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Systematic Review of Digital Interventions for Pediatric Asthma Management

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Abstract

Background: Pediatric patients with asthma only take approximately half of their prescribed medication. Digital interventions to improve adherence for youth with asthma exist and have the potential to improve accessibility, cost-effectiveness, and customizability.

Objective: To systematically review published research examining digital interventions to promote adherence to the treatment of pediatric asthma.

Methods: A systematic search of PubMed, Scopus, CINAHL, PsycINFO, and reference review databases was conducted. Articles were included if adherence was an outcome in a randomized controlled trial of a digital intervention for children with asthma. We compared samples, intervention characteristics, adherence measurement and outcomes, as well as additional health outcomes across studies.

Results: Of the 264 articles reviewed, 15 studies met inclusion criteria and were included in the review. Overall, 87% of the digital interventions demonstrated improved adherence and 53% demonstrated improved health outcomes. All of the promising interventions included a behavioral component and the majority were 3-6 months in length, delivered through a digital stand-alone medium (e.g., automated personalized texts, mobile health apps, website), and assessed adherence to controller medication.

Conclusions: Overall, digital interventions aimed at improving adherence are promising and also improve health outcomes in addition to medication adherence. Although future studies using evidence-based adherence assessment and multi-factorial design should be conducted, the current

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literature suggests that both digital stand-alone interventions and interventions combining digital technology with support from a healthcare team member result in improved adherence and asthma outcomes. Recommendations for digital interventions for pediatric asthma patients with adherence concerns are provided.

Keywords

Asthma; adherence; self-management; digital intervention; mHealth; internet; mobile health

Introduction

Despite the importance of daily preventative medication to decrease airway inflammation, up to 70% of pediatric patients with asthma are nonadherent to their prescribed medical treatments.(1-14) Suboptimal management of pediatric asthma often leads to increased illness exacerbations, health care utilization, and missed days of school.(15, 16) Barriers to pediatric asthma management often include individual factors (e.g., forgetting, medication beliefs, depressive symptoms), social context factors (e.g., socioeconomic status, race/ethnicity, family functioning), and patient-provider communication factors (e.g., limited discussions about medication, language barriers).(17, 18)

Face-to-face, in-person, interventions have been designed to promote adherence and self-management for youth with asthma. These interventions have demonstrated effectiveness by improving adherence to medication, lung function, self-efficacy, and school attendance as well as decreasing activity limitations and emergency department visits.(19-22) Effective interventions have also been implemented in individual patients, families, or groups of patients across various settings (e.g., home, school, clinic).(22) However, there are often significant barriers to implementing these face-to-face interventions. Several barriers to patient medication adherence are also barriers to patient and family participation and engagement in in-person pediatric asthma management interventions. For example, transportation barriers may prevent a family from obtaining refills and may also make appointment attendance difficult. In addition, patient and family access to in-person interventions is often limited by health care systems factors, including provider characteristics (e.g., inadequate training to address nonadherence) and logistical barriers (e.g., clinic hours/locations, time constraints preventing conversations about nonadherence), all of which have also been documented as barriers to adherence in pediatric asthma.(17) Additionally, these interventions are often labor intensive and not easily translated to large clinical settings.

Over the past decade digital interventions utilizing technology aimed at improving adherence including text messaging, mobile health apps, and interactive websites have increasingly been developed and tested. Digital interventions are effective for increasing asthma knowledge, reducing activity limitations, improving self-management (e.g., use of action plans, self-efficacy), improving quality of life, and optimizing medication use.(23) There are several advantages to digital interventions for youth with asthma including accessibility, cost-effectiveness, and customizability.(20) Youth with asthma express preferences for digital health interventions to support their asthma management(24-27) and

value digital technology that allows them to track asthma symptoms and medications, set medical reminders, and receive asthma knowledge related to medications and action plans. (28) In turn, providers are increasingly recommending that pediatric patients utilize digital interventions to enhance self-management. (29)

Given the advantages of using digital technology in youth with asthma and the increase in the quantity and breath of digital asthma interventions, the present paper aims to systematically review digital interventions designed to promote adherence to the treatment of pediatric asthma. In addition to assessing the overall efficacy of digital adherence-promotion interventions for youth with asthma, this review will also examine the intervention components, digital mediums, and adherence assessment measures utilized in the digital interventions.

Methods

Initial Search

A systematic review of the literature was completed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) reference standards. (30) The search examined the following electronic databases: PubMed, EBSCO, and Scopus and the search strategy can be found in Figure 1. Titles and abstracts were limited to those focusing on humans and published in English. The search was initially conducted in May 2018 and updated in January 2019 to ensure the most up-to-date data for this manuscript. The original search was not limited by age to ensure that studies including a wide age range or multiple age groups were not missed; however, only articles whose population included children up to 18 years of age were reviewed.

To be included in the analysis, a study had to meet the following criteria: (1) conducted in an asthma population, (2) included primarily children or adolescents, (3) included a randomized controlled trial of a digital intervention, (4) examined adherence as a primary or secondary outcome. All types of intervention studies across a variety of health care, community, and home settings that incorporated a digital intervention were included. Both national and international studies written in English were included.

To ensure that no digital intervention studies were missed, review articles of asthma interventions in this age group and their references were reviewed. References of the included studies were reviewed as well. Unpublished data, abstracts, and dissertations were excluded from analyses.

Article Selection

Title and abstract reviews were completed by the authors (JMP, RG, SK, RRR). Articles were excluded if they were not asthma-focused, included primarily participants older than 18 years of age, or did not include an RCT of a digital intervention. If this information was not obvious from the title or abstract review, the full-text article was reviewed. Study authors independently reviewed each of the remaining full-text articles. The final inclusions were then further reviewed and finalized by the first author to ensure that all criteria were adequately met.

Grouping of Intervention Studies

For each article, the sample size, patient population, length of intervention, intervention components, digital medium, adherence behavior and method of measurement, adherence-specific outcomes, and additional health-related outcomes were summarized. For the purposes of this review, we have categorized adherence as a primary outcome even if adherence was a secondary outcome in the original manuscript.

Results

Database searching identified 264 articles. Once duplicates were removed, abstracts and/or full texts were reviewed for inclusion criteria, fifteen reports describing 15 unique studies and 3,739 participants ($M_{\text{sample size}}$ = 249.27, SD = 287.49) with pediatric asthma were included in the current review (Figure 2). Details from these studies can be found in Table 1. Patients between the ages of 0 and 59 years were included in these studies. Six studies (40%) included only young children under the age of 12 years(31-36) and seven studies (47%) included children between 6 and 22 years of age(37-43). Control groups included usual care (n = 13, 87%), education only (n = 1, 6.5%), and attention control (n = 1, 6.5%) conditions.

Intervention Characteristics

Interventions lasted between three weeks and 24 months with the majority (n = 9, 60%) of interventions lasting between three and six months. Four interventions (27%) included post-intervention follow-up measures of adherence(35, 41, 43, 44), one of which only obtained post-intervention measures of adherence for a sub-set of participants(41) and one of which offered access, but not incentive, to utilize the intervention during the post-intervention follow-up period(35). All 15 of the interventions included a behavioral intervention component. Forty percent of the studies (n=6) included only behavioral strategies while the remaining nine interventions featured the following additional component(s): education (n=7, 47%), family therapy (n=3, 20%), social support (n=3, 20%), cognitive-behavioral (n=2, 13%), health-care system (n=2, 13%), and organizational (n=1, 6.5%).

Intervention Digital Medium

Ten interventions (67%) were delivered via a digital stand-alone medium indicating that healthcare providers were not required for the intervention to be delivered (Table 1, Digital Stand Alone section).(32, 35-38, 41-45) Five studies (50%) delivered the intervention via automated personalized text messages(37, 41, 43-45), two (20%) utilized an interactive website or mobile health app (e.g., Health Buddy)(35, 38) and one (10%) study provided adherence reminders via electronically-triggered speech recognition phone calls.(36)

Five studies (33%) used a combination of digital technology and health care team member to deliver the intervention (Table 1, Combination section).(31, 33, 34, 39, 40) Three of the five studies (60%) utilized an interactive website plus phone follow-up with the medical team (e.g., nurse care management, physician).(33, 34, 40) One study (20%) utilized a smart nebulizer and an app by which physicians monitored adherence and communicated with

families when necessary.(31) A final study (20%) provided participants with motivational digital recordings by physicians in conjunction with weekly in-person support groups.(39)

Adherence Behavior and Measures

Adherence was measured in several different ways within the included studies. Most of the studies (n=10, 67%) assessed adherence to controller inhalers, while three studies (20%) measured overall medication adherence, and two studies (13%) measured medication acquisition (medication possession ratios from pharmacies). Electronic monitoring of medication taking, the gold standard for measuring adherence to medication,(46) was utilized to assess controller inhaler adherence in six of the studies (40%).(31, 32, 37, 39-41) Two of these studies, however, only examined adherence in a subset of their sample.(40, 41) Seven studies (47%) assessed adherence through self-report, three of which used evidence-based self-report assessments including the Morisky Medication Adherence Scale (MMAS(47))(45) or daily diaries,(33, 34) and four of which assessed adherence with a single item.(35, 38, 42, 44)

Adherence Effectiveness

Improvements in adherence were documented in thirteen (87%) of the fifteen studies.(31-38, 40-42, 44, 45) Specifically, ten studies (67%) demonstrated that adherence was significantly better in the intervention group compared to the control group at post intervention.(31, 32, 34-38, 40, 42, 44) Three studies (20%) demonstrated improvement in adherence in the intervention group compared to baseline, but did not significantly differ from the control group.(33, 41, 45) Five studies (33%) did not include a baseline measure of adherence(31, 32, 34, 36, 43) preventing pre-post comparisons of adherence. Two studies (13%) demonstrated no improvement in adherence post-intervention(39) and at post-intervention follow-up.(43, 48) Only one of the four studies that documented adherence after a post-intervention follow-up period demonstrated significantly improved adherence (10%) compared to the control group after 6 and 9 months.(44) Two of the studies assessing adherence at follow-up did not demonstrate sustain improvements in adherence over 3 months(41) or 6 month(35) while the final study assessing adherence at follow-up did not demonstrates a significant increase in adherence at post-intervention(43).

Additional Health Outcomes

Eight of the digital interventions (53%) reviewed also demonstrated potential for improving health outcomes in addition to adherence. Five interventions (33%) improved asthma control/reduced exacerbation,(31, 33, 34, 37, 43) four interventions (27%) improved quality of life,(34, 41-43) three (20%) decreased healthcare utilization,(31, 38, 43) two (13%) improved lung function,(34, 38) two (13%) decreased activity limitation,(38, 43) and one (6.5%) reduced the number of missed school/work days.(43)

Discussion

National guidelines and task forces have identified adherence to medications as an essential component of asthma clinical care and self-management. This systematic review sought to evaluate published literature examining digital interventions which aim to improve

adherence in children with asthma to highlight specific components of successful adherence-promotion interventions that can be incorporated into both future research and pediatric clinical practice. Although previous reviews(22, 23, 49, 50) have commented on the promise of the use of digital technologies to improve adherence in asthma, they have not focused on randomized controlled trials in children and adolescents specifically, nor have they examined specific components (e.g., behavioral) and mediums (e.g., digital stand-alone) of effective interventions from a multi-disciplinary perspective. Nearly all of the included interventions(31-38, 40-42, 44, 45) yielded significant improvements in adherence and a majority of the interventions demonstrated additional significant improvements in health outcomes such as asthma control, quality of life, and healthcare utilization suggesting that digital interventions are promising. The variability in the included studies' aims and outcomes of the extant literature did not allow for a quantitative examination (i.e., meta-analysis) of the studies; therefore, this review followed PRISMA guidelines for systematic reviews to provide a comprehensive review of the efficacy as well as the characteristics, components, and delivery mediums for these digital interventions and was conducted by a multi-disciplinary team of experts.

All the interventions reviewed utilized behavioral strategies delivered via digital technologies; however, the specific intervention characteristics, behavioral strategies, components, and delivery mediums varied widely across studies. Similar to previous adherence intervention meta-analyses documenting that multi-component interventions may be the most effective,(51) many of the digital interventions utilized multiple components with education being the most common additional component. The types of digital mediums used varied widely across the included studies; interventions utilized personalized text messaging, websites, apps, digital recordings and speech recognition phone calls. Personalized text messaging was the most common intervention and typically included automated messages (i.e., standardized messages sent at the same time every day regardless of whether medication had already been taken),(41, 44, 45) though several studies utilized text messaging in response to missed doses (e.g., text messages sent at 8:30 if the 8:00 dose has been missed).(32, 37) This type of text messaging may prevent "reminder burnout" that often comes with daily automated text messages and may continue to improve adherence, or at least allow for maintained adherence gains over time. Existing digital mediums allow for delivery of multi-component interventions and can include mechanisms for behavioral strategies (e.g., symptom logging, adherence monitoring, educational strategies (e.g., informational videos, learning modules), and others (e.g., family and provider portals) supporting the promise of these digital interventions.

Although most interventions in this review utilized only digital mediums to deliver interventions (i.e., digital stand-alone interventions), several of the interventions combined a digital intervention with interactions with medical professionals. Based on the studies reviewed, it is unknown whether the inclusion of contact with a medical professional is a crucial intervention component, or whether including medical professionals promotes engagement with the intervention and in turn improves outcomes. The inclusion of medical professional interaction certainly has the potential to increase engagement; however, it also likely increases the cost of the intervention. Given that both digital stand-alone and combination interventions yielded positive adherence and health outcomes, it will be

important for future research to conduct larger trials with multifactorial and cost-effectiveness analyses to assess the benefit of including interactions with medical professionals in adherence interventions. It may also be advantageous and cost-effective to examine stepped-care intervention systems that deliver digital stand-alone interventions initially and then “step-up” patients who do not improve to combination interventions with additional support.

One concern with the state of the digital intervention literature in pediatric asthma is the way in which adherence behaviors have been measured. First, only four studies utilized electronic monitoring of adherence - the gold standard in adherence measurement - and only an additional three studies utilized an evidence-based assessment of adherence. The remaining eight studies assessed adherence through non-evidence-based assessments (e.g., 1-item questions, researcher-developed questionnaires) or distal adherence proxies (e.g., medication possession ratios). Objective monitoring of adherence via electronic monitoring is the most accurate method of measuring adherence as youth and families tend to overestimate their adherence via subjective measures(52-55). Second, five of the studies did not assess baseline adherence and therefore were unable to assess treatment effects on change in adherence or control for baseline adherence in the final analyses. Without baseline adherence assessment, the conclusion that differences in adherence due to treatment effects (and not baseline differences) cannot be made. Last, only four studies measured adherence after a post-intervention follow-up period, two of which did not collect this data systematically across all participants. Of these studies, only 3 digital interventions demonstrated significant improvements in adherence post-intervention and adherence improvements were only sustained at follow-up for one of these studies. This is comparable to rates of post-intervention follow-up in adherence interventions across pediatric chronic conditions(19) Post-intervention follow-up is critical to assessing long-term efficacy of an intervention. Advances in technology, including electronic monitoring, have made passive, objective data collection feasible and therefore should be utilized across digital adherence interventions to assess baseline and long-term adherence in pediatric asthma.

Given adolescents’ preferences for using technology to improve adherence, clinicians may consider recommending digital tools to patients and families in the context of clinical care. Although there remains a need for larger randomized controlled trials with consistent adherence baseline and outcome measurement, the state of the current literature suggests that both digital stand-alone intervention and interventions combining digital technology with support from a healthcare team member are promising. If staff support allows, placing a referral for or implementing interventions combining digital technologies with medical staff follow-up based on symptoms or medication adherence may increase engagement and improve adherence. For practitioners in busy clinics with less staff support, digital stand-alone interventions are likely more feasible. Specifically, recommending that patients and families set electronic reminders or use an app to track medication use and asthma symptoms are excellent steps towards improving patient adherence using digital stand-alone interventions. Ratings of asthma management apps based on the inclusion of behavioral strategies and app quality are available(56) and can be used to “prescribe” self-management apps for children with asthma. In addition to considering behavioral strategies, physicians

and nurses should provide additional digital asthma and asthma treatment education to those patients and families struggling with adherence and self-management.

Conclusions

Overall, digital interventions to promote asthma management in youth demonstrate promise and warrant further testing in rigorous controlled trials. Digital interventions demonstrated improvements in adherence, as well as health outcomes such as improved asthma control, quality of life, and healthcare utilization. Specifically, randomized controlled trials with evidence-based adherence assessment (e.g., electronic monitoring, evidence-based self-report, persistence data) and rigorous baseline and post-intervention follow-up assessments of adherence with large samples (n >100) and robust control groups should be conducted to strengthen the evidence for digital interventions as a whole. In addition, studies should further examine various digital intervention mediums (apps, social media, text messaging) to assess the effectiveness and engagement of youth with asthma to determine the level of intervention and human interaction that is both necessary and optimal for improved, long-term adherence.

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Highlights Box

What is already known about this topic?

Digital interventions improve asthma self-management in adults and have the potential to improve adherence to asthma treatment in children and adolescents. Youth prefer digital health interventions and providers are increasingly recommending them to patients.

What does this article add to our knowledge?

Overall digital interventions improve adherence and health outcomes in pediatric asthma. Results across digital mediums inform future research of digital interventions to improve asthma management and provide recommendations for practitioners with nonadherent pediatric asthma patients.

How does this study impact current management guidelines?

Given the promising evidence for digital interventions in pediatric asthma, practitioners should support the use of evidence-based behavioral strategies to improve asthma management and health outcomes by recommending digital technologies and providing asthma education.

PubMed Search Strategy: (((((("Computer-Assisted Instruction"[Mesh] OR "software"[MeSH Terms] OR "Cell Phone"[Mesh] OR "Text Messaging"[Mesh] OR "Smartphone"[Mesh] OR "Computers, Handheld"[Mesh] OR "Telemedicine"[Mesh] OR "Social Media"[Mesh] OR "Mobile Applications"[Mesh] OR "social media"[tiab] OR "mobile phone"[tiab] OR "mobile app"[tiab] OR software[tiab] OR smartphone[tiab] OR "smart phone"[tiab] OR "mobile application"[tiab] OR telemedicine[tiab] OR telehealth[tiab] ORinter "cell phone"[tiab] OR "cellular phone"[tiab] OR "text messaging"[tiab] OR "mobile application"[tiab] OR "computer assisted instruction"[TIAB])) AND ("Asthma"[Mesh] OR asthma[tiab])) AND ("Self Care"[Mesh] OR "self care"[tiab] OR "self management"[tiab] OR "Treatment Adherence and Compliance"[Mesh] OR adherence[tiab]))) AND ((infant OR child OR adolescent OR pediatric)))) AND english[filter].

Scopus Search Strategy: (TITLE-ABS-KEY ("computer assisted instruction" OR "social media" OR "mobile phone" OR "mobile app" OR software OR smartphone OR "smart phone" OR "mobile application" OR telemedicine OR telehealth OR "cellular phone" OR "cell phone" OR "text messaging" OR "mobile application") AND TITLE-ABS-KEY (asthma) AND TITLE-ABS-KEY ("self care" OR "self management" OR adherence)) AND (TITLE-ABS-KEY (infant OR child OR adolescent OR pediatric)) AND (LIMIT-TO (LANGUAGE , "English"))

Searched simultaneously via EBSCO: CINAHL (via EBSCO), PsycINFO, Education Research Complete, ERIC, Psychology and Behavioral Sciences Collection, Sociological Collection

Figure 1. Search Strategy Text Box
describing the search strategy implemented to execute this systematic review.

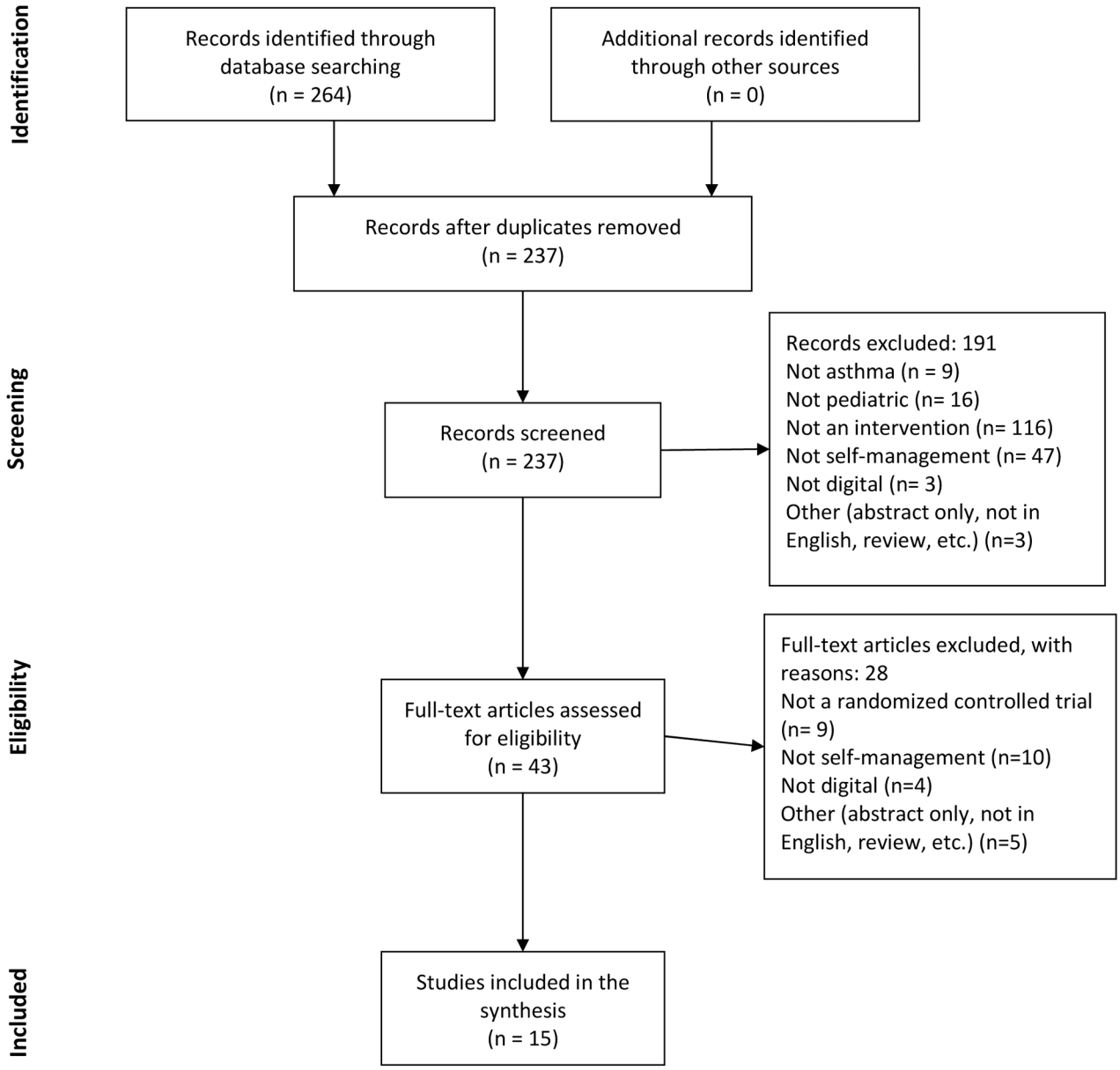

Figure 2. The PRISMA four-phase flow diagram
detailing study selection.

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Table 1.

Characteristics of Included Studies

	Author (year)	*n*	Patient ages (range)	Length of Intervention, Follow-up (FU)	Intervention Components	Intervention Medium	Adherence Behavior	Adherence Measure	Adherence Results	Additional Outcomes
Digital Stand Alone	Bender (2015)	1187	Ages 3-12	24 months	B, E, H, F	Automated telephone calls triggered when ICS refill was overdue per medical record	Proportion of days covered by controller inhaler	Medication possession ratio	**24 month mean adherence was 44.5% in the intervention group compared to 35.5% in the control group**	Healthcare utilization, Patient satisfaction
	Britto (2017)	64	Ages 12-22	3 months FU: 6 months for select participants	B, O	Personalized scheduled text messages	Controller inhaler	Electronic monitoring	**Receiving the texting intervention resulted in an increase of adherence by 2.75% each month relative to controls,** improvements did not sustain at 6 months	Asthma control, Feasibility and acceptability, Quality of life[≠]
	Chan (2015)	220	Ages 6-15	6 months	B	Electronic monitor with audiovisual reminders, can prevent reminder by taking early/on-time	Controller inhaler	Electronic monitoring	**Median adherence was 84% in the intervention group vs. 30% in the control group**	Asthma control [≠], Healthcare utilization, Lung function, Missed school/work
	Christakis (2012)	603	Ages 2-10 years	6 months FU: 12 months	B, C, F	Assessment and feedback via an interactive website	Controller inhaler	Self-report 1 question Likert scale "How many days did you use controller medication?"	**Significantly better adherence at 6 month in intervention group (69% at baseline vs 76% at 6 months) compared to control group (69% at baseline vs 63% at follow-up)**; For patients with persistent asthma, no differences at baseline (69.4% vs 67.36%) but intervention arm had better adherence than those in control arm at 6 months (77%vs 50%); No difference in adherence rates between groups at 12 months	Asthma control
	Guendelman (2002)	134	Ages 8-16 years	12 weeks	B	Interactive web-based device providing questions and information	Overall medication adherence	Self-report 1 item Likert scale takes asthma medication without reminder	**Caregivers reported that significantly more children in the intervention groups took their asthma medications with few or no reminders (74%) compared to those in the control group (50%) at 12 weeks**	Activity limitation[≠], Healthcare utilization[≠], Lung function[≠], Perceived symptoms, Missed school/work

	Author (year)	*n*	Patient ages (range)	Length of Intervention, Follow-up (FU)	Intervention Components	Intervention Medium	Adherence Behavior	Adherence Measure	Adherence Results	Additional Outcomes
	Johnson (2016)	89	Ages 12-17	3 weeks	B	Interactive website and text message reminders	Controller inhaler	Self-report number of days adherent out of the previous 7 days	**Pre-post improvements in self-reported adherence in the intervention group (mean change = 0.61) compared to controls (mean change = −1.35)**	Asthma control, Self-efficacy ‡, Quality of life ‡
	Joseph (2007)	314	Ages 15-19	6 months	B, E	Interactive website	Obtaining medications	Pharmacy records	Significantly fewer students in the intervention group were adherent compared to the control group; More participants engaged in positive controller medication adherence behaviors (e.g., obtaining controller medication) in the intervention group (20.4%) compared to controls (12.6%)	Activity limitation ‡, Healthcare utilization ‡, Missed school/ work ‡, Perceived symptoms ‡, Quality of life ‡
	Pernell (2017)	47	Ages 3-59	4-8 weeks	B	Two-way automated reminders texts	Overall medication adherence	Self-report MMAS-8	**Significant improvement in medication adherence in the intervention group from pre to post (3.42 to 5.46), but not the control group (3.90 to 4.75)**; Change in adherence between intervention and control groups was not significant	None
	Petrie (2012)	216	Ages 16-45	4.5 months FU: 6 & 9 months	B, E	Tailored, automated text messages	Controller inhaler	Self-report adherence percent via phone call	**Intervention group showed increases in adherence (57.8% vs. 43.2% in control group); Increase in intervention group compared to baseline; In the intervention group, 25.9% had average adherence of 80% or above across the intervention compared to 10.6% of the control group; Intervention group had higher adherence than the control group (~10%) over the follow-up period**	Asthma knowledge †
	Vasbinder (2016)	209	Ages 4-11	12 months	B	Electronic monitoring system and text message reminders, only received text	Controller inhaler	Electronic monitoring	**Adherence was higher in the intervention (69.3%) vs. the control group (57.3) over the whole study; The treatment effect was**	Asthma control, Asthma exacerbations, Healthcare utilization, Missed

	Author (year)	*n*	Patient ages (range)	Length of Intervention, Follow-up (FU)	Intervention Components	Intervention Medium	Adherence Behavior	Adherence Measure	Adherence Results	Additional Outcomes
						reminders with missed doses			**greater during the first 6 months (15%) compared to the second 6 months (9%)**	school/work, Quality of life
	Gustafson (2012)	301	Ages 4-12	12 months	B, E, H, S, F	Online modules via a website and monthly nurse care management via telephone	Controller inhaler	Self-report via asthma diaries, Medication possession ratio	Self-reported adherence scores and medication refills did not differ between intervention (69.8%) and control groups (73.5%); **Medication refills improved for both intervention (17.7%) and control groups (13.8%)**	Asthma control †, Perceived symptoms
	Jan (2007)	164	Ages 6-12	12 weeks	B, E	Interactive website with electronic daily diary, symptom scores, and peak flow variability features and communication with medical team based on web-reported symptoms	Overall medication adherence and inhaler technique	Self-reported controller medication use via asthma diaries and DPI/MDI test scores with spacer technique	Adherence rates declined for both intervention (83.5% to 63.2%) and control groups (82.3% to 42.1%); **At post-intervention adherence rates were significantly higher for the intervention group (63.2%) compared to the control group (42.1%)**	Asthma control‡ Asthma knowledge†, Lung function†, Quality of life†
Combination	Mosnaim (2013)	68	Ages 11-16	10 weeks	B, E, C, S	Recordings promoting adherence via handheld MP3 players and weekly in-person motivational interviewing support groups led by social workers	Controller inhaler	Self-report, Electronic monitoring	No statistical difference in adherence between the intervention group (7.1%) and the control group (14.3%) at 10 weeks; Adherence declined in both groups; Self-reported adherence was significantly higher than objective measures of adherence at week 10 in both groups ($p < .0001$)	Asthma exacerbations, Asthma knowledge, Self-efficacy, Social support
	Wiecha (2015)	58	Ages 9-17	6 months	B, E, S	Interactive website with education and symptom logging; PCPs monitored and communicated with patients regarding website/ medication use as needed	Controller inhaler	Electronic monitoring for MDIs and dose counter numbers for diskus inhalers	**Participants with low adherence at baseline (< 75%) improved significantly only in the intervention group (mean change: 29.8%)**	Asthma Knowledge‡
	Zhou (2018)	65	Ages 0-5	12 weeks	B	Smart nebulizer with a paired mobile app and interactive website for parent- and physician-	Controller inhaler	Electronic monitoring	**Percent of participants in the intervention group with "good" adherence was significantly greater at all time points (86.67%, 76.67%, 67.33) than in the**	Asthma exacerbations†, Healthcare utilization†,

	Author (year)	*n*	Patient ages (range)	Length of Intervention, Follow-up (FU)	Intervention Components	Intervention Medium	Adherence Behavior	Adherence Measure	Adherence Results	Additional Outcomes
						monitored reminders for missed doses			**control group (62.86%, 51.42%, 40.00%)**	Perceived symptoms[†‡]

Note. Bolded text in the Adherence Results column indicates improved adherence pre-post intervention

[*] B= behavioral; O= organizational; E= education; H=health-care system; C= cognitive-behavioral S= social support; F= family therapy

[†] Denotes significant improvements pre-post intervention

[‡] Denotes a significant difference between groups post-intervention.

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