

Mobile Health and Inhaler-Based Monitoring Devices for Asthma Management



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Overall Purpose/Goal: To provide excellent reviews on key aspects of allergic disease to those who research, treat, or manage allergic disease.

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Learning objectives:

1. To describe the current landscape of mobile health and inhaler-based monitoring devices available for asthma management.
2. To appreciate the promise and demonstrated utility of such tools.
3. To recognize barriers that must be overcome to enable the widespread use of mobile health and inhaler-based monitoring devices for disease self-management and to improve health.

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Mobile health and web applications (apps), wearables, and other personal monitoring devices have tremendous potential to improve the management of asthma. More than 500 asthma-related apps, whether standalone or paired with sensors on inhalers, are currently available for health education, symptom recording, tracking of inhaler use, displaying environmental alerts, and providing medication reminders. Benefits of these

tools include the ability to longitudinally collect symptom, trigger, and inhaler usage data, allowing the detection of significant changes over time to help patients and their caregivers determine whether symptoms are worsening. In addition, data from external information sources, including weather, allergen, and air quality reports, can be integrated with user-specific data to enhance predictions on when patients may experience symptoms and/or need to avoid triggers. Barriers to adoption of asthma-related apps and inhaler-based devices include uncertain efficacy and effectiveness, potential high cost, sustained user engagement, and concerns about privacy. Moreover, ensuring the acceptability and utility of asthma management apps for individuals of all races/ethnicities, socioeconomic groups, ages, genders, and literacy levels is necessary. Based on studies thus far, mobile health apps and inhaler-based devices have great potential to serve as useful tools in the patient-doctor relationship and revolutionize asthma care. © 2019 American Academy of Allergy, Asthma & Immunology (*J Allergy Clin Immunol Pract* 2019;7:2535-43)

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Asthma, a chronic lung disease characterized by variable airflow limitation, affects 22 million Americans and costs the US \$81.9 billion annually.¹ No methods to prevent or cure asthma

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*Abbreviations used**ACT*-Asthma Control Test*ED*-Emergency department*EHR*-Electronic health record*FDA*-US Federal Drug Administration*INCA*-INhaler Compliance Assessment*SABA*-Short-acting β -agonist

exist, but clinical therapy following established guidelines successfully controls symptoms in most patients.² Asthma management includes the identification and avoidance of triggers that worsen symptoms, and the proper use of appropriately prescribed inhaler medications. Patients do not always adhere to their asthma medication plans, with nonadherence estimates ranging between 30% and 70%.^{3,4} Furthermore, patients who are adherent to their treatment plans may not use their inhalers appropriately, decreasing their effectiveness.⁵⁻⁷ Thus, patient education, including guidance to improve the inhaler technique, is an important aspect of asthma disease management.⁸⁻¹³ Because asthma severity is determined partly based on the frequency of symptoms and exacerbations, knowing whether patients are adhering to and properly using inhaler medications helps health care providers treat their patients with proper disease management strategies.¹⁴ In addition to improving patient quality of life, improved asthma management is associated with reduced burden and costs to health care systems.^{15,16}

Mobile health and web applications (apps), wearables, and other personal monitoring devices are becoming mainstream tools to assist patients in disease decision making, with some models allowing patients to share data with health care providers.¹⁷⁻¹⁹ Personal computer and smartphone use is widespread in the United States, with over 77% of Americans owning smartphones in 2018.²⁰ Because of the ubiquity of internet-connected devices and the fact that smartphones are becoming the main source of contact for most people, the digital health marketplace has surged over the past decade.²¹ Android and Apple devices are the main platforms used for app development, and Apple created 2 software frameworks fit specifically for developers of health care apps. ResearchKit (released March 2015) was designed to assist in medical research patient enrollment and data collection, and CareKit (released March 2016) was designed for patient-centered disease self-management (<http://www.apple.com/researchkit/>). As evidenced by the growth of asthma-related apps and devices, as well as publications related to their design and use,^{17,22-24} there has been sustained interest in the use of asthma management apps and devices as a means to improve health outcomes and facilitate research studies. Here, we summarize mobile health and inhaler-based monitoring devices available for asthma management, discuss the promise and demonstrated utility of such tools, and review barriers that must be overcome to enable their widespread use for disease self-management and to improve health.

SYNOPSIS OF ASTHMA MOBILE HEALTH APPLICATIONS

Many asthma apps have been produced over the past decade, offering functions that span health education, symptom tracking, environmental alerts, and medication reminders. The number of asthma apps continues to grow: we reported 209 English-

language asthma-related apps in the Apple Store and/or Google Play in a 2015 review,²² and that the number is now over 500. The few current standalone asthma apps with research reporting their ability to improve asthma management are summarized in Table 1.

The Asthma Mobile Health Study, one of the first Apple ResearchKit apps tested to demonstrate the feasibility of using health apps, is one of the largest asthma mobile health tracking efforts.³⁵ In this study, 7593 participants in the United States were monitored remotely by smartphone. Data gathered, which consisted of self-reported symptoms over a 6-month period, showed expected regional trends based on environmental characteristics (eg, increased symptoms in regions with more pollen). Challenges encountered were broadly valuable to inform mobile health research efforts. Specifically, the initial enthusiasm of using the app decreased quickly over time, there was selection bias in those enrolling and providing information, and data security concerns limited some subjects' willingness to share data. For example, demonstrating high upfront enrollment with waning interest, 6470 subjects responded to at least 1 question, but only 175 completed a 6-month milestone survey. The app used in this study was withdrawn when the study was completed.

The "physician on call patient engagement trial" (POPET) was a clinical trial that measured the impact of a mobile patient engagement application on quality of life and health outcome measures for patients with allergic rhinitis and asthma.²⁸ The study enrolled 136 patients with asthma and 12 physicians (6 ear, nose, and throat and 6 chest specialists) in Turkey. Patients were provided with the POPET app, which allowed users to submit their overall health status on a 7-point scale with an emoticon, share a 140-character status update, send and receive messages, ask for immediate assistance with an urgent message option, track medication use with a diary, receive automated reminders according to the patient's prescribed treatment plan, and, for patients with asthma, complete the Asthma Control Test (ACT) within 24 hours after enrollment and 3 months later. Physicians were allowed to view a list of their patients in order of severity of health status, respond to message with texts or likes, view all of their patients' input, and broadcast messages or multimedia simultaneously. The study found that patients who received intervention with POPET had improved clinical outcomes, including better controlled asthma and fewer unplanned hospitalizations and emergency department (ED) visits. Thus, digital communication was found to be an important tool for the future of health care.

SYNOPSIS OF INHALER-BASED MONITORING DEVICES

Because self-management in assessing symptoms and adhering to medication regimens are especially important, people with asthma may be particularly interested in apps that are paired with sensors on inhalers to offer help with symptom and inhaler use monitoring. Apps that include sensors on inhalers can also be used to benefit people broadly. For example, a recent report used integrated sensor data corresponding to rescue medication use with measures of particulate matter to quantify cost savings and illustrate decreased health care utilization that occurs with pollution reduction.³⁶ Currently available inhaler-based monitoring devices use various approaches to measure adherence, including capturing the time and date of medication use,

TABLE I. Standalone apps for asthma management: a selection of mobile applications that have been evaluated for their ability to improve asthma control

App name	Major function	Secondary functions	Study population characteristics	Evidence/impact
Health App	Tracks symptoms and peak flow	Receives customized advice Medication reminders General asthma information reminders	20 patients aged 12-17 y with persistent asthma recruited from pediatric specialty clinics at Arkansas Children's Hospital	ACT score improved from 16 to 18 and asthma attack prevention domain improved from 34 to 36 ²⁵
t+ Asthma App	Tracks symptoms, drug use, and peak flow	Sends information from patient to provider	288 patients aged 12+ y with poorly controlled asthma recruited from UK primary care practices	No significant change in asthma control, exacerbations, steroid courses, or unplanned clinic visits ²⁶
My Asthma Portal App (MAP) (web-based application)	Tracks symptoms, physical activity, and medication	Real-time feedback and monitoring from a nurse	100 patients aged 18-69 y with poor asthma control recruited from pulmonary clinics in 2 tertiary care hospitals located in Montreal, Canada	Increased quality of life but no better control over asthma ²⁷
POPET App (Physician On-call Engagement Trial)	Tracks health and medication compliance	Sends information from patient to provider	136 patients aged 25-41 y with a diagnosis of mild-to-severe persistent asthma recruited from Pulmonary Diseases Departments across Turkey	ACT score improved ²⁸
SPA (Smartphone Application)	Tracks symptoms	Receives environmental alerts and treatment advice	22 patients aged 18+ y with a physician diagnosis of asthma who reported symptoms worsening with exposure to air pollution recruited from the Primary Care Asthma Program in Windsor, Ontario	Quality of life improved ²⁹
Breathe App (Available on iOS)	Tracks symptoms	Gives customized advice based on asthma action plan General asthma information Send warning and risk reminders	344 patients with asthma and mean age 45.3 y recruited from 6 primary care and 2 specialty asthma clinics in Ontario, Canada	Increased adherence to control plan and quality of life ³⁰
PCHMS App (Personally Controlled Health Management System)	Gives information on asthma and management tools	Access to medical records	330 patients aged 18+ y with asthma recruited via advertisement through Asthma Foundation Australia and the National Asthma Council Australia	No decreased hospitalization or increased adherence to asthma action plan ³¹
AsthmaCare App	Medication and treatment plan reminders	Trigger reminders	239 patients aged 6 mo to 21 y with persistent asthma were recruited when presenting with an asthma exacerbation to the Emergency Department from Nationwide Children's Hospital in Columbus, Ohio	No decrease in hospital visits; however, increased asthma control 6 months later ³²
ASTHMAXcel App (Available on iOS)	Videos teach about how and when to use inhalers and spacers	Teaches how to reduce triggers at home	130 participants aged 15-21 y with persistent asthma recruited at Montefiore Medical Center, Bronx, NY	Decreased hospitalizations, increased control and quality of life ^{33,34}

ACT, Asthma Control Test.

recording audio during inhaler use, and providing telemonitoring based on remotely captured spirometry measures. Pharmaceutical companies are using some of these tools to monitor medication adherence during clinical studies and better understand circumstances surrounding medication use. Table II contains a summary of inhaler-based monitoring devices with apps paired to them, along with studies providing evidence that their use improved asthma management.

A sensor made by Propeller Health that attaches to both rescue and controller inhaler devices and can record date, time, and number of puffs taken is one of the most extensively evaluated. When paired with its app, data from the sensor can be matched with a person's location (obtained from a smartphone's GPS coordinates). The app also serves to record patient triggers and symptoms, and can integrate online data streams (eg, weather) to provide comprehensive reports of data relevant to asthma management. In a 2013 pilot study, 30 individuals used these sensors along with their corresponding app for 4 months, resulting in preliminary evidence that asthma control could improve by use of this digital health platform.⁴⁸ A subsequent randomized control trial in 495 patients, with 245 receiving routine care and 250 receiving Propeller Health sensor-based feedback, found that those receiving sensor-based feedback had decreased daily short-acting β -agonist (SABA) use during the study period (up to 1 year per person), with an effect that was more pronounced among those participants who began the trial with uncontrolled asthma. The mean daily SABA per person for the study period was 0.25 in routine care arm versus 0.19 in intervention arm.⁴⁴ Although the decrease in SABA use was quite small and may not have clinical meaning, the ACT scores of adults who initially had uncontrolled asthma and received feedback were improved relative to those receiving usual care. Another report evaluated the Propeller Health digital platform that displayed results in a provider-facing web interface and found that asthma-related ED visits and hospitalizations decreased with platform use.⁴³ An additional study of 120 participants enrolled in a single-arm trial of the Propeller Health digital platform found that SABA use dropped by 39%, and symptom-free days increased by 12%.⁴² Propeller Health has received 8 US Federal Drug Administration (FDA) approvals for its devices and apps since 2012, and is currently being used in a variety of studies, including collaborations with Novartis and GlaxoSmithKline.

The SmartTrack device, which pairs with the Hailie app, is a tool focused on improving medication adherence by recording the date and time of actuations, the total number of actuations used, and missed doses. The app displays long-term use and trends in activity and can provide reminder notifications so that patients use their inhalers on schedule. Preliminary testing of the device in 10 participants found that its reliability and utility for data upload, reminders, and display of medication use over time were acceptable.⁴⁹ A subsequent study of the SmartTrack device involving 220 participants, with an intervention consisting of ringtone reminders that rung twice daily and stopped when a person's correct dose was used (reminders were automatically stopped if the proper dose was taken within 6 hours before the set time), showed that the intervention group had 84% adherence by the end of the study, whereas the control group had 30% adherence.⁴⁰

Although SmartTrack is focused primarily on medication reminders and tracking of actuations, and Propeller Health also

integrates geospatial information, the INhaler Compliance Assessment device (INCA) is an alternative tool that, in addition to adherence, can be used to assess a proper inhaler technique. Specifically, INCA creates audio recordings as a person uses an inhaler device, and based on analysis of sound, it can determine whether there was a proper inhaler technique by measuring time-stamped failure to prime, low inhalation flow, and dose dumping. These data can be used to determine when less medication is delivered because of inhaler technique errors, and thus, the INCA device can be used to assess differences between "attempted" adherence, or adherence based on time of medication use and "actual" adherence, or adherence based on proper use of the inhaler.³⁷ In one report based on 184 persons with chronic obstructive pulmonary disease, the mean rate of controller medication attempted adherence was 58.7%, whereas actual adherence was only 23%, and only 7% of participants had actual adherence above 80%, underscoring the importance of providing patients with tools to learn the proper inhaler technique.³⁸ The INCA device is currently being evaluated for its ability to improve uncontrolled asthma in the Inhaler Compliance Assessment Device in Symptomatic Uncontrolled Asthma (INCA Sun) study.⁵⁰

Teva's ProAir Digihaler is the first digital inhaler with built-in sensors to be approved by the FDA.^{51,52} An accompanying smartphone app is set to be released for both Google and iOS systems, and the national launch of the app and inhaler is set for 2020. A pilot study of 360 participants showed that a predictive model was created with data recorded by the Digihaler predicted asthma exacerbations with an area under the receiver operating characteristic curve of 0.75.⁴⁷ The most predictive factor in the model was the average number of albuterol inhalations per day during a period of 5 days before an exacerbation. In addition to monitoring time of use, the inhaler sensors are able to detect whether the inhaler was used correctly via measures of peak inspiratory flow, inhalation duration, and other metrics. Further studies have not evaluated the efficacy of Digihalers; however, their pilot data and FDA approval support the movement toward more sensor-based data collection to improve inhaler use and asthma self-management.

POTENTIAL BENEFITS OF USING MOBILE HEALTH AND INHALER-BASED MONITORING DEVICES FOR ASTHMA MANAGEMENT

The ability to longitudinally collect symptom, trigger, and inhaler usage data from individuals with asthma permits the detection of significant changes over time to help patients and their caregivers determine whether symptoms are worsening. Data from external information sources, including weather, allergen, and air quality reports, can be integrated with user-specific data to enhance predictions on when patients may experience symptoms and/or need to avoid triggers. For these data from external sources to be effective in asthma management, summaries of the relationships among symptoms, triggers, and inhaler usage must be presented appropriately to patients and their caregivers to reinforce positive behaviors (eg, medication adherence) and provide alerts when symptoms are expected to worsen (eg, downward pulmonary function trend, increased triggers). Similarly, appropriately summarized data from apps and inhaler-based monitors can be integrated into data streams facing health care providers to help them determine whether

TABLE II. Inhaler-based monitoring devices available for asthma management: a selection of inhaler-monitoring devices, along with mobile applications, that may improve asthma control

Device name	Device function	Corresponding app	Data/results reported	Study population characteristics	Evaluation
Inhaler Compliance Assessment (INCA)	Time-stamped audio recording of inhaler use	Onboard data storage/ no app	Raw audio files must be transferred to a computer for analysis	184 participants with mean age 70.9 $\pm$ 9.65 y and asthma recruited at an academic teaching hospital in Dublin, Ireland	Can measure the impact of technique errors (failure to prime inhaler, low inhalation flow, dose dumping) on reduced medication delivery ³⁷ Can distinguish between intentional and unintentional adherence ³⁸
Flo-Tone	Inhaling speed and volume can be measured by sound and length of inhalation. Measures if user coordinates actuation with inhalation	No data storage	Inhalation causes a whistle to sound as a signal to dispense medication. Keeping the whistle sounding is indicative of good technique. The function of the device is to give feedback on and improve inhaler usage technique	62 patients aged 17-82 y with asthma (n = 30) COPD (n = 27), and asthma + COPD (n = 5) were recruited from both inpatient wards and outpatient respiratory clinics at Beaumont Hospital, Dublin, Ireland	Analysis of the audio-based method of data collection showed a frame-by-frame accuracy of 88.2% in classifying actuation, inhalation, and exhalation. The analysis showed that 89% of patients made at least 1 technique error, even after training by an expert clinical reviewer ³⁹
SmartTrack	Records date, time, and number of actuations used, missed doses, and when inhaler is inserted and removed	Hailie	App displays data to help track medication usage; provides alerts when medications are missed	2045 patients aged 6-15 y were recruited when admitted to the Auckland regional ED with a possible asthma diagnosis	Use of device resulted in 84% median percentage of adherence in an intervention group vs 30% in the control group ⁴⁰
SmartInhaler	Records date and time of inhaler use Emits an audible reminder at preset times The device has a light, which is green before MDI use, changing to red once used	Onboard data storage	Sensor data can be sent to a computer with a communication link, USB, or cellular upload for analysis	110 patients aged 12-65 y with a diagnosis of asthma were recruited from research volunteer databases, newspaper advertisements, and informal contacts in Wellington, New Zealand	Those using device as intervention adhered to medication use 18% percentage points more than the control group; more participants in the intervention group used >50%, >80%, and >90% of their medication, with proportion ratios of use (compared with the control group) being 1.33, 2.27, and 3.25, respectively ⁴¹
Propeller Health	Records date and time of inhaler use Records geographic location of use via the paired smartphone app	Propeller Health	Records symptoms, medication usage, and environmental factors Tracks inhaler usage data automatically so triggers and symptoms can be followed and recorded Customizable schedule available to set medication reminders Uses the ACT or CAT to assess control of asthma or COPD, respectively Integrates data to be able to see inhaler use along with possible triggers App can send information from patient to the provider	Barrett et al ⁴² : 120 participants aged 5-67 y with a physician diagnosis of asthma were recruited from community asthma activities, clinics, and retail pharmacies Merchant et al ⁴³ : 224 patients aged 3-88 y with a diagnosis of asthma were recruited during routine asthma care in specialty and primary care clinics Merchant et al ⁴⁴ : 495 participants with a mean age of 36 y with a diagnosis of asthma were recruited from Woodland Healthcare and Mercy Medical Group in Yolo and Sacramento, California	Daily average SABA uses per person decreased by 0.41 for the intervention arm and by 0.31 for control arm between the first week and the remainder of the study period ⁴⁴ Asthma-related ED visits and combined ED and hospitalization events decreased before and after use of the Propeller Health system ⁴³ SABA use was shown to drop by 39%, and symptom-free days were shown to increase by 12% in first month of intervention; each intervention month showed an increase in percent of patients with well-controlled asthma ⁴²

(continued)

TABLE II. (Continued)

Device name	Device function	Corresponding app	Data/results reported	Study population characteristics	Evaluation
HeroTracker	Records date and time of inhaler use	BreathSMART	Reminds users to take medication per prescribed plan Tracks inhaler use over time Permits symptom recording	100 study subjects aged 18+ y with a self-identified diagnosis asthma were recruited within the United States through social media websites and ad placements online	This device is currently being tested in a clinical trial ⁴⁵
Human Augmentics (HA)	Records date and time of inhaler use	Social Persuasive Visualization (SPV) app—not publicly available	Reminds users to take medication per prescribed plan Tracks inhaler use over time App developed specifically for use by minority adolescents using captoplogy and the Elaboration Likelihood Model to persuade users to regularly adhere to medication	12 patients aged 11–16 y with persistent asthma were recruited from Rush Pediatric Primary Care Center in Chicago, IL	Pilot study showed an 83% acceptance rate and improved adherence. 8% and 58% of patients achieved clinically significant adherence targets at baseline and last week of the study period, respectively ⁴⁶
ProAir Digihaler	Records date and time of inhaler use Records peak inspiratory flow, volume inhaled, time to peak flow, and inhalation duration	ProAir Digihaler app	Can share daily, weekly, and monthly reports of inhaler use with caregivers and health care professionals Has a built-in electronic module that stores data on inhaler events	360 patients aged 18+ y with exacerbation prone-asthma	Pilot study showed that data recorded by the Digihaler could predict asthma exacerbations with an area under the receiver operating characteristic curve (AUC) of 0.75 ⁴⁷

ACT, Asthma Control Test; CAT, COPD assessment test; COPD, chronic obstructive pulmonary disease; ED, emergency department; MDI, metered dose inhaler; SABA, short-acting β -agonist.

medication plans should be altered or if further education on adherence or inhaler usage is needed.

Because of the importance of a proper inhaler technique and medication adherence in asthma management, education on app and inhaler-based device usage is essential, whether included in app materials or provided via in-person education before long-term use. Monitoring use of controller medications for asthma (eg, inhaled corticosteroids) is most valuable to assess medication adherence, whereas tracking use of rescue medications (ie, β_2 -agonists) is valuable to both assess medication adherence and determine when symptoms are worsening. Beyond monitoring individuals, integrating data on rescue medication usage more broadly can point to geographic regions or events that trigger symptoms in large numbers of people, and thus, advise susceptible individuals on regions or events that should be avoided as well as suggest potential community-level interventions to improve health.⁵³

As the above studies show, the effective combination of educational material and actionable feedback into apps, including those paired with inhaler-based monitoring devices, could support population care of individuals with asthma and enhance personalized interventions informed by patient-specific data. Thus, when apps and inhaler-based monitoring devices for disease self-management are designed as telehealth interventions to enable shared decision making and proactive care by both patients and health care providers—core elements of the chronic care model^{54,55}—they have the potential to improve health care performance. Use of the apps with effective feedback shifts chronic disease management from a reactive position, in which patients seek care after a problem has occurred, to a proactive stance in which at-risk patients are identified early and supported to avoid exacerbations. Clinical decision support systems can be built to aid health care providers in identifying individuals who are not adhering to recommended treatment, are at risk for exacerbations, and/or have uncontrolled disease. Alternatively, individuals with asthma can use information gathered from such apps to seek care and share data with providers at the point of care. The end result of either system would be improved health care performance.

BARRIERS TO THE ADOPTION OF MOBILE HEALTH AND INHALER-BASED MONITORING DEVICES

Some progress has been made in the evaluation of apps and inhaler devices to establish their utility, but barriers remain for asthma apps to be widely adopted by patients or recommended by providers. First, few efficacy and effectiveness studies have been conducted or demonstrated effectiveness of mobile health and inhaler-based monitoring devices for asthma. No accepted measure of app quality exists, and apps are not regulated or approved by the FDA unless they involve connection to a regulated medical device for the purposes of controlling its operation, function, or energy source, and displaying, transferring, storing, or converting patient-specific medical device data, which few do. Because there is no standard measure or approach to determine whether apps are of high quality, comparison of various apps is challenging. Some independent organizations have noted this knowledge gap, and efforts to create frameworks for assessing health care apps are underway.

Another potential barrier to adoption of mobile health devices is cost. Inhaler-based monitoring devices are expensive for some

patients to pay out-of-pocket, especially because the data to support their use are based on relatively small studies. If health insurers were to cover the cost of inhaler-based monitoring devices, demonstrations of widespread effectiveness would be needed. Increasing affordability of such devices may increase the rate of adoption.

For data from apps and inhaler-based monitoring devices to be most useful to health care providers, they must be integrated seamlessly into existing electronic health record (EHR) systems or other provider-facing dashboards. Accomplishing this important task requires local information technology support and can be slowed by local processes and regulations. Although the technology and standards to integrate app data into EHRs exist,^{56,57} health care providers already face more data streams and alerts than they can effectively pay attention to, and thus, designing and testing the integration of app data looms as another potentially laborious process that may bring negative results.⁵⁸ Furthermore, some providers may have concerns regarding liability they incur when recommending apps/devices to patients, monitoring data collected by the apps, and responding to potential alerts. Including input from health care providers is thus critical when a goal of apps/devices is their eventual integration into clinical practice.

Usability of apps and devices, and human factors issues are critical considerations for initial and sustained user engagement, yet they are not sufficiently considered in studies published thus far.^{59,60} To overcome barriers related to engagement, usability evaluation sessions should be conducted in the early stages of design, in pilot tests, and subsequently, during formal evaluation studies, as doing so reduces costs and increases the likelihood of technology adoption in the long run. Strategies for increased engagement include gamification (present in several educational tools), personalized recommendations (eg, Propeller Health app), and incorporating persuasive design/behavior change principles, which is a prominent predictor of adherence to apps.⁶¹ A successful model of the application of user-centered design principles to create an asthma mHealth app is that by Rudin et al⁶²: their team conducted 19 design sessions with 9 adult patients and 7 clinicians to identify core components of a symptom monitoring tool before actually building one.

In addition to sustaining user interest, apps must also ensure data privacy and security before some individuals will be comfortable using them and health care providers will feel comfortable recommending them. Apps that involve tracking individual locations and for which individuals enter personal data are the most vulnerable for loss of privacy or possible unwanted disclosure of personal health information. One study that systematically assessed availability of privacy statements for the most commonly used apps found that only 30% had privacy statements that addressed whether entered information could be shared with third parties.⁶³

Finally, greater reliance on apps and inhaler-based monitoring devices for asthma management necessitates an understanding of the acceptability and utility of these tools among *all* patients, including those who are disproportionately affected by diseases. In the case of asthma, tools must be designed to address the concerns and barriers faced by racial/ethnic minority groups, women, children, and those of low socioeconomic status, all of whom are disproportionately affected by asthma.^{64,65} Evidence exists showing that digital interventions targeting asthma populations at greatest risk are helpful,¹³ but digital health tools must

continue to be designed and tested in these populations while considering their cost. The design of apps/technology for asthma management across the lifespan will continue to differ, as children (and their parents) require different strategies than adults, but it is possible that single apps may offer different displays to engage users of different ages. With the effective design, adoption, and use of asthma apps and inhaler devices, asthma morbidity may be reduced in high-risk groups.

CONCLUSION

Mobile health and inhaler-based devices have great potential to revolutionize care for asthma by becoming mainstream tools to assist patients in self-monitoring and decision making, especially patients with persistent asthma and those who have difficulty keeping symptoms under control. Although the number of asthma apps and inhaler-based monitoring devices is rapidly increasing, most are currently limited by the lack of demonstrated efficacy and effectiveness. Initial use of such tools has found that sustaining user engagement is challenging and some people have concerns with data privacy. Potential high costs are also a salient limitation for the widespread use of inhaler-based monitoring devices. Addressing these barriers as the asthma mobile health landscape expands is critical. Future efforts that evaluate individual apps, as well as compare usability and effectiveness of various apps in single studies, are necessary to provide evidence regarding their suitability for clinical use.

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