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Digital technologies for monitoring and improving treatment adherence in children and adolescents with asthma: A scoping review of randomised controlled trials

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Abstract

Background: Inadequate paediatric asthma care has resulted in potentially avoidable unplanned hospital admissions and morbidity. A wide variety of digital technologies have been developed to help monitor and support treatment adherence for children and adolescents with asthma. However, existing reviews need to be updated and expanded to provide an overview of the current state of research around these technologies and how they are being integrated into existing healthcare services and care pathways.
Objective: The purpose of this scoping review is to provide an overview of the current research landscape and knowledge gaps regarding the use of digital technologies to support the care of children and adolescents with asthma.
Methods: The review was structured according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) and Population, Intervention, Comparator, Outcome, and Study (PICOS) frameworks. Five databases (PubMed, the Cochrane Central Register of Controlled Trials (CENTRAL), Web of Science, EMBASE, and PsycINFO) were systematically searched for studies published in English from 2014 on. Two reviewers independently screened the references and selected studies for inclusion based on the eligibility criteria. Data was systematically extracted per research questions, which were synthesised in a descriptive analysis.
Results: A wide variety in study characteristics - including the number and age of participants, study duration, and type of digital intervention - was identified. There was mixed evidence for the effectiveness of the interventions; 7 of the 10 studies that evaluated treatment adherence found improvements, but the evidence was inconsistent for asthma control (6/9 reported improvement or maintenance, but only one was significantly different between groups) and health outcome variables (5/9 found no evidence of effectiveness). The 6 studies that examined patient perceptions and assessments of acceptability and usability had generally positive findings.
Conclusions: A wide range of different digital interventions are being developed and evaluated to support the monitoring and treatment adherence of children and adolescents with asthma. Meta-analyses are inhibited by the use of samples with a variety of overlapping age ranges; a theoretical framework for evaluating specific age groups would aid comparison between studies. Most studies found significant evidence for improved adherence to treatment or medications, but there was mixed evidence of the impact of the digital interventions on asthma control and other health outcomes. There are gaps in the literature relating to cost-effectiveness and integration with existing clinical care pathways; this research will be necessary to determine which digital interventions for children and young people with asthma are worth supporting and adopting in the clinical care pathways.

Keywords

Asthma (MeSH); Disease Management (MeSH); Child (MeSH); Adolescent (MeSH); Telemedicine (MeSH)

Introduction

Background

Globally, asthma is the most common chronic illness affecting children [1–3] and can have serious health consequences. It is one of the key causes of urgent hospital admissions and morbidity in children [3,4]. This is a particularly urgent problem in the UK: out of all the Organisation for Economic Co-operation and Development (OECD) countries, the UK has the third highest risk of death due to paediatric asthma [3,4]. Although specific data is not available for many countries, asthma has high costs worldwide [5]. The variation of mortality across countries suggests that many of the negative outcomes of childhood asthma - for patients and healthcare systems - are potentially avoidable [6]. Effective management programs are likely to be a cost-effective means of improving asthma control and reducing economic burden across countries by enabling early and preventive measures to be taken [5].

A growing number of digital technologies are being developed to help self-management of people with asthma [7–9]. Broadly, digital technologies are electronic systems that can collect, analyse, and share data; common examples include mobile or web applications, smart devices, and other phone or internet-based interventions. Some evidence suggests that digital interventions can help support asthma health management, particularly by improving medication adherence [10,11]. However, other results, particularly in terms of effectiveness (depending on the outcome examined) [9] and app quality [8], are mixed. Research has also identified limitations in the studies examining these interventions, including inadequate descriptions of the digital interventions, a lack of economic analyses, and small sample sizes [10,12].

For digital interventions to be effective, people need to be willing to use them. While digital interventions have been shown to be generally acceptable to the wider population [11], special consideration is needed when evaluating digital interventions for children and young people. Adolescents are a particularly challenging group to treat; poor health literacy and self-management skills can affect their treatment adherence and health outcomes [2]. Attitudes towards electronic monitoring devices were found to be mixed in adolescents, depending on how they perceived the intervention [13]. Among those who viewed asthma as a serious threat, the monitoring device was viewed as reassuring. However, many adolescents were suspicious of the device, reporting concerns that it would get them in trouble if they didn't not adhere properly to their medication and beliefs that their healthcare providers did not trust them to take the medication [13]. This demonstrates the need to examine digital interventions tailored specifically at children and young people, as their needs and responses to the interventions may not be the same as the general population.

Rationale

Although several systematic reviews have examined various topics related to digital interventions for asthma management, there is a need for a comprehensive overview of the evidence being gathered to assess the effectiveness of a variety of types of digital interventions for children and young people with asthma. No previous reviews have been identified that are specific to this population but broad in terms of the digital interventions examined.

Of the systematic reviews that have focused specifically on children and young people, scope was limited either with respect to outcome (e.g. a focus on treatment adherence [14]) or type of digital technology (e.g. only mobile apps [10] or smart devices [15]). One review did provide a comprehensive assessment of other systematic reviews [12]. However, this review was published in 2014; given the rapid evolution of digital technology [16], the state of the field has changed since the review was conducted. For instance, electronic inhaler monitoring is a relatively new development [17,18], with smart inhalers only recently becoming commercially available [19]. Another review analysed studies of children with a wide range of outcomes - adherence, health outcomes, and user perceptions - but only searched PubMed and EMBASE databases were searched for the study, which raises the concern that some relevant studies might have been missed [9]. To determine if any relevant reviews were in progress, PROSPERO was searched using several combinations of keywords ("asthma" and "child" OR "paediatric" OR "pediatric" and "digital OR technology OR mHealth OR eHealth"). These searches identified one relevant registration: a review that was planned, but not executed, by academics associated with the current research team [20].

No reviews were found that examined how the technologies are integrated into current clinical care pathways for children and adolescents with asthma. This is an important area to examine, because digital technologies can provide healthcare professionals with a large body of information that enables them to personalise asthma care plans and focus on preventative measures [21]. A small study of American physicians identified a mix of perceived benefits, barriers, and concerns about integrating digital technologies in asthma care for adolescents [22]. , Further research is needed into how digital interventions are currently integrating with healthcare services [21] to inform the development of integrated clinical care pathways. An overview of the different types of digital technologies and the different ways they are being integrated with healthcare systems will help to inform the development of effective, technologically enhanced care pathways for children with asthma.

Objectives and Research Questions

The primary objectives of the scoping review were to assess and summarize the current state of the literature on digitally enhanced asthma care for young people and to identify any gaps [23]. Three research questions were developed to focus the review:

1. How are randomised controlled trials of technologically supported asthma pathways being conducted?
2. What is known about the effectiveness of digital technologies to support treatment adherence and remote symptom monitoring in children and adolescents?
3. How are studies examining the integration of digital technology into clinical care pathways for paediatric asthma?

Methods

The review was structured following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR; Appendix A) [24] and the search strategy was developed using the Population, Intervention, Comparator, Outcome, and Studies (PICOS) framework (see Table 1). No protocol was registered or published for this review. A preliminary review of the literature was used to extract MeSH terms and keywords for the search. The search was performed in five databases (PubMed, the Cochrane Central Register

of Controlled Trials (CENTRAL), Web of Science, EMBASE, and PsycINFO) using the University of Plymouth's search tool Primo, with slightly adjusted search terms to fit the specific structure of each database. The search terms were grouped into four themes joined in this structure: asthma (MeSH OR Keywords) AND asthma management (MeSH OR Keywords) AND children (MeSH OR Keywords) AND digital technology (MeSH OR Keywords). Appendix B lists a complete record of the specific search terms and strings used for each database and the number of references returned. The database searches were completed on 30 December 2020, except for the CENTRAL database, which was searched on 31 December 2020.

Table 1. PICOS framework

Population	Children and young people under 18 years old with asthma
Intervention	Any digital health technology aiming to support monitoring or treatment adherence of children and adolescents with asthma
Comparator	No comparator is required
Outcome	The primary outcome was the evidence for the digital interventions at improving monitoring or treatment adherence. Secondary outcomes included how the research was conducted, evidence for improved health outcomes, cost-effectiveness, and integration of the technology with healthcare systems.
Study types	Randomised controlled trials that evaluate at least one digital technology to support the care of children with asthma.

Inclusion criteria

The review included studies evaluating digital technologies that aim to support the monitoring or treatment adherence of children and adolescents under 18 years old with asthma. Digital technologies included, but were not limited to, mobile or web applications, smart devices, and other phone or internet-based interventions. Initially, randomised controlled trials (RCTs), quantitative, qualitative, cohort, and case study types were eligible for inclusion. Given the number of studies identified, only RCTs were included in the review. As the scope of the review was focused on assessing evidence of the effectiveness of digital technologies for asthma monitoring and treatment adherence, it was appropriate to limit the included studies to randomised controlled trials that can evaluate effectiveness.

Exclusion criteria

Studies with adult participants were excluded during screening, and studies that only included adults were excluded during full text review. Studies published before 2014 were excluded to limit the review to current technologies. Studies that merely describe an intervention without evaluating it were excluded. Studies that are published in languages other than English were also excluded, as the review team did not have the necessary resources to assess them.

Screening and Article Selection

References were exported to the citation management software EndNote X9 for storage and duplicate removal. Due to the large number of references returned, an initial screening was conducted by inputting keywords relating to the inclusion and exclusion criteria into the EndNote X9 search function. This was done in several stages, with each subsequent screening being conducted on the subset of studies retrieved in the previous stage. For example, keywords relating to digital technologies were searched for in any field, and studies that did not contain at least one of those keywords were excluded. Subsequent searches used keywords to exclude studies that used terms unrelated to the topic (e.g. cancer, diabetes, enzyme, etc.). Appendix C contains a full description of the searches conducted. Searches of keywords to exclude were based on common features of irrelevant studies that were identified in a manual search. The remaining titles and abstracts were screened by two reviewers (MMI and CL) independently(with articles excluded with reasons), and final eligibility was determined by full-text reviews of the remaining references. Any discrepancies that arise between the reviewers were discussed until consensus was reached.

Data Extraction

Outcomes were extracted by the reviewer (MMI) into a table structured according to the three research questions (see Appendix D) and verified by a second reviewer (CL). Key outcomes were pre-determined based on a preliminary review of the literature; however, because of the expected variety of reported outcomes, relevant outcomes that were not pre-specified in the PICOS or data extractions tables were also considered for inclusion in the final review.

Table 2. Article information and data extraction

Article information	**Data to be extracted**
General study information	
	Year of publication
	Sample size
	Age of participants
Digital technology	
	Type of digital technology
	Healthcare setting used in
Evaluation	
	Effect of technology on behavioural outcomes (e.g. medication adherence, symptom monitoring and reporting, etc.)
	Effect of technology on health outcomes

	Cost-effectiveness of the intervention
	Integration of the technology with a health system / care pathway
	Participant perceptions
	Acceptability
	Usability
	Other key performance indicators reported

Data Analysis and Synthesis

The data extracted from the studies about the key outcomes listed in Table 2 were assessed using a descriptive analysis and summarised to provide an overview of the state of the literature. For the outcomes relating to effectiveness, the number of studies that found strong evidence of effectiveness was compared to the number of studies that assessed that outcome to provide a synthesis of the state of the evidence for that outcome. Implications of the findings were examined in the discussion.

Results

Included Studies

6,314 articles were retrieved from the search of the five databases (see Appendix B). 1,029 duplicates were removed by the EndNote X9 software, and a further 5,193 were screened out using keyword searches in EndNote (see Appendix C). The titles and abstracts of 92 studies were screened and articles were excluded with reasons. Of these articles, 25 were selected for the full-text review, and 20 were selected for inclusion in the review. Six of the references referred to one study and were either conference abstracts or did not include the final results of the randomised controlled trial. The paper with published results of the RCT of that study was identified and included [25]. Three references that only provided abstracts subsequently had full texts identified; these full texts were cited and used for data extraction and analysis. The reasons for exclusion in the full-text review stage are detailed in Figure 1.

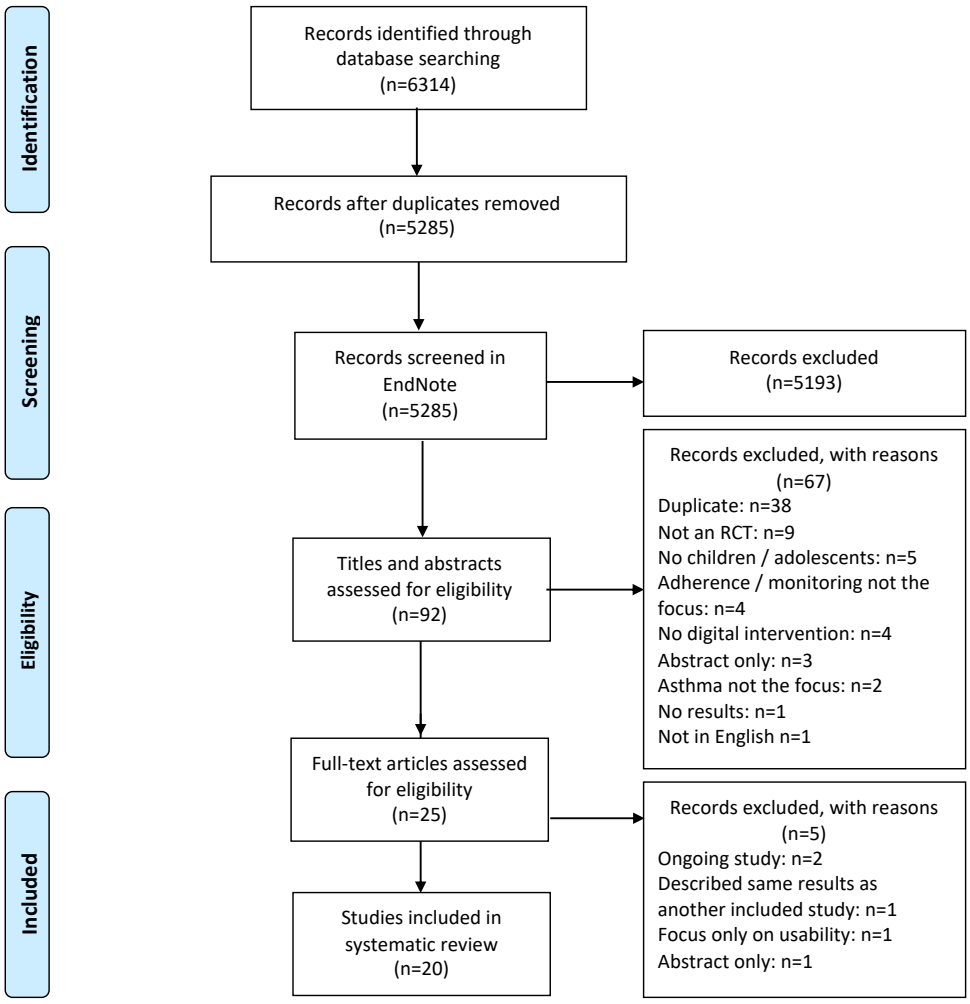

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram

Study Characteristics

All the studies included in the review were randomised controlled trials (RCTs) and were limited to those that included monitoring or adherence functions and aims. Despite these restrictions to the scope of the review, the included studies had a wide variety of study durations, sample sizes, age ranges, and types of digital intervention (see Table 3 for a summary).

Over a third of the references identified as eligible during title and abstract screening only had abstracts available (7/20) [26–32]. They were included in the analysis where relevant data was available; one of the abstracts only presented interim results [26]. Full texts were found for 3 of these 7 references [27,30,32] and data from those papers was used. Four studies were analysed by nine separate articles and abstracts: the ADolescent Adherence Patient Tool (ADAPT) study [25,33,34], a study comparing web-ACT and FENO monitoring with standard care [35,36], a study of inhaler electronic monitoring devices (EMDs) with audiovisual reminders [37,38], and a study of a real-time medication monitoring (RTMM) device with SMS reminders [28,39].

There was a wide range in study durations, from 3 weeks [40] to 24 months [41], with the most common length of follow-up being 6 or 12 months (n=4 [25,31,33,34,37,38,42] and n=3 studies [27,28,35,36,39] for each). There was also a wide range of numbers of participants included in the 15 studies, ranging from 22 [30] to almost 1200 [41], with an average of approximately 230 participants and a median of 209 [28,39].

There were no distinctive categories of ages that emerged from the studies. Of the 15 distinct studies, only two pairs used the same age range (4-11 years old [28,39,43] and 6-16 years old [27,32]). Three studies included adult participants as well as child or adolescent participants [26,29,42]. The youngest participants included in a study were 3 years old [41]. Of the studies that focused on participants under 18, the span of ages eligible for inclusion in each study ranged from 6 years (ages 12-17 [40]) to 15 years (ages 4-18 [35,36]).

4 studies took place across multiple centres [26,28,32,35,36,39], and most of the rest were associated with large medical centres [40–43] or clinics [27,31]. The remaining 5 studies recruited from or were associated with a hospital emergency department [37,38], community pharmacies [25,33,34], outpatient appointments in a hospital or Asthma Clinic [30], Howard University [29], and impoverished, rural school districts [44].

Table 3. Summary of study characteristics

First author [citation]	**Year**	**Study duration**	**Number of participants**	**Age of participants (years)**	**Type of digital intervention**
Beerthuizen [35]	2016	12 months	272 (280 enrolled)	4-18	Web-based monitoring
Bender [41]	2015	24 months	1187	3-12	Speech recognition automated telephone program
Britto [42]	2017	6 months	64	12-22	Text message reminders
Chan [37]	2015	6 months	220	6-15	Inhaler electronic monitoring device (EMD) with audiovisual reminders
Chan [38]	2017				
Goossens [28]	2014	12 months	209	4-11	EMD with text messages
Johnson [40]	2016	3 weeks	98	‘Adolescents’	Website and text-based reminder system (MyMediHealth)
Kosse [25]	2019	6 months	234 (66 pharmacies)	12-18	App (ADolescent Adherence Patient Tool; ADAPT)
Kosse [33]	2019				
Kosse [34]	2019				
Merchant [26]	2014	100 days	368 (490 enrolled)	5-80	EMD with feedback and educational content
Morton [27]	2017	12 months	77 (90 enrolled)	6-16	EMD with alarms and feedback
Perry [44]	2018	3 months	393	7-14	School-based educational telemedicine intervention
Real [43]	2019	4 months	40	4-11	Gamified app (CHANGE Asthma)

Reece [29]	2017	4 months	48	13-60	App (AsthmaWin)
Shields [30]	2017	12 weeks	22	2-16	Mobile directly observed therapy (MDOT)
Simoneau [31]	2019	6 months	43	8-17	EMD with reminders
van den Wijngaart [32]	2017	16 months	210	6-16	Web-based monitoring (Virtual Asthma Clinic)
Vasbinder [39]	2016	12 months	209	4-11	EMD with text messages
Voorend-van Bergen [36]	2015	12 months	268 (280 enrolled)	4-18	Web-based monitoring

Types of Digital Interventions

Several different types of digital interventions for monitoring and/or improving medication adherence were examined in the studies included in this review (summarised in Table 3). The most common type of intervention, evaluated by a third of the studies (5/15), was EMDs. However, these EMDs all varied on their features, which included: audiovisual reminders [37,38], text messages [28,39], alarms [27], and app or online sources that could be synced to provide personal feedback [26,27], educational content [26], reminders [31], and capture adherence data [31].

Apps were another common intervention evaluated; three studies specifically evaluated 3 different app-based interventions. These included the ADolescent Adherence Patient Tool (ADAPT) app that connects adolescents to their community pharmacist through a desktop application and enables them to monitor symptoms and adherence, chat with peers and their pharmacist, watch short educational movies, and set medication alarms [25,33,34]. Another app, CHANGE Asthma, was developed for children by five pediatricians and modified based on feedback from a pilot of 24 caregivers. It uses short videos and games and an asthma action plan to improve asthma knowledge and control [43]. The third app evaluated (AsthmaWin) also included an asthma action plan but focused more on monitoring symptoms and medication adherence [29].

Other types of interventions evaluated included web-based monitoring programs [35,36] (one of which was a component of a Virtual Asthma Clinic [32]), a speech recognition automated telephone program to improve medication adherence [41], text message medication reminders [42], a website and text-based reminder system (MyMediHealth) [40], a remote directly observed therapy (R-DOT) tool to improve inhaler use and adherence [30], and a school-based educational telemedicine intervention that provided interactive video sessions for children, caregivers, and school nurses [44].

Evidence of Effectiveness

Several different outcome measures were used by the studies to evaluate the interventions, but results about effectiveness were inconsistent. Outcome with the highest proportion of studies finding a significant, positive effect was for improving medication

adherence. The reported effectiveness of interventions and improving asthma control and health outcomes was very mixed. Patient feedback regarding acceptability and usability was generally high.

Treatment or Medication Adherence

10 studies evaluated the effectiveness of their intervention at improving treatment or medication adherence. Over two thirds (7/10) reported significantly higher adherence in the intervention group compared to the control group [25,27,28,31,37,39–41]. Of the remaining three studies, one reported higher adherence in the intervention group compared to the control group but no analysis of significance was provided [44] and one reported a trend towards improvement over time [30]. The final study, which evaluated a SMS reminder system, found a decline in adherence over the intervention and control periods in both groups [42].

3 of the 6 studies that found a significant difference in adherence between groups evaluated EMDs [28,31,37,39]. The others evaluated the speech recognition automated telephone program [41], the website and text-based reminder system (MyMediHealth) [40], and the ADAPT app [25].

Only one study each evaluated the effectiveness of improving inhaler use and symptom monitoring, both of which found improvements. Shields et al. found that R-DOT improved inhaler technique equally in immediate and delayed intervention groups [30]. Perry et al. found significantly higher self-reports of peak flow meter use in the intervention group compared to the control group [44].

Asthma Control and Healthcare Visits

There were very mixed results in the nine studies that evaluated asthma control as an outcome. Four of the nine studies found either no effect of the intervention on asthma control [25,26,39] or no significant difference between groups [43]. However, Real et al. did find an significant positive association between degree of app use and asthma control [43].

Another four studies reported improved asthma control in the intervention group compared to the control group [27,29,30,32], although only one of these studies demonstrated statistical significance [32]. One of the other studies analysed the two groups together and reported a significant improvement of asthma control over time [30]. The final study found that asthma control could be maintained after a clinically relevant reduction in inhaled corticosteroids in the web-based monitoring condition [35,36].

Only two studies evaluated the effect of the intervention on healthcare visits, but neither found any differences [32,41].

Health and Quality of Life Outcomes

The overall effect of digital interventions on health outcomes is also unclear. Five of the nine studies that evaluated health outcomes (including quality of life or symptom free days) found no significant improvement [25,27,28,35,36,39,44]. However, three studies reported significant improvements in self-reported quality of life [40], asthma morbidity scores [37], and number of symptom free days [32]. One study reported significant improvement of parents' self-reported quality of life over time and a non-significant trend towards improvement of the children's quality of life [30].

Patient Perceptions, Acceptability, and Usability

Six studies examined outcomes related to patient perceptions, acceptability, or usability. These all reported generally high satisfaction and acceptability [33,34,38,40], a desire to continue using the intervention [29,31], or positive feedback [30].

Cost-effectiveness

Only one study (two articles) explicitly assessed cost-effectiveness [28,39]. The authors found that costs were higher in the intervention group, and although this difference was not statistically significant [39], the technology was deemed not cost-effective because it was not associated with significant improvements in health outcomes [28]. Upon closer inspection of reported mean adjusted costs per patient, whilst the hospital costs in the intervention arm is lower, the medication cost and parental production loss due to absence from paid work to care for child have been calculated to be higher by 16% and 141.8% respectively [28]. One other study discussed the potential cost savings but did not analyse them as part of the study [27].

Integration with clinical care pathways

Half of the studies included in the review (8/15, or 10 of the 20 articles) did not explicitly discuss how the digital intervention they were evaluating was integrated with clinical care pathways [28–31,37–40,42,43]. There were a few studies that described sending data from the interventions back to physicians to update the patients' health records or inform care, although this potential would likely be feasible for many of them. For the few that did, integration of the intervention with the healthcare system was generally reported positively.

Even among those that did describe a specific link between the intervention and the healthcare system, the specific details about integration were not a primary focus of the paper. For instance, one study noted that the intervention was built into routine clinical care in the study and described how data could be uploaded to a website for patients, parents/carers, and clinicians to review adherence data together at appointments [27]. Some of the studies that monitored symptoms or adherence produced treatment advice based on data analysis from the system algorithms [35,36], sent physicians warnings if a patient was out of a certain threshold [26]. The Virtual Asthma Clinic, which also sent feedback to physicians if a patient's asthma control scores were low, was found to be successful at increasing asthma control and symptom-free days and was proposed by the authors as a partial replacement for outpatient visits [32]. Details of how these systems were integrated with the healthcare system were not described.

One study whose intervention was significantly integrated with the healthcare system was the ADAPT app study [25,33,34]. One of the aims of the intervention was to increase collaboration and communication between adolescents and pharmacists because of the increasing role of pharmacists as healthcare providers in the Netherlands [25]. Pharmacists involved in the intervention reported valuing the improved contact with patients and found the intervention satisfactory, useful in fulfilling their role, and not time-consuming [34]. This contrasted with the perceptions of pharmacists who did not participate in the intervention, who identified time constraints as a barrier to the use of mHealth [34]. However, a barrier was identified because the ADAPT app's 'stand-alone' desktop interface for pharmacists was not integrated with the pharmacy's general information system [34]. This study highlights the potential value of deliberate and considered efforts to integrate new digital health technologies for asthma management with existing health systems.

The speech recognition telemedicine intervention was another study that demonstrated integration with the healthcare system: the telemedicine system was integrated with the hospital's electronic health record (EHR; EpicCare) to provide personalised calls to patients and is compatible with all standard EHR systems [41].

The attempt of one study [44] to involve primary care providers in the intervention was not successful. Treatment prompts with medication recommendations based on caregiver reports and guidelines were provided to the participants' primary care providers. These were found to be ineffective; of the 141 prompts sent out for individual participants, the request for feedback received a response from only one primary care provider [44].

Discussion

Summary of Findings

There was a lot of variety in the studies examined in this review; study duration ranged from 3 weeks to 2 years, the number of participants ranged from 22 of 1187, and - although the review was focused on children and adolescents - there was a wide range of ages studied, with no distinct age groups emerging from the studies. There were also several different types of digital interventions analysed in the RCTs, with electronic monitoring devices and mobile apps the most common. Moreover, the integration of these technologies with existing clinical care pathways and health systems was not extensively discussed in most studies.

The review found inconsistent evidence for the effectiveness of the digital technologies at achieving their various aims. The most support was found for the effectiveness of the interventions at improving treatment or medication adherence (7/10 studies found significant evidence of effectiveness). The results of studies assessing the impact of the intervention on asthma control and health outcomes were mixed, with some studies reporting positive effects and others no significant effect. Across the studies, evaluations of patient perceptions, acceptability, and usability were generally positive. Only one study evaluated the cost-effectiveness of these solutions, but due to insignificant improvement in health outcome, the intervention was not found to be cost-effective [28].

Limitations

One limitation of this review is that a risk of bias assessment was not performed on the studies. While this is not a standard requirement for scoping reviews, it is a limitation of the study, as it would have contributed to the assessment of the first research question by providing an analysis of the quality of the research being conducted on technologically supported asthma pathways.

Another limitation is that the research questions and aims were adjusted after the search had been performed. They were changed before any screening or selection took place but may have resulted in relevant articles being missed because the search terms were established for a slightly different scope. Because of time limitations, no hand searches of the references of reviews retrieved in the initial search were performed, which also could have resulted in eligible articles being overlooked.

Meaning and Future Research

The large number of studies identified in the initial search and the variety of technological interventions to support paediatric asthma care demonstrate the broad scope of this research area. This review identified few strong trends with regards to how technologically supported asthma pathways for children and young people are being researched. The studies used a large range of sample sizes and participants of varying ages, which makes it difficult to make valid comparisons or conduct meta-analyses across different studies. A theoretical framework for determining what ages to study or how to stratify children and young people into age groups would therefore be useful for the future. Currently, there is no consensus in the literature on how to group children of various ages for research, which is a significant limitation in the field.

This review found that there are a wide variety of different digital interventions being explored. Although many of the studies examined reported positive results, strong evidence of their effectiveness at achieving various aims is still lacking. The strongest evidence was for improving treatment and medication adherence. However, the more mixed evidence of asthma control, health, and quality of life outcomes suggests that there might be a disconnect between the behaviour change and the health outcome. With asthma being a long-term condition, the study duration of included studies (from 3 weeks to 24 months) may not be long enough to observe significant health impacts; or maybe there are other factors influencing the relationship between treatment adherence and health outcomes (e.g. technique). Understanding why this discrepancy was observed could help inform the design of more effective digital interventions and better study designs.

Another notable area that was missing from many of the studies was an assessment of the cost-effectiveness of the intervention. Considering that a key aim of many digital health technologies is to reduce burden on healthcare systems by improving patient self-management, the benefit and cost of the intervention compared to the current standard of care is essential in the decision to integrate digital interventions into clinical care pathways. This will be a key area for future evaluations of these technologies to consider, so that limited healthcare resources can be deployed to create the greatest value [45].

The overall findings are generally consistent with the previous reviews described in the introduction. Collectively, they identified at least some evidence of benefits (depending on outcomes) of various digital health technologies on asthma-related outcomes [9-12,14]. One review also noted a lack of data about the cost-effectiveness of the digital asthma self-management interventions and patient perspectives [12]. This is also consistent with this review; patient perspectives were generally high when reported but were only examined in about a quarter (6/20) of the included studies.

Another key area for future research will be around the integration of these digital solutions into clinical pathways. As with cost-effectiveness, this review found that most studies did not explicitly consider or evaluate how the technology they were examining would interact with existing health systems. The potential benefit of integrating patient-reported data with patients' health records to inform care plans and pathways is likely feasible for many of the technologies assessed but was not examined as a key outcome of the technology. Acceptability and usability data likewise focused primarily on patient users. Understanding how these technologies can best support and interact with existing clinical pathways could help to inform their design, improvement, and sustainable adoption.

Conclusion

The purpose of this scoping review was to summarise the state of the literature on technologically enhanced asthma care pathways for children and young people. A large body of research is ongoing in this area and spans a wide range of technologies and ages. Although there was some evidence found for the effectiveness of the digital interventions examined - particularly for improving treatment and medication adherence - further research is needed to establish the effectiveness of the interventions at improving asthma control and other health outcomes. This apparent discrepancy between significant evidence for behaviour change and a lack of significant evidence for subsequent health impacts should be further examined, as it could indicate factors other than treatment adherence that affect health outcomes and could also be targeted for intervention. A couple of gaps in the literature were identified around cost-effectiveness and integration with existing care pathways. Both of these aspects are essential for the successful adoption, scale-up, and sustained use of digital health interventions and are key areas for future research.

Author Contributions

IW conceived the key research questions. JG and KH developed and submitted the previous PROSPERO registration that was used as the basis for the protocol. The scoping review was executed by MMI and CL and drafted by MMI with revisions from CL and EM.

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Appendices

Appendix A. PRISMA-ScR Checklist

Appendix B. Search record

Database	Search String	Articles
PubMed	((asthma[MeSH Terms]) OR (Asthma[Title/Abstract] OR wheez*[Title/Abstract] OR dyspnea[Title/Abstract] OR cough*[Title/Abstract] OR (chest ADJ2 tight*)[Title/Abstract] OR "shortness of breath"[Title/Abstract])) AND ((Drug Therapy OR Medication Adherence OR Patient Compliance OR Treatment Adherence and Compliance OR Self-Management OR Disease Management OR Patient Education OR Patient Care Management[MeSH Terms]) OR (Self-management[Title/Abstract] OR "self care"[Title/Abstract] OR "self-care" [Title/Abstract] OR "disease management"[Title/Abstract] OR (medication[Title/Abstract] OR treatment[Title/Abstract] OR drug[Title/Abstract] OR patient ADJ3 adherence[Title/Abstract] OR compliance[Title/Abstract] OR persistence)[Title/Abstract] OR "patient education"[Title/Abstract] OR (treatment[Title/Abstract] OR care[Title/Abstract] OR action[Title/Abstract] OR asthma ADJ2 plan)[Title/Abstract] OR engagement[Title/Abstract] OR asthma control[Title/Abstract])) AND ((Adolescent OR Adolescent Health OR Child OR Child Health OR Pediatrics OR Family[MeSH Terms]) OR (Pediatric*[Title/Abstract] OR paediatric*[Title/Abstract] OR child[Title/Abstract] OR children[Title/Abstract] OR kid[Title/Abstract] OR kids[Title/Abstract] OR teen[Title/Abstract] OR teens[Title/Abstract] OR adolescen*[Title/Abstract] OR family[Title/Abstract] OR youth[Title/Abstract] OR "young people"[Title/Abstract] OR "young person"[Title/Abstract])) AND ((Cell Phone OR Telemedicine OR Computers OR Computers, Handheld OR Internet OR Internet-based Intervention OR Mobile Applications OR Internet of Things[MeSH Terms]) OR ("mHealth"[Title/Abstract] OR "mobile health"[Title/Abstract] OR "eHealth"[Title/Abstract] OR ((mobile[Title/Abstract] OR phone[Title/Abstract] OR smartphone[Title/Abstract] OR cell) ADJ3 "app" OR "apps" OR "application*")[Title/Abstract] OR web[Title/Abstract] OR internet[Title/Abstract] OR online intervention[Title/Abstract] OR web-based intervention[Title/Abstract] OR digital intervention[Title/Abstract] OR virtual[Title/Abstract] OR web[Title/Abstract] OR "smart device*"[Title/Abstract] OR "IoT"[Title/Abstract] OR "internet of things"[Title/Abstract] OR "smart inhaler*"[Title/Abstract] OR monitor*[Title/Abstract] OR wearable[Title/Abstract]))	2,858
Cochrane Central Register of	#1 MeSH descriptor: [Asthma] explode all trees #2 MeSH descriptor: [Drug Therapy] explode all trees #3 MeSH descriptor: [Patient Compliance] explode all trees	755

Controlled Trials (CENTRAL)	#4	(Asthma OR wheez* OR dyspnea OR cough* OR (chest NEAR/2 tight*) OR "shortness of breath"):ti,ab,kw (Word variations have been searched)	
	#5	MeSH descriptor: [Medication Adherence] explode all trees	
	#6	MeSH descriptor: [Treatment Adherence and Compliance] explode all trees	
	#7	MeSH descriptor: [Self-Management] explode all trees	
	#8	MeSH descriptor: [Disease Management] explode all trees	
	#9	MeSH descriptor: [Patient Education as Topic] explode all trees	
	#10	MeSH descriptor: [Patient Care Management] explode all trees	
	#11	#2 OR #3 OR #5 OR #6 OR #7 OR #8 OR #9 OR #10	
	#12	MeSH descriptor: [Adolescent] explode all trees	
	#13	MeSH descriptor: [Adolescent Health] explode all trees	
	#14	MeSH descriptor: [Child] explode all trees	
	#15	MeSH descriptor: [Child Health] explode all trees	
	#16	MeSH descriptor: [Pediatrics] explode all trees	
	#17	MeSH descriptor: [Family] explode all trees	
	#18	#12 OR #13 OR #14 OR #15 OR #16 OR #17	
	#19	MeSH descriptor: [Cell Phone] explode all trees	
	#20	MeSH descriptor: [Telemedicine] explode all trees	
	#21	MeSH descriptor: [Computers] explode all trees	
	#22	MeSH descriptor: [Computers, Handheld] explode all trees	
	#23	MeSH descriptor: [Internet] explode all trees	
	#24	MeSH descriptor: [Internet-Based Intervention] explode all trees	
	#25	MeSH descriptor: [Mobile Applications] explode all trees	
	#26	MeSH descriptor: [Internet of Things] explode all trees	
	#27	#19 OR #20 OR #21 OR #22 OR #23 OR #24 OR #25 OR #26	
	#28	(Self-management OR "self care" OR "self-care" OR "disease management" OR (medication OR treatment OR drug OR patient NEAR/3 adherence OR compliance OR persistence) OR "patient education" OR (treatment OR care OR action OR asthma NEAR/2 plan) OR engagement OR asthma control):ti,ab,kw	
	#29	(Pediatric* OR paediatric* OR child OR children OR kid OR kids OR teen OR teens OR adolescen* OR family OR youth OR "young people" OR "young person"):ti,ab,kw	
	#30	("mHealth" OR "mobile health" OR "eHealth" OR ((mobile OR phone OR smartphone OR cell) NEAR/3 "app" OR "apps" OR "application*") OR web OR internet OR online intervention OR web-based intervention OR digital intervention OR virtual OR web OR "smart device*" OR "IoT" OR "internet of things" OR "smart inhaler*" OR	

	monitor* OR wearable):ti,ab,kw #31 #1 OR #4 #32 #11 OR #28 #33 #18 OR #29 #34 #27 OR #30 #35 #31 AND #32 AND #33 AND #34 with Publication Year from 2014 to 2020, in Trials	
Web of Science	TS=(Asthma OR wheez* OR dyspnea OR cough* OR (chest NEAR/2 tight*) OR "shortness of breath") AND TS=(Drug Therapy OR Medication Adherence OR Patient Compliance OR Treatment Adherence and Compliance OR Patient Care Management OR Self-management OR "self care" OR "self-care" OR "disease management" OR (medication OR treatment OR drug OR patient NEAR/3 adherence OR compliance OR persistence) OR "patient education" OR (treatment OR care OR action OR asthma NEAR/2 plan) OR engagement OR asthma control) AND TS=(Adolescent OR Adolescent Health OR Child OR Child Health OR Pediatrics OR Family OR Pediatric* OR paediatric* OR children OR kid OR kids OR teen OR teens OR adolescen* OR youth OR "young people" OR "young person") AND TS=(Cell Phone OR Telemedicine OR Computers OR Computers, Handheld OR Internet OR Internet-based Intervention OR Mobile Applications OR "mHealth" OR "mobile health" OR "eHealth" OR ((mobile OR phone OR smartphone OR cell) NEAR/3 app*) OR web OR online intervention OR web-based intervention OR digital intervention OR virtual OR "smart device*" OR "IoT" OR "internet of things" OR "smart inhaler*" OR monitor* OR wearable)	1,505
EMBASE (Ovid)	(asthma/ or (asthma or wheez* or dyspnea or cough* or (chest adj2 tight*) or shortness of breath).ti,ab.) AND (drug therapy/ or medication compliance/ or patient compliance/ or self care/ or disease management/ or patient education/ or (Self-management or self care or self-care or disease management or (((medication or treatment or drug or patient) adj3 adherence) or compliance or persistence) or patient education or ((treatment or care or action or asthma) adj2 plan) or engagement or asthma control).ti,ab.) AND (adolescent/ or adolescent health/ or child/ or child health/ or pediatrics/ or family/ or (Pediatric* or paediatric* or child or children or kid or kids or teen or teens or adolescen* or family or youth or young people or young person).ti,ab.) AND (mobile phone/ or telemedicine/ or computer/ or personal digital assistant/ or Internet/ or web-based intervention/ or mobile application/ or "internet of things"/ or (mHealth or mobile health or eHealth or ((mobile or phone or smartphone or cell) adj3 app*) or web or	1,098

	internet or online intervention or web-based intervention or digital intervention or virtual or web or smart device* or IoT or internet of things or smart inhaler* or monitor* or wearable).ti,ab.)	
PsycINFO (ProQuest)	((ab(Asthma OR wheez* OR dyspnea OR cough* OR (chest NEAR/2 tight*) OR "shortness of breath")) OR (ti(Asthma OR wheez* OR dyspnea OR cough* OR (chest NEAR/2 tight*) OR "shortness of breath"))) AND ((ab(Drug Therapy OR Medication Adherence OR Patient Compliance OR (Treatment NEAR/2 Adherence OR Compliance) OR Patient Care Management OR Self-management OR "self care" OR "self-care" OR "disease management" OR (medication OR treatment OR drug OR patient NEAR/3 adherence OR compliance OR persistence) OR "patient education" OR (treatment OR care OR action OR asthma NEAR/2 plan) OR engagement OR asthma control)) OR (ti(Drug Therapy OR Medication Adherence OR Patient Compliance OR (Treatment NEAR/2 Adherence OR Compliance) OR Patient Care Management OR Self-management OR "self care" OR "self-care" OR "disease management" OR (medication OR treatment OR drug OR patient NEAR/3 adherence OR compliance OR persistence) OR "patient education" OR (treatment OR care OR action OR asthma NEAR/2 plan) OR engagement OR asthma control))) AND ((ab(Adolescent OR Adolescent Health OR Child OR Child Health OR Pediatrics OR Family OR Pediatric* OR paediatric* OR children OR kid OR kids OR teen OR teens OR adolescen* OR youth OR "young people" OR "young person")) OR (ti(Adolescent OR Adolescent Health OR Child OR Child Health OR Pediatrics OR Family OR Pediatric* OR paediatric* OR children OR kid OR kids OR teen OR teens OR adolescen* OR youth OR "young people" OR "young person"))) AND ((ab(Cell Phone OR Telemedicine OR Computers OR (Computer* NEAR/1 Handheld) OR Internet OR Internet-based Intervention OR Mobile Applications OR "mHealth" OR "mobile health" OR "eHealth" OR ((mobile OR phone OR smartphone OR cell) NEAR/3 “app” OR “apps” OR “application*”) OR web OR online intervention OR web-based intervention OR digital intervention OR virtual OR "smart device*" OR "IoT" OR "internet of things" OR "smart inhaler*" OR monitor* OR wearable)) OR (ti(Cell Phone OR Telemedicine OR Computers OR (Computer* NEAR/1 Handheld) OR Internet OR Internet-based Intervention OR Mobile Applications OR "mHealth" OR "mobile health" OR "eHealth" OR ((mobile OR phone OR smartphone OR cell) NEAR/3 “app” OR “apps” OR “application*”) OR web OR online intervention OR web-based intervention OR digital intervention OR virtual OR "smart device*" OR "IoT" OR "internet of things" OR "smart inhaler*" OR monitor* OR wearable)))	98

[a]Web of Science and PsycINFO do not have a specific search for MeSH terms, so all keywords and MeSH terms were included (with exact duplicates removed). In Web of Science, they were searched for in 'Topic', which searches title, abstract, author keywords, and Keywords Plus. In PsycINFO, they were searched for in Title and Abstract.

Appendix C: Endnote search criteria

Pass[a]	Search string	# of references remaining
1	Year = greater than or equal to 2014	5242
2	Title = NOT (review OR protocol OR case OR guideline* OR handbook* OR position paper OR meta-analysis OR conference OR congress)	4402
3[b]	Any Field = Cell Phone OR smartphone OR mobile OR telemedicine OR Internet OR web OR online OR digital OR virtual OR mHealth OR eHealth	1691
4[b]	Any Field = smartphone app* OR phone app* OR mobile app* OR smart device* OR smart inhaler* OR internet of things OR IoT OR wearable OR Title = monitor*	469
5	Pass 3 AND 4 (with duplicates removed)	1892
6	Any Field = asthma NOT (dermatitis OR food allerg* OR sickle cell OR cystic OR cancer OR carcinoma OR diabetes OR pregnan* OR bowel OR virus OR viral)	1119
7	Any Field = NOT (biomarker* OR phenotype* OR genotype* OR genetic* OR agonist* OR enzyme)	966
8	Any Field = NOT (anaphylaxis OR immunotherapy OR influenza OR flu OR vaccine*)	839
9	Title = NOT (adult* OR face mask* OR access OR design OR method OR oscillometry OR FENO OR fractional exhaled nitric oxide OR asthma control assessment)	740
10	Any Field = child* OR teen* OR adolescen* OR youth* OR family OR parent* OR caregiver* OR paediatric* OR pediatric*	702
11	Any Field = NOT (oximetry OR spirometry OR physiotherap* OR phototherap* OR intubation OR injection OR expiratory variability OR breath temperature OR lung sound)	626
12	Any Field = NOT (optic OR ADHD OR eczema OR cardi* OR metabolic OR otitis OR sleep OR diet OR drug misuse OR withdrawal)	544
13	Any Field = NOT (antileukotriene OR inflammatory marker* OR omalzimub OR eosinophil* OR tiotropium), Title = NOT (college OR university OR military OR drug misuse)	528

14	Any Field = NOT (oscillation OR motivational interview* OR body weight OR hair OR claims data OR wikipedia OR environmental factor* OR nutrition OR RSV)	495
15	Any Field = NOT (microbiome OR pathogen* OR bronchiectasis OR vascular disease OR dysplasia OR infection OR tuberculosis OR toxocara OR depression)	471
16	Any Field = NOT (gastro* OR multisystemic OR transport OR forum OR antibiotic OR inpatient OR PM2.5 OR acupuncture OR administration form)	436
17	Any Field = develop* OR creat* NOT (evaluat* OR accept* OR feasibility OR assess* OR pilot OR usability OR test*)	408
18	Any Field = adhere* OR monitor*	262
19	Any Field = randomised control* OR randomized control*	92

[a]Each pass was conducted on the subset of studies retrieved in the previous pass.
[b]EndNote was unable to include all of the search terms at once, so passes 3 and 4 were both conducted on pass 2 and then combined (with duplicates removed) in pass 5

Appendix D. Data Extraction Table

Paper	RQ1. How is research on tech-supported asthma pathways being designed and conducted?	RQ 2. What is known about the effectiveness of tech to support treatment adherence and remote symptom monitoring?	RQ 3. What is the state of knowledge about integrating tech into clinical care pathways?
[35] NOTE: same study as Voorend-van Bergen	- 1 year study, children 4-18, comparing monitoring strategies to adapt care - standard care (ACT once every 4 months) vs monthly web-ACT vs ACT every 4 months + FENO - Recruited by their own paediatrician from general hospitals and tertiary referral centres - Multicentre, prospective, partly blinded, parallel-group, three-arm randomised controlled superiority trial on monitoring strategies in asthmatic children with a follow-up of 1 year	- neither strategy improved symptom free days compared to standard care after 1 year - Monthly web-based ACTs resulted in a clinically relevant decrease of ICS dose, while maintaining asthma control. - FENO group: increase in asthma control in children under 12	-not specifically discussed - both strategies provided in addition to usual care - integrated?
[41]	-24 month study, ages 3-12, computerized speech recognition telephone intervention vs usual care condition - SR program created with parent focus groups, script development, and beta testing - personalised with data from EHR and automated, option to get callback from nurse/pharmacist - study was conducted within Kaiser Permanente Colorado, a large, group-model health maintenance organization	-inhaled corticosteroid adherence was 25.4% higher in the intervention group than in the usual care group (24-month mean [SE] adherence, 44.5% [1.2%] vs 35.5% [1.1%], respectively; $P < .001$) - no differences in healthcare visits - strong potential for low-cost SR adherence programs integrated with an electronic health record	- intervention integrated in addition to usual care - integrated with an electronic health record - more than half of physicians use an EHR and current projections indicate that more than 90% of clinicians will be using an EHR within the decade.[21] Further, the intervention in this study leveraged EpicCare, the most widely used ambulatory care EHR in the United States. The capacity to identify and sort patients by EHR indicators in this project is standard in all EHR

			systems, including eClinicalWorks, McKesson, Cerner, Allscripts, and GE Healthcare
[42]	-64 patients age 12 to 22 years with a diagnosis of poorly controlled persistent asthma in a 6-month longitudinal crossover study - Adherence was objectively monitored in 22 of the participants - participants were given the opportunity to personalize their text message reminders. They could schedule non–asthma medication reminders, appointment reminders, or other messages of their choice	- adherence declined in both groups over the intervention and control periods. This suggests that 3 months of messages did not create a long-term habit of ICS use	- not discussed explicitly - were recruited at clinic visits - should be easy to incorporate alongside standard care
[37]	- patients aged 6–15 years who attended the regional emergency department - followed up every 2 months for 6 months - randomly assigned patients to receive an electronic monitoring device for use with their preventer inhaler with the audiovisual reminder functions either enabled to support adherence to inhaled corticosteroids (intervention group) or disabled (control group)	- Median percentage adherence was 84% (10th percentile 54%, 90th percentile 96%) in the intervention group, compared with 30% (8%, 68%) in the control group ($p<0{\cdot}0001$) - significant improvements in adherence to inhaled corticosteroids in school-aged children with asthma - change in asthma morbidity score from baseline to 6 months was significantly greater in the intervention group than in the control group ($p=0{\cdot}008$) (more reduce in int group)	- Not explicitly discussed
[38]	- Children 6 to 15 years presenting with asthma to the hospital emergency department and prescribed inhaled corticosteroids were included - Device quality control tests were conducted. Questionnaires on device acceptability, utility and ergonomics were completed at six months	- Acceptability scores were high, with higher scores in the reminder than non-reminder group (median, 5th-95th percentile: 4.1, 3.1–5.0 versus 3.7, 2.3–4.8; $p < 0.001$). - Most (>90%) rated the device easy to use. - Feedback was positive across five themes: device acceptability, ringtone acceptability, suggestions for improvement, effect on medication use, and effect on asthma control	- Not specifically discussed

		- failure rates of 13–16% indicate the importance of quality control	
[28] *NOTE: conference abstract only	- multi-center, randomized controlled trial. Included were 209 children (<12 years) with moderate to severe asthma, followed for 12 months - all received a Real-Time Medication Monitoring system, in intervention group it sent texts to parents whose child appeared to miss a dose	- RTMM increases inhalation adherence, but there is no evidence of better health outcomes in this patient population within the first year. In these circumstances, this is not a cost-effective intervention. - Costs were higher in the intervention group	- Not specifically discussed
[40]	- impact of MyMediHealth (MMH) – a website and a short messaging service (SMS)-based reminder system – on medication adherence and perceived self-efficacy in adolescents with asthma - block-randomized controlled study in academic pediatric outpatient settings, 98 adolescents enrolled - MMH users were asked to create a medication schedule and receive SMS reminders at designated medication administration times for 3 weeks	- Compared to controls, we found improvements in self-reported medication adherence (P = .011), quality of life (P = .037), and self-efficacy (P = .016). - Subjects reported high satisfaction with MMH; however, the level of system usage varied widely - significant racial disparity in the rate of MMH adoption	- not specifically discussed
[25]	- Cluster randomized controlled trial in 66 Dutch community pharmacies. - Asthma patients aged 12–18 years were invited to participate, based on pharmacy medication refill records. - 234 adolescents (147 in the control group and 87 in the intervention group) completed the study - The main study outcome was self-reported medication adherence, measured with the Medication Adherence Report Scale (MARS). - Secondary outcomes were asthma control and quality of life. Outcomes were measured at start (t = 0 months) and at the end of follow-up (t = 6 months)	- We did not find an intervention effect in the total study population, i.e., only in non-adherent patients. - there was a positive effect of the intervention on medication adherence (MARS +2.12, p = 0.04). - This effect was stronger (MARS +2.52, p = 0.02) in poor adherent adolescents with uncontrolled asthma (n = 74). - No effect of the intervention was observed on asthma control or quality of life.	- current study used pharmacists as the healthcare provider, because pharmacists are increasingly expected to support appropriate use of medication in integrated care settings - Increased collaborations between pharmacists and physicians may facilitate the identification of uncontrolled patients with low adherence rates.

			- Pharmacists can subsequently support these patients with their medication use, by implementing mHealth interventions. - Adherence could also be measured by using pharmacy refill records. However our study period covered only six months, and in the Netherlands patients usually collect chronic medication once every three months.
[34] *NOTE: same study as above	- explore experiences, barriers, and facilitators of pharmacists and patients towards the use of the interactive ADolescent Adherence Patient Tool (ADAPT) - the perceptions of pharmacists towards mHealth interventions in general were explored - setting: dutch community pharmacies	- Most patients (78%) would recommend the ADAPT intervention to others, and thought that the pharmacy was the right place for mHealth aiming to support adherence (63%). - The possibility to monitor asthma symptoms was highly appreciated by patients and pharmacists. - Pharmacists were satisfied with ADAPT intervention (96%), and using the intervention was not time consuming (91%). - The ADAPT intervention promoted contact with patients (74%) and facilitated the healthcare providing role of pharmacists (83%).	- Providing extra care for patients was one of the main reasons for using mHealth (by both pharmacist groups). - Pharmacists who delivered the ADAPT intervention valued the improved patient contact - Another important facilitator for further implementation is the integration of mHealth in the pharmacy information system, because a 'stand-alone' desktop program restrained the integration with the

			pharmacist's workflow - MHealth interventions can facilitate the pharmacist's responsibilities and promote contact with patients. This is important nowadays, because pharmacists are expected to combine their management role with more healthcare providing roles, and there is an ongoing shift towards integrated care settings
[33] *NOTE: same study as above	- Explore the use and the effective engagement of adolescents (aged 12 to 18 years) with the Adolescent Adherence Patient Tool (ADAPT) - The ADAPT app was connected to a desktop application of the patient's own community pharmacist - included: questionnaire to monitor symptoms, peer and pharmacist chats, medication alarm, short movies, adherence questions	- 86 adolescents (mean age 15.0, SD 2.0 years) used the ADAPT app 17 times (range 1-113) per person. Females used the app more often than males (P=.01) and for a longer period of time (P=.03). - The questionnaires to monitor symptoms and adherence were used by most adolescents. - The total app use did not affect adherence; however, activity in the pharmacist chat positively affected medication adherence (P=.03), in particular, if patients sent messages to their pharmacist (P=.01) - Adolescents have different preferences when using an mHealth app, as there was a wide variety in app usage per person - The questionnaires to monitor asthma symptoms and adherence were used by most adolescents, which provided valuable data for health care providers and	

		patients. Moreover, the use of the pharmacist chat positively affected adherence.	
[26] *NOTE: abstract only, interim results	- intervention: inhaler sensors, personalised feedback and educational content (apps and online interfaces) - control group had sensors only - children and adults (5-80) - 490 enrolled, 368 active/completed at 16 months	- sig diff in rescue inhaler use between groups after 100 days (fewer for int group) -	- physicians could monitor intervention group patients and received proactive warnings if they fall below a threshold
[27] *NOTE: abstract only, interim results	- complex intervention comprising electronic adherence monitoring with feedback and reminder alarms can improve clinical outcomes and adherence in childhood asthma - 90 participants were recruited, 25 have completed study, and 60% of follow-up visits have been completed - Children with asthma in the UK were recruited and followed up in standard clinics for 12 months	- At 12 months, the mean adherence in the intervention arm is currently 83%, compared to 34% in the control arm - The mean number of oral steroid courses in the 12 months is 1.7 in the intervention group and 2.7 in the control group	- not specifically discussed
[44]	- cluster randomized trial with rural children, ages 7–14 years (393 enrolled), comparing a school-based telemedicine asthma education intervention to usual care - Each student participated in five 30–45 minute age-appropriate asthma education sessions via telemedicine (live interactive video) - Telemedicine sessions were also conducted for intervention parents/caregivers and school nurses. Each 60–90 minute session was conducted at the school (local community center on weekend/nights). Caregivers participated in 2 sessions and school nurses participated in 1 session. - Telemonitoring sessions were completed prior to the first child education session and at 3 months. During the session, intervention participants described symptoms for the preceding 2 weeks and completed the PedsQL 3.0 survey	- At the end of the intervention, there were no statistically significant differences in reported symptom free days (primary outcome) for either the intervention or usual care group. - Participants in the intervention group reported significantly higher utilization of peak flow meters to monitor asthma and reported taking their asthma medications as prescribed more frequently when compared to the usual care group. - There were no changes in other outcome measures including quality of life, self-efficacy, asthma knowledge, or lung function between groups - Although there was some evidence of behavior change among intervention participants, these changes were inadequate to	- The Primary Care Provider of each intervention participant received a prompt with guidelines-based asthma management19 at baseline and 3 months. Caregivers and school nurses received copies of the prompt to reinforce recommendations. The prompt included: 1) a summary of education sessions, 2) blank AAP with completion instructions, 3) synopsis of

		overcome the significant morbidity experienced by this highly symptomatic rural, impoverished population.	caregiver-reported symptoms and medications and 4) treatment recommendations according to guidelines.19 For example, if a participant's caregiver reported uncontrolled, recommendations for initiation or step-up of controller therapy were given.19 PCPs received a 7-question survey to confirm receipt of the prompt, verify accuracy of asthma severity and control assessment. We provided a self-addressed stamped envelope to return the survey and phone/fax/mailing contacts for the research team to answer any questions or to receive additional feedback. - Simply providing a treatment prompt to PCPs with medication recommendations was proven to be ineffective.
[43]	- developed and implemented a smartphone application (app) leveraging gamified features entitled CHANGE Asthma ("Clinic, Home, And on the Go Education for Asthma"). We subsequently assessed its impact on asthma control.	- The control and intervention groups both included 20 caregivers with 75% of participants completing follow-up. - Although C-ACT scores among intervention participants	- not discussed

	- Patients aged 4–11 years with a previously documented childhood asthma control test (C-ACT) score of <20, indicating poor control, were recruited - App usage was monitored for 4 months - curriculum iteratively developed by 5 pediatricians and 2 app developers - piloted with caregivers and modified accordingly	significantly improved at follow-up, compared to their own baseline (P = 0.04), the change of C-ACT score did not significantly differ from that of the control group (P = 0.78). - Among the intervention participants, there was a positive, dose-dependent relationship between app usage time and positive change in C-ACT score (P = 0.03).	
[29] *NOTE: abstract only	- AsthmaWin is an iPhone app, developed by CooperSoft Inc. that incorporates a physician-generated asthma action plan & involves daily recording of: (a) peak flow measurements, (b) medication usage—documented with a self-photo, (c) daily symptoms with an automatic reminder to take medications and that can reward completion of data, is intended to enhance patient physician communication - whether the use of this app would improve medication adherence & improve asthma self-management as measured by Asthma Control Test (ACT) scores and peak expiratory flow rate (PEFR) measurements - Forty eight asthmatics, predominantly African American, 13-60 years old were recruited from the Howard University Faculty Practice Plan -	- Documented daily use of the Asthma Action plan leads to improvement in ACTs. PEFRs and medication adherence. Focus groups indicated patient willingness to use the app on an ongoing basis to assist in asthma management and an unwillingness to continue paper journaling. - Reported controller medication usage was 86% among app users and 90% in the paper group. ACT scores in the app group improved by a mean of 3.8 points and by 2.4 points in the paper group. PEFRs improved an average of 9.09% in the app group and 7.82% in the paper group.	- not discussed, although enhanced communication was an aim
[30]*NOTE: abstract only	- determine if remote directly observed therapy (R-DOT) could monitor adherence and inhaler technique in children with Difficult to Treat Asthma (DTA) - pilot study: 22 children (aged <15 yrs) with DTA were randomised to either immediate R-DOT for 6 weeks or delayed entry (R-DOT after 6 weeks) and asthma control was assessed at 12 weeks. - mobile phone platform was used to record and send a short video clip (timed and dated, twice a day) of children using their inhaler. The videos were reviewed by a nurse and if needed the child/parent was provided with reminders/re-instruction	- Despite all children being able to demonstrate good inhaler technique at study entry, 80% were deemed not to have good inhaler technique while using R-DOT at home during the first week. - By the end of the 3rd week after nurse led re-instructions all children had good inhaler technique. Both groups improved equally. - R-DOT can test for and improve inhaler technique and monitor adherence and can be used to ensure that a period of	- not discussed in abstract, but intervention required nurse involvement

		optimised therapy has been delivered in DTA. The approach is not device specific and can be used with any type of inhaled therapy. - Engagement with the process was generally good although cases of non-adherence with video uploads included living with a different parent at weekends, life too busy and mobile phone memory issues	
[31] *NOTE: abstract only	- 8-17 years, 43 enrolled - Breathe Smart EMD, one each for rescue and controller inhalers - synced with mobile app, sends reminders and captures adherence data	- adherence based on pharmacy records after 3 months was significantly greater in int group than control, equal to mean adherence captured by EMD - 83% desired to continue using EMD - however, adherence in both groups still low	- not discussed
[32] *Abstract only	- multicentre, randomised controlled trial with a 16-month follow-up, 210 asthmatic children (6–16 years) treated in eight Dutch hospitals were randomised to usual care (4-monthly outpatient visits) and online care using a virtual asthma clinic (VAC) (8-monthly outpatient visits with monthly web-based monitoring) - In between VAC visits, asthma control was monitored online, filling in a (C-)ACT monthly. - If the (C-)ACT score was ≥20, automatic default messages were emailed with positive and encouraging content. - If the (C-)ACT score was <20, feedback to the participants included advice to check their medication use, an individual action plan and a request to contact their asthma team when symptoms persisted. - In addition, feedback was sent to the asthma team with the request to contact the participant within 2 working days to address the clinical condition of that moment.	- After follow-up, symptom-free days differed statistically between the usual care and VAC groups (difference of 1.23 days, 95% CI 0.42–2.04; p=0.003) in favour of the VAC. In terms of asthma control, the Childhood Asthma Control Test improved more in the VAC group (difference of 1.17 points, 95% CI 0.09–2.25; p=0.03). No differences were found for other outcome measures.	- Routine outpatient visits can partly be replaced by monitoring asthmatic children via eHealth. - physicians contacted if issues identified - demonstrates that eHealth using the VAC can substitute 50% of routine outpatient visits in paediatric asthma care while the number of SFDs improved significantly after a 16-month follow-up
[39] *NOTE same as	- multicentre, randomised controlled trial, 209 children (aged 4–11 years) using ICS	- Mean adherence was higher in the intervention group: 69.3%	- not discussed

Goosens study	were recruited from five outpatient clinics and were given an real-time medication monitoring (RTMM) device for 12 months - The intervention group also received tailored SMS reminders, sent only when a dose was at risk of omission	versus 57.3% (difference 12.0%, 95% CI 6.7%–17.7%). - No differences were found for asthma control, quality of life or asthma exacerbations. - Costs were higher in the intervention group, but this difference was not statistically significant	
[36]	- multicentre trial with a 1-year follow-up, children aged 4–18 years with a doctor's diagnosis of asthma treated in seven hospitals were randomised to one of the three groups. In the web group, treatment was adapted according to ACT obtained via a website at 1-month intervals; in the FENO group according to ACT and FENO, and in the SC group according to the ACT at 4-monthly visits - 280 included, 268 completed	- change from baseline in symptom-free days did not differ between monitoring strategies. With web-based ACT monitoring, ICS could be reduced substantially while control was maintained.	- treatment was adapted monthly according to the web-based ACT score, while in the FENO group, treatment was adapted to FENO and ACT score at clinic visits every 4 months - The treating physicians were blinded to randomisation group, FENO and ACT. The local investigators, unblinded to ACT and FENO, provided the physicians with treatment advice based on the study algorithms and on the treatment plan - Physicians could deviate from this advice for documented clinical reasons only.