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New Concepts and Technological Resources in Patient Education and Asthma Self-Management

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Abstract

Asthma is a chronic disease that is associated with significant morbidity and mortality. In general, the use of technology resources or electronic health (e-health) has been shown to have beneficial effects on patients with asthma. E-health can impact a broad section of patients and can be cost-effective and associated with high patient satisfaction. E-health may enable remote delivery of care, as well as timely access to health care, which are some of the common challenges faced by patients with asthma. Web-based asthma self-management systems have been found to improve quality of life, self-reported asthma symptoms, lung function, reduction in asthma symptoms/exacerbations, and self-reported adherence for adults. Social media is commonly being used as a platform to disseminate information on asthma to increase public awareness. It can facilitate asthma self-management in a patient friendly manner and has shown to improve asthma control test scores as well as self-esteem. Text massages reminders can increase awareness regarding asthma treatment and control, thus potentially can improve adherence to medications and asthma outcome. Mobile health applications can support asthma self-management, improve a patient's quality of life, promote medication adherence, and potentially reduce the overall costs for asthma care. Inhaler trackers have shown to be beneficial to asthma outcome in various populations by improving adherence to asthma medications. Barriers such as physician financial reimbursement as well as licensing for rendering tele-healthcare services are important concerns. Other limitations of using technology resources in health care are related to liability, professionalism, and ethical issues such as breach of patient confidentiality and privacy. Additionally, there may be less face-to-face interaction and care of the patient when e-health is used.

Keywords Asthma self-management · Technology tools for asthma education · Electronic health · Telemedicine · Web-based asthma self-management systems · Mobile health applications · Inhaler trackers · Asthma medication adherence

Abbreviations

AAAAI	American Academy of Allergy, Asthma and Immunology
AAP	Asthma Adherence Pathway
ACAAI	American College of Allergy, Asthma and Immunology
ACT	Asthma control test
eAMS	Electronic Asthma Management System
ED	Emergency department
E-Health	Electronic health
EMR	Electronic medical record
FeNO	Fractional exhaled nitric oxide
FEV1	Forced Expiratory Volume
GINA	Global initiative for asthma
HIPAA	Health Insurance Portability and Accountability Act
IBS	Internet-based monitoring systems
IBSM	Internet-based self-management
ICS	Inhaled corticosteroid
ICT	Information and communication technology
MAP	My Asthma Portal
mHealth apps	Mobile health applications
P'ASMA	Portal for Assessment and Self-management of Asthma
PCA	Perceived control of asthma
PEF	Peak expiratory flow
PHR	Personal health record
RCT	Randomized controlled trial
RTMM	Real-time medication monitoring

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SABA	Short-acting beta agonist
SARP-3	Severe Asthma Research Program-3
SMS	Short message service
SMT	Social media technology
VAC	Virtual asthma clinic

Introduction

Asthma is a chronic respiratory disease that affects children and adults. It is associated with significant socioeconomic burden in terms of quality of life and healthcare-related costs. Despite recent advances, asthma morbidity and mortality continue to be high. More than 300 million people worldwide presently have asthma [1]. Optimal asthma control is the primary focus of asthma guidelines and is assessed by frequency of symptoms as well as exacerbations. Poor adherence with asthma medications is a commonly encountered challenge which further contributes to increased morbidity and mortality [2, 3].

Asthma control is affected by multiple factors including education and involvement of patients/families. Studies have evaluated the role of technology tools or electronic health (e-health) in monitoring and improving inhaler use and treatment adherence in asthma. These include mobile health (mhealth), electronic reminders, telemedicine, and inhaler tracker interventions. In general, the term e-health encompasses different health services that are delivered by information technology. The term telemedicine or technology-based medical interventions refers to exchange of medical information between patients and health care professionals who are separated by distance or time [4]. This saves time and avoids travel.

Synchronous or real-time telemedicine involves connection with medical professional and exchange of information [5]. However, it is inconvenient to both the patient and the physician and may be affected by video connection at that time. On the other hand, asynchronous internet-based telemedicine system is an effective and acceptable method for in-home monitoring of patients with asthma. The latter involves patients' data to be stored in an online, electronic repository and then forwarded to the physician or health care professional upon request [5].

Another related term, telemanagement, is more focused on the ongoing management of the individual patient by employing information and communication technology (ICT) applications. In an individual patient, telemanagement of asthma includes education, self-monitoring, written action plans, setting of goals, and regular review of medical records. Patients receive medical and motivational feedback from their physician using ICT tools. These include technologies and tools that can be used to communicate, gather, and store data by electronic means. ICT includes social media (e.g., Facebook or Twitter), e-mails, short message service (SMS) or text messages, and video chat (e.g., Skype or Hangouts). This also includes mobile-type devices (e.g., smartphones) and computing devices (e.g., tablets) [6].

In general, the use of ICTs has been shown to have beneficial effect on patients with asthma. ICTs facilitate communication between physicians and patients and also allow patients to learn more about daily asthma care and management [1]. ICTs can be integrated into the personal health record (PHR) used by the patients and the electronic medical record (EMR) used by the physician. Educational tools can also be incorporated in telemanagement such as asthma action plans and the use of inhalers.

An observational, cross-sectional study was conducted in Latin America to study which type of ICTs are most often used by patients with asthma. A survey was administered to patients with asthma in five Latin American countries. Results of the survey showed that SMS (69.9%) was the most frequently used ICT [7]. SMS and e-mail are helpful for communicating with asthma patients of all ages. Participants rated social media such as WhatsApp (61.5%) and Facebook (32.0%) as the most interesting methods of communication. Also, younger and educated patients used almost all forms of ICTs [7]. In a single-site survey study conducted in the USA, e-mail was the most preferred ICT to receive asthma information amongst asthma patients 12–40 years of age [8]. Text messaging and Facebook were other preferred ICTs by the participants. Other social media (e.g., Twitter, Myspace) were the least preferred method. It was also noticed that female and African American or Hispanic participants expressed more interest in using ICTs for asthma care. Many participants expressed privacy concerns in using social media for asthma care and that social media sites are more suitable platform for connecting with friends rather than health care providers [8]. Another US-based, single-site survey of patients' perspective on using digital technology to communicate with their primary care providers indicated similar results. In this survey, the majority of the patients reported using Facebook (58%) and SMS (64.1%). However; few participants were willing to communicate about their health via Facebook (3.1%) or SMS (13.3%), compared to e-mail (48.8%) or phone (75.5%). The authors also reported that female, African American or Hispanic, and younger participants were more interested in engaging in peer coaching through social media [9].

Large-scale, randomized controlled, multicenter studies on adoption rates of telemedicine are lacking and vary by specialty; however, smaller studies suggested that telemedicine is increasingly well adopted over time in general. A study indicated that the number of ICU beds in the USA covered by telemedicine increased from 598 (0.9%) to 5799 (7.9% of total) over the previous decade especially in large, teaching hospitals in urban setting [10]. Patient satisfaction, perceived usefulness, and social influences are key factors of how well

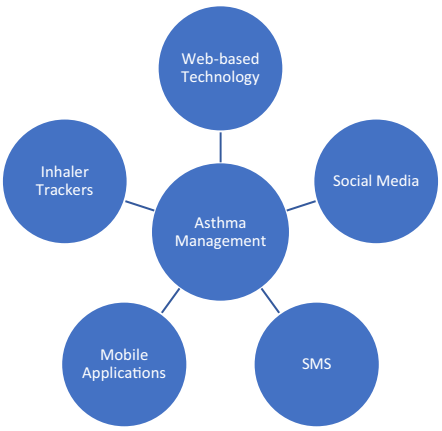
the telemedicine modality is adopted [11]. Important factors associated with effectiveness and efficacy of telemedicine include modality that improves outcomes, is easy to use, has low cost, improves communication, and decreases travel time [12]. For health care providers' perspective, telemedicine's potential to reduce cost and its usefulness to the medical profession are important factors to adopt telemedicine [13].

Various ICT tools are presently available for management of asthma as shown in Fig. 1 and Table 1. This includes use of tools such as e-mails and Internet-based health information to provide continuous communication between physician and patients. However, there is limited data available regarding their effectiveness and their role in asthma/asthma self-management. In this review, we have discussed various technology tools available for asthma care.

Web-Based Technology

Web-based asthma self-management systems are found to improve quality of life [14–18], self-reported asthma symptoms [14, 15], lung function [14], reduction in asthma symptoms/exacerbation [19, 20], and adherence to asthma medications [14, 21–24].

Internet-based management systems have been developed to improve monitoring of asthma symptoms at home and asthma self-management in both adults [25] and children [21] with asthma. Finkelstein et al. developed internet-based asthma monitoring systems wherein portable spirometers and pocket-sized palmtop computers were provided to patients to register lung functions and symptoms at home [25]. The results were transmitted from patients' homes to the medical record database for physician to review and help providing feedback. This allowed monitoring of asthma symptoms in patients' home and reduced severity of asthma. This may in turn help reduce asthma exacerbations and subsequent hospitalizations [25].



SMS: Short message service

Fig. 1 Technology tools available for asthma management. SMS, short message service

Internet-based telemedicine is an adjunctive and cost-effective measure to monitor children with asthma in their home environment. Internet-based at-home asthma monitoring has been shown to be comparable to office-based asthma care. Chan et al. conducted an asthma in-home-monitoring trial [21]. The study included 120 children, 6–17 years of age with persistent asthma. In this study, the authors compared office-based visits to in-home, internet-based asthma education. When compared to standardized office-based asthma care, this form of therapy has resulted in increased adherence to medications. Both groups had excellent asthma therapeutic and disease control outcomes including emergency department (ED) visits, hospitalizations, and use of rescue medications. In both groups, caregiver reported an increase in quality of life and asthma knowledge [21].

Studies have shown that internet-based management is also effective in children who have severe or poorly controlled asthma and those who reside in inner-city areas [19, 22]. It is particularly effective for asthmatic children who do not have easy access to specialty asthma care. In a randomized clinical trial in inner-city areas, children with persistent asthma were randomized to the Health Buddy [19] or assigned to an asthma diary. Health Buddy is an interactive health communication device which enabled children to monitor their asthma symptoms and transmit this information through a secure website to their health care professional. Children in the Health Buddy group were noted to have lesser activity limitation, improved peak flow readings, and made fewer urgent calls to hospitals. Self-care behaviors also improved in this group. Web-based devices such as Health Buddy may help to reduce asthma symptoms and health care use in children [19]. Another web-based technology inner-city asthma trial in children, Boston Breathes, helped improve adherence and asthma-related knowledge in children with persistent asthma in inner-city areas in Boston, MA, though there was no change in ED visits for asthma [22].

In inner-city adolescents with asthma, Puff city is a web-based asthma intervention that targets high-risk urban asthmatic teenagers in Detroit, MI [20]. It uses computer algorithms to deliver personalized asthma education. The intervention resulted in fewer daytime and nocturnal symptoms as well as fewer school absences. Puff City, thus, represents another effective tool and intervention in high-risk asthmatic teenagers who are otherwise resistant to any behavioral changes.

Internet-based technology is also shown to be beneficial in inner-city asthmatic adults. A study reported that internet-based home asthma telemonitoring was found to be user friendly and was widely accepted by adults who do not have any computer background. The majority of patients in the study (87.1%) expressed interest in using internet-based asthma telemonitoring at home in the future [26].

Table 1 Examples of technology tools for asthma care and their advantages/disadvantages

Technology	Examples	Advantages	Disadvantages
Web-based technology	-Health Buddy -Boston Breathes -Puff City -My Asthma Portal -My Child's Asthma -P'ASMA	-Delivery of health care not limited by time or distance -Access to health care and advise in a timely fashion -Self-monitoring of asthma symptoms -Improve medication adherence -Improve quality of life -Assist patient education regarding avoidance of triggers	-Ethical issues (privacy of patients' information, lack of informed consent) -Less patient-physician direct interaction -Lack of physician financial reimbursement -Lack of licensing for rendering tele-healthcare services
Social media	-Facebook -Snapchat -Twitter -Instagram -Pinterest -Google + -YouTube -Blog posts	-Increase social connectivity amongst patients and caregivers -Provide social feedback and can improve self-esteem -Increase public education and awareness	-Breach of patient confidentiality/ privacy -Cyber bullying -Can increase stress, loneliness and depression
Short message services	-eCARE	-Improve medication adherence -Improve asthma outcome -Convenient to use -Can improve patient satisfaction	-Annoyance are reported in some patients -Lack of comprehensive care
Mobile health applications	-POPET -ADAPT	-Improve medication adherence -Reduce asthma morbidity -Increase patient satisfaction -Assist asthma self-management	-Lack of FDA regulation -Lack of medical guidelines -Lack of compliance by underrepresented, low socioeconomic status patients -May not be cost-effective
Inhaler tracker devices	-Propeller -SmartTrack device -Doser -MDILog -SmartMist	-Increase medication adherence -Reduce asthma morbidity -Increase patient satisfaction	-Long-term compliance is questionable
Other devices for asthma monitoring	-AMS -ADAM -MyAirCoach	-Improve asthma control -Improve quality of life -Decrease health care utilization	-Unknown or unchanged effects on asthma morbidity -Unknown effects of medication adherence

ADAM automated device for asthma monitoring, *ADAPT* adolescent adherence patient tool, *AMS* asthma monitoring system, *P'ASMA* Portal for Assessment and Self-management of Asthma, *POPET* physician on call patient engagement trial

Other than asthma outcome, web-based asthma interventions also have resulted in significant improvement in quality of life. Several internet-based interventions focused on quality of life improvement are reviewed here [14–18, 27]. The first study was conducted in 300 asthmatic subjects in Denmark where the use of an interactive internet-based asthma monitoring tool resulted in better asthma control and quality of life as compared to treatment in specialist clinic or in primary clinic [14]. Participants in the study group also reported improved asthma symptoms, medication adherence, pulmonary function, and airway responsiveness [14].

Another web-based asthma self-management support system called My Asthma Portal (MAP) included behavior change components e.g., self-monitoring of symptoms, adherence to medications, and physical activity coupled with real-time monitoring by health care professional. The study group was noted to have higher quality of life related to asthma as well as an improvement in self-efficacy, depression, and self-reported asthma control [15]. However, the effects were lost once the intervention was discontinued. Thus, ongoing support is necessary for sustained results.

The third study compared the clinical efficacy of web-based application, called Portal for Assessment and Self-management of Asthma (P'ASMA), vs standard paper-based asthma self-management. Similar to the first two studies mentioned previously, the authors reported a significant improvement in quality of life in the web-based group. Fractional exhaled nitric oxide (FeNO) levels were also reduced significantly in the study group. More than half of the patients (57%) were interested in continuing web-based approach compared to paper-based [16]. A systematic review of internet-based interventions for asthma also showed that these interventions may help in improving quality of life, asthma-related knowledge, and the use of asthma medications, as well as decreased activity limitations [28].

Asthma self-management is an essential component of asthma control [29]. It helps patients to achieve their treatment goals and manage their asthma symptoms. It also enables them to manage lifestyle changes associated with a chronic illness [30]. The last study was conducted to evaluate the role of internet as a medium to support self-management of asthma along with evaluating its' effect on patients' quality of life. Patients were randomized to receive Internet-based self-management (IBSM) support (e.g., weekly asthma control monitoring, treatment advice, asthma education, and communication with a respiratory nurse) or usual asthma care. The authors reported that the IBSM support also improved quality of life as well as asthma control in adult patients with asthma [17, 18]. Additionally, other than increasing their quality of life and asthma control, the adolescents who received IBSM support also had improved lung function [27].

Not only that the internet-based technology can help improve asthma outcome and quality of life, studies have also shown that web-based strategies can be helpful in increasing adherence to asthma medications. A pilot study was conducted in adult patients with asthma to evaluate effectiveness of the Asthma Adherence Pathway (AAP) with electronic adherence monitors on asthma control. AAP is an internet application that was developed to promote medication adherence. The study showed that AAP was effective in improving asthma control and promoting adherence. Adherence to medications was 81% in the intervention group. The authors also noticed strong correlation between improved medication adherence and asthma control resulting in fewer exacerbations requiring albuterol [23].

Another randomized controlled trial (RCT) was conducted to determine if adherence to medications and quality of asthma care would improve by using an asthma management website. "My Child's Asthma" website was developed to improve asthma care by promoting adherence with controller medication amongst children with persistent asthma. The study showed that use of an interactive asthma management website can lead to improved adherence to the controller medication during initial 6 months and thus improved the quality of asthma care. However, the use of the intervention must continue for long to result in sustained benefits [24].

Internet-based monitoring systems (IBS) can help facilitate real-time monitoring of asthma symptoms. IBS survey was used to monitor asthma control in adult patients enrolled in Severe Asthma Research Program-3 (SARP-3) wherein participants were required to complete monthly asthma control survey. Asthma morbidity was evaluated in patients with low, medium, and high asthma control test (ACT) variability. The highest variability in the ACT score was seen in patients who had severe asthma. IBS can thus help to identify patients who are more likely to have asthma exacerbations and thus receive interventions such as higher dose of inhaled corticosteroid (ICS) in order to prevent exacerbations in these patients. It also helps in understanding of behavior of chronic diseases like asthma [31].

Simple tools using internet such as online reminders may be useful for improving asthma control. A RCT evaluated the efficacy of online reminders to improve asthma care in 408 adults with persistent asthma. Participants were noticed to have greater improvement in their ACT scores though there was no improvement in medication adherence [32].

Another benefit of internet-based program was discussed in a case report wherein a patient was able to contact his asthma clinic staff during an exacerbation while traveling and thus was able to avoid emergency room visit [33].

Children with asthma often experience lack of support and social isolation from their peers. A pilot study was conducted with the aim to assess online support interventions for children with asthma. Support groups sessions were conducted every week over 8 weeks where support was delivered by a professional and peer mentor who also had asthma. Social connections were organized in between these sessions. During post-test interviews, participants reported significant increase in self-confidence and decreased loneliness and sense of isolation. Patients also reported improvement in depression and self-reported asthma control [34].

In the Netherlands, a web-based portal, Virtual asthma clinic (VAC) was developed in 2011 to monitor children with asthma and to investigate if web-based monitoring can partially substitute outpatient asthma care. Children in VAC group were required to make clinic visits every 8 months whereas children in usual asthma care followed up every 4 months. In between these visits, their symptoms and asthma control were monitored online. Children who received care using VAC were noted to have improvement in the number of symptom-free days and the degree of asthma control [35]. It was also noted to be more cost-effective.

The investigators found that in the VAC group, the direct cost (median VAC €726.52 vs usual care (UC) €875.86 ($p = 0.01$)) and the indirect cost per patient (median VAC €102.79 vs UC €124.56 ($p = 0.02$)) were significantly lower as compared to patients in the UC group. This also resulted in lower costs for VAC from a societal perspective (median VAC €889.77) compared to UC (median UC €124.56) ($p = 0.014$). Also, tele-asthma management was more cost-effective to patients due to fewer clinic visits (median VAC €237.09 vs UC €385.15 ($p < 0.000$) and lower travel related costs (median VAC €94.09 vs UC €120.15, $p = 0.003$) [36]. However, there was no significant difference in healthcare costs related to pediatric/general practioner consultations, telephonic consultation, ED visits, or hospitalizations. This study concluded that an e-health intervention can partially replace regular outpatient visits.

A survey study was then conducted subsequently in the Netherlands to identify the barriers and facilitators for implementation of VAC into routine asthma care in children. Main

advantages perceived by physicians included physicians' positive attitude toward e-health, benefits for the patients, individualized patient care ("personalized e-health"), long-term benefits and efficiency, and ease of health care delivery using the VAC [37]. Major barriers reported by physicians included concerns about lack of integration of e-health with EMR, additional burden of e-health use on clinicians' existing workload, lack of internet access for some patients, lack of reimbursement for electronically delivered health care, and less face-to-face contact with the patient resulting in altered patient-physician relation [37].

The majority of the patients found VAC to be user friendly and very useful. Since they were more aware of asthma symptoms, it led to better asthma control. Other advantages reported by patients were lesser outpatient visits and thus less absence from school and work. Limitations of this study were that data was collected using questionnaires. There were no interviews conducted to obtain information from physicians regarding benefits and drawbacks of this system. Moreover, the length of the study period was 6 months which was too short to obtain information regarding all important factors. Also, bias could play a role since some physicians did not participate or respond to the questionnaire [37].

Tele-healthcare can impact a broad section of patients with asthma. It can be cost-effective and associated with patient satisfaction. Barriers such as physician financial reimbursement as well as licensing for rendering tele-healthcare services are important concerns, especially in countries such as Canada and the USA where physician are paid fee for service from health insurance providers [38].

Advantages of tele-healthcare interventions include access to health care and advice in a timely fashion, delivery of health care not limited by time or distance, encouraging self-monitoring of symptoms, and medication adherence as well as educating patients regarding avoidance of triggers. Tele-healthcare may thus enable remote delivery of care, as well as timely access to health care, which are some of the common challenges faced by patients with asthma.

Limitations of telemanagement are related to ethical issues such as privacy of patients' information and informed consent. Others may be related to patients' autonomy and empowerment including ability to access and use technology. This may have adverse consequences as in making patients too dependent on technology rather than making them more independent. Additionally, there may be less face-to-face interaction and care of the patient when tele-healthcare is used. This may result in decrease in the intensity of health care rendered to the patient which may place the patient at further risk.

Social Media

Low cost, broad availability, and widespread use of ICT make social media an attractive platform for asthma management. Internet-based social media has increased communication and social connectivity to a great extent [39]. Online social network sites (e.g., Facebook, Snapchat, Twitter, Instagram, Pinterest, and Google +) help to connect patients with asthma, their parents/caregivers, and others to share their experiences and discuss other relevant information. The use of internet-based media and social network has markedly increased especially in adolescents and young adults. Health care researchers are now exploring this as a platform to monitor chronic diseases such as asthma as well to improve adherence and compliance with treatment [39].

Social media is now commonly being used as a platform to disseminate information on asthma and other chronic conditions to increase public awareness. This is particularly helpful in countries where asthma is not widely discussed. A comprehensive communication strategy involving social media can significantly improve public awareness [40].

Social media platforms are increasingly being used to facilitate asthma self-management in a patient friendly manner. An example of this includes a private Facebook group for adolescents with asthma which is coordinated by The Center for Connected Health. This secure website contains educational information regarding asthma and reminders to take monthly ACT score. There was improvement in ACT scores compared to the control group. Patients with lower ACT scores were referral to an asthma specialist. Social media can have a positive impact on one's self-esteem which has helped in control of asthma symptoms in patients.

Social media sites and networks can help children and adolescents with asthma. Benefits for children and adolescents with asthma include support from their health care professionals as well as peers, which enables these patients and their caregivers to overcome some of their feelings of social isolation. A study was conducted to analyze the use of social media and the Internet, self-esteem, and sociodemographic data in children with asthma. It was noted that asthmatic teens, especially girls use social media more frequently which provides social feedback to compensate their self-esteem [41].

Pediatricians involved in care of adolescents with asthma were interviewed regarding role of social media technology (SMT) including social media (Facebook) and digital media (Internet-enabled cellular telephones) to improve asthma management in this population. Reported benefits of SMT as perceived by these physicians included improved patient-physician relationships, better understanding of adolescents' perception of asthma and improve self-management practices including tracking peak flow readings. Barriers included time constraints during office hours, personal commitments, work schedules, lack of comfort with the technology, and perceived liability issues [42].

Social media platforms are also increasingly being used by allergists to educate patients about asthma and other allergic conditions. This helps to generate awareness amongst patients with asthma and general population as well improve patient

care. It has been shown that social media can be a helpful measure to stay current with the new advances and developments in field of allergy and immunology. Allergists, professional society organizations (the American Academy of Allergy Asthma and Immunology [AAAAI], and the American College of Allergy, Asthma and Immunology [ACAAI]) and patient support groups are increasingly using social media. Allergy practices have been using social networks to educate patients and recruit them to their practice. Professional organizations have also been active users of social networks for member relations, public advocacy, and education.

Other than the social media platforms mentioned previously, YouTube is increasingly being used by patients to find information about asthma and other health conditions. Furthermore, Blog posts are used by allergists and professional organizations to highlight and discuss about news event or a particular issue for a detailed commentary/"blog." This helps in patient and professional education [43].

Social media monitoring has been used to collect asthma surveillance data. It has been shown to be an important source of information to identify and monitor asthma and other chronic conditions as well as track people's sentiment. In a study, when asthma prevalence data from traditional surveys was compared with that social media monitoring from Twitter, it was noted that social media is an efficient platform to gather asthma-related information [44]. They provide valuable information including people's attitude and behavior since social media serves as a platform where people openly express their opinion and sentiments. Identification of risk factors for asthma at the community level could also help physicians to provide improvised health practices and thus prevent minority communities from further worsening of asthma-related health [44].

However, the use of social media is associated with negative effects such as stress, depression, and loneliness [45]. "Facebook depression" a new form of depression has been described. Other problems include internet addiction and sleep deprivation due to excess use of the internet-based resource and social networks. These effects could have a negative impact on control and self-perception of asthma symptoms. Case reports of asthma exacerbation related to Facebook use have been published [46]. Emotional stressors related to use of social networks can trigger asthma exacerbation, especially in a poorly controlled asthma patients, because of a coexisting depressive state. Furthermore, cyber bullying is a growing phenomenon in the social media world and has been linked to social anxiety and depression [47]. The use of social media is also related to risks such as breach of patient confidentiality, privacy, professionalism, malpractice, and liability.

Short Message Services (SMS)

Poor adherence with asthma medications is a commonly encountered challenge which further contributes to increased morbidity and mortality associated with asthma as well as increased utilization of health care resources [2, 3, 48]. SMS reminders can increase awareness regarding asthma treatment and control, thus contribute to increased adherence to medications. They can help improve asthma outcomes, can be implemented conveniently in asthma clinics, and overcome constraints of time and distance in participation in educational activities.

First, we reviewed four SMS studies that investigated the improvement of adherence to asthma medications [49–52]. The majority of these studied showed improvement of medical adherence, however, the results on asthma outcome are variable.

The first RCT was conducted in 26 adult patients with asthma to evaluate the impact of daily SMS reminder on patients' cell phone [49]. These reminders increased adherence to asthma medications that the study group used 18% more doses of ICS compared to the control. In this study, there was no difference in FeNO, lung functions, or airway responsiveness between the two groups. However, the small sample size and short duration of follow-up were the main limitations of this study [49].

The second study was a multicenter RCT conducted in children (4–11 years) using ICS to investigate the effectiveness of tailored SMS reminders on adherence to ICS and if that would improve asthma control, quality of life and decrease exacerbations. All the participants were given real-time medication monitoring (RTMM) devices. The intervention group received tailored SMS reminders (e.g., only if the dose was likely to be omitted). Medication adherence was significantly higher in the intervention group (69.3%) compared to the control group (57.3%). However, there was no difference in quality of life, asthma exacerbations or asthma control between the two groups [50].

The third RCT study was conducted in adolescents with asthma to study the impact of MyMediHealth (web site and SMS reminder system) on medication adherence and asthma self-management. Participants were randomized to either MyMediHealth (patients received SMS reminders for 3 weeks) or control group (patients received action lists). The authors also reported improvement in medication adherence; however, in contrast to the previous two studies mentioned earlier, the authors reported improvement in the quality of life and asthma self-management in the study group. Satisfaction level was also high with the reminder system. However, the usage pattern of the web site was very variable, with the lowest rate amongst African American patients [51].

The last RTC evaluated 16 patients with asthma. Other than evaluating adherence to asthma medications, the authors also evaluated the role of SMS as a method of telemonitoring peak expiratory flow (PEF) [52]. Patients in the study group were required to measure PEF three times a day which guided asthma specialist to adjust their medications every week. There

was no significant difference in PEF values in the two groups, however, PEF variability was noted to be smaller in the study group. There was a slight but significant increase in forced expiratory volume (FEV1) in the study group. Interesting, in contrast to the first three studies mentioned earlier, this study found no significant difference in adherence or the use of ICS between the groups. Regardless, SMS can be a reliable and secure mode of telemedicine which can help to improve asthma control used in conjunction with action plan and standard treatment [52].

Other studies were more focused on asthma outcome [53–55]. Lv et al. [53] conducted a study in patients with asthma to identify if SMS can improve intrinsic barriers of asthma control including perceived control of asthma (PCA). The authors randomized patients to SMS, traditional, and control group. Asthma education was given to all groups. Traditional group was given individualized asthma action plan and PEF home monitoring. SMS group received additional daily SMS reminders. At 12 weeks, patients in traditional and SMS group had significantly higher PCA scores compared to control group. All groups experienced improved FEV1 and fewer ER visits. The quality of life and follow-up rate were better in the SMS group [53].

In 2007, eCARE home-monitoring service was initiated in Singapore wherein patients with asthma who were discharged from hospital were sent SMS reminders to remind them to take their medications [54]. The majority of the patients (82%) were compliant to responding to SMS messages. SMS reminders improved asthma control scores. However, there was no change in number of ED visits or hospitalizations. Most of the patients (95%) expressed satisfaction with this service. In 2012, eCARE was upgraded to asthma patients discharged from ED. Patients were randomized to eCARE group and asthma counseling vs control group (received usual asthma care). The intervention helped to achieve asthma control in more patients with poorly controlled asthma compared to the routine asthma care; however, there was no significant difference between the two groups. There was no difference between the two groups in the number of ED visits and hospitalizations [55].

The last SMS study reviewed in this article was conducted to evaluate patients' (13–40 years) perspective of SMS service for asthma management, including contents of the messages. Most patients expressed interest in SMS program especially the tailored and interactive messages. Also, most adolescents were in favor of enhanced care which included sending SMS texts to a support person (parent/guardian). On the other hand, adults were not interested in this. Participants also preferred directive educational messages and cues to action, while general messages reminding them of their asthma diagnosis were viewed less favorably [52].

Some pitfalls of sending SMS reminders repeatedly at preset time intervals are that their effect may wean over time. Some patients perceive daily reminders irritating and prefer monitoring on a weekly basis. Multiple factors can contribute to clinical outcome in patients with asthma including presence of comorbid conditions, triggers, adherence to medications, and asthma severity. Monitoring by SMS reminders can address only some of these factors. Thus, other interventions are required in addition to SMS monitoring to enhance its effectiveness.

Mobile Applications

Mobile health (mHealth) applications (apps) can support asthma self-management and improve patients' quality of life [56–59]. Nowadays, mHealth apps have incorporated to people's daily lifestyle and have been accepted as a tool for health monitoring [56, 60]. Theoretically, mHealth apps can promote medication adherence and potentially reduce the overall costs for asthma care [56, 57]. However, mHealth apps are frequently lack of comprehensive or universal clinical evaluation/clinical trials, are not necessary based on medical guidelines, and are not regulated by public authorities such as the U.S. Food and Drug Administration (FDA) [57]. Moreover, almost half of patients stopped using a mHealth app after downloading it [60]. Therefore, it is necessary for the future mHealth apps to not only be more comprehensive and standardized, but also be able to attract and sustain the users to ongoing use of the applications. In this article, we reviewed existing well-utilized asthma mHealth apps, their characteristics, and important clinical findings. The first three proof-of-concept studies [58, 61, 62] mentioned here were conducted in the USA.

A mHealth app, proof-of-concept study by Cook et al. investigated adults with poorly controlled asthma. They reported a significant improvement on the ACT scores (16.6 to 20.5), increased in FEV1, and decrease in the courses of systemic corticosteroids use [58]. The majority of the patients reported high satisfaction toward the app and the user engagement continued beyond the 4-month study period, with two-third of the patients recording ongoing use despite no further monetary incentives. However, this study did not include underrepresentation of minorities, the uninsured, and those who might be less motivated to use a mobile app and that the study used a single-arm, treatment-only design.

Two other similar proof-of-concept, single-arm, mHealth app studies focused on minority adolescents with asthma also reported positive results on asthma outcome. One of the studies performed by Burbank et al. identified an improvement in the ACT scores particularly in patients with uncontrolled asthma (16 to 18) [61]. The adolescents in this study also reported high satisfaction with the mHealth app. The other study by Mosnaim et al. investigated the use of mHealh app in low health literacy, African American adolescents with persistent asthma [62]. Unlike the previous first two mHealth app

studies that used only a mobile app, in this study, the investigators used the Mobile Adolescent's Disease Empowerment and Persistency Technology (M-ADEPT) electronic medication monitor, which is an electronic inhaler tracker, along with their mHealth app. Similarly, the authors reported the median ACT scores increased from 18 to 23. Furthermore, the investigators found that ICS adherence increased from 8 to 58%. The median short-acting beta agonist (SABA) use is also decreased from 3 puffs/week to 0 puffs/week. It is to be noted that the positive effects of this study are rather be from the M-ADEPT electronic medication monitoring combined with the mHealth app, but not from the mHealth app alone. In these later two studies that performed in underrepresented adolescents with asthma, it is not known if the user engagement will continue beyond the study period.

The other RCTs performed in the past were from outside of the USA. Here, we reviewed two major trials [63, 64]. Both of the studies showed positive findings on asthma outcome; however, it is also unknown if the user engagement will continue beyond the study period.

The first study reviewed here is a multicenter RCT in Turkey by Cingi et al. This physician on call patient engagement trial (POPET) measured the impact of a mHealth app on health outcomes and quality of life in adults with persistent asthma [63]. More asthmatic participants who used the app (study group) significantly achieved a well-controlled ACT score of > 19, compared with the control group (49% vs 27%). The study group had less emergency/unplanned hospital visits, used less rescue inhaler, felt less impaired in their activities, and felt that they had better control of their asthma than the control group. The majority of the study group (88%) completed the study vs of the control group (43%).

The second single-site RCT was done in Taiwan by Liu et al. [64] which involved adults with moderate to severe persistent asthma. The authors reported greater mean FEV1 and mean PEF in the study group vs the control group. The patients who used the app reported to have fewer episodes of asthma exacerbation, unscheduled health care visits, and have better quality of life. The mean daily dose of ICS use was also increased in the study group compared with the control group. Regardless of the positive results, the authors reported the dropout rate of 28.3% in the study group vs 23.3% in the control group. One of the reasons of the withdrawal was that the patients were not able to use the app/had problems with the app. It is to be noted that this study was reported in 2011, so the app that was used then may not be as appealing or user friendly as the mobile apps today.

A large-scale multicenter RCT is being conducted in the Netherlands by Kosse et al. The investigators conduct a mHealth intervention to support asthma self-management in 352 adolescents [65]. This Adolescent Adherence Patient Tool (ADAPT) study involves an interactive smart phone app of the patients connected to a desktop app of the community pharmacists. The investigators are monitoring asthma control, illness perceptions, medication adherence, and asthma-related quality of life in the subjects. The results of this study are still underway.

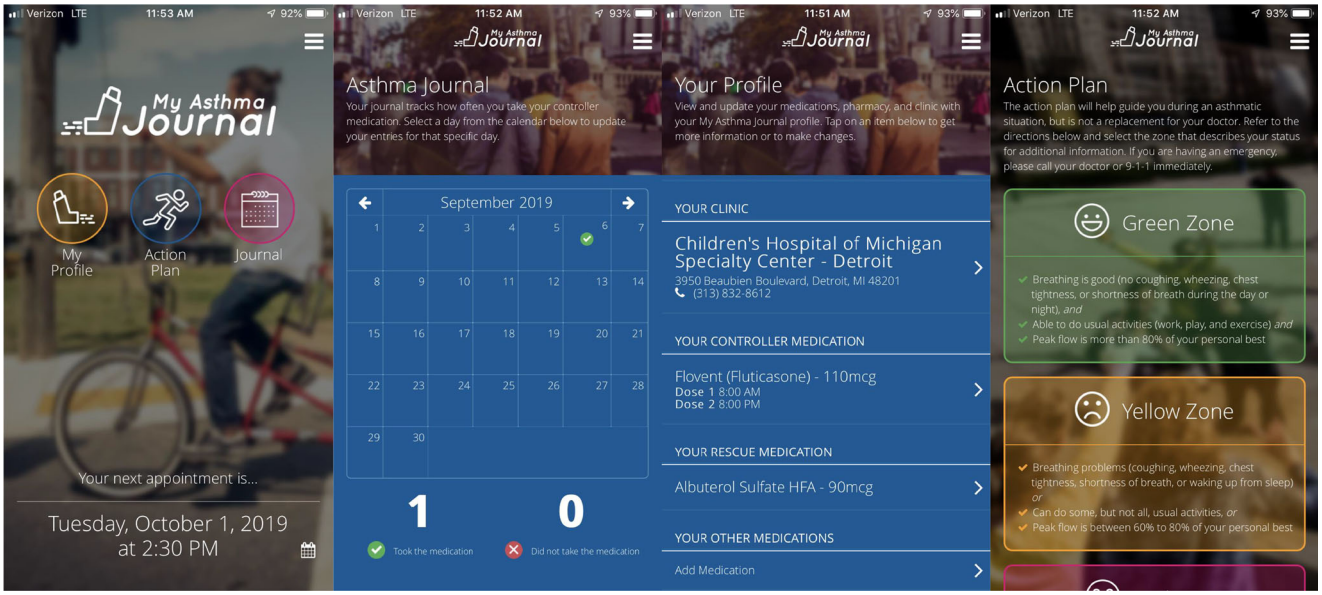
Other mHealth app studies focused more on the patient's perspective of the app programs. A large survey study conducted by Simpson et al. [66] reported that asthmatic adults most frequently requested a mHealth system to monitor asthma over time (72%) and to collect data to present to healthcare teams (70%). Two smaller interview studies by Schneider et al. reported that their participants requested more asthma-related content that educates them about their condition [67] and that the app assisted them with asthma self-management through tracking of asthma status and text reminders to test their peak flow regularly [68].

Although many recent studies reported that mHealth apps are beneficial to asthma patients, other earlier study has shown negative results. Ryan et al. [69] conducted a large multicenter RCT involved adolescents and adults with poorly controlled asthma in 2008–2009. The participants were randomized to the mobile phone-based transmission of symptoms, drug use, and peak flow with immediate feedback prompting action according to an agreed plan or paper-based monitoring. The authors found no difference in the change in asthma control or self-efficacy between the two groups. The numbers of acute exacerbations, steroid courses, and unscheduled consultations were similar in both groups, with similar healthcare costs. While the mobile phone service was more expensive because of the expenses of telemonitoring. The authors concluded that their app did not improve asthma control or increase self-efficacy compared with paper-based monitoring when both groups received clinical care to guidelines standards and the app was not cost-effective [69]. It is to be noted that in this trial, the control group also participated the same, intensive symptoms recording through papers, received education and feedback prompting action; hence, it could lead to positive asthma outcome. Furthermore, their app was developed prior to 2008, so it may not be appealing or user friendly as the apps today.

In summary, the majority of the newer studies have shown promising results that mHealth app is beneficial to help improve asthma outcome in various populations by increasing adherence to asthma medication, increasing ACT scores and reducing asthma morbidity. The majority of the patients reported high satisfaction toward mHealth app although it is unknown if the user engagement will continue beyond the study period in many studies. Figure 2 demonstrated an example of mHealth applications used for asthma care.

Inhaler Trackers

Nonadherence to daily controller asthma medication is common, leading to more severe symptoms, overuse of rescue



Courtesy of Elizabeth Secord, M.D. Division of Allergy/Immunology, Department of Pediatrics, Children's Hospital of Michigan, Wayne State University, Detroit, MI. Unpublished data.

Fig. 2 An example of mHealth applications for asthma care. Courtesy of Elizabeth Secord, M.D. Division of Allergy/Immunology, Department of Pediatrics, Children's Hospital of Michigan, Wayne State University, Detroit, MI. Unpublished data

medication, and increase in asthma morbidity especially in the inner-city patients with asthma [2, 3]. Electronic monitoring of inhaled asthma medications is one of the methods to measure medication adherence and patterns of use. Electronic tracker devices which provide patient-directed reminder and personalized feedback massages have shown modest results in improving adherence to asthma medications, particularly devices that give feedback to health care providers to encourage discussion with patients [48, 70–72]. Figure 3 demonstrated an inhaler tracker device and a web-based interface for health care provider. Here, we reviewed existing well-utilized inhaler trackers, their characteristics, and important clinical findings on asthma outcome.

The first two studies reviewed here focused on asthma symptoms, and SABA use has shown somewhat different results [73, 74].

The first study is a two-site study performed by Merchant et al., evaluated the effectiveness of the Propeller Health Asthma Platform to reduce the use of SABA, improve asthma control, and facilitate asthma self-management by providing a personalized data-driven feedback [73]. The Propeller Health Platform involves an FDA-approved sensor that measured the use of inhaled medications that is available to public. It recorded the date, time, and number of uses of the inhalers, then transmitted the data via Bluetooth to a paired smart phone app. The app recorded the location of the event and transmitted the data to secured remote servers where patients and providers can access. This study enrolled 495 adults and children with asthma for 12 months of monitoring SABA use. Half of the patients received access to and feedback from the Propeller Health Platform (intervention group), while the other half of the patients were outfitted with sensors but did not receive feedback (control group). The investigators reported that the study group had significantly decreased SABA use and increased SABA free days comparing to the control group. The ACT scores were not different between the groups; however, the adults with initially uncontrolled asthma showed a significantly larger improvement of the ACT scores.

The second study is a much smaller, single-arm study performed by Van Sickle et al. The group investigated an investigational electronic medication sensor attached to SABA inhaler of teenagers and adults with asthma [74]. In contrast to the first study by Merchant et al., this study reported mean ACT scores increased for each subsequent study month, while daytime symptoms and nighttime symptoms decreased significantly. No significant change in activity was observed. Participants also reported increased awareness and understanding of asthma patterns, level of control, SABA use (timing, location, and triggers), and improved preventive practices.

Other investigators focused particularly on pregnant women with asthma. The study group received a telehealth program (Management of asthma with supportive telehealth of respiratory function in pregnancy; MASTERY) supported by a handheld respiratory device and an Android smart phone application (Breathe-easy) and written asthma action plan [75]. The authors reported that the study group had better asthma control and asthma-related quality of life compared with usual care, although there were no significant differences between groups in lung function, unscheduled health care

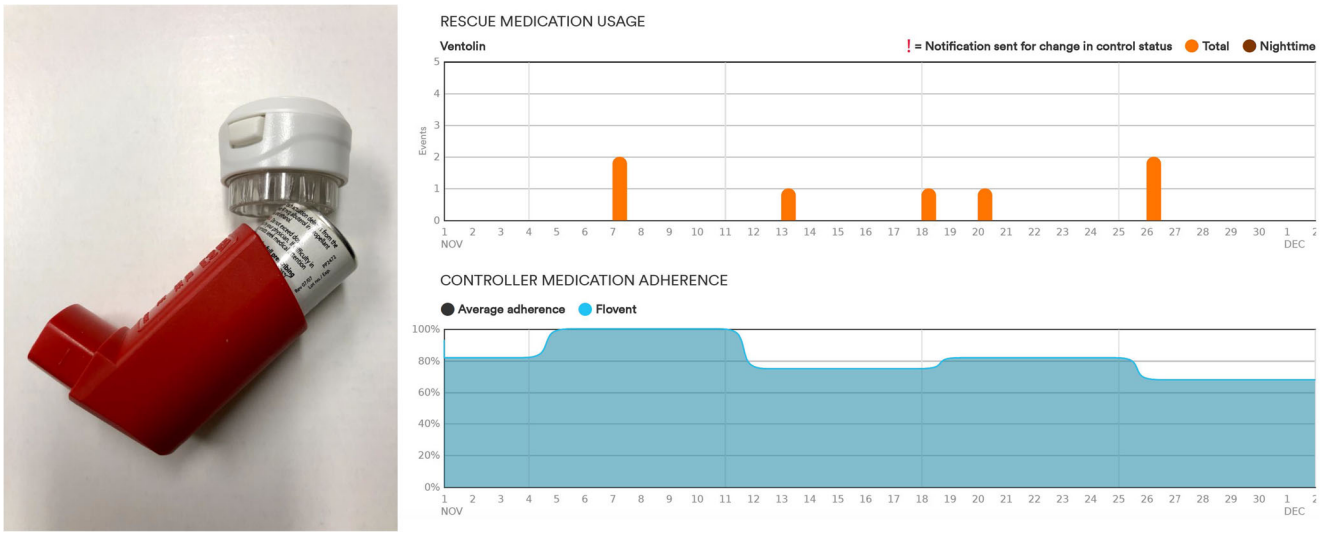


Fig. 3 An example of inhaler tracker devices and web-based interfaces

visits, days off work/study, oral corticosteroid use, or perinatal outcomes.

The next two studies reviewed here focused on the use of inhaler tracker to improve asthma medication adherence. Both of the studies showed positive outcome in increasing adherence; however, asthma outcome was slightly variable [76, 77]. These two studies were performed outside of the USA.

The first RCT by Foster et al. evaluated the inhaler tracker called SmartTrack device [76]. This inhaler tracker electronically recorded the date/time of every ICS actuation. The investigators compared inhaler reminders and feedback with active usual care alone in adult with moderate to severe persistent asthma. The intervention group was able to see the screen display (time since last dose taken). The intervention group and their primary care provider also received feedback on a secure web site and received feedback e-mails every 30 days. The authors reported that adherence was significantly higher in the study group than in the control group (73% vs 46%). The ACT scores improved overall with no significant difference among groups. Severe exacerbations were experienced by 11% of the patients in the study group vs 28% of the patients in the control group ($P = 0.013$).

The second RCT was performed by the same group of authors. The investigators also evaluated the SmartTrack device; however, this trial involved children and adolescents with persistent asthma [77], not in adults as seen in the first trail. The authors reported that median adherence was significantly higher in the study group (84% vs 30% in control group). The change in asthma morbidity score was significantly greater in the study group than in the control group ($P = 0.008$).

The SmartTrack device is a product of Adherium (formerly Nexus6), Auckland, New Zealand [70, 71]. The company has made several other inhaler tracker devices for different type of inhalers including Smartinhaler Tracker, SmartTouch, SmartDisk, SmartTurbo, SmartFlow, SmartMat, and SmartSpray. Out of these products, the SmartTouch is approved by FDA [71]; however, the available study on the SmartTouch device focused on accuracy and validation of the device [78], not on asthma outcome. Various other studies from Adherium/Nexus6 also focused on the inhaler tracker device reliability, accuracy, and validation [79–82], which are beyond the scope of this review.

Another older US-based, FDA-approved inhaler tracker device that is still available to public is known as Doser by Meditrack Products, Hudson, MA. Few studies on Doser focused on the device accuracy and validation [83, 84]. The data on asthma outcome is not available. There were also two other older US-based, non-FDA-approved inhaler tracking devices called the MDILog (Medtrac Technologies; Lakewood, CO) and the SmartMist (Aradigm Corporation; Hayward, CA). The available studies on these two devices also focused on the device accuracy and validation [84–86], while the data on asthma outcome is not available. These two devices, however, are currently not available to public.

Few other studies have focused on patient's acceptability to the tracker devices. A small study in adolescents with asthma by Cushing et al. used inhaler tracker with or without a mobile app [87]. Those participants who used the inhaler tracker with mobile app showed interest in continued use of the device and would recommend the app to friends. Unstructured interviews and focus groups revealed that patients felt that the intervention helped their sense of asthma control.

Chan et al. also evaluated the acceptability of an inhaler tracker in children and adolescents with asthma [88]. The authors reported that the acceptability scores were high and more than 90% of the patients rated the device easy to use. Feedback was positive for device acceptability, effect on medication use, and effect on asthma control.

In summary, the majority of the studies have shown positive results that inhaler trackers are beneficial to asthma

outcome in various populations. Inhaler trackers have shown to help improving adherence to asthma medication, increasing ACT scores, and reducing asthma morbidity. Similar to mHealth apps for asthma, the majority of the patients reported high acceptability toward inhaler trackers although it is unknown if the user engagement will continue beyond the study period in many studies.

Other Devices for Asthma Monitoring

Fewer studies investigated other electronic devices used for asthma monitoring. The impacts on asthma in these various devices are mixed and have not shown to be as beneficial in asthma outcome as seen in mHealth apps or inhaler trackers. Few of these studies are reviewed below [89–91].

A multicenter RCT performed by Jacobson et al. evaluated the efficacy of an electronic asthma monitoring system (AMS) (study group) vs a paper dairy (control group) in children and adolescent with asthma [89]. The AMS is hand-sized electronic device installed in patients' homes to help them track their status with respect to their asthma condition, to remind them to take their medication as prescribed, to instruct them to consult their provider when necessary, and to keep their case manager informed of their status. In this study, the authors reported that the two groups had no statistically significant differences in the numbers of or charges associated with ED visits or hospitalizations for asthma. Although their primary outcome did not show positive results, more participants of the study group used the device and logged on more days comparing to the paper diary group (83% vs 43%).

Rhee et al. developed an Automated Device for Asthma Monitoring (ADAM) to increase the objectivity of asthma symptoms monitoring and to facilitate adherence in adolescents with asthma [90]. The device employed audio analysis technology to recognize asthma symptoms, particularly coughs and used a mobile system, iPod, as a platform. The investigators reported that ADAM data (cough counts) were significantly and negatively associated with FEV1, forced vital capacity (FVC), and asthma control. The ADAM data were significantly and positively associated with daily activity limitation, nighttime symptoms, daytime symptoms, and health care utilization. The device data were also a significant predictor of asthma control, quality of life, and health care utilization. It is to be noted that this study only examined the validity of ADAM; it is unknown whether using the device vs conventional asthma treatment will have different impacts on asthma outcome/morbidity or if it will improve medication adherence.

A larger multicenter trial, MyAirCoach [91], funded by EU Horizon 2020, is ongoing. The investigators evaluate the use of home-monitoring and mHealth systems to predict deterioration in asthma control and the occurrence of asthma exacerbations in adults with uncontrolled asthma. Patients will be provided with mHealth and home-monitoring systems to record their symptoms. The association of physiological, behavioral, and environmental data, with episodes of uncontrolled asthma and occurrence of moderate and severe asthma exacerbations, and the user acceptance of mHealth and home-monitoring systems are being evaluated.

Tools for Asthma Patient Education and Asthma Self-Management

Several tools are used for asthma education and promote asthma self-management. One of the important tools used for asthma patient education is an asthma action plan. Asthma action plan is a written action plan generated by a physician/health care professional that is tailored to an individual patient with asthma. An asthma action plan outlines steps for asthma management for the patient and their caretakers in a "traffic light" representation [29, 92]. In an asthma action plan, the "green zone" represents adequate control of asthma symptoms and asks the patient to continue the use of regular home medications. The "yellow zone" represents acute loss of asthma control and outlines the necessary steps for intensifying medical therapy. Lastly, the "red zone" represents severe exacerbation of asthma symptoms requiring prompt medical attention [93].

Asthma guidelines recommend that all patients with asthma should be provided with an asthma action plan [94]. Asthma action plan can be used as an effective tool for patient education and showed to decrease healthcare utilization, improve asthma symptoms, and patients' quality of life [29]. Regardless, a study showed that only 30% asthmatic patients received an asthma action plan [95]. This can be contributed to the lack of time of the health care provider [96]. With this limitation, a new technology tool called Electronic Asthma Management System (eAMS) was developed by researchers from Canada. eAMS allows health care providers to overcome time and knowledge constraints by conducting algorithms for intensification of medical therapy in yellow zone based on asthma guidelines from several sources. Patients will complete questionnaire prior to clinic visit through a smartphone or tablet then individualized asthma action plans reflecting medication adjustments by health care providers are generated by the eAMS. A clinical trial of this system is currently underway [97].

Asthma self-management is a complex, multi-component intervention that includes asthma education, avoidance of triggers, provision of asthma action plan/treatment plan, patients' self-monitoring, and behavior changes such as improving medication adherence and regular medical follow up [92, 98]. Self-management has been recommended by the Global initiative for asthma (GINA) for asthma management [94] as it is an important element of asthma control that helps patients managing their asthma symptoms, achieving treatment goals, and adapting with lifestyle changes related with chronic

illnesses [29, 30]. Asthma self-management are reported to help reduce asthma-related ED visits, hospitalizations, the use of oral corticosteroids, school/work absenteeism, and improved patients' quality of life [29]. However, asthma self-management requires diligent and dynamic interaction between patients, physicians, and community pharmacists. This includes recognition of the condition, appropriate treatment plan, and periodic review of efficacy of medications. It is reported that patients with asthma and allergic rhinitis tend to neglect the severity of their diseases, overestimate their self-management ability, and, thus, not seek appropriate medical attention [99, 100].

Various technology tools such as web-based technology and mobile applications are used to assist asthma self-management. To help with asthma self-management, diverse domains such as patients' self-monitoring of symptoms, physical activity, and medication adherence are monitored by web-based technology tools combined with feedback, education, and treatment advice from their health care providers. My Asthma Portal (MAP) [15], Portal for Assessment and Self-management of Asthma (P'ASMA) [16] and Internet-based self-management (IBSM) [17, 18, 27] are the examples of web-based technology that are used to assist asthma self-management. These three web-based technology tools have consistently shown to improve patients' quality of life. Both MAP and IBSM improved self-reported asthma control. Additionally, objective measures such as reduction of FeNO and improvement of lung function were seen in patients using P'ASMA and IBSM, respectively. Regardless of the positive results, many of these studies found that their effects were diminished over time once the intervention was discontinued [15, 27]. The details of each studies were discussed previously in web-based technology section.

Other than web-based technology tools, many smartphone applications are used to assist asthma self-management. A recent study in Australia identified smart phone applications that assist in self-monitoring and medication adherence, thus allowing patients' self-management of their asthma and allergic rhinitis. This study retrieved 418 mHealth apps, and among these, 31 were analyzed. In this study, MASK-Air was noted to rank highest in various self-assessment domains including symptom control self-assessment, monitoring of symptoms, medication adherence, physician appointment reminder, and communication with health care provider [101].

Other studies reported that smartphone applications focusing on asthma self-management can benefit asthma outcomes. The first example is "Asthma Tuner," which is a self-management system based in Sweden that consists of a mHealth app, a cloud-based storage and a healthcare interface. Patients used Bluetooth spirometers to measure lung function (FEV1) and registered their symptoms. Immediate feedback was given to the patients regarding their asthma control and the type and dose of inhaler(s) to be used. In this randomized cross-over trial, the authors compared Asthma Tuner (study group) with conventional treatment. Symptom control as measured by ACT score improved significantly with Asthma Tuner. However, medication adherence improved only in some patients [102].

Another example is "Kiss myAsthma" which is a smartphone app that supports asthma self-management. This pilot study primarily investigated the usefulness and acceptability of the mobile app in teenagers and young adults. The authors showed that the mobile app can improve asthma-related quality of life and also can change health behavior in young people with asthma [103].

Asthma self-management should include knowledge about asthma, patient skills training for self-management (use of inhalers and peak flow), feedback and monitoring, and non-pharmacological interventions such as avoidance of triggers, setting goals, and messages/prompts. Several other studies focused on which features of the technology tools that are more efficacious for asthma self-management. In a study conducted in China, quality of smartphone apps was assessed for asthma self-management education and behavior change. Among these factors, skills training for effective self-management was identified as the most important factor for asthma self-management [104]. Other studies have shown that smartphone apps that aimed at behavior change techniques were also very effective for many chronic diseases [105].

For web-based technology tools, the interventions that involved barrier identification and problem solving in combination with providing rewards for behavior change appear to be more effective in changing health behavior [106]. Technology tools that take little time to understand and use are more likely to be more effective as well [106]. For asthma self-management in particular, interventions which were tailored to individual patient needs and cultural values were noted to be more effective especially when the interventions were delivered by nurses to small groups of patients who were less educated [107].

Cost-Effectiveness and Barriers of Using Technological Resources in Asthma Management

Telemedicine system can allow monitoring of asthma symptoms at home for patients who have poorly controlled asthma. This has been shown to decrease ED visits and ED visit-related costs and improved activities of daily living [108]. Telehealth may be cost-effective to patients as well as physicians. From patients' perspective, lower travel related costs, fewer absences from work and school and improvement in activities of daily living are beneficial. The increase in accessibility to specialists can increase patient satisfaction and retention. Telehealth can be more comfortable and more affordable for patients.

From physician's perspective, remote care provided by telehealth can reduce costs for major hospitals and health care systems especially in rural areas where there is limited access to health care. It can also reduce costs related to no-show rates in clinics and allow empty slots to be filled. Telemedicine allows easy access to providers and decrease wait times [109]. It can also help to improve adherence with medications and treatment plan. It can generate revenue for the providers by billing for unpaid phone conversations/e-mails into a billable encounter.

Literatures indicate that there is a lack of solid evidence to completely evaluate the economic impact of telemedicine, e-health, and mHealth care [110, 111]. There is no data available on actual numbers or how significant is it in large scales. There are few cost-utility and cost-effectiveness studies for telemedicine, e-health, and mHealth care. Some of these studies suggested that telemedicine can reduce the costs especially in the fields of ophthalmology [112–114], dermatology [115], psychology [116–118], and cardiology [119, 120]. However; lack of randomized control trials, small sample sizes, and the absence of quality data and appropriate measures are main limitations of these studies.

A study based in Milwaukee, WI, indicated that adult outpatient pulmonary subspecialty consultations via telemedicine are cost-effective for the delivery of care for rural populations with limited access to subspecialty services. The authors reported that telemedicine was found to be more cost-effective ($335 per patient/year) compared to routine care which patients traveled from a remote site to the hub site to receive care ($585 per patient/year) and on-site care which patients received care at the remote site ($1166 per patient/year) [121]. This cost-effectiveness depended on cost sharing (adequate patient volume and sharing of telemedicine infrastructure within various providers), efficacy of telemedicine in terms of patient utility and clinical consultations, and indirect cost savings from reducing cost of patients' lost productivity [121].

Telemedicine reimbursement policies for Medicaid/Medicare and commercially insured patients may be cumbersome. These can be a barrier that prevents clinicians from using telemedicine. Medicare tends to reimburse for telemedicine services only in the areas where there is shortage of clinicians. In most states, some types of live video reimbursement may be offered under the Medicaid program. Medicare will reimburse for telehealth services delivered but not for the use of mobile devices. Also, there are restrictions on types of facility where patients can receive telemedicine services. These include rural health clinics, skilled nursing facilities, federally qualifies health centers, and community mental health centers [122].

Unfortunately, rules for Medicare/Medicaid and private insurances are different and also vary from state to state. Details for billing and reimbursement for telemedicine have not been well outlined in the literature. In fact, many physician offices have been charging a self-pay rate for telemedicine appointments for individuals who are not eligible for telemedicine due to insurance restrictions or if the patients are willing to pay out-of-pocket [122].

Issues with reimbursement is one of the barriers of using telemedicine but studies indicated it is not one of the top three barriers to adopting telemedicine worldwide. In fact, the top three barriers preventing the use of telemedicine, e-health, and mHealth appeared to be related to the use of technology. These barriers include issues with technically challenged staff (11%), resistance to change (8%), cost (8%), reimbursement (5%), age of patient (5%) and level of education of patient (5%) [123]. The authors concluded that these technology-specific barriers could be overcome by focused policies, including training, change-management techniques, and alternating delivery by telemedicine and personal patient-to-provider interaction [123].

Summary

Asthma control is affected by multiple factors including education and involvement of patients/families. Despite existing asthma management guidelines, the burden of the disease continues to increase for patients and their families. Several information and communication technology (ICT) tools/resources are being explored to improve asthma control and outcome and thus decrease disease burden. ICT tools include web-based technology system, social media, SMS, mHealth app, and inhaler tracker. Usually, technology is well accepted. Low cost, easy accessibility, and availability of these technology tools make them an attractive platform for asthma management, though there are concerns for patients' privacy and ethical issues. Armed with this knowledge, clinicians will have more refined understanding on using/choosing technology resources to improve asthma care and understand risks and benefits on each available technology tools for different patient populations.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Approval and Informed Consent This article does not contain any studies with human participants or animals performed by any of the authors. Informed consent is not applicable.

References

1. Lombardi C, Passalacqua G, Canonica GW (2015) The WEB-based asthma control: an intriguing connection or a dangerous hazard? Asthma Res Pract 1:15. https://doi.org/10.1186/s40733-015-0017-z
2. Poowuttikul P, Hart B, Thomas R, Secord E (2017) Poor adherence with medication refill and medical supplies maintenance as risk

factors for inpatient asthma admission in children. Glob Pediatr Health 4:2333794X17710588. https://doi.org/10.1177/2333794X17710588
3. Poowuttikul P, Saini S, Seth D (2019) Inner-city asthma in children. Clin Rev Allergy Immunol 56(2):248–268. https://doi.org/10.1007/s12016-019-08728-x
4. Eliasson AH, Poropatich RK (1998) Performance improvement in telemedicine: the essential elements. Mil Med 163(8):530–535
5. Romano MJ, Hernandez J, Gaylor A, Howard S, Knox R (2001) Improvement in asthma symptoms and quality of life in pediatric patients through specialty care delivered via telemedicine. Telemed J E Health 7(4):281–286. https://doi.org/10.1089/15305620152814683
6. Perron BE, Taylor HO, Glass JE, Margerum-Leys J (2010) Information and communication technologies in social work. Adv Soc Work 11(2):67–81
7. Calderon J, Cherrez A, Ramon GD, Lopez Jove O, Baptist A, Matos E, Morfin Maciel B, Calero E, Sanchez-Borges M, Cherrez S, Simancas-Racines D, Cherrez Ojeda I (2017) Information and communication technology use in asthmatic patients: a cross-sectional study in Latin America. ERJ Open Res 3(3). https://doi.org/10.1183/23120541.00005-2017
8. Baptist AP, Thompson M, Grossman KS, Mohammed L, Sy A, Sanders GM (2011) Social media, text messaging, and email-preferences of asthma patients between 12 and 40 years old. J Asthma 48(8):824–830. https://doi.org/10.3109/02770903.2011.608460
9. Jenssen BP, Mitra N, Shah A, Wan F, Grande D (2016) Using digital technology to engage and communicate with patients: a survey of patient attitudes. J Gen Intern Med 31(1):85–92. https://doi.org/10.1007/s11606-015-3517-x
10. Kahn JM, Cicero BD, Wallace DJ, Iwashyna TJ (2014) Adoption of ICU telemedicine in the United States. Crit Care Med 42(2):362–368. https://doi.org/10.1097/CCM.0b013e3182a6419f
11. Harst L, Lantzsch H, Scheibe M (2019) Theories predicting end-user acceptance of telemedicine use: systematic review. J Med Internet Res 21(5):e13117. https://doi.org/10.2196/13117
12. Kruse CS, Krowski N, Rodriguez B, Tran L, Vela J, Brooks M (2017) Telehealth and patient satisfaction: a systematic review and narrative analysis. BMJ Open 7(8):e016242. https://doi.org/10.1136/bmjopen-2017-016242
13. Saigi-Rubio F, Jimenez-Zarco A, Torrent-Sellens J (2016) Determinants of the intention to use telemedicine: evidence from primary care physicians. Int J Technol Assess Health Care 32(1–2):29–36. https://doi.org/10.1017/S0266462316000015
14. Rasmussen LM, Phanareth K, Nolte H, Backer V (2005) Internet-based monitoring of asthma: a long-term, randomized clinical study of 300 asthmatic subjects. J Allergy Clin Immunol 115(6):1137–1142. https://doi.org/10.1016/j.jaci.2005.03.030
15. Ahmed S, Ernst P, Bartlett SJ, Valois MF, Zaihra T, Pare G, Grad R, Eilayyan O, Perreault R, Tamblyn R (2016) The effectiveness of web-based asthma self-management system, my asthma portal (MAP): a pilot randomized controlled trial. J Med Internet Res 18(12):e313. https://doi.org/10.2196/jmir.5866
16. Araujo L, Jacinto T, Moreira A, Castel-Branco MG, Delgado L, Costa-Pereira A, Fonseca J (2012) Clinical efficacy of web-based versus standard asthma self-management. J Investig Allergol Clin Immunol 22(1):28–34
17. van Gaalen JL, Bakker MJ, van Bodegom-Vos L, Snoeck-Stroband JB, Assendelft WJ, Kaptein AA, van der Meer V, Taube C, Thoonen BP, Sont JK, group Is (2012) Implementation strategies of internet-based asthma self-management support in usual care. Study protocol for the IMPASSE cluster randomized trial. Implement Sci 7:113. https://doi.org/10.1186/1748-5908-7-113
18. van Gaalen JL, Beerthuizen T, van der Meer V, van Reisen P, Redelijkheid GW, Snoeck-Stroband JB, Sont JK, Group SS (2013) Long-term outcomes of internet-based self-management support in adults with asthma: randomized controlled trial. J Med Internet Res 15(9):e188. https://doi.org/10.2196/jmir.2640
19. Guendelman S, Meade K, Benson M, Chen YQ, Samuels S (2002) Improving asthma outcomes and self-management behaviors of inner-city children: a randomized trial of the Health Buddy interactive device and an asthma diary. Arch Pediatr Adolesc Med 156(2):114–120
20. Joseph CL, Ownby DR, Havstad SL, Saltzgaber J, Considine S, Johnson D, Peterson E, Alexander G, Lu M, Gibson-Scipio W, Johnson CC, Research team m (2013) Evaluation of a web-based asthma management intervention program for urban teenagers: reaching the hard to reach. J Adolesc Health 52 (4):419–426. https://doi.org/10.1016/j.jadohealth.2012.07.009
21. Chan DS, Callahan CW, Hatch-Pigott VB, Lawless A, Proffitt HL, Manning NE, Schweikert M, Malone FJ (2007) Internet-based home monitoring and education of children with asthma is comparable to ideal office-based care: results of a 1-year asthma in-home monitoring trial. Pediatrics 119(3):569–578. https://doi.org/10.1542/peds.2006-1884
22. Wiecha JM, Adams WG, Rybin D, Rizzodepaoli M, Keller J, Clay JM (2015) Evaluation of a web-based asthma self-management system: a randomised controlled pilot trial. BMC Pulm Med 15:17. https://doi.org/10.1186/s12890-015-0007-1
23. Weinstein AG, Singh A, Laurenceau JP, Skoner DP, Maiolo J, Sharara R, Ma K, Cheema T, Butler E, Kong A, Thakkar P, Gentile DA (2019) A pilot study of the effect of an educational web application on asthma control and medication adherence. J Allergy Clin Immunol Pract 7(5):1497–1506. https://doi.org/10.1016/j.jaip.2018.12.024
24. Christakis DA, Garrison MM, Lozano P, Meischke H, Zhou C, Zimmerman FJ (2012) Improving parental adherence with asthma treatment guidelines: a randomized controlled trial of an interactive website. Acad Pediatr 12(4):302–311. https://doi.org/10.1016/j.acap.2012.03.006
25. Finkelstein J, Hripcsak G, Cabrera M (1998) Telematic system for monitoring of asthma severity in patients' homes. Stud Health Technol Inform 52(Pt 1):272–276
26. Finkelstein J, Cabrera MR, Hripcsak G (2000) Internet-based home asthma telemonitoring: can patients handle the technology? Chest 117(1):148–155. https://doi.org/10.1378/chest.117.1.148
27. Rikkers-Mutsaerts ER, Winters AE, Bakker MJ, van Stel HF, van der Meer V, de Jongste JC, Sont JK, Group SS (2012) Internet-based self-management compared with usual care in adolescents with asthma: a randomized controlled trial. Pediatr Pulmonol 47(12):1170–1179. https://doi.org/10.1002/ppul.22575
28. Morrison D, Wyke S, Agur K, Cameron EJ, Docking RI, Mackenzie AM, McConnachie A, Raghuvir V, Thomson NC, Mair FS (2014) Digital asthma self-management interventions: a systematic review. J Med Internet Res 16(2):e51. https://doi.org/10.2196/jmir.2814
29. Gibson PG, Powell H, Coughlan J, Wilson AJ, Abramson M, Haywood P, Bauman A, Hensley MJ, Walters EH (2003) Self-management education and regular practitioner review for adults with asthma. Cochrane Database Syst Rev 1:CD001117. https://doi.org/10.1002/14651858.CD001117
30. Barlow J, Wright C, Sheasby J, Turner A, Hainsworth J (2002) Self-management approaches for people with chronic conditions: a review. Patient Educ Couns 48(2):177–187
31. Wong-McGrath K, Denlinger LC, Bleecker ER, Castro M, Gaston B, Israel E, Jarjour NN, Mauger DT, Peters S, Phillips BR, Wenzel SE, Fahy JV, Peters MC, National Heart L, Blood Institute's Severe Asthma Research Program I (2018) Internet-based monitoring in the severe asthma research program identifies a subgroup

of patients with labile asthma control. Chest 153(2):378–386. https://doi.org/10.1016/j.chest.2017.10.017
32. Pool AC, Kraschnewski JL, Poger JM, Smyth J, Stuckey HL, Craig TJ, Lehman EB, Yang C, Sciamanna CN (2017) Impact of online patient reminders to improve asthma care: a randomized controlled trial. PLoS One 12(2):e0170447. https://doi.org/10.1371/journal.pone.0170447
33. O'Hara C, Vethanayagam D, Majaesic C, Mayers I (2006) Internet-based asthma education - a novel approach to compliance: a case report. Can Respir J 13(1):30–32. https://doi.org/10.1155/2006/435028
34. Stewart M, Letourneau N, Masuda JR, Anderson S, McGhan S (2013) Impacts of online peer support for children with asthma and allergies: it just helps you every time you can't breathe well. J Pediatr Nurs 28(5):439–452. https://doi.org/10.1016/j.pedn.2013.01.003
35. van den Wijngaart LS, Roukema J, Boehmer ALM, Brouwer ML, Hugen CAC, Niers LEM, Sprij AJ, Rikkers-Mutsaerts E, Rottier BL, Donders ART, Verhaak CM, Pijnenburg MW, Merkus P (2017) A virtual asthma clinic for children: fewer routine outpatient visits, same asthma control. Eur Respir J 50(4). https://doi.org/10.1183/13993003.00471-2017
36. van den Wijngaart LS, Kievit W, Roukema J, Boehmer ALM, Brouwer ML, Hugen CAC, Niers LEM, Sprij AJ, Rikkers-Mutsaerts E, Rottier BL, Verhaak CM, Pijnenburg MW, Merkus P (2017) Online asthma management for children is cost-effective. Eur Respir J 50(4). https://doi.org/10.1183/13993003.01413-2017
37. van den Wijngaart LS, Geense WW, Boehmer AL, Brouwer ML, Hugen CA, van Ewijk BE, Koenen-Jacobs MJ, Landstra AM, Niers LE, van Onzenoort-Bokken L, Ottink MD, Rikkers-Mutsaerts ER, Groothuis I, Vaessen-Verberne AA, Roukema J, Merkus PJ (2018) Barriers and facilitators when implementing web-based disease monitoring and management as a substitution for regular outpatient care in pediatric asthma: qualitative survey study. J Med Internet Res 20(10):e284. https://doi.org/10.2196/jmir.9245
38. Duvvuri VR, Jianhong W (2007) Information and communication technology developments in asthma management: a systematic review. Indian J Med Sci 61(4):221–241
39. Walther JB (1996) Computer-mediated communication: impersonal, interpersonal, and hyperpersonal interaction. Commun Res 23:3–43
40. Mydin HHA, Ampikaipakan S, Shayaa S, Partridge MR (2018) The effect of an asthma awareness campaign on social media users. Eur Respir J 52:PA3137
41. Jozsa T, Papp A, Gonczi F, Balla G, Nagy BE (2018) Studying the health behavior of asthmatic children regarding the dimensions of media and internet usage and self-esteem. Orv Hetil 159(47):1971–1980. https://doi.org/10.1556/650.2018.31203
42. Martinasek MPP, Panzera AD, Schneider T, Lindenberger JH (2011) Benefits and barriers of pediatric healthcare providers toward using social media in asthma care. Am J Health Educ 4(42):213–221
43. Dimov V, Gonzalez-Estrada A, Eidelman F (2016) Social media and the allergy practice. Ann Allergy Asthma Immunol 116(6):484–490. https://doi.org/10.1016/j.anai.2016.01.021
44. Dai HL, Lee BR, Hao J (2017) Predicting asthma prevalence by linking social media data and traditional surveys. Annals of the American Academy of Political and Social Science 669:75–92
45. Selfhout MH, Branje SJ, Delsing M, ter Bogt TF, Meeus WH (2009) Different types of internet use, depression, and social anxiety: the role of perceived friendship quality. J Adolesc 32(4):819–833. https://doi.org/10.1016/j.adolescence.2008.10.011
46. D'Amato G, Liccardi G, Cecchi L, Pellegrino F, D'Amato M (2010) Facebook: a new trigger for asthma? Lancet 376(9754):1740. https://doi.org/10.1016/S0140-6736(10)62135-6
47. Hinduja S, Patchin JW (2010) Bullying, cyberbullying, and suicide. Arch Suicide Res 14(3):206–221. https://doi.org/10.1080/13811118.2010.494133
48. Charles T, Quinn D, Weatherall M, Aldington S, Beasley R, Holt S (2007) An audiovisual reminder function improves adherence with inhaled corticosteroid therapy in asthma. J Allergy Clin Immunol 119(4):811–816. https://doi.org/10.1016/j.jaci.2006.11.700
49. Strandbygaard U, Thomsen SF, Backer V (2010) A daily SMS reminder increases adherence to asthma treatment: a three-month follow-up study. Respir Med 104(2):166–171. https://doi.org/10.1016/j.rmed.2009.10.003
50. Vasbinder EC, Goossens LM, Rutten-van Molken MP, de Winter BC, van Dijk L, Vulto AG, Blankman EI, Dahhan N, Veenstra-van Schie MT, Versteegh FG, Wolf BH, Janssens HM, van den Bemt PM (2016) E-monitoring of asthma therapy to improve compliance in children (e-MATIC): a randomised controlled trial. Eur Respir J 48(3):758–767. https://doi.org/10.1183/13993003.01698-2015
51. Johnson KB, Patterson BL, Ho YX, Chen Q, Nian H, Davison CL, Slagle J, Mulvaney SA (2016) The feasibility of text reminders to improve medication adherence in adolescents with asthma. J Am Med Inform Assoc 23(3):449–455. https://doi.org/10.1093/jamia/ocv158
52. Ostojic V, Cvoriscec B, Ostojic SB, Reznikoff D, Stipic-Markovic A, Tudjman Z (2005) Improving asthma control through telemedicine: a study of short-message service. Telemed J E Health 11(1):28–35. https://doi.org/10.1089/tmj.2005.11.28
53. Lv Y, Zhao H, Liang Z, Dong H, Liu L, Zhang D, Cai S (2012) A mobile phone short message service improves perceived control of asthma: a randomized controlled trial. Telemed J E Health 18(6):420–426. https://doi.org/10.1089/tmj.2011.0218
54. Prabhakaran L, Chee WY, Chua KC, Abisheganaden J, Wong WM (2010) The use of text messaging to improve asthma control: a pilot study using the mobile phone short messaging service (SMS). J Telemed Telecare 16(5):286–290. https://doi.org/10.1258/jtt.2010.090809
55. Prabhakaran L, Yap CW, Neo LP, Gan CC, Tham LM, Wong WM, Abisheganaden J, Lim TK (2018) Effectiveness of the eCARE Programme: a short message service (SMS) for asthma monitoring. Ann Acad Med Singap 47(6):233–236
56. Hui CY, Walton R, McKinstry B, Jackson T, Parker R, Pinnock H (2017) The use of mobile applications to support self-management for people with asthma: a systematic review of controlled studies to identify features associated with clinical effectiveness and adherence. J Am Med Inform Assoc 24(3):619–632. https://doi.org/10.1093/jamia/ocw143
57. Tinschert P, Jakob R, Barata F, Kramer JN, Kowatsch T (2017) The potential of mobile apps for improving asthma self-management: a review of publicly available and well-adopted asthma apps. JMIR Mhealth Uhealth 5(8):e113. https://doi.org/10.2196/mhealth.7177
58. Cook KA, Modena BD, Simon RA (2016) Improvement in asthma control using a minimally burdensome and proactive smartphone application. J Allergy Clin Immunol Pract 4(4):730–737 e731. https://doi.org/10.1016/j.jaip.2016.03.005
59. Wu AC (2016) The promise of improving asthma control using mobile health. J Allergy Clin Immunol Pract 4(4):738–739. https://doi.org/10.1016/j.jaip.2016.04.003
60. Krebs P, Duncan DT (2015) Health app use among US mobile phone owners: a national survey. JMIR Mhealth Uhealth 3(4):e101. https://doi.org/10.2196/mhealth.4924
61. Burbank AJ, Lewis SD, Hewes M, Schellhase DE, Rettiganti M, Hall-Barrow J, Bylander LA, Brown RH, Perry TT (2015) Mobile-based asthma action plans for adolescents. J Asthma 52(6):583–586. https://doi.org/10.3109/02770903.2014.995307

62. Mosnaim G, Li H, Martin M, Richardson D, Belice PJ, Avery E, Silberstein A, Leigh J, Kenyon R, Jones S, Bender B, Powell LH (2015) A tailored mobile health intervention to improve adherence and asthma control in minority adolescents. J Allergy Clin Immunol Pract 3(2):288–290 e281. https://doi.org/10.1016/j.jaip.2014.10.011
63. Cingi C, Yorgancioglu A, Cingi CC, Oguzulgen K, Muluk NB, Ulusoy S, Orhon N, Yumru C, Gokdag D, Karakaya G, Celebi S, Cobanoglu HB, Unlu H, Aksoy MA (2015) The "physician on call patient engagement trial" (POPET): measuring the impact of a mobile patient engagement application on health outcomes and quality of life in allergic rhinitis and asthma patients. Int Forum Allergy Rhinol 5(6):487–497. https://doi.org/10.1002/alr.21468
64. Liu WT, Huang CD, Wang CH, Lee KY, Lin SM, Kuo HP (2011) A mobile telephone-based interactive self-care system improves asthma control. Eur Respir J 37(2):310–317. https://doi.org/10.1183/09031936.00000810
65. Kosse RC, Bouvy ML, de Vries TW, Kaptein AA, Geers HC, van Dijk L, Koster ES (2017) mHealth intervention to support asthma self-management in adolescents: the ADAPT study. Patient Prefer Adherence 11:571–577. https://doi.org/10.2147/PPA.S124615
66. Simpson AJ, Honkoop PJ, Kennington E, Snoeck-Stroband JB, Smith I, East J, Coleman C, Caress A, Chung KF, Sont JK, Usmani O, Fowler SJ (2017) Perspectives of patients and healthcare professionals on mHealth for asthma self-management. Eur Respir J 49(5). https://doi.org/10.1183/13993003.01966-2016
67. Schneider T, Panzera AD, Couluris M, Lindenberger J, McDermott R, Bryant CA (2016) Engaging teens with asthma in designing a patient-centered mobile app to aid disease self-management. Telemed J E Health 22(2):170–175. https://doi.org/10.1089/tmj.2015.0041
68. Schneider T, Baum L, Amy A, Marisa C (2019) I have most of my asthma under control and I know how my asthma acts: Users' perceptions of asthma self-management mobile app tailored for adolescents. Health informatics J:1460458218824734. https://doi.org/10.1177/1460458218824734
69. Ryan D, Price D, Musgrave SD, Malhotra S, Lee AJ, Ayansina D, Sheikh A, Tarassenko L, Pagliari C, Pinnock H (2012) Clinical and cost effectiveness of mobile phone supported self monitoring of asthma: multicentre randomised controlled trial. BMJ 344: e1756. https://doi.org/10.1136/bmj.e1756
70. Bender BG (2018) Technology interventions for nonadherence: new approaches to an old problem. J Allergy Clin Immunol Pract 6(3):794–800. https://doi.org/10.1016/j.jaip.2017.10.029
71. Chan AH, Harrison J, Black PN, Mitchell EA, Foster JM (2015) Using electronic monitoring devices to measure inhaler adherence: a practical guide for clinicians. J Allergy Clin Immunol Pract 3(3):335-349–e331-335. https://doi.org/10.1016/j.jaip.2015.01.024
72. Apter AJ, Wang X, Bogen DK, Rand CS, McElligott S, Polsky D, Gonzalez R, Priolo C, Adam B, Geer S, Ten Have T (2011) Problem solving to improve adherence and asthma outcomes in urban adults with moderate or severe asthma: a randomized controlled trial. J Allergy Clin Immunol 128(3):516-523–e511-515. https://doi.org/10.1016/j.jaci.2011.05.010
73. Merchant RK, Inamdar R, Quade RC (2016) Effectiveness of population health management using the propeller health asthma platform: a randomized clinical trial. J Allergy Clin Immunol Pract 4(3):455–463. https://doi.org/10.1016/j.jaip.2015.11.022
74. Van Sickle D, Magzamen S, Truelove S, Morrison T (2013) Remote monitoring of inhaled bronchodilator use and weekly feedback about asthma management: an open-group, short-term pilot study of the impact on asthma control. PLoS One 8(2): e55335. https://doi.org/10.1371/journal.pone.0055335
75. Zairina E, Abramson MJ, McDonald CF, Li J, Dharmasiri T, Stewart K, Walker SP, Paul E, George J (2016) Telehealth to improve asthma control in pregnancy: a randomized controlled trial. Respirology 21(5):867–874. https://doi.org/10.1111/resp.12773
76. Foster JM, Usherwood T, Smith L, Sawyer SM, Xuan W, Rand CS, Reddel HK (2014) Inhaler reminders improve adherence with controller treatment in primary care patients with asthma. J Allergy Clin Immunol 134(6):1260–1268 e1263. https://doi.org/10.1016/j.jaci.2014.05.041
77. Chan AH, Stewart AW, Harrison J, Camargo CA Jr, Black PN, Mitchell EA (2015) The effect of an electronic monitoring device with audiovisual reminder function on adherence to inhaled corticosteroids and school attendance in children with asthma: a randomised controlled trial. Lancet Respir Med 3(3):210–219. https://doi.org/10.1016/S2213-2600(15)00008-9
78. Pilcher J, Holliday M, Ebmeier S, McKinstry S, Messaoudi F, Weatherall M, Beasley R (2016) Validation of a metered dose inhaler electronic monitoring device: implications for asthma clinical trial use. BMJ Open Respir Res 3(1):e000128. https://doi.org/10.1136/bmjresp-2016-000128
79. Pilcher J, Shirtcliffe P, Patel M, McKinstry S, Cripps T, Weatherall M, Beasley R (2015) Three-month validation of a turbuhaler electronic monitoring device: implications for asthma clinical trial use. BMJ Open Respir Res 2(1):e000097. https://doi.org/10.1136/bmjresp-2015-000097
80. Foster JM, Smith L, Usherwood T, Sawyer SM, Rand CS, Reddel HK (2012) The reliability and patient acceptability of the SmartTrack device: a new electronic monitor and reminder device for metered dose inhalers. J Asthma 49(6):657–662. https://doi.org/10.3109/02770903.2012.684253
81. Burgess SW, Wilson SS, Cooper DM, Sly PD, Devadason SG (2006) In vitro evaluation of an asthma dosing device: the smartinhaler. Respir Med 100(5):841–845. https://doi.org/10.1016/j.rmed.2005.09.004
82. Patel M, Pilcher J, Travers J, Perrin K, Shaw D, Black P, Weatherall M, Beasley R (2013) Use of metered-dose inhaler electronic monitoring in a real-world asthma randomized controlled trial. J Allergy Clin Immunol Pract 1(1):83–91. https://doi.org/10.1016/j.jaip.2012.08.004
83. O'Connor SL, Bender BG, Gavin-Devitt LA, Wamboldt MZ, Milgrom H, Szefler S, Rand C, Wamboldt FS (2004) Measuring adherence with the Doser CT in children with asthma. J Asthma 41(6):663–670
84. Julius SM, Sherman JM, Hendeles L (2002) Accuracy of three electronic monitors for metered-dose inhalers. Chest 121(3): 871–876. https://doi.org/10.1378/chest.121.3.871
85. Apter AJ, Tor M, Feldman HI (2001) Testing the reliability of old and new features of a new electronic monitor for metered dose inhalers. Ann Allergy Asthma Immunol 86(4):421–424. https://doi.org/10.1016/S1081-1206(10)62488-X
86. Wamboldt FS, Bender BG, O'Connor SL, Gavin LA, Wamboldt MZ, Milgrom H, Szefler SJ, Ikle D, Rand C (1999) Reliability of the model MC-311 MDI chronolog. J Allergy Clin Immunol 104(1):53–57. https://doi.org/10.1016/s0091-6749(99)70113-2
87. Cushing A, Manice MP, Ting A, Parides MK (2016) Feasibility of a novel mHealth management system to capture and improve medication adherence among adolescents with asthma. Patient Prefer Adherence 10:2271–2275. https://doi.org/10.2147/PPA.S115713
88. Chan AHY, Stewart AW, Harrison J, Black PN, Mitchell EA, Foster JM (2017) Electronic adherence monitoring device performance and patient acceptability: a randomized control trial. Expert Rev Med Devices 14(5):401–411. https://doi.org/10.1080/17434440.2017.1322505
89. Jacobson JS, Lieblein A, Fierman AH, Fishkin ER, Hutchinson VE, Rodriguez L, Serebrisky D, Chau M, Saperstein A (2009) Randomized trial of an electronic asthma monitoring system

among New York City children. Am J Manag Care 15(11):809–814
90. Rhee H, Belyea MJ, Sterling M, Bocko MF (2015) Evaluating the validity of an automated device for asthma monitoring for adolescents: correlational design. J Med Internet Res 17(10):e234. https://doi.org/10.2196/jmir.4975
91. Honkoop PJ, Simpson A, Bonini M, Snoeck-Stroband JB, Meah S, Fan Chung K, Usmani OS, Fowler S, Sont JK (2017) MyAirCoach: the use of home-monitoring and mHealth systems to predict deterioration in asthma control and the occurrence of asthma exacerbations; study protocol of an observational study. BMJ Open 7(1):e013935. https://doi.org/10.1136/bmjopen-2016-013935
92. Gibson PG, Powell H (2004) Written action plans for asthma: an evidence-based review of the key components. Thorax 59(2):94–99. https://doi.org/10.1136/thorax.2003.011858
93. Gupta S, Wan FT, Hall SE, Straus SE (2012) An asthma action plan created by physician, educator and patient online collaboration with usability and visual design optimization. Respiration 84(5):406–415. https://doi.org/10.1159/000338112
94. Global Initiative for Asthma. Global strategy for asthma management and prevention (2015)
95. Cazzoletti L, Marcon A, Janson C, Corsico A, Jarvis D, Pin I, Accordini S, Almar E, Bugiani M, Carolei A, Cerveri I, Duran-Tauleria E, Gislason D, Gulsvik A, Jogi R, Marinoni A, Martinez-Moratalla J, Vermeire P, de Marco R, Therapy, Health Economics Group of the European Community Respiratory Health S (2007) Asthma control in Europe: a real-world evaluation based on an international population-based study. J Allergy Clin Immunol 120(6):1360–1367. https://doi.org/10.1016/j.jaci.2007.09.019
96. To T, McLimont S, Wang C, Cicutto L (2009) How much do health care providers value a community-based asthma care program? A survey to collect their opinions on the utilities of and barriers to its uptake. BMC Health Serv Res 9:77. https://doi.org/10.1186/1472-6963-9-77
97. Kouri A, Boulet LP, Kaplan A, Gupta S (2017) An evidence-based, point-of-care tool to guide completion of asthma action plans in practice. Eur Respir J 49(5). https://doi.org/10.1183/13993003.02238-2016
98. Pearce G, Parke HL, Pinnock H, Epiphaniou E, Bourne CL, Sheikh A, Taylor SJ (2016) The PRISMS taxonomy of self-management support: derivation of a novel taxonomy and initial testing of its utility. J Health Serv Res Policy 21(2):73–82. https://doi.org/10.1177/1355819615602725
99. Brozek JL, Bousquet J, Agache I, Agarwal A, Bachert C, Bosnic-Anticevich S, Brignardello-Petersen R, Canonica GW, Casale T, Chavannes NH, Correia de Sousa J, Cruz AA, Cuello-Garcia CA, Demoly P, Dykewicz M, Etxeandia-Ikobaltzeta I, Florez ID, Fokkens W, Fonseca J, Hellings PW, Klimek L, Kowalski S, Kuna P, Laisaar KT, Larenas-Linnemann DE, Lodrup Carlsen KC, Manning PJ, Meltzer E, Mullol J, Muraro A, O'Hehir R, Ohta K, Panzner P, Papadopoulos N, Park HS, Passalacqua G, Pawankar R, Price D, Riva JJ, Roldan Y, Ryan D, Sadeghirad B, Samolinski B, Schmid-Grendelmeier P, Sheikh A, Togias A, Valero A, Valiulis A, Valovirta E, Ventresca M, Wallace D, Waserman S, Wickman M, Wiercioch W, Yepes-Nunez JJ, Zhang L, Zhang Y, Zidarn M, Zuberbier T, Schunemann HJ (2017) Allergic Rhinitis and its Impact on Asthma (ARIA) guidelines-2016 revision. J Allergy Clin Immunol 140(4):950–958. https://doi.org/10.1016/j.jaci.2017.03.050
100. Cvetkovski B, Kritikos V, Yan K, Bosnic-Anticevich S (2018) Tell me about your hay fever: a qualitative investigation of allergic rhinitis management from the perspective of the patient. NPJ Prim Care Respir Med 28(1):3. https://doi.org/10.1038/s41533-018-0071-0
101. Tan R, Cvetkovski B, Kritikos V, O'Hehir RE, Lourenco O, Bousquet J, Bosnic-Anticevich S (2019) Identifying an effective mobile health application for the self-management of allergic rhinitis and asthma in Australia. J Asthma:1–12. https://doi.org/10.1080/02770903.2019.1640728
102. Ljungberg H, Carleborg A, Gerber H, Ofverstrom C, Wolodarski J, Menshi F, Engdahl M, Eduards M, Nordlund B (2019) Clinical effect on uncontrolled asthma using a novel digital automated self-management solution: a physician-blinded randomised controlled crossover trial. Eur Respir J 54(5). https://doi.org/10.1183/13993003.00983-2019
103. Davis SR, Peters D, Calvo RA, Sawyer SM, Foster JM, Smith LD (2019) A consumer designed smartphone app for young people with asthma: pilot of engagement and acceptability. J Asthma:1–9. https://doi.org/10.1080/02770903.2019.1680997
104. Guan Z, Sun L, Xiao Q, Wang Y (2019) Constructing an assessment framework for the quality of asthma smartphone applications. BMC Med Inform Decis Mak 19(1):192. https://doi.org/10.1186/s12911-019-0923-8
105. Walsh JC, Corbett T, Hogan M, Duggan J, McNamara A (2016) An mHealth intervention using a smartphone app to increase walking behavior in young adults: a pilot study. JMIR Mhealth Uhealth 4(3):e109. https://doi.org/10.2196/mhealth.5227
106. van Genugten L, Dusseldorp E, Webb TL, van Empelen P (2016) Which combinations of techniques and modes of delivery in internet-based interventions effectively change health behavior? A meta-analysis. J Med Internet Res 18(6):e155. https://doi.org/10.2196/jmir.4218
107. Dailah H, Brettle A, Ormandy P (2019) A self-management education programme for adults with asthma. Clin Med (Lond) 19(Suppl 3):42. https://doi.org/10.7861/clinmedicine.19-3-s42
108. Kokubu F, Suzuki H, Sano Y, Kihara N, Adachi M (1999) Telemedicine system for high-risk asthmatic patients. Arerugi 48(7):700–712
109. Naka F, Lu J, Porto A, Villagra J, Wu ZH, Anderson D (2018) Impact of dermatology eConsults on access to care and skin cancer screening in underserved populations: a model for teledermatology services in community health centers. J Am Acad Dermatol 78(2):293–302. https://doi.org/10.1016/j.jaad.2017.09.017
110. Davalos ME, French MT, Burdick AE, Simmons SC (2009) Economic evaluation of telemedicine: review of the literature and research guidelines for benefit-cost analysis. Telemed J E Health 15(10):933–948. https://doi.org/10.1089/tmj.2009.0067
111. de la Torre-Diez I, Lopez-Coronado M, Vaca C, Aguado JS, de Castro C (2015) Cost-utility and cost-effectiveness studies of telemedicine, electronic, and mobile health systems in the literature: a systematic review. Telemed J E Health 21(2):81–85. https://doi.org/10.1089/tmj.2014.0053
112. Aoki NDK, Fukui T, Beck JR, Schull WJ, Li HK (2004) Cost-effectiveness analysis of telemedicine to evaluate diabetic retinopathy in a prison population. Diabetes Care 27:1095–1101
113. Rachapelle SLR, Alavi Y, Lindfield R, Sharma T, Kuper H, Polack S (2013) The cost-utility of telemedicine to screen for diabetic retinopathy in India. Ophthalmology 120:566–573
114. Jackson KM, Scott KE, Graff Zivin J, Bateman DA, Flynn JT, Keenan JD, Chiang MF (2008) Cost-utility analysis of telemedicine and ophthalmoscopy for retinopathy of prematurity management. Arch Ophthalmol 126(4):493–499. https://doi.org/10.1001/archopht.126.4.493
115. van Os-Medendorp H, Koffijberg H, Eland-de Kok PC, van der Zalm A, de Bruin-Weller MS, Pasmans SG, Ros WJ, Thio HB, Knol MJ, Bruijnzeel-Koomen CA (2012) E-health in caring for patients with atopic dermatitis: a randomized controlled cost-effectiveness study of internet-guided monitoring and online

self-management training. Br J Dermatol 166(5):1060–1068. https://doi.org/10.1111/j.1365-2133.2012.10829.x

116. Lokkerbol J, Adema D, Cuijpers P, Reynolds CF 3rd, Schulz R, Weehuizen R, Smit F (2014) Improving the cost-effectiveness of a healthcare system for depressive disorders by implementing telemedicine: a health economic modeling study. Am J Geriatr Psychiatry 22(3):253–262. https://doi.org/10.1016/j.jagp.2013.01.058
117. Pyne JM, Fortney JC, Tripathi SP, Maciejewski ML, Edlund MJ, Williams DK (2010) Cost-effectiveness analysis of a rural telemedicine collaborative care intervention for depression. Arch Gen Psychiatry 67(8):812–821. https://doi.org/10.1001/archgenpsychiatry.2010.82
118. Crow SJ, Mitchell JE, Crosby RD, Swanson SA, Wonderlich S, Lancanster K (2009) The cost effectiveness of cognitive behavioral therapy for bulimia nervosa delivered via telemedicine versus face-to-face. Behav Res Ther 47(6):451–453. https://doi.org/10.1016/j.brat.2009.02.006
119. Mistry H, Gardiner HM (2013) The cost-effectiveness of prenatal detection for congenital heart disease using telemedicine screening. J Telemed Telecare 19(4):190–196. https://doi.org/10.1258/jtt.2012.120418
120. Kildemoes HW, Kristiansen IS (2004) Cost-effectiveness of interventions to reduce the thrombolytic delay for acute myocardial infarction. Int J Technol Assess Health Care 20(3):368–374. https://doi.org/10.1017/s0266462304001205
121. Agha Z, Schapira RM, Maker AH (2002) Cost effectiveness of telemedicine for the delivery of outpatient pulmonary care to a rural population. Telemed J E Health 8(3):281–291. https://doi.org/10.1089/15305620260353171
122. Greiwe J (2019) Using telemedicine in a private allergy practice. J Allergy Clin Immunol Pract 7(8):2560–2567. https://doi.org/10.1016/j.jaip.2019.07.012
123. Scott Kruse C, Karem P, Shifflett K, Vegi L, Ravi K, Brooks M (2018) Evaluating barriers to adopting telemedicine worldwide: a systematic review. J Telemed Telecare 24(1):4–12. https://doi.org/10.1177/1357633X16674087