscle hypertrophy, this condition may lead to adaptation failure (Watanabe et al., 2025). The results suggest that this subgroup of military personnel, who had been using standard physical therapy protocols for an extended period, exhibited a clearly pronounced state of non-functional overstrain (NFOR). In other subgroups, the observed changes in HRV parameters and blood biomarkers clearly demonstrated features of functional overstrain (FOR). In response to repeated test loads over a long period, a persistent rise in cortisol concentration exceeding normal physiological limits was observed, together with enhanced sympathetic tone. Such sustained alterations may indicate an adaptation failure (Cadegiani et al., 2019).

Conclusions

The study findings indicate limited effectiveness of standard physical therapy protocols during the long-term rehabilitation of military personnel with musculoskeletal limb injuries. Using these protocols over the previous 10 months of inpatient rehabilitation caused the development of non-functional overstrain (NFOR) in 50% of the participants. A follow-up study conducted over a 15-day inpatient period to evaluate the impact of the recommended physical therapy protocols on the neuromuscular re-adaptation process verified the earlier findings.

A detailed analysis of the adaptive and compensatory reactions to the applied test loads provided evidence of low functional reserves in most participants, relative to their specific pathology and type of heart rate regulation. Across both stages of the study, most subgroups exhibited compensatory reactions to the applied loads. These responses appear to result from insufficient muscle glycogen reserves and low stress resistance. There was an enhancement of central control of the sinus rhythm, accompanied by a decrease in cortisol concentration and an increase in blood LDH activity in response to the stressor. The stress stimulus caused an increased central control of the sinus rhythm. This was accompanied by a decrease in cortisol concentration and a concomitant rise in blood LDH activity.

These manifestations of adaptation failure when using standard physical therapy protocols for military personnel with musculoskeletal limb injuries will inevitably lead to exhaustion of adaptive reserves and low effectiveness of long-term rehabilitation. The results clearly highlighted one of the main problems in the development of FOR and NFOR states in military personnel with these pathologies. They demonstrated the necessity of using a broad spectrum of biomarkers to evaluate their adaptive and compensatory reactions to physical loads.

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Supplementary Information

Author’s contribution

Andrii Chernozub: Conceptualization, Methodology; **Oleh Olkhovyi:** Investigation; **Lesia Korobeinikova:** Software, Resources, Supervision; **Alina Kizilova:** Formal

Analysis, Resources, Writing – Review and Editing, Project Administration; **Oleksandr Zavizion:** Check, Writing – Rough Preparation; **Andrii Maidachenko:** Data Curation, Visualization. All authors have read and agreed with the published version of the manuscript.

Declarations

Conflict of Interest
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Effect of Swiss Ball Versus Floor Exercises in Patients with Mechanical Low Back Pain: A Comparative Study

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Abstract

Purpose. Mechanical low back pain is a prevalent health issue that necessitates effective non-surgical treatment options. While exercise therapy is a fundamental component of conservative care, further research is needed to compare the efficacy of various exercise approaches. This study aimed to determine the effectiveness of Swiss ball exercises and floor-based exercises in individuals with mechanical low back pain.

Material & Methods. A comparative study was conducted with participants divided into two intervention groups. Group A received a moist heat pack application for 15 minutes, followed by Swiss ball exercises, while Group B received a moist heat pack application for 15 minutes, followed by floor exercises. Outcome measures included the Visual Analog Scale (VAS) for pain intensity, the Oswestry Disability Index (ODI) for functional disability, and the Dynamic Abdominal Endurance Test (DAET), the Dynamic Extensor Endurance Test (DEET), and the Manual Testing (MT) for muscle endurance and strength evaluation. Assessments were performed at baseline and after the intervention period.

Results. Both intervention groups demonstrated significant improvements across all outcome measures. Analysis of pre- and post-intervention data revealed that both Swiss ball exercises and floor exercises effectively reduced pain intensity scores on VAS, decreased functional disability ratings on ODI, and improved muscle endurance and strength as measured by DAET DEET and MT.

Conclusions. Both Swiss ball exercises and floor exercises, when combined with moist heat application, provide effective therapeutic benefits for patients with mechanical low back pain, including pain reduction, decreased functional disability, and enhanced muscle endurance and strength.

Keywords: Mechanical low back pain, Swiss ball exercises, floor exercises, rehabilitation, pain management, muscle endurance.

Introduction

In today's society, modern work patterns, including increased sedentary office roles, corporate lifestyles, and the recent shift to remote work, have led to a significant decline in physical activity. This reduction in movement has corresponded with a rise in lower back pain (LBP) and related musculoskeletal issues (Hartvigsen et al., 2018). LBP typically manifests as pain, stiffness, or discomfort, primarily localized in the gluteal fold, with leg muscle pain being less common (Khan et al., 2018). While approximately half of the cases resolve spontaneously, 30-35% of patients require therapeutic intervention, and the remaining cases develop into chronic conditions demanding specialized, long-term care (Foster et al., 2018).

Core abdominal musculature plays a crucial role in the rehabilitation of patients suffering from LBP. These muscles provide essential support, strength, and protection to the lumbar region (Coulombe et al., 2017). Research demonstrates that insufficient trunk muscle development significantly increases vulnerability to LBP compared to individuals with well-developed core strength (Akhtar et al., 2017). Various etiologies can underlie LBP, including nerve compression and herniated discs, highlighting the complex nature of this condition (Maher et al.,2017).

The lower back is anatomically complex, featuring multiple joints, intervertebral discs, and an abundant muscular network. Somatic dysfunction within these muscles frequently contributes to LBP, emphasizing the importance of comprehensive patient assessment (Allegri et al., 2016). Clinicians must consider multiple factors when evaluating LBP patients, including age, pain duration, occupation, and risk factors such as obesity, poor general health, frequent heavy lifting, and weak abdominal muscle tone (Parreira et al., 2018). Even student populations carrying heavy backpacks demonstrate increased susceptibility to developing LBP (Yamato et al., 2018; Nageswari et al., 2025).

Swiss ball exercises have gained popularity as an effective intervention for LBP rehabilitation, with studies suggesting improvements in core stability and proprioception (Searle et al., 2015). Conventional floor exercises also demonstrate effectiveness in managing LBP through targeted strengthening of paraspinal and abdominal muscles (Owen et al., 2020; Rajan Balakrishnan et al., 2016). This study aims to compare the therapeutic efficacy of Swiss ball exercises versus conventional floor exercises in reducing pain and disability while improving muscle endurance in patients with mechanical LBP. By examining these distinct exercise modalities, we seek to provide evidence-based recommendations for clinical rehabilitation protocols that optimize patient outcomes and recovery.

Material and Methods

Subjects

This comparative study recruited thirty subjects (7 males and 23 females) aged between 20-30 years from Delhi and Delhi NCR residential areas. All participants were diagnosed with mechanical low back pain with symptoms lasting more than 6 weeks. The study excluded individuals with congenital disorders, degenerative conditions, and pregnant females. Subjects who met the inclusion criteria were provided with detailed information about the study, and informed consent was obtained from each participant before enrollment. The subjects were then randomly assigned to either Group A or Group B, with 15 participants in each group.

Assessment

Assessment of all participants was conducted using validated tools, including the Visual Analog Scale (VAS) for pain intensity, the Oswestry Disability Index (ODI) questionnaire for functional disability, the Dynamic Abdominal Endurance Test (DAET), the Dynamic Extensor Endurance Test (DEET), and the Manual Testing (MT) for muscle endurance and strength evaluation. The assessment was performed twice - at baseline (pre-intervention) and after completion of the 4-week intervention program (post-intervention). These tools were selected to comprehensively evaluate pain levels, functional limitations in activities of daily living, and muscle endurance capacity in patients with mechanical low back pain.

Protocol

The intervention protocol consisted of two distinct exercise regimens. Group A received a moist heat pack application for 15 minutes, followed by Swiss ball exercises, while Group B received a moist heat pack application for the same duration, followed by floor exercises. Both groups performed similar exercise types, including multifidus exercises, back extension exercises, and abdominal crunches, with the only difference being the exercise surface (Swiss ball vs. floor). The intervention was conducted over 4 weeks with a frequency of 3 sessions per week. Each session was carefully monitored to ensure proper execution of exercises. The study tools utilized included a mattress, a towel, a moist heat pack, a Swiss ball, and standard assessment forms.

Data Extraction and Analysis

The data extraction process was systematically conducted at baseline (pre-intervention) and after completion of the 4-week intervention (post-intervention). All 30 participants (15 in each group) completed the full 12 training sessions over the 4-week intervention period. The collected data included demographic information (age and gender), pain intensity measured using VAS, functional disability assessed through ODI, and muscle endurance evaluated using DAET, DEET), and MT.

All collected data was systematically organized and entered into SPSS version 20.0 for statistical analysis. Descriptive statistics including means and standard deviations were calculated for each parameter. Independent t-tests were used to compare baseline characteristics between groups to ensure homogeneity. Paired t-tests were employed to analyze within-group changes from pre- to post-intervention. Between-group comparisons for post-intervention measures were conducted using independent t-tests. Statistical significance was established at $p<0.05$ for all analyses.

Table 1. Demographic Characteristics of Study Participants

	Group A	Group B	P- Value
Age (years)	23.1±2.1	22.1±2.1	0.213
Male	4 (26.7%)	3 (20%)	0.673
Female	11 (73.3%)	12 (80%)	0.673

Results

Analysis of baseline data revealed no significant differences between Group A and Group B in terms of demographic characteristics and outcome measures, indicating successful randomization and homogeneity between groups at the start of the intervention (Table 1). The normality of the data was assessed using the Kolmogorov-Smirnov and Shapiro-Wilk tests. Data was found to be near normal, and parametric t-test statistical methods were considered. Paired t-test for within-group analysis and unpaired t-test for between-group analysis. Both groups showed substantial improvements in all outcome measures following the 4-week intervention period.

The statistical analysis of within-group changes from pre- to post-intervention demonstrated significant improvements in all outcome measures for both groups. For Group A, ODI scores decreased by 58.60%, from a pre-intervention average of 45.67% to a post-intervention average of 18.6%, indicating substantial improvement in functional ability. VAS scores showed a remarkable reduction of 96.22%, decreasing from an average of 5.67 to 0.2, suggesting a nearly complete resolution of pain. Muscle endurance measures also showed significant improvements, with DAET scores increasing by 35.56% (2.43 to 3.63), DEET scores improving by 30% (2.60 to 3.60), and MT scores enhancing by 28.89% (2.97 to 4.03) (Table 3).

Similarly, Group B demonstrated significant improvements in all parameters. ODI scores (Tareen, I., Singla, D., & Gupta, S., 2024). decreased by 56.20%, from 43.20% to 18.87%. VAS scores reduced by 89%, from 5.33 to 0.60. Endurance

Table 2. Tests of Normality

GROUP		Kolmogorov-Smirnova			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Group A	Age	.146	15	.200*	.944	15	.432
	Gender	.419	15	.000	.603	15	.000
	PREODI	.201	15	.103	.910	15	.137
	PREVAS	.237	15	.023	.881	15	.049
	PREDAET	.485	15	.000	.499	15	.000
	PREDEET	.485	15	.000	.499	15	.000
	PREMT	.271	15	.004	.815	15	.006
Group B	Age	.319	15	.000	.815	15	.006
	Gender	.514	15	.000	.413	15	.000
	PREODI	.195	15	.129	.912	15	.145
	PREVAS	.258	15	.008	.881	15	.049
	PREDAET	.514	15	.000	.413	15	.000
	PREDEET	.344	15	.000	.817	15	.006
	PREMT	.371	15	.000	.780	15	.002

**. This is a lower bound of the true significance.*
a. Lilliefors Significance Correction.

Table 3. Comparison of Pre- and Post-intervention Values for Group A (Swiss Ball) and Group B (Floor Exercises)

Parameter	Group A (n=15)		Group B (n=15)	
	Pre (Mean±SD)	Post (Mean±SD)	Pre (Mean±SD)	Post (Mean±SD)
ODI (%)	45.67±4.32	18.60±1.06	43.20±2.86	18.87±1.51
VAS	5.67±0.98	0.20±0.56	5.33±0.82	0.60±0.63
DAET	2.43±0.19	3.63±0.31	2.33±0.19	3.43±0.26
DEET	2.60±0.21	3.60±0.35	2.63±0.33	3.70±0.36
MT	2.97±0.33	4.03±0.30	2.93±0.30	3.87±0.28

measures also improved substantially, with DAET increasing by 33.33% (2.33 to 3.43), DEET improving by 31% (2.63 to 3.70), and MT enhancing by 24.44% (2.93 to 3.87) (Table 4).

Table 4. Percentage Improvement in Outcome Measures for Both Groups

Parameter	Group A (%)	Group B (%)	Difference (A-B) (%)
ODI (%)	58.60	56.20	2.40
VAS	96.22	89.00	7.22
DAET	35.56	33.33	2.23
DEET	30.00	31.00	−1.00
MT	28.89	24.44	4.45

The statistical significance of within-group changes was assessed using paired t-tests. All parameters showed highly significant improvements ($p<0.001$) for both groups, as detailed in (Table 5).

Between-group comparison of post-intervention values revealed no statistically significant differences between Group A and Group B for any of the outcome measures, indicating that both interventions were equally effective in improving pain, disability, and muscle endurance (Table 6).

Pain intensity (VAS) showed substantial improvement in both groups: Group A (Swiss ball) had a 96.22% reduction, while Group B (floor exercises) showed an 89% reduction ($p=0.077$). Despite the higher reduction in Group A, the difference was not statistically significant, indicating both approaches are highly effective in pain relief.

Functional disability (ODI) also improved markedly – by 58.60% in Group A and 56.20% in Group B ($p=0.557$) – exceeding the MCID and confirming strong clinical benefits in both groups.

Muscle endurance parameters (DAET, DEET, and MT) improved significantly and comparably across both groups, highlighting the role of core muscle enhancement in preventing recurrence and supporting long-term management of mechanical low back pain.

Discussion

The primary aim of this study was to evaluate and compare the efficacy of Swiss ball exercises versus floor exercises in reducing pain, improving functional disability, and enhancing muscle endurance among patients with mechanical low back pain. Our findings demonstrate that both interventions, when combined with moist heat therapy, are highly effective, with no statistically significant differences observed between them across all measured outcomes.

Consistent with previous research, both groups experienced substantial reductions in pain intensity, as indicated by VAS scores. Specifically, Group A (Swiss ball exercises) achieved a 96.22% reduction, while Group B (floor exercises) demonstrated an 89% reduction. Although this difference favored the Swiss ball group, it did not reach statistical significance ($p=0.077$). Similar findings have been reported by Gauri Shankar and Vinod Chaurasia (2012), who observed that Swiss ball exercises tend to elicit higher electromyographic activity in core muscles compared to traditional floor exercises. However, our results align with those of Bala and Gakhar (2018), who found that both types of exercise significantly improved pain

Table 5. Within-Group Comparison

Parameter	Group A		Group B	
	t-value	p-value	t-value	p-value
ODI (%)	24.36	<0.001*	28.15	<0.001*
VAS	19.21	<0.001*	18.53	<0.001*
DAET	12.65	<0.001*	11.21	<0.001*
DEET	9.87	<0.001*	8.96	<0.001*
MT	10.32	<0.001*	9.15	<0.001*

**p<0.05 indicates statistical significance*

Table 6. Statistical Significance of Within-Group Improvements

Parameter	Group A (Mean±SD)	Grop B (Mean±SD)	Mean Difference	t-value	p-value
ODI (%)	18.60±1.06	18.87±1.51	0.27	0.594	0.557
VAS	0.20±0.56	0.60±0.63	0.40	1.836	0.077
DAET	3.63±0.31	3.43±0.26	0.20	1.282	0.210
DEET	3.60±0.35	3.70±0.36	0.10	1.521	0.139
MT	4.03±0.30	3.87±0.28	0.16	1.304	0.203

and function over a 4-week period, with no clear superiority of one modality over the other.

Improvements in functional disability, measured via ODI, were similarly notable, with reductions exceeding 56% in both groups. This aligns with the literature emphasizing that targeted core strengthening and stabilization exercises can produce clinically meaningful improvements in disability scores within a short duration (Kavcic, Hodges, & Richer, 2004). The lack of significant difference between the groups suggests that the specific modality – Swiss ball versus floor exercise – may be less critical than the targeted engagement of stabilizing musculature and the inclusion of adjunct therapies like moist heat.

Muscle endurance parameters (DAET, DEET, and MT) were significantly enhanced in both groups, supporting previous studies that highlight the importance of core muscle strengthening in the management of low back pain (Akuthota & Nadler, 2004). The enhancement of trunk muscle endurance is widely recognized as a key factor in preventing recurrence and promoting long-term spinal stability, as also discussed by Gakhar et al. (2018) and others in this domain.

The comparable effectiveness of Swiss ball exercises and traditional floor exercises echoes findings from the literature, which suggest that while Swiss ball exercises are theoretically advantageous due to their capacity to enhance proprioception and muscle activation through instability, these benefits do not necessarily translate into superior clinical outcomes over short-term interventions (Shankar & Chaurasia, 2012; Maher et al., 2017).

Several factors may explain the lack of significant differences observed. Both interventions targeted the same key muscles involved in lumbar stabilization, and the application of moist heat likely enhanced muscle readiness and exercise efficacy. Moreover, the relatively short duration of 4 weeks might be insufficient to manifest differences that could emerge over longer periods, a hypothesis supported by studies indicating that differences between unstable and stable exercises become more apparent with extended training (Hides et al., 2008).

Clinically, the findings suggest flexibility in choosing either exercise modality based on patient preference, resource availability, or specific clinical scenarios, without compromising outcomes. Notably, the slight numerical advantages in certain measures for the Swiss ball group, though not statistically significant, warrant further investigation in larger, longer-term studies.

Limitations and Future Directions

This study's limitations include a small sample size, which may have limited the detection of subtle differences, and the short intervention period. Additionally, the absence of long-term follow-up restricts conclusions regarding the sustainability of benefits or recurrence prevention. The study population was limited to young adults aged 20-30 years, which may affect the generalizability to older or more diverse populations.

Future research should involve larger cohorts, extended intervention durations, and follow-up assessments to better understand the long-term comparative benefits. Incorporating standardized assessments like the Sorensen or MMT tests could provide a more comprehensive evaluation of trunk muscle strength, and gender-specific analyses might reveal differential responses to these interventions (Sullivan et al., 2009).

Conclusion

Both Swiss ball exercises and floor exercises, when combined with moist heat application, are highly effective in reducing pain, improving functional ability, and enhancing muscle endurance in patients with mechanical low back pain. The choice between these two approaches can be based on practical considerations, patient preference, and specific clinical factors without significantly affecting treatment outcomes.

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Supplementary Information

Author's contribution

Sakshi Parmar: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – Rough Preparation, Project Administration; **Sachin Gupta:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – Rough Preparation, Project Administration; **Ambreen Fatima:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – Rough Preparation, Project Administration; **Nidhi Singh:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – Rough Preparation, Project Administration; **Sonika Girsa:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – Rough Preparation, Project Administrationt. All authors have read and agreed with the published version of the manuscript.

Declarations

Conflict of Interest

There are no financial conflicts of interest to disclose. The authors declare no conflict of interest.

Ethical Approval and Consent

The study involved a non-invasive intervention and outcome measures, posing minimal risk to participants. All subjects were thoroughly informed about the purpose, procedures, and their rights regarding participation, including the freedom to withdraw at any time without penalty. Written informed consent was obtained from all participants prior to their involvement in the study.

Data Declaration

The data used in this study were collected from patients diagnosed with mechanical low back pain based on clinical criteria. All data were collected following informed consent.

Data Availability

The data supporting the findings of this study are not publicly available to protect patient privacy and confidentiality.

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Comprehensive assessment of heart rate variability, blood pressure, sleep quality, and anxiety in athletes with persistent fatigue

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Abstract

Purpose. To provide a comprehensive assessment of heart rate variability, arterial blood pressure, sleep disorders, and anxiety in athletes with persistent fatigue.

Material & Methods. In total, 52 track and field athletes participated in the study. We divided them into groups according to their scores on the Fatigue Assessment Scale (FAS): the main group consisted of 11 athletes with scores of 22 points or higher, while the control group comprised the participants with scores below this threshold. There were no significant differences between groups in age, sex, training intensity, or representation in athletics disciplines. All study participants underwent assessment with the WHO-5 Well-Being Index, the Athens Insomnia Scale (AIS), the Epworth Sleepiness Scale (ESS), and the Hospital Anxiety and Depression Scale (HADS). We measured heart rate variability using the Cardio+ monitor during a 4-6 minute recording period.

Results. The findings showed that athletes with fatigue lasting more than two weeks demonstrated lower well-being, sleep disturbances, and higher levels of anxiety ($p<0.001$). The strongest correlation was observed between FAS scores and WHO-5 well-being ($r=-0.902$, $p<0.001$). Weaker correlations were observed between FAS scores and insomnia (AIS, $r=0.691$, $p<0.001$) and daytime sleepiness (ESS, $r=0.684$, $p<0.001$). No correlation between fatigue and anxiety was detected in the main group ($r=0.340$, $p=0.306$), and the overall correlation across all participants was weak ($r=0.431$, $p<0.001$). This indicates that anxiety is a distinct symptom, which, although more common in persistent fatigue, may have an independent significance, thus requiring a comprehensive approach that considers the psychosomatic status of the athletes. Our analyses confirmed reductions in both time- and frequency parameters of heart rate variability ($p<0.05$), indicating deterioration of autonomic regulation in athletes with persistent fatigue. The fact that this was mostly true for the parasympathetic part of the autonomic nervous system (HF, LF/HF, $p<0.001$) may indicate that the main mechanism of fatigue is insufficient post-load recovery. Although indirectly, this also evidenced resting hemodynamic parameters, in particular, a higher heart rate and arterial blood pressure level in the main group.

Conclusions. Athletes with clinically significant persistent fatigue demonstrated poorer indices reflecting subjective well-being (sense of well-being, anxiety, and sleep quality) and autonomic regulation of cardiac function (arterial blood pressure and heart rate variability parameters). The strongest correlations of fatigue levels were recorded with the WHO-5 Well-Being Index (r=–0.902), insomnia severity (r=0.691), and daytime sleepiness (r=0.684), indicating the systemic nature of these changes. The findings suggest that the disturbances in functional indicators may result from insufficient post-load recovery, which underscores the need for further research on the effectiveness of various recovery interventions aimed at optimizing the physiological state of athletes.

Keywords: heart rate variability, blood pressure, sleep quality, anxiety, persistent fatigue, athletes.

Introduction

The relevance of the present study is determined by the high prevalence of overtraining symptoms among athletes of various specializations. According to several sources, approximately one in five athletes experiences symptoms of functional overreaching during a single training cycle (Bell et al., 2021 and Matos et al., 2011). During physical training and sports activities, the body undergoes significant physical exertion, which in some cases may exceed its adaptive capacity. To prevent the negative effects of excessive load, athletes and coaches apply a set of recovery measures, commonly referred to as post-load recovery. It includes various forms of active and passive rest, physiotherapy procedures, rational nutrition, and permissible pharmacological support through nutrients. The selection of specific interventions is individual and depends on the preferences of athletes and coaches, the conditions of the training process, the availability of resources, and the quality of the relevant services (Kreher, 2016).

At the same time, if the applied recovery measures are insufficient or inadequately selected, athletes may experience symptoms of varying severity, with physical and mental fatigue being predominant. Their persistence and intensity may vary depending on the phase of the training macrocycle. Although the sensation of fatigue is a natural consequence of an effective training load, persistent general weakness lasting more than two weeks, lack of full recovery after sleep, and a high level of fatigue (over 21 points on the Fatigue Assessment Scale) usually indicate the development of undesirable changes in the athlete's condition (Kreher, 2016 and Armstrong et al., 2022). Fatigue assessment is an important criterion for identifying the reasons behind failure to comply with the training plan, as well as uncompensated physiological changes that are not accompanied by supercompensation and may signal the onset or progression of overtraining. Under conditions of severe and persistent fatigue, other adverse functional and metabolic disorders may occur, among which the syndrome of autonomic dysfunction stands out. This syndrome reduces the quality of life, affects the motivational component of athletes' activities, limits their sports performance, and increases the risk of injury (Kellmann, 2010).

Diagnosing autonomic dysfunction in athletes is complicated because its symptoms are often disguised as normal manifestations of overwork or adaptive reactions to training load. The subjectivity of complaints, individual differences in reactions to exercise, and the influence of the psycho-emotional state make it difficult to establish clear diagnostic criteria for detecting autonomic dysfunction under conditions of non-functional overreaching and overtraining. In this regard, research methods aimed at early detection of signs of dysautonomia are of particular importance (Kajaia et al., 2021). These include long-term ECG recording (Holter monitoring), which allows for precise assessment of heart rate variability (HRV). The study of the parameters reflecting the adaptive capacity of cardiac regulation, the effect of different levels of physical load on the heart rate, and the possibility of detecting early signs of cardiac remodeling and cardiomyopathy caused by excessive physical exertion make this method unique for sports medicine. In addition, researchers can use HRV assessment for comparison with clinical symptoms in general, as well as for studying the interactions between the central nervous system and the autonomic nervous system (Barnett, 2006). Undoubtedly, sleep disturbances and the development of anxiety in athletes with persistent fatigue are significant symptoms that sometimes require targeted symptomatic interventions. At the same time, they can be subjective markers of dysfunctional disorders that can develop in the body of athletes under insufficient post-load recovery, act as early indicators of overtraining syndrome and trigger of more systemic alterations (Bezuglov et al., 2021 and Li et al., 2024). On the other hand, the lack of clear diagnostic criteria for identifying the boundary between adaptation and pathology often leads to underdiagnosis or overdiagnosis in sports medicine. At the same time, each of the symptoms studied in this paper may play a primary role in triggering a cascade of pathological reactions, not excluding its independent clinical significance, which further complicates the diagnosis and interpretation of symptoms. The literature review showed that studies addressing the role of fatigue in athletes in the development of cardiovascular regulatory disorders and psychophysiological disorders remain insufficient. The aim of this study was to provide a comprehensive assessment of heart rate variability, arterial blood pressure, sleep disorders, and anxiety in athletes with persistent fatigue.

Material and methods

Participants

52 track and field athletes participated in the study, and we observed them at the Sports Medicine Center of Sumy State University. The average age of the participants was 22.35 (3.28) years; 20 of them were females (38.5%). The average athletic experience of the participants was 8.9 (2.14) years, and their average weekly training load during the two weeks preceding the study was 18.12 (4.98) hours. Among the examined athletes, 20 individuals (38.5%) represented endurance disciplines in track and field. We conducted the study in accordance with the principles of the Declaration of Helsinki, and all participants provided informed consent before participation.

Procedure

All study participants underwent assessment for fatigue severity using the Fatigue Assessment Scale (FAS), which was developed by H. J. Michielsen, J. De Vries and G. L. Van Heck and first described in 2003 (Michielsen et al., 2003) – also translated into Ukrainian (Chaban et al., 2021). Based on the obtained results, we divided all athletes into two groups. The main group (MG) consisted of 11 athletes with FAS scores 22 points and above, which indicated significant fatigue. In contrast, in the control group (CG), which consisted of 41 athletes, the FAS scores were 21 points or lower, corresponding to values within the normal range. Both groups showed no significant differences in age, sex distribution, or other characteristics, as presented in Table 1. In addition, our team assessed all study participants with the WHO-5 Well-Being Index (Chaban et al., 2021). We evaluated the degree of insomnia with the Athens Insomnia Scale (AIS) (Okajima et al., (2020), assessed the daytime sleepiness using the Epworth Sleepiness Scale (ESS) and determined the anxiety levels with the Hospital Anxiety and Depression Scale (HADS) (Chaban et al., 2021).

Methods

HRV assessment took place through ECG recording lasting 4-6 minutes by means of the automated diagnostic system Cardio+. We analyzed the time characteristics by calculating RMSSD, SDNN, and PNN50 and studied the HRV using the Fast Fourier Transform (FFT) method, which helped determine the power of the main frequency bands: high-frequency (HF, 0.15–0.40 Hz), low-frequency (LF, 0.04–0.15 Hz), as well as the total spectral power and the LF/HF ratio. Furthermore, to calculate the standard deviation, we determined the geometric nonlinear index SD1, perpendicular to the central axis of the main distribution (Electrophysiology, T. F. o. t. E. S., 1996). After obtaining the parameters, we compared them with the reference values.

Statistical analysis

We conducted statistical analysis with the web resource http://socscistatistics.com. To test the distribution of variables, we applied the Kolmogorov-Smirnov test. For continuous variables, we reported the mean and standard deviation (for normally distributed data) or the median and interquartile range (for non-normally distributed data). We present nominal variables as percentages. To compare the differences between groups, we used a two-sided t-test for normally distributed data and the Mann-Whitney test when at least one of the groups deviated from normal distribution. We applied the χ^2 test with the Yates correction to compare frequencies. Afterwards, we conducted correlation analysis with Pearson's correlation coefficient and considered the results statistically significant at $P<0.05$.

Table 1. **Characteristics of the study groups**

Variable	Total (N=52)	MG (N=11)	CG (N=41)	p (comparison between MG and CG)
Sex (% female)	38.5	54.5	34.0	0.217
Age (years)	22.35 (3.28)	21.36 (2.98)	22.61 (3.35)	0.268
Athletic experience (years)	8.9 (2.14)	8.18 (2.44)	9.1 (2.03)	0.210
Weekly training load (hours per week)	18.12 (4.98)	18.0 (4.29)	18.15 (5.19)	0.932
Endurance vs. non-endurance disciplines (%)	61.5	72.73	58.54	0.260

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Results

The examinations revealed that in all athletes of the main group (MG), weakness was not the only symptom, usually accompanied by other symptoms of overwork, such as decreased motivation to train, lower reaction time, impaired coordination, etc. It is noteworthy that in this group, fatigue was generally moderate, although in three athletes (27% of the MG) its severity approached the threshold interpreted as severe, with all scoring 32 points on FAS. At the same time, the mean FAS score was 27.45 (3.70), which significantly exceeded the norm and, accordingly, the value of 17.56 (2.29) observed in the CG (<0.001). However, the purpose of our study was to investigate the peculiarities of the psychosomatic disorders development under this condition; therefore, we focused primarily on changes that could be objectively assessed, in particular, the relationship between well-being and heart rate regulation.

When analyzing the well-being of the participants, we found a higher WHO-5 score in the CG (<0.001). In this group, the index corresponded to a high level of well-being, whereas in the MG it indicated a moderate level with a risk of decline (Table 2). The Pearson's correlation between FAS and WHO-5 scores was −0.902 ($p<0.001$), indicating a strong correlation. This correlation was weaker when comparing only the corresponding pairs of indicators in the MG −0.7 ($p=0.016$), which may indicate a greater influence of other symptoms in these athletes.

When assessing anxiety levels using HADS, most athletes (31 individuals, 60%) scored within the normal range (less than 8 points). 15 athletes (29%) demonstrated borderline values (11 athletes of the CG and 4 of the MG), while six athletes (12%) exhibited pronounced clinically significant anxiety (2 in the CG and 4 in the MG). After comparing the mean values in the groups, we revealed a significantly higher level of anxiety in the MG ($p<0.001$). Overall, a weak positive correlation between FAS and HADS scores took place ($r=0.431$, $p<0.001$); however, within the MG, this correlation was absent ($r=0.340$, $p=0.306$). These findings may indicate that weakness and anxiety are less related symptoms, with the latter having a greater independent significance. Anxiety is an emotional state characterized by a feeling of tension, restlessness, and anticipation of danger or threat, often without a clear cause. It is a normal reaction of the body to stress or uncertainty. For athletes, this condition may be seen as an occupational hazard associated with competitions, frequent traveling, and the risk of injury or other pathological conditions. When assessing the significance of anxiety for an athlete, it is essential to consider individual psychological characteristics, previous experience, and overall psychosocial status.

Sleep disorders are central to the development and progression of psychosomatic diseases, acting as early markers and aggravating factors. We studied such sleep disorders as insomnia and daytime sleepiness. In both cases, the results were better in the CG compared to the MG ($p<0.001$). At the same time, only two athletes (both from the MG and representing less than 4% of the total participants) met criteria for clinically significant insomnia and three athletes (6%, all from the MG) demonstrated excessive sleepiness (13 ESS points). We observed a notable moderate positive correlation between FAS and AIS ($r=0.691$, $p<0.001$), and between FAS and ESS scores ($r=0.684$, $p<0.001$), indicating the important role of sleep disorders in athletes with persistent fatigue.

The analysis of hemodynamic parameters showed higher values of heart rate (HR) and blood pressure (BP) in the MG as compared to the CG (Table 3). Most CG athletes exhibited resting bradycardia along with systolic (SBP) and diastolic blood pressure (DBP) values corresponding to optimal normal levels (<120/80 mmHg). At the same time, five athletes (10%) demonstrated high normal BP values exceeding 130/85 mmHg, four of whom belonged to the MG. Our findings suggest that prehypertension may play an independent role in the development of overtraining in athletes (Brizhatyi et al., 2020) and may influence the electrophysiological function of the heart.

The HRV assessment revealed that athletes in the MG demonstrated consistently lower values across most parameters, which may reflect the onset of adverse physiological adaptations associated with chronic fatigue. Although the obtained

Table 2. **Survey results of the athletes (all results are presented in scores)**

Variable	Total (N=52)	MG (N=11)	CG (N=41)	p (comparison between MG and CG)
Fatigue (FAS-scale)	19.65 (4.82)	27.45 (3.70)	17.56 (2.29)	<0.001
Well-being (WHO-5)	20.63 (2.66)	16.55 (1.57)	21.73 (1.60)	<0.001
Anxiety (HADS)	7.23 (3.05)	9.91 (3.30)	6.51 (2.58)	<0.001
Insomnia (AIS)	3.60 (2.79)	8.0 (1.84)	2.41 (1.52)	<0.001
Daytime sleepiness (ESS)	6.27 (3.62)	11.64 (1.29)	4.83 (2.50)	<0.001

Table 3. **Hemodynamic parameters and heart rate variability in the study groups**

Variable	MG	CG	p
HR (beats per minute)	68.91 (9.81)	57.22 (8.41)	<0.001
SBP (mmHg)	124.73 (9.55)	117.02 (7.31)	0.005
DBP (mmHg)	77.82 (7.86)	72.44 (6.61)	0.026
RRNN (ms)	870.70 (123.85)	1048.58 (154.12)	<0.001
SDNN (ms)	54.64 (9.22)	67.1 (18.78)	0.039
RMSSD (ms)	36.0 (6.29)	43.43 (11.82)	0.054
PNN50 (%)	8.36 (1.80)	11.51 (2.93)	0.001
LF (ms^2)	606.36 (106.55)	735.88 (196.03)	0.041
HF (ms^2)	342.82 (108.63)	555.71 (174.32)	< 0.001
LF/HF	1.82 (0.40)	Mdn (IQR): 1 (1–2)	< 0.001
SD1 (ms)	26.09 (4.74)	31.73 (8.62)	0.043

indices in both groups generally remained within the normative range, the trend toward reduction in the MG suggests an imbalance in autonomic regulation. In particular, the mean RRNN was significantly shorter in the MG compared to the CG, indicating an elevated resting heart rate and a decrease in overall cardiac rhythm stability. This pattern reflects a shift toward sympathetic predominance and reduced vagal activity, characteristic of incomplete recovery after repeated physical loading. Statistically significant intergroup differences were also found for SDNN (p=0.039), PNN50 (p=0.001), and SD1 (p=0.043), all of which are sensitive indicators of parasympathetic tone and short-term HRV. The RMSSD approached statistical significance (p=0.054), further supporting the tendency toward decreased vagal influence on heart rhythm. A similar pattern emerged in the frequency domain. The LF component (p=0.041), which reflects the mixed influence of sympathetic and parasympathetic modulation, was significantly lower in the MG, while the HF component (p<0.001), a key marker of parasympathetic activity, showed an even more pronounced decline. Consequently, the LF/HF ratio, which reflects the overall sympathovagal balance, was also significantly reduced (p<0.001), indicating a deterioration of autonomic homeostasis during the resting state. These findings suggest that athletes experiencing persistent fatigue exhibit a marked reduction in autonomic adaptability and recovery efficiency, primarily due to suppressed parasympathetic modulation and relative sympathetic dominance. Such alterations are consistent with early signs of autonomic dysregulation often observed in the initial stages of overtraining and may serve as objective physiological markers for identifying insufficient post-load recovery in high-performance athletes.

Discussion

The study proved that athletes with persistent fatigue lasting more than two weeks demonstrate decreased WHO-5 Well-Being Index scores, sleep disturbances, and higher levels of anxiety. The strongest correlation of fatigue level (FAS) was found with well-being (WHO-5), and to a lesser extent with insomnia (AIS) and daytime sleepiness (ESS). Interestingly, there was no correlation between the levels of fatigue and anxiety in the MG, and this relationship was weak when calculated across all participants. This suggests that anxiety represents a distinct symptom that, although more commonly observed in cases of persistent fatigue, may have independent significance. Anxiety in athletes is a common mental health issue that can negatively impact performance, focus, and overall well-being. It often arises from pressure to succeed, fear of failure, or high expectations from coaches, teammates, and fans. Symptoms of anxiety may include racing thoughts, muscle tension, rapid heartbeat, and difficulty concentrating during training or competition. If left unaddressed, anxiety can lead to burnout, decreased motivation, or withdrawal from sport altogether. Supportive coaching, mental skills training, and access to sports psychologists can help athletes manage anxiety effectively. Therefore, its interpretation calls for a systematic approach that takes into account the psychosomatic status of the athletes (Tossici et al., 2024 and Wang et al., 2025).

Insufficient post-load recovery in athletes can lead to cumulative fatigue, which progressively diminishes physical and mental capacity. This ongoing fatigue not only impairs immediate performance but also disrupts the body's ability to adapt to training over time (Chernozub et al., 2025). Chronic inadequate recovery has been shown to alter neuromuscular function and increase markers of systemic inflammation (Davis et al., 2021 and Rochaj et al., 2019). Moreover, disrupted recovery cycles can negatively affect psychological well-being, leading to decreased motivation and increased perception of effort. As a result, athletes may experience stagnation or decline in performance despite consistent effort. Prolonged recovery deficits can also increase the risk of overuse injuries, hormonal imbalances, and immune suppression (Soronovych et al., 2025). Therefore, adequate recovery protocols are essential to support long-term performance, health, and training progression.

The results of the present study are consistent with and complement the findings reported by Olkhovyi et al. (2025), who investigated the impact of rapid pre-competition weight loss on HRV in qualified female powerlifters. In that study, short-term weight reduction led to a marked decrease in parasympathetic activity (significant reductions in SDNN, rMSSD, and HF) and a concomitant increase in sympathetic dominance (elevated LF and LF/HF ratio), reflecting a state of acute physiological stress. In our study of athletes with persistent fatigue, a somewhat similar direction of autonomic alterations was observed, but with lower absolute HRV indices and reduced parasympathetic modulation during rest, suggesting a chronic rather than acute adaptation deficit. Whereas the powerlifters exhibited temporary, stress-induced autonomic imbalance following rapid weight manipulation, the track-and-field athletes in our research demonstrated sustained suppression of vagal activity and impaired post-load recovery, indicative of long-term dysregulation of autonomic control. Thus, both studies highlight the vulnerability of the autonomic nervous system to cumulative training or nutritional stressors, but they differ in the time scale and nature of the physiological response—acute sympathetic activation in the case of rapid weight loss versus persistent autonomic under-recovery accompanying prolonged fatigue.

The results of this study also align conceptually with the findings of Romanchuk et al. (2025), who examined volumetric respiratory variability as a marker of recovery after physical exercise. Their data showed significant fluctuations in high-frequency respiratory components (HFR) and total power (TPR) immediately after training, with normalization by the following morning, reflecting rapid functional recovery of respiratory control mechanisms. In contrast, the athletes in our investigation exhibited prolonged disturbances of autonomic balance, including reduced parasympathetic modulation and incomplete post-load recovery of cardiac regulation. Thus, while Romanchuk and colleagues demonstrated short-term, reversible adaptations of respiratory variability to physical stress, our results indicate a persistent dysregulation of cardiovascular autonomic function in athletes with chronic fatigue (Tsos et al., 2025). Together, these findings emphasize the interconnectedness of respiratory and cardiac autonomic responses and suggest that delayed normalization of HRV may serve as a reliable marker of insufficient recovery capacity in athletes exposed to sustained training or cumulative stress.

The deterioration of autonomic regulation in athletes with persistent fatigue is confirmed by a decrease in both time and frequency parameters of HRV. The fact that these changes primarily relate to the parasympathetic part of the autonomic nervous system (HF, LF/HF) suggests that the main mechanism of fatigue is insufficient post-load recovery. Indirectly, resting hemodynamic parameters, particularly higher HR and BP values in the MG, also supported this interpretation. Insufficient post-load recovery in athletes can lead to cumulative fatigue, impairing both performance and adaptation to training stimuli. Inadequate recovery time disrupts physiological processes such as muscle repair, hormonal balance, and glycogen replenishment (Chernozub et al., 2025). Over time, this can increase the risk of overtraining syndrome, injury, and immune suppression. Monitoring recovery through biomarkers, performance metrics, and subjective assessments is essential for optimizing training outcomes. Therefore, implementing individualized recovery strategies is crucial to maintaining athlete health and maximizing long-term performance. These findings highlight the need for further research aimed at exploring the potential of biomedical and psychological recovery methods for athletes with intensive training loads. This may contribute to improving their functional state, well-being, overall health, and competitive performance.

Conclusions

Athletes with clinically significant persistent fatigue demonstrated worse scores of subjective well-being (sense of well-being, anxiety, sleep quality) and the state of autonomic regulation of cardiac activity (BP and HRV parameters). We recorded the strongest correlations of fatigue levels with the WHO-5 Well-Being Index (r=−0.902), insomnia severity (r=0.691), and daytime sleepiness (r=0.684), indicating the systemic nature of these changes. The findings suggest that the disturbances in functional indicators may result from insufficient post-load recovery, which underscores the need for further research on the effectiveness of various recovery interventions aimed at optimizing the physiological state of athletes.

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Supplementary Information

Author's contribution

Yurii Ataman: Conceptualization, Methodology; **Oleksandr Shevchenko:** Writing – Reviewing and Editing, Project Administration; **Iryna Brizhata:** Formal analysis, Investigation, Supervision, Writing – original draft; **Oleh Liebiediev:** Resources, Software; **Oleksandr Tykhorskyi:** Validation, Visualization. All authors have read and agreed with the published version of the manuscript.

Declarations

Conflict of Interest
The authors declare that there is no conflict.

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Biomechanical aspects of measurement in musculoskeletal physical therapy

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Abstract

Purpose. The purpose of the study: to investigate the effectiveness of comprehensive treatment for patients with stage 2-3 coxarthrosis, utilizing a combination of therapeutic exercises, Neurac methodology on the Redcord system, and biomechanical methods with a personalized approach, and to theoretically and practically justify the rationale for this approach. This study involved 26 patients aged 45 to 65 with stage 2-3 coxarthrosis and functional deficiency grade 2. The main group received a program including Redcord/Neurac and Mulligan techniques, while the control group received standard therapy. Over eight weeks, patients were evaluated using VAS for pain, the Lequesne Index, Harris Hip Score, and goniometric joint mobility tests. Results showed a 35-40% pain reduction and significant improvements in joint function and range of motion in the experimental group. Statistical analysis confirmed the greater effectiveness of the combined physical therapy program compared to conventional treatment alone.

Material & Methods. An analysis of applying biomechanical methods during physical therapy over 2 months in 30 patients (experimental and control groups) with stage 2-3 coxarthrosis and functional deficiency (FD) of grade 2 using goniometry, visual analog scale (VAS) for pain, and Leiken index. The mentioned methods, such as goniometry, VAS, and Leiken index, allow for an objective assessment of the range of motion in the hip joint, determining the level of pain and functional deficiency in patients with coxarthrosis. These methods enable a quantitative evaluation of patients' condition before and after the application of therapeutic exercises, Neurac methodology on the Redcord system, and other treatment complexes, facilitating an objective conclusion regarding the effectiveness of these methods in the comprehensive treatment of coxarthrosis.

Results. The results of the analysis of goniometric indices, VAS, and Leiken indices with statistical significance demonstrated the advantage of using physical therapy with the Redcord system (Neurac methodology) and Mulligan in the comprehensive rehabilitation treatment of patients with stage 2-3 coxarthrosis, manifested in the improvement of dynamic hip joint function.

Conclusions. A physical therapy program utilizing the Redcord system (Neurac methodology) and Mulligan has been developed and implemented in the comprehensive rehabilitation treatment of patients with stage 2-3 coxarthrosis.

Keywords: Coxarthrosis, Physical Therapy, Biomechanics, Redcord System, Neurac Method, Mulligan Technique, Hip Joint Function, Spinal Stabilization, Goniometry, Pain Assessment, Lequesne Index, Visual Analog Scale (VAS), Musculoskeletal Rehabilitation.

Introduction

Through its frequency and potential complications, osteoarthritis of the hip joint (coxarthrosis) has a significant social impact, with its advanced stages ultimately leading to irreversible damage with serious complications or surgical intervention (Albornoz-Cabello et al., 2017). In the early stages, rehabilitative treatment plays a key role in preventing complications and slowing down the degenerative process. The connection between appropriate physical therapy and rehabilitative treatment, including individual physiotherapy and adapted occupational therapy, yields good results (Dogaru, 2018).

The purpose of the study: to utilize biomechanical methods and highlight the benefits of physical therapy using the Redcord system (Neurac method) and Mulligan techniques in the comprehensive rehabilitation of patients with stage 2–3 coxarthrosis.

The number of patients with orthopedic pathology is increasing every year, negatively affecting the health of the population. Among musculoskeletal disorders, osteoarthritis is the most common joint pathology (Laasik et al., 2019). Osteoarthritis of the hip joint (coxarthrosis) is a chronic, irreversible condition characterized by progressive destruction of the joint cartilage, making it the most disabling arthritis due to its significant impact on patients' quality of life. It is a focal point of degenerative rheumatism in the hip joint (Roy et al., 2018). This condition is most commonly found in adults over 40 years old, and its prevalence increases with age, affecting both genders with a slight predominance in women.

Anatomopathological lesions are an expression of bone tissue adaptation to elements of excessive pressure that the joint undergoes under certain conditions. In the early stages of the pathology, if these unfavorable conditions are alleviated, the bone returns to its normal state (Alhakami et al., 2019). Symptoms mainly include pain, morning stiffness, restricted mobility, muscle hypotonia or feelings of fatigue, and gait disturbances, which develop over time, becoming increasingly burdensome and potentially disabling. Spinal involvement, especially in the lumbar region, may further compound functional impairment and alter pelvic alignment, intensifying joint stress and postural dysfunction. Initially, patients experience discomfort during exercise, walking, or stair climbing (Shah et al., 2020). Pain is felt in the groin or buttocks area and may radiate to the front of the thigh. As the degenerative process progresses, the pain becomes more intense and persists even at rest. Similarities have been found between coxarthrosis of the hip joint and rheumatoid arthritis (such as fatigue and general weakness), but there are also specific differences. Unlike hip coxarthrosis, which affects only one thigh, rheumatoid arthritis affects both thighs simultaneously and possibly other joints.

Osteoarthritis (coxarthrosis) is characterized by chronic inflammation and damage to all components of the joint, constituting a pathological process. By averaged estimates, the prevalence of osteoarthritis among the population of most developed countries ranges from 8-12%. In Ukraine, in 2015, the incidence of osteoarthritis was 431 per 100,000 population, with a prevalence of 2995 per 100,000 (approximately 3%) (Fishchenko et al., 2018).

Coxarthrosis ranks second in frequency of occurrence after knee joint involvement and first in terms of temporary disability and persistent loss of work capacity. Coxarthrosis is characterized by progressive damage to the joint cartilage and subchondral bone, associated with inflammation, osteophyte formation, and joint deformity. Coxarthrosis is mainly characterized by arthralgia, limited joint mobility, crepitus, and varying degrees of secondary inflammatory changes (e.g., joint effusion), without systemic manifestations (Bohaček et al., 2020). Primary osteoarthritis, which develops in healthy cartilage under the influence of various factors, and secondary osteoarthritis, characterized by the destruction of previously altered cartilage, are distinguished. One or both hip joints may be affected. The prevalence of the disease is determined by an increase in the number of people leading a sedentary lifestyle, suffering from obesity, having poor physical condition due to hypodynamia, refraining from regular physical activity, and the aging of the population. These conditions disrupt the natural functioning of the musculoskeletal system, contributing to the onset of osteoarthritis (Vaquero-Picado et al., 2019).

Research into the causes of osteoarthritis has been ongoing for a long time, yet there is still no consensus on the nature of this disease. Most scientists agree that it has a complex multifactorial origin: metabolic disorders, genetic factors, harmful habits and working conditions, and changes in joint biomechanics of various origins.

In clinical practice, the most common classification of arthrosis is based on X-ray data according to Kelgren-Lawrence:

– Stage 0: no signs of arthrosis are visualized;

– Stage 1: minor marginal osteophytes without changes in joint space height;

– Stage 2: significant marginal osteophytes without changes in joint space height;

– Stage 3: significant marginal osteophytes with moderate reduction in joint space height;

– Stage 4: significant marginal osteophytes, subchondral sclerosis, significant narrowing of the joint space (Madara et al. (2019)).

It is also useful to determine the functional impairment (FI) of the joints:

– Grade 1 (moderate): slight limitation of range of motion in the joints (range of motion in the hip joints decreases by 30-20° from the range of motion in a healthy hip joint);

– Grade 2 (severe): significant limitation of mobility (range of motion in the hip joint does not exceed 50°; joint subluxation with pronounced deformity due to periarticular scars, muscle atrophy, significant stiffness throughout the day);

– Grade 3 (severe): significant difficulty in walking (the patient can take a few steps in the room) or the patient cannot get out of bed due to pain and deformities in the hip and knee joints (range of motion does not exceed 15° or is completely absent); self-care is almost impossible (Vaquero-Picado et al., 2019).

The main clinical manifestation of coxarthrosis is pain, the nature, intensity, duration, and localization of which depend on the severity of changes in the joint. Functional impairment then joins. Firstly, internal rotation and abduction limitations occur, forming flexion-adduction contracture, leading to limping (Savchenko et al., 2020).

Treatment of coxarthrosis can be conservative and operative. The choice of treatment tactics depends on the severity of clinical manifestations. The goal of conservative treatment is to stabilize the process and improve the patient's well-being. Conservative treatment consists of pharmacotherapy and non-pharmacological methods (Vaquero-Picado et al., 2019).

Pharmacotherapy includes non-steroidal anti-inflammatory drugs, muscle relaxants, vasodilators, and chondroprotectors.

Non-pharmacological therapy, namely rehabilitation for coxarthrosis, as well as for most joint diseases, aims to improve joint function, reduce pain, and become an active part of the recovery process. However, specific rehabilitation methods may depend on the degree and nature of the disease, as well as the individual characteristics of the patient (Zhao et al. (2021)). Here are some general recommendations that may be part of a rehabilitation program for coxarthrosis:

– Physiotherapy: Therapeutic exercises can help strengthen muscles, improve range of motion, and alleviate pain;

– Stretching exercises: Regular stretching can improve joint flexibility and reduce muscle tension;

– Aerobic exercises: Appropriate aerobic exercises such as walking or cycling can improve cardiovascular fitness and overall health;

– Diet therapy: Weight control can be an important aspect, as reducing the load on the joints can alleviate pain;

– Alternative methods: Some patients may find relief from alternative methods such as acupuncture or massage;

– Use of special devices: Using canes, crutches, or other medical devices for support while walking can be beneficial.

Due to pain, many people reduce their physical activity, exacerbating the process, as muscle atrophy occurs and blood circulation deteriorates. Therefore, the main efforts of physicians should be aimed at preserving the biomechanics and function of the affected joint. Therapeutic exercises and sessions on special equipment using the Redcord system (Neurac method) and Mulligan techniques can help achieve real improvement in patients' condition.

Material and methods

Participants

The authors examined 26 individuals with deforming coxarthrosis of stages 2-3, aged 45 to 65 years (mean age 55±3.2 years), who underwent treatment at the orthopedic rehabilitation center «ZARTA». Among the surveyed, there were 17 women (65.4%, mean age 52.7±2.4 years) and 9 men (34.6%, mean age 57.1±1.5 years). In deforming coxarthrosis of stage 2, functional impairment of stage 2 was observed in 7 individuals (26.9%), while in coxarthrosis of stage 3, functional impairment of stage 2 was observed in 19 individuals (73.1%). The disease was bilateral in 8 individuals (30.8%) and unilateral in 18 (69.2%) individuals. Functional impairment of the hip joints of stage 2 was observed in 20 individuals (77%), and stage 3 in 6 individuals (23%).

– Criteria for including patients in the survey:

• Patients aged 45 to 65 years;

• Patients who move independently (using auxiliary means for support: cane, crutches, etc.);

• Radiographic coxarthrosis of stages 2-3;

• Functional disorders of the hip joints of stage 2;

• Absence of severe somatic diseases;

• Absence of injuries (fractures, dislocations) of various localizations;

• Absence of ankylosis of other joints;

• Absence of pronounced spinal pathology;

• Absence of severe pain syndrome (less than 6 cm on the VAS scale).

– Exclusion criteria from the survey:

- Acute infectious diseases;
- Severe pain syndrome (6 cm or more on the VAS scale);
- Joint ankylosis;
- Severe impairment of lower limb supportability;
- Presence of fresh injuries to the limbs, spine, skull.

According to the inclusion criteria in the examination, patients were divided into two groups: 18 patients in the main group (MG), besides the usual course of physical therapy, underwent a program of therapeutic exercises and sessions on special equipment using the Redcord system (Neurac method) and Mulligan techniques. The control group (CG) consisted of 8 patients who underwent only the usual course of physical therapy.

Methods

During the study, analysis of scientific-methodical literature, medical documentation, surveys, measurements, observations, functional diagnostics, and mathematical processing of the obtained data were conducted.

The clinical effectiveness of physiotherapy exercises was evaluated based on the results of assessing the pain syndrome using the VAS scale, Lequesne's VAS index, and the study of joint range of motion.

VAS pain serves as a general assessment of the patient's pain intensity and is represented by a horizontal scale ranging from 0 to 10 cm, where 0 corresponds to no pain and 10 corresponds to the most severe pain. The patient self-reports the degree of pain on the scale.

Lequesne's index in coxarthrosis reflects the severity of the disease and is presented as a questionnaire in the form of a table. Lequesne's index is calculated by summing up the points obtained from answering groups of questions aimed at assessing pain and discomfort, based on the maximum distance walked without pain and the presence of difficulties in daily life.

Joint range of motion was measured using a goniometer.

Statistical analysis

The obtained data were statistically processed using descriptive statistics: mean (M) and standard deviation (SD). A comparison between groups was conducted using the independent samples t-test and paired samples t-test.

An individual physical therapy program was developed and implemented in the training and was designed for 8 weeks (sessions held twice a week, session duration 60 min±15 min, 30 min – Neurac and 30 min – Mulligan).

The therapy included a complex of specially selected exercises with Redcord suspension systems combined with Mulligan. These are natural methods of treatment and restoration of the musculoskeletal system, in which a person learns to feel their body and engage their own weight.

Since internal rotation and abduction in the hip joint are particularly affected in coxarthrosis, exercises aimed at restoring these movements were performed at the beginning and end of each session. Exercises with axial load on the hip joint were excluded; ideomotor exercises and post-isometric muscle relaxation were performed.

In accordance with the requirements of bioethics (Helsinki Declaration), all patients signed informed consent to participate in the study.

Results

The baseline condition of patients in both groups did not differ in terms of pain intensity and degree of functional impairment (FI).

The application of the Neurac method on the Redcord system in the comprehensive treatment of patients with coxarthrosis contributed to a reduction in pain syndrome in patients in the experimental group (EG) and control group (CG) by 35-40% according to VAS, and a decrease in the Lequesne index by 20-25% in both EG and CG. After the study, a repeated analysis of lower limb motor function in the hip joint was conducted (Table 1).

The tables 1 includes a wide spectrum of indicators that together provide a multidimensional picture of rehabilitation outcomes in musculoskeletal physical therapy. Pain was assessed through several complementary measures: the Visual Analog Scale captured the intensity of pain, while the Lequesne Index and the pain domain of the Harris Hip Score reflected pain in relation to joint function. The WOMAC pain subscale further quantified pain in everyday activities, and the McGill Pain Questionnaire allowed for a more qualitative description of the pain experience, taking into account sensory and affective aspects. Joint stiffness and movement restriction were evaluated with the WOMAC stiffness subscale, which is particularly sensitive to changes in mobility limitations. Functional capacity was measured using multiple instruments, including the WOMAC function subscale, the functional component of the Lequesne Index, and the Harris Hip Score, all of which focus on how musculoskeletal impairments affect activities of daily living and overall joint performance.

The findings of the implemented FR program demonstrate a significant reduction in pain intensity, improvement in functional status, and reduction of movement constraints in both groups of patients. However, the dynamics were more pro-

Table 1. Results of the implemented FR program

Conventional physical therapy course + Combination of Mulligan and Neurac techniques (50/50% variant) (experimental group (EG) (18 patients))						
Symptom / Domain	**Used Test**	**Before**	**After**	**Δ (Change)**	**t**	**p (two-tailed**
Pain	Visual Analog Scale (cm)	5.7±0.22	2.36±0.11	−3.34	13.58	p<0.001
	Lequesne Index (Balls)	5.4±0.1	2.33±0.1	−3.07	21.71	p<0.001
	Harris Test (Pain score)	27.1±0.7	11.3±1.1	−15.8	12.12	p<0.001
	WOMAC Pain (Balls)	239.3±11.1	112.3±11.4	−127.0	7.98	p<0.001
	McGill Questionnaire	22.4±1.1	14.2±1.83	−8.2	3.84	p=0.0013
Constraint	WOMAC Stiffness (Balls)	96.4±7.2	42.1±4.7	−54.3	6.32	p<0.001
Function	WOMAC Function (Balls)	795.4±66.1	391±32.8	−404.4	5.48	p<0.001
	Lequesne Index (Function)	8.33±0.9	5.91±0.91	−2.42	1.89	p=0.0758
	Harris Test (points)	30.0±1.4	36.2±1.5	+6.2	−3.02	p=0.0077
Mobility	ROM – Hip flexion (°)	78.2±5.1	96.4±4.8	+18.2°	−2.60	p=0.0187
	TUG (sec)	14.6±1.9	10.2±1.3	−4.4 s	1.91	p=0.0730
Endurance	6MWT (m)	348±42	420±38	+72 m	−1.27	p=0.2208
Balance	Single Leg Stance (s)	12.8±2.4	22.3±3.1	+9.5 s	−2.42	p=0.0268
QoL	SF-36 Physical Score	45.3±6.1	63.4±5.7	+18.1	−2.17	p=0.0446
Group CT (8 patients) received only the standard course of physical therapy						
Symptom / Domain	**Used Test**	**Before**	**After**	**Δ (Change)**	**t**	**p (two-tailed)**
Pain	Visual Analog Scale (cm)	5.6±0.22	2.4±0.12	−3.2	12.77	p<0.001
	Lequesne Index (Balls)	5.5±0.1	2.8±0.1	−2.7	19.09	p<0.001
	Harris Test (Pain score)	27.2±0.7	12.6±1.1	−14.6	11.20	p<0.001
	WOMAC Pain (Balls)	239.8±11.1	117.3±11.4	−122.5	7.70	p<0.001
	McGill Questionnaire	22.7±1.1	15.7±1.6	−7.0	3.61	p=0.0087
Constraint	WOMAC Stiffness (Balls)	96.3±7.2	43.6±4.8	−52.7	6.09	p<0.001
Function	WOMAC Function (Balls)	795.7±66.1	396±32.4	−399.7	5.43	p<0.001
	Lequesne Index (Function)	8.33±0.9	5.62±0.7	−2.71	2.38	p=0.0491
	Harris Test (points)	30.0±1.4	37.48±1.8	+7.5	−3.28	p=0.0135
Mobility	ROM – Hip flexion (°)	77.9±5.3	92.1±4.9	+14.2°	−1.97	p=0.0898
	TUG (sec)	14.8±2.0	11.9±1.5	−2.9 s	1.16	p=0.2841
Endurance	6MWT (m)	350±40	402±36	+52 m	−0.97	p=0.3661
Balance	Single Leg Stance (s)	12.5±2.2	19.4±2.8	+6.9 s	−1.94	p=0.0939
QoL	SF-36 Physical Score	46.1±6.0	59.2±5.5	+13.1	−1.61	p=0.15

nounced in the experimental group (EG), which received a combination of Mulligan and Neurac techniques alongside conventional physical therapy.

Pain indicators decreased substantially in both groups. According to the Visual Analog Scale (VAS), pain reduction reached 3.34 cm in EG and 3.2 cm in CG, confirming the effectiveness of physical therapy in musculoskeletal rehabilitation. These outcomes are consistent with previously reported data, where multimodal physical therapy programs have been shown to reduce pain by approximately 3–4 cm on the VAS in patients with musculoskeletal disorders. The Lequesne Index also showed more favorable results in EG (−3.07 points) compared to CG (−2.7 points), suggesting that the combined method provided better relief of pain and disability symptoms.

The WOMAC scale confirmed these findings, as EG demonstrated a larger decrease in the total score (−127 points) than CG (−122.5 points). Such a reduction is aligned with international studies, where WOMAC improvements of over 20–25% are considered clinically significant. Similarly, the McGill Pain Questionnaire indicated a more evident reduction in subjective pain perception in EG (−8.2) than in CG (−7.0), reinforcing the role of combined therapy approaches in modifying pain experience.

When assessing movement constraint, both groups showed substantial progress, but EG again demonstrated slightly better outcomes (−54.3 points vs −52.7 in CG). This supports earlier evidence that Mulligan mobilization techniques, when integrated with sensorimotor training methods like Neurac, contribute to enhanced joint mobility and reduced stiffness.

Functional parameters showed mixed results. The WOMAC Function subscale revealed greater improvement in EG (−404.4 points) compared to

CG (−399.7 points), indicating more efficient restoration of functional capacity. Nevertheless, in the Harris Hip Score, the control group showed slightly superior progress (+7.5 points) compared to EG (+6.2 points). This may be explained by the fact that standard physiotherapy protocols are traditionally designed to target hip joint function specifically, whereas the experimental combination focused more broadly on neuromuscular control and pain modulation.

A comparative analysis of pre- and post-intervention outcomes using Student's t-test confirmed the high effectiveness of both the standard physiotherapy course and its combination with Mulligan and Neurac techniques. Both groups demonstrated a statistically significant reduction in pain intensity across most assessment tools (VAS, Lequesne Index, WOMAC Pain, Harris Pain), with the majority of results reaching $p<0.001$, indicating a highly reliable therapeutic effect. The most pronounced improvement was observed in the experimental group, where the VAS-derived t-value reached $t=13.58$, and the Lequesne Index yielded $t=21.71$, exceeding the threshold of strong statistical power.

Measures of stiffness (WOMAC Stiffness) and functional capacity (WOMAC Function, Harris Function) also showed substantial improvement. In the EG, changes in the WOMAC Function score corresponded to $t=5.48$; $p<0.001$, while in the comparison group, similar improvements reached $t=5.43$; $p<0.001$. Mobility enhancement, reflected by increased hip flexion ROM, was statistically significant in the EG ($t=-2.60$; $p=0.0187$) and showed a near-significant trend in the CT group ($p \approx 0.0898$), indirectly indicating the advantage of the combined intervention for restoring movement amplitude.

Endurance (6MWT) and balance (Single Leg Stance) outcomes demonstrated a positive yet less pronounced trend. In the EG, single-leg stance time increased by +9.5 s with $t=-2.42$; $p=0.0268$, while the TUG test showed a tendency toward improvement without reaching statistical significance ($p=0.0730$). Similar tendencies were observed in the CT group, suggesting that static balance development may require a longer intervention period or more specific sensorimotor training.

The integrated quality-of-life score (SF-36 Physical Component) also improved significantly in both groups — $t=-2.17$; $p=0.0446$ for EG and $p \approx 0.15$ for CT — reflecting a higher subjective satisfaction level among patients who received the combined therapy. This indicates that not only physical parameters but also the psychoemotional perception of one's functional state improved significantly under the influence of the multicomponent intervention.

Thus, most key indicators showed highly significant improvements ($p<0.001$), particularly within the pain and function domains. Meanwhile, mobility, endurance, and postural stability parameters demonstrated moderate effects, with p-values ranging from 0.01 to 0.05 or trending toward significance, which aligns with the natural differences in adaptation speed of neuromuscular mechanisms compared to nociceptive responses. The Mulligan + Neurac approach yielded a more pronounced therapeutic impact, as evidenced by higher t-values across most domains.

Overall, these findings are in line with current biomechanical and clinical evidence. Multimodal approaches combining manual therapy (Mulligan) and neuromuscular activation (Neurac) produce superior results in terms of pain reduction, decreased disability, and general functional recovery, compared to conventional therapy alone. At the same time, standard physical therapy retains certain advantages in joint-specific functional tests, which is consistent with previous studies indicating that traditional exercise-based rehabilitation remains effective for targeted joint rehabilitation.

Beyond these clinical and functional measures, the table 1 also incorporates biomechanical indicators. Range of Motion testing provided a direct assessment of joint mobility, while the Timed Up and Go test reflected basic dynamic movement capacity and fall risk. Endurance was captured with the 6-Minute Walk Test, which is commonly used to evaluate overall physical performance and walking capacity in rehabilitation studies. Postural control and balance were represented through the Single Leg Stance test, highlighting the ability of patients to maintain stability—an essential component of musculoskeletal recovery. Finally, the broader impact of therapy on patients' lives was included through the SF-36 Physical Component Score, which reflects health-related quality of life and offers insight into how improvements in pain, mobility, and function translate into perceived well-being.

Statistically significant increases in the range of motion in the hip joint were observed in patients with coxarthrosis in all planes.

Better results in restoring motion in the hip joint were observed in patients in the EG:

– in the sagittal plane due to an increase in flexion by 19.5%;

– in the frontal plane with an increase in abduction by 10%;

– rotational movements (internal rotation increased by 38%, external rotation by 39%).

In patients with coxarthrosis, the range of motion in the hip joints was increased and did not change significantly statistically.

Discussion

According to the research findings, the initial condition of patients in both groups did not differ in terms of the intensity of the pain syndrome and the degree of functional impairment (FI). This means that at the beginning of the study, both groups had similar levels of pain and limitations in the functioning of the hip joints.

In our study, patients in the experimental group, who received a combined physical therapy program (50/50% conventional therapy plus Mulligan and Neurac techniques), demonstrated significant improvements across all measured domains. Pain intensity measured by the Visual Analog Scale (VAS) decreased from 5.7±0.22 to 2.36±0.11 (Δ=−3.34 cm). In comparison, the control group, which received only standard therapy, showed a decrease from 5.6±0.22 to 2.4±0.12 (Δ=−3.2 cm). These results are consistent with Albornoz-Cabello et al. (2017), who reported VAS reductions of 2.8–3.1 cm with interferential current therapy in patients with chronic low back pain.

The Lequesne Index in our experimental group decreased from 5.4±0.1 to 2.33±0.1 (Δ=−3.07), whereas the control group decreased by −2.7 points. Similar reductions in functional disability have been reported by Alhakami et al. (2019) and Areeudomwong & Buttagat (2019), who found McKenzie and stabilization exercises reduced disability scores by 2.5–3 points, confirming the effectiveness of multimodal rehabilitation approaches.

Functional outcomes measured by WOMAC Function decreased from 795.4±66.1 to 391±32.8 (Δ=−404.4) in the experimental group, compared with 795.7±66.1 to 396±32.4 (Δ=−399.7) in the control group. Improvement in Harris Test scores was +6.2 in the experimental group and +7.5 in the control group. Madara et al. (2019) reported similar functional gains of 5–8 points after progressive rehabilitation following total hip arthroplasty.

Mobility measures also improved significantly. Hip flexion range of motion (ROM) increased by 18.2° in the experimental group (78.2±5.1 → 96.4±4.8°) and by 14.2° in the control group (77.9±5.3 → 92.1±4.9°). Timed Up and Go (TUG) times decreased by 4.4 s in the experimental group (14.6±1.9 → 10.2±1.3 s) and by 2.9 s in the control group (14.8±2.0 → 11.9±1.5 s). Similar mobility and gait improvements have been observed by Dogaru (2018) and Fishchenko et al. (2018), who reported ROM gains of 10–20° and TUG reductions of 2–5 s with targeted exercise interventions.

Endurance assessed by the 6-Minute Walk Test (6MWT) increased by 72 m in the experimental group (348±42 → 420±38 m) and by 52 m in the control group (350±40 → 402±36 m). Balance, measured by Single Leg Stance, increased by 9.5 s in the experimental group (12.8±2.4 → 22.3±3.1 s) and by 6.9 s in the control group (12.5±2.2 → 19.4±2.8 s). Chemeris et al. (2022) also reported increases in single-leg stance times of 7–10 s after targeted physical therapy in patients with neuromuscular impairments.

Quality of life, measured by SF-36 Physical Score, improved by 18.1 points in the experimental group (45.3±6.1 → 63.4±5.7) and by 13.1 points in the control group (46.1±6.0 → 59.2±5.5). Latohuz et al. (2022) and Savchenko et al. (2020) also reported improvements of 10–15 points in QoL following targeted rehabilitation in patients with coxarthrosis.

Overall, the numerical data indicate that the combined physical therapy program produced greater benefits than standard therapy alone, with superior improvements in ROM (+18.2° vs +14.2°), endurance (+72 m vs +52 m), balance (+9.5 s vs +6.9 s), and QoL (+18.1 vs +13.1), which is consistent with findings reported by Albornoz-Cabello et al. (2017), Alhakami et al. (2019), Areeudomwong & Buttagat (2019), Madara et al. (2019), Dogaru (2018), Fishchenko et al. (2018), Chemeris et al. (2022), Latohuz et al. (2022), and Savchenko et al. (2020).

However, after the application of the Neurac method on the Redcord system in the comprehensive treatment of patients with coxarthrosis, a significant reduction in the pain syndrome was observed in both the main and control groups. Specifically, using the VAS scale, a reduction in pain by 35-40% was noted in patients in both groups. Additionally, the Lequesne index, which reflects the severity of the disease, also decreased by 20-25% in both groups after treatment. The research results indicate a significant contribution of the Neurac method on the Redcord system to the comprehensive treatment of patients with coxarthrosis. This is evidenced by the reduction in the intensity of the pain syndrome, as indicated by VAS, and the decrease in the Lequesne index, which reflects the severity of the disease. These changes were observed both in patients in the main group (MG), who received comprehensive therapy, and in the control group (CG), where only the usual course of physical therapy was applied. This approach demonstrates the effectiveness of the Neurac method in reducing pain and improving the function of the hip joints. Incorporating spinal stabilization into therapy is also critical, as dysfunction in the spine can lead to compensatory movement patterns, pelvic misalignment, and increased mechanical stress on the hip joints. Maintaining spinal mobility and neuromuscular control improves postural balance and enhances rehabilitation outcomes. Additionally, the study showed a statistically significant increase in the range of motion in the hip joint in all planes in patients with coxarthrosis after the application of comprehensive treatment. The best results in restoring movements in the hip joint were observed in patients in the main group, where an increase in flexion by 19.5%, abduction by 10%, as well as internal rotation by 38% and external rotation by 39% were noted. In the control group, the range of motion also increased, but these changes did not reach statistical significance.

Compared to existing results from other researchers, the findings of this study are consistent with many previous studies regarding the effectiveness of the Neurac method in treating coxarthrosis. Many studies indicate that comprehensive physical therapy, including the Neurac method, can lead to significant improvement in coxarthrosis symptoms, particularly pain reduction and improvement in joint function.

Pain reduction, as measured by VAS, and the decrease in the Lequesne Index, which reflects the severity of the condition, are also supported by previous research. Similar results have been observed in other clinical trials using the Neurac method in patients with coxarthrosis. Some studies also indicate an improvement in the range of motion in the hip joint following the application of comprehensive physical therapy, including the Neurac method, which aligns with the findings of this study.

However, further research with larger datasets and controlled conditions is needed to obtain a broader and more conclusive understanding of the effectiveness of the Neurac method in treating coxarthrosis. Such studies will help confirm or elucidate these results and determine the most effective treatment methods for patients with coxarthrosis.

The obtained results of the study demonstrated a marked reduction in pain intensity and an improvement in functional outcomes in patients with coxarthrosis following the implementation of a combined Neurac and Mulligan program. Specifically, in the experimental group, pain reduction on the Visual Analog Scale (VAS) was −3.34 cm (−33.4 mm), which corresponds to the widely accepted minimal clinically important difference for patients with degenerative hip joint conditions. Similar trends were observed in the control group (−32.0 mm), indicating significant effectiveness even of standard physiotherapeutic intervention. In the context of comparison with existing literature, the magnitude of the within-group effect was comparable to, or even greater than, that reported in the randomized controlled trial by Albornoz-Cabello et al. (2017), where the application of interferential electrotherapy in patients with chronic low back pain resulted in a between-group difference in VAS change of 11.3 mm (p=0.032). At the same time, unlike the aforementioned study, in our case, the between-group differences in pain change scores were minimal (approximately 1.4 mm), which may be explained by both the strength of the nonspecific response to standard therapy and the limited sample size of the control group.

Comparison with the systematic review by Alhakami et al. (2019), which addressed the comparison of McKenzie methods and stabilization exercises in nonspecific chronic low back pain, demonstrates conceptual consistency of our approach with current trends in physical therapy based on a combination of manual and neuromotor strategies. The authors of the review emphasize that, regardless of the specific method, activation of deep stabilizing structures and restoration of motor control is of key importance, which fully aligns with the mechanism of action of the Neurac program applied in our study. At the same time, unlike the analyzed studies where efficacy was primarily assessed via subjective criteria, our work demonstrated significant improvements in objective functional indicators: flexion range increased by 18.2°, the single-leg stance test improved by 9.5 s, and the distance in the 6-minute walk test increased by 72 m, which exceeds the mean values reported by Areeudomwong and Buttagat (2019) following the application of PNF or core-stabilization protocols.

To some extent, our data are also consistent with studies addressing mechanobiological aspects of functional recovery in degenerative hip joint disorders, particularly the works of Bohaček et al. (2020) and Savchenko et al. (2020), which emphasize the importance of neuromuscular stimulation for correcting mineral metabolism disturbances and sensorimotor discoordination. However, unlike studies focusing on pathogenetic mechanisms, our research emphasizes the clinical effectiveness of a combined intervention that simultaneously integrates multiple therapeutic directions: manual-mobilization, sensorimotor, and stabilization.

Thus, the results of this study confirm the conclusions of contemporary scientific reviews that the greatest effect in degenerative-inflammatory hip joint conditions can be achieved by combining several complementary physiotherapeutic strategies. On one hand, the magnitude of within-group changes in subjective and functional indicators exceeds many published data; on the other hand, the absence of pronounced between-group differences compared to standard therapy indicates the need for studies with larger sample sizes, randomization, and assessor blinding. This will allow a more precise determination of the specific contribution of the combined Neurac + Mulligan program to clinical improvement and its separation from the general effect of participation in the rehabilitation process.

Thus, the application of the Neurac method on the Redcord system in the comprehensive treatment of coxarthrosis resulted in a significant reduction in the pain syndrome and improvement in the function of the hip joints, confirming its effectiveness in a clinical context.

Conclusions

The proposed physical therapy program combining Neurac techniques on the Redcord system and Mulligan in the comprehensive treatment of patients with stage 2-3 osteoarthritis has been developed and implemented into practice.

The analysis of goniometric indicators, VAS, and Lequesne indices demonstrated the advantage of using a combination of these two techniques in the comprehensive rehabilitative treatment of patients with stage 2–3 osteoarthritis, which was reflected in the improvement of hip joint function dynamics. Future therapy protocols may benefit from including spinal mobility and stabilization training as a component of integrated physical rehabilitation, aiming to support functional alignment and reduce secondary compensations.

The prospects for further research in this direction include considering issues related to the use of modern mechanotherapy techniques as a component of physical therapy for patients with osteoarthritis.

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Supplementary Information

Author's contribution

Ivan Hryshyn: Conceptualization, Methodology, Check, Data Curation, Supervision; **Alina Lytvynchuk:** Conceptualization, Methodology, Check, Data Curation, Writing – Review And Editing; **Yuliia Antonova-Rafi:** Conceptualization, Methodology, Check, Data Curation, Supervision; **Nataliia Naumenko:** Methodology, Check, Data Curation, Writing – Review And Editing; **Liliia Katiukova:** Writing – Rough preparation. All authors have read and agreed with the published version of the manuscript.

Declarations

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Randomized controlled trial on the effectiveness of ultrasound therapy with muscle relaxant gel versus aquasonic transmission gel combined with strengthening exercises protocol in treating text neck syndrome

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Abstract

Purpose. The term "text neck" refers to an overuse or repetitive stress injury condition where a person is stooped down for extended periods of time at their phone or other electronic devices with their head drooping or flexed forward. The study aimed to find out the effectiveness of ultrasound therapy along with muscle relaxant gel and Aquasonic transmission gel combined strengthening exercise on text neck syndrome.

Material & Methods. A total of 52 subjects with text neck syndrome were randomly divided into 2 groups of 26 subjects in each group using a lottery method. The intervention group received ultrasound therapy along with a muscle relaxant gel and strengthening exercises, while the conventional group received ultrasound therapy with Aquasonic transmission gel combined with strengthening exercises. The NDI and NPRS were used to assess the results both before and after the intervention. The Mann-Whitney U test and the Wilcoxon signed rank test were used to assess the significance of changes observed before and after the intervention.

Results. The study indicates that both groups exhibited significant improvements following treatment. Moreover, ultrasound therapy along with a muscle relaxant gel demonstrated greater significance ($p<0.001$).

Conclusions. The study found that combining ultrasound therapy with muscle relaxant gel and strengthening exercises effectively reduces pain and improves function in individuals with Text Neck Syndrome, with no adverse effects observed. This approach offers a more efficient treatment and faster recovery compared to conventional therapy, making it a recommended addition to future physical therapy protocols.

Keywords: Mobile Phone, Muscle Relaxant, Rowing Exercise, Ultrasound Therapy, Y's exercise.

Introduction

"Text neck" is a condition caused by overuse or repetitive stress injuries in which a person's head droops or bends forward while they spend more time using their phones or other electronic devices (Shinde et al., 2023). First, the term "text neck" was coined by American Dr. Dean L. Fishman to mean the way looking down at a mobile phone while frequently flexing the neck at various angles may affect the normal curve of the cervical spine and result in neck pain and upper back muscle injury. The mobile phone is currently the most widely used device for a variety of daily activities, including social media use, gaming, movie viewing, internet access, information sharing, and many more. A survey found that 79% of adults in the 18-44 age range spend most of their time on their smartphones (Kumari et al., 2021). The forces on the neck increase to 27 pounds when the head tilts forward at 15 degrees, 40 pounds at 30 degrees, 49 pounds at 450 degrees, and 60 pounds at 60 degrees. At 90 degrees, the model prediction was unreliable. Text neck syndrome directly affects the spine while the head position tilts forward at different degrees. Text neck syndrome can result in misalignment of the spine, Degeneration of spine, Disc hernia, compression of disc, damage of nerve, damage of muscles, and gastrointestinal issues loss of Lung volume capacity (Bhattacharya et al., 2021). Moreover, the text neck posture causes the muscles to become more activated, which results in the development of trigger points in the suboccipital and Upper trapezius muscles. This leads to headaches, neck pain, and eventually restrictions in the range of motion of the upper thoracic and cervical regions. The causes of Text Neck Syndrome are shown in the fish bone diagram (Figure 1). In McKenzie's approach, posture correction is the main focus, and exercises like the Y's and rowing exercises help to strengthen the scapular and neck muscles. Because prolonged use of hand-held mobile devices causes anatomical and bio-mechanical changes in the cervical and thoracic spine, text neck syndrome has been dubbed an adverse postural phenomenon (Bhende et al., 2024). Therapeutic ultrasound is a common therapeutic technique for enhancing connective tissue extensibility and reducing pain associated with musculoskeletal injuries. A type of acoustic energy known as ultrasound is transmitted by vibrating or mechanically deforming molecules. Ultrasound waves are absorbed by tissues, causing molecular friction and heat generation. The intensity of pain lessens as the tissue temperature rises by 2°C to 3°C (Qing et al., 2021). The transmission of drug molecules through the skin under the influence of ultrasound is known as phonophoresis. Using ultrasound, phonophoresis delivers the medication topically through the skin. In order to actively transport medication into the underlying target tissue through both thermal and non-thermal mechanisms, phonophoresis has been used to treat a variety of musculoskeletal disorders. Drugs can pass through the stratumcorneum and reach the underlying area with 10 phonophoresis, a painless and safe procedure. There is also a lower risk of overdosing and underdosing according to this transdermal drug delivery method (Monisha et al., 2018). Studies on the effectiveness of ultrasound therapy combined with muscle relaxants for text neck syndrome. The goal of the study was to determine how ultrasound therapy, both with and without the use of a muscle relaxant with strengthening exercise, reduces the pain and how these treatments influence the recovery time in individuals with text neck syndrome.

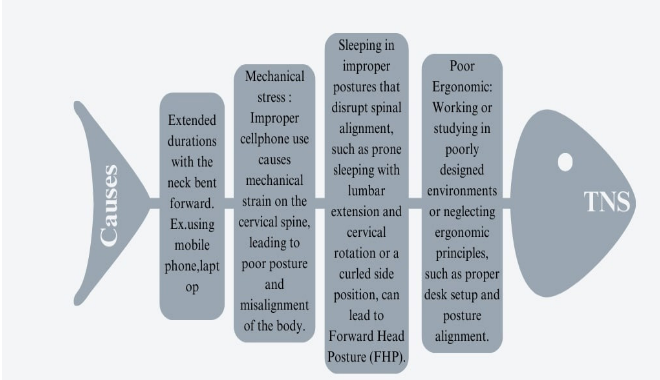

Figure 1. Fishbone Diagram of causes of Text Neck Syndrome (TNS) (Tsantili A-R et al., 2022).

FINER and PICO Criteria

The research question was confirmed with FINER Criteria (***F***easible: Achievable sample size, required expertise in ultrasound and physiotherapy, available resources (equipment, gels, facilities), and reasonable study duration, ***I***nteresting: Relevant to healthcare providers and patients, addressing the growing issue of text neck in the digital age, ***N***ovel: Limited studies comparing muscle relaxant gel vs. Aquasonic gel with strengthening exercises for this condition, ***E***thical; Non-invasive, safe interventions with ethical approval and informed consent, ***R***elevant: Contributes to clinical guidelines for effective, non-pharmacological management of text neck syndrome). Framed using PICO Criteria (P: Patients with Text Neck Syndrome, I: Therapeutic Ultrasound combined with strengthening exercise protocol, C: Comparing therapeutic ultrasound with muscle relaxant gel versus Aquasonic transmission gel, O: NPRS and NDI).

Research Question Statements:

1. How is the combination of therapeutic ultrasound and muscle relaxant gel with a strengthening exercise protocol effective in treating text neck syndrome?
2. In what ways is the combination of therapeutic ultrasound and Aquasonic transmission gel with a strengthening exercise protocol effective in treating text neck syndrome?

Material and methods

Study Design and Ethical Clearance

A Randomized Controlled Trial was conducted at the Saveetha Hospital, Chennai, India, from November 2024 (3rd week) to December 2024 (1st week). A total of 52 patients, aged between18-45 (Participants include College students and normal individuals), who met the inclusion criteria, were selected using a simple random sampling technique from the orthopedic department. The study approved from the Institutional Scientific Review Board (409/07/2024/ISRB/UGSR/SCPT).

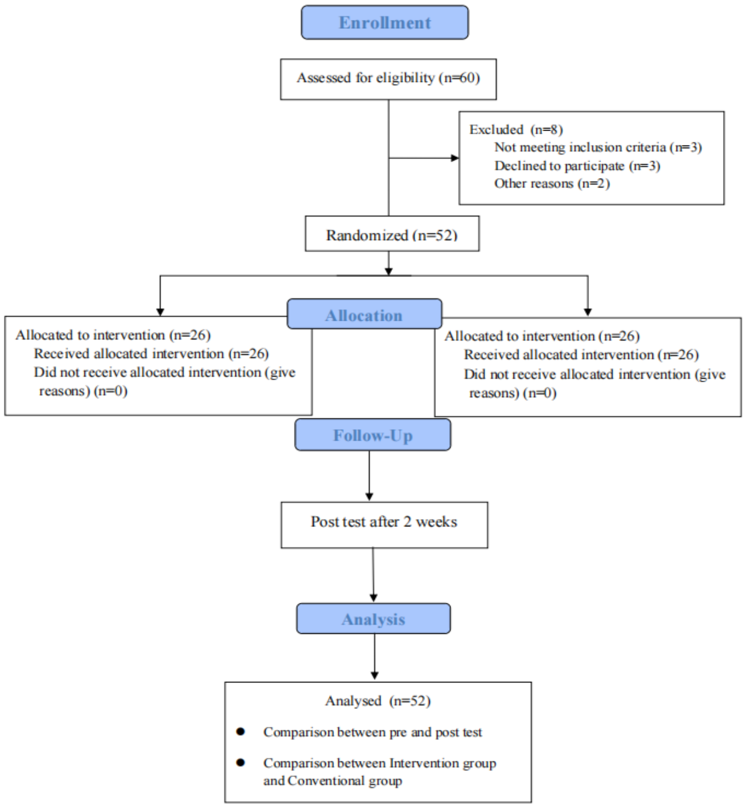

Figure 2. CONSORT Flow chart of the study.

Study Guideline

The research followed the CONSORT (Consolidated Standards of Reporting Trials) guidelines throughout the study (Figure 2).

Participants

Selection Criteria

This study included Patients with Text Neck syndrome (Diagnosis based on patient history and physical examination includes Restricted range of motion, Spasm with trigger points in suboccipital and upper trapezius muscle, X-ray revealing forward neck Posture), both Male and Female, both Acute and Chronic pain, Age between18-45 (Participants includes College students and normal individual), Patients with pain score between 5 to 8 in Numerical Pain Rating Scale and Using mobile phones for more than 3-4 hours per day. This study excluded Individuals with a recent history of neck or back surgery, a recent history of trauma or fracture, congenital disorders of the cervical spine, patients have any psychiatric diseases, patients with skin infections and patients suffering from any other condition that could cause myofascial or neuropathic pain in the Upper limb.

Sample Size Calculation

A Priori type of power analysis performed in G*Power (3.1.9.7). The total sample size required for a two-sample t-test with the selected parameters is 52 participants (26 in each group). This sample size ensures a balanced allocation (1:1 ratio) and sufficient power (0.80) to detect a meaningful difference between the two groups with an effect size of 0.80 at the α=0.05 significance level.

Group Allocation

A total of 52 patients, who were selected based on the inclusion criteria, were selected using a simple random sampling technique from orthopedic department. After obtaining informed consent from all participants, they were split into two groups of 26 subjects each at random using a computer-generated technique. The Group A referred to as the interventional group, received ultrasound therapy along with a muscle relaxant and strengthening exercises. The Group B referred to as the conventional group, received ultrasound therapy along with Aquasonic transmission gel combined with strengthening exercises. Demographic data were collected from each participant before treatment (Table 1).

Procedure

Study Intervention

The 26 patients in the interventional group received Therapeutic ultrasound with muscle relaxant Gel along with Strengthening Exercises for 3 sets of 10 repetitions at 10 RM with 2 min rest for each set, 4 sessions per week, conducted on two consecutive days, for a duration of 2 weeks. Total treatment times per session were 30 minutes. The 26 patients in the conventional group

Table 1. Demographic Data

Gender	Male	32
	Female	20
Age	18-25	18
	26-35	22
	36-45	12
Comorbidities	Diabetes mellitus	8
	Hypertension	7
	Thyroid	8
Body Mass Index	16.5 to 18.5 (Underweight)	15
	19.5 to 24.9 (Normal weight)	27
	25 to 29.9 (Overweight)	10
Hours of mobile phone & other electronic use per day	3-4 hours	24
	5-6 hours	18
	>6 hours	10

received Therapeutic ultrasound with Aquasonic transmission gel, along with strengthening exercise, has protocol followed in the interventional group.

Therapeutic Ultrasound for Conventional and Interventional Groups

Electroson 900, Technomed Electronics ultrasound, Mephenesin, Methyl nicotinate, and Capsicum oleoresin (Phonophoresis) gel were utilized using continuous mode to provide ultrasound into the tissue at a frequency of 1 MHz and 1.2 W/cm^2. The treating physical therapist will use slow, circular motions to place the transducer head over the back of the neck. The treatment lasted for 15 minutes in a session on interventional group, while the Conventional group utilized the Aquasonic transmission gel with the same dosage of the interventional group (Monisha et al., 2018).

Strengthening Exercises

Strengthening Exercises Protocol was 3sets of 10 repetitions at 10 RM. 2 min rest for each set.

Y's exercise (Bhende R et al., 2024):

Position: Prone with arms extended overhead, forming a "Y" shape with your body. Movement: While keeping your thumbs up and maintaining a straight spine, raise your arms in a controlled manner, focusing on squeezing your shoulder blades downward and inward. The Y's exercise improves posture and shoulder stability by strengthening the rotator cuff, upper back, and shoulders. It reduces the possibility of shoulder injuries by increasing scapular flexibility and mobility. It also improves general upper body strength and helps in rehabilitation (Figure 3).

Rowing exercise (Bhende R et al., 2024):

Position: sit or stand upright with chest open and shoulders back. With arms out in front, grip the TheraBand in both hands. Movement: Squeeze the shoulder blades together and draw your elbows back to pull the TheraBand towards the torso in a rowing motion. Rowing exercise improves posture and upper body strength by strengthening the arms, shoulders, and upper back. Through the maintenance of muscle balance, rowing reduces the risk of injury while also enhancing endurance and coordination (Figure 4).

Figure 3. Y's exercise- Position with thumbs up and straighten spine with squeezing shoulder blades downwards and inwards.

Figure 4. Rowing exercise with TheraBand Squeezing the shoulder blades together and pulling the TheraBand towards the torso.

Outcome Measure

All subjects were assessed using the Neck Disability Index and Numerical Pain Rating Scale both before and after the intervention (on the 1st day and after 2 weeks of intervention).

The Neck Disability Index (NDI)

It is a self-reported scale of ten items that was used to assess disability. Every item responds to different grievances regarding neck pain that mostly manifests as restrictions on day-to-day activities. Six distinct statements, each representing an item, are graded on a scale of 0 to 5, where 5 represents severe disability and 0 indicates no disability at all. The overall score ranges from zero to fifty. The most widely accepted method for reporting neck pain in the literature is the NDI. The total possible score is 50, and it is then converted into a percentage by multiplying by 100 (Irmak et al., 2019).

Numerical Pain Rating Scale (NPRS)

It is a self-reported measure of 0 to 10 score. The score 0 represents no pain and 10 represents severe pain. It helps to assess the level of pain (Afzal et al., 2023).

Statistical Analysis

All data were analyzed using SPSS version 27. The Wilcoxon test was applied to Groups A and B, while the Mann-Whitney U test was used to compare the two groups. Age and Sex distribution of samples were illustrated in Table 2 and Table 3 illustrates the difference in Numerical Pain Rating Scale (NPRS) scores within Groups A and B, and Table 4 shows the difference in Neck Disability Index (NDI) scores within two groups. Table 5 illustrates the difference between group A and B for Numerical Pain Rating Scale, while the Table 6 shows the difference between the two groups for Neck Disability Index (NDI).

Results

The study noted that among the 26 patients in the interventional group, 10 (38.46%) were aged 18-25 years, 8 (30.76%) were aged 26-35 years, and 8 (30.76%) were aged 36-45 years. In contrast, in the conventional group, out of 26 patients, 8 (30.76%) were aged 18-25 years, 14 (53.84%) were aged 26-35 years, and only 4 (15.38%) were aged 36-45 years (Table 2).

Table2. Age and Sex distribution of samples

Age	Group A			Group B		
	Male	Female	Total	Male	Female	Total
18-25	6	4	10	4	4	8
26-35	6	2	8	10	4	14
36-45	2	6	8	4	0	4
Total	14	12	26	18	8	26

A Wilcoxon signed-rank test revealed that after a 2-week interventional treatment course, administered 4 times a week, produced a statistically significant reduction in the numerical pain rating scale (Fig. 5) for individuals with text neck syndrome (Z=−4.214, p=<0.001). For the Conventional treatment course, administered 4 times a week, produced a statistically significant reduction in numerical pain rating scale (Table 3) for individuals with text neck syndrome (Z=−2.003, p=0.045).

Table 3. Comparison of NPRS within Group A & Group B

Groups	Pre-Test Mean±SD	Post-Test Mean±SD	Z value	P-value
Group A (N=26)	7.38±1.359	5.12±1.751	−4.214	<0.001
Group B (N=26)	7.62±1.098	7.23±1.070	−2.003	0.045

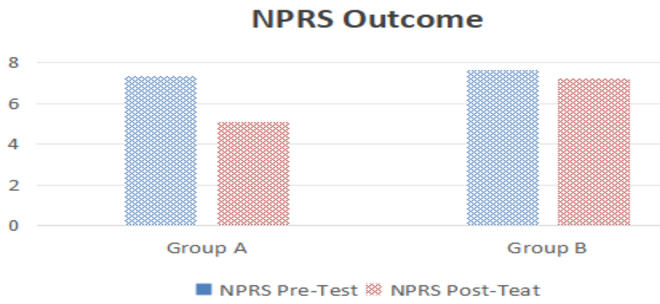

Figure 5. Graphical Representation of NPRS outcome for pre and post Test.

A Wilcoxon signed-rank test showed that over a 2-week interventional treatment course, given four times a week, resulted in a statistically significant decrease in the Neck Disability Index (Figure 6) for individuals with text neck syndrome (Z=−4.228, p<0.001). Similarly, the conventional treatment course, also administered four times a week, led to a statistically significant reduction in the Neck Disability Index (Table 4) for individuals with text neck syndrome (Z=-2.058, p=0.040).

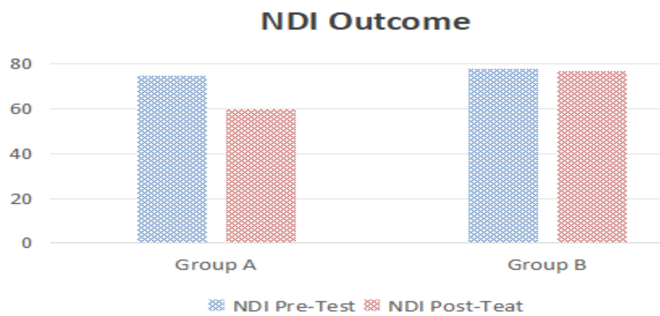

Figure 6. Graphical Representation of NDI outcome for pre and post Test.

The Mann-Whitney U test revealed a greater significant difference in posttest were as pretest exhibited insignificant difference on NPRS (Ta-

Table 4. Comparison of NDI within Group A & Group B

Groups	Pre-Test Mean±SD	Post-Test Mean±SD	Z value	P-value
Group A (N=26)	74.73±14.024	60±13.002	−4.228	<0.001
Group B (N=26)	77.81±13.799	77±14.083	−2.058	0.040

Table 5. Comparison of NPRS between Group A & Group B

Tests	Mean±SD	Z value	W	U	P-value	r-value
Pre-test	7.50±1.229	−0.369	669.50	318.50	0.712	0.05
Post-test	6.17±1.790	−4.578	442.50	91.50	<0.001	0.63

Table 6. Comparison of NDI between Group A & Group B

Tests	Mean±SD	Z value	W	U	P-value	r-value
Pre-test	76.27±13.862	−0.779	646.50	295.50	0.436	0.10
Post-test	68.50±15.929	−3.829	480.00	129.00	<0.001	0.53

ble 5) between two groups Group-A & Group-B (U=91.50, p=<0.001). Since the p-value is less than the alpha level of 0.05, the null hypothesis is rejected, suggesting that the treatment method had a significant impact on text neck syndrome. The calculated r value for pre-test is approximately 0.051, indicating a very small effect size, while calculated the posttest r value is approximately 0.635, indicating a large effect size.

The Mann-Whitney U test showed a significant difference in post-test scores on the NDI (Table 6) between Group A and Group B (U=129.00, p<0.001). Given that the p-value is smaller than the 0.05 alpha level, study reject the null hypothesis, indicating that the treatment method had a meaningful effect on text neck syndrome. The calculated r value for pre-test is approximately 0.108, indicating a small effect size, while the calculated posttest r value is approximately 0.531, indicating a large effect size.

Discussion

The study aimed to find out the effectiveness of ultrasound therapy along with muscle relaxant gel and Aquasonic transmission gel combined strengthening exercise on text neck syndrome. Text neck is spreading like wildfire and causing irreversible harm. Sixty-two percent of smartphone users report having shoulder or neck pain. Because text neck is not severe enough to require surgery, protective measures are advised (Sarraf et al., 2023). One of the most well-known poor sagittal plane postures is forward head posture, which results in overstretching and shortening of muscle fibers. Overuse syndrome may develop if text neck syndrome is not addressed or treated in a timely manner, which could cause irreversible harm (Sathya et al., 2020). Most smartphone activities involve users extending their arms forward or looking downward to view the screen. This posture places stress on the cervical spine and neck muscles by pushing the head forward, leading to increased anterior curvature in the lower cervical vertebrae and heightened posterior curvature in the upper thoracic vertebrae to maintain balance. One of the most prevalent bad sagittal plane postures is forward head posture. Chronic musculoskeletal pain has been linked to incorrect head and neck posture (Shah et al, 2018). Therapeutic Ultrasound is one of the most popular physical therapy modalities for treating soft tissue injuries. Therapeutic US can be administered in two ways: 1) Continuous mode 2) Pulsed mode. Thermal and non-thermal effects are the two categories of US therapeutic effects. The conduction velocity of nerve impulses, enzymatic activity, skeletal muscle contractile activity, the flexibility of collagen tissue, regional blood circulation, pain sensitivity, and muscle tension reduction have all been demonstrated to be impacted by this elevated temperature, also referred to as thermal effects (Abdel-aziem et al., 2014). A customized physiotherapy treatment plan is very successful in helping people who are addicted to smartphone use manage their TNS and SMS thumb. By carefully analyzing pain levels, hand discomfort, neck disability, and general well-being, our results highlight the notable gains made possible by customized interventions. To ensure long-term management of these common conditions in populations with smartphone addiction, more research is necessary to optimize treatment protocols (Nathani et al., 2024). Every member who has been identified as having issues with limited range of motion (ROM) should receive physiotherapy services. Members should be trained to carry out McKenzie exercises on their own. Assess this activity's progress on a regular basis (Kurniawati et al., 2021). According to available data, US therapy may have a major impact on MPS patients' pain but not their range of motion. The effects of US on pain and range of motion are inconclusive due to the high risk of bias. Because of the extremely small sample sizes, incomplete patient-reported outcomes, and the extremely poor quality of some studies, the relevant evidence is very weak. However, large-scale, high-quality RCTs with bias-checking measures and key outcome assessments should validate the effects of US therapy on MPS (Xia et al., 2017). In individuals with chronic neck pain, incorporating static ultrasound or diadynamic currents on upper trapezius myofascial trigger points into a manual therapy program offered no additional benefits compared to manual therapy on its own (Dibai-Filho et al., 2017). Text neck is common among young people in Islamabad, and it is more common among those who use their phones for longer than three hours every day. To prevent more injuries and disability, it is important to regularly strengthen the neck muscles and maintain proper cervical spine alignment when using a cell phone (Purushothaman et al 2023). Finally, this study demonstrated how extended mobile phone use impacts JPE, which in turn causes musculoskeletal symptoms and changes in neck posture. Therefore, in order to maintain a healthy lifestyle, doctors, physical therapists, and smartphone users must be aware of these negative effects and health risks and take the necessary precautions (Nawaz et al., 2021). Research indicates that continuous ultrasound therapy is more effective than pulsed or sham ultrasound in alleviating pain at rest in individuals with MPS. Additionally, both continuous and pulsed ultrasound therapies outperform sham ultrasound in enhancing psychological well-being (Ilter et al., 2015). Although it's commonly believed that adults are more likely to experience this kind of issue, prolonged and excessive use of computers or smartphones can cause a number of physical issues during adolescence, which is marked by periods of rapid growth. The literature has recently drawn attention to problems that can develop into major health issues, like the rise in young people's excessive use of electronic devices and sedentary lifestyles (David et al., 2021). Physiotherapists providing personalized exercise and related programs should educate individuals of all ages on maintaining proper posture while using handheld mobile devices. Prolonged use of such devices can lead to Text Neck Syndrome, which may adversely impact the growth and development of children and adolescents (Tsantili et al., 2022). Text neck pain was common in female student with the usage of smartphones in daily life. The lack of knowledge about warm-up exercise, posture change and break-away while using smart-phone was lacking in most of the students (Khan et al., 2018). Using a smartphone while seated in a chair without back support significantly contributes to poor posture compared to other smartphone usage positions. Hence, it is essential to provide guidance and education on proper smartphone usage conditions to reduce head strain and minimize pressure on this area (Sarraf et al., 2023). The present study concluded that text neck has progressed and has not received enough treatment. Deformation of the cervical spine will result from prolonged neck flexion. It has been demonstrated that when cervical misalignment is corrected, radiographic and electromyological changes also improve neurologic symptoms (Chu et al., 2022).The neck pain caused by smartphones and related issues is chronic and progressive in nature, prompt diagnosis and the key to treating Text Neck Syndrome will be interventions and a thorough understanding of postural correction. When creating an evidence-based protocol, more clinical trials confirming the efficacy of current practice will be very helpful (Neupane et al., 2017, Sri Lekha et al., 2025, Balaji, 2025, M. K. et al.,2024).

Conclusion

The study concluded that ultrasound therapy combined with muscle relaxant and strengthening exercises is effective in reducing pain and improving functional activity in individuals with Text Neck Syndrome. No adverse effects were observed in either the interventional or conventional groups during the study. Therefore, ultrasound therapy with muscle relaxant and strengthening exercises offers a more effective treatment with a shorter recovery time for Text Neck Syndrome compared to conventional therapy. This intervention is thus recommended for inclusion in future physical therapy treatment protocols.

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Supplementary Information

Author's contribution

Boopathy D.: Conceptualization, Methodology, Software, Check, Formal Analysis, Investigation, Resources, Data Curation, Writing – Rough Preparation, Writing – Review and Editing, Visualization, Supervision, Project Administration, Receiving Funding; **Sathya Siva:** Conceptualization, Methodology, Software, Check, Formal Analysis, Investigation, Resources, Writing – Rough Preparation, Writing – Review and Editing, Visualization, Supervision, Project Administration, Receiving Funding; **Logeshwari V.:** Conceptualization, Methodology, Software, Check, Formal Analysis, Investigation, Resources, Writing – Rough Preparation, Writing – Review and Editing, Visualization, Supervision, Project Administration, Receiving Funding; **Dilip G.:** Conceptualization, Methodology, Software, Check, Formal Analysis, Investigation, Resources, Writing – Rough Preparation, Writing – Review and Editing, Visualization, Supervision, Project Administration, Receiving Funding; **Madhubala V.:** Conceptualization, Methodology, Software, Check, Formal Analysis, Investigation, Resources, Writing – Rough Preparation, Writing – Review and Editing, Visualization, Supervision, Project Administration, Receiving Funding. All authors have read and agreed with the published version of the manuscript.

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Declarations

Conflict of Interest
The authors declare no conflict of interest.

Institutional Review Board Statement
The research was approved by the Institutional Scientific Review Board at the Saveetha College of Physiotherapy, Saveetha Institute of Medical and Technical Sciences (409/07/2024/ISRB/UGSR/SCPT).

Informed Consent Statement
Informed consent was obtained from all subjects involved in the study.

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Characteristics of the level of the biogeometric profile of posture in women aged 41-45 with risk factors for cardiovascular diseases

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Abstract

Purpose. To assess the impact of the corrective and preventive program on the biogeometric profile of women aged 41-45 for the further development of the concept of physical culture and sports rehabilitation for women in the second period of mature age at risk of developing cardiovascular diseases.

Material & Methods. The study was conducted at the Profizio Medical Center in Kharkiv, which organizes a "Women's Health School."Women aged 41-45 were divided into groups at their own request: OG (n=15) and CG (n=16). The programs differed in their psychocorrection methods, and the women in the CG did not perform myofascial release using a massage roller.

Results. Before the experiment, the stoop index values in the main group ranged from 65% to 80%, meaning that none of the participants had a normal posture. The dynamics of changes showed an increase in the stoop index in almost all participants, indicating an improvement in the position of the shoulder girdle and a decrease in the severity of deformation. In women in the control group before the experiment, the stoop index ranged from 72% to 86%. After completing the program, these ranges remained unchanged; none of the participants achieved improvement or transition to another category. The dynamics of the cervical spine curvature depth index in groups of women aged 41-45 before and after the experiment also indicate changes only in the main group. After completing the program, all participants in the main group showed an increase in the depth of the cervical curve, which ranged from 4.1 to 4.7 cm, i.e., the values were noticeably closer to normal. No changes were recorded in the women in the control group.

Conclusions. After completing the program, all participants in the main group showed a reduction in stooped posture and an improvement in cervical curvature to normal values. It strengthens the muscles of the cervical and thoracic spine, improves muscle tone and elasticity, and reduces functional limitations.Classes based on the author's corrective and preventive program contributed to the normalization of the functional state of the cervical spine and the restoration of its natural shape in all participants of the main group aged 41-45 years. No changes in dynamics were observed in women in the control group, which emphasizes the advisability of using targeted rehabilitation measures to optimize posture.

Keywords: women, second period of mature age, cardiovascular risk, biogeometric posture profile.

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Introduction

Common features of the second period of adulthood are the onset of age-related changes in the musculoskeletal system, decreased ligament elasticity, reduced strength and endurance of the back and abdominal muscles. Age-related changes in the intervertebral discs occur, affecting posture. Due to physical inactivity, excess weight, and emotional stress, women often develop compensatory deviations (Lorbergs, 2017; Lazko, 2021; Asauliuk, 2023; Kozlovska, 2023; Kashuba, 2025).

The biogeometric profile of the posture of women in the second period of middle age is characterized by age-related increase in thoracic kyphosis, asymmetries of the trunk and shoulder girdle, decreased muscle tone, possible scoliosis changes, and functional disorders of the spinal stabilization system. It has been proven that the biogeometric profile of posture in this category of women has a direct and indirect impact on the development of cardiovascular diseases (Silva, 2023; Kashuba & Ruban, 2025; Fedynak & Vypasyak, 2025). Incorrect posture restricts respiratory and circulatory function, causes congestion, and increases the risk of arterial hypertension. Posture is a factor that modulates the development of cardiovascular diseases through respiratory, hemodynamic, vegetative, and motor links. We consider the condition of the musculoskeletal system to be one of the indicators of women's overall physical health, on which their physical activity and mobility depend. Changes in posture, disturbances in the physiological curves of the spine, and the development of deformities not only reduce motor function but can also lead to pain, discomfort, circulatory disorders, and a decline in overall health (Carini, 2017; Harvey, 2020; Ruban, 2021; Samoiluk, 2025; Grygus, 2025). It is particularly important to study these parameters in women in the second period of middle age, as it is during this period that age-related changes in the musculoskeletal system often occur, associated with a decrease in physical activity, the influence of hormonal changes, and the development of degenerative-dystrophic processes. The significance of the biogeometric profile of posture is shown in Fig. 1.

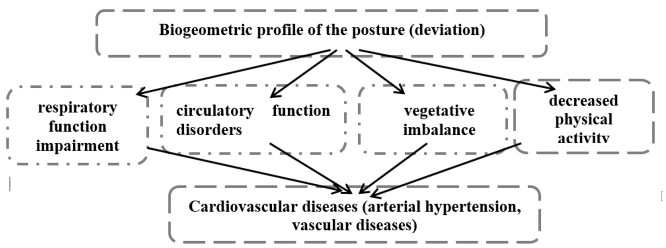

Figure 1. **Diagram of the influence of the biogeometric profile of posture on the risk of developing cardiovascular diseases**

The results of our preliminary study showed that in the second period of adulthood, the biogeometric profile of posture is characterized by a certain tendency toward stooping, which is more pronounced in women aged 41–45 than in women aged 36–40. The depth of the cervical spine curvature was also less in women in the older group, indicating an increase in physiological posture disorders, as well as fluctuations in cardiovascular system parameters (Kashuba & Ruban, 2025).

There is a lack of research in scientific literature on the development and implementation of corrective and preventive programs for restoring the biogeometric profile of posture and the functional state of the cardiovascular system in women in the second period of mature age.

The ***purpose of the study*** – to assess the impact of the corrective and preventive program on the biogeometric profile of women aged 41-45 for the further development of the concept of physical culture and sports rehabilitation for women in the second period of mature age at risk of developing cardiovascular diseases.

Material and Methods

Participants

The study was conducted at the Profizio Medical Center in Kharkiv, which organizes a "Women's Health School." A total of 47 women aged 36-45 participated in the study. The selection criterion was the presence of modified risk factors for cardiovascular disease. All respondents were informed about the scientific study and provided written consent to participate in the study. The confidentiality of information about the participants was ensured by explaining that all data would be anonymous and used for research purposes.

Ethics Statements

The study was conducted in compliance with all relevant national regulations and institutional policies, the principles of the Declaration of Helsinki adopted by the General Assembly of the World Medical Association (1964-2000), and the Council of Europe Convention on Human Rights and Biomedicine (1997).

Study design

Posture was examined in the frontal and sagittal planes using the REEDCO posture scale. The REEDCO (Reedco Posture Scale) is one of the most well-known methods for qualitative and quantitative assessment of posture in the frontal and sagittal planes. The scale includes 10 criteria that are assessed in points: 5 criteria in the frontal plane (symmetry of the head, shoulders, shoulder blades, pelvis, knees) and 5 criteria in the sagittal plane (position of the head, thoracic

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kyphosis, lumbar lordosis, abdomen, legs/knees). Interpretation of results: 17-20 points – correct posture; 13–16 points – minor deviations; 9–12 points – significant deviations; less than 9 points – pronounced posture disorders.

The depth of the physiological cervical curve (cervical point) was measured using the method developed by Z.P. Kovalkova. With correct posture, the depth of the cervical curve of the spine is within the range of 5-5.5 cm.

The study was conducted in two stages. The first stage was a transformative pedagogical experiment involving women aged 36-40 (n=16), which lasted 3 months. The "Women's Health School" used an author's corrective and preventive program. The women performed therapeutic exercises aimed at stretching and strengthening the muscles of the trunk and limbs; exercises for the muscles that stabilize the spine; a set of McGill exercises; and flossing. Specialists from the Women's Health School held talks on the need to change their lifestyle, aimed at motivating and directing women towards physical activity in the context of preventing cardiovascular disease; they taught women how to perform breathing and relaxation exercises and myofascial release using a massage roller. Three times a week, under the supervision of a physical education and sports rehabilitation specialist, women engaged in training walks. A psychologist taught women exercises using the Shulz method. With the help of an online calorie calculator, women monitored the calorie content of their food. The use of the author's corrective and preventive program significantly improved the biogeometric profile indicators on the REEDCO posture scale and the change in the depth of the spine curvature according to the method of Z.P. Kovalkova (p<0.05) (Kashuba & Ruban, 2025).

Stage two: women aged 41-45 were divided into a main group (n=15) and a control group (n=16) at their own request. The main group (MG) followed the author's program, while the control group (CG) followed the Profizio program. The programs differed in their use of various methods of kinesiotherapy and psychocorrection, and the women in the control group did not perform myofascial release using a massage roller.

Statistical analysis

Statistical processing of the obtained results was performed using the statistical software package Statistica 13.0. Descriptive statistics were obtained, which included calculations of the arithmetic mean (M), standard deviation (s), standard error of the mean (m), median (Me), minimum (min) and maximum values (max), as well as quartiles of distributions (25%, 75%). To compare independent samples, the t-value of Student's criterion for paired samples was used; the level of reliability of changes (p) was determined by the following critical values: t_kr(15; 0.001)=4.07.

Results

Analysis of changes in the stoop index allowed us to record shifts in the posture of participants in the main group after the implementation of the corrective and preventive program (Fig. 2).

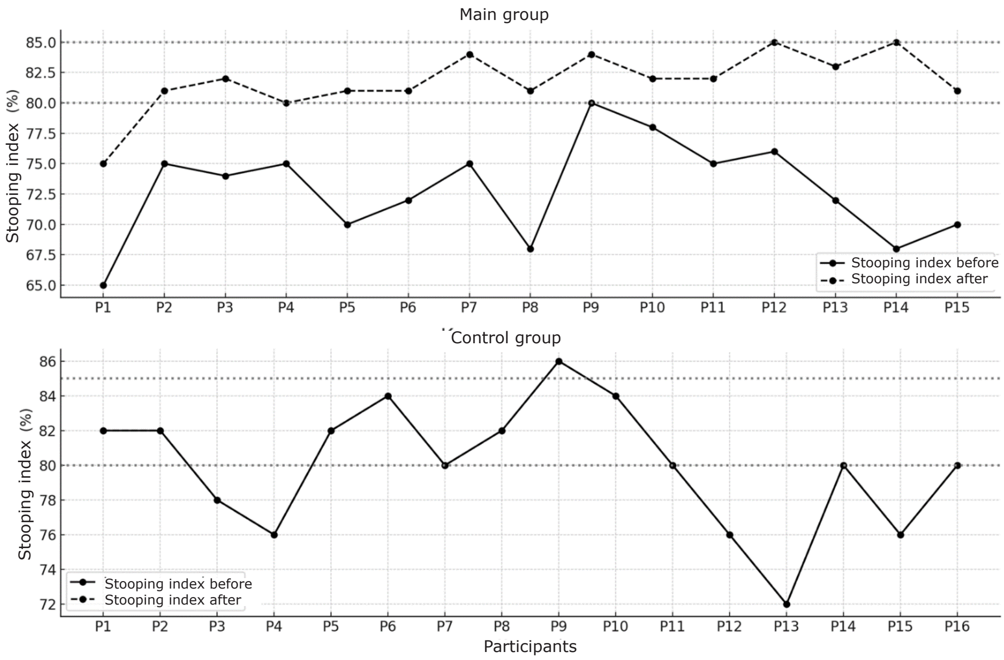

Figure 2. Individual stoop indices of women aged 41–45 from the main (n=15) and control (n=16) groups before and after the experiment, where the solid line represents before the experiment, the dotted line represents after the experiment, the horizontal lines indicate the upper limits of the posture assessment, and the marks Pn represent the code of the study participant.

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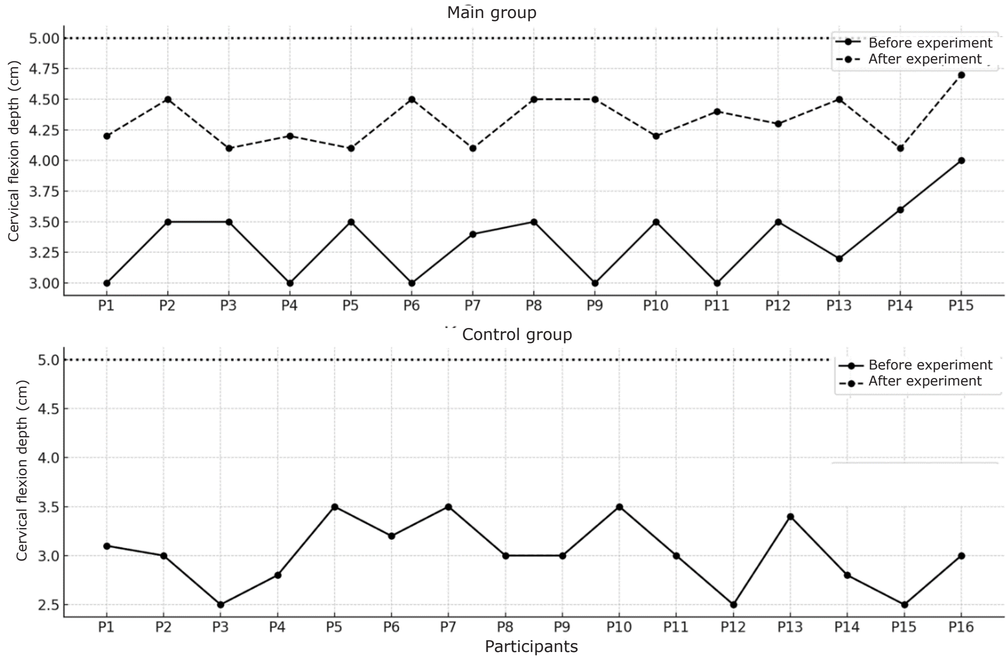

Figure 3. **Depth of the cervical spine curvature (in cm) in women aged 41-45 from the main (n=15) and control (n=16) groups before and after the experiment, where the solid line – before the experiment, dotted line – after the experiment, horizontal line indicates normal limits, marks Pn – code of the study participant.**

As can be seen from the graph, almost all participants in the main group showed an increase in the stoop index, indicating an improvement in the position of the shoulder girdle and a reduction in the severity of the deformity. Before the experiment, the stoop index ranged from 65% to 80%, meaning that none of the participants had normal posture. In 20% of women, the index was below 70% (severe stoop). Another 60% had values between 70% and 75%, and only 20% were in the range of 76% to 80%, which corresponded to the borderline condition. After the experiment, none of the participants had an index below 75%. All values increased and ranged from 75% to 85%, which, according to the classification, corresponds to a tendency to stoop. Thus, after the program was implemented, the index limits shifted by 6-15% towards the norm, and in 86.6% of women, the values reached the 81–85% range. Two more participants (13.4%) remained at 80%, i.e., at the upper limit of the borderline condition.

In the CG before the experiment, the stoop index values ranged from 72% to 86%. Half of the participants were in the 76–80% range, 37.5% were in the 81-85% range, another 6.25% were in the 70–75% range, and only one woman had a normal score above 85%.

After completing the program, these ranges remained unchanged; none of the participants achieved improvement or transitioned to another category. This fact is clearly visible in the graph, where the before and after lines almost completely coincide, demonstrating the consistency of results when using the traditional approach. Thus, we have a marked increase in stoop indices in women with MG and a shift towards a better posture category. At the same time, the absence of changes in the CG further justifies the use of a comprehensive author's program as an effective tool for correcting posture disorders in women aged 41-45. The indicators of the depth of the cervical spine curvature in groups of women aged 41-45 before and after the experiment also indicate changes only in the CG (Fig. 3).

No changes were recorded in the CG women. The values of the cervical curvature depth after the experiment remained unchanged – from 2.5 to 3.5 cm, which makes the traditional health program for correcting the cervical curvature depth insufficiently effective.

As we can see, classes based on the author's program contributed to a reduction in stooping, normalization of the functional state of the cervical spine, and restoration of its natural shape in all participants from the MG aged 41-45 years. No dynamics were observed in the CG, which emphasizes the advisability of using targeted rehabilitation measures to optimize posture.

Regarding the analysis of changes in quantitative indicators, it was appropriate to use the Wilcoxon criterion in the MG to assess their reliability, while in the CG all indicators were normally distributed, i.e., they needed to be compared using the t-criterion.

Having done this, we found that the changes in the MG were statistically significant (Table 1).

Before the experiment, the average stoop index in the main group was 72.87±4.09%, which

Table 1. Dynamics of biogeometric profile indicators in women aged 41–45 from the main (n=15) and control (n=16) groups during the experiment

Testing time	Statistical indicators	Biogeometric posture profile indicators			
		Main group		Control group	
		Stoop index, %	Depth of spinal curvature in the cervical region, cm	Stoop index, %	Depth of spinal curvature in the cervical region, cm
Before the experiment	**M**	72,87	3,35	80	3,02
	s	4,09	0,30	3,65	0,34
	min	65	3	72	2,5
	max	80	4	86	3,5
	25%	70	3	76,5	2,8
	Me	74	3,5	80	3
	75%	75	3,5	82	3,35
After the experiment	**M**	81,80	4,33	80	3,02
	s	2,46	0,20	3,65	0,34
	min	75	4,1	72	2,5
	max	85	4,7	86	3,5
	25%	81	4,1	76,5	2,8
	Me	82	4,3	80	3
	75%	84	4,5	82	3,35
Reliability of changes	t	-	-	-	-
	Z	−3,414	−3,413	-	-
	p	p<0,01	p<0,01	-	-

corresponded to a pronounced stoop according to the classification scale. The median was 74%, and the minimum was 65%, which indicated the prevalence of posture disorders in this group. After the experiment, this indicator increased to 81.80±2.46% (by 8.93%), and the median value reached 82% ($p<0.01$). That is, a transition from a pathological state to a zone of susceptibility to stooping or even normality was recorded, indicating objective improvements in posture.

The depth of the cervical curve in women with MG also increased from 3.35±0.30 cm to 4.33±0.20 cm (an average of 0.98 cm or 29.28% of the initial level), which corresponded to a statistical significance level of $p<0.01$. At the beginning and end of the experiment, none of the participants had normal values (5-5.5 cm), but after completing the program, the indicators were significantly closer to normal. The increase in average, minimum, and maximum values, as well as the decrease in data dispersion, indicated a stable effect of posture correction in the participants.

In the control group, all indicators remained unchanged: the stoop index remained stable at 80±3.65%, and the depth of the cervical curve was 3.02±0.34 cm with no signs of dynamics, demonstrating the absence of a positive effect from the use of traditional health-improving techniques.

Thus, the author's corrective and preventive program provided statistically significant and clinically important improvements in the biogeometric profile of posture in women aged 41-45 who had musculoskeletal disorders. At the same time, the use of the traditional program in the control group proved ineffective in changing posture.

Discussion

A systematic analysis of the literature confirms the authors' (Kashuba V., Samoiliuk O. et. al. 2025) opinion that in recent years there has been increased interest among specialists in the diagnosis of a growing number of posture disorders, diseases of the musculoskeletal system, and the systematic and quantitative assessment of the degree of existing motor dysfunctions in humans.

In the course of the study, scientists confirmed (Alkhawajah et al., 2025) that the level of the biogeometric profile of women's posture has a significant impact on physical fitness. In particular, the authors observed better physical fitness in women with a high biogeometric posture profile compared to women with scoliosis and a low biogeometric profile.

The aim of the study (Wang H. Gao et. al. 2022) was to investigate which postures lead to chronic sympathetic activation and may affect the cardiovascular and autonomic nervous systems. In a pilot study, the authors demonstrated that regular and moderate physical activity improves the functioning of the cardiovascular and autonomic nervous systems, but few studies that have examined the effect of posture changes during movement on the functioning of the heart and autonomic nervous system.

Research (Fathima et al., 2024). expanded the knowledge about the relationship between heart rate variability and posture in people who lead a sedentary lifestyle. The results of the study showed that changes in posture led to vegetative adjustments in the parasympathetic and sympathetic nervous systems, as indicated by the difference in heart rate variability parameters. In other words, prolonged sitting can have negative consequences for cardiovascular health.

We agree with the authors (Quintero Santofimio et al., 2023), who concluded in their work that reducing sedentary behavior to less than 3 hours and promoting proper sitting posture (reducing forward leaning and sitting with a straight back) can improve autonomic function and should be a key focus of future ergonomic interventions.

The results of this study (Sureshbabu et al., 2025) are consistent with the theoretical understanding that posture can affect autonomic function. Poor posture, commonly referred to as "text neck," is associated with an imbalance in cardiac autonomic regulation, specifically an increase in sympathetic nervous system activity and a decrease in parasympathetic modulation, as measured by heart rate variability. The authors confirm the growing body of literature suggesting that poor posture alignment, especially of the head and neck, may contribute to autonomic imbalance. This study provides compelling evidence that when developing a program for middle-aged women with changes in their biogeometric profile, more attention should be paid to therapeutic exercises for the cervical spine.

Based on an analysis of the results of the work of scientists (Sepehri et al., 2024), it can be concluded that performing therapeutic exercises in the form of strength exercises, stretching, shoulder exercises, and incredibly complex exercises that affect all muscles can be effective in reducing forward head posture, "text neck," slouching shoulders, and thoracic kyphosis.

Conclusions

The overall level of the biogeometric profile of the posture in the women studied before the implementation of the corrective and preventive program showed significant changes. The difference between the programs for women in the main and control groups was the different methods of kinesiotherapy and psychocorrection, and the women in the control group did not perform myofascial release using a massage roller.

The dynamics of the stoop index in women in the experimental group indicated an improvement in the position of the shoulder girdle and a decrease in the severity of the deformity. In the control group, these limits remained unchanged after the completion of the program; none of the participants achieved improvement or transition to another category.

After completing the program, all participants in the MG showed an increase in the depth of the cervical curve, i.e., the values approached the norm. The strengthening of the muscles of the cervical and thoracic spine, improvement in muscle tone and elasticity, and reduction in functional limitations provided by the author's program made the tendency toward restoration of physiological curves evident, although the normal value (5-5.5 cm) was not achieved. Classes based on the author's program contributed to a reduction in stooped posture, normalization of the functional state of the cervical spine, and restoration of its natural shape in all participants with MG aged 41-45 years. No dynamics were observed in the CG, which emphasizes the advisability of using targeted rehabilitation measures to optimize posture.

Prospects for further scientific research are related to the analysis of the dynamics of cardiocirculatory parameters based on the results of the formative experiment.

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Supplementary Information

Author's contribution

Larysa Ruban: Conceptualization, Methodology, Check, Data Curation, Supervision; **Victor Dzhym:** Methodology, Check, Data Curation, ; **Inna Torianyk:** Conceptualization, Methodology, Writing – Review And Editing; **Olena Anosova:** Writing – Rough preparation, Check, Data Curation; **Marina Dzhym:** Visualization, Investigation; **Mykhailo Sanin:** Software, Validation. All authors have read and agreed with the published version of the manuscript.

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