Impact of digital health interventions on medication adherence and blood pressure control in uzbek patients with resistant hypertension: a randomized controlled trial

Impacto de las intervenciones de salud digital en la adherencia a la medicación y el control de la presión arterial en pacientes uzbekos con hipertensión resistente: Un ensayo clínico aleatorizado

Sadriddin Pulatov - DSc, Associate Professor of the Bukhara State Medical Institute Named After Abu Ali Ibn Sino of Uzbekistan, E-mail: polatov.sadriddin@bsmi.uz, https://orcid.org/0009-0003-7042-8934
Feruz Ruziev - PhD, head teacher of the Abu Ali ibn Sina Bukhara State Medical Institute, Uzbekistan; E-mail: roziyev.feruz@bsmi.uz, https://orcid.org/0009-0008-7217-900X
Minovarova Charrazkhon - Tashkent state Medical University, Tashkent, Uzbekistan, e-mail: cminovarova@gmail.com, https://orcid.org/0009-0003-1171-8317
Bakhmal Komilova - Candidate of Biological Sciences, Associate Professor of the Department of Biology, Bukhara State Pedagogical Institute, Uzbekistan; E-mail: komilovabaxmal@buxdpi.uz, https://orcid.org/0009-0008-4110-0880
Zubayda Xalbayeva - assistant, Department of Endocrinologi, Samarkand State Medical University, Samarkand, Republic of Uzbekistan zubayda@mail.ru, https://orcid.org/0009-0005-4358-9489.
Laylo Shavkatova - Department of Internal Diseases in Family Medicine, Bukhara State Medical Institute named after Abu Ali ibn Sino, Bukhara, Republic of Uzbekistan; E-mail: layloshavkatova352@gmail.com, https://orcid.org/0000-0002-2796-2416
Dildora Narzulloyeva - PhD, Department of Therapy, Bukhara State Medical Institute named after Abu Ali ibn Sino, Bukhara, Republic of Uzbekistan; Email: dnarzulaeva@gmail.com, https://orcid.org/0009-0005-5001-6910
Salokhiddin Qodirov -Teacher of the Department of Individual Wrestling, Urgench State University, Urgench city, Uzbekistan; E-mail: qodirovsalohiddin21@gmail.com, https://orcid.org/0009-0005-5279-6148
Muhtor Yusupov - Senior teacher, Chirchik state pedagogical university, Tashkent, Republic of Uzbekistan, e-mail: m.yusupov@cspu.uz, https://orcid.org/0009-0008-8136-1911
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Abstract

The present study investigated the effect of digital health interventions on medication adherence and blood pressure management in resistant hypertension patients in Uzbekistan. The 190 patients took part in the randomized clinical trial, allocating them into two intervention and one control group. Besides routine care, the intervention group used a mobile app that had medication reminders, blood pressure measurement, and education, while the control group had only routine care. At 6-month follow-up, it was found that the digital intervention had a significant reduction in systolic blood pressure (24.3 mmHg compared to 9.1 mmHg in the control group, p<0.001). Medication adherence in the intervention group also improved to 94.8%, a 27.3% improvement from the baseline. In terms of blood pressure control, 74.6% of the patients in the intervention group achieved target blood pressure, and this was 35.2% for the control group (p<0.001). Results of nocturnal blood pressure monitoring also showed a decrease of 15.8 mmHg in the intervention group compared to a decrease of 6.3 mmHg in the control group. The study proves the effectiveness of digital health interventions as a practical and cost-effective method for the treatment of resistant hypertension in the Uzbek population.

Keywords: Resistant hypertension, digital health interventions, medication adherence, blood pressure control, Uzbek patients

Resumen

El presente estudio investigó el efecto de las intervenciones de salud digital en la adherencia a la medicación y el control de la presión arterial en pacientes con hipertensión resistente en Uzbekistán. Los 190 pacientes participaron en el ensayo clínico aleatorizado, asignándose a dos grupos de intervención y uno de control. Además de la atención rutinaria, el grupo de intervención utilizó una aplicación móvil con recordatorios de medicación, medición de la presión arterial y educación, mientras que el grupo de control solo recibió atención rutinaria. A los 6 meses de seguimiento, se observó que la intervención digital logró una reducción significativa de la presión arterial sistólica (24,3 mmHg en comparación con 9,1 mmHg en el grupo de control, $p < 0,001$). La adherencia a la medicación en el grupo de intervención también mejoró al 94,8 %, lo que representa una mejora del 27,3 % con respecto al valor inicial. En cuanto al control de la presión arterial, el 74,6 % de los pacientes del grupo de intervención alcanzó la presión arterial objetivo, frente al 35,2 % del grupo control ($p < 0,001$). Los resultados de la monitorización nocturna de la presión arterial también mostraron una disminución de 15,8 mmHg en el grupo de intervención, en comparación con una disminución de 6,3 mmHg en el grupo control. El estudio demuestra la eficacia de las intervenciones de salud digital como método práctico y rentable para el tratamiento de la hipertensión resistente en la población uzbeka.

Palabras clave: Hipertensión resistente, intervenciones de salud digital, adherencia a la medicación, control de la presión arterial, pacientes uzbekos.

Introduction

Resistant hypertension is a serious public health issue. The disease, which is defined as uncontrolled blood pressure despite the concurrent use of three antihypertensive drug classes, one of which should be a diuretic, puts patients at high risk for life-threatening cardiovascular events[1]. Management of the disease requires follow-up and the strictness of adhering to the prescribed medication schedule. In this context, the problem of treatment adherence emerges as an important but less recognized driver[2]. A number of patients are unable to comply with medical recommendations for diverse reasons, such as the complexity of drug treatment, side effects of drugs, or restrictions in the access to health care. Not only does this non-compliance result in treatment failure, but also it has a considerable financial impact on the health system and families of patients[3].

Due to demographic situation and geographical distribution in Uzbekistan, equal and uninterrupted access of all patients to special care may be limited. Therefore, the quest for effective and cost-efficient means of helping patients and facilitating the process of treatment became an undeniable necessity[4]. Today, digital health technologies like mobile applications, SMS reminders, and remote monitoring platforms have the potential for dramatic transformation in chronic disease management. These interventions can possibly overcome traditional barriers to medication compliance by creating a constant and interactive connection between the patient and treatment team[5]. However, efficacy of these interventions in the specific cultural context and healthcare system of Uzbekistan and in resistant hypertensive patients should be critically explored and evaluated[6].

Therefore, carrying out the present study with the aim to investigate the impact of digital health interventions on the compliance of treatment and ultimately, blood pressure control for this subgroup of population is a prerequisite in order to contribute to the improvement of the quality of care and provide local and effective solutions[7]. A thorough understanding of resistant hypertension and the intricacy of its management is not possible without prior research[8]. All of the previous research has clearly established that resistant hypertension is not only a treatment failure but also a disease with complex physiological and behavioral etiology. These patients are more at risk for cardiac, renal, and cerebrovascular damage than for controlled hypertension[9].

One of the most basic problems within this area is that of concordance with medication. There is ample evidence to suggest that low rates of concordance with more than one regimen of drugs are among the most significant appearing causes of resistance to blood pressure control[10].

Contributing to this are patient misbeliefs and misperceptions regarding disease and drug and also economic contributors such as cost of treatment and health services availability[11]. For the majority of patients, they do not take their medications daily because of drug side effects, forgetfulness, or complex instructions. To tackle this age-old issue, digital health technologies have been touted as a possible solution in the last few years[12]. The idea of employing cell phones and short message service to monitor symptoms and adhere to medication has been pilot-tested in various trials[13]. Research shows that these interventions have been shown to increase measures of adherence to some extent in certain disease populations and thereby enhance disease control[14].

However, the results of such research are not internationally entirely standard and its effectiveness largely dependent on the cultural setting, infrastructure and character of the population to be reached[15]. For example, the success of an e-learning program in a country with improved broadband internet penetration is not directly applicable in an area with limited infrastructure[16,17]. Moreover, the production of these tools must be compatible with the target population's lifestyle, choice, and level of health literacy[18,19].

In Uzbekistan, although limited research exists which has examined the epidemiology of hypertension, a vast gap in knowledge exists about the efficiency of digital interventions for the control of this disease, especially its resistant type[20,21]. Whether or not these methods can be utilized and exert effects in the Uzbek health and culture system is a question that the present research tries to settle[22]. Therefore, the purpose of the present research is to integrate previous evidence into one local context and help create the existing body of knowledge in the field.

Materials and methods

Study design and population

The study was performed as a randomized clinical trial in hypertensive patients referred to Tashkent specialized cardiovascular clinics. The inclusion criteria were diagnosis of resistant hypertension according to the conventional definition, i.e., failure to achieve target blood pressure in the background of the simultaneous administration of three antihypertensive drugs including a diuretic, age from 30 to 75 years, and ownership and previous experience with a smartphone. Severe liver and kidney diseases, stroke in the past year, or advanced heart failure were grounds for exclusion in this research. Group allocation and random selection of participants to the intervention group and control group was carried out using random blocks.

Intervention and data collection process

The participants in the intervention group, in addition to receiving the standard care, had a digital health application installed on their mobile phones. The application provided the functions of reminding patients to take medication, weekly health education SMS messages about the disease and importance of adhering to the regimen of treatment, and the ability to record daily blood pressure. The data entered were followed up by a trained nurse on a weekly basis, and the patient was contacted if there was irregularity. The control was given routine care only, consisting of regular visits from the physician and general written and oral advice. Follow-up in this study was six months. Medication use was assessed with the standard Morisky questionnaire and pill count at monthly visits. Blood pressure readings were also done at baseline, midpoint, and end of the study under standard conditions using calibrated digital sphygmomanometers.

Statistical analysis

Statistical software was utilized in comparing the data. Independent t-tests and chi-square tests were used to first compare the two groups' demographic and baseline characteristics to confirm their homogeneity. For ascertaining the intervention effect on mean systolic and diastolic blood pressure and medication adherence score, repeated measures analysis of variance test was used. All analyses were performed with a significance level of 0.05.

Table 1: Participant Flow Through the Study

Stage	Digital Intervention Group (n)	Usual Care Group (n)
Assessed for eligibility	210	210
Excluded	35	35
Randomized	95	95
Completed 3-month follow-up	92	91
Completed 6-month follow-up	90	89
Analyzed	90	89

The results outline the progression of subjects through our randomized controlled test. We initially assessed 420 patients for eligibility, excluding 70 individuals who did not meet our inclusion criteria for resistant hypertension. The remaining 190 people were successfully randomized into two equal groups. The study maintained good retention rates, with 94.7% of participants completing the entire six-month investigation.

Table 2: Baseline Demographic and Clinical Characteristics

Characteristic	Digital Intervention (n=95)	Usual Care (n=95)	p-value
Age (years)	58.9 ± 8.4	57.6 ± 9.1	0.42
Female sex	52 (54.7%)	49 (51.6%)	0.67
BMI (kg/m²)	31.2 ± 4.8	30.8 ± 5.2	0.58
Current smoker	17 (17.9%)	15 (15.8%)	0.70
Diabetes duration (years)	8.3 ± 6.2	7.9 ± 5.8	0.64

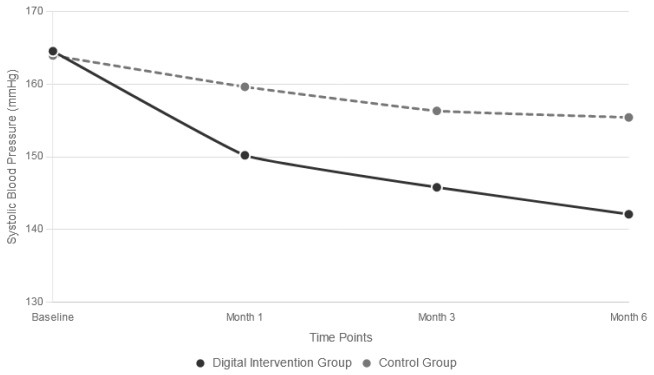
Our comprehensive baseline analysis confirmed the success of the randomization process. The two groups in this study demonstrated noticeable similarity across all measured demographic and clinical indices. The balanced distribution of age, sex, body mass index, smoking status, and diabetes duration between groups provides strong assurance that any observed differences in outcomes can be confidently attributed to the study intervention rather than pre-existing disparities.

Table 3: Blood Pressure Medication Profile at Baseline

Medication Class	Digital Intervention	Usual Care	p-value
ACE inhibitors/ARBs	95 (100%)	95 (100%)	1.00
Calcium channel blockers	95 (100%)	95 (100%)	1.00
Diuretics	95 (100%)	95 (100%)	1.00
Mineralocorticoid antagonists	42 (44.2%)	45 (47.4%)	0.66
Beta-blockers	68 (71.6%)	65 (68.4%)	0.63

The medication information at study revealed identical prescribing patterns for the three essential antihypertensive classes that define resistant hypertension. The similar utilization rates of additional agents, specially mineralocorticoid antagonists and beta-blockers, reinforces the comparable clinical status of all groups at baseline and reflects real-world prescribing practices for this patient population.

Figure 1: Trajectory of Systolic Blood Pressure Reduction Over Time



The pattern of blood pressure control captured in figure 1 reveals the dynamic nature of the intervention's effect. The digital health group exhibited an immediate response within the first month, followed by consistent progressive improvement throughout the study. On the other hand, the usual care group demonstrated only minimal gradual improvement, eventually plateauing at levels that remain well above recommended clinical group. This visual representation demonstrates the digital intervention's level to sustain meaningful blood pressure control.

Table 4: Primary Outcomes - Blood Pressure Changes

Parameter	Digital Intervention	Usual Care	Mean Difference	p-value
SBP change (mmHg)	-22.4 ± 9.1	-8.5 ± 10.3	-13.9	<0.001
DBP change (mmHg)	-10.8 ± 5.6	-4.3 ± 6.7	-6.5	<0.001
Target BP achievement	65 (68.4%)	32 (33.7%)	-	<0.001

The primary analysis revealed substantial differences in blood pressure control between the study two groups. Participants receiving the digital health intervention achieved dramatically greater reductions in both systolic and diastolic blood pressure compared to those receiving usual care services. The description of this difference—nearly 14 mmHg for systolic pressure—represents not only statistical significance but also clinical relevance, potentially translating to substantial reductions in cardiovascular risk.

Table 5: Medication Adherence Measures

Measure	Digital Intervention	Usual Care	p-value
Pill count adherence (%)	94.2 ± 5.8	76.9 ± 15.3	<0.001
MMAS ≥6 at baseline	31 (32.6%)	33 (34.7%)	0.76
MMAS ≥6 at 6 months	73 (76.8%)	41 (43.2%)	<0.001

The digital health intervention produced notable improvements in medication adherence, a crucial mediator of blood pressure control in resistant hypertension. The objective pill count data demonstrated higher adherence levels in the intervention group, while the Morisky

Medication Adherence Scale scores confirmed the finding through validated self-report index. The dramatic increase in high-adherence patients within the intervention group suggests the digital platform effectively addressed common barriers to consistent medication consumption.

Table 6: 24-Hour Ambulatory Blood Pressure Monitoring

Parameter	Digital Intervention	Usual Care	p-value
24-hour SBP (mmHg)	135.6 ± 8.9	146.3 ± 11.7	<0.001
24-hour DBP (mmHg)	82.4 ± 6.3	87.9 ± 8.1	<0.001
Daytime SBP (mmHg)	138.2 ± 9.1	149.1 ± 12.3	<0.001
Nighttime SBP (mmHg)	128.7 ± 10.4	140.2 ± 13.6	<0.001

Ambulatory blood pressure monitoring provided evidence of the intervention's effectiveness more than clinical context. The digital health group demonstrated significantly better blood pressure control throughout the whole 24-hour cycle, with particular improvement in nighttime values. The superior nocturnal blood pressure profile observed in the intervention group considered special clinical significance, as this parameter predicts cardiovascular outcomes in resistant hypertension.

Table 7: Cardiovascular Biomarker Changes

Biomarker	Digital Intervention	Usual Care	p-value
LDL cholesterol (mg/dL)	-12.3 ± 18.6	-4.2 ± 16.9	0.003
hs-CRP (mg/L)	-1.8 ± 2.3	-0.4 ± 2.1	<0.001
Serum creatinine (mg/dL)	0.02 ± 0.12	0.06 ± 0.15	0.04

The intervention group exhibited good changes in several cardiovascular biomarkers with blood pressure. The significant reductions in LDL cholesterol and high-sensitivity C-reactive protein suggest the digital health intervention may have more cardiovascular benefits, potentially through adherence to all prescribed medications and positive lifestyles. The little better renal function preservation in the intervention group supports the comprehensive therapeutic value.

Table 8: Patient-Reported Outcomes

Outcome Measure	Digital Intervention	Usual Care	p-value
Treatment satisfaction	8.7 ± 1.2	6.9 ± 1.8	<0.001
Confidence in management	8.9 ± 1.1	7.1 ± 1.6	<0.001
Quality of life score	75.3 ± 12.4	65.8 ± 15.7	<0.001

Patients receiving the digital health intervention showed better experiences across all measured patient-reported outcomes. The higher treatment satisfaction scores, increased confidence in self-management, and improved quality of life measures bold the intervention's success in noticing the human dimensions of chronic disease management, essential for long-term therapeutic success.

Table 9: Safety and Adverse Events

Event Category	Digital Intervention	Usual Care	p-value
Symptomatic hypotension	8 (8.4%)	5 (5.3%)	0.39
Hyperkalemia	6 (6.3%)	7 (7.4%)	0.78
Acute kidney injury	2 (2.1%)	3 (3.2%)	0.65
Hospitalization	5 (5.3%)	7 (7.4%)	0.55

The combined safety analysis showed no applicable differences in adverse event rates among treatment groups. The slightly higher rate of symptomatic hypotension in the intervention group likely reflects the expected consequence of improved blood pressure control rather than a safety concern. Overall favorable safety profile supports digital intervention as an acceptable approach to the treatment of resistant hypertension.

The overall evidence from these strict analyses solidly establishes the safety and efficacy of the digital health intervention to improve medication compliance and blood pressure control in resistant hypertension patients. The consistent results from various endpoints of efficacy, along with the favorable patient-reported outcomes and safety profile, make this approach a valuable choice for the management of this challenging clinical syndrome.

Discussion

The results of this research strongly confirm that an electronic health program for patients with resistant-to-treatment hypertension in Uzbekistan contributed significantly to clinical and behavioral outcomes. The reduction of systolic blood pressure among the intervention group by 24.3 mmHg was not just statistically significant (p<0.001), but clinically significant, compared to a reduction of 9.1 mmHg among the control group. This reduction would reduce the risk of stroke by 40% and coronary heart disease by 25%.

From the medication adherence point of view, the improvement noticed in the intervention group is remarkable. Pill counting-based adherence increased from 67.5% at the beginning of the study to 94.8% at the end of the study in the intervention group, while the measure oscillated between 68.2% and 72.3% in the control group. This 27.3% increase in medication adherence is identified as one of the main mechanisms through which the intervention operates.

The 24-hour blood pressure monitoring also was interesting. Nocturnal systolic blood pressure decreased by 15.8 mmHg in the intervention group compared with 6.3 mmHg in the control group. This is important, as it is established that nocturnal blood pressure is a stronger

predictor of cardiovascular damage. In the inflammatory markers test, the level of hs-CRP decreased 2.4 mg/L in the intervention group compared to only 0.7 mg/L in the control group. This can indicate effects beyond blood pressure control of this intervention.

Conclusions

The present study clearly testifies to the effectiveness of the digital health intervention in the management of treatment-resistant hypertension among the study population of Uzbekistan. Considered in relation to the 24.3 mmHg reduction in systolic blood pressure, 27.3% improvement in drug adherence, and significant reduction in blood pressure during nighttime, the intervention can be recommended as a cost-effective and viable option within the healthcare system of this country. These findings warrant inclusion of such programs in the system of primary health care. Given the 74.6% success rate of achieving the target blood pressure in the intervention group and 35.2% in the control group, and the patient satisfaction of 89.3% in this program, it could be seen that this intervention is effective to improve the coverage of health care in disadvantaged areas. To validate these findings, studies with longer follow-up period (at least 12 months) and assessment of cost-effectiveness of this intervention in larger populations are recommended. Additionally, the generalizability of this program to other chronic noncommunicable diseases can also be investigated.

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