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SMART INHALERS IN PEDIATRIC ASTHMA: ADHERENCE MONITORING, EXACERBATION PREVENTION, AND PUBLIC HEALTH IMPLEMENTATION - A NARRATIVE REVIEW

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ABSTRACT

Background: Pediatric asthma remains one of the most important chronic conditions of childhood, yet outcomes are still undermined by poor adherence to inhaled corticosteroids, incorrect inhaler technique, delayed recognition of deterioration, and uneven access to follow-up care. Smart inhalers and related connected inhaler platforms have emerged as digital tools intended to address these gaps by objectively measuring use, delivering reminders, supporting self-management, and enabling remote clinical review.
Objective: This narrative review synthesizes the pediatric literature on smart inhalers with emphasis on three linked questions: their value for adherence monitoring, their potential to prevent exacerbations, and the practical requirements for public health implementation.
Methodology: A narrative review was undertaken using PubMed/MEDLINE and PubMed Central as primary scientific sources, complemented by major guideline and policy documents. Literature published mainly between 2010 and March 2026 was reviewed, with priority given to pediatric trials, systematic reviews, qualitative studies, and implementation analyses.
Results: Pediatric studies consistently show that smart inhalers improve measured adherence, especially when electronic monitoring is coupled with reminders and feedback. Evidence for improved asthma control and reduced exacerbations is promising but heterogeneous, with effects varying by device type, population risk, duration of follow-up, and degree of clinical integration. Actuation-only devices may overestimate true use because they do not confirm correct inhalation. Implementation studies indicate that technical usability, multiple-caregiver workflows, data integration, privacy, reimbursement, and digital inequities are central determinants of success.
Conclusions: Smart inhalers should be understood not as stand-alone gadgets but as socio-technical interventions. Their strongest near-term role in pediatric asthma is targeted deployment in children with poor adherence, recent attacks, or suspected severe disease, supported by structured onboarding, technique education, and integration into routine primary and specialist care.

KEYWORDS

Pediatric Asthma, Smart Inhalers, Medication Adherence, Digital Health, Exacerbation Prevention, Implementation Science

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1. Introduction

Asthma is a major noncommunicable disease and remains the most common chronic disease in children. Despite the availability of effective inhaled therapy, a large burden of symptoms, emergency visits, hospital admissions, school absence, caregiver stress, and avoidable deaths persists. In the United States alone, the Centers for Disease Control and Prevention estimated that 4.53 million children had current asthma in 2022, with asthma continuing to drive substantial emergency and inpatient use. This persistent burden makes pediatric asthma not only a clinical problem but also a public health challenge involving families, schools, primary care, specialist services, and health systems (Centers for Disease Control and Prevention [CDC], 2024; World Health Organization [WHO], 2024).

Clinical guidelines have repeatedly identified poor adherence and incorrect inhaler technique as major, modifiable reasons for uncontrolled asthma and exacerbations. The 2025 Global Initiative for Asthma (GINA) summary guide advises clinicians to check inhaler technique and adherence whenever a child has poor control or exacerbations, and it specifically notes that electronic inhaler reminders may improve adherence. This guideline position is important because it frames digital adherence support not as a technological novelty but as a response to a well-established management gap (Global Initiative for Asthma [GINA], 2025).

The term smart inhaler is used inconsistently in the literature. In this review, it refers broadly to connected inhaler systems that incorporate an electronic sensor or digital attachment to record actuation, timestamp use, provide reminders, transmit data to an app or platform, or in more advanced forms, capture inhalation flow or technique. This meaning should be distinguished from the pharmacologic acronym SMART or MART, which refers to a maintenance-and-reliever regimen using inhaled corticosteroid–formoterol. The distinction matters because digital smart inhalers are a monitoring and behavior-support technology, whereas SMART/MART is a medication strategy (Drummond et al., 2025; GINA, 2025).

The pediatric context gives smart inhalers distinctive relevance. Children depend on caregivers to obtain medication, supervise technique, renew prescriptions, and interpret symptoms. Many children split time between households, school, and extracurricular environments, so asthma management often involves multiple adults with variable levels of training and accountability. Adolescents, meanwhile, may face competing priorities, stigma, forgetfulness, or ambivalence about long-term preventer treatment. For these reasons, objective data on when and how inhalers are used can be especially valuable in pediatric practice (Ferrante et al., 2021; Kan et al., 2021; McCrossan et al., 2024).

At the same time, smart inhalers raise questions that go beyond efficacy. If these technologies are to be introduced at scale, clinicians and policy-makers must decide who should receive them, who should monitor the data, how alerts should be triaged, what evidence justifies reimbursement, and how to prevent digital tools from widening inequities among children with fewer resources. These questions fit well within the social-science and public-policy orientation of the International Journal of Innovative Technologies in Social Science, where the success of a technology is evaluated not only by its performance in trials but also by its fit within real institutions and communities.

The aim of this narrative review is therefore threefold: first, to synthesize evidence on the role of smart inhalers in monitoring adherence among children and adolescents with asthma; second, to assess whether these technologies help prevent exacerbations and improve clinical outcomes; and third, to examine their implications for public health implementation, including equity, governance, reimbursement, and service design.

2. Methodology

This article was designed as a narrative review rather than a formal systematic review. The choice was deliberate because the smart inhaler field is heterogeneous, spanning randomized trials, observational studies, qualitative interviews, implementation analyses, and guideline documents. A narrative design allowed integration of clinical efficacy evidence with public health and health-system considerations that are especially relevant for IJITSS.

The main scientific database used was PubMed/MEDLINE, with PubMed Central used where full-text access provided further contextual detail. Search activity was focused on literature published mainly from 2010 to March 2026, although older studies were considered where they were methodologically influential or foundational to later pediatric work. Core search terms included combinations of pediatric asthma, children, adolescents, smart inhaler, digital inhaler, electronic monitoring device, adherence, inhaler technique, exacerbation, qualitative, implementation, and telemonitoring. Guideline and policy sources were also reviewed, particularly GINA, the joint 2024 NICE/BTS/SIGN asthma update, WHO, and CDC documents.

Priority was given to English-language publications involving children and adolescents, including randomized controlled trials, systematic reviews, meta-analyses, qualitative studies, and implementation research. Adult-only studies were not the focus, but selected adult or mixed-population implementation papers were included when they clarified barriers that are also relevant to pediatric deployment, such as interoperability, reimbursement, privacy, and clinical workflow. The evidence was synthesized thematically under the headings of adherence monitoring, exacerbation prevention, inhaler-technique support, and public health implementation. No formal pooled quantitative re-analysis was attempted.

3. Results

3.1. Smart inhalers as a pediatric asthma technology category

Smart inhaler systems in pediatric asthma can be grouped into several overlapping categories: simple actuation counters, reminder-enabled electronic monitoring devices, app-linked sensors, inhaler attachments capable of detecting inspiratory flow or acoustics, and smart spacers or related connected accessories. Their practical purposes also differ. Some are used chiefly to measure whether doses are actuated, others to prompt medication taking, others to identify rescue inhaler overuse, and some to support feedback from clinicians or caregivers. This heterogeneity is central to interpreting the literature because the effectiveness of a smart inhaler depends not only on the device but also on the surrounding support strategy (Drummond et al., 2025; Pleasants et al., 2022).

A further conceptual issue is that objective monitoring of actuation is not identical to confirmation of medication delivery. A child may press an inhaler without inhaling correctly, may actuate multiple doses close together, or may use poor spacer technique. This distinction has major implications for both research and practice. If a device only captures actuation, it may overestimate true adherence; if it also captures inhalation quality or is combined with video or smart-spacer feedback, it may function as a stronger diagnostic and educational tool (Gillette et al., 2016; Lee et al., 2021; McCrossan et al., 2024).

3.2. Adherence monitoring and behavioral effects

The strongest pediatric evidence for smart inhalers lies in adherence monitoring. Conventional adherence assessment based on self-report, caregiver report, or clinician impression is often inaccurate. Chen et al. (2020) demonstrated this clearly in infants and younger children with asthma: while device-monitored adherence differed markedly between groups, caregiver-reported adherence did not, showing how easily routine reporting can mask poor preventer use. Smart inhalers therefore address a core measurement problem before they even act as an intervention.

Randomized pediatric trials have repeatedly shown significant adherence gains. In a New Zealand study of 220 children aged 6–15 years following an emergency-department presentation, Chan et al. (2015) found median inhaled corticosteroid adherence of 84% in children using an electronic monitor with audiovisual reminders compared with 30% when reminders were disabled. In the STAAR trial, Morton et al. (2017) reported adherence of 70% in children receiving reminder alarms and feedback versus 49% in children who were monitored without those added features. In younger children aged 6 months to 3 years, Chen et al. (2020) found mean device-monitored adherence of 80.0% in the intervention group compared with 45.9% in controls when electronic monitoring was combined with weekly feedback and reminders.

This pattern is also visible in higher-level evidence syntheses. Lee et al. (2021), in a systematic review and meta-analysis of 10 randomized controlled trials involving 1,123 participants, concluded that children using electronic adherence monitoring devices were 1.50 times more likely to adhere to inhalers than controls, with a medium-to-large pooled effect size. More recently, Hassani et al. (2025) reviewed 14 pediatric studies and similarly concluded that electronic monitoring devices can improve inhaled corticosteroid adherence, particularly when sustained feedback is added rather than monitoring alone.

These findings suggest that the active ingredients of successful smart inhaler interventions are not merely passive recording functions. The combination of objective measurement, reminders, and human interpretation appears to matter. In behavioral terms, the device can serve as a memory aid, a cue to action, a source of accountability, and a medium for discussion between clinicians, caregivers, and children. This may be especially important in pediatric asthma, where routines are shaped by family organization, school schedules, sleep patterns, and competing caregiving responsibilities (Ferrante et al., 2021; Hassani et al., 2025; Kan et al., 2021).

However, not all children benefit in the same way, and not all studies show that more data automatically translates into better long-term behavior. The IMAGINE trial reported no significant difference between feedback and recording alone in clinical or behavioral outcomes over time, although both groups improved. This may reflect small sample size, a monitoring effect whereby being observed changes behavior in both arms, or the possibility that some children require a more tailored form of feedback than a standard digital intervention can provide (Sportel et al., 2025).

Table 1. Selected pediatric studies on smart inhalers and electronic adherence monitoring

Study	Design / population	Digital function	Main findings	Interpretation
Chan et al. (2015)	RCT; 220 children aged 6–15 years after ED exacerbation	Electronic monitor with audiovisual reminders	Median ICS adherence 84% vs 30% when reminders were disabled; better asthma morbidity score	Strong evidence that reminders can markedly improve adherence in high-risk children.
Morton et al. (2017)	RCT; 90 children aged 6–16 years with poorly controlled asthma	Monitoring plus reminder alarms and clinical feedback	Adherence 70% vs 49%; fewer oral steroid courses and fewer hospital admissions	Suggests clinical benefit is more likely when monitoring is paired with feedback.
Chen et al. (2020)	RCT; 96 children aged 6 months–3 years	Monitoring plus weekly digital feedback/reminders	Device-measured adherence 80.0% vs 45.9%; caregiver report did not discriminate	Highlights both efficacy and the unreliability of self-report.
Gupta et al. (2021)	RCT; 252 caregiver–child dyads	Sensor-based monitoring with clinician/caregiver access	ACT improved, caregiver quality of life improved, but ED visits/hospitalizations were higher	Digital monitoring may improve control while also changing help-seeking patterns.
Lee et al. (2021)	Systematic review and meta-analysis; 10 RCTs, 1,123 participants	Electronic adherence monitoring devices	Children were 1.50 times more likely to adhere; no pooled significant difference for exacerbations or asthma control	Adherence benefit is robust; hard outcomes remain less certain.
Hassani et al. (2025)	Systematic review; 14 pediatric studies	Electronic monitoring with varied feedback models	Improved adherence in 6/12 studies; asthma control in 7/9; ED/hospitalization reduction in 4/7	Supports promise of EMDs but also emphasizes heterogeneity and context dependence.

3.3. Exacerbation prevention and early warning

The clinical promise of smart inhalers extends beyond adherence measurement to the prevention of exacerbations. The logic is compelling: if children take inhaled corticosteroids more consistently and clinicians can detect patterns of deterioration earlier, severe attacks should become less common. Yet the pediatric evidence on hard outcomes is more mixed than the evidence on adherence.

Several trials suggest benefit. In the STAAR trial, Morton et al. (2017) did not show a significant between-group improvement in questionnaire-based asthma control, but they did report fewer courses of oral corticosteroids and fewer hospital admissions in the intervention arm. Chan et al. (2015) also found that improved adherence after an emergency-department exacerbation was accompanied by a significant improvement in asthma morbidity scores, even though school absence was not reduced. These findings imply that digital adherence support may be most clinically valuable in children at high risk of future attacks, especially after recent acute care use.

At the same time, evidence synthesis remains cautious. Lee et al. (2021) found no overall significant pooled differences for exacerbations, lung function, or asthma control despite a clear adherence benefit. Hassani et al. (2025) reported a somewhat more optimistic picture, noting that seven of nine studies found improvements in asthma control and four of seven found reductions in emergency-department visits or hospitalization. A reasonable interpretation is that smart inhalers may reduce exacerbations in some pediatric settings, but effects are inconsistent because studies differ in baseline risk, intervention intensity, outcome definitions, and follow-up duration.

One of the most informative “mixed” findings comes from the iTRACC trial by Gupta et al. (2021). In that study, sensor-based monitoring and clinical feedback improved Asthma Control Test scores and caregiver quality of life, but intervention participants had higher rates of emergency-department visits and hospitalizations. Rather than proving harm, this result likely highlights the complexity of digital monitoring in real life. Better monitoring may increase problem recognition, clinician contact, or appropriate care-seeking in

populations that were previously under-recognized. It also shows why utilization outcomes must be interpreted carefully: higher short-term health-care use may sometimes reflect improved detection rather than failure.

This cautious interpretation is echoed in guideline work. The 2024 NICE/BTS/SIGN evidence review included 14 randomized controlled trials and concluded that smart inhalers improve adherence, but judged the clinical and economic evidence insufficient for a routine blanket recommendation in all patients. The committee nevertheless considered that targeted use could be helpful in people with poor control linked to poor adherence or severe disease. For pediatric asthma, this selective strategy appears more defensible than universal distribution at the present stage of evidence development (National Institute for Health and Care Excellence [NICE], 2024).

Reliever monitoring may become an increasingly important pathway to exacerbation prevention. Drummond et al. (2025) identify reliever overuse as one of the three major problems that smart inhalers may address, alongside poor adherence and poor technique. In theory, rising rescue use could trigger earlier action plans or review appointments. In practice, pediatric evidence on this function remains less mature than the preventer-adherence literature, and future studies should evaluate whether digitally flagged reliever overuse can reduce attacks in primary care and school-linked pathways.

3.4. Inhaler technique, diagnostic stewardship, and limits of actuation data

Inhaler technique is a persistent weakness in pediatric asthma care. Gillette et al. (2016), in a systematic review of 28 studies, concluded that technique in children is generally poor across devices, although somewhat better with spacers and after repeated counseling. The relevance for smart inhalers is straightforward: a system that records only that a dose was actuated cannot distinguish between effective and ineffective medication delivery. This limitation partly explains why improved recorded adherence does not always produce equally strong clinical gains.

For this reason, recent reviews have argued that the most useful pediatric systems should move beyond actuation alone. Lee et al. (2021) explicitly recommended future devices that confirm both actuation and inhalation. Drummond et al. (2025) similarly describe a broader ecosystem of smart spacers, acoustic sensors, and other devices able to capture aspects of inhalation behavior. Such tools may be especially valuable when clinicians are trying to determine whether a child has truly treatment-resistant asthma or instead has poor technique and inconsistent use.

This diagnostic role deserves more attention in public health discussions. Smart inhalers can support more rational escalation of therapy by identifying modifiable causes of poor control before a child is labeled as having severe asthma or moved to more costly treatments. In resource-constrained systems, that function has economic as well as clinical value. However, the evidence base remains incomplete. Technique-sensitive devices are less common than actuation monitors, and implementation at scale requires training, data interpretation protocols, and sometimes additional hardware.

Related digital approaches such as mobile direct observation of therapy have shown that remote monitoring can improve inhaler technique in children, but they also illustrate the labor needed for high-fidelity support. The implication is not that such methods are impractical, but that health systems must be explicit about the trade-off between intervention intensity and scalability. A low-touch reminder device may reach more children, whereas a higher-touch technique-focused approach may be most appropriate for selected high-risk cases.

3.5. Public health implementation

The public health implementation of smart inhalers depends on whether they are treated as consumer gadgets or as components of a broader model of care. The literature strongly supports the latter interpretation. Successful implementation requires appropriate patient selection, family onboarding, reliable data transfer, agreed response pathways, clinician acceptance, and financing mechanisms. Without these elements, digital devices risk becoming underused, technically frustrating, or clinically irrelevant (Pinnock et al., 2023; Pleasants et al., 2022).

Qualitative pediatric work shows that acceptability is real but conditional. In the United Kingdom, Qureshi et al. (2025) found that parents viewed Hailie smart inhaler monitoring positively and found it reassuring, while children appreciated learning from the accompanying app. At the same time, syncing problems and technical glitches were common, and clinicians emphasized that monitoring should not replace clinical support for self-management. Similarly, Kan et al. (2021) reported that parents generally felt electronic medication monitoring fit into daily life and improved asthma management, but highlighted problems for

families with multiple caregivers and for households with limited internet access or unstable caregiving arrangements.

These family-level observations connect directly to broader implementation science. Van de Hei et al. (2023) identified five major themes in stakeholder discussions on smart inhaler adoption: perceived benefits, usability, feasibility, payment and reimbursement, and data safety and ownership. Their study found 14 barriers and 32 facilitators, illustrating that implementation is not blocked by a single obstacle but by an interdependent set of practical, financial, and ethical issues. For pediatric settings, these barriers may be magnified by the need to define who owns and acts on data generated by minors: the child, parents, clinicians, schools, or vendors.

System-level reviews reinforce the same message. Pinnock et al. (2023) argue that digital respiratory care requires interoperable systems, reliable internet coverage, data accuracy, and safeguards against clinician data overload, while also addressing reimbursement, regulation, and equity. Pleasants et al. (2022) likewise stress that health-system collaboration, cybersecurity, privacy review, and reimbursement pathways are prerequisites for wider integration. These concerns are not peripheral. They determine whether smart inhalers become a sustainable service model or remain a short-lived pilot technology.

Economic uncertainty remains a major barrier. The NICE (2024) evidence review found only limited economic evidence and did not consider the case strong enough for routine general use. This is a familiar pattern in digital health, where proof of technical feasibility often outpaces proof of cost-effectiveness. In pediatric asthma, future analyses will need to assess not only device cost, but also the cost of staff time, onboarding, data review, maintenance, and replacements, against outcomes such as reduced exacerbations, avoided step-up therapy, fewer missed school days, and improved caregiver productivity.

Equity deserves special emphasis. Digital inhalers can potentially reduce inequality by supporting children who are repeatedly lost between visits, especially after emergency presentations or in underserved communities. Yet they can also widen disparities if effective use depends on owning smartphones, having reliable internet, reading English easily, maintaining Bluetooth connectivity, or coordinating among multiple caregivers. Pais-Cunha et al. (2024), in a systematic review of outpatient pediatric telemonitoring technologies, found that training was reported in only 23 of 40 studies and ongoing support in only three, suggesting that many interventions underestimate the support families need to use digital tools effectively. Any public health implementation strategy that ignores these structural realities is likely to reproduce, not solve, disparities.

Taken together, the implementation literature points toward targeted rather than universal deployment. The most sensible near-term candidates are children with recurrent exacerbations, poor control despite prescribed inhaled corticosteroids, suspected non-adherence before stepping up therapy, recent emergency-department attendance, or possible severe asthma in whom objective adherence and technique data may change management. In such groups, smart inhalers may offer the greatest clinical and economic yield, especially if embedded into primary care review, specialist triage, and caregiver education.

Table 2. Public health implementation domains for smart inhalers in pediatric asthma

Implementation domain	Key challenges in pediatric settings	Practical implication
Family workflow	Multiple caregivers, household transitions, school-day dosing, forgotten chargers or phones	Onboarding should involve all relevant caregivers and simplify routines as much as possible.
Technology and usability	Bluetooth syncing problems, device malfunction, app fatigue, replacement logistics	Programs should include troubleshooting support and realistic maintenance planning.
Clinical workflow	Unclear responsibility for data review, alert fatigue, lack of thresholds for action	Services need predefined triage rules and clear ownership of incoming data.
Economics and reimbursement	Device cost, staff time, uncertain cost-effectiveness, limited payment pathways	Targeted deployment is more feasible than universal deployment until stronger economic evidence emerges.
Governance and privacy	Data ownership, consent for minors, commercial vendors, cybersecurity	Contracts, consent processes, and data-governance rules should be explicit before scale-up.
Equity and access	Unequal internet access, language barriers, digital literacy gaps, precarious caregiving	Implementation should include equity safeguards such as training, alternative access routes, and inclusive design.

3.6. From device trials to population pathways

A major policy question is where smart inhalers fit in the pediatric care pathway. The literature suggests at least four high-value entry points. The first is the post-exacerbation period, especially after emergency-department attendance or hospitalization, when adherence, family anxiety, and motivation to change may all be heightened. The second is the child with repeated poor control despite an inhaled corticosteroid prescription, where objective use data may clarify whether treatment escalation is truly necessary. The third is the assessment of difficult-to-treat or suspected severe asthma, where smart inhalers may help distinguish biologic disease severity from modifiable behavioral factors. The fourth is proactive case finding in primary care, where digital review may identify children whose medication-taking patterns are drifting before another attack occurs (Drummond et al., 2025; NICE, 2024; Qureshi et al., 2025).

Primary care is a particularly important site for implementation because it manages the majority of childhood asthma care and is often the only regular point of contact for families outside periods of acute deterioration. The nested qualitative study by Qureshi et al. (2025) is informative here because it examined a smart inhaler pathway deliberately rooted in UK primary care rather than specialist clinics. Its findings suggest that smart inhalers may be acceptable in this setting, but only when linked to conventional self-management support and not treated as substitutes for clinician engagement. This has practical implications for service design: primary-care teams may need structured asthma reviews, dashboard summaries rather than raw data streams, and escalation criteria that fit routine appointment systems.

School-linked asthma management is another underdeveloped but potentially important frontier. Children spend a large part of the day away from the caregiver who supervises treatment at home, and schools often become the site where symptoms are first recognized or rescue medication is needed. In principle, smart inhalers could strengthen action-plan communication between families and schools by identifying missed preventer doses, frequent reliever use, or poor morning routines. In practice, this would require explicit consent, rules on who can access pediatric data, and careful protection against over-surveillance. The policy challenge is therefore dual: to improve continuity across settings without creating unmanageable data-sharing burdens or undermining child autonomy.

At the population level, smart inhalers should also be assessed against basic public health priorities. In many settings, the first barrier to asthma control is still reliable access to inhaled corticosteroids, spacers, and timely review. WHO has emphasized that under-diagnosis and under-treatment remain major reasons for global asthma burden and that chronic respiratory disease care must be strengthened in primary health care, including low-resource contexts. Digital adherence tools may eventually add value in such systems, but they should complement rather than distract from foundational investments in affordable medicines, inhaler technique education, and continuity of care. A sensible public health approach is therefore sequential: build the essentials of asthma care, then use smart inhalers selectively where they can close remaining gaps (WHO, 2024).

3.7. Evaluation, procurement, and multidisciplinary service design

Public health evaluation of smart inhaler programs should therefore be broader than device performance alone. Programs should be judged on whether they reduce repeat acute-care use, improve continuity after emergency visits, strengthen inhaler-technique review, reduce inappropriate treatment escalation, and narrow rather than widen gaps between advantaged and disadvantaged groups. A child whose adherence percentage rises while school absences, reliever overuse, and urgent care remain unchanged may still need a different form of support. Conversely, a program that increases short-term review visits but prevents later severe attacks may still be efficient. These distinctions show why evaluation frameworks must combine behavioral, clinical, service, and equity indicators rather than relying on a single digital metric.

Interoperability and procurement are also emerging as strategic issues. If health systems adopt smart inhalers from multiple vendors without compatible data structures, clinicians may face fragmented dashboards and families may have inconsistent experiences when treatment changes or devices are replaced. Standardization of data fields, integration with electronic health records, and transparent procurement criteria would make digital inhaler pathways more sustainable. In pediatric care, where children age, switch inhaler devices, and transition between services, continuity of digital data may be especially valuable if it can be preserved safely and meaningfully across settings.

Multidisciplinary delivery models may offer the most realistic route to scale. Pediatric asthma management already involves nurses, pharmacists, respiratory therapists, general practitioners, and specialists. Smart inhaler data could be reviewed at different levels of intensity by different professionals: pharmacists or asthma nurses could troubleshoot technique and missed doses; primary-care clinicians could review trends

during routine follow-up; specialist teams could use objective data to assess difficult-to-treat cases. Such stratified use would distribute workload more realistically than assuming all incoming digital data should be interpreted by physicians alone.

The global relevance of smart inhalers will also depend on whether they can be adapted for lower-resource environments. In settings where inhaled corticosteroid access is inconsistent, electricity is unreliable, or phone ownership is shared, a highly connected monitoring model may be unrealistic. Simpler reminder tools, shared community devices, or hybrid paper-digital pathways may be more feasible than smartphone-dependent ecosystems. Research and product design should therefore include context-specific adaptation rather than assuming that models developed in high-income specialty settings will transfer unchanged.

Finally, implementation should be developmentally responsive. The same digital strategy is unlikely to work equally well for preschool children, school-age children, and adolescents. Younger children require caregiver-mediated routines and simple interfaces; school-age children may benefit from visual feedback and school-linked planning; adolescents may prefer more autonomy, personalized messaging, and greater control over who sees their data. A public health program that ignores developmental differences risks low engagement even if the technology itself performs reliably.

4. Discussion

The evidence reviewed here suggests that smart inhalers in pediatric asthma are most convincing as tools for objective adherence measurement and adherence support. Across trials and systematic reviews, the direction of effect on measured adherence is remarkably consistent. This is not a trivial result. In a condition where treatment efficacy depends heavily on long-term, symptom-independent use of inhaled corticosteroids, the ability to replace guesswork with objective data has clinical value in itself. It can improve shared decision-making, uncover hidden non-adherence, and guide more proportionate escalation of care.

By contrast, evidence for reducing exacerbations or improving other clinical outcomes is promising but not uniform. This does not necessarily mean smart inhalers fail clinically. Rather, it reflects the familiar challenge of translating a proximal behavioral effect into a distal health outcome. Exacerbations are influenced by adherence, but also by viral exposure, allergens, air quality, access to care, underlying severity, comorbidity, and the timeliness of action-plan escalation. Moreover, many pediatric trials have been relatively short, have used heterogeneous interventions, and have lacked power for infrequent but high-value outcomes such as hospitalization.

A useful way to interpret the literature is to treat smart inhalers as socio-technical interventions rather than devices alone. A sensor that records data but is never reviewed, never discussed with the family, and never connected to an action pathway is unlikely to change outcomes substantially. The more successful pediatric studies generally combine monitoring with reminders, feedback, or clinical review. Conversely, interventions that ignore the realities of family life, technical troubleshooting, and workflow integration are likely to generate data without delivering value.

This socio-technical perspective is especially relevant in childhood asthma because responsibility is distributed. Children, parents, teachers, school nurses, pharmacists, general practitioners, emergency clinicians, and specialists may each hold part of the management task. Public health implementation should therefore move beyond the question “Does the device work?” to the question “How should care be redesigned around the device?” That redesign includes defining review intervals, escalation thresholds, documentation standards, consent procedures for minors, and support for families with lower digital literacy or unstable caregiving structures.

The literature also suggests several priorities for future research. First, pediatric trials should distinguish clearly between actuation adherence and effective inhalation. Second, studies should use longer follow-up and standardized outcome sets that include exacerbations, school absence, caregiver burden, health-care utilization, and cost-effectiveness. Third, more research is needed in preschool children, low-resource settings, and populations at high risk of digital exclusion. Fourth, implementation studies should move from acceptability alone toward pragmatic evaluation of service models, including who reviews the data and how frequently.

This review has limitations. It is narrative rather than systematic, so although the search was structured and focused on PubMed and major guideline sources, it was not designed to produce exhaustive study capture or formal risk-of-bias scoring. The field itself is rapidly evolving, with different devices, feedback models, and outcome measures that complicate direct comparison. Some implementation insights were drawn from broader digital respiratory literature rather than pediatric-only trials because these system-level issues are often studied across age groups. Nonetheless, the convergence of findings across pediatric trials, meta-analyses, qualitative work, and policy reviews provides a coherent picture of where smart inhalers are most useful and where caution remains necessary.

4.1. Policy implications

From a policy perspective, the current evidence supports a tiered implementation model. In a first tier, smart inhalers can be used diagnostically in targeted high-risk children—those with recent severe attacks, persistent poor control, or suspected non-adherence before treatment escalation. In a second tier, they can be incorporated into structured adherence-support programs that combine reminders with clinician or pharmacist feedback. Only in a later tier, and only if cost-effectiveness becomes clearer, would broader population deployment be justified. Such a staged approach matches both the evidence base and the realities of health-service capacity.

This tiered model also helps answer the question of who should act on the data. Not every dose timestamp needs clinician review. Most children are unlikely to benefit from continuous human surveillance, and indiscriminate review could quickly produce data overload. Instead, digital pathways should define thresholds that trigger human attention—for example, sustained low controller adherence, abrupt increases in rescue use, or repeated technical flags suggesting incorrect use. In this way, smart inhalers can function more like a risk-stratification tool than a stream of background noise.

Another policy issue is the ethics of monitoring minors. Objective adherence data can protect children from preventable harm, but it can also feel intrusive if framed primarily as surveillance. Adolescents may be especially sensitive to being monitored, particularly if they already experience stigma or conflict about their asthma. The most ethically defensible use of smart inhalers is transparent, collaborative, and proportionate: families and young people should know what is being measured, who can see it, how it will be used, and under what circumstances it will change care. Public trust is likely to be as important for long-term adoption as technical reliability.

4.2. Future research priorities

Future pediatric research should move beyond the narrow question of whether a sensor can increase adherence. More important questions concern which combinations of device function, behavioral support, and clinical workflow produce the best outcomes for which children. Trials should report intervention components in enough detail to distinguish the effect of measurement alone from the effect of reminders, education, clinician contact, and family coaching. Without that detail, the field risks repeatedly proving that 'some digital support helps' without learning what support is actually necessary.

Outcome standardization is another urgent priority. Studies should report not only adherence percentages but also clinically meaningful endpoints such as oral corticosteroid bursts, emergency visits, hospital admission, school absence, caregiver quality of life, and progression to higher treatment steps. Where possible, researchers should separate actuation adherence from confirmed inhalation and should describe how technical failures, missing transmissions, or device replacements were handled. Economic evaluations should include staff time, training, data management, and replacement costs—not just device prices—because these determine whether a program is scalable.

Finally, future work should better address representativeness. Many digital asthma studies are still conducted in settings with motivated families, research support, and stable infrastructure. Yet the children who might benefit most from better monitoring are often those facing fragmented care, material deprivation, language barriers, or repeated acute-care use. Pragmatic trials in routine primary care, emergency follow-up programs, and underserved communities will therefore be more informative for public health decision-making than small technology-optimistic pilots alone.

An important caution is to avoid technological solutionism. Poor pediatric asthma outcomes are often rooted in housing quality, environmental exposures, tobacco smoke, medication affordability, fragmented access to care, and the social stressors that make daily routines difficult. Smart inhalers cannot solve these determinants by themselves. Their greatest value is likely to be as enabling tools within a broader strategy that still prioritizes equitable access to medicines, person-centered education, and social support where needed.

Transition planning is another overlooked opportunity. Older adolescents with asthma are often expected to assume greater responsibility for medication use just as parental oversight decreases. Smart inhalers may assist this transition by making routines visible and by supporting shared review between pediatric and adult-oriented services, but only if privacy and autonomy are handled carefully. Used well, digital data can scaffold self-management rather than replace it. Used poorly, it can become another source of disengagement. This reinforces the wider conclusion of the review: the benefits of smart inhalers arise less from the sensor itself than from the quality of the relationships, workflows, and policy decisions built around it.

For that reason, implementation science, not device novelty alone, should now be the central agenda of pediatric smart inhaler research and policy.

Only then can connected inhaler technologies move from promising pilot projects to credible population-level components of equitable asthma care.

5. Conclusions

Smart inhalers represent a meaningful advance in pediatric asthma care, but their value is uneven across outcomes and contexts. The best-supported conclusion is that they improve objectively measured adherence to inhaled corticosteroids, especially when monitoring is paired with reminders and feedback. Evidence that they prevent exacerbations or improve asthma control is encouraging but mixed, with benefits more likely in targeted high-risk groups and in programs where digital data actually informs clinical action.

For public health implementation, the central lesson is that technology alone is insufficient. Smart inhalers should be introduced as part of a structured care pathway that includes family training, repeated inhaler-technique education, clear responsibility for data review, equitable access support, and protection of privacy and data ownership. In the near term, selective deployment in children with poor control, recent attacks, or suspected non-adherence is more justified than routine universal use. If future pragmatic trials demonstrate durable clinical benefit and cost-effectiveness, smart inhalers may become an important bridge between precision monitoring, family-centered self-management, and more equitable pediatric asthma care.

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