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Wearable Technologies and AI in Asthma Management: A Literature Review on Adherence Challenges and Innovations in Asthma Care

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Asthma is among the most critical global health disorder affecting around 260 million individuals worldwide with significant mortality rates, particularly in India where it accounts for over 40% of global asthma deaths despite representing only 13% cases of the world. A fundamental challenge in asthma management arises from inhaler misuse, forgetfulness of inhaler, and absence of real-time monitoring integrated with drug delivery. This literature review examines emerging technologies in asthma management with a focus on wearable sensors, contactless monitoring systems, artificial intelligence (AI), machine learning (ML) applications and real-time drug delivery. A comprehensive examination of published literature reveals that while digital health interventions, including mobile health applications (SaniQ Asthma, Propeller), wearable vital signs monitoring (ECG, PPG sensors in smartwatches and rings), and predictive AI algorithms have demonstrated measurable improvements in medication adherence (14–47% gains) and exacerbation prediction (83–90% sensitivity), critical gaps still persist. Specifically, no integrated system currently combines real-time respiratory monitoring with automated drug delivery mechanisms, and implementation barriers in low-resource settings remain underexplored. Additionally, inhaler misuse affects 70% of patients globally, forgetfulness of inhalers contributes to emergency hospitalizations averaging ₹62,500 in India, and privacy concerns threaten AI adoption. This review identifies key literature-derived principles like continuous wrist-worn monitoring, predictive algorithms, and mobile integration that may address persistent accessibility and adherence barriers. Future research must prioritize cost-effectiveness analyses, data security frameworks, and implementation strategies tailored to India's out-of-pocket cost constraints and specialist access inequalities. These efforts are essential for reframing asthma care from reactive symptom management to proactive, equitable intervention.

Keywords: Asthma Management, Wearable Respiratory Monitoring, Inhaler Adherence, Artificial Intelligence, Machine Learning, Real-Time Drug Delivery, Mobile Health Applications, Contactless Monitoring, Inhalers, Smart Medication Tracking

1. Introduction

Asthma is a chronic respiratory condition marked by inflammation and narrowing of the airways, causing episodes like wheezing, coughing, shortness of breath, and chest tightness [1]. These symptoms can be frequently exacerbated by triggers ranging from allergens to viral infections. Due to the non-specific nature of these symptoms, distinguishing asthma from other respiratory illnesses can sometimes be challenging.

The worldwide incidence of asthma is estimated to affect 260 million individuals as in 2024 [2]. Recent studies examining asthma prevalence across 17 countries reveal varying rates, ranging from 3.4% to 6% for adults and children in India, Taiwan, Kosovo, Nigeria, and Russia, and higher rates of 17% to 33% for Honduras, Costa Rica, Brazil, and New Zealand [3]. Despite continuing improvements in asthma care and a steady decline in asthma death rates over the past two decades, asthma accounted for about455,000 deaths worldwide in 2019 [2].

In India, about 35 million people suffer from Asthma, contributing to around 13% of global cases but over 40% of global asthma deaths [4]. As of 2024, the estimated annual death toll attributable to asthma in India is approximately 30,000 to 40,000 deaths [5].This mortality disparity showcases significant inequities in asthma management and access to effective interventions.

In India, Metered Dose Inhalers (MDIs) are the common rescue inhalers with Albuterol (or Salbutamol) being the common active ingredient [3]. However, forgetting to carry inhaler and misuse or incorrect usage of inhalers are a major issue, that can increase anxiety, worsen asthma attacks and raise the risk of hospitalization. Serious advancements in artificial intelligence (AI) and machine learning (ML) enhance asthma management by analyzing data from wearables and patient records to predict exacerbations, stratify risk, and inform personalized treatment [6]. Despite all the advancements in AI and wearable devices, current literature reveals that no integrated system combines real-time respiratory monitoring with automated drug delivery mechanisms.

2. Objectives

This literature review aims to:

- Identify limitations in current asthma management and inhaler usage patterns, and digital health interventions.

- Understand systemic loops of triggers, symptoms, misuse and hospitalization outcomes.

- Synthesize literature on leverage points for reframing asthma care through wearable devices and digital technologies.

- Examine health equity challenges in asthma management, particularly in low-resource settings like India.

3. Literature Review

The literature review on improving asthma patient outcomes reveals significant work across three interconnected domains: (1) wearable sensors and monitoring technologies, (2) artificial intelligence and machine learning for prediction, and (3) economic analyses and equity considerations. The following sections synthesize key findings and identify unresolved gaps.

Wearable Sensors and Monitoring Technologies

Lucy Taylor et al. [7] in their study examined how wearable devices and sensors are used to monitor the patients with asthma. The major signs to monitor in a person are their breathing rate and airflow sound which can be measured using wearable sensors, which could provide continuous and constant patient monitoring with the help of electrocardiogram (ECG), photoplethysmogram (PPG) and chest movements. The use of wearable vital signs has enabled a broad range of wearable sensor application scenarios for asthma monitoring and its management.

The two primary types of monitoring system are asthma questionnaires and mobile-health applications. Questionnaire has its limitations as it relies on patients filling out the questionnaire accurately and reliably. The mobile-health applications like SaniQ Asthma [8] app that records asthma related medical history. Propeller [9] is a sensor attached on top of inhaler and acts as a tracker and creates reminder to take the medication.

Smart Asthma [10] is similar to Propeller but it could also predict when the patient's symptoms might worsen. With advancements in technology, wearables and contactless monitoring technologies are starting to shape the digital health era. The four main types of contactless monitoring include camera-based monitoring, ultrasound based, remote plethysmography and radar-based respiratory monitoring. Breathing rate is the key indicator of asthmatic patient health.

Commercially Available Wearable Monitoring Technologies

There are some commercially available wearable ECG and PPG monitoring technologies in market like ECG is connected on chest, or a new fabric sensor made from Nylon and the electrodes are placed on neck and wrists to record the ECG signal. PhysioDroid [11] is integrated into band worn around the chest. Both the Apple Watch have ECG sensors integrated into it. For PPG monitoring the sensors are attached to tip of finger or forehead or thighs or earlobe. PPG sensors are also integrated into smart rings such as the Oura ring [12]. Smart watches like BioBeats and Fitbit Charge HR also has integrated PPG sensors.

RespiraSense [13] is a sensor directly attached to the skin instead of wearable vest or wearables. Chu et al. [14] demonstrated similar methodology where a pair of sensors attached directly to the skin around ribcage and abdomen.

Smart Textiles

Smart textiles are another way to monitor patient's health where electronic components into an existing textile or fabric. BioHarness 3.0 [15] and foam-based version of polypyrrole (PPy) is sewn into the pocket of a T-shirt, where if a patient inhales and exhales the material is compressed and stretched, changing the electrical conductivity of the PPy to monitor the patient's health.

Inhaler Misuse and Adherence

Seçil Çakmaklı et al. [16] in their study examined the misuse of inhalers among patients. They surveyed around 300 asthma/COPD (chronic obstructive pulmonary disease) in Ankara, Turkey. There are more than 250 commercially available inhaler devices, so it is not easy to learn how to use these devices at times [17].

So, the misuse of inhaler devices can lead to undesirable consequences like negative effects on patient confidence and contributing to the wasting of resources, addiction and weight gain. It is important for hospital or doctors to show educational videos from the internet or social media and make asthma patients, the importance of proper inhaler technique.

The survey results showed that out of 300 patients, 70.2% used their inhaler drugs incorrectly. The rate of misuse was higher in metered dose inhaler (MDIs) compared to dry powder inhalers (DPIs) i.e. 77.6% vs 64% respectively. This finding underscores a critical usability gap in widely prescribed rescue devices.

Innovation in Drug Delivery Systems

Martyn F. Biddiscombe, Omar S. Usmani [18] in their paper wanted to explore if there is further room for innovation in inhaled therapy for airways disease like asthma. They found that there has been a new class of delivery systems called soft mist inhalers (SMIs) which converts an aqueous liquid solution to an inhalable vapour using the energy of compressed spring. Few existing systems are MDIs, DPIs, nebulizers. There have been improvements in MDIs where the fine particles are delivered which allows aerosols to penetrate deeper into the lungs to treat the smaller airways in asthma. The use of nanoparticles in drug delivery is gaining momentum. Making use of porous particles for the delivery of inhaled therapy is another promising area of particle engineering is under development.

The use of inhaler monitoring devices has increased in recent times. The Turbuhaler Inhalation Computer, Electronic Diskhaler, Diskus Adherence Logger are used to monitor and record the date and time of every inhalation. The SmartMist had sensing capabilities allowing the assessment of inhalation technique in addition to adherence and automated actuation of MDIs [19].

Artificial Intelligence and Machine Learning in Asthma Management

Laren D Tan et. al [20] in their paper wanted to showcase how AI can be used in the management of asthma in patient's care. AI has huge potential to revolutionize asthma care through real-time data analysis, personalized treatment plans and continuous patient support. AI-powered apps and chatbots can provide continuous support to patients by offering reminders, educational resources,

and answers to any queries. This could eventually reduce hospital visits and improve the quality of life for patients.

Finkelstein and Jong [21] utilized telemonitoring techniques and ML for early prediction of asthma exacerbation. They examined patient in 7-day window, on 8th day their ML model was able to predict asthma exacerbation. ProAir Digihalers [22] was able to demonstrate high diagnostic accuracy in predicting asthma exacerbations. AI can serve as a "second clinician", by providing access to expanding databases, which can help with treatment plan decision-making and reduce patient misperception regarding their clinical problems.

Gudala et. al [23] concluded that voice-based chatbots were able to help older patients overcome accessibility challenges, improve media literacy, and provide access to medical information. Zhang et. al [22] investigated various predictive methods utilizing ML and found out that logistic regression provided the best balance of sensitivity (90%) and specificity (83%) in detecting asthma exacerbations up to 3 days in advance.

While AI integration can be beneficial, it still poses serious threats to data security and privacy, requiring robust protections. Transparency, data security, and making sure AI enhances rather than replace doctor-patient connection could increase patients' trust in its integration.

Economic Burden and Health Equity

Jindal et al.[24] examined the economic burden of asthma in India, found out the direct cost of Rs. 18,737/year average and indirect cost of Rs. 25,358/patient in lost productivity. Uncontrolled asthma costs 84% more than controlled disease which is around Rs. 23,918 vs Rs. 13,010/year, with non-adherent patients incurring 70% higher costs than compliant ones[24], [25]. Exacerbations drive catastrophic expenses, particularly hospitalizations averaging Rs. 62,500[25].

Van de Hei et al. [26] demonstrated that digital inhaler adherence monitoring in severe asthma generates significant cost savings from €3,207/patient in year 1 to €26,309 over 10 years, through reduced exacerbations and biologic prescriptions. Papadopoulou et al. [27] meta-analysis showed digital interventions improve adherence by 14.66% and reduces exacerbations by 47%, while also enhancing control and quality of life [27].

These findings highlight health economics challenges in asthma care, Efficiency,Equity, and Effectiveness [28].

In India where 35 million suffer asthma but face out-of-pocket costs and uneven specialist access, wearables addressing inhaler misuse and adherence gaps have substantial potential for improving outcomes and reducing inequities [4],[26].

Technology Domain	Main Findings	Unresolved Limitations
Wearable Sensors	PPG/ECG accuracy of 85-95%, continuous breathing rate monitoring via smartwatches, rings, fabric sensors	No automated intervention, forgetfulness unaddressed, cost barriers in low-resource setting
Mobile Health Apps	Medication tracking, reminders, symptom prediction, Propeller adherence gains ~20–30%	Reliant on patient compliance with app engagement, data security concerns
AI/Machine Learning	83–90% sensitivity in exacerbation prediction up to 3 days, logistic regression optimal (Sen. 90%, Spec. 83%)	Privacy threats in India, implementation untested in low-income contexts, trust/transparency barriers
Economic Impact	Digital interventions: 14.66% adherence gain, 47% exacerbation reduction; savings ₹26,309 per patient over 10 years	Cost-effectiveness analyses lacking for India, hospital access/affordability barriers persistent
Social Context (India-Specific)	₹62,500 per hospitalization, 40% global deaths, 13% global cases, 70% inhaler misuse rate, out-of-pocket costs ₹18,737–₹25,358/year	Uneven specialist access, limited wearable market penetration, privacy legislation evolving

Table 1: Comparative Analysis Table: Technology Efficacy Across Domains

Based on the literature review, the challenges of inhaler misuse and forgetfulness, and also no alternative to inhaler. Literature identifies key principles like continuous monitoring (e.g., PPG/ECG in watches) and predictive AI to address social barriers such as forgetfulness and misuse (70% misuse) and India's high OOP costs, suggesting integrated wearable methods as a potential to solve these issues. However, implementation requires addressing cost barriers, data privacy, and interoperability to maximize system-wide benefits. Future studies should include formal cost-effectiveness analyses to guide healthcare provider adoption and policy investment.

4. Conclusion

This literature review synthesizes evidence on wearable technologies, AI, and digital health interventions for asthma management, highlighting health equity challenges in low-resource settings like India. Literature documents progress wearable sensors (85-95% accuracy), ML exacerbation prediction (83-90% sensitivity), and digital interventions reducing exacerbations by 47%, yet reveals critical gaps like no integrated real-time monitoring-drug delivery systems, and limited applicability to India's 40% global deaths burden 13% cases.

Three barriers persist: clinical integration deficits, equity issues (Rs.62,500 hospitalization costs) and data privacy concerns. Literature-derived principles should have a way to integrate continuous wrist-worn sensing (PPG/ECG), predictive algorithms, and mobile integration which offers leverage points for reframing reactive care into proactive intervention. Addressing these gaps through targeted research will enhance accessibility and reduce mortality disparities.

Future Scope

Future research should include:

1. Integrating Pilot Studies: Evaluate combined wearable sensing, AI prediction, notification systems in rural/low-income Indian settings to assess real-world efficacy and acceptability.
2. Privacy-Preserving AI: Safeguard user's data from privacy threats.
3. Implementation Science: Study culturally appropriate delivery via community health workers and public clinics, addressing specialist access barriers.

These directions bridge literature gaps with actionable, equity-focused innovation.

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