

Development and preliminary results of an Electronic Medical Record (EMR)-integrated smartphone telemedicine program to deliver asthma care remotely

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Abstract

Introduction: Technology-based interventions that can function within real-world practice and improve outcomes *without* increasing provider burden are needed, yet few successfully cross the research-to-practice divide. This paper describes the process of developing a clinically integrated smartphone-telemedicine program for adults with asthma and results from proof-of-concept testing.

Methods: We used a contextually grounded intervention development approach and May's implementation theory to design the intervention, with emphasis on systems capabilities and stakeholder needs. The intervention incorporated symptom monitoring by smartphone, smartphone telemedicine visits and self-management training with a nurse, and clinical decision-support software, which provided automated calculations of asthma severity, control and step-wise therapy. Seven adults (aged 18–40) engaged in a 3-month beta-test. Asthma outcomes (control, quality of life, FEV₁) and healthcare utilisation patterns were measured at baseline and end-of-study.

Results: Each participant averaged four telemedicine visits (94% patient satisfaction). All participants had uncontrolled asthma at baseline; end-of-study 5/7 classified as well-controlled. Mean asthma control improved 1.55 points (CI = 0.59–2.51); quality of life improved 1.91 points (CI = 0.50–3.31), FEV₁ percent predicted increased 14.86% (CI = –3.09–32.80); effect sizes of $d = 1.16$, 1.09, and 0.96, respectively. Preventive healthcare utilisation increased significantly (1.86 visits/year vs. 0.28/year prior, CI 0.67–2.47) as did prescriptions for controller medications (9.29 prescriptions/year vs. 1.57 prescriptions/year, CI 4.85–10.58).

Discussion: Smartphone telemedicine may be an effective means to improve outcomes and deliver asthma care remotely. However, careful attention to systems capabilities and stakeholder acceptability is needed to ensure successful integration with practice.

Clinical Trials registration #: NCT03648203

Keywords

E-health, self-care, telemedicine, telenursing

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Introduction

Asthma remains one of the most common chronic health conditions, affecting 8.2% of adults, of which approximately 63% have persistent disease.^{1,2} Typically, correct use of controller medication and effective self-management can alleviate symptoms, prevent exacerbations, and reduce risk of long-term lung damage.³ Yet while morbidity and mortality due to asthma are preventable, nearly 62% of adults with asthma remain uncontrolled, and implementation of potentially effective new interventions within real-world contexts has been limited.⁴

There is no doubt that careful assessment, close follow-up, medication reminders, and self-management training all improve adherence and outcomes.⁴ However, these approaches require personnel and time resources that may not exist within overburdened healthcare systems. With the growing shortage of primary care providers (PCPs) and the increasing complexity of clinical care, it is unlikely that PCPs can carve out additional time to focus on asthma management.⁵ For this reason, interventions that can function effectively within existing systems' constraints and improve patient outcomes *without* increasing provider burden are urgently needed.

There is growing evidence that use of e-health technology (e.g. smartphones, electronic medical record (EMR), and computer decision-support software (CDSS)) can address common asthma management issues.^{6,7} However, most technology-based interventions do not integrate with the EMR, and are thus not currently clinically sustainable. While researchers may be optimistic about the ability to integrate *ex post facto*, few tech-based interventions cross the research-to-practice divide, typically due to unforeseen systems implementation issues or incompatibility with existing clinical workflow.

Thus, in designing a new technology-based intervention for asthma management, we adopted a contextually grounded intervention development approach that allowed for consideration of implementation issues during the development process.⁸ Specifically, we sought to develop a smartphone-based telemedicine program that could address common asthma management problems (e.g. patient non-adherence,^{9–11} inaccurate symptom reporting,^{12,13} poor self-management,^{14,15} access to care,^{16–18} and provider non-adherence to asthma guidelines^{19–21}) and integrate with the EMR and existing clinical practice. The goal in developing the intervention was to increase the accuracy, effectiveness, and convenience of care for patients, while avoiding increased clinician burden and promoting guideline-based care.^{22–26} In this manuscript, we describe the process of contextually grounded

intervention development, the resulting technology, and proof-of-concept testing in a small, real-world sample of adult patients in a large urban medical centre. We hypothesised that the intervention would show preliminary evidence of feasibility and acceptability and potential to improve asthma outcomes in younger adults with asthma.

Methods

Intervention development

As shown in Table 1, we navigated an extensive 2-year planning and development process aligning with May's implementation theory,²⁷ including identifying problems and solutions, target environments, system capabilities, key stakeholders, practice policies, and credentialing processes. Development required establishing key relationships: assembling a representative team, creating and testing the technology, obtaining approval to launch, and proof-of-concept testing with patients in the clinical setting.

Technology Enabled Asthma Management System (TEAMS) is a fully integrated EMR-based intervention designed for use in primary care. Based on the process described above, three technological components were selected to augment routine asthma care: (a) remote smartphone symptom monitoring, (b) synchronous smartphone telemedicine follow-up and self-management training with a nurse, and (c) computer-guided EMR assessments using built-in CDSS. Patients recorded home-entered symptoms using their smartphones and a patient portal app (Mychart; Epic Systems Corporation, Wisconsin USA), which uploaded symptom data directly to the Epic EMR. One nurse (JRM) conducted telemedicine visits using Zoom's HIPAA-compliant secure video-conferencing platform (Zoom Video Communications Inc. California USA). The nurse reviewed home-entered symptoms and entered a detailed asthma assessment into the TEAMS CDSS flowsheet (see Figure 1), which is a complex clinical documentation and decision-making tool embedded in the EMR. Guideline-based algorithms in the CDSS tool instantaneously calculated asthma severity, control, and provided a comparison of recommended versus prescribed step-wise therapy. The CDSS tool was designed to improve assessment accuracy, guide step-wise medication management,⁴ inform providers, and help patients achieve better asthma control. Results of the analyses were shared with the participant and evidence-based self-management training was provided using the free online resource *Let's Talk About Asthma!* e-series for smartphone developed in our prior work.^{28,29} A detailed progress note auto-generated by the CDSS

Table 1. Process of contextually grounded intervention development

	Key components of process	Examples
PLANNING STAGE		
Problems and potential solutions	• Identify target population and specific problems • Assess population capabilities, barriers, facilitators • Define approaches that might work for problem and population using prior evidence and theory	Population: Adults at risk for uncontrolled asthma (urban, minority, underserved, low SES, low health literacy) Problems: Poor access to care; no-show and transportation issues; non-adherence; poor follow-up; poor self-management. Opportunity: 85% adults < 40 years of age use smartphones regularly Environment: Urban primary care ‘safety-net’ practice
Target environment	• Identify environments with access to target population • Assess clinical capability, preparedness, and willingness to adopt a new intervention • Identify current clinical structure (physical resources, ways of operating, workflow and scheduling patterns) • Develop awareness of general and specific barriers (staff, provider, or clinic resource limitations) • Determine approaches that might work for clinical context, patient population, and identified problems	• Practice willing to support a tech-based asthma intervention <u>if no negative impact on workflow</u> • EMR/smartphone intervention run by nurses would be acceptable and integrate with practice • Modification to work flow/documentation patterns would not be supported by providers due to increased work burden • Limited availability of clinic appointments = delayed follow-up • Hours of operation: Weekdays until 4:30 p.m., conflicts with patient needs for afterhours and weekend care
System capabilities	• Identify system capabilities (technological, programmatic, IT resources, supports/barriers) • Identify implementation barriers (e.g. moratorium on new EMR build, anticipated build time and available build resources (personnel and systems access issues), willingness to support novel research-based build)	Capabilities: Symptoms can be monitored remotely with smartphones via patient portal to EMR interface • Guideline-based algorithms and decision-support tools in EMR can minimise inaccuracies in clinical care • Home-based telemedicine can improve access to care Barriers: Institutional cap on EMR build >10 h, requires formal review for priority and funding; research considered lower priority than clinical applications; limited funding available; initial plan to have clinic nurses do telemedicine visit was found to be non-viable due to patient need for evening and weekend visits, resulting in use of dedicated nurse interventionist
Key stakeholders	• Define potential impact of intervention (development and implementation) on patient, staff, and systems revenue or resources to identify stakeholders • Recognise and respect needs and perspectives of stakeholders who may impact intervention uptake (e.g. patient, community, support staff, nursing, provider, administrative, IT and data security, research, reporting, insurers)	Interviews and community engagement studios to engage: • admin: support for hybrid clinical/research program • medical faculty: support for program w/ resident participation • residents: support shared patient management; InBasket notification of nursing assessments; <u>not supportive</u> of any workflow change/disruption; low interest in using CDSS

(continued)

Table 1. Continued

	Key components of process	Examples
Practice policies	Identify practice policies and incorporate into design	- nursing: gatekeeper for clinical communication pathways; open to workflow changes if practicable, interested in maximising scope of practice, including use of CDSS and telemedicine follow-up - IT department: gatekeepers for new build; review/approve build - research community: requires rigorous science/data - patient and community: feedback on design, problems - Factor for established communication pathways, scheduling procedures, usual follow-up protocols - Identify internal 'champions' who can facilitate implementation
Credentialing and approval	- Determine what certifications may be necessary to obtain approval or facilitate development of the intervention (e.g. specific build or reporting certifications) - Identify needed permissions (e.g. IRB, clinical administration, provider/staff approvals or 'buy-in')	(Urgent) Epic Builder certification of researcher needed due to limited build resources; EMR build had to be performed by researcher, and administrative approval was needed at multiple levels to support this (Delayed) Asthma Educator certification necessary for eventual insurance billing
Funding sources	Identify immediate funding sources and potential for long-term sustainable funding	- Immediate: departmental and research funding - Eventual: foundation funding → insurer reimbursement - Current insurer policy does not reimburse for site-to-home telemedicine by nursing for asthma care; however demonstration of long-term cost savings could be used to drive policy changes
DEVELOPMENT STAGE		
Establishing relationships, assembling the team	Representative of key internal stakeholders	- Relationships: Faculty/staff, patient and community, administrative, clinical, research, and information technology - Team members: clinical, research, IT, administration, pharmacy, community liaison
Developing technology – a systems approach	- Translate guidelines to algorithms conceptually - Draft (code), revise and test technology - Build for compatibility with existing workflow - Minimise disturbances to current clinical patterns - Seek additional feedback from key stakeholders - Modify algorithms and output based on feedback	- Determine quantity, granularity, and specificity of data capture (categorical, interval, or narrative) - Determine approach to data entry (e.g. smartform, flowsheet) - Assess if data capture approach is well situated for reporting and statistical analyses and impact on workflow of data entry method - Identify evidence-based guidelines and write code for CDSS - Obtain expert review of CDSS

(continued)

Table 1. Continued

Key components of process		Examples
		(clinician, pharmacist, nursing)
		• Test program comprehensively for analytic functioning – 200 unique clinical scenarios evaluated across multiple iterations • Design + test CDSS auto-generated progress note, obtain clinician review of note content and format
IMPLEMENTATION STAGE		
Final approvals and launch	• Review of the final product by stakeholders	• Clinic permission to launch • IRB approvals • Beta testing with patient feedback and revision as indicated

Notes: CDSS = clinical decision-support software; EMR = electronic medical record; IT = information technology; SES = socioeconomic status; IRB = internal review board.

tool (see Figure 1, online supplement) was filed in the EMR for each telemedicine visit. Per protocol, an EMR InBasket message with a visit summary was sent to the PCP team if the patient had uncontrolled asthma and needed medication adjustments or office follow-up, with a back-up phone call for urgent issues. To ensure safety and monitor for correct functioning of EMR algorithms, all telemedicine visits in this phase were conducted by an advanced practice nurse with IT training (JRM), and each calculated output was verified for accuracy.

CDSS calculations used National Asthma Education Prevention Program guidelines⁴ but are adaptable to other guidelines. Program components are likely compatible with other EMRs.

Approach (Proof-of-concept testing)

This study was approved by the University of Rochester Internal Review Board (RSRB67900). A mixed methods approach was used. The quantitative portion consisted of a single-arm pilot study with pre-post and longitudinal collection of outcomes over 3 months (asthma control, quality of life, forced expiratory volume in 1 s (FEV₁)), emergency department (ED) visits, hospitalisations, feasibility/acceptability surveys). The qualitative portion used descriptive methodology and open-ended interviews to capture patients' experiences and perceptions of TEAMS, to explore acceptability and perceived impact. Staggered enrolment was used to account for seasonal variation in symptoms.

Setting and sample

Participants were randomly selected from clinic rosters in an urban safety-net resident-run primary care clinic

in Western New York (NY). Eligibility criteria were: ages 18–40, with any diagnosis of current asthma, English speaking and having a smartphone. Age range was restricted to younger adults (18–40 years) on the basis of smartphone prevalence and technology uptake. Patients with confounding comorbidities (e.g. heart failure chronic obstructive pulmonary disease, cystic fibrosis) and pregnant patients were excluded. Patients with psychiatric diagnoses were not excluded. Ten patients, randomly selected from clinic rosters, were screened; all had smartphones. One was ineligible on the basis of heart failure and two who were eligible could not be re-contacted after screening. The remaining seven consented and completed the beta-test (3-month duration).

Intervention delivery

Written informed consent and all study procedures were performed by a trained non-medical research assistant in patients' homes due to high office-visit no-show rates. Technology set-up and training occurred at the baseline visit. Participants were asked to record symptoms, medication use, and peak expiratory flow (PEF) using a Microlife³⁰ digital peak flow meter (PFM) (Microlife, USA) via smartphone, daily, for 3 months. A nurse (JRM) initiated follow-up smartphone telemedicine visits with patients every 2 weeks until asthma control was achieved, as calculated by the TEAMS CDSS tool. All visits were scheduled by text messaging and text message reminders were sent the day prior to or the day of appointment. Following each visit, if the CDSS tool indicated that the patient's asthma was uncontrolled, a brief synopsis was sent to PCP via EMR InBasket messaging with urgent messages also conveyed via phone call. The PCP then initiated medication adjustments via e-prescribing,

Nurse (computer) side - TEAMS CDSS tool:

*Values corresponding with uncontrolled asthma highlight in red with (!)

0700

SUBJECTIVE	(Quick tab #) = (Narrative text)
Patient perceived asthma control	1 = Not well controlled
Days per week with asthma symptoms	5 = Five days per week (!)
Wake up due to asthma per week	3 = Three nights per week (!)
Rescue inhaler for active symptoms per week	1 = One day per week
Rescue inhaler use BEFORE exercise	0 = Rarely using
Activity limitations due to asthma	1 = Some limitation (!)
Current respiratory illness	0 = No respiratory illness
Any smoking in the past 6 months	No
NOTES	Symptoms are worse at night than daytime...

OBJECTIVE	
Patient appearance	0 = Appears well
Respiratory effort	0 = Normal respiratory effort
Peak Flow	350
PFM personal best	450
• PFM % of personal best	78% (calculated)
FEV1 (today)	2.06
FEV1 Predicted	2.46
• FEV1 % of predicted	84% (calculated)
• FEV1 or PFM Zone	Green (calculated, FEV1 preferred)

NOTES

NURSING ASSESSMENT	
ICS formulation details (Rx)	Fluticasone MDI 220 mcg
Remaining inhalations (# on back of ICS inhaler)	85
Maximum prescribed puffs per day (AM + PM)	2
Actual puffs ICS (AM)	1
Actual puffs ICS (PM)	0
Other asthma control medications	0 = None
Current rescue medication	Albuterol (Proair)
Actual puffs rescue inhaler (describe)	Rarely using - rationing/holding off
Any symptoms of life-threatening asthma	N = None
Asthma safety assessment	N = No Safety concerns
NOTES	Having trouble remembering nighttime dose...

ANALYSIS + RECOMMENDATIONS (Calculated)

Asthma control	Not Well Controlled
Asthma severity (EPR3)	Moderate Persistent asthma
Guideline based assessment of controller therapy	Insufficient control medication
• Guideline recommended stepwise therapy	Step 3-4
• Provider prescribed stepwise therapy level	Step 3
• Patient using stepwise therapy level	Step 2
• Can still increase ICS by (#) puffs/day	1
• Recommended ICS adjustments	Increase to full prescribed dose
• Recommended follow up	Telemedicine follow up

NURSING PLAN

Follow up plan	2 = Follow up in 2 weeks
Medication refill	0 = No refills needed
NOTES	Continue to work on adherence, strategies to...

PLAN: Education

1. What is asthma: what causes symptoms	X = Demonstrates understanding
2. What happens when asthma is uncontrolled	X = Demonstrates understanding
3. How do you know if your asthma is controlled	X = Demonstrates understanding
4. Control vs. rescue medications	X = Demonstrates understanding
5. Recognizing symptoms of asthma	X = Demonstrates understanding
6. What to do during an asthma attack	
7. How to recognize life threatening asthma	
8. How to take inhalers correctly	N = Needs reinforcement !
9. How and why you should use a spacer	N = Needs reinforcement !
10. How to use a peak flow meter	
11. Asthma triggers and how to handle them	
12. Managing exercise induced asthma	
13. Keeping track of asthma symptoms	
14. Using an asthma action plan	
Personal goals for asthma management	Wants to improve exercise tolerance for basketball...
NOTES	Good return demo of inhaler technique, needs...
Total minutes asthma education	20

Patient (smartphone) side - LTAA series:

Let's Talk About Asthma®

Check your ASTHMA CONTROL:

	ALL green = WELL CONTROLLED	ANY yellow but NO red = NOT WELL CONTROLLED	ANY red = VERY POORLY CONTROLLED
OVER THE LAST MONTH symptoms	2 or LESS times a week	3 or MORE times a week	MANY times a day
night time wake up for symptoms	2 or LESS times a month	3 or MORE times a month	4 or MORE times a week
using rescue inhaler	2 or LESS times a week	3 or MORE times a week	3 or MORE times a day
activity limitations	NONE	SOME limitation	VERY limited
Peak Flow	MORE THAN 80 % of best	50 to 80% of best	LESS THAN 50 % of best

Your asthma is: Not Well Controlled

adapted from the National Guidelines (2007) Figure 3-4c

Let's Talk About Asthma®

Don't forget to use a Spacer!

Spacers help more medicine get in your lungs. When you use your inhaler with out a spacer a lot of the medicine gets lost.

1. Shake the inhaler and attach it to the spacer
2. Breathe OUT
3. Put the spacer mouth piece in your mouth, squirt in one puff into the chamber, and then inhale slowly through your mouth
4. Hold for 10 seconds
5. Wait 1 minute and repeat as directed
6. Clean your spacer as directed




get more medicine in your lungs!!

Let's Talk About Asthma! copyright J. Mammen. Used with permission.

Figure 1. Illustration of the TEAMS CDSS tool used by nurse for data entry and guideline-based assessments during telemedicine visits (left), including built-in patient educational modules from the Let's Talk About Asthma series for smartphone (right).

if warranted, and determined medically appropriate follow-up. The TEAMS nurse then helped to coordinate care and ensure follow-up. Once the patient achieved good asthma control, follow-up frequency decreased to once a month. There was no minimum requirement for participation in self-monitoring or telemedicine visits and patients participated in each activity as often as they were motivated to. Intervention dose for each participant was tracked and correlated with outcomes.

Outcome measures

Feasibility. Feasibility was measured by: a) frequency of participation in symptom monitoring, b) number of visits needed to achieve/maintain asthma control, c) duration of visits, and d) no-show and reschedule rates. Similar to clinical practice, length of visit was driven by the time it took to complete the asthma assessment, teach participants specific self-management skills and relay follow-up documentation to PCP/clinic. Thresholds for minimum or maximum

intervention dose were not predefined, as the goal was not to deliver a standard intervention dose, but to assess dose needed to achieve good control or dose tolerated (e.g. frequency of voluntary participation), and relationship between intervention dose, asthma control and quality of life.

Efficacy. Primary outcomes (asthma control, quality of life, and FEV₁ percent predicted) were collected at baseline and end-of-study. Asthma control and quality of life were measured using the Asthma Control Questionnaire (ACQ)³¹ and Asthma Quality of Life Questionnaire (AQLQ), respectively.³²

ACQ. The ACQ is a well-established 7-item questionnaire with a score range of 0–6 (lower scores represent better control). A score of ≤ 0.75 has a positive predictive value of 0.85 for controlled asthma, and a score of ≥ 1.5 has a positive predictive value of 0.88 for uncontrolled asthma.³¹ Minimum important difference (MID) is a change score of 0.5.³³

AQLQ. The AQLQ measures the physical and emotional impact of disease with high test–retest reliability (>0.90).³² Averaged total scale and subscale scores range from 1–7, with higher scores representing better quality of life. MID is 0.5 per domain and overall quality of life.³⁴

FEV₁ was measured using Microlife digital PFM.³⁰ FEV₁ percent predicted was calculated using NHANES III criteria.^{35,36} Number of prescriptions written by providers for asthma medications were obtained through EMR review for the year pre and post intervention. Actual refills by patients could not be accurately determined due to external pharmacy data storage procedures.

Acceptability. Acceptability was assessed at the end of the study through 1:1 interview and the Usability, Satisfaction and Ease of Use Questionnaire (USE-Q). The USE-Q³⁷ is a validated 21-item instrument with a 7-point Likert scale format (1 = strongly disagree to 7 = strongly agree). Higher scores represent more positive perceptions, with 7 being the most positive possible score and 1 representing the most negative possible score. Minimum acceptability thresholds were a score ≥ 5 = somewhat agree on at least 70% of USE-Q items. Exit interviews were conducted to qualitatively explore acceptability.

Demographics were collected via survey and the EMR.

Data analysis

Descriptive statistics were computed for demographics, feasibility and USE-Q data. Paired *t*-tests were used to compare baseline and end-of-study scores for ACQ,

AQLQ and FEV₁ percent predicted, and effect sizes (Cohen's *d*) were calculated. Unadjusted bivariate correlation was used to explore associations between asthma control and quality of life (ACQ, AQLQ) and intervention dose (frequency of self-monitoring and telemedicine visits). Audio-recorded interviews were transcribed and qualitative content analysis techniques³⁸ were used to explore participants' perceptions of the program.

Results

Baseline asthma and demographic data are presented in Table 2.

Feasibility

Of 42 scheduled telemedicine visits, 7 were no-shows (16%; 4/7 patients), 7 rescheduled (16%; 4/7 patients), and 28 were conducted as expected (68%). Participants averaged four telemedicine visits (range 3–5), for a grand mean of 114 min spent with the asthma telemedicine nurse (range 88–160 min; SD 25.07; average

Table 2. Sample baseline characteristics (*n* = 7).

Variable	N (%)
Single (% Yes)	6 (86)
Low income ^a (% Yes)	5 (71)
Employed full time (% Yes)	5 (71)
Public insurance (% Yes)	4 (57)
High school graduate (% Yes)	5 (71)
Sex (% Female)	6 (86)
Comorbid mental illness (% Yes) ^b	5 (71)
Comorbid substance use disorder (% Yes) ^c	4 (57)
Ethnicity (%)	
African American	4 (57)
Hispanic/Latino	2 (29)
Caucasian	1 (14)
Any controller medication use past month? (% Yes)	3 (43)
Asthma control (%)	
Well-controlled	0
Not well-controlled	2 (29)
Very poorly controlled	5 (71)
Asthma severity (%)	
Mild persistent	0
Moderate persistent	2 (29)
Severe persistent	5 (71)
	Mean (SD)
Age	29.5 (5.22)
Years diagnosed with asthma	16.57 (8.33)

Notes: ^aLow income: <200% US Federal poverty level (\$12,140 individual; \$25,100 for a family of four).³⁹

^bMental illness: bipolar, PTSD, panic disorder, anxiety/depression.

^cSubstance use disorders: marijuana, tobacco, alcohol.

Table 3. Change pre to post intervention for key clinical asthma outcomes.

	Baseline mean (SD)	End mean (SD)	Change mean (SD)	Effect (d)	P-value	CI
ACQ ^a	2.75 (1.27)	1.20 (1.35)	−1.55 (1.02)	1.16	0.007	0.59–2.51
Morning symptoms	2.00 (0.82)	1.00 (1.00)	1.00 (1.00)	1.09	0.045	0.075–1.93
Nighttime waking	2.43 (1.71)	0.57 (1.13)	1.86 (1.95)	1.28	0.038	0.052–3.66
Activity limitations	3.00 (1.92)	1.73 (1.90)	1.57 (1.27)	0.66	0.017	0.40–2.75
Shortness of breath	4.00 (1.52)	2.00 (2.00)	2.00 (1.00)	1.13	0.002	1.08–2.93
Wheezing	2.86 (1.22)	1.00 (1.29)	1.87 (1.34)	1.48	0.011	0.61–3.10
SABA use	2.14 (2.04)	1.29 (1.60)	0.86 (1.57)	0.46	0.20	−0.60–2.31
AQLQ ^a	3.69 (1.27)	5.60 (2.13)	1.91 (1.53)	1.09	0.016	0.50–3.31
Symptom domain	3.49 (1.60)	5.69 (2.13)	2.20 (1.52)	1.17	0.009	0.79–3.61
Activity domain	4.12 (1.15)	5.57 (2.21)	1.45 (1.44)	0.82	0.037	0.12–2.79
Emotional domain	3.49 (1.59)	5.77 (1.99)	2.29 (2.17)	1.27	0.032	0.28–4.29
Environmental domain	3.39 (1.18)	5.18 (2.29)	1.79 (1.86)	0.98	0.044	0.06–3.51
FEV ₁ %Pred	76.14% (17.79)	91.00% (12.99)	14.86% (19.4)	0.96	0.089	−3.09–32.80
	Year prior (SD)	Year post (SD)	Change (SD)	Effect (d)	P-value	CI
Emergency visits	0.28 (0.76)	0 (0.0)	0.28 (0.76)	0.52	0.356	−0.41–0.98
Preventive office visits	0.29 (0.49)	1.86 (0.69)	1.57 (0.96)	2.62	0.005	0.67–2.47
Prescriptions – controller medication	1.57 (2.70)	9.29 (3.50)	7.71 (3.09)	2.47	0.001	4.85–10.58
Prescriptions – SABA	4.29 (3.30)	10.57 (7.02)	6.29 (6.55)	1.14	0.044	0.22–12.34
Prescriptions – OCS	0.43 (0.79)	0.14 (0.38)	0.28 (0.95)	0.47	0.457	−0.59–1.17

Notes: ACQ = Asthma Control Questionnaire; AQLQ = Asthma Quality of Life Questionnaire; OCS = oral corticosteroid; SABA = short acting beta agonist.

^aMinimum important difference = 0.5 per domain and total score.

Large effect size (*d*) is considered >0.80.

61 min self-management training and 53 min nursing-assessment per participant). Participants logged symptoms remotely an average of 32 days over 3 months (range 15–64; SD 15.56). Participants were asked to set a daily reminder on their smartphone; no external reminders were provided for self-monitoring. Average telemedicine visit duration was 29 min (range 20–45 min), and the majority of visits (17/28; 61%) were delivered after 5 p.m. or on weekends to accommodate participants' work schedules.

Efficacy

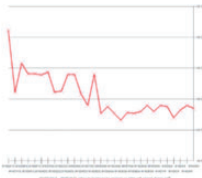
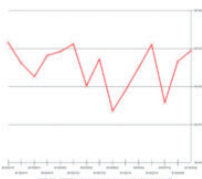
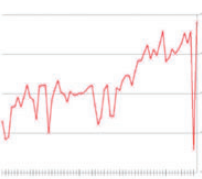
At baseline, all participants had uncontrolled asthma. At 3 months, 6/7 participants had a marked reduction in symptoms with 5/7 classifying as well-controlled.⁴⁰ Effect sizes were large for improvements in control, quality of life, and FEV₁ percent predicted (*d* = 0.96–1.16). Table 3 shows pre–post scores for asthma outcomes with effect sizes and confidence intervals. On average, asthma control improved 1.55 points – more than three times the clinical MID. Significant improvements were seen in morning symptoms, nighttime waking, activity limitations and shortness of breath, with greatest effects on reductions in wheezing (*d* = 1.48).

Quality of life improved an average of 1.91 points, nearly four times the MID. Improvements were evenly distributed across all domains (symptoms, activity limitations, emotional functioning, and environmental stimuli). There was also an average increase of approximately 15% in FEV₁ percent predicted.

Table 4 shows individual peak flow graphs (extracted from the EMR) with a noticeable upward trend in PEF for most participants. Graphs for the first two participants showed downward or neutral trends. Association between number of days participants performed home self-monitoring, length of visit, and improvement in asthma control was moderate (*r* = 0.67 and *p* = 0.10).

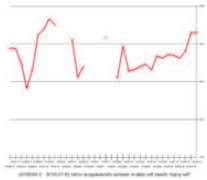
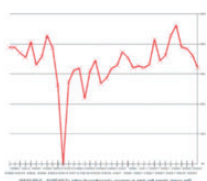
An average of 2 (range 1–4; SD 1.29) InBasket messages per participant were sent by the TEAMS nurse to the participants' PCP (*n* = 4) over 3 months, to coordinate follow-up care and medication adjustments, with 100% PCP response. As seen in Table 3, there were significant and clinically meaningful increases in use of preventive health services and written prescriptions for controller medications, and a corresponding decrease in prescriptions for oral corticosteroids in the year following intervention.

Table 4. Key outcomes and qualitative data by case for patients participating in TEAMS beta-test.

P# (Sex) Race Age	Graph of daily PEF (extracted from EMR) Baseline → end	Measure	Pre	Post	Perceived impact of intervention (exit interviews)
P#1 (F) AA 40		ACQ AQLQ FEV1%pred # Televisits # Entries ^a	4 2.43 67 29	4 1.19 68 3 29	[Before] I didn't realize my asthma wasn't controlled, I was wheezing but I just thought I had a cold all the time ... I thought I was doing pretty good even though I be out of breath. But when I started using [the peak flow] I saw the numbers and realized I couldn't breathe, and that made me want to get my lungs healthy ... I'll be honest, I didn't used to take my pump, but now I use it every day.
P#2 (F) AA 32		ACQ AQLQ FEV1%pred # Televisits # Entries	2.14 3.97 85 15	1.29 5.84 84 4 15	The program helped me recognize the symptoms of my asthma ... I learned if you don't take your control medicine you can scar your lungs – that got me to pay attention! Now that I'm daily taking my medicine—it's given me a whole 'nother breath ... I thought I didn't need it, 'til I found out how to use it and what it does for your body. I'm recommending this to my family and friends – I'm spreading the word!
P#3 (F) HL/AA 29		ACQ AQLQ FEV1%pred # Televisits # Entries	5 1.88 46 64	1.71 4.59 100 5 64	I realized I have the right to control my asthma. First time we met I was crying 'cause all I wanted to do is breathe, but I felt powerless. This changed my life – I'm like 100% better. [Before] I didn't use my inhalers cause of how I was raised. Now I take my [control inhaler] every day. ... I had a medication that could've been helping me the whole time, but I didn't know what it was for, so I'm not gonna take it!
P#4 (F) AA 24		ACQ AQLQ FEV1%pred # Televisits # Entries	2.29 4.41 102 24	0.43 6.94 103 4 24	I used to have symptoms for hours every day, and now I almost never do. I take my control inhaler every day and I work out – and I couldn't do that before. And before, if I had an asthma attack, I wouldn't take my inhaler, I would've just called the ambulance and gone to the hospital. But [now] I take it and it works! I have the knowledge and confidence that I can take care of myself – This changed my life!
P#5 (M) AA 29		ACQ AQLQ FEV1%pred # Televisits # Entries	2.43 3.28 85 24	0.43 6.88 95 3 24	I'm not really having symptoms anymore, maybe once a week. Before I was wheezing all the time, and I didn't have any medication, and I didn't know what was causing it. I was suffering. Now, I take my control medication every day. It takes a load off a person when you get the education and you can monitor it and control it ... it changed my life dramatically. I can breathe, and I can control it. I feel like a regular person. It's amazing. I recommend <i>anyone</i> do this.

(continued)

Table 4. Continued

P# (Sex) Race Age	Graph of daily PEF (extracted from EMR) Baseline → end	Measure	Pre	Post	Perceived impact of intervention (exit interviews)
P#6 (F) C 24		ACQ AQLQ FEV ₁ %pred # Televisits # Entries	1.57 5.50 80 5 34	0.29 6.81 103 5 34	I'm more aware and more educated about my symptoms now, and I take my control meds every day. I used to wait out my symptoms, thinking 'it'll go away, it's OK'. I'm less accepting of symptoms now because I know I'm doing damage – I was never taught that. It's kind of embarrassing . . . I'm a nurse and I should've known these things. Now I can better educate my patients and even my doctors.
P#7 (F) HL 24		ACQ AQLQ FEV ₁ %pred # Televisits # Entries	1.71 4.47 68 4 36	0.29 6.94 84 4 36	[Crying] Six months ago I was scared. I was out of work for a month because of asthma. Now I'm not scared and I know what to do to prevent something small from getting big. Before, I never paid for my control inhaler because it was expensive and I didn't know why I should get it when I could use the cheap one. I don't freak out now if I leave home without my rescue inhaler because I almost never need it.

Notes: ^aEntries = home-entered symptoms; AA = African American; ACQ = Asthma Control Questionnaire (range 0–6; lower scores represent better asthma control: <1.5 is predictive of controlled asthma); AQLQ = Asthma Quality of Life Questionnaire (range 1–7; higher scores represent better quality of life); C = Caucasian; HL = Hispanic/Latino; F = Female; M = Male; P# = Participant(#); Visits = telemedicine visits with a nurse; Recordings = daily home symptom and peak flow recordings via smartphone patient portal. (PEF graph images extracted from the EMR show peak flow over time and have been flipped to display data in left to right chronological order.) PEF images © 2019 Epic Systems Corporation. Used with permission.

Acceptability

As shown in Table 5, acceptability and satisfaction was high (93.9%). At exit interviews, six of seven participants reported that the intervention 'changed my life' and enabled them to take control of their asthma for the first time. Qualitative data on the perceived impact of the intervention are presented in Table 4.

Discussion

Data from this proof-of-concept study suggest that use of an integrated smartphone and EMR/practice-based intervention might be an effective means to supplement primary asthma care and improve outcomes. The underlying importance of this approach lies in the ability to reduce barriers to accessing primary care.¹⁸ Telemedicine is inherently more flexible than office care, and does not require that patients travel to a given location. Extending telemedicine into patients' homes via ubiquitously available smartphones could make communities the front line for primary care. Because of the ability to supersede geographic boundaries, smartphone technology could increase clinical

reach, and may thus be the key to delivering care to underserved populations locally and globally.

Prior studies have demonstrated that use of remote monitoring, self-management training, telemedicine, smartphones, and CDSS tools, individually, can improve outcomes.^{41–43} To our knowledge, however, this is the first intervention to combine these components into a single technological package that effectively integrates with real-world medical practice and the live EMR.

In contrast to studies that have sought to isolate and quantify the impact of individual factors,^{44,45} this study adopted a broad-spectrum approach with simultaneous intervention across multiple patient, provider and systems levels, as we theorised that the impact of a multifaceted program would likely be different from the impact of individual components in isolation.^{46,47} The marked improvement in outcomes, as evidenced by large effect sizes on key outcomes ($d=0.96$ to 2.62), supports this holistic approach. On average, participants achieved a 15% increase in FEV₁, crossing the critical clinical threshold of >80%.⁴⁰ Additionally, improvements in asthma control and quality of life were 3 to 4 times the MID.^{31,34}

Table 5. Item scores for the Usability, Satisfaction and Ease of Use Questionnaire

	Mean	Range (1–7)	SD
It helps me be more effective.	7	7	0
It helps me be more productive.	6.86	6–7	0.378
It is useful.	6.71	6–7	0.488
It gives me more control over the activities in my life.	6.71	6–7	0.488
It makes the things I want to accomplish easier to get done.	6.43	4–7	1.134
It saves me time when I use it.	6.14	4–7	1.215
It does everything I would expect it to do.	6.43	4–7	1.134
It is easy to use.	6.29	5–7	0.951
It is easy to use. It is simple to use.	6.86	6–7	0.378
It is user friendly.	6.86	6–7	0.378
It requires the fewest steps possible to accomplish what I want to do with it.	6.57	5–7	0.787
I learned to use it quickly.	6.57	5–7	0.787
I easily remember how to use it.	6.57	6–7	0.535
It is easy to learn to use it.	6.71	6–7	0.488
I am satisfied with it.	6.86	6–7	0.378
I would recommend it to a friend.	6.57	5–7	0.787
It is fun to use.	6.43	4–7	1.134
It works the way I want it to work.	6.43	4–7	1.134
It is wonderful.	6.43	5–7	0.976
I feel I need to have it.	6.14	3–7	1.574
It is pleasant to use.	6.43	4–7	1.134
Average score for survey	6.57	5.6–7	0.654

Notes: Likert scale range 7 = Very satisfied to 1 = Very dissatisfied.

Patients' perceptions of acceptability and feasibility were high, and while participants recorded symptoms only 33% of the time on average, greater engagement was associated with improved asthma control. Lastly, the significant increase in written prescriptions for controller medications and in-office PCP follow-up suggest that the intervention can promote provider adherence to guideline-based care, in addition to improving patient-specific outcomes.^{20,48}

From a systems standpoint, clinical feasibility and affordability has yet to be determined. In this small sample, no-show and reschedule rates for telemedicine visits was only slightly better than office-visit attendance rates (66%), with 68% of telemedicine visits conducted as expected.⁴⁹ Further research is needed to determine cost-effectiveness and institutional capability to run a program that operates predominantly during evening and weekend hours. Furthermore, given that participants required an average of 114 min of individualised asthma education with a nurse to achieve and maintain control, the TEAMS approach is likely to require greater upfront investment by insurers and the medical community to achieve long-term societal gain. Yet, it is abundantly clear that current approaches to 'feasible and affordable care' are not effective, as the majority of patients with asthma remain chronically uncontrolled. Thus, it may be necessary to stretch healthcare boundaries and explore ways to make *effective* care *affordable*, rather than

perpetuating systems that are *affordable* but largely *ineffective*. In short, moving towards aggressively proactive rather than reactive approaches to asthma management is essential to changing long-term health trajectories.⁴⁷

Limitations

This proof-of-concept study used a small sample. Patients were predominantly younger, minority, lower socioeconomic status, lower health literacy, with moderate/severe uncontrolled asthma, and the intervention was delivered by a single nurse. Further research in a larger and more representative population, with diverse interventionists is needed to replicate findings, evaluate who the intervention is most effective for, and determine if all intervention components are necessary to achieve similar outcomes.

Despite limitations, we believe these data are compelling, and the processes delineated herein will be useful to those seeking to develop and implement technology-based clinical interventions. Several important lessons were learned: First, the technology took nearly 2 years to conceptualise, build, and integrate into practice, which was longer than anticipated. The majority of this time was spent navigating systems-level barriers, gaining access to EMR build/programming environments, and getting healthcare provider buy-in. It is well-known that many potentially effective

interventions are never integrated into clinical practice or the EMR. Our experience suggests that this may be partly due to failure to account for powerful real-world constraints. As seen throughout the development process (Table 1), we found that wherever the intervention disrupted existing practice (even by small amounts), it was met with resistance. Conversely, by avoiding workflow changes and carefully incorporating stakeholder feedback, we were able to minimise resistance and increase support for the intervention. It is also worth noting that even with using a contextually grounded intervention development approach, where the intervention was crafted to the clinical context, there was still a requirement for additional on-the-ground customisation to account for unanticipated barriers (e.g. trouble engaging patients in office settings; preference of clinic providers to delegate use of the CDSS tool to nursing care). Thus, the final intervention that was implemented was noticeably different than originally conceptualised. Use of focus groups, interviews, community engagement studios, and close collaboration with key stakeholders are important precursors to developing a clinically sustainable intervention.²⁷ Additionally, careful negotiation of institutional practices for new EMR build and IT and administrative support will be essential, as there are substantial barriers to new technology within the EMR due to the potential for far-reaching negative systems impact. Based on these experiences, we conclude that use of advanced EMR, CDSS, and smartphone technology has strong potential to improve asthma care, but premature intervention development without sufficient groundwork could be detrimental to long-term success.

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