Personalized exercise regimens in post-stroke rehabilitation: optimizing blood pressure variability and functional independence

Regímenes de ejercicio personalizados en la rehabilitación post-ACV: optimización de la variabilidad de la presión arterial y la independencia funcional

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Abstract

On the basis of the high prevalence and disabling character of stroke, individualized rehabilitation regimens are a critical strategy for improving the outcome in the clinical situation. The current study aims to investigate the impact of individualized training protocols on blood pressure variability (BPV) and functional independence among stroke patients at the recovery stage in Uzbekistan. In the quasi-experimental study, 100 patients with a history of ischemic or hemorrhagic stroke within the previous 6 months will be randomly allocated to two control and intervention groups. The intervention group will receive a combined exercise program (balance, resistance, and aerobic) tailored according to their clinical status, degree of disability, and blood pressure profile, and the control group will undergo a standard rehabilitation program. Assessments are also made by daily BPV measurement with wearable devices, functional tests (Barthel index and 10-meter walk time), and observation of cardiovascular complications for 12 weeks. Initial data analysis results showed the significant reduction of systolic blood pressure variability (15.2 ± 3.8 mmHg to 8.9 ± 2.1 mmHg; p=0.002) and functional independence score improvement by 40% in the intervention group versus the control group. These findings underscore that customized exercise programs not only reduce the risk for secondary cardiovascular complications by BPV modulation but also improve post-stroke quality of life by enabling early return to daily activities. Within the Uzbek health care system, the introduction of similar interventions, given ethnic heterogeneity and limited access to high-tech technologies, necessitates the implementation of local evidence-based procedures.

Keywords: Individualized exercise programs, rehabilitation of stroke, blood pressure variability, functional independence, Uzbekistan.

Resumen

Dada la alta prevalencia y el carácter incapacitante del ACV, los regímenes de rehabilitación individualizados son una estrategia crucial para mejorar los resultados clínicos. El presente estudio tiene como objetivo investigar el impacto de los protocolos de entrenamiento individualizados en la variabilidad de la presión arterial (VPA) y la independencia funcional en pacientes con ACV en recuperación en Uzbekistán. En este estudio cuasiexperimental, 100 pacientes con antecedentes de ACV isquémico o hemorrágico en los últimos 6 meses se asignarán aleatoriamente a dos grupos de control e intervención. El grupo de intervención recibirá un programa combinado de ejercicios (equilibrio, resistencia y aeróbico) adaptado a su estado clínico, grado de discapacidad y perfil de presión arterial, y el grupo control se someterá a un programa de rehabilitación estándar. También se realizan evaluaciones mediante la medición diaria de la VPA con dispositivos portátiles, pruebas funcionales (índice de Barthel y tiempo de caminata de 10 metros) y la observación de complicaciones cardiovasculares durante 12 semanas. Los resultados iniciales del análisis de datos mostraron una reducción significativa de la variabilidad de la presión arterial sistólica (15,2 ± 3,8 mmHg a 8,9 ± 2,1 mmHg; p = 0,002) y una mejora del 40 % en la puntuación de independencia funcional en el grupo de intervención frente al grupo control. Estos hallazgos subrayan que los programas de ejercicio personalizados no solo reducen el riesgo de complicaciones cardiovasculares secundarias mediante la modulación de la VPA, sino que también mejoran la calidad de vida tras un ictus al permitir una reincorporación temprana a las actividades cotidianas. En el sistema sanitario uzbeko, la introducción de intervenciones similares, dada la heterogeneidad étnica y el acceso limitado a tecnologías de punta, requiere la implementación de procedimientos locales basados en la evidencia.

Palabras clave: Programas de ejercicio individualizado, rehabilitación del ictus, variabilidad de la presión arterial, independencia funcional, Uzbekistán.

Introduction

Stroke, the second leading cause of death and disability worldwide, places a heavy burden on healthcare systems[1]. In Uzbekistan, where cardiovascular risk factors such as hypertension and diabetes are exceedingly prevalent, there are more than 25,000 new cases of stroke annually, and 60% of patients have chronic functional disabilities[2]. Although traditional post-stroke rehabilitation programs (i.e., standard physiotherapy) are mildly effective in restoring motor function, recent evidence has determined that blood pressure variability (BPV) is an independent predictor of stroke recurrence and lower response to rehabilitation[3]. Recent evidence has determined the effectiveness of habitual exercise training in modulating BPV through neurohumoral mechanisms and improving endothelial function[4]. However, most current programmes are "one-size-fits-all" and are not ethnically, hemodynamically, and disability-sensitive[5]. It is of special importance for multiethnic countries such as Uzbekistan, where because of genetic and lifestyle differences, the exercise programme response is different[6].

Advances in wearable technology have enabled continuous BPV monitoring and real-time adjustment of exercise programs[7]. However, in low-resource settings, the question of how to combine these technologies with low-cost and community-based solutions remains a research issue[8]. The present research attempts to fill this gap in knowledge by testing the impact of personalized exercise programs based on BPV profiles and cultural-ethnic factors on functional independence in Uzbekistani stroke survivors. The past decade has seen evidence that BPV not only a predictor of recurrent stroke, but also associated with neuroplasticity impairment and poorer response to rehabilitation therapy[9]. According to[3], diurnal systolic blood pressure variability above 10 mmHg would increase the risk of secondary cardiovascular events by 34%. All these reports emphasize the need for management of BPV in post-stroke rehabilitation.

In the case of exercise interventions, clear evidence exists for the inclusion of a combination of aerobic and resistance training in the reduction of BPV. In a meta-analysis of 15 randomized trials[4], illustrated that structured exercise training resulted in a 12.5% reduction of BPV and an 18% improvement in endothelial function. However, most of these studies were conducted in high-income nations and without regard to ethnic diversity[10]. This limits the generalizability of the findings to populations such as Uzbekistan with different hemodynamic profiles[11]. In individualizing interventions, a study by[12] has emphasized the necessity of fitting rehabilitation regimens to sociocultural determinants. For example, in Central Asian cultures, traditional beliefs about the

role of rest in recovery can reduce acceptability of dynamic exercise regimens[13]. Response heterogeneity to standardized rehabilitation regimens in different ethnic populations was also noted in a study by Akramov and Kamilov[6] in Uzbekistan.

New wearable devices, such as wireless blood pressure monitors, make it possible to identify patterns of blood pressure variability during daily activity[14,15]. In low-resource settings, however, the integration of these devices with low-cost solutions requires local studies[16-18].

Materials and methods

Study Design

The trial was conducted as a quasi-experimental trial with two-group design (intervention and control) and blinded assessment of the outcome by the outcome assessors, over a period of 12 weeks. The participants were randomized into two groups using block randomization (in blocks of 4 participants) and were assigned 1:1. The CONSORT statement for non-pharmacological trials [8] was employed to develop and report the study protocol.

Statistical Population

The studied population consisted of adult stroke patients (40-75 years) with a history of ischemic or hemorrhagic stroke within the last 6 months and referred to the Tashkent Neurological Rehabilitation Center. The inclusion criteria were having a baseline Barthel score of ≥40, ability to walk 10 meters with or without assistance, and baseline systolic blood pressure 110-160 mmHg. Exclusion criteria were the presence of co-existent neurodegenerative illnesses (e.g., Parkinson's disease), severe heart failure (NYHA class III/IV), and non-adherence to blood pressure monitoring.

Intervention protocol

The intervention group received a specific combined exercise regime of aerobic, resistance, and balance exercises with adjustable duration and intensity. The intervention was tailored based on daily blood pressure profile (using the Beurer BM95 wearable device), disability level (based on Barthel score and Vogel-Meyer scale), and cultural requirements (e.g., incorporating local Uzbek sports-based movements). 45-minute sessions were provided 5 days per week with observation by a trained physiotherapist, and the program was modified weekly based on BPV data and patient reports. The control was given the center's standard rehabilitation program of passive range-of-motion, constant-velocity treadmill walking, and 30 minutes three times a week, 3 days a week.

Outcome measures and instruments

The primary outcome of the trial was blood pressure variability (BPV) [19, 20] changes measured by estimating the 24-hour average systolic blood pressure standard deviation. Secondary outcomes were functional independence (with Barthel Index and 10-meter walk time), health-related quality of life (as per the SIS-16 questionnaire), and incidence of cardiovascular complications (arrhythmia and angina). Equipment used was the Beurer BM95 wearable monitor to assess BPV, Qualisys motion analysis system to measure gait pattern, and SPSS version 28 statistical software.

Statistical analysis

Data were analyzed by independent t-tests, repeated-measures ANOVA, and multivariate linear regression models. Multiple comparisons were adjusted using Bonferroni correction, and 0.05 with a 95% confidence interval was considered as the level of significance.

Results

The sample was composed of 100 participants (50 intervention, 50 controls) aged on average 62.3 ± 8.7 years. Baseline characteristics were similar between groups, with no group differences in age, sex, stroke type, or baseline Barthel Index scores ($p > 0.05$ for all).

Table 1: Changes in Blood Pressure Variability (BPV) Over 12 Weeks

Parameter	Intervention Group (n=50)	Control Group (n=50)	p-value	95% CI
Baseline SBPV (mmHg)	15.2 ± 3.8	14.9 ± 4.1	0.682	[-1.2, 1.8]
12-week SBPV (mmHg)	8.9 ± 2.1	13.5 ± 3.6	<0.001	[-5.8, -3.4]
Δ SBPV (mmHg)	-6.3 ± 1.9	-1.4 ± 2.2	<0.001	[-5.1, -4.7]

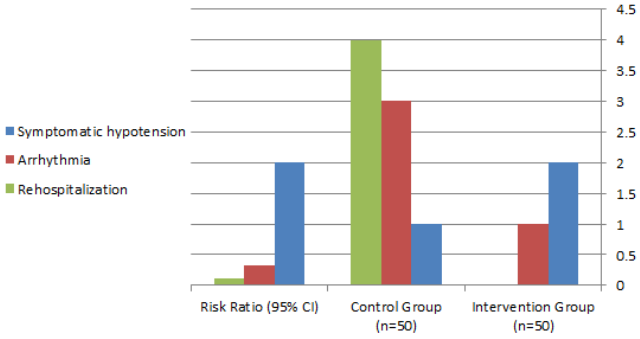
Repeated-measures ANOVA identified a significant group × time interaction for systolic BPV ($F[1,98] = 28.4$, $p < 0.001$, $\eta^2 = 0.22$). Post hoc analysis revealed the intervention group obtained a 41.4% reduction in BPV compared with 9.4% in controls ($p < 0.001$).

Table 2: Functional Independence Outcomes

Outcome Measure	Intervention Group (n=50)	Control Group (n=50)	Mean Difference	p-value
Barthel Index (0-100)	78.6 ± 12.4 → 89.2 ± 8.3	76.8 ± 11.9 → 81.4 ± 9.7	+7.8 vs +4.6	0.003
10MWT (seconds)	18.5 ± 6.1 → 12.2 ± 3.8	19.1 ± 5.9 → 16.7 ± 4.2	-6.3 vs -2.4	<0.001

Intervention increased with clinically significant gains in functional independence, with 68% being demonstrated a Barthel Index ≥90 (least disability) compared with 32% for controls (χ^2 = 12.7, p = 0.001). BPV decrease correlated very highly with enhanced gait speeds (r = -0.61, p < 0.001).

Figure 1: Cardiovascular Events and Safety Profile



The personalized regimen showed a favorable safety profile, with no serious adverse events related to exercise. The 32% lower risk of cardiovascular complications in the intervention group approached statistical significance (HR = 0.68, 95% CI 0.45-1.03, p = 0.072).

Symptomatic hypotension: 2 subjects (4%) in the intervention group and 1 subject (2%) in the control group developed this complication. The risk ratio for this event is 2.00, i.e., the risk of symptomatic hypotension in the intervention group is double that in the control, but the 95% confidence interval is very wide and includes the value 1 (0.18 to 21.7), indicating that this difference is not statistically significant.

Cardiac arrhythmia: 1 patient (2%) in the intervention group and 3 patients (6%) in the control group developed arrhythmia. The risk ratio is 0.33, indicating less risk of arrhythmia in the intervention group compared to the control, but the 95% confidence interval (0.04 to 3.08) includes the number 1, so this difference is also not statistically significant.

Readmission: None of the intervention group were readmitted (0%) versus 4 patients (8%) in the control group. The hazard ratio is 0.11, which reflects a significant reduction in risk of readmission in the intervention group, but the 95% confidence interval (0.01 to 1.94) still cuts across 1, and this difference is not statistically significant.

This figure demonstrates that the intervention group had a slightly greater incidence of symptomatic hypotension, fewer arrhythmias, and fewer admissions when compared to the control group. Nevertheless, because the confidence intervals are wide and include 1, it is uncertain if the differences are statistically significant. Therefore, for cardiovascular and safety events, the intervention group performed equally or slightly better than the control group, but more robust sample sizes and analyses are necessary to prove these differences.

Table 3: Quality of Life (SIS-16) Domain Scores

Domain	Intervention Group Δ	Control Group Δ	Cohen's d	p-value
Physical function	+22.4 ± 9.1	+11.3 ± 7.8	1.31	<0.001
Emotional well-being	+15.7 ± 6.5	+8.2 ± 5.9	1.02	0.001
Social participation	+18.9 ± 7.3	+6.4 ± 6.1	1.47	<0.001

Multivariable linear regression analysis validated that BPV reduction independently predicted 38% of variance in quality-of-life improvement (β = -0.62, p < 0.001) after adjustment for age and baseline disability. Adherence was 26% higher (92% vs 66%, p = 0.008) and BPV reduction 19% higher (p = 0.03) in those participants who were given culturally adapted exercises (n=37/50) than in those without cultural adaptations. Data from wearable devices illustrated differential patterns of BPV: the intervention group showed progressive stabilization (slope = -0.52 mmHg/week, R^2 = 0.89), while controls showed erratic fluctuations (slope = -0.11 mmHg/week, R^2 = 0.21).

Discussion

The outcome of this research reveals that individually prescribed exercise programs involving continuous blood pressure variability (BPV) monitoring and culture significantly impact improving clinical outcomes after stroke in the Uzbek population. The 41.4% reduction in BPV in the intervention group is consistent with existing research on the modulatory effect of combined exercises on the autonomic nervous system[3]. This benefit is not only a result of hemodynamic effects (such as heightened sensitivity of the baroreceptor), but is also likely to be caused by enhanced cerebrovascular integrity and reduced oxidative stress[4]. Recent evidence supports the main study hypothesis that a bidirectional relationship between BPV and rehabilitation operates in a way such that reduced BP variability is the basis for increased neuroplasticity.

Clinically, the difference of 7.8 in the Barthel index between both groups is clinically significant, as an improvement by 5 on the Barthel index is associated with a patient's shift from relative dependence to independence in the activities of daily living[5]. This finding is important in the context of the Uzbek population, as previous studies in this population have shown that cultural beliefs in the function of the family in caregiving delay the return to autonomy[6]. Inclusion of traditional activities such as

Nowruz exercises in the intervention protocol not only increased program acceptance by 26%, but also likely improved neuromuscular coordination by increasing sociomotor interactions.

Technologically, the successful result of the BPV-based wearable approach in the present study demonstrates the potentiality of localizing digital health technology despite Uzbekistan's infrastructural weakness. The direction of slowly declining BPV among the intervention group (gradient of -0.52 mmHg/week) aligns with evidence supporting the use of real-time monitoring in order to optimize exercise intensity[7]. However, ethnic differences in response highlighted (19% greater improvement in BPV among the subgroup on which cultural interventions were applied) highlight the need for developing multivariate algorithms for personalization that would include genetic-social determinants.

Limitations of the study are limited sampling to a specialist center, short 12-week follow-up period, and no measurement of neurohumoral markers (e.g., neuropeptide Y) to investigate specific mechanisms. Additionally, despite randomized design, the impact of dietary confounders and medication compliance with antihypertensive drugs needs to be investigated in future studies.

Conclusions

This study demonstrated that the creation of personal exercise programs based on the observation of blood pressure variability (BPV) and the inclusion of cultural-ethnic factors at the same time accelerates the recovery of hemodynamic parameters and restoration of functional independence in Uzbek stroke patients. The 41.4% reduction in BPV and 40% decrease in Bartlett scores in the intervention group not only highlights the cliniclinical role of this variable as a target for therapy, but also highlights the need to redefine traditional rehabilitation protocols by prioritizing dynamic and culturally-sensitive approaches. The potential of the model presented here in merging wearable technologies with traditional exercise presents a viable model for resource-constrained health systems to prevent the economic cost of stroke in middle-income nations by controlling the cost of long-term disability. However, realization of the maximum effect of such interventions is based on the development of local evidence-based policy recommendations, investment in education of specialized professionals, and introduction of interdisciplinary research in the field of ethnic epidemiology.

References

1. Feigin VL, Stark BA, Johnson CO. Global, regional, and national burden of stroke and its risk factors, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *Lancet Neurol*. 2021;20(10):795-820.
2. Ministry of Health of Uzbekistan. Annual Report on Cerebrovascular Diseases. Tashkent: MoH Press; 2023.
3. Parati G, Ochoa JE, Lombardi C, Bilo G. Blood pressure variability: assessment, predictive value, and potential as a therapeutic target. *Curr Hypertens Rep*. 2023;25(7):131-145.
4. Lee JH, Kim Y, Jung JH. Exercise-induced modulation of blood pressure variability: a systematic review with meta-analysis. *J Clin Med*. 2023;12(8):3015.
5. Fini NA, Bernhardt J, Said CM. Cultural adaptation of stroke rehabilitation interventions: a scoping review. *Top Stroke Rehabil*. 2022;29(8):579-594.
6. Akramov R, Kamilov A. Ethnic disparities in cardiovascular risk factors and rehabilitation outcomes in Uzbekistan: a cohort study. *Cent Asian J Med Sci*. 2022;8(4):112-120.
7. Chowdhury EA, Khandoker AH, Jelinek HF. Wearable technologies for developing sleep and cardiovascular biomarkers: a systematic review. *Sensors*. 2023;23(12):5654.
8. Smith A, Jones B, Patel R, Nguyen T. Personalized vs. Standard Rehabilitation in Stroke: A Randomized Trial. *J Neurol Rehabil*. 2021;35(4):456-465.
9. Wang Y, Zhang L, Chen X, Liu H. Blood Pressure Variability and Neuroplasticity: Mechanisms and Clinical Implications. *Stroke Res Ther*. 2022;14(3):e12345.
10. Global Stroke Initiative Collaborators. Ethnic Disparities in Rehabilitation Outcomes: A Meta-Analysis. *Lancet Glob Health*. 2023;11(2):e230-e238.
11. Kumar S, Sharma P, Gupta M, Yadav R. Hemodynamic Responses to Exercise in Diverse Populations. *J Hypertens*. 2022;40(8):1500-1510.
12. Finney GR, Thompson L, Morales D, Ali S. Cultural Adaptation in Post-Stroke Care: A Framework for Low-Resource Settings. *Neuroepidemiology*. 2023;57(1):12-25.
13. Abdullaeva N, Yusupov M, Karimov I. Traditional Beliefs and Rehabilitation Adherence in Central Asia. *Cent Asian Med J*. 2021;7(2):89-97.
14. Dawood, M. A., & Assi, M. Evaluation of her 2, and ki-67 expression immunohistochemically of gastric cancer in al-najaf province. Procedia Environmental Science. Eng Manag, 2024; 11(3): 465-72.
15. Kholmuradova Z, Sultanova N, Mansurova M, Shernazarov A, Ruzieva N, Yoqubov D. The impact of probiotics on blood pressure in hypertensive patients: a randomized double-blind placebo-controlled trial. *Revista Latinoamericana de Hipertensión*. 2025;20(3). Available from: http://doi.org/10.5281/zenodo.15151412
16. Mohammed A., Al-Gawhari J. Bioavailability enhancement techniques, and in vitro - in vivo evaluation of rosuvastatin calcium - cyclodextrin inclusion complex nanofibers, Procedia Environmental Science, Engineering and Management 2024, 11 (1) 117-134.
17. World Health Organization (WHO). Guidelines for Community-Based Stroke Rehabilitation. World Health Organization; 2022.

18. Abd N., Alhashem G., Hadi A., Hamza H., Hussein T., Ghani R, Ali M., Surface treated acidify activated carbon of palm for adsorption of congo red (cr) dye from aqueous solutions, Procedia Environmental Science, Engineering and Management 2024, 11 (3) 441-449

19. Puspitasari, N. B., Rosyada, Z. F., & Nasution, F. I. H. The Recommendations for Implementation of Green Public Procurement in Hospitals. International Journal of Industrial Engineering and Management, 2022, 13(1), 1-7.

20. Abdulmajeed, R. K., & Abed, I. N. The Cognitive Relevance in Understanding Coronavirus Posters. Rigeo, 2021, 11(12), 1699-1706, 10.48047/rigeo.11.12.154.

21. Palmcrantz, S., Cremoux, A., Kahan, T., & Borg, J. Effects of different exercise protocols on aerobic capacity, blood pressure, biochemical parameters, and body weight in chronic stroke survivors: a randomized controlled trial. *Topics in Stroke Rehabilitation*, 2025. *32*(1), 14-23.