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Engineering Smart Inhalers for Asthma Management

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ABSTRACT

Asthma, a chronic respiratory condition affecting approximately 12% of the global population, is primarily managed using inhalers that deliver medication directly to the lungs. However, traditional inhalers face significant challenges related to patient adherence, correct usage, and accessibility. In recent years, smart inhalers, equipped with sensors and connectivity features, have emerged as a promising solution. These devices are designed to enhance medication adherence, provide real-time feedback, and monitor patient behavior through data analytics. This review examines the role of smart inhalers in asthma management, discussing their key components, benefits, and clinical efficacy. Additionally, it highlights ongoing research, future directions, and potential improvements to optimize the functionality of these devices for better patient outcomes.

Keywords: Asthma, Smart Inhalers, Medication Adherence, Sensors, Data Analytics, Digital Health, Healthcare Technology.

INTRODUCTION

Asthma is a chronic condition of the respiratory system characterized by recurring symptoms such as wheezing, dyspnea, chest tightness, and coughing. All of these occur due to varying degrees of lung inflammation, intermittent bronchoconstriction, and bronchial hyper-responsiveness. Airflow obstruction arises from the constriction of smooth muscle that wraps around the airways, mucus plugging, and epithelial remodeling. Apart from systemic medications, inhalers are also the prime treatment option for asthmatics and patients with chronic obstructive pulmonary disease because the medication administered through them directly reaches the lungs with minimal side effects [1, 2], Inhalers allow the patient to breathe in the medication in the form of aerosols containing small droplets of drug solution, large drug particles, or fine dry powder; but how they are prepared and the location for drug deposition in the respiratory system are different. Metered-dose inhalers were introduced in 1950, pressurized metered-dose inhalers in 1955, and dry powder inhalers in 1970 as alternatives to metered-dose inhalers. There are mainly two types of dry powder inhalers: resistance-based inhalers and vibration-based inhalers. Currently, 12% of the global population suffers from asthma, and it is estimated that by the end of 2025, 100,000,000 people will have this disease. With the advent of steady progress in inhaler technology, different types of smart inhalers have been developed for identifying and controlling the disease efficiently. Smart inhalers are used in combination with radios, sensors, analytics-related software, and wireless communications. In the present review, the role of inhalers in disease management is discussed [3, 4].

Challenges in Traditional Inhaler Use

There are numerous hurdles in the effective delivery of asthma medication through traditional inhaler devices. Among them is the fact that many patients with asthma fail to use their inhaler devices correctly, which can result in less effective medication delivery, inadequate control of their disease, and an increased risk of health complications. Poor adherence to treatment regimens, owing to forgetfulness or a lack of understanding about the necessity of taking controller medications, is also a contributing factor to uncontrolled asthma. Additional limitations in traditional inhaler function stem from patients' insufficient ability to use inhaler devices because of their young age, older age, or limited cognitive, dexterity, hearing, or vision abilities. Controllable environmental elements, including socio-economic factors such as low income, low health literacy, poor health, and unaffordable inhaler devices, might also affect people's usage of conventional inhalers [5, 6]. To address disparities in patient inhaler technique, researchers have designed new sensor-based technologies, often known as smart inhalers, to help consumers improve how they use their inhalers. These tools are designed to solve challenges with traditional inhaler use, thereby bolstering patient engagement and clinical outcomes. Smart inhalers come in a variety of models. Only intelligent spacers are available, while others are fitted with a dry powder inhaler, an inhaled corticosteroid MDI, or a rapid-acting agonist bronchodilator MDI. Pulmonary physicians and researchers have been able to categorize the possible applications of these tools. Many studies have not yet made a categorical distinction. Currently, none of the commercially available inhaler technologies have been combined with smartphone technologies, particularly smart inhaler interfaces [7, 8].

Emergence of Smart Inhaler Technology

In recent years, remarkable advancements have been achieved in the treatment of respiratory diseases like asthma through the implementation of smart inhaler technologies. Smart inhalers represent advanced versions of traditional inhaler devices, embedded with digital features or capabilities. The principal objective of these technological advancements is to transform inhaler devices for better asthma patient adherence and monitoring. When focused on better adherence, it is evident that basic inhaler devices designed earlier did not possess multifaceted tracking capabilities, and thus, adherence or non-adherence data were not retained. In contrast, smart inhalers characterize themselves by an ability to chronologically monitor and store the adherence data of patients using propellant inhalers or dry powder inhaler devices in an internal computer or a compatible add-on tool, paired with the standard inhaler device [9, 10]. In addition, advancements in asthma management have led to the development of mobile smartphone applications and cloud computing, which are capable of ensuring the real-time availability of asthma control data to concerned patients using smart inhalers. This data can further help healthcare professionals discuss the latest trends in asthma control or prescribe an alternative treatment plan during the next clinical visit. Smart inhalers can also be more interventional, helpful, and empowering to asthma patients, as these devices can provide feedback or recommendations to individuals according to their latest data trends. This feedback can include advice during the process of emergency rescue inhaler therapy and/or connect to ambulatory alert systems, leading to improvements in asthma prescriptions or interventions by healthcare professionals. Some smart inhaler prototypes are able to communicate with patients when they are supposed to administer a particular dose or can provide predictive insights based on user history data, generating an action plan for the user to execute after the occurrence of a particular situation. All these latest advancements in traditional inhaler devices can be clubbed under the term "smart inhalers." Although different smart inhaler prototypes have been developed with their unique capabilities and limitations, none have reached the point of everyday use in asthma clinics, mainly because of their ability to be tested intimately in clinical practice or upcoming pilot studies [11, 12].

Key Components of Smart Inhalers

The integration of sensors is the essential feature of smart inhaler devices, especially in the context of asthma management. Added sensors on the inhaler are used for observation of the inhaler usage pattern as well as monitoring adherence to the medication. Data generated by the sensors can be transmitted via connectors to a storage device for further data analytics. The connectivity options available in smart inhaler devices include Bluetooth and Wi-Fi, which allow data to be easily transferred to mobile applications for further data analytics. Smart inhalers are built using a user-friendly interface that provides real-time feedback to the user in an attempt to improve their experience with the device and ultimately their adherence to their treatment regimen. The processor integrated into the device performs the drug metering function and stores the inhalation data until the time of transfer. The inhalation cycle data can be used to infer flow rate and volumes [13, 14]. Collection of data from the user device allows fast inhaler usage data analytics. Data can be categorized by individual, dosage, frequency of use, and time of inhalation. Patient-specific drug consumption patterns over time can be identified for individuals as well as groups with common characteristics. Inhaler performance data are also captured, which can provide the user with feedback on good and poor usage of the inhaler. Users can be issued alerts at the first instance of a diverging data trend that may indicate potential exacerbation and avoid unnecessary healthcare visits. Stored drug data and timing of inhalations can be transmitted to patient databases for patient mobile applications designed for recording and tracking inhaler usage and outcomes. The data are essential for informing the patient when the next dose is due and for coordinating with the healthcare provider. Data stored and captured from the device can be transmitted to servers located in clinics or hospitals for healthcare provider follow-up. Moreover, the user's nomadic devices, such as tablets or smartphones, can transmit the data to the healthcare provider databases from the home care clinic or hospital and can be used for appointment scheduling or confirmation. The inhalation and data transfer processes now have an increasing degree of patient participation and input, which in turn can also take the form of ethical considerations for the overall expected outcomes. These components should culminate in better therapy and potential improvement in care that can lead to better patient outcomes [15, 16].

Sensors and Connectivity

The main aim of a smart inhaler is to track inhaler user behavior in terms of timing and frequency of usage. Sensors fitted inside the device work as an accelerometer that reports device actuation and motion artifacts. These sensors play three primary roles in an inhaler device: to track the inhalation profile, to validate a user's inhalation to ensure drug deposition in the lungs, and to monitor the dosing after the dose delivery. More generally, the accumulated data provide details about a user's adherence in real time or at a predetermined threshold as input to the HIS. Various sensors have been employed, such as capacitance sensors, ultrasonic sensors, optical sensors, inertial sensors, and accelerometers, and they provide information on inspiratory flow profiles, inspiratory volume, and inspiratory efforts [17, 18, 19]. Using time-stamped data on the date and time of device actuations indicated timing and adherence issues of inhaled corticosteroids. A study demonstrated that compliance with inhaled corticosteroids for one month was suboptimal for half of the children enrolled. Therefore, a monitoring and reminder method was proposed as a solution. Since then, the world has seen the development of non-pharmacology intervention tools, including alarm systems, patient diaries, and electronic monitoring. The Bluetooth feature in a daily smart inhaler pairs the inhaler to a mobile device, after which the device can then send the pairing data to the cloud. A practical outcome of these technologies is that the HIS can manage and analyze which medication measurements to transmit to the patient; this structure also prevents the multiplicity of drug dosages generating random notifications. In terms of user anonymity, data security of such smart inhalers is a crucial factor in the days of health informatics [20, 21].

Data Analytics and Feedback Systems

While stand-alone medication reminders have limited value, there is a growing recognition of the role of data analytics and feedback systems in improving patient care and management at the individual patient level. Such systems primarily analyze the data from the sensors to give a clearer indication of when medications were taken and to provide insight into the individual's patterns of medicine use over time, giving a picture of their compliance. The availability of this kind of evidence-based data has the potential to enhance the discussion during healthcare contacts, but also to provide an opportunity for the use of machine learning techniques to predict how well a course of medicine is progressing, and/or to generate recommended changes to the management plan based on the profile of medicine use or to offer customized behavior change techniques to support a participant or patient in taking their medicines [22, 23]. The feedback loops generated by these solutions also allow us to provide a more direct and immediate means of engagement with people. It can range from a mobile app that uses a sensor in an inhaler to remind a patient when to take their treatment, to monitoring the use of medicines and automatically alerting the patient and a healthcare professional when the usage pattern indicates that the patient's control of asthma is reducing. At the population health level, access to aggregated compliance data could be used by healthcare providers to monitor how well a new program, medication, or intervention is being taken up by a cohort of patients and to track their medicine-taking over time to evaluate if they are sticking to the medication regimen. However, these analytics vary in their levels of sophistication. While some may be able to measure the user's dosage, others can combine this information with additional health data, such as asthma attacks or smart inhaler sensor activations, to develop a more complete picture. There is a danger of paralysis by analysis and that the output will not be properly understood or communicated effectively during the appointment. Furthermore, there may be ethical concerns about the use of this data, including questions about interpretation and accuracy of electronic monitoring, the impact of possible inaccuracies on individuals and their healthcare, and the potential stigma for those using inhaled therapy for whom it is not best practice. Nevertheless, this data provides an opportunity to substantially reduce avoidable emergency hospital admissions and avoidable deaths in healthcare systems by being more proactive in the care provided. By using data analytics to provide a better understanding of patient compliance or adherence and applying an appropriate range of behavior-changing techniques to help address poor patterns of adherence, the frequency of poor outcomes for patients due to poor compliance may be subsequently reduced, and the cost and burden for healthcare systems relating to avoidable care and treatments could be reduced. The level of regulation regarding these solutions is currently being discussed as part of regulatory reforms [24, 25].

Benefits and Clinical Efficacy of Smart Inhalers

In addition to improving medication adherence among asthma patients, the initial applications and efficacy of smart inhaler devices should be evaluated in the real-world setting. Studies suggest that healthcare professionals place great importance on objective data related to illness and treatment; most have indicated that smart inhalers could support better patient outcomes by complementing their clinical decision-making. The feasibility and acceptability of health and patient care centers' stakeholders using data and insights supplied by digital technologies have also been validated. At an individual level, this simple form of communication between patients and healthcare professionals is precisely what the NBAI aims to achieve. Continuous patient data collection through digital technologies provides a detailed, objective, and long-term view of a patient's disease profile and treatment response, which may allow identification of asthma patients eligible for a different treatment option. Consequently, improved treatment outcomes may occur through the earlier implementation of more personalized treatment approaches. Smart inhaler technology could act as the tool for necessary treatment in line with current asthma management guidelines and treatment strategies [10, 26]. Clinical evidence shows that a person with well-grounded, disease-specific confidence has a good understanding of his or her illness and its management. A 6-month usual-care asthma management study demonstrated a higher level of confidence in the usual care of the digital intervention group and a higher level of knowledge; this approach encourages a collaborative relationship between the patients and professionals. An intervention that improves confidence with a tailored information function was considerably more effective than routine care. The use of smart inhaler devices represents a reasonable option to address the multiple dimensions of the cost-utility analysis of a given treatment – both cost and consequences – compared with alternative medications. They could be of particular interest as an alternative option to market access for individuals who are currently not offered access to eligible and needed therapies, based on their history or likelihood of being offered. A smart inhaler could reflect the increased value of that treatment approach due to the potentially higher baseline value of associated fees in other, more severe and difficult patient populations who would benefit [27, 28].

Current Research and Future Directions

Peers are addressing several areas of research that can be advanced. There are a number of studies that are ongoing worldwide and will help determine patient health outcomes from the long-term use of these devices. A program is evaluating both patient experiences of using a commercial device and the linkage with patient outcomes from across the studies. This large system-wide study collates data from various sources and investigates how people use a novel app-linked medication as well as assessing the potential for the use of inhaler data as a phenotyping tool. Researchers in other teams have taken the step of engaging the input of commercial manufacturers, the regulatory authority, and healthcare professionals to ask how they see the 'next step' developing for smart inhalers to become adopted into clinical practice. This work has explored how to interpret the multitude of data generated by smart inhalers through the development of algorithms to highlight those with deteriorating control. Another activity looked at the perspective of why someone may not use a smart inhaler – providing data on features that are of less or more interest to users. Indeed, they may have researched what additional features individuals want to see in a smart inhaler, with the potential for wider functionality such as add-ons to devices, diet, and activity tracking. These investments in the smart inhaler 'who benefits' studies from various stakeholders and the engagement of users, manufacturers, researchers, and others are reflective of the considerable effort being placed into this area of current and emerging interest. They demonstrate that the area of smart inhalers and devices continues to attract considerable interest from multiple stakeholders with an interest in understanding the current and potential future contribution of such devices to asthma management. There are developments occurring in relation to smart inhalers that do not make the landscape in the UK that are discussed at a commercial and academic level. These focus mainly on the development of inhalers for use in newly diagnosed patients [29, 14].

CONCLUSION

Smart inhalers represent a significant technological advancement in asthma management. By integrating sensors and connectivity, these devices provide real-time tracking of medication use and adherence, allowing for personalized asthma management. The feedback systems and data analytics capabilities of smart inhalers offer opportunities to improve patient outcomes, reduce emergency hospital visits, and optimize treatment plans. Despite challenges related to widespread adoption and clinical integration, the growing body of research supports the potential for these devices to revolutionize asthma care. As technology continues to evolve, smart inhalers will likely play a crucial role in enhancing the quality of life for asthma patients worldwide. Future research should focus on further improving device accessibility, refining data interpretation, and ensuring broad clinical adoption to maximize their impact on asthma management.

REFERENCES

1. Cataldo D, Hanon S, Peche RV, Schuermans DJ, Degryse JM, De Wulf IA, Elinck K, Leys MH, Rummens PL, Derom E. How to choose the right inhaler using a patient-centric approach?. Advances in therapy. 2022 Mar;39(3):1149-63. springer.com
2. Jansen EM, van de Hei SJ, Dierick BJ, Kerstjens HA, Kocks JW, van Boven JF. 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. Journal of thoracic disease. 2021 Jun;13(6):3846. nih.gov
3. López-Tiro J, Contreras-Contreras A, Rodríguez-Arellano ME, Costa-Urrutia P. Economic burden of severe asthma treatment: A real-life study. World Allergy Organization Journal. 2022 Jul 1;15(7):100662. sciencedirect.com
4. Skevaki C, Ngocho JS, Amour C, Schmid-Grendelmeier P, Mmbaga BT, Renz H. Epidemiology and management of asthma and atopic dermatitis in Sub-Saharan Africa. Journal of Allergy and Clinical Immunology. 2021 Dec 1;148(6):1378-86. jacionline.org
5. Roche N, Aggarwal B, Boucot I, Mittal L, Martin A, Chrystyn H. The impact of inhaler technique on clinical outcomes in adolescents and adults with asthma: a systematic review. Respiratory Medicine. 2022 Oct 1;202:106949. sciencedirect.com
6. Papaioannou AI, Bartziokas K, Hillas G, Fouka E, Dimakou K, Kallieri M, Tsikrika S, Papadaki G, Papathanasiou E, Papaporfyriou A, Apollonatou V. Device use errors among patients with asthma and COPD and the role of training: a real-life study. Postgraduate Medicine. 2021 Jul 4;133(5):524-9. [HTML]
7. Favara G, Barchitta M, Maugeri A, San Lio RM, Agodi A. Sensors for Smoking Detection in Epidemiological Research: Scoping Review. JMIR mHealth and uHealth. 2024 Oct 30;12(1):e52383. jmir.org
8. Khusial RJ, Sont JK, Usmani OS, Bonini M, Chung KF, Fowler SJ, Honkoop PJ. The Effect of Inhaled Beta-2 Agonists on Heart Rate in Patients With Asthma: Sensor-Based Observational Study. JMIR cardio. 2024 Dec 11;8(1):e56848. jmir.org
9. Pleasants RA, Chan AH, Mosnaim G, Costello RW, Dhand R, Schworer SA, Merchant R, Tilley SL. Integrating digital inhalers into clinical care of patients with asthma and chronic obstructive pulmonary disease. Respiratory medicine. 2022 Dec 1;205:107038. sciencedirect.com
10. van de Hei SJ, Stoker N, Flokstra-de Blok BM, Poot CC, Meijer E, Postma MJ, Chavannes NH, Kocks JW, van Boven JF. Anticipated barriers and facilitators for implementing smart inhalers in asthma medication adherence management. NPJ Primary Care Respiratory Medicine. 2023 May 20;33(1):22. nature.com
11. Date C, Tiwari V, Malviya M, Rane N. Innovations in Inhaler Technology: Advancing Medication Delivery Devices. In2024 2nd World Conference on Communication & Computing (WCONF) 2024 Jul 12 (pp. 1-5). IEEE. [HTML]
12. Kokori E, Olatunji G, Mustapha MJ, Fawehinmi P, Onyia A, Omoworare O, Akinmeji O, Solomon S, Olafimihan A, Ologbe D, Aderinto N. The potential of smart inhaler for asthma management in Sub-Saharan Africa. Annals of Medicine and Surgery. 2024 May 1;86(5):2408-10. lww.com
13. Nguyen E, Miao B, Pugliese N, Huang D, Sobieraj DM. Systematic review of mHealth applications that interface with inhaler sensors in asthma. The Journal of Allergy and Clinical Immunology: In Practice. 2021 Feb 1;9(2):844-52. [HTML]
14. Tay TR, van Boven JF, Chan A, Hew M. Electronic inhaler monitoring for chronic airway disease: development and application of a multidimensional efficacy framework. The Journal of Allergy and Clinical Immunology: In Practice. 2022 May 1;10(5):1189-201. rug.nl

15. Lima JJ, Thomas CD, Barbarino J, Desta Z, Van Driest SL, El Rouby N, Johnson JA, Cavallari LH, Shakhnovich V, Thacker DL, Scott SA. Clinical pharmacogenetics implementation consortium (CPIC) guideline for CYP2C19 and proton pump inhibitor dosing. Clinical Pharmacology & Therapeutics. 2021 Jun;109(6):1417-23. nih.gov
16. Boogaerts T, Ahmed F, Choi PM, Tscharke B, O'Brien J, De Loof H, Gao J, Thai P, Thomas K, Mueller JF, Hall W. Current and future perspectives for wastewater-based epidemiology as a monitoring tool for pharmaceutical use. Science of the Total Environment. 2021 Oct 1;789:148047. uantwerpen.be
17. Van De Hei SJ, Poot CC, Van Den Berg LN, Meijer E, Van Boven JF, Flokstra-de Blok BM, Postma MJ, Chavannes NH, Kocks JW. Effectiveness, usability and acceptability of a smart inhaler programme in patients with asthma: protocol of the multicentre, pragmatic, open-label, cluster randomised controlled ACCEPTANCE trial. BMJ open respiratory research. 2022 Dec 1;9(1):e001400. bmj.com
18. Mehta PP. Dry powder inhalers: a concise summary of the electronic monitoring devices. Therapeutic Delivery. 2021 Jan 1;12(1):1-6.
19. Dierick BH, Achterbosch M, Been-Buck S, Klemmeier T, van de Hei SJ, Hagedoorn P, Kerstjens HA, Kocks JW, van Boven JF. Can electronic monitoring with a digital smart spacer support personalised medication adherence and inhaler technique education in patients with asthma?: Protocol of the randomised controlled OUTERSPACE trial. BMJ open. 2022 Jun 1;12(6):e059929. bmj.com
20. Duvnjak JP, Ursic A, Matana A, Mikic IM. Parents' Beliefs about Medicines and Their Influence on Inhaled Corticosteroid Adherence in Children with Asthma. Children. 2024 Jan 27;11(2):167.
21. Pearce CJ, Chan AH, Jackson T, Fleming L, Foot H, Bush A, Horne R. Features of successful interventions to improve adherence to inhaled corticosteroids in children with asthma: a narrative systematic review. Pediatric pulmonology. 2022 Apr;57(4):822-47. wiley.com
22. Dwivedi R, Mehrotra D, Chandra S. Potential of Internet of Medical Things (IoMT) applications in building a smart healthcare system: A systematic review. Journal of oral biology and craniofacial research. 2022 Mar 1;12(2):302-18. nih.gov
23. Ali O, Abdelbaki W, Shrestha A, Elbasi E, Alryalat MA, Dwivedi YK. A systematic literature review of artificial intelligence in the healthcare sector: Benefits, challenges, methodologies, and functionalities. Journal of Innovation & Knowledge. 2023 Jan 1;8(1):100333. sciencedirect.com
24. Dhruve H, Jackson DJ. Assessing adherence to inhaled therapies in asthma and the emergence of electronic monitoring devices. European Respiratory Review. 2022 Jun 30;31(164).
25. Pradeesh EL, Vivek VV, Bhuvaneshwari M, Thilakavarshini T, Guruprasad V, Vaishnavi AS. Investigation on IoT based smart E-Inhaler integrated with mobile application. Materials Today: Proceedings. 2022 Jan 1;66:1082-7. [HTML]
26. Eikholt AA, Wiertz MB, Hew M, Chan AH, van Boven JF. Electronic monitoring devices to support inhalation technique in patients with asthma: a narrative review. Current Treatment Options in Allergy. 2023 Mar;10(1):28-52. springer.com
27. Bousquet J, Sousa-Pinto B, Puggioni F, Anto A, Balli F, Casale T, Czarlewski W, Bedbrook A, Brussino L, Gaga M, Gemicioglu B. Asthma in the digital world. InAsthma in the 21st Century 2023 Jan 1 (pp. 231-244). Academic Press.
28. Codispoti CD, Greenhawt M, Oppenheimer J. The role of access and cost-effectiveness in managing asthma: a systematic review. The Journal of Allergy and Clinical Immunology: In Practice. 2022 Aug 1;10(8):2109-16. nih.gov
29. Poplicean E, Crișan AF, Tudorache E, Hogea P, Mladin R, Oancea C. Unlocking Better Asthma Control: A Narrative Review of Adherence to Asthma Therapy and Innovative Monitoring Solutions. Journal of Clinical Medicine. 2024 Nov 7;13(22):6699. mdpi.com

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