Journal of Asthma

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/ijas20

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To cite this article: Jennifer R. Mammen, Judith D. Schoonmaker, James Java, Jill Halterman, Marc N. Berliant, Amber Crowley, Marina Reznik, Jonathan M. Feldman, Robert J. Fortuna, Sean M. Frey, Kelsey Turgeon, Ashley Philibert & Kimberly Arcoleo (2022) Going mobile with primary care: smartphone-telemedicine for asthma management in young urban adults (TEAMS), Journal of Asthma, 59:1, 132-144, DOI: 10.1080/02770903.2020.1830413

To link to this article: https://doi.org/10.1080/02770903.2020.1830413

JOURNAL OF ASTHMA
2022, VOL. 59, NO. 1, 132–144
https://doi.org/10.1080/02770903.2020.1830413

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ARTIFICIAL INTELLIGENCE

Going mobile with primary care: smartphone-telemedicine for asthma management in young urban adults (TEAMS)

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ABSTRACT

Background: The majority of adults with persistent asthma have chronically uncontrolled disease and interventions to improve outcomes are needed. We evaluated the efficacy, feasibility, and acceptability of a multi-component smartphone-telemedicine program (TEAMS) to deliver asthma care remotely, support provider adherence to asthma management guidelines, and improve patient outcomes.

Methods: TEAMS utilized: (1) remote symptom monitoring, (2) nurse-led smartphone-telemedicine with self-management training for patients, and (3) Electronic medical record-based clinical decision support software. Adults aged 18-44 ($N = 33$) and primary care providers ($N = 4$) were recruited from a safety-net practice in Upstate New York. Asthma control, quality of life, and FEV_1 were measured at 0, 3 and 6 months. Acceptability was assessed via survey and end-of-study interviews. Paired t-test and mixed effects modeling were used to evaluate the effect of the intervention on asthma outcomes.

Results: At baseline, 80% of participants had uncontrolled asthma. By 6-months, 80% classified as well-controlled. Improvements in control and quality of life were large ($d = 1.955$, $d = 1.579$). $FEV_{\%pred}$ increased 4.2% ($d = 1.687$) with the greatest gain in males, smokers, and lower educational status. Provider adherence to national guidelines increased from 43.3% to 86.7% (CI = 22.11-64.55) and patient adherence to medication increased from 45.58% to 85.29% (CI = 14.79-64.62). Acceptability was 95.7%; In follow up interviews, 29/30 patients and all providers indicated TEAMS worked better than usual care, supported effective self-management, and reduced symptoms over time, which led to greater self-efficacy and motivation to manage asthma.

Discussion: Based on these findings, we conclude that smartphone telemedicine could substantially improve clinical asthma management, adherence to guidelines, and patient outcomes.

ARTICLE HISTORY
Received 17 July 2020
Revised 2 September 2020
Accepted 26 September 2020

KEYWORDS
Asthma; self-management; telemedicine; clinical decision support; patient education; clinical asthma management

Introduction

Under-treatment of asthma, non-adherence, and poor outcomes persist across the U.S. and globally (1,2). Individuals' with uncontrolled asthma have increased risk of morbidity and mortality, diminished quality of life, and elevated symptom burden, and ways to improve clinical care and asthma outcomes are needed (3). Fundamental to this objective is promoting multi-level adherence to evidence-based guidelines (4). It is commonly acknowledged that patients ignore symptoms, take medications inconsistently, and have poor self-management (5,6). However, nonadherence extends beyond patients. Healthcare providers (HCP) conduct sub-standard assessments (7), lack familiarity with guidelines (8), and fail to impart essential self-management skills (9). Furthermore, healthcare

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Supplemental data for this article can be accessed at publisher's website.

systems have limited resources to provide care (e.g. appointment availability, specialist care), and may be difficult for some patients to access (9). Cumulatively, this translates to nonadherence at patient, provider, and systems levels and a reinforcing cycle of inadequate asthma management, with the result that most adults with asthma have chronically uncontrolled disease (10,11).

Improving outcomes is undoubtedly challenging in an era of over-burdened health systems. Physical access has been increasingly constrained due to COVID-19 and resources to provide care are limited. In recent months, telemedicine has been extensively adopted as a means to deliver care safely and remotely (12). This is logical, as there is evidence telemedicine reduces barriers to care, is desirable to patients, and is associated with good outcomes (13,14). However, evidence of efficacy derives predominantly from computer- and site-based programs (15), or asynchronous remote monitoring interventions, whereas many telemedicine visits are now being conducted via *smartphone* video conferencing to patients *at home*, representing a substantial change in application (16). This shift is due to the fact that smartphones are more ubiquitous than computers, and smartphone-telemedicine (i.e. mobile visits) has tremendous potential to increase both demographic and geographic reach (17). However, research supporting efficacy of this approach for asthma management is scarce (18). Furthermore, while traditional telemedicine has been shown to improve asthma outcomes in younger patients (19–21), few interventions have been tested in adults with asthma or in real-world practice contexts (22–24). Thus, a sustainable, practice-integrated, smartphone-telemedicine intervention to improve asthma outcomes and multi-level adherence (i.e. patient, HCP, and systems) is greatly needed. We developed a multi-component smartphone/telemedicine program for adults with asthma (*Technology Enabled Asthma Management System* – TEAMS). TEAMS capitalizes on low-cost electronic medical record (EMR) and smartphone technology to provide guideline-based clinical decision support (CDS), remote symptom monitoring, self-management support, and convenient asthma follow-up. The purpose of this study was to evaluate efficacy and acceptability of the TEAMS smartphone-telemedicine program when implemented in a real-world clinical practice context. We hypothesized patients would have improved asthma outcomes at three- and six-months as compared to baseline.

Methods

Setting and study sample

This study was approved by the University of Rochester Institutional Review Board [NCT03648203] (18,25). Adult patients ($n = 33$) were recruited from a safety-net practice in NY to participate in a single-arm study. Eligibility criteria for patients were: (1) English speaking, (2) with persistent asthma based on EPR-3 criteria (26), (3) having a smartphone, (4) not pregnant and (5) without confounding comorbidities (cardiac, respiratory). Age range was restricted to younger adults (18–44 years) on the basis smartphone usage (17). A randomized roster of potential participants ($n = 140$) and their primary care providers ($N = 5$) was generated using the EMR. Patients were recruited by a research assistant (JS) via phone call, and providers were recruited by personal email from the primary investigator.

Intervention

Technology Enabled Asthma Management System (developer JM) is a multi-component program designed to support predominantly remote primary care management of asthma, and is the first reported program of this type. Full details of development have been published elsewhere (18). Briefly, TEAMS incorporates 3 technological components to augment usual care: (1) smartphone asthma symptom monitoring via a patient's personal smartphone and the MyChart patient portal (Epic EMR), (2) smartphone-based telemedicine follow-up and self-management training (SMT) with a nurse via Zoom video-conferencing, and (3) guideline-based clinical decision support (CDS) software in the EMR that calculates asthma severity, control, and recommended step-wise therapy based on Expert Panel Report-3 (EPR3) guidelines (26,27).

For the intervention, patients were asked to log asthma symptoms (non-urgent) daily via their smartphone, answering questions such as, "Did you have any symptoms of asthma in the past 24 h?" and "What was your peak flow today?" Patients were instructed to call the HCP or seek care for any urgent symptoms as per routine care.

A nurse interventionist conducted home telemedicine follow-up with the patient every 2-6 weeks until the asthma was well-controlled. Once good control was achieved, follow-up occurred every 2-3 months. Symptoms recorded by the patient in the EMR were reviewed prior to the visit. Each video visit included

assessment of symptoms, lung function (FEV_1), and recent medication use. Using data verified by the nurse, the CDS tool then calculated a detailed asthma assessment, including asthma severity, current control, prescribed step-wise level of therapy, guideline-recommended level of step-wise therapy, dose of inhaled corticosteroid (low, medium, high, micrograms), patient adherence to medication, and an appropriate follow-up plan. An auto-generated progress note was posted by the nurse in the EMR and shared with the HCP to support clinical management and e-prescribing. Patients identified as having uncontrolled asthma received electronic medication adjustments prescribed by the HCP. Phone calls to the HCP were used for urgent follow-up only. Office visits were initiated if indicated by the CDS, or requested by the HCP, nurse, or patient. Self-management training (SMT) occurred at each visit using the *Let's Talk About Asthma!* series for smartphone, which contains 14 single-page modules covering pathophysiology, symptom monitoring, prevention, management, and communication (28,29). Modules were designed to be covered at least once, with repetition of modules until mastery was demonstrated by the patient.

Data collection and measures

Technology set-up and 0-, 3- and 6-months data collection were conducted in participants' homes by a trained research assistant (JS; years 2018—2020). Each patient received $250 for data collection over 6-months. Demographics and baseline asthma information were assessed using smartphone surveys and chart review. Asthma severity was assessed by frequency of symptoms, nocturnal awakening, activity limitations, and short-acting beta-agonist (SABA) use, using EPR3 criteria (27).

Primary efficacy outcomes (0, 3, 6 months)

Asthma control was measured using the *Asthma Control Questionnaire (ACQ)* (30), a 7-item Likert-scale ranging from 0-6. Lower scores indicate better asthma control and a score of 1.5 has a positive predictive value of 0.88 for uncontrolled asthma (31). FEV_1 was measured at 0, 3, and 6, months, and each telemedicine visit using an individual Microlife peak flow meter (PFM) provided to each patient, which are accurate to within 5% of the reading or ± 0.1 liters when compared to traditional spirometry (32). Training in maximal expiration was provided along with the PFM at the baseline visit. Quality of life (QoL) was assessed using the *Asthma Quality of Life Questionnaire* (AQLQ, 32-item Likert-scale, range 1-7, higher scores indicate better QoL) (33).

Secondary efficacy outcomes (baseline, end-of-study)

Healthcare utilization, corticosteroid use, prescriptions/refills, emergency care, and treatment of comorbidities were assessed via chart review. Emergency care utilization was also assessed by self-report to capture out-of-network visits. Adherence to guideline-based therapy (patient and provider) was calculated by the CDS tool during telemedicine visits based on symptoms, medication, and missed doses.

Usability and Acceptability were measured with the Usability Satisfaction and Ease of Use Questionnaire (USE-Q (34)), a 21-item, 7-point Likert scale (range 1-7), with 7 being the most positive possible score. Usability and acceptability were also assessed via 1:1 interview.

Qualitative interviews

Patient participants engaged in audio-recorded 1:1 interviews to explore experiences and perceptions of the TEAMS program. Interviews lasted about 45 min, used a semi-structured protocol (Appendix A), and were conducted by a trained older, White female research assistant (JS) known to patient participants from prior data collection visits. HCPs participated in 1:1 end-of-study interviews with the RA (unknown to HCP) to evaluate their experiences with the TEAMS program.

Feasibility and intervention dose

Intervention dose was calculated as the (a) total number of mobile visits, (b) average visit duration (minutes), (c) SMT dose (minutes of training and modules delivered), and (d) smartphone symptom monitoring dose (days monitoring was performed). Scheduling statistics, visit duration, and technical feasibility data were collected using Redcap surveys completed by the RN at each visit. SMT and symptom monitoring dose were measured using the TEAMS CDS tool. Cost of program implementation was calculated based on total visits (kept and no-show visits), time to conduct visits (minutes late, visit time, documentation, and follow up), median nursing salary ($30/hour) (35) and equipment provided to patients, excluding cost of research-related incentives ($250).

Data analysis

Statistical analysis

Distributional characteristics of the data were assessed using descriptive statistics. Missing data were <1%.

Bivariate correlations were examined between demographic and outcome variables using SPSS 25. Paired t-tests were used to compare primary and secondary outcomes from baseline to end-of-study, and Cohen's d was used to evaluate effect size. Independent t-tests were used to examine change in ACQ, AQLQ and FEV1%$_{pred}$ by gender, smoking status, comorbid mental illness, and ANOVA was used to compare outcomes by race/ethnicity and educational level. To confirm the t-test results, linear mixed-effects modeling was conducted using R statistical software to evaluate if ACQ, AQLQ, and FEV1%$_{pred}$ changed over time while controlling for demographic- and health-related factors (age, gender, race/ethnicity, income, smoking status, and education).

Qualitative analysis

Transcribed interviews were analyzed using a consensus approach (JM, JD, KT, AP) and Nvivo12 software (36). Traditional content analysis techniques were used to analyze data for patterns of symptoms and self-management responses (37). Descriptive coding was used to explore perceptions and experiences with the TEAMS program (provider and patient), and pattern coding was used to further develop the themes and clarify concepts (38). Structured memos, member checking, and peer-debriefing were used to maximize validity (39).

Results

Demographics

Of 140 patients, 65 were reached and screened by phone: 38 were eligible, 1 declined (too busy) and 4 were lost to contact after screening. Thirty-three provided informed consent. Three females dropped out after consenting (2 Black, 1 White). One dropped out prior to intervention due to anxiety, one during the intervention due to time burden, and one was unenrolled by the healthcare provider (HCP) due to suicidal ideation. All others received the intervention and completed the full study ($n = 30$). Of the five HCP solicited by email, 4 responded, consented, and participated (80%). Sample characteristics are shown in Tables 1 and 2. Patient participants ($N = 30$) were predominantly minority (80%), employed, single, and lower socioeconomic status.

Efficacy

Most patients had uncontrolled asthma at baseline (80%, defined as ACQ > 1.50). At 3-months, 70% had well-controlled asthma, with 80% being well-controlled at 6-months. Effect sizes for improvements in asthma control and QoL were large (Table 3) and double to triple the minimum clinically important difference. Mean FEV1%$_{pred}$ increased 4.20%. Improvements in FEV1%$_{pred}$ were greatest for smokers (+10.27% vs. nonsmokers +0.68%, CI = 1.72-17.45), males (+11.27% vs. females +0.11%, CI = 3.62-18.72), and those with high-school education or less (+7.94% vs. any college education −0.071%, CI = 0.20-15.82). Patients with worse asthma control benefited most,

Table 1. Patient demographics and baseline asthma characteristics.

Patient Demographics ($N = 30$)	*N* (%)
Sex (Female)	19 (63.3%)
Race/Ethnicity	
Black	15 (50.0%)
White	6 (20.0%)
Hispanic/Latino	4 (13.3%)
Multiracial	4 (13.3%)
Asian	1 (3.3%)
Insurance (public)	23 (76.7%)
Education (Highschool or less)	16 (53.3%)
Marital status (Single)	19 (66.3%)
Transportation (public, no car)	16 (53.3%)
Employed full or part time	19 (63.4%)
Current smoker	11 (36.7%)
Comorbid mental illness	17 (56.7%)
Comorbid substance use disorder	4 (13.3%)
Had asthma related emergency visit past 12 months	15 (37.5%)
Satisfied with current asthma care	17 (51.5%)
Average age (years)	32.97 (SD 6.33)
Body Mass Index (chart review)	34.36 (SD 11.29)
Average years with asthma (years)	19.55 (SD 10.17)
Average household Income (in $1,000 USD)	27.53 (SD 13.97)
Patient Smartphone usage	
Has cell phone with unlimited data	24 (80.0%)
Uses phone to make video calls	25 (83.3%)
Uses phone to access health information	19 (63.3%)
Uses phone to set health reminders	17 (56.7%)
Ever had trouble keeping phone plan active	9 (30.0%)
Has smartphone available most or all the time	30 (100%)
Ever used phone to access patient portal	22 (73.3%)
Owns a computer	7 (23.3%)
Patient Asthma Severity[a]	
Intermittent	2 (6.7%)
Mild	1 (3.3%)
Moderate	11 (36.7)
Severe	16 (53.3%)
Patient Asthma Control[a]	
Well controlled	2 (6.7%)
Not well controlled	12 (40%)
Very poorly controlled	16 (53.3%)

Notes. [a]Expert Panel Report 3, guidelines from the National Heart Lung and Blood Institute (2007).

Table 2. Provider characteristics.

Provider Demographics ($N = 4$)	
Sex (female)	4 (100%)
Race/Ethnicity, White	3 (75%)
Race/Ethnicity, Asian	1 (25%)
Role, MD	1 (25%)
Role, NP	2 (50%)
Role, PA	1 (25%)
Average age (years (SD))	36.50 (SD 15.33)
Average years in current professional role (SD)	3.63 (SD 3.59)

Table 3. Primary and secondary patient outcomes for TEAMS intervention.

	Mean (SD)	Mean (SD)	(d)	(p)
Primary Outcomes	Baseline(0m)	End (6 m)	Effect	Significance
Asthma control (ACQ)	2.157 (0.848)	0.975 (0.111)	1.955	<0.001
Asthma quality-of-life (AQLQ)	4.418 (1.121)	6.019 (0.894)	1.579	<0.001
FEV1 % predicted	81.17% (2.273)	85.37% (2.689)	1.687	0.046
Secondary Outcomes	0 months	6 months	Effect	Significance
PCP prescribed therapy aligns with EPR3[a]	43.3% (50.400)	86.7% (34.574)	1.004	<0.001
PCP prescribed Stepwise level of therapy[c]	2.23 (1.478)	3.60 (1.423)	0.944	<0.001
Adherence to prescribed controller medication[d]	45.58% (41.678)	85.29% (25.091)	1.154	0.004
Mean stepwise level actually taken by patient[b]	1.90 (1.423)	3.10 (1.348)	0.866	<0.001
Secondary Outcomes	Year prior	Year following	Effect	Significance
Prescriptions for controller medication (ICS, LTRA)[e]	3.39 (4.565)	7.89 (4.254)	1.020	<0.001
Preventive office visits for asthma	0.62(1.115)	1.76 (2.459)	0.597	0.004
Prescriptions for SABA[e]	4.0(4.329)	6.36 (4.961)	0.507	0.022
Treatment of related comorbidities[f]	0.64 (0.951)	1.18 (1.188)	0.502	0.022
Asthma related emergency visit (chart review)	0.70 (1.236)	0.33 (0.922)	0.339	0.054
Asthma related emergency visit (self-report)	1.36 (2.959)	0.71 (1.384)	0.281	0.288
Systemic corticosteroid use	0.54(0.838)	0.68(2.001)	0.091	0.641

Notes: [a]Therapy prescribed by PCP is appropriate for level of asthma severity based on EPR3 stepwise treatment recommendations (binary). [b]Stepwise level of therapy actually used by the patient accounting for medication adherence; [c]Stepwise level according the EPR3 guidelines. [e]Short acting beta agonist (SABA) and controller therapy (ICS = Inhaled corticosteroids, LTRA = Leukotriene receptor agonists) measured as months of coverage; [f]PCP initiated treatment of related comorbidities : rhinitis, allergies, obesity, esophageal reflux, tobacco dependence, counted once per diagnosis.

with a strong correlation between baseline ACQ and improvement in symptoms by end-of-study (r=-0.82, $p < 0.001$). There were no other significant differences in intervention effects based on gender, smoking status, education, race/ethnicity, or presence of comorbid mental illness. Improvement in QoL was strongly associated with improved control ($r = 0.80$, $p < 0.001$) but not with FEV1%$_{pred}$ ($r = 0.087$, $p = 0.648$). The linear-effects models broadly confirmed the t-test results for the outcomes: with statistical significance, ACQ decreased over time, and both AQLQ and FEV1%$_{pred}$ increased over time, indicating better asthma control, quality of life, and pulmonary function.

Adherence to guideline-based therapy, Table 3

HCP adherence to EPR3 guidelines increased significantly (+1.367 steps, SD = 1.377), with 86.7% of prescribed therapy matching the EPR3-recommendations by end-of-study vs. 43.3% at baseline (CI = 22.11–64.55). Patient adherence to control medication increased from 45.58% to 85.29% (CI = 14.79–64.62). Preventive visits for asthma and treatment of related comorbidities increased significantly in the year following start of intervention as compared to the year prior. Emergency care utilization decreased marginally, however, use of oral corticosteroids remained unchanged.

Feasibility and intervention dose, Table 4

Nearly 38% of visits occurred after-hours or on weekends, with 93.2% of telemedicine visits having no disruptive technical issues. On average, patients received five 30-min visits over 6-months. Improvements in ACQ, AQLQ and FEV1%$_{pred}$ were not significantly associated with intervention dose, excluding a marginal association between FEV1%$_{pred}$ and the number of days home symptom monitoring was performed ($r = 0.339$, $p = 0.06$). The most commonly repeated SMT topics were knowing if asthma was controlled, understanding different medications, demonstrating correct inhaler technique, and using a PFM. Based on the average nursing time per visit (44.47 min including visit, documentation and follow up), total visits (148 kept, 47 no-show), median nursing salary ($30/hour) (35) and equipment provided to patients (PFM + spacer=$42), the cost of delivering the intervention was estimated at $186.52 per person over 6-months.

Acceptability (HCP), Table 5

HCPs expressed strong satisfaction with the intervention, indicating it saved time and improved workflow, patient/provider knowledge, communication, and adherence to medication. HCPs also noted that their patients increased engagement in care for asthma *and* other chronic conditions, a finding that was supported in patients' interviews.

Acceptability (patient)

Usability and acceptability were high (mean score = 6.61; SD = 0.47). In interviews, many reported the intervention changed their life, enabling them to take control of their asthma and be active "like a regular person" for the first time as adults.

Table 4. Feasibility and intervention dose.

Scheduling and Technical data	N (%)
Visits kept as originally scheduled	148/277 (53.4%)
Rescheduled by text message	81/277 (29.2%)
No show	47/277 (17.0%)
Visits occurred on weekend	26/148 (12.8%)
Visits occurred after 5 PM	39/148 (25.7%)
Visits without any Audio/Visual problems	109/148 (73.6%)
Visits with major Audio/visual problems	10/148 (6.8%)
Smartphone telemedicine visits dose	**Mean (SD)**
Total smartphone visits per patient	5 (2.04)
Minutes late to smartphone visit	6.37 (10.68)
Visit duration (minutes)	26 (11.39)
Documentation and follow up time per visit (minutes)	12.05 (13.28)
Total nursing time per visit (minutes)	44.47 (21.67)
CDSS recommended asthma follow up interval (weeks)	3.67 (2.49)
Self-management training (SMT) dose	**Mean (SD)**
Total minutes of SMT (range 33-177)	80.50(42.467)
Specific SMT modules[a]	
Module 3: Is your asthma controlled?	4.10 (1.626)
Module 4: Different types of asthma medications	3.40 (1.276)
Module 8: How to take puffer and powder inhalers	3.37 (1.608)
Module 9: Why you should use a spacer	2.90 (1.242)
Module 10: Measure your lung function (PFM)	2.73 (1.015)
Module 15: Smoking cessation strategies (smokers)	2.45 (1.572)
Module 2: Uncontrolled asthma can scar your lungs	2.30 (0.988)
Module 11: Asthma triggers and what to do	2.13 (1.655)
Module 5: Know the symptoms of asthma	2.07 (1.230)
Module 1: What is asthma?	1.93 (0.82)
Module 6: Guidelines for treating an asthma attack	1.73 (1.337)
Module 7: Life threatening symptoms	1.67 (1.322)
Module 13: Keeping track of symptoms	1.60 (1.429)
Module 12: Managing exercise asthma	1.27 (1.437)
Module 14: Action plans	0.10 (0.409)
Smartphone symptom monitoring dose	**Mean (SD)**
Symptom/PEF tracking (# of days recorded over 6 months)	23.73 (38.403)

Notes. [a]Average number of times each module was delivered to each patient.

Overview of qualitative themes (patient)

Nine themes were seen across patient interviews. Nearly all (29/30) reported that: (1) TEAMS worked better for managing asthma than usual care, and (2) greater physical, social and emotional support to manage asthma along with (3) internalized self-management knowledge led to (4) changes in self-management behaviors, which (5) dramatically reduced symptoms over time. When participants saw that self-management changes alleviated symptoms, *then* they experienced (6) greater self-efficacy; (7) changed beliefs about asthma; and had (8) greater motivation to manage asthma. However, many indicated that (9) ongoing challenges remain. Delineation of these themes and supporting coding schema are presented in Figure 1 with illustrative quotes of individual experiences in Table 6. Key points are described below.

Theme 1: This works. Participants indicated TEAMS was "better than the doctor" because it was more *comfortable* (i.e. visits could be done from home with less stress), *convenient* (flexible, no lost work or travel time), *effective*, and *personal*. In particular, participants reported feeling connected to the nurse because of being "face-to-face" via video conferencing, whereas in office visits a provider often faces a computer. For example:

> **P13**: Being face to face, there's more of a connection. You feel like the person's listening - they're actually looking at you.

Theme 2: Greater support—"Someone cares." Having a nurse who transparently cared, initiated regular asthma follow up, was easily accessible, and assisted with medication management, changed participants willingness to engage in preventive care. This is evident in the following quote:

> **P9**: There was no space for me giving me up—I had help and support right there. … Having someone [care]—that helped *me* to care about me.

Being in the program not only made participants feel supported by the nurse, but also enabled them to self-advocate for their asthma needs and develop supportive relationships with family, friends, and HCPs. As one man explained, "It helps me to get the support I need not just from my primary care physician, but people around me." (P17). For many, support included facilitating access to effective controller medication (i.e. medication/dose adjustments), which often required multiple attempts:

> **P24**: We found [medication] that worked. You didn't just say, "okay, just give it more time." The symptoms weren't [controlled] and you stayed on it and made me feel like my health mattered. …

Theme 3: Internalized knowledge from self-management training (SMT).

Many participants indicated the biggest "eye opener" was realizing uncontrolled asthma causes remodeling (i.e. "scars your lungs"). As one woman remarked, "People don't know about scarred tissue in their lungs if they don't take the preventive [medication], or what the long-term effect is. They just think it's shortness of breath, like I did." (P10). Others commented similarly, indicating that this "scary" information caused them to be more aware and less accepting of symptoms.

> **P4**: "I realized uncontrolled my asthma was scarring my lungs, and that's not good—things that I didn't pay attention to [before], now I'm mindful of those symptoms."

Other key capabilities included being able to differentiate asthma symptoms (vs. cold), understanding differences between control vs. rescue medication, using a spacer, knowing when an inhaler is running out, and being able to manage an asthma attack.

Table 5. Key themes and quotes from end of study interviews with Healthcare Providers ($N = 4$) exploring perceptions of the TEAMS smartphone-telemedicine program for adults with asthma.

PERCPETION OF TEAMS TELEMEDICINE PROGRAM • More efficient process • Reduced barriers to care for vulnerable population • Better educated HCP • Better educated patient • Better patient outcomes	**MD**: it's all been positive … one patient I had never met before but her pulmonary function testing was really poor and TEAMS was working on escalating her step wise treatment … so when she came to see me she was already doing a lot better …. we were able to work behind the scenes to figure out what worked … so, I didn't have to see her in clinic, change her meds, send her out, and then have her come back in—that can be really hard for patients to come in repeatedly. it's hard for our patient population to make it to appointments with social determinants of health causing barriers … so I really appreciate the TEAMS program **NP1**: It's a great program – I'd get a message in my inbox with the record that told me that a patient was enrolled and their level of asthma control. And it was pretty easy to read and assess how the patient was doing, even if I hadn't met them before. **NP2**: The patients that went through the program that I touched, they all got better … and they showed up to their appointments. One patient, he was very excited. Now, he can tell me what his pulmonary functions test, and he can tell me the impact of his smoking, and how it changed his asthma when he stopped and when he started again – he really understood what was going on. **PA**: I loved it. [The telemedicine nurse] would send me an encounter describing what she did, and follow up, and she would ask, "Can you prescribe meds if you agree?" So, we would get things moving, and then the patient would come and see me [in the office], and we would kind of go through with how the changes are helping or not helping. It actually taught me a lot about titration and protocols for asthma. It not only helped the patient, but it helped my education as well.
IMPACT ON PATIENT CARE • Increased adherence to controller medication • Better symptom control • Happy patients • Empowered patients • Educated patients • More engaged in healthcare	**MD**: I really appreciate that the program teaches compliance and proper usage of inhalers … usually I don't have time to do that at clinic … I'm trying to cover a lot of things at once [and] I only see these patients once in a blue moon **NP1**: There was a significant benefit to the patient. Two patients I'm thinking of specifically were just so *happy* - they just didn't know that they could get control, because they hadn't been involved in care previously. I think people just accept that they have asthma and don't realize they can get control. **NP2**: Often times our patients end up in the emergency room. We talk to them, they don't understand what controller medications are, and that they have to take to keep them out of the emergency room. They always told me tell me, "these don't work." I'm like, "well, they don't work because you don't take them every day." Somehow, TEAMS was able to get through to them that this was very important stuff. Part of the problem with controlling asthma is that people don't have the education and with [this program] they got the education and understood why they needed to take their inhalers and started to feel better. That was amazing. **PA**: A lot of patients I normally don't see actually came more because they were feeling better and they had a connection, so they actually came to their appointments. [We]would talk about their asthma, and they'd be so happy about it. Like, "I never knew that I wasn't controlled … now I feel amazing." And I'm like, "that is how you're supposed to feel!" The patients really turned around … I don't know, they were just different people. It ties into everything, like their attitude toward medical care. And they want to learn more now, they want to connect with their health and be more in tune, because they feel better.
IMPACT ON WORKFLOW • Saves time for HCP • Saves follow up visits • Makes job easier	**MD**: It saved me a lot of time because I wouldn't have to make an extended visit or 2 appointments … the population we work with transportation is a big limiting factor, they have to take off work and they can't afford to miss a day's pay, or they have children they need child care for, [so] they miss their appointments. **NP1**: it made [my job] really easy. So sometimes we would increase the stepwise therapy before they came back in, so when you saw the patient, you get like two for one—you see the patient and they've already done what you wanted to do, so they don't have to then come in for a second visit to reassess. So, it made it a lot easier, for the patient, but also for me … it saves office visits **NP2**: it didn't really increase my workload at all … the information would be documented in the TEAMS note, and the patients were actually able to tell me the information, which is huge … I got more information, what their peak flow was, objective information. **PA**: It made it easier. Way less work. The education was the best. Education is the part that takes longest … understanding how to use their inhaler takes a long time, understanding what asthma is, what triggers asthma, or what inhaler to use at what times, that takes a long time. And when we're in a visit, we're not just focusing on one thing. Patients are complex and have multiple things … If their diabetes is uncontrolled [or] they feel bad, they're going to put asthma to the wayside.
ADVANTAGES, DISADVANTAGES • Improved access to care • 1:1 education • Focused on asthma • Better communication	**MD**: It's important to have one-on-one communication [like this] where they're only focusing on one chronic medical condition—[patients] need someone monitoring them more carefully than the PCP can. Even in a private setting, I would see patient 3 or 4 times a year, which is not enough, because asthma changes. **NP1**: I found [the telemedicine visit notes] helpful – It's a lot easier to read it than it is to try to get all that information out of a patient … it was like somebody did a pre-assessment, and you could just confirm it with the patient. It made the visit easier, because all the education was done, and education can be the hardest part, especially in an office setting. I didn't really see any disadvantages. But, if every single patient had asthma, I could see it being a little bit more cumbersome. **NP2**: I've been in practice over 30 years, and asthma has been one of the things that is hardest for the working poor to control because of their barriers … They can't get to the doctor, can't get off work, don't have extra time, *but* they have smart phone … I think it benefits those. This would help reduce admissions and ED visits. **PA**: This was just so helpful - I mean, it would be awesome if we could implement that into primary care. I wish we could do more telemedicine like this.

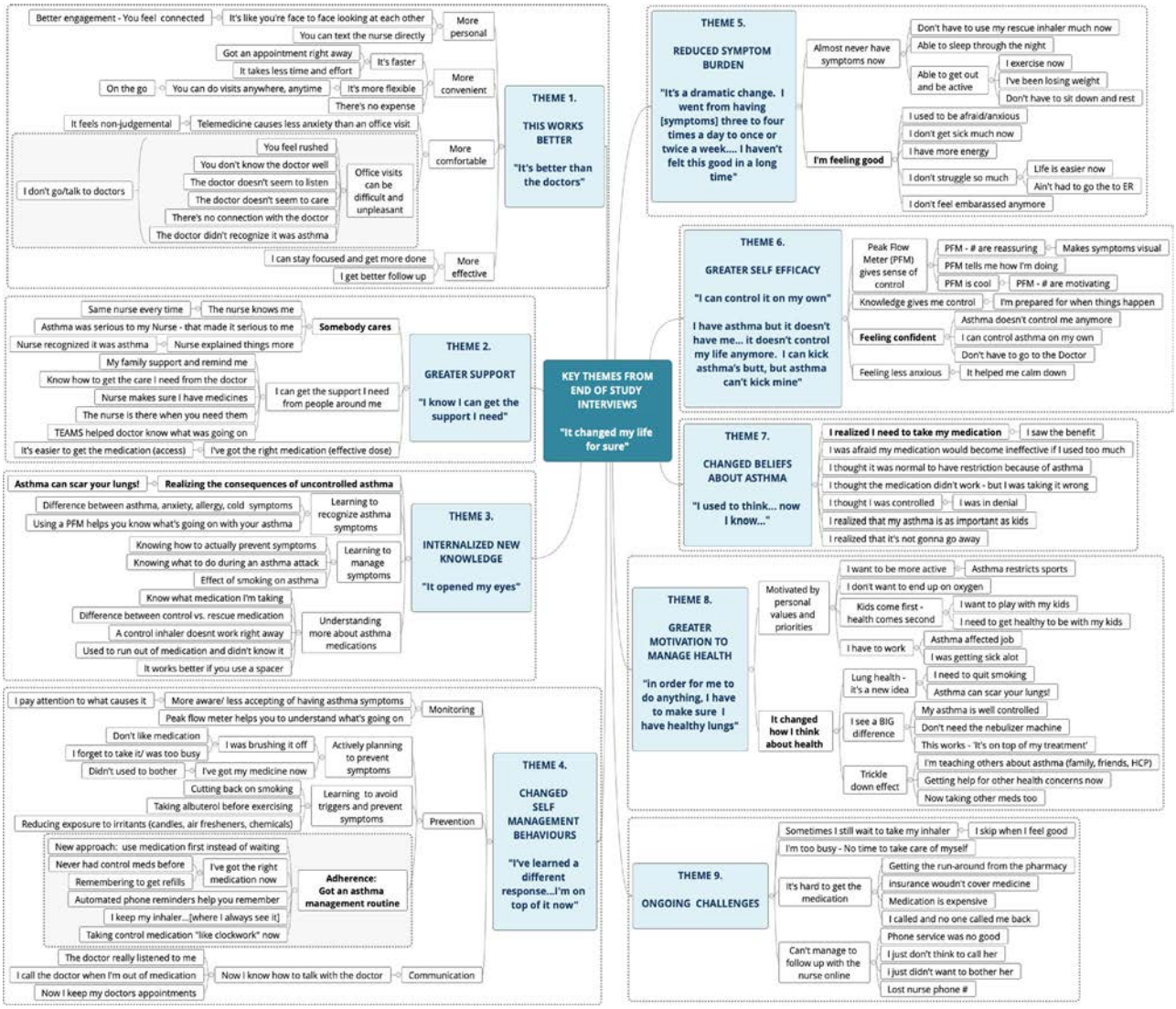

Figure 1. Thematic map of key findings from exit interviews with patient participants regarding the impact of the TEAMS smartphone telemedicine.

Many reported the digital PFM was essential to recognizing symptoms, providing reassurance and objective evidence of progress:

> **P5**: It's hard for someone who has asthma for so long that isn't controlled. You get used to feeling a certain way [and] it feels normal. The meter lets you know your airflow is [low] … I didn't know that it was that bad … Now, I'm more aware.

Theme 4: Changed self-management. As a result of increased support and SMT, participants began implementing behavior changes. In general, heightened awareness of symptoms corresponded with more proactive self-management approach:

> **P17**: This helped me to monitor and recognize my symptoms … I've learned a different response. I know what to do. [Now] I'm taking my preventative … I don't tough it out anymore.

For many, establishing an *individualized asthma management routine* was key to supporting medication adherence. As one woman explained, "I was not good on taking my meds before … now I have an alarm [and] I'll take my meds because I got it on the clock" (P12). Routines included keeping control inhalers in one or more high-visibility, easy-access locations, and setting medication reminders on the smartphone. For example:

> **P13**: I used to put [my inhalers] away and forget about it, out of sight out of mind. Now I have medication regiments. If it's in front of my face, I remember to do it.

> **P1**: I have one [inhaler] at my toothbrush and one next to the bed at night. It helps me stay on top of my medicine.

Table 6. Quotes from Patient exit interviews ($N = 30$) exploring personal experiences and impact of the TEAMS smartphone-telemedicine program for adults with asthma.

P1 (M, AA): it's a dramatic change …. I went from having [symptoms] three to four times a day to once or twice a week …. I haven't felt this good in a long time. I feel like, okay I can do this … before I just postponed taking the medicine and just tried to not do much … now, I take my medicine like clockwork …. Life has been a lot better.

P3 (M, C): I've learned I can control my asthma … [Before] I'd have gone to the doctor to get treated for an infection. [Now] I've been telling other people that have asthma to get on control medicine. My buddy at work has way worse asthma … I talked him into getting control medicine. I'm coaching my nephew, and my grandmother with COPD how to use her inhalers properly.

P4 (F, AA): I couldn't run around and play with the kids—now I can. It changed my life, for sure. I went from [having] asthma, terrible, can't do nothing, to now my asthma is well-controlled. I don't have to use my rescue inhaler, I don't have to worry when I go outside, I really don't have any symptoms …. I got a regimen and a reminder in my phone, and I was able to stick with it.

P5 (F, AA): it feels like a doctor visit, but at your leisure, on your own schedule. That was important, otherwise I wouldn't have had a visit at all. I haven't been to a doctor's office in a long time.

P6 (F, AA): I know how to keep it under control now—that's a big improvement. Before I was using it [albuterol] every 2 h. [The ICS] helped me a lot, it's keeping me from using my rescue inhaler. Even though it irks my nerves and stresses me out keeping track of it, I got myself better. My mom she wanna join this too.

P7 (M, C): It was a blessing that it was the same person [every time]—It was actually like she was sitting in front of me. The phone reminders were a very, very big help. [Now] I'm able to actually take a deep breath without freaking choking … [We've] gotten my breathing under control. Everybody who has asthma should be in this program.

P9 (F, AA): What makes a difference with me is doing the peak flow, being able to see how my breathing is … Soon as I see the numbers start to rise, I felt that I was doing it right. if I see my numbers are up above 430, I'm taking my control medications right, I'm taking everything right. It helps me keep track … [Before} I was guessing.

P10 (F, AA): [Before] I was not controlled. I wasn't taking my asthma medicine … I just be brushing it off, like hit and miss … Now I take them regularly I don't wake up with barely any symptoms

P11 (M, AA): I'm more of a hands-on person, [I'd rather] go to a building. If I'm not face-to-face, I'm distracted, [and] I didn't like [doing] the PFM - It kind of hurts when you blow into it.

P12 (F, AA): I was not good at taking my meds before this program at all … I be thinking I'm fine, but when my doctor listens to me, she be like,"Oh you're wheezing pretty bad", and like, I don't be really hearing it. I have an alarm now for my meds, and I'll take it because I got it on the clock … the [control medicine] really helps.

P13 (F, MR): [Before] I was feeling like I might just die because I couldn't breathe. I don't feel like that anymore …. I feel way more confident. [Now] I walk either in the morning or at night … I couldn't do that before. Being face to face with somebody [on the smartphone], there's more of a connection. You feel like the person's listening when they're actually looking at you.

P14 (F, AA): it's a life changing experience … I've never been in control of my asthma like I am now … Before I used to panic, because I have so many problems breathing, and the pumps didn't work …. then they showed me the proper way of using the pump and the spacer [and] It works! [Now] I walk everyday, I play with kids … before it was 'I can't play with you, I can't breathe if I do.'

P15 (M, C): I don't like going to the doctors [because of] social anxiety and PTSD. [This works] because … it's through the phone. If I want to, I can set the phone down and she can't see me I can't see her. I think that's the biggest problem why people don't have controlled asthma, … no one is educated. I didn't know half the shit that [[She]] told me until afterwards.

P16 (F, HL): I learned it was actually asthma symptoms that I was having … I feel more confident knowing more about it … I know what what can happen if you don't get any treatments

P17 (M, HL): I'm able to pick up on things that are triggering [symptoms] symptoms I didn't think were attributed to asthma I come to learn are. … It causes me to change the way I take my medications … I used to see asthma as a burden and something that would always limit me in some way. It's not the case anymore, really.

P18 (F, AA): I was taking the inhaler wrong, using so much clean up products and scented candles … [they] showed me something different that I should've been doing, using the [spacer]so all of it [medication] goes into your lungs … that improved me a whole lot … now I could walk up and down the stairs, without huffing and puffing! It taught me a whole different route for treating my asthma. That little spacer thing, that little peak thing … it was very useful. It showed me different numbers of how I was breathing, [if] your lungs wasn't functioning right

P20 (M, AA): I feel amazing, now … [before] I was all horrible, I was having bad-bad symptoms, and now I feel like I can run around, and do everything that I really, really want to do.

P21 (F, HL): I can do stuff that I wouldn't do before. Like, I can go upstairs, downstairs, through the whole house. When I used to do that, I breathed so hard, sweat so hard, my asthma be bothering me [so] I don't do them. Now I don't have the symptoms anymore, It's amazing. [It's] a big change in my life ….I can be happy with myself, instead of being always down.

P22: (F, HL): I didn't know about the scarring and the swelling. I didn't know that asthma can do that to your lungs … I've been talking to my little brother and sister about it, because they have asthma [and] they have no idea. I feel like now-since I know how to use [control medication] better that I am able to take care of my asthma by myself now.

P23 (F, As): I didn't know untreated asthma can like, really damage your lungs, like really badly. This taught me like, I don't have to live life miserably every day. [Before] I thought it was normal. This was perfect, I don't have time to go to an office to talk to somebody … [with this] I can just video call [the nurse], it was super easy, and it was really good quality video too

P24 (F, MR): I feel in control, and I actually bragged about this. It makes me feel safe. I actually feel confident. I can pace myself and walk to the pharmacy, and I don't feel labored. I don't feel like my lungs are bleeding, I'm not coughing, throwing up and dizzy. This gave me a blanket of security." [Now] I'm not worried if I don't have my [albuterol] on me … I'm not so scared or worried.

P25 (F, HL): I learned a whole lot from this, and I even taught my husband. He didn't know things either and he's asthmatic. Like, I didn't that the lungs get swelled up … I'm like "Whoa!.. I need to control my asthma!" … now I'm taking my medication. Before I wasn't because I feel like it wasn't useful, like, "Eh, don't need it, that's not doing anything for me."

P26 (F, AA): [This] changed my outlook on everything. It changed my life. it showed me how to control my asthma and keep me from getting sick and almost dying. [Now] I can be active more and play with my son and do the things I want to do. It helps you stay focused … [like] how to keep up with my meds and how to know when [the inhaler] is getting low.

P27 (M, AA): It improved the way I breathe, the way I live. I don't struggle as much as before. [Asthma] was restricting my life, [this] pushed me to do better with my own health, give me tools that no one else has given me. [And] it was convenient. I don't have to get up and drive during snowing weather. It was personable, I really liked that, and it was the same doctor all the time.

P28 (M, MR): My awareness is different. how I approach my health [is] a more active as opposed to just going with the flow and hoping that you know my symptoms get better.

(*Continued*)

P29 (M, C): It is so comfortable … I didn't have to go somewhere for a visit. Like it doesn't matter if you had pants or shoes on, you didn't have to be dressed up to go out … It's less stress.
P30 (F, MR): I had asthma for 25 years and no one gave me a control inhaler, only albuterol. I was walking around like an 80-year old, exhausted every day. [Now] I keep up with the control inhaler. I have no symptoms, I feel wonderful, I can run around with my kids. I control my life now, participate in things, not be sick everyday. I don't have problems with my asthma anymore.
P31 (M, C): Video chats made all the difference …. I did all my visits on the road. If I have to take a day off work or go without [healthcare], I'll go without. [Now] I'm doin' stuff I didn't use to [be able] do; movin' around quicker. I used to ignore my asthma … now, I take the meds and I actually see a difference … so now it's worth doin' ….
P32 (F, AA): I feel like my asthma's under control. [Now] I gotta work with my brother to get *his* asthma under control. I told him about the inhalers, how to properly use them. I got him using his because he takes a controlled inhaler so I've been helping monitoring him, reminding him to take that every day [and] use a spacer.
P33 (F, AA): Before, I was scared … I would be taking medicines just to take it … now I know how to take it and what to do … I have asthma but it doesn't have me. It doesn't control my life anymore. I can kick asthma's butt, but asthma can't kick mine. I feel so good about myself … This helped save my life, cause asthma was getting the better of me.

Notes. Quotes are presented sequentially by Participant# (sex, race), excluding non-completers #2, 8, 19 ($n = 3$). F = female; M = male; AA = African American; C = Caucasian; HL = Hispanic/Latino.

Theme 5: Reduced symptoms. As a result of these changes, participants indicated they experienced a dramatic reduction in symptoms, better quality of life, increased ability to be physically active, and reduced anxiety/depression. For example:

> **P30**: Before, I was totally drained, walking around like an 80-year-old. I couldn't do anything because of asthma. [Now] I can breathe. I feel wonderful! I can do things with my kids, like running around.

> **P25**: I felt better and it helped me calm down and relax.

Theme 6, 7, and 8: Changed beliefs about asthma, greater self-efficacy, and greater motivation to manage asthma. Experiencing the benefit of effective self-management was key to changing beliefs about asthma. Many adults indicated they previously refrained from taking medications due to misconceptions, fear of dependence, and beliefs that having symptoms was "normal," *but* that these belief barriers changed when they saw the medication worked (i.e. *seeing* benefits is *believing* medication will work). For example:

> **P13**: I used to think maybe I shouldn't take [medication] so often 'cause I'll get dependent on it, but now that my symptoms have started to clear, I don't feel that way. I feel like it's something that prevents it.

> **P31**: I actually see a difference. Before I didn't, so what's the point? Why bother if it's not doing anything? Now I can tell—so it's worth doing.

"Seeing is believing" also impacted approach to and perspectives of medical care:

> **P9**: Since doing this [my asthma] has progressed [gotten better], and I've actually been going to my appointments, [Before] I would refuse going to the doctor, like, "Oh, they're just going to tell me this is not right, that's not right … " But when I seen I was actually making progress, I have more confidence going to the doctor.

It is particularly important to note that it was only *after* implementing behavior changes *and* observing a reduction in symptoms that participants developed greater confidence in medical treatment and their personal ability to manage asthma:

> **P24**: [They] found a plan and *showed me it can work*, and *helped me get into a schedule* of seeing it work and *actually putting it into use*, and checking up and following up with me. I have a treatment plan in place, *and I'm confident* with my treatment of asthma.

This translated to increased motivation to sustain new behaviors, which were now perceived as effective and beneficial:

> **P14**: Before this, I would go to the doctor and they told me to do it, but I didn't ever have nobody to push me to doing it. Once I did start taking it and I noticed it was working, I kept doing it.

Lastly, there was an unexpected trickle-down effect of increased adherence to non-asthma medications, and a more proactive approach to managing other chronic conditions:

> **P17**: With me being more on my asthma medication, I've been taking all my other medications too, so it's helped me address those issues as well.

Theme 9: Ongoing challenges. While participants experienced improvements in symptoms and quality-of-life, ongoing challenges were still present. As seen in Figure 1, these included trouble accessing medications, being busy and forgetting to take care of oneself, and trouble following up with the telemedicine nurse due to personal or technology issues. Most participants felt they would have participated in the program regardless of incentives, however others indicated that incentivizing was essential to their initial willingness to participate:

> **P20**: a lot of people probably wouldn't do it [without] incentive. When I first heard about it, I was like "oh

yeah, I get paid taking my medicine!" Now that I know how helpful it was, I will [keep taking it].

Despite challenges, most patients indicated that for the first time they felt empowered and in control of their asthma. As one woman expressed so powerfully:

P33: Now, I know what to do. I have asthma, but it doesn't have me. It doesn't control my life anymore. I can kick asthma's butt, but asthma can't kick mine. I feel so good about myself…

Discussion

Most young-adults with persistent asthma have poor asthma control under current approaches to care. Our data suggest smartphone-telemedicine could extend healthcare reach and improve outcomes with minimal cost, little workflow disruption, and high patient and provider satisfaction. These findings are timely given the increased use of telemedicine in response to the COVID-19 pandemic, and the absence of best-practice guidelines for delivering asthma care remotely. This manuscript provides details on components of high-quality virtual-care, and compelling preliminary evidence of efficacy, feasibility, and acceptability.

This study utilized a small sample of lower socio-economic status, urban young-adult patients from a single hospital-based clinic, and one nurse interventionist. Furthermore, remuneration for patient participation may have increased participation and retention, resulting in a positive outcome bias. Therefore, broader generalizability may be limited. Nonetheless, it is important to note that most of these "hard-to-treat" patients had achieved good control by end-of-study. This could be attributable to several factors, including increased follow up (40), HCP adherence to stepwise therapy (4), patient adherence to control medication (41), and training in inhaler technique (42), which cumulatively resulted in a higher dose of controller medication being consumed by patients. A randomized trial with more diverse participants is indicated to evaluate replicability, generalizability, and sustainability.

Beyond efficacy and acceptability, other findings emerged that are worth noting. In particular, self-efficacy is often considered a necessary precursor to behavior change (8,43,44). In this study, it appeared that behavior change occurred *prior to* increasing self-efficacy, suggesting a cyclical rather than linear relationship between concepts (45). In other words, patients who implemented new behaviors *and* saw evidence of effectiveness developed self-efficacy to continue behaviors, which is consistent with the common-sense model for illness self-management (46). The clinical significance is worth considering: changing asthma management might require a "trial" of new behaviors to demonstrate benefits, develop confidence, and increase willingness to sustain change. Simply put, patients might *try it* for a period, *test it* to see if it works, and *take it* if there is clear observable benefit.

Unfortunately, healthcare providers often ask patients to engage in behaviors they have *not* observed the value of, as was evident in our baseline interviews. Thus, effort may be needed to overcome apathy and reluctance to change, particularly among those diagnosed with asthma for an extended time. A simple application of the "try it—test it—take it" principle would be to treat aggressively early on. This might include beginning with *higher* initial dose of controller medication to achieve rapid relief of symptoms, and *deescalating* to the lowest dose needed to maintain control, as opposed to the usual practice of increasing dose when symptom relief is not achieved after weeks or months.

Second, patients might need more follow-up and SMT than is common in practice (47). At present, most SMT is geared toward children/adolescents, caregivers, or high-risk older-adults (48). However, evidence indicates young-adults have poor understanding of asthma management and may recall little of asthma education as children (49). Thus, retraining for these patients may be warranted. Our participants were encouraged to follow up *every 2 weeks* until good control was achieved, amounting to 5 visits and 80 min of personalized SMT, per patient. Based on this, we conclude it is unlikely adults can be supported to achieve good control under current care models. Improving outcomes will require a system-level commitment to aggressive follow-up, training, and support to overcome the many barriers to change.

Conclusion. Good asthma control may be achievable using revolutionary care models (i.e. smartphone telemedicine with clinical decision support) as an extension of usual care. This approach can enable quality care for patients with asthma in a way that does not increase risk of exposure to infectious diseases, such as COVID-19.

Acknowledgements

The authors wish to thank the patients and providers who participated in this study.

Declaration of interest

No potential competing interest was reported by the authors.

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