

IMPACT OF DIGITAL HEALTH INTERVENTIONS ON DRUG COMPLIANCE AND OUTCOMES AMONG ASTHMATIC CHILDREN IN PAKISTAN

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Abstract

Background: Pediatric asthma is a growing public health concern in Pakistan, often compounded by poor medication adherence and low asthma control levels. Digital health interventions (DHIs) are emerging as promising tools to enhance treatment compliance and improve clinical outcomes.

Objective: This study aimed to evaluate the effectiveness of DHIs in improving medication adherence and clinical outcomes among asthmatic children in Pakistan.

Methods: A prospective, randomized controlled trial was conducted at Children's Hospital Lahore from January 2024 to January 2025. A total of 240 children aged 6–17 years with diagnosed persistent asthma were randomly allocated to the intervention group (n=120), receiving a DHI package (smart inhaler, mobile app, educational content, and teleconsultations), or to the control group (n=120), receiving standard care. Outcomes measured included medication adherence, Asthma Control Test (ACT) scores, frequency of asthma-related emergency department (ED) visits, and spirometric measures (FEV₁%). Statistical analyses were performed using SPSS v28.

Results: The intervention group demonstrated significantly higher medication adherence (mean 86.2%) vs. the control group (65.5%, $p<0.001$). ACT scores improved more significantly in the intervention group (mean 22.4 vs. 18.1, $p<0.001$). The frequency of ED visits was reduced by 39% in the intervention group. FEV₁ values improved significantly from baseline in the intervention group (mean increase of 13.1%) compared to the control group (4.6%, $p=0.002$).

Conclusion: Digital health interventions significantly improve medication compliance and clinical outcomes among asthmatic children in Pakistan. These findings support the integration of DHIs into routine pediatric asthma management in low- and middle-income countries.

INTRODUCTION

Asthma is one of the most common chronic respiratory conditions among children, affecting approximately 339 million individuals globally (Global Burden of Disease Collaborative Network, 2023). In low- and middle-income countries (LMICs) such as Pakistan, pediatric asthma presents a significant burden due to diagnostic delays, poor disease awareness, limited access to care, and non-adherence to controller medications (Mushtaq et al., 2021; Siddiqui et al., 2022). The World Health Organization (WHO) has emphasized that improving adherence to long-term asthma treatment regimens is vital to reducing morbidity and preventing exacerbations (WHO, 2021).

In Pakistan, studies have reported that fewer than 50% of children regularly adhere to prescribed inhaled corticosteroids (ICS), which are the cornerstone of asthma management (Khalid et al., 2022; Baig et al., 2020). Non-adherence is multifactorial and includes poor caregiver knowledge, social stigma, lack of follow-up, and challenges in medication access (Rasheed et al., 2021). Compounding this issue is the limited availability of pediatric pulmonologists and structured asthma education programs in public health facilities (Hussain et al., 2022).

Digital health interventions (DHIs) offer a promising solution to bridge these gaps in care. DHIs include a broad set of tools such as mobile health applications, Bluetooth-enabled smart inhalers, teleconsultations, and patient engagement platforms (Majeed et al., 2023). These technologies can facilitate real-time monitoring of medication usage, provide individualized education, enable timely clinical feedback, and enhance self-management behaviors (Chaudhry et al., 2022; Nazir et al., 2023). Globally, several randomized controlled trials have shown that the integration of DHIs into asthma care improves adherence, symptom control, and lung function parameters (Chan et al., 2021; Milani et al., 2022). However, data from Pakistan and other South Asian LMICs remain scarce.

This study, conducted at a tertiary pediatric care center in Pakistan, aimed to evaluate the impact of a comprehensive digital health intervention package on medication adherence and clinical outcomes among children with persistent asthma. By

generating local evidence, this research seeks to inform policy and guide the integration of DHIs into national asthma control strategies.

METHODOLOGY

Study Design and Setting

A 12-month, single-center, prospective randomized controlled trial was conducted at the Pediatric Pulmonology Department of Children's Hospital Lahore, a leading tertiary care hospital in Pakistan, from January 2024 to January 2025. The study received ethical approval from the Institutional Review Board of King Edward Medical University (Ref No: KEMU/IRB/2023/CH-028).

Participants

Children aged 6 to 17 years with physician-diagnosed persistent asthma (as defined by GINA 2022 criteria) and prescribed daily ICS therapy were eligible for inclusion. Exclusion criteria included:

- Comorbid chronic respiratory diseases (e.g., cystic fibrosis, bronchiectasis)
- Cognitive or developmental impairments limiting use of mobile technology
- Previous participation in digital asthma management programs

Written informed consent was obtained from parents/guardians, and assent was obtained from children aged ≥ 10 years.

Sample Size Calculation

The primary outcome was medication adherence. According to previous regional studies (Khalid et al., 2022), the mean adherence rate under standard care is approximately 65%. A 15% improvement in adherence (to 80%) was considered clinically significant. Using a two-sided alpha of 0.05 and power of 90%, the sample size was calculated using the formula for comparing two means:

Using Sample Size Formula for Comparing Two Independent Means (Two-Sample t-test) (Charan, J., & Biswas, T., 2013);

$$n = \frac{2 \times (Z_{1-\alpha/2} + Z_{1-\beta})^2 \times \sigma^2}{\delta^2}$$

Where:

- $Z_{1-\alpha/2} = 1.96$
- $Z_{1-\beta} = 1.28$

- $\sigma=20\%$ (estimated SD of adherence)
 - $\delta=15\%$ (expected difference)
- $$n = \frac{2 \times (1.96 + 1.28)^2 \times (0.20)^2}{(0.15)^2}$$
- n=108 per group
Considering a 10% attrition rate, a total of **240 participants** (120 per group) were enrolled.

Randomization and Blinding

Participants were randomized 1:1 into intervention and control groups using computer-generated block randomization stratified by age group (6–11 vs. 12–17 years) and asthma severity. Outcome assessors and data analysts were blinded to group assignment.

Interventions

- **Intervention Group (n=120):**
 - **Smart Inhaler:** Bluetooth-enabled inhalers logging medication usage.
 - **Mobile App** (Urdu/English): Daily medication reminders, symptom tracker, and asthma education.
 - **Telemedicine:** Monthly video consultations with a pediatric pulmonologist.
 - **Gamification Module:** Age-appropriate rewards for adherence.
- **Control Group (n=120):**
 - Received standard asthma education and follow-up as per national guidelines.

Outcome Measures

- **Primary Outcome:**
 - **Medication adherence**, measured by smart inhaler logs and monthly pharmacy refill records.
- **Secondary Outcomes:**
 - Asthma Control Test (ACT) scores at baseline, 6, and 12 months
 - Frequency of asthma-related ED visits
 - Spirometric measures (FEV₁%) at baseline and 12 months

Statistical Analysis

Data were analyzed using SPSS v28. Descriptive statistics were used to summarize baseline characteristics. Independent *t*-tests and Mann-Whitney U tests were used for continuous variables. Chi-square tests assessed categorical differences. A *p*-value <0.05 was considered statistically significant. Missing data were handled using multiple imputation.

RESULTS

A total of 240 children were enrolled and randomized equally into intervention and control groups. The mean age of participants was 11.0 ± 2.9 years, with a male predominance of 53%. There were no statistically significant differences between groups in terms of age, gender, asthma severity, or baseline spirometry as in table 1.

Table 1: Baseline characteristics of the patients

Variable	Intervention (n=120)	Control (n=120)	<i>p</i> -value
Mean Age (years)	10.9 ± 2.8	11.1 ± 3.0	0.62
Male (%)	54.2%	51.7%	0.74
Baseline ACT Score	15.1 ± 2.7	15.3 ± 2.5	0.58
Baseline FEV ₁ (%)	71.4 ± 9.2	72.0 ± 8.7	0.49

* ACT=Asthma Control Test

* FEV₁=Spirometric measures

The mean medication adherence over 12 months was significantly higher in the intervention group (86.2 ± 5.9%) compared to the control group (65.5 ±

6.5%, *p* < 0.001). Additionally, the proportion of children achieving ≥80% adherence was 88.3% in the intervention group versus 44.2% in the control group as in table 2.

Table 2: Medication adherence among patients.

Measure	Intervention	Control	pvalue
Mean Adherence (%)	86.2 ± 5.9	65.5 ± 6.5	<0.001
Adherence (%)	88.3	44.2	<0.001

ACT scores improved significantly in the intervention group at both 6 and 12 months. The final mean ACT score at 12 months was 22.4 ± 1.9 in the DHI group compared to 18.1 ± 2.8 in the control group ($p < 0.001$). The number of asthma-

related ED visits was significantly reduced in the intervention group, with a 39% relative reduction compared to the control group. Spirometric improvement (FEV₁%) was also significantly higher in the DHI group as in table 3.

Table 3: Digital health interventions outcomes among patients.

Outcome	Intervention	Control	pvalue
ACT Score (12 months)	22.4 ± 1.9	18.1 ± 2.8	<0.001
ED Visits (mean per patient)	0.39 ± 0.6	0.64 ± 0.8	0.02
FEV ₁ Change from Baseline (%)	+13.1 ± 4.2	+4.6 ± 3.9	0.002

* ACT=Asthma Control Test

* ED=emergency department

* FEV₁=Spirometric measures

DISCUSSION

This randomized controlled trial demonstrates that digital health interventions significantly improve drug compliance and clinical outcomes among asthmatic children in a resource-constrained setting like Pakistan. Children in the intervention arm, who received a package comprising smart inhalers, a bilingual mobile app, and teleconsultations, showed higher adherence rates, improved asthma control, fewer exacerbations, and better lung function compared to those receiving standard care.

The observed 20.7% increase in adherence is consistent with findings from international studies where digital monitoring and reminders have led to similar improvements in pediatric asthma populations (Milani et al., 2022; Chan et al., 2021). Adherence $\geq 80\%$ is considered the threshold for achieving optimal asthma control (GINA, 2023). The DHI group not only surpassed this benchmark but maintained adherence over the 12-month period, indicating sustained engagement, likely due to the gamification and personalized feedback features of the app.

Improved ACT scores and FEV₁ values in the DHI group reflect better symptom control and airway function. These outcomes are clinically significant, as poor control is a major predictor of exacerbations, missed school days, and impaired quality of life in

children (Haroon et al., 2020; Rashid et al., 2023). The reduction in ED visits further indicates a decrease in acute exacerbation frequency, aligning with findings from similar interventions in LMICs (Iqbal et al., 2023; Nguyen et al., 2022).

The success of this intervention in Pakistan can be attributed to several contextual adaptations. The app was developed in both Urdu and English, catering to linguistic diversity. The teleconsultation model was integrated into existing outpatient workflows, reducing caregiver burden. Monthly digital follow-ups allowed for timely treatment adjustments, reinforcing adherence and trust.

Despite these promising results, several limitations should be acknowledged. The study was conducted in a single urban tertiary center, potentially limiting generalizability to rural settings where smartphone access and internet connectivity may be lower (Khan et al., 2023). Additionally, while adherence monitoring through smart inhalers is objective, it may not account for correct inhaler technique—a known determinant of treatment efficacy (Qureshi et al., 2021). Future studies should incorporate inhaler technique assessments and include cost-effectiveness analyses to evaluate scalability.

Nonetheless, this study adds valuable evidence to the growing body of literature supporting the use of DHIs in asthma care, particularly in LMICs. It

highlights the feasibility and effectiveness of leveraging digital tools to overcome structural and behavioral barriers to asthma management in children.

CONCLUSION

Digital health interventions significantly enhance medication adherence, asthma control, and pulmonary function in asthmatic children in Pakistan. These findings underscore the potential of DHIs to transform pediatric asthma care, especially in resource-limited settings. Policymakers and healthcare providers should consider integrating these technologies into national asthma strategies to reduce morbidity and optimize long-term outcomes.

Limitations

- Single-center design may limit generalizability.
- Short follow-up duration (12 months).
- Reliance on digital literacy and smartphone availability.

Recommendations

Future multicenter studies with longer follow-up are recommended to assess sustainability and cost-effectiveness.

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