International Journal of Basic & Clinical Pharmacology
Bataduwaarachchi VR et al. Int J Basic Clin Pharmacol. 2026 Jan;15(1):125-138
http://www.ijbcp.com
pISSN 2319-2003 | eISSN 2279-0780

DOI: https://dx.doi.org/10.18203/2319-2003.ijbcp20254163

Meta-Analysis

Global trends in using digital technology and smart inhalers in asthma management, problems, challenges and future directions

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Received: 08 October 2025
Revised: 07 November 2025
Accepted: 10 November 2025

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ABSTRACT

Asthma management is increasingly patient-centred and tailored to individual needs. Medication non-adherence and a shortage of skilled personnel continue to pose challenges in asthma care. Digital health solutions and smart inhalers have shown promise in addressing these issues; however, they have not been assessed by meta-analysis. This systematic review and meta-analysis assess the effectiveness of using digital technology and smart inhalers in asthma care, exploring challenges and future directions in depth. We followed the preferred reporting items for systematic reviews and meta-analyses. The selected outcomes, compliance with asthma management and the level of asthma control were assessed separately. The results were displayed using a Forest plot and tables. Our data demonstrate significant effectiveness in achieving compliance and asthma control with digital health and smart inhaler interventions compared with controls. The pooled odds ratio for compliance was 2.64 (95% CI: 1.49-4.68); digital health and smart inhaler interventions have been shown to improve compliance significantly. However, its use is significantly limited, and differences are observed. Factors affecting these are further discussed with possible solutions. Based on the controlled trials, digital health and smart inhalers can revolutionize asthma care. To overcome current challenges, close collaboration between healthcare and technology teams is necessary, with implementation targeted to select groups and cost-effective. Although the initial investment is substantial, the long-term cost-effectiveness of digital applications in asthma care is likely to be favourable.

Keywords: Digital health, Smart inhalers, Asthma control, Treatment compliance, Health economics

INTRODUCTION

Asthma is a chronic respiratory disease which presents as exacerbations demarcated by wheezing, chest tightness and breathlessness.[1] Successful asthma control depends on long-term, satisfactory treatment. Despite the use of a variety of treatment protocols and the wide use of inhaler devices, most patients do not achieve satisfactory asthma control.[1,2] Suboptimal control invariably contributes to high morbidity due to increased symptom burden, increased health care utilisation, and overall increase in health economic burden.[3-5] Approximately 1.8 million emergency department visits occur annually in the United States (US) due to asthma, costing the healthcare system $56 billion each year, and the average charge for an outpatient emergency department visit was $1,502.[6] One major factor for unsatisfactory asthma control is poor adherence to inhalers.[7,8] Although multiple methods exist to assess compliance in patients with asthma, such as checking medicine dispensing records, questionnaires, canister weighing, and verbal questioning, these are often unreliable and over-/or underestimate compliance.[9] Compliance assessment is crucial in managing challenging asthma and identifying patients suitable for advanced asthma treatments, such as expensive monoclonal antibodies. With the integration of digital technologies and smart inhalers, asthma management has entered a transformative era. It offers new possibilities for patient monitoring, adherence improvement, and personalised care. Digital technologies and smart inhalers have emerged as promising solutions to these persistent challenges.[10]

An electronic monitoring device is a more objective way to determine compliance, and it uses electronic sensors attached to inhalers to detect inhaler use.[11] Various devices and platforms using digital technology have been developed, ranging from simple devices that track medication use to more advanced devices known as smart inhalers.[9] Smart inhalers offer additional options via smartphone applications, including sending reminders, motivational messages, personalised feedback, and monitoring asthma symptoms. Electronic recordings of real-life inhaler use can capture valuable, objective information that could immensely help disease management and clinical decision-making.[12] Smart inhalers also help healthcare professionals effectively provide self-management plans for asthma patients.[5,13] Digital health technologies provide new opportunities to monitor treatment behaviours, improve communication between healthcare providers and patients, and generate data that inform educational interactions.[10]

Although there is growing evidence for the effectiveness of digital-based self-management applications in managing asthma, most of these have not been successfully integrated into practice.[14,15] Failure to implement such technology has several reasons, including a lack of required technology, data security issues, high costs, and a lack of motivation.[16,17] Still, the challenges of applying digital technology in various healthcare settings have not been fully explored. Up-to-date meta-analyses covering a global sample concerning this topic are quite rare. It is essential to thoroughly explore them before undertaking expensive work to develop digital technology for asthma care. Identifying the success of use will help to create more customised systems that adopt more suitable functionalities. This systematic review and meta-analysis explore the implementation of digital-based technologies and smart inhalers for various purposes in asthma management, focusing on practical problems, challenges and possible solutions.

METHODS

Eligibility criteria

We included peer-reviewed, randomised controlled trials (RCTs) available in full text in English, published from January 1, 2003, to December 31, 2024. Experimental designs that provided data on two major outcomes-level of compliance and level of asthma control-using digital technology and smart inhalers as a controlled intervention were separately categorized. Articles were not excluded based on sample size.

As RCTs in this area are rare, we included studies that employed various methods to measure asthma control, including the asthma control test (ACT), achieving clinically meaningful asthma control, SABA-free days, and reductions in steroid use. As per PICO criteria-study parameters were defined:

Population-children, adults and older individuals with moderate to severe asthma; Interventions, digital-based tools including electronic monitoring, reminders to biofeedback, clinician feedback and smartphone app-based adherence tracking and smart inhalers for asthma medicine delivery; comparators-asthma patients on standard care; outcomes-Improvement in compliance on asthma management and/or improvement in asthma control.

Information sources and search strategy

We conducted a comprehensive search using the following electronic databases: PubMed, Embase, Medline, and Google Scholar. Snowballing of the references in the selected full texts was also performed.

The keywords "Asthma" AND "smart inhaler" OR "Digital health" OR " Inhaler tracking" OR "telemedicine" OR "remote monitoring" OR "data sharing" OR "mobile health app" OR "Digital inhaler" OR "Inhaler usage pattern" OR "technology-assisted inhalers" OR "Personalized inhalers" OR "Cloud-connected inhalers" OR "sensor-based inhalers" OR "Habit trackers" OR "Electronic monitoring devices" OR "Electronic reminders" OR "digital feedback" OR "Bronchodilators" were adopted accordingly for different databases. For example, the PubMed search strategy was: (Severe asthma [Title/Abstract]) AND (Smart Inhalers [Title/Abstract]). Searches were re-run before the final analysis.

Selection process

Search results were exported to 'Rayyan' online systematic review software.[18] Three investigators independently screened the titles and abstracts against the eligibility criteria, and disagreements were resolved by majority consensus. In the next stage, the full texts of the selected studies were retrieved and screened to confirm eligibility.

This review is reported in accordance with preferred reporting items for systematic reviews and meta-analyses guidelines.

Figure 1 summarizes the selection process for the studies as shown below.[19]

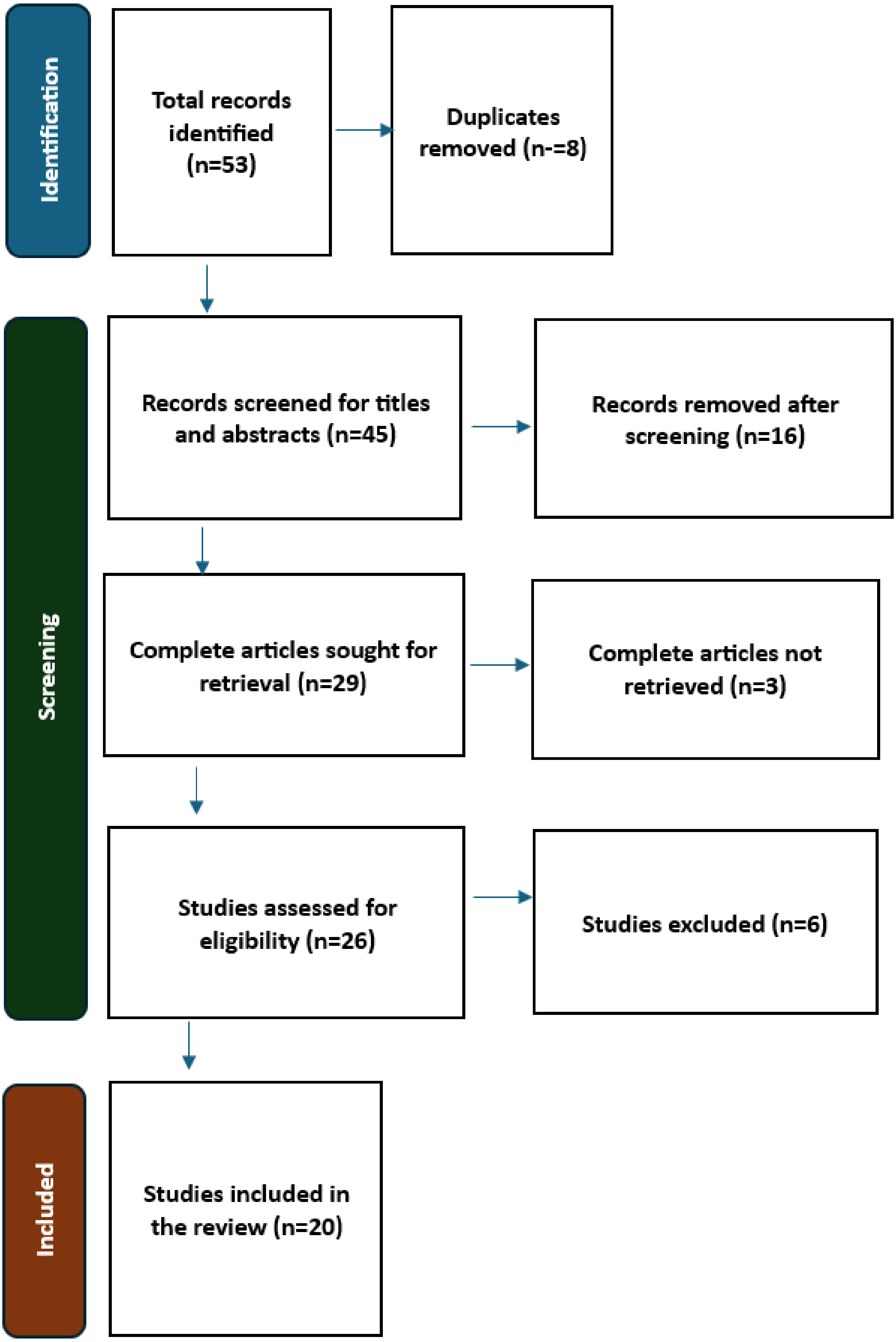

Figure 1: The PRISMA flow diagram summarises each step of the selection process.

Data extraction

One investigator (VB) initially performed data extraction, and the other investigators (AG) independently cross-examined the extracted datasets from each study for accuracy. The primary outcome variables were compliance level and asthma control level. The other variables extracted were the type of study, study setting, sample size, participant characteristics, and study instrument. Where data were missing, the original authors were contacted for additional details.

Data analysis

Primary data were represented in comprehensive tables, which included the level of compliance and asthma control of the patient tested. Selection bias was assessed with a funnel plot for compliance. Odd ratios were calculated with confidence intervals (CI) for compliance level using primary data from the selected studies, which were transformed into a Forest plot with a data table.

There was insufficient data on asthma control to calculate odds ratios and create Forest plots. Subgroup analysis was also not possible due to small sample sizes for the different outcome measurement methods in asthma controls.

RESULTS

For the treatment adherence analysis, 3,530 patients from 17 studies representing 08 countries were included, while 2,839 patients from 14 studies representing 08 countries were included for the asthma control analysis.

Table 1 summarises the findings from multiple RCTs investigating the impact of digital technologies and smart inhalers on asthma patient compliance. These studies include children, adults and older individuals with moderate to severe asthma. The interventions ranged from electronic monitoring and reminders to biofeedback, clinician feedback and smartphone app-based adherence tracking. In nearly all cases, the intervention groups (IG) demonstrated significantly higher adherence to inhaler treatments compared to the control groups (CG), with statistically significant results reported in most trials (p<0.0001 to 0.02). Charles et al and Foster et al found that e-monitoring, combined with reminders and feedback, substantially increased adherence rates. Similarly, trials incorporating biofeedback mechanisms, such as those by O'Dwyers et al have shown improvements in inhalation technique and long-term adherence. Furthermore, Ljungberg et al demonstrated no significant improvement in adherence across all patients. Primary care patients who used digital management tools (Asthma tuner) more frequently showed better compliance. In contrast, Mosnaim et al reported declines in adherence, particularly with reliever medications, highlighting challenges to sustain patient engagement. However, underlying factors are not assessed. The findings suggest that while digital interventions and smart inhalers effectively enhance adherence in many cases, the degree of impact varies based on factors such as the type of intervention, duration of study, patient demographics, and engagement levels.

Table 2 summarises the findings from ten RCTs selected for meta-analysis investigating the impact of digital technologies on adherence to asthma management. The table compares adherence rates between the IG (using digital technologies) and controlled groups (standard care) across the selected studies. Of 1,412 participants, 526 in the IG adhered to their medication regimen, compared to the 370 in the CG. Statistically significant improvements in adherence were observed in several studies, indicating a positive effect of digital interventions. The pooled results demonstrate a highly significant overall difference (p<0.0001) between studies. However, some studies have again shown no significance, such as Apter et al and Dierick et al suggesting variability in outcomes that may be due to study design, sample size, or the type of digital intervention used.

Figure 2 presents a funnel plot assessing the publication bias among the studies included in the meta-analysis. The plot displays the ORs on the X axis against the standard error on the Y axis. The triangular region defined by dashed lines shows the expected dispersion due to sampling variability. In this plot, there appears to be some asymmetry with more studies clustered on the right side of the line, indicating potential publication bias or minor study effects. In particular, the study by Dierick et al lies far to the left and lower on the plot, indicating a smaller effect size and a higher standard error than the others. However, most studies are included in the funnel, and only a limited number of RCTs are available in the literature focusing on this area.

The Forest plot, shown in Figure 3, illustrates an analysis of ten individual studies evaluating effect size, represented by odds ratios (OR) and 95% confidence interval. Most studies favoured a positive effect, with an OR greater than 1, indicating a statistically significant association, including Chan et al (OR=11.93, 95% CI: 6.23-22.83) and Charles et al (OR=4.78, 95% CI: 1.47-15.53). Pooled OR is 2.64 (95% CI: 1.49-4.68), indicating a significant positive association across studies and suggesting that digital technologies improve treatment adherence.

Table 3 presents a comprehensive summary of RCTs investigating asthma control outcomes in patients using smart inhalers and other digital technologies. The studies span different countries and age groups, including children and adults with uncontrolled asthma. Most interventions involved electronic monitoring, feedback systems, reminder functions, and smartphone-based platforms. The outcomes were measured using validated tools, including the ACT, the ACQ, and other clinical indicators. Overall, the results demonstrate that digital interventions significantly improved asthma control in most trials. For instance, Wu et al and Morton et al reported improvement in ACT and ACQ scores, respectively, alongside reduced hospitalisation and corticosteroid use. Similarly, Chan et al and Merchant et al observed fewer exacerbations and a higher proportion of SABA-free days in the intervention groups. Some studies, such as that by Ryan et al didn't show a statistically significant difference, highlighting the variability in effectiveness depending on the digital solution and population studied. In conclusion, the table supports the growing evidence that smart inhalers and digital health technologies can improve asthma control and clinical outcomes. However, the magnitude of benefit may vary depending on the nature of the intervention and patient characteristics.

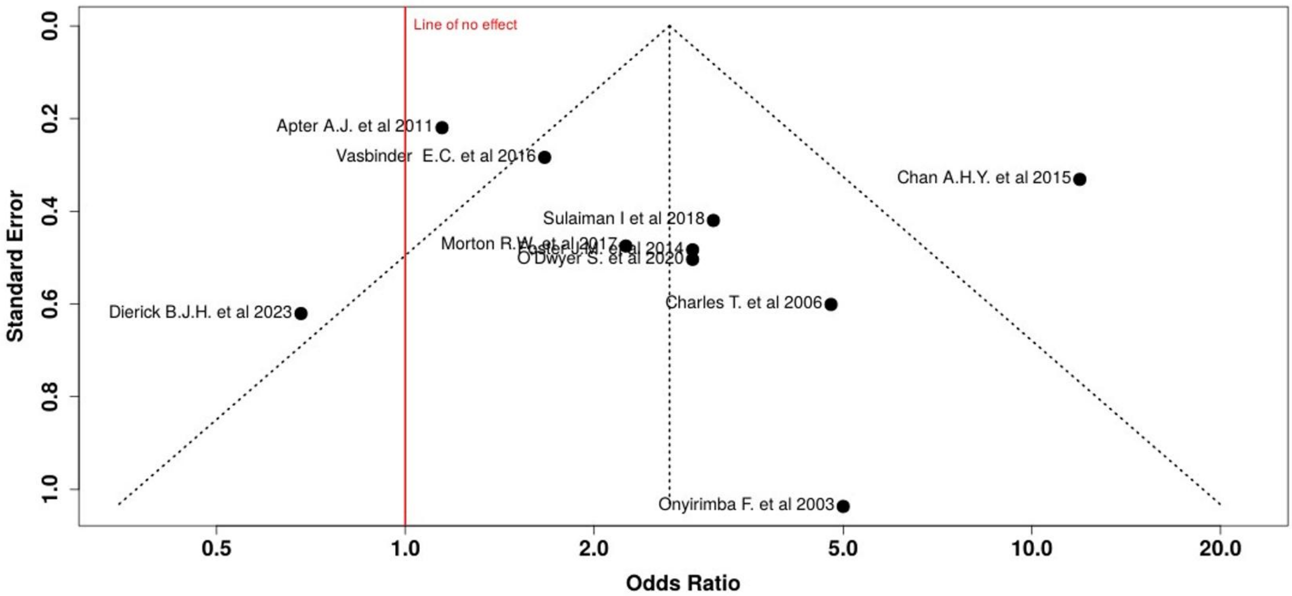

Figure 2: Funnel plot assessing the publication bias among studies included in the meta-analysis.

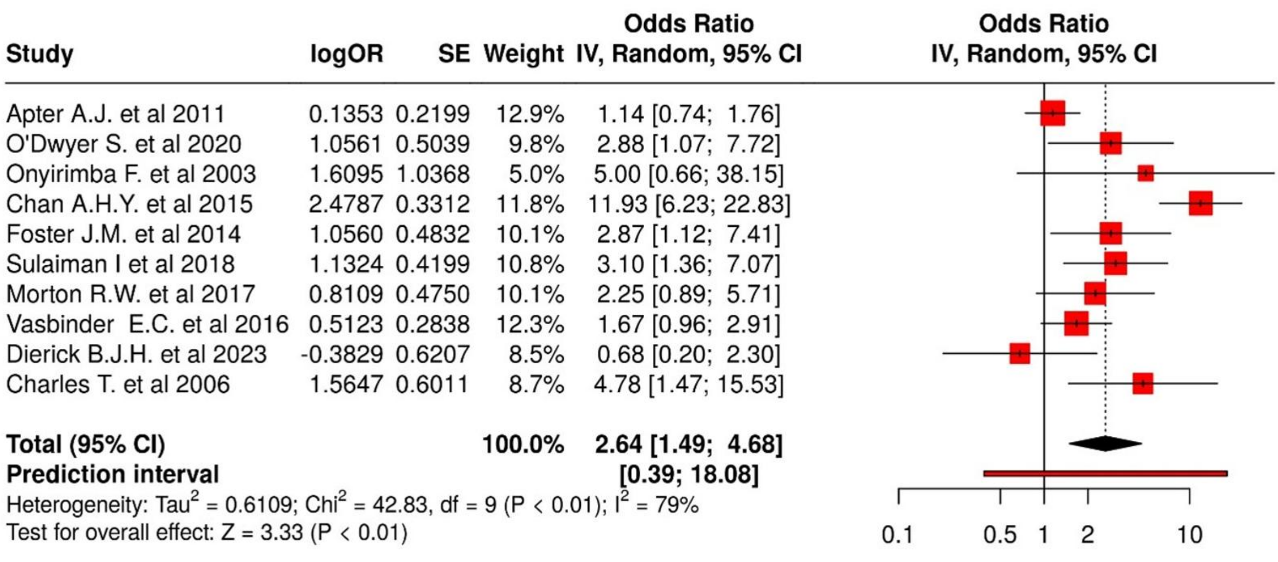

Figure 3: Forest plot shows analysis of 10 individual studies evaluating effect size, represented by odds ratios.

*Prediction interval-implies that future studies may yield broad range of outcomes; heterogeneity-indicates notable variability in study results.

Table 1: Summary of treatment adherence with digital technology and smart inhalers tested in randomised controlled trials among asthma patients.

References	Country	Sample	Smart inhaler-based intervention and population	Adherence in the IG	Adherence in the CG	Significance	Other effects
Aptar et al[20]	USA	333	Adults with moderate or severe asthma, IG-problem-solving/ CG-standard asthma education, 3 months. 35-63 years of age	61% to 14%	10%	p=0.0004	Declined in the IG
O'Dwyer et al[21]	Ireland	152	Biofeedback in adult, asthma and COPD, 6 months, IG1-Biofeedback group, personalised inhaler training, IG2-Demonstration group, inhaler training, by physical demonstration with a placebo inhaler, CG-Usual care.	62% by 2 Mon. IGI-18% >IG2, 24% >CG, By 6 Mon.IGI-14% >IG2, 31% >CG	N/A	By 2 Mon.IG1>IG2-p=0.004, IGI>CG-p=0.003, By 6 Mon. IG1>IG2-p=0.07, IGI>CG-p=0.001	Increased in IG1 and IG2
Onyirimba et al[22]	USA	30	Inhaled steroid and β-agonist use were electronically monitored, IG-Direct clinician-to-patient feedback on treatment, CG-No feedback	81% by 2 weeks. ↑ to 81±7%	By 2 wks. IG- ↓ to 47±7%	p=0.003	Increased in IG
Charles et al[23]	New Zealand	110	E-monitoring, reminding and feedback on asthma patients, 13-65 years	88% (Last 12 wks.)	66% (Last 12 wks.)	p<0.0001	Increased in IG
Foster et al[24]	Australia	143	E-monitoring, reminding and feedback in adult and children with asthma, 14-65 yrs	76%	46%	p<0.0001	Increased in IG
Chan et al[25]	New Zealand	220	E-monitoring and reminding children with asthma (6-15 years)	84%	30%	p<0.0001	Increased in IG
Merchant et al[26]	USA	495	E-monitoring, reminding and feedback on children and adults with asthma (>5 yrs), IG-access to and feedback from propeller health system, CG Outfitted with sensors, no feedback.	0.31/person/day (Daily SABA use)	0.41-/person/ day (Daily SABA use)	p<0.001	Increased in IG
Sulaiman et al[27]	Ireland	218	E-monitoring and biofeedback on adherence and inhalation technique in adult asthma, 49.2±16.5 years	73%	63%	p=0.02	Increased in IG
Morton et al[28]	UK	90	E-monitoring, reminding and feedback on children with asthma (6-16 years)	70%	49%	p<0.001	Increased in IG fewer
Vasbinder et al[29]	The Netherlands	219	E-monitoring and reminding children with asthma (4-11 years)	69.3%	57.3%	N/A	Increased in IG
Dierick et al[30]	The Netherlands	42	Comparing personalised smart spacer-based inhaler education vs. usual care, 2 Mon.	N/A	12% ↑	N/A	Increased in CG
Rumi et al[31]	Italy	661	An electronic device attached to the patient's inhalers for ≥90 days, medication use data to a smartphone app, budesonide and formoterol as maintenance therapy	70.2% (average) (1-BID: 66.5%; 1-BID and reliever: 71.0%; 2-BID: 67.4%; 2-BID and reliever: 70.7%). 56.6% (proportion of adherent days) (1-BID and reliever vs 1-BID: 60.0% vs 52.7%; 2-BID and reliever vs 2-BID: 52.9% vs 50.6%)		1-BID and reliever vs 1-BID: p<0.001; 2-BID and reliever vs 2-BID: 52.9% p=0.02).	Increased in MART

Continued.

References	Country	Sample	Smart inhaler-based intervention and population	Adherence in the IG	Adherence in the CG	Significance	Other effects
Mosnaim et al[32]	USA	100	Impact of patient self-monitoring via electronic medication monitor and mobile app plus remote clinician feedback on adherence to inhaled corticosteroids, adults with uncontrolled asthma and prescribed ICS and SABA, 14-weeks	ICS adherence ↓ minimally. (-2%; 95% CI, -7 to 3; p=0.40)	15% (95% CI, 4 to 25. ICS adherence decreased (-17%; 95% CI, -26 to -8	ICS adherence - p<0.01 ↓ in ICS adherence- p<0.01	Decreased in the CG
Sulaiman et al[33]	Ireland	239	A method to calculate adherence to inhaled therapy that reflects the changes in clinical features of asthma, 3 months, a cohort of patients with asthma	Adherence based on the dose counter-84.4%, actual adherence-61.8%	N/A	Actual adherence- p<0.01	Actual adherence was less compared to dose counter
Mosnaim[34]		181	Effectiveness of a maintenance and reliever Digihaler System (DS) in Asthma: 24-Weeks (CONNECT2), 13 years or older, uncontrolled asthma ACT score <19)	Maintenance treatment adherence: Mon. 1: 79.2%; Mon. 6: 68.6%) reliever use adherence: ↓ by 38.2% vs baseline	N/A	N/A	Decrease in adherence more in reliever group.
Ljungberg et al[35]	Sweden	77	Clinical effect on uncontrolled asthma using a novel digital automated self-management solution (AsthmaTuner): a physician-blinded randomised controlled crossover trial, participants in a primary or paediatric care setting with an asthma diagnosis, uncontrolled symptoms, ACT score <20	NA N/A		Mean MARS difference 0.45, 95% CI 0.13-0.77; p=0.01	No significant improvement in all participants. Improved among primary care patients who used asthma tuner an average of once a week
Hale et al[36]	Across Ireland, Northern Ireland, and England	220	Use of digital measurement of medication adherence and lung function to guide the management of uncontrolled asthma (INCA Sun): 18 years or older, uncontrolled asthma, ACT score of 19 or less, despite treatment with high-dose ICS, at least one severe exacerbation	Week 20-32: actual mean adherence, 64·9% (SD 23·5)	Week 20-32: actual mean adherence, 55·5% (26·8)	Between-group difference 11·1% [95% CI 4·4-17·9], p=0·0012	Increased in IG

*IG-Interventional group; CG-Control group; SABA-Short-acting beta-agonist; ACT-Asthma control test; CI-Confidence interval; DS-Digihaler system; BID-bis in die / twice-daily dosage; USA-United States of America; ICS-Inhaled corticosteroids; MARS-Medication adherence report scale; SD-Standard deviation.

Table 2: Randomised control trials investigating adherence using digital technologies for asthma management.

Reference	Total	Interventional group		Control group		P value
		Adhered	Not adhered	Adhered	Not adhered	
Apter et al[20]	333	91	74	87	81	0.5382
O'Dwyer et al[21]	96	46	28	8	14	0.0361
Onyirimba et al[22]	19	8	2	4	5	0.1206
Chan et al[25]	220	92	18	33	77	<0.0001
Foster et al[24]	78	25	10	20	23	0.0288

Continued.

Reference	Total	Interventional group		Control group		P value
		Adhered	Not adhered	Adhered	Not adhered	
Sulaiman et al[33]	218	102	9	84	23	0.0070
Morton et al[28]	77	27	12	19	19	0.0878
Vasbinder et al[29]	219	75	33	64	47	0.0711
Dierick et al[30]	42	9	12	11	10	0.5373
Charles et al[23]	110	51	4	40	15	0.0092
Total	1,412	526	202	370	314	<0.0001

Table 3: Summary of asthma control achieved with digital technologies and smart inhalers tested in randomised controlled trials for asthma patients.

Reference	Country	Sample	Smart inhaler-based intervention and population	Asthma control IG	Asthma control CG	Significance	Other effects
Ryan et al[37]	UK	288	Adolescents and adults with poorly controlled asthma (asthma control questionnaire (ACQ) score ≥1.5), 32 practices, IG -Randomised to twice daily recording and mobile phone-based transmission of symptoms, drug use, and peak flow with immediate feedback (MG) or paper-based monitoring (PG)	ACQ: Mean change 0.75 in MG vs. 0.73 in PG, mean difference in change -0.02 (95% CI-0.23 to 0.19); KASE-AQ score: mean change -4.4 v -2.4, mean difference 2.0 (-0.3 to 4.2)			No significant difference in the change in asthma control or self-efficacy between MG vs. PG
Hoyte et al[38]	USA	333	12-week study, aged 13 years or older with ACT <19, randomised to use either Reliver Digihaler System (RDS) or SoC albuterol reliever inhalers.	Probability of greater Odds of clinically meaningful asthma control RDS (n=167) 85.3% at 3 Mon.	Probability of greater odds of clinically meaningful asthma control SoC (n=166) at 3 mon at 3 months [mean OR=1.33]	N/A	Better control in the RDS group
Dierick et al[30]	The Netherlands	42	Two-month trial, comparing personalised smart spacer-based inhaler education versus usual care.	N/A	N/A	N/A	No difference between two groups
Ljungberg et al[35]	Sweden	77	Clinical effect on uncontrolled asthma using a novel digital automated self-management solution (AsthmaTuner): a physician-blinded randomised controlled crossover trial, participants in a primary or paediatric care setting with an asthma diagnosis, uncontrolled symptoms, ACT score <20	NA	N/A	Mean ACT difference 0.70, 95% CI 0.06-1.34; p=0.03	Significantly improved with asthma tuner
Wu et al[39]	China	108	Effectiveness of specialist nurse-led WeChat mini program management for disease control in children with asthma, 6-month follow-up.	At 3 and 6 mon, significantly higher C-ACT scores and a lower exacerbation frequency. PEFR improved, FEV1, predicted (FEV1%) and FEV1/FVC did not change significantly.	N/A	p<0.05	Increased in the IG

Continued.

Reference	Country	Sample	Smart inhaler-based intervention and population	Asthma control IG	Asthma control CG	Significance	Other effects
Morton et al[28]	UK	90	E-monitoring, reminding and feedback on children with asthma (6-16 years)	ACQ-1.14 [-1.6 to -0.7]	ACQ score -0.95 [-1.3 to -0.6]	Fewer hospitalisations (p<0.01) and fewer courses of oral CS (p=0.008) in IG vs. CG	Better control in IG no significant difference between ACQ means between the two groups (p=0.51)
Vasbinder et al[29]	The Netherlands	209	E-monitoring and reminding children with asthma (4–11 years)	N/A	N/A	N/A	ACT, QoL: PAQLQ and exacerbation – No difference between IG and CG
Other measures of asthma control							
Hale et al[36]	Across Ireland, Northern Ireland, and England	220	Use of digital use of digital measurement of medication adherence and lung function to guide the management of uncontrolled asthma (INCA Sun): Eighteen years or older, uncontrolled asthma, ACT score of nineteen or less, treatment with high-dose ICS, at least one severe exacerbation in the past year.	↓medication from fluticasone propionate 1000 µm once daily to 500 µg once daily: 26 (31%) n=83	↓medication from fluticasone propionate 1000 µm once daily to 500 µg once daily: 13 (18%) n=73	OR 2·43 [1·13-5·20], p=0·022	Better control in the IG
Hoyote et al[38]	USA	333	Effectiveness of a digital inhaler system for patients with asthma: a 12-week, open-label, randomized study (CONNECT1). The albuterol Digihaler (albuterol 90 µg/dose), 13 years or older with suboptimal ACT score < 19	At 3 Mon. Clinically meaningful asthma control 85.3% (n = 167)	N/A	Mean odds ratio 1.33; 95% credible interval 0.813-2.050. RDS group had 33% higher odds of achieving meaningful improvement than those in the SoC group	Better control in the IG
Mosnaim[34]	USA	181	Effectiveness of a Maintenance and Reliever Digihaler System (DS) in asthma: 24-week randomized study (CONNECT2), 13 years or older, uncontrolled asthma ACT score <19	At 24 weeks: 88.7% probability of DS group have greater odds of improving asthma		Mean odds ratio (95% credible interval) for DS vs. SoC was 1.35 (0.846-2.038)	35% higher odds of improved asthma control with DS.

Continued.

Reference	Country	Sample	Smart inhaler-based intervention and population	Asthma control IG	Asthma control CG	Significance	Other effects
Foster et al[24]	Australia	143	E-monitoring, reminding and feedback in adult and children with asthma, 14-65 yrs	Severe Exacerbations: 11%	Severe Exacerbations: 28%	P=0.013	Better control in IG Asthma control improved overall (mean change in ACT score, 4.5±4.9; p<0.0001), with no significant difference among groups (p=0.14). Severe exacerbations were experienced by 11% of the patients in IRF groups and 28% of the patients in non-IRF groups (p=0.013; after adjustment for exacerbation history; p=0.06).
Chan et al[25]	New Zealand	220	E-monitoring and reminding children with asthma (6-15 years)	Exacerbations: 6% (IG) at 2 Mon.	Exacerbations: 24% at 2 Mon.	Asthma morbidity: at 6 Mon. IG >CG p=0.008	Better control in IG Asthma morbidity is worse in IG
Merchant et al[26]	USA	495	E-monitoring, reminding and feedback on children and adults with asthma (>5 yrs), IG-Access to and feedback from the propeller health system, CG Outfitted with sensors, no feedback.	The proportion of SABA-free days: ↑ by 21% Uncontrolled asthma scores 63%	The proportion of SABA-free days: ↑ by 17% Uncontrolled asthma scores 49%	(p<0.01 comparing the 2-improvements of SABA free days) Uncontrolled asthma scores p<0.05	Better control in IG
Mosnaim et al[32]	USA	100	The impact of patient self-monitoring via electronic medication monitors and mobile app plus remote clinician feedback on adherence to inhaled corticosteroids, adults with uncontrolled asthma and prescribed ICS and SABA, 14-weeks	The % of SABA-free days: 19%; 95% CI, 12 to 26; p<0.01	The % of SABA-free days: 6%, 95% CI, -3 to 16; p=0.18	Difference: 13% (95% CI, 1-26; p=0.04)	Better control in IG

*IG-Interventional group; CG-Control group; SABA-Short-acting beta-agonist; QoL-Quality of life; ACT-Asthma control test; ACQ-Asthma control questionnaire; PAQLQ-Pediatric asthma quality of life questionnaire; CI-Confidence interval; KASE-AQ, Knowledge, attitude and self-efficacy asthma questionnaire; RDS-Reliever Digihaler system; SoC-Standards of care, INCA-Inhaler treatment adherence assessment; CI-Confidence interval; OR-Odds ratio; ICS-Inhaled corticosteroids; FEV1-Forced expiratory volume in 1 second; FVC-Forced vital capacity; DS-Digihaler system; PEFR-Peak expiratory flow rate; MG-Mobile group; PG-Paper group; INCA-Inhaler treatment adherence assessment, IRF-inhaler reminders and feedback.

DISCUSSION

Modern asthma care has been significantly reshaped by integrating digital technologies and smart inhalers, presenting opportunities for enhanced monitoring, personalised treatment, and improved patient outcomes.[10] The cornerstone of effective asthma management lies in consistently and frequently monitoring inhaler technique and treatment adherence. The correct utilisation of inhalers is a critical factor influencing patient outcomes within inhaled therapies, as poor technique can substantially diminish the effectiveness of prescribed medications.[40] Digital technologies offer innovative solutions to address these challenges, empowering patients to participate in their care actively and enabling healthcare providers to deliver more targeted and efficient interventions.[10] These technologies include a wide array of tools and platforms, including mobile apps, wearable sensors, and connected inhalers, all designed to collect and transmit real-time data on various aspects of asthma control.[16] This data-driven approach facilitates a more objective and comprehensive understanding of individual patient needs, allowing for tailored treatment plans and timely adjustments.[41]

Smart inhalers are innovative medical devices that combine traditional inhalation therapy with digital monitoring capabilities. These devices integrate with mobile apps via Bluetooth, recording detailed data about medication use, including time, date, and, often, the location of each actuation. Some advanced models can even evaluate inhalation techniques and provide real-time feedback.[10,16] These devices form comprehensive digital health platforms that typically include a sensor-equipped inhaler, a patient-facing smartphone application, a secure cloud server for data storage, and a clinician dashboard for remote monitoring.[42]

This meta-analysis encompassed various types of digital technologies employed across a larger sample. Smart inhalers have demonstrated significant improvements in medication adherence through various mechanisms, such as reminder systems that are audible or visual alerts for scheduled doses, helping address forgetfulness, a major cause of non-adherence.[43] Some devices have motivational feedback where positive reinforcement messages and visual progress tracking encourage consistent use. The knowledge that usage is being monitored can positively influence patient behaviour.[44] Smart inhaler systems also facilitate a new model of collaborative care. Patients and clinicians can review actual usage patterns rather than relying on recall. Healthcare providers can track adherence and symptoms between visits, and the data allow for tailored education and treatment adjustments, which are important for personalised asthma care.[45] This data-driven approach helps address the common disconnect between patients' perceptions of control and their actual asthma status.

In our analysis, IGs demonstrated significantly higher adherence to inhaler treatments than CGs. E-monitoring combined with reminders and biofeedback mechanisms showed improvements in inhalation technique and long-term adherence. However, one study reported declines in adherence, particularly with reliever medications. This could also be due to patients achieving better control. Therefore, studies that achieve both treatment adherence and asthma control simultaneously will answer this question. Patients who used digital management tools (Asthma tuner) more frequently showed better outcomes. Overall, our findings suggest that digital interventions and smart inhalers effectively enhance adherence. However, the degree of impact varies based on factors such as the type of intervention, study duration, patient demographics, and engagement levels. The pooled OR was 2.64 (95% CI: 1.49-4.68), indicating a significant positive association across studies and suggesting that digital technologies significantly improve treatment adherence.

Our results also showed that digital interventions significantly improved asthma control in most trials. These results support the growing evidence that smart inhalers and digital health technologies can significantly improve asthma control and clinical outcomes. The methods used to assess asthma control varied across studies. However, the magnitude of benefit may vary depending on the nature of the intervention and patient characteristics. Proper inhaler technique is crucial for effective medication delivery. Some devices measure inspiratory flow rates and provide immediate correction suggestions. Some apps and smart inhalers include integrated tutorials and visual guides within companion apps. Notifications can be issued when persistent technical issues are detected.[46] By addressing adherence and technique barriers, smart inhalers contribute to improved clinical outcomes, such as reduced exacerbation rates, fewer hospitalisations and emergency visits, and improved quality-of-life measures.[47] Real-world data from digital inhaler platforms can also help identify patients at risk of exacerbation by detecting patterns of increased rescue medication use.

Challenges to overcome and future prospects

Although the digital platforms vary in their specific features, they share the common goal of improving asthma management through digital monitoring and feedback. Despite their potential, several challenges hinder the widespread adoption of smart inhalers. Kaplan A identifies several key issues, including inconsistent funding mechanisms and insurance coverage, limited accessibility, difficulties integrating data review into existing workflows, poor technology, data privacy concerns, and a lack of standardization across systems.[10] Addressing these challenges will be crucial for realising the full potential of digital inhaler technologies. The future of digital asthma care is evolving, and several promising developments are emerging. These include integration with other digital health tools, such as combining inhaler data with symptom trackers and environmental monitors, artificial intelligence applications such as predictive analytics for exacerbation risk, expanded remote care models enabling more virtual asthma management and clinical trial applications using digital data for more precise research.[48] Industry experts predict that digital inhalers will become standard components of asthma management. However, there are population-specific limitations, such as a lack of funds, accessibility, feasibility, and acceptability in developing countries.[49] Therefore, more funds should be allocated to these countries after careful situational surveys. Digital technology will be cost-effective in the long term because more patients will achieve satisfactory asthma control. A study has shown long-term cost-effectiveness of digital inhalers in patients with difficult-to-treat asthma, due to a lower proportion of patients needing add-on biologic therapy.[50] However, health economic studies are needed to assess this more objectively. Lack of sustainability is another potential challenge that must be addressed using simple protocols, sustainable fund allocation, regular updates, and staff training.[51]

We suggest implementing digital technology initially among a specific group of patients, such as those with strong digital literacy and poor compliance. A low-cost approach is always better to ensure the sustainability of programs with digital technology integration. Before asthma digital health applications are fully integrated into routine care, data security and privacy concerns must be addressed because digital tools may be the targets of cyberattacks.[48,52] Multilingual support tailored to users' demographics is necessary to make smart inhalers and digital devices more user-friendly. Poor digital literacy among patients and inequitable access are also suggested barriers to introducing these methods. A study conducted in the US found that without internet access, web-based dissemination of information, health promotion, and health care will not reach a significant segment of the population, further exacerbating health inequalities among races and ethnicities. This aspect also needs to be addressed.[53] Another study has found that the digital divide persisted despite the availability of devices and internet access, and traditional age and race disparities were the commonly detected associated factors, which also might need further attention.[54] A study done among primary health care clinicians who treat underserved communities in the Southeast US, regarding adopting digital health tools, revealed that cost, time and limited workflow integration were found to be the common barriers to implementing these services, whereas meeting patient needs, ease of workflow integration, and improvement of patient health were the identified facilitators to adopt these tools. These factors may need to be addressed, and clinician input may be needed before implementing digital and smart tools to achieve sustained use.[55] In the future, one-to-one comparison trials will be necessary to select the most effective technology or device. However, major questions remain unresolved, such as who might fund future large-scale studies, how guidelines committees may consider them, and how to implement them effectively.[43] The limited number of studies from developing countries and the scarcity of research on various digital interventions were notable limitations.

CONCLUSION

This meta-analysis has proven that digital technologies and smart inhalers represent a significant advancement in asthma care, addressing long-standing challenges of adherence and techniques that have limited treatment effectiveness. By providing objective usage data, real-time feedback, and enhanced patient-clinician collaboration, these innovations offer the potential to improve outcomes for millions of asthma patients worldwide. While implementation challenges remain, ongoing technological advancements and healthcare system adaptations promise to integrate these tools increasingly into routine asthma management, moving toward a future of more personalised, data-driven asthma care. In future, randomised trials comparing different technologies and studies from developing countries are needed.

Funding: No funding sources
Conflict of interest: None declared
Ethical approval: Not required

REFERENCES

1. Price D, Fletcher M, Van Der Molen T. Asthma control and management in 8,000 European patients: The REcognise Asthma and LInk to Symptoms and Experience (REALISE) survey. NPJ Prim Care Respir Med. 2014;24:14009.
2. Demoly P, Annunziata K, Gubba E, Adamek L. Repeated cross-sectional survey of patient-reported asthma control in europe in the past 5 years. European Respiratory Rev. 2012;21(123):66-74.
3. Guilbert TW, Garris C, Jhingran P, Bonafede M, Tomaszewski KJ, Bonus T, et al. Asthma that is not well-controlled is associated with increased healthcare utilization and decreased quality of life. J Asthma. 2011;48(2):126-32.
4. Godard P, Chanez P, Siraudin L, Nicoloyannis N, Duru G. Costs of asthma are correlated with severity: A 1-yr prospective study. European Respiratory J. 2002;19(1)61-7.
5. Global Initiative for Asthma. Global Initiative for Asthma: Global strategy for asthma management and prevention 2020.
6. Wang T, Srebotnjak T, Brownell J, Hsia RY. Emergency department charges for asthma-related outpatient visits by insurance status. J Health Care Poor Underserved. 2014;25(1):396-405.
7. Engelkes M, Janssens HM, De Jongste JC, Sturkenboom MCJM, Verhamme KMC. Medication adherence and the risk of severe asthma exacerbations: A systematic review. European Respirat J. 2015;45(2):306-407.
8. Boulet LP, Vervloet D, Magar Y, Foster JM. Adherence. The Goal to Control Asthma. Clin Chest Med. 2012;33(3):405-17.
9. Jansen EM, van de Hei SJ, Dierick BJH, Kerstjens HAM, Kocks JWH, van Boven JFM. Global burden of medication non-adherence in chronic obstructive

pulmonary disease (COPD) and asthma: A narrative review of the clinical and economic case for smart inhalers. J Thorac Dis. 2021;13(6):3846-64.

10. Kaplan A. The emerging role of digital health in the management of asthma. Ther Adv Chronic Dis. 2023;14:20406223231209329.
11. Chan AHY, Harrison J, Black PN, Mitchell EA, Foster JM. Using Electronic Monitoring Devices to Measure Inhaler Adherence: A Practical Guide for Clinicians. J Allergy Clin Immunol. 2015;3(3):335-49.
12. Levy ML, Kocks JWH, Bosnic-Anticevich S, Safioti G, Reich M, Depietro M, et al. Uncovering patterns of inhaler technique and reliever use: the value of objective, personalized data from a digital inhaler. NPJ Prim Care Respir Med. 2024;34(1):23.
13. Tinschert P, Jakob R, Barata F, Kramer JN, Kowatsch T. The potential of mobile apps for improving asthma self-management: A review of publicly available and well-adopted asthma apps. JMIR Mhealth Uhealth. 2017;5(8):e113.
14. Van Gemert-Pijnen JEWC, Nijland N, Van Limburg M, Ossebaard HC, Kelders SM, Eysenbach G, et al. A holistic framework to improve the uptake and impact of e-health technologies. J Med Internet Res. 2011;13(4):e111.
15. Huckvale K, Morrison C, Ouyang J, Ghaghda A, Car J. The evolution of mobile apps for asthma: An updated systematic assessment of content and tools. BMC Med. 2015;13(1):58.
16. Himes BE, Leszinsky L, Walsh R, Hepner H, Wu AC. Mobile Health and Inhaler-Based Monitoring Devices for Asthma Management. J Allergy Clin Immunol Pract. 2019;7(8):2535-43.
17. Alwashmi MF, Fitzpatrick B, Farrell J, Gamble JM, Davis E, Nguyen H Van, et al. Perceptions of Patients Regarding Mobile Health Interventions for the Management of Chronic Obstructive Pulmonary Disease: Mixed Methods Study. JMIR Mhealth Uhealth. 2020;8(7):e17409.
18. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan-a web and mobile app for systematic reviews. Syst Rev. 2016;5(1):1-11.
19. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. The BMJ. 2021;372:n71.
20. Apter AJ, Wang X, Bogen DK, Rand CS, McElligott S, Polsky D, et al. Problem solving to improve adherence and asthma outcomes in urban adults with moderate or severe asthma: A randomized controlled trial. J Allergy Clin Immunol. 2011;128(3):516-23.
21. O'Dwyer S, Greene G, MacHale E, Cushen B, Sulaiman I, Boland F, et al. Personalized Biofeedback on Inhaler Adherence and Technique by Community Pharmacists: A Cluster Randomized Clinical Trial. J Allergy Clin Immunol. 2020;8(2):635-44.
22. Onyirimba F, Apter A, Reisine S, Litt M, McCusker C, Connors M Lou, et al. Direct clinician-to-patient feedback discussion of inhaled steroid use: Its effect on adherence. Ann Allergy Asthma Immunol. 2003;90(4):411-5.
23. Charles T, Quinn D, Weatherall M, Aldington S, Beasley R, Holt S. An audiovisual reminder function improves adherence with inhaled corticosteroid therapy in asthma. J Allergy Clin Immunol. 2007;119(4):811-6.
24. Foster JM, Usherwood T, Smith L, Sawyer SM, Xuan W, Rand CS, et al. Inhaler reminders improve adherence with controller treatment in primary care patients with asthma. J Allergy Clin Immunol. 2014;134(6):1260-8.
25. Chan AHY, Stewart AW, Harrison J, Camargo CA, Black PN, Mitchell EA. The effect of an electronic monitoring device with audiovisual reminder function on adherence to inhaled corticosteroids and school attendance in children with asthma: A randomised controlled trial. Lancet Respir Med. 2015;3(3):210-9.
26. Merchant RK, Inamdar R, Quade RC. Effectiveness of Population Health Management Using the Propeller Health Asthma Platform: A Randomized Clinical Trial. J Allergy Clin Immunol. 2016;4(3):455-63.
27. Sulaiman I, Greene G, MacHale E, Seheult J, Mokoka M, D'Arcy S, et al. A randomised clinical trial of feedback on inhaler adherence and technique in patients with severe uncontrolled asthma. European Respiratory J. 2018;51(1):1701126.
28. Morton RW, Elphick HE, Rigby AS, Daw WJ, King DA, Smith LJ, et al. STAAR: A randomised controlled trial of electronic adherence monitoring with reminder alarms and feedback to improve clinical outcomes for children with asthma. Thorax. 2017;72(4):347-54.
29. Vasbinder EC, Goossens LMA, Rutten-Van Mölken MPMH, De Winter BCM, Van Dijk L, Vulto AG, et al. E-Monitoring of Asthma Therapy to Improve Compliance in children (e-MATIC): A randomised controlled trial. European Respiratory J. 2016;48(3):758-67.
30. Dierick BJH, Achterbosch M, Eikholt AA, Been-Buck S, Klemmeier T, van de Hei SJ, et al. Electronic monitoring with a digital smart spacer to support personalized inhaler use education in patients with asthma: The randomized controlled OUTERSPACE trial. Respir Med. 2023;218:107376.
31. Rumi G, Canonica GW, Foster JM, Chavannes NH, Columbro C, Valenti G, et al. Digital Coaching Using Smart Inhaler Technology to Improve Asthma Management in Patients With Asthma in Italy: Community-Based Study. JMIR Mhealth Uhealth. 2022;10(11):e25879.
32. Mosnaim GS, Stempel DA, Gonzalez C, Adams B, BenIsrael-Olive N, Gondalia R, et al. The Impact of Patient Self-Monitoring Via Electronic Medication Monitor and Mobile App Plus Remote Clinician Feedback on Adherence to Inhaled Corticosteroids: A Randomized Controlled Trial. J Allergy Clin Immunol. 2021;9(4):1586-94.
33. Sulaiman I, Seheult J, MacHale E, Boland F, O'Dwyer SM, Rapcan V, et al. A method to calculate adherence

to inhaled therapy that reflects the changes in clinical features of asthma. Ann Am Thorac Soc. 2016;13(11):1894-903.

34. Mosnaim GS, Hoyte FCL, Safioti G, Brown R, Hill TD, Li T, et al. Effectiveness of a Maintenance and Reliever Digihaler System in Asthma: 24-Week Randomized Study (CONNECT2). J Allergy Clin Immunol. 2024;12(2):385-95.
35. Ljungberg H, Carleborg A, Gerber H, Öfverström C, Wolodarski J, Menshi F, et al. Clinical effect on uncontrolled asthma using a novel digital automated self-management solution: A physician-blinded randomised controlled crossover trial. Eur Respiratory J. 2019;54(5):1900983.
36. Hale E Mac, Greene G, Mulvey C, Mokoka MC, van Boven JFM, Cushen B, et al. Use of digital measurement of medication adherence and lung function to guide the management of uncontrolled asthma (INCA Sun): a multicentre, single-blinded, randomised clinical trial. Lancet Respir Med. 2023;11(7):591-601.
37. Ryan D, Price D, Musgrave SD, Malhotra S, Lee AJ, Ayansina D, et al. Clinical and cost effectiveness of mobile phone supported self monitoring of asthma: Multicentre randomised controlled trial. BMJ (Online). 2012;344(7854):e1756.
38. Hoyte FCL, Mosnaim GS, Rogers L, Safioti G, Brown R, Li T, et al. Effectiveness of a Digital Inhaler System for Patients With Asthma: A 12-Week, Open-Label, Randomized Study (CONNECT1). Journal of Allergy and Clinical Immunology: In Practice. 2022;10(10):2579-87.
39. Wu JM, Yang TH, Qin X, Liu D, He Y. Effectiveness of specialist nurse-led WeChat mini program management for disease control in asthma: A randomized controlled study. J Pediatr Nurs. 2024;79:e93-9.
40. Jahedi L, Downie SR, Saini B, Chan HK, Bosnic-Anticevich S. Inhaler Technique in Asthma: How Does It Relate to Patients' Preferences and Attitudes Toward Their Inhalers? J Aerosol Med Pulm Drug Deliv. 2017;30(1):42-52.
41. Cascini F, Santaroni F, Lanzetti R, Failla G, Gentili A, Ricciardi W. Developing a Data-Driven Approach in Order to Improve the Safety and Quality of Patient Care. Front Public Health. 2021;9:667819.
42. Demiris G, Iribarren SJ, Sward K, Lee S, Yang R. Patient generated health data use in clinical practice: A systematic review. Nurs Outlook. 2019;67(4):311-30.
43. Zabczyk C, Blakey JD. The Effect of Connected "Smart" Inhalers on Medication Adherence. Front Med Technol. 2021;3:657321.
44. Lauffenburger JC, Yom-Tov E, Keller PA, McDonnell ME, Crum KL, Bhatkhande G, et al. The impact of using reinforcement learning to personalize communication on medication adherence: findings from the REINFORCE trial. NPJ Digit Med. 2024;7(1):39.
45. Fenerty SD, West C, Davis SA, Kaplan SG, Feldman SR. The effect of reminder systems on patients' adherence to treatment. Patient Prefer Adherence. 2012;6:127-35.
46. Eikholt AA, Wiertz MBR, Hew M, Chan AHY, van Boven JFM. Electronic Monitoring Devices to Support Inhalation Technique in Patients with Asthma: a Narrative Review. Curr Treat Options Allergy. 2023;10(1):28-52.
47. Pleasants RA, Chan AH, Mosnaim G, Costello RW, Dhand R, Schworer SA, et al. Integrating digital inhalers into clinical care of patients with asthma and chronic obstructive pulmonary disease. Respir Med. 2022;205:107038.
48. Zhang H, Cao Y, Jiang H, Zhou Q, Yang Q, Cheng L. The present and future of digital health, digital medicine, and digital therapeutics for allergic diseases. Clin Transl Allergy. 2025;15(1):e70020.
49. Kokori E, Olatunji G, Mustapha MJ, Fawehinmi P, Onyia A, Omoworare O, et al. The potential of smart inhaler for asthma management in Sub-Saharan Africa. Ann Med Surg (Lond). 2024;86(5):2408-10.
50. van de Hei SJ, Kim CH, Honkoop PJ, Sont JK, Schermer TRJ, MacHale E, et al. Long-Term Cost-Effectiveness of Digital Inhaler Adherence Technologies in Difficult-to-Treat Asthma. Journal of Allergy and Clinical Immunology: In Practice. 2023;11(10):3064-73.
51. Kaboré SS, Ngangue P, Soubeiga D, Barro A, Pilabré AH, Bationo N, et al. Barriers and facilitators for the sustainability of digital health interventions in low and middle-income countries: A systematic review. Front Digit Health. 2022;4:1014375.
52. van de Hei SJ, Stoker N, Flokstra-de Blok BMJ, Poot CC, Meijer E, Postma MJ, et al. Anticipated barriers and facilitators for implementing smart inhalers in asthma medication adherence management. NPJ Prim Care Respir Med. 2023;33(1):22.
53. Dolcini MM, Canchola JA, Catania JA, Mayeda MMS, Dietz EL, Cotto-Negrón C, et al. National-level disparities in internet access among low-income and black and hispanic youth: Current population survey. J Med Internet Res. 2021;23(10):e27723.
54. Walker DM, Hefner JL, Fareed N, Huerta TR, McAlearney AS. Exploring the digital divide: Age and race disparities in use of an inpatient portal. Telemedicine and e-Health. 2020;26(5):603-13.
55. Blount MA, Douglas MD, Li C, Walston DT, Nelms PL, Hughes CL, et al. Opportunities and Challenges to Advance Health Equity Using Digital Health Tools in Underserved Communities in Southeast US: A Mixed Methods Study. J Prim Care Community Health. 2023;14: 21501319231184789.

Cite this article as: Bataduwaarachchi VR, Gunasekara AI, Cruz LGD. Global trends in using digital technology and smart inhalers in asthma management, problems, challenges and future directions. Int J Basic Clin Pharmacol 2026;15:125-38.