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Early View

Original article

The Electronic Asthma Management System (eAMS) Improves Primary Care Asthma Management

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The Electronic Asthma Management System (eAMS) Improves Primary Care Asthma Management

Running title: Electronic Asthma Management System (eAMS)

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TAKE HOME MESSAGE:

The Electronic Asthma Management System - a systematically developed and evidence-based computerized decision support tool that engages both patients and healthcare providers - improves the quality of asthma care in real-world primary care settings.

TWITTER MESSAGE: The Electronic Asthma Management System (eAMS) - a systematically developed and evidence-based computerized decision support tool that engages both patients and healthcare providers - improves the quality of asthma care in real-world primary care settings.

ABSTRACT

A high prevalence of suboptimal asthma control is attributable to known evidence-practice gaps. We developed a computerized clinical decision support system (the Electronic Asthma Management System – eAMS) to address major care gaps and sought to measure its impact on care in adults with asthma.

This was a 2-year interrupted time series study of usual care (year 1) versus eAMS (year 2) at 3 Canadian primary care sites. We included asthma patients aged $\geq$ 16 years receiving an asthma medication within the last 12 months. The eAMS consisted of a touch tablet patient questionnaire completed in the waiting room, with real-time data processing producing electronic medical record-integrated clinician decision support.

Action plan delivery (primary outcome) improved from 0/412 (0%) to 79/443 (17.8%) eligible patients [absolute increase 0.18 (0.14,0.22)]. Time series analysis indicated a 30.5% increase in physician visits with action plan delivery with the intervention ($p < 0.0001$). Assessment of asthma control level increased from 173/3497 (4.9%) to 849/3062 (27.7%) eligible visits [adjusted OR 8.62 (5.14, 12.45)]. Clinicians escalated controller therapy in 108/3422 (3.2%) baseline visits versus 126/3240 (3.9%) intervention visits ($p=0.12$). At baseline, a short-acting beta-agonist alone was added in 62 visits and a controller added in 54 visits; with the intervention, this occurred in 33 and 229 visits, respectively ($p<0.001$).

The eAMS improved asthma quality of care in real-world primary care settings. Strategies to further increase clinician uptake and a randomized controlled trial to assess impact on patient outcomes are now required.

Registration: ClinicalTrials.gov: NCT01070095

INTRODUCTION

Asthma affects 339 million people globally and is increasing in prevalence.[1] Although well-controlled asthma is achievable in most patients, more than half of patients remain poorly controlled.[2-4]

Three evidence-based care gaps are major contributors to poor asthma control[5, 6]: 1) Control monitoring: assessment of asthma control using guideline criteria is performed in as few as 1% of clinical encounters,[7] resulting in under recognition of suboptimal control.[2, 8]; 2) Medication adjustment: only 39% of physicians report basing asthma therapy on guideline recommendations,[8] leading to asthma under treatment.[2, 8]; and 3) Asthma action plan (AAP) delivery: only 4% of primary care physicians report consistently providing a written AAP[9] and only 2% of asthma patients actually receive one.[10]

Applying the Knowledge-to-Action Framework,[11] we hypothesized that the underlying barriers to these key practices could be addressed by a point-of-care computerized clinical decision support system (CDSS). Given that a majority of patients with asthma are managed in primary care, we designed and integrated a CDSS - the Electronic Asthma Management System (eAMS) - into an electronic medical record system (EMR). We sought to measure the impact of the eAMS on evidence-based care.

METHODS

Study Design, Setting, Population

This was a two year prospective interrupted time series (ITS) design study of usual asthma care (baseline period) (year one) followed by implementation of the eAMS (intervention period) (year two). The study was approved by the St. Michael's Hospital and Hamilton Integrated Research Ethics Boards, registered, and carried out across a convenience sample of two academic primary care sites in Hamilton, Ontario (population ~550K) (sites 1,2) and one non-academic primary care site in Brampton, Ontario (population ~570K) (site 3). All prescribing clinicians were invited. We developed and validated an EMR search algorithm for asthma,[12] then applied this to the practices of consented clinicians. We included asthma patients aged $\geq$ 16 years who understood English and had been on an asthma medication in the prior year. We excluded patients who had been on a COPD medication in the prior year.[12]

Further details are provided in an online data supplement.

Intervention

Overview

During the baseline period, all clinicians were emailed a link to an online educational module on how to complete an AAP, and paper/electronic copies of a blank AAP. As reported previously, we developed the AAP for this trial through a systematic analysis of existing AAPs,[13] patient and provider stakeholder wiki-based collaborative editing, and usability optimization.[14, 15] During the intervention period, the eAMS was available in e-charts of all included patients (access was chart-based and not clinician-based). The eAMS consisted of: 1) a touch tablet patient questionnaire used in the clinic waiting room; and 2) a five screen point-of-care CDSS that received and processed questionnaire data to produce decision support integrated into the

EMR in real-time (Figure 1). We developed the eAMS user interface through serial testing and user feedback and implemented it through rounds presentations before and after launch, written pamphlets, and online resource materials.

Patient Questionnaire

We developed the patient questionnaire and optimized content and usability through serial focus groups with asthma patients (described elsewhere)[16, 17], as previously recommended.[18] The questionnaire required five to ten minutes to complete and ascertained: asthma control (using Canadian guideline-recommended symptom-based criteria);[19] medication use; and details required for AAP personalization [e.g. symptoms, activities (including sports), triggers, allergies]. Patients were provided with the tablet questionnaire by a clinic staff member (e.g. receptionist) upon arrival for their appointment. An embedded questionnaire message encouraged patients to prompt their practitioner to provide an AAP.

CDSS

Upon opening the chart of any patient who had completed the questionnaire, clinicians saw a notification indicating the patient's current asthma control and prompting them to open the CDSS. The CDSS provided: the patient's control criteria and self-reported medication use (screen 1); evidence-based medication escalation/de-escalation recommendations (screen 2); AAP yellow zone (acute loss of control zone) medication recommendations (screen 3); a pre-populated AAP (screen 4); and a reminder to book follow-up and provide a pre-printed sticky-note with an educational website URL (screen 5)[20] (the website included inhaler technique videos and a self-directed web-based asthma educational program). If users progressed through at least one of these screens, a documentation note was automatically written to the EMR chart. If clinicians approved the AAP, it was sent to the chart for printing.

The CDSS development process is described elsewhere. This included development of medication escalation/de-escalation logic rules through a review of existing international asthma guidelines,[21] establishment of evidence-based rules for AAP yellow zone medications through a systematic review,[22] and application of evidence-based methods to optimize the language and format of provided guidance.[23] The AAP populated by the eAMS was the same as that used in the baseline phase (details above).

Further intervention details are provided in an online data supplement.

Outcomes

Four trained reviewers performed an electronic chart audit of all outpatient visits and asthma-related telephone interactions (see details in the online data supplement). The primary outcome was AAP delivery, measured by the proportion of patients/visits with written AAP delivery during the intervention versus baseline period [comparison of cumulative proportion of *patients* receiving an AAP, ITS analysis with autoregressive integrated moving average (ARIMA) model for *visits* with AAP delivery]. Secondary outcomes included: comparison of the cumulative proportion of patients/visits with asthma control determined according to symptom-based criteria (control determination required meeting one or more criteria for uncontrolled asthma or all criteria for controlled asthma; see online data supplement Table 1); and the proportion of patients/visits with escalation of controller therapy (including initiation of controller therapy), during the intervention versus baseline period. We attempted to identify predictors of these outcomes through a generalized linear mixed model (GLMM) including the following candidate parameters, defined a priori: clinic, appointment provider practitioner type, prior objective diagnosis of asthma, documented physician diagnosis of asthma, presenting complaint type,

billing physician (most responsible physician/other), previous emergency department (ED) visits/hospitalizations for asthma, and current asthma control. We compared the proportion of oral corticosteroid prescriptions and rescue to controller medication prescriptions between periods. During the intervention period, we measured the proportion of visits where patients had good control in which medications were de-escalated, proportion of patients in whom discussions about medication adherence took place, and system uptake.

Analysis

The intervention period included all visits that occurred while all components of the eAMS were active, in each respective clinic. We compared patient variables between baseline and intervention periods with Fisher's exact/chi square tests and ANOVAs, as appropriate. We compared outcome proportions between periods with the chi square test. AAP delivery measured the proportion of patients on an asthma controller medication for at least 1 visit who received an AAP (excluding those who had received/reviewed an AAP in the last 6 months). In the ITS analysis, we compared outcomes rates in 26 consecutive 2-week intervals prior to the intervention to those in 26 consecutive 2-week intervals following the intervention, using an ARIMA model. Model checking examined autocorrelation and partial autocorrelation plots and the Augmented Dicky-Fuller test and Ljung-Box test. In measuring asthma control assessment, we eliminated visits in which control had been assessed within 28 days.[5] In measuring therapy escalation, we eliminated visits in which escalation had been made within three months. To account for individual and clinical risk factors as well as the longitudinal component, we used a GLMM with a logit link to identify predictors of main outcomes among patients seen in both the baseline and intervention periods. A random effect was included to account for within subject correlation (confidence intervals were bootstrapped). Analyses were performed using R

Statistical Software (Version 3.4.0). Statistical significance was defined at a two-sided 0.05 level. Sample size calculations and further analytic details are presented in the online data supplement.

RESULTS

Chart Review

Agreement between reviewers in chart abstraction was 82.8–97.3% for control criteria, 97.5% for assessment of medication changes, and 100% for AAP delivery (the kappa statistic could not be computed due to perfect agreement for the primary outcome).

Population

We recruited 19/37 (51.4%) approached physicians and 1/3 (33%) approached nurse practitioners (NPs). One physician withdrew consent before intervention launch, leaving 18/37 (48.4%) physicians. The NP managed patients from an additional 5 physicians, enabling us to include patients from 23/37 (62.2%) physicians. These physicians had been in practice for 16.1 +/- 8.9 years (range 2-33 years) and 15/23 were female (65.2%). They were the most responsible physician for 830 eligible patients seen in the baseline period (3565 eligible visits) and 890 seen in the intervention period (3444 eligible visits) (Table 1). There were 1272 unique patients seen over the study period, with 382 (30.0%) seen exclusively in the baseline period, 442 (34.8%) seen exclusively in the intervention period, and 448 (35.2%) seen in both periods. Given that patients occasionally saw clinicians other than their most responsible physician for urgent issues, these patients received care from 237 unique providers: 156 residents, 60 staff physicians [41 (68.3%) female, in practice for 16.6 ± 11.8 years (range 2-52)], 20 NPs, and 3 PAs. Each provider averaged 29.6 ± 58.2 visits (range 1-439). In the baseline period, 140/3565 (3.9%) visits

were related to asthma, compared to 158/3444 (4.6%) visits in the intervention period (p=0.19), and 276/830 (33.3%) patients had at least one visit for a respiratory complaint, compared to 281/890 (31.6%) in the intervention period (p=0.49).

Table 1. Patient Characteristics

Characteristic	Baseline Period (n=830)	Intervention Period (n=890)	p-value
Mean age +/- SD (years)	45.9 ± 17.4	47.3 ± 17.2	0.084
Female Sex, n (%)	602 (72.5%)	632 (71.0%)	0.519
Smoking status, n (%)			0.001
Non-smoker	411 (49.5%)	460 (51.7%)	
Ex-smoker	161 (19.4%)	185 (20.8%)	
Current Smoker	124 (14.9%)	157 (17.6%)	
Not documented	134 (16.1%)	88 (9.9%)	
Comorbidities, n (%)			
Atopy	331 (39.9%)	350 (39.3%)	0.285
COPD	62 (7.5%)	68 (7.6%)	0.966
Other Respiratory Diagnosis	16 (1.9%)	13 (1.5%)	0.573
Prior objective testing, n (%)			
Spirometry	529 (63.7%)	579 (65.1%)	0.600
Methacholine challenge	74 (8.9%)	73 (8.2%)	0.658
Prior Asthma Care (since 2003)			
Seen by pulmonologist or allergist	136 (16.4%)	158 (17.8%)	0.491
Seen in ER or hospitalized for asthma	51 (6.1%)	38 (4.3%)	0.100
Baseline Medications (first study visit), n (%)┼			
Short-acting bronchodilator	469 (56.5%)	544 (61.1%)	0.058
Inhaled corticosteroid alone*	147 (17.7%)	173 (19.4%)	0.391
Inhaled corticosteroid with long-acting beta-agonist	125 (15.1%)	158 (17.8%)	0.150
Long-acting beta-agonist alone	6 (0.7%)	4 (0.4%)	0.669
Leukotriene receptor antagonist	21 (2.5%)	26 (2.9%)	0.727
Long-Acting Muscarinic Antagonist	6 (0.7%)	13 (1.5%)	0.218
Prednisone†	8 (1.0%)	6 (0.7%)	0.689

┼ formal assessment of asthma severity was not possible, as this requires knowledge of which medications are required to achieve good control, and asthma control itself was not known for most patients. A breakdown of baseline medications by control status is provided in the online data supplement

* without concurrent use of a long-acting beta-agonist in a combination inhaler or as a separate inhaler

† includes only those patients using prednisone chronically

COPD denotes chronic obstructive pulmonary disease; ER denotes emergency room

System Uptake

In the intervention period, 551/890 (61.2%) patients completed the questionnaire at least once. Clinicians accessed the CDSS in 174 of the 505 patients (34.4%) in whom actions were required. A detailed mixed-methods system uptake analysis will be reported separately.

Primary Outcome

The proportion of patients on a controller medication who received an AAP was 0/412 (0%) in the baseline period and 79/443 (17.8%) in the intervention period [absolute increase 0.18 (0.14,0.22)]. In the ITS analysis, there was an increase in the proportion of visits where patients received an AAP from 0 at baseline to 0.305 at the time of intervention ($p < 0.0001$) (Figure 2). There was no significant decreasing trend as the intervention period progressed ($p=0.17$). Modelling was not possible due to the absence of AAP delivery in the baseline period.

Secondary Outcomes

Asthma Control Monitoring

Practitioners determined asthma control according to symptom-based criteria in 173/3497 (4.9%) eligible visits in the baseline period, and 849/3062 (27.7%) in the intervention period ($p<0.001$). Control was determined at least once in 118/830 (14.2%) and 523/890 (58.8%) patients, respectively ($p<0.001$). After adjusting for other variables, control was more likely to be ascertained during the intervention period [odds ratio (OR) 8.62 (5.14, 12.45)] (Table 2).

Table 2. Predictors of Asthma Control Assessment

Variable	Control Not Assessed (n=5537 visits)	Control Assessed (n=1022 visits)	GLMM Model (OR, 95% CI) (n=4143 visits)*
Period†			
Baseline	3324 (95.1%)	173 (4.9%)	
Intervention	2213 (72.3%)	849 (27.7%)	8.51 (5.51, 11.52)
Clinic			
1	2290 (79.8%)	578 (20.2%)	
2	1052 (86.4%)	166 (13.6%)	0.63 (0.46, 0.90)
3	2195 (88.8%)	278 (11.2%)	0.28 (0.21, 0.41)
Practitioner Type			
Physician	2705 (84.9%)	481 (15.1%)	
Nurse Practitioner	506 (88.9%)	63 (11.1%)	0.93 (0.59, 1.49)
Resident	1924 (82.0%)	423 (18.0%)	1.38 (0.99, 1.86)
Physician Assistant	402 (88.2%)	54 (11.8%)	1.22 (0.74, 2.01)
Objective Asthma Diagnosis			
No	3308 (85.2%)	576 (14.8%)	
Yes	2229 (83.3%)	446 (16.7%)	0.78 (0.61, 0.99)
Physician-Documented Asthma Diagnosis			
No	2251 (88.8%)	283 (11.2%)	
Yes	3286 (81.6%)	739 (18.4%)	1.35 (1.01, 1.75)
Presenting Complaint			
Asthma	148 (54.6%)	123 (45.4%)	
Non-respiratory	4874 (87.7%)	684 (12.3%)	0.11 (0.08, 0.18)
Respiratory (non-asthma)	515 (70.5%)	215 (29.5%)	0.65 (0.43, 1.06)
Previous ED visit(s)/hospitalization(s)			
No	5278 (84.8%)	948 (15.2%)	
Yes	259 (77.8%)	74 (22.2%)	1.97 (1.18, 3.06)
Seen by MRP			
No	3676 (84.0%)	701 (16.0%)	
Yes	1861 (85.3%)	321 (14.7%)	1.12 (0.83, 1.53)

* the model included only the 448 subjects seen in both baseline and intervention periods (4143 total visits)

† both in the baseline and intervention periods, there was no association between time and the outcome
GLMM denotes generalized linear mixed model; OR denotes odds ratio; CI denotes confidence interval; ED denotes emergency department; MRP denotes most responsible physician

Controller Therapy Escalation

Practitioners escalated controller therapy in 108/3422 (3.2%) eligible visits in the baseline period, and 126/3240 (3.9%) in the intervention period (p=0.12). At least one therapeutic escalation occurred in 106/830 (12.8%) and 117/890 (13.1%) patients, respectively (p= 0.87). After adjusting for other variables, therapy was less likely to be escalated during the intervention period [OR 0.55 (0.28, 0.99] (Table 3). In the baseline period, a short-acting beta-agonist (SABA) alone was added to therapy in 62 visits and a controller medication added in 54 visits (ratio 1.15); compared to 33 and 229 visits in the intervention period, respectively (ratio 0.14) (p<0.001). Oral corticosteroids were prescribed in 28/3565 (0.79%) visits and 24/830 (2.89%) patients in the baseline period, and in 16/3444 (0.46%) visits (p=0.089) and 15/890 (1.69%) patients (p=0.093) in the intervention period.

In the intervention period, clinicians de-escalated therapy in 7/459 (1.5%) visits in which asthma control was adequate, and documented medication adherence discussions in 219/890 (24.6%) patients.

Table 3. Predictors of Controller Therapy Escalation

Variable	Controller Escalation Not Made (n=6428 visits)	Controller Escalation made (n=234 visits)	GLMM Model (OR, 95% CI) (n=4204 visits)*
Period†			
Baseline	3314 (96.8%)	108 (3.2%)	
Intervention	3114 (96.1%)	126 (3.9%)	0.55 (0.28, 0.99)
Clinic			
1	2947 (97.7%)	67 (2.3%)	
2	1244 (97.6%)	31 (3.4%)	0.82 (0.42, 1.44)
3	2237 (94.3%)	136 (5.7%)	2.19 (1.51, 3.53)
Practitioner Type			
Physician	3087 (96.0%)	130 (4.0%)	
Nurse Practitioner	547 (96.5%)	20 (3.5%)	0.82 (0.38, 1.74)
Resident	2368 (97.3%)	66 (2.7%)	0.79 (0.46, 1.41)
Physician Assistant	425 (95.9%)	18 (4.1%)	0.55 (0.19, 1.16)
Objective Asthma Diagnosis			
No	3736 (95.9%)	158 (4.1%)	
Yes	2692 (97.3%)	76 (2.7%)	0.46 (0.31, 0.68)
Physician-Documented Asthma Diagnosis			
No	2507 (97.7%)	60 (2.3%)	
Yes	3921 (95.8%)	174 (4.2%)	1.35 (0.90, 2.05)
Presenting Complaint			
Asthma	201 (76.4%)	62 (23.6%)	
Non-respiratory	5610 (98.5%)	85 (1.5%)	0.06 (0.04, 0.10)
Respiratory (non-asthma)	617 (87.6%)	87 (12.4%)	0.51 (0.33, 0.85)
Previous ED visit(s)/hospitalization(s)			
No	6096 (96.5%)	221 (3.5%)	
Yes	332 (96.2%)	13 (3.8%)	1.18 (0.36, 2.25)
Seen by MRP			
No	4308 (96.6%)	151 (3.4%)	
Yes	2120 (96.2%)	83 (3.8%)	0.89 (0.58, 1.45)

Current Level of Asthma Control			
Not Documented	4587 (97.5%)	117 (2.5%)	
Poor control	1302 (92.4%)	107 (7.6%)	2.23 (1.52, 3.30)
Good control	539 (98.2%)	10 (1.8%)	0.52 (0.09, 1.15)

* the model included only the 448 subjects seen in both baseline and intervention periods (4204 total visits)

† both in the baseline and intervention periods, there was no association between time and the outcome

GLMM denotes generalized linear mixed model; OR denotes odds ratio; CI denotes confidence interval; ED denotes emergency department; MRP denotes most responsible physician

On Treatment Analysis

Counting only intervention period visits in which patients completed the questionnaire and the notification prompted clinicians to open the CDSS to take action, 81/265 (30.6%) patients received an AAP, control was assessed in 656/770 (85.2%) visits, and medications were escalated in 69/1001 (6.9%) visits.

DISCUSSION

We demonstrated that an evidence-based CDSS improves the quality of asthma care in real-world primary care settings while requiring minimal changes to local resources for successful implementation.

Asthma action plan delivery increased from zero at baseline to 17.8% of patients and 30.5% of visits with the intervention. Our nil baseline rate was comparable to the 2% rate described in a previous primary care chart audit.[10] Guidelines dating back to 1990 British Asthma Guideline and the 1996 Canadian Asthma Guideline call for all patients to receive a written AAP. A majority of physicians consider AAPs important, but fail to provide them due to lack of time and confidence in generating AAP recommendations.[8, 24] Although we previously published basic principles for populating the AAP yellow zone,[22] experts suggested that an information technology approach would be essential to operationalizing these in the real world.[18] Correspondingly, the eAMS targeted time and knowledge/skill barriers by leveraging the CDSS

to auto-populate the AAP. Studies have also shown that when AAPs are tailored and provided along with education, patients view them favorably and are more adherent.[25] The eAMS created a highly personalized AAP reflecting self-described symptoms, activities, and triggers, and provided access to an asthma education program. A primary care study identified the following enablers of AAP delivery: patients requesting an AAP; adding a blank AAP to the chart; and receiving a completed copy of the AAP.[9] Indeed, the eAMS questionnaire asked patients to prompt their practitioners to provide them with the AAP, and the CDSS auto-completed a blank AAP for clinicians.

Asthma control monitoring also improved with the intervention. Control was assessed in 4.9% of baseline visits, comparable to a US primary care chart review in which all control criteria were assessed in 1% of patients.[7] In a UK review, only 27% patients who died of asthma had had control assessed at their most recent primary care visit.[26] Improving control monitoring could improve health-related quality of life, avoid lost productivity, and reduce healthcare costs through better disease management and adherence.[27] However barriers are multi-fold. Physicians often pose an open-ended control question (e.g. "How is your asthma")[8]. However, most patients are unaware of their poor control. In a European survey of 8000 patients with asthma, 20.1% had controlled asthma, yet 90.5% self-identified as well controlled.[4] Correspondingly, a failure to probe *each* control parameter leads to under-reporting of poor control.[8] Physicians may also overestimate control. In a practice-based assessment, physicians labeled 31% of their inadequately controlled patients as "well controlled."[2] Failure to assess control objectively may be due to lack of familiarity with criteria. Canadian primary care physicians identified an average of 2.2 of 8 control criteria,[28] and 26% of US primary care physicians were confident that they could assess asthma control.[7] Additional barriers include

lack of time and simply forgetting to assess control.[28] The eAMS attempted to address these barriers by posing control questions in the patient questionnaire and "pushing" results to clinicians.

We did not identify a higher proportion of controller medication escalations with the intervention. The eAMS attempted to address known barriers to appropriate adjustment, including failure to recognize poor control and lack of knowledge regarding asthma pharmacotherapeutic.[29] However, patient factors including inhaled corticosteroid aversion and affordability may also play a role.[8] We noted that presenting clinicians with patient-reported medication use (CDSS screen 1) led to discussions about adherence in 24.6% of patients. Given reported controller adherence rates of only 30-40%,[30] it is conceivable that adherence counselling discussions obviated the need for medication escalation in many patients. There was an improvement in the ratio of rescue to controller medication prescriptions in the intervention period (a metric associated with reduced healthcare utilization and systemic steroid requirements).[31] This suggests that although the *quantity* of prescriptions did not improve, their *quality* may have. We also note that therapeutic de-escalations occurred in only 1.5% of visits in which asthma control was adequate, despite eAMS recommendations for de-escalation. Determinants of de-implementation may be different than those of implementation, and require further study.

Other asthma care CDSSs have been reported. Between two 2014 systematic reviews of trials of airways disease-related eHealth interventions, we identified three included studies describing EMR-integrated clinician-facing CDSSs which provided complex patient-tailored decision support (beyond simple reminders) for non-emergent adult asthma management.[32, 33] Tierney and colleagues' system[34] used EMR data to generate suggestions regarding immunization,

prescriptions and smoking cessation (no AAP), and showed no effects on guideline-based care. Kuilboer and colleagues' system[35] used EMR data to generate critiques of physician treatments (no AAP), demonstrating increased lung function testing and reduced cromogylate prescriptions. Finally, Plaza and colleagues'[36] system used chart and clinician-entered data to determine asthma control and provide corresponding medication recommendations (no AAP). They demonstrated improved pharmacotherapy and symptoms, but results were confounded by a concurrent nurse education program.[36] More recently, Tamblyn and colleagues reported a system comparable to ours that assessed control, provided medication recommendations, and auto-populated an AAP.[37] The system estimated control on the basis of rescue medication refills and healthcare utilization from administrative databases, requiring clinician entry for other control criteria. In an RCT, the primary outcome (out-of-control asthma events) did not differ between groups, though as in our study the ratio of SABA to controller medication prescriptions improved.[37] Kuhn and colleagues described an electronic AAP which required physician activation and data entry. In an observational study, an "on treatment" analysis suggested lower oral corticosteroid requirements and exacerbations among children (but not adults).[38] Although these two studies provided an auto-populated AAP, neither used a validated nor personalized AAP designed with human factors optimization (as our tool does). Furthermore, none of the above systems engaged patients to reduce data collection and entry burdens on clinicians (addressed through the pre-visit questionnaire in our tool), therefore failing to address clinician time constraints at the point-of-care.[38] Qualitative studies confirm that even when CDSSs improve care, time constraints are a critical barrier to their usage.[39]

Clinicians accessed the eAMS in 34.4% of patients in whom actions were required. This uptake rate compares favourably to that of previous asthma CDSSs.[33] Among evidence-based

predictors of successful CDSSs presented in the recent GUIDES checklist,[40] the eAMS includes automatic prompting (a "push" strategy), "just-in-time" information delivery (during the clinical visit), clinical workflow integration (integration with existing EMR), patient-targeted information, patient-medicated clinician prompts, and individualized recommendations. Strategies to drive improvement of may include formal usability and workflow analysis and optimization,[40] features to address multiple morbidities, prompts/advice that can be tailored to clinician preferences, detailed explanations/references for recommendations, and a requirement that practitioners supply a reason for over-riding advice.[40]

Our study has several limitations. Measurements of control assessment may have been underestimated due to poor chart documentation. However, we believe that clinicians would be very likely to document poor control if ascertained, given its clinical relevance and influence on treatment decisions. An ITS design is vulnerable to temporal factors affecting behaviour. To our knowledge, no such changes (e.g. changes in payment models, new educational programs, or allied health support) occurred during the study. We chose behavioural outcomes based on guideline recommendations and known correlations to patient outcomes, but did not directly measure patient outcomes.

In summary, we describe improvements in the quality of asthma care after implementation of a complex eHealth intervention in a real-world setting. System improvements may be considered to further drive uptake, and a future RCT should assess impact on patient-level outcomes.

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DATA SHARING

We will share individual participant data that underlie the results reported in this article, after de-identification, as well as analytic code. Data will be available immediately following article publication and ending 3 years following publication. Data requests will be considered from investigators whose proposed use of the data has been approved by our independent review committee for this purpose, and for any proposed analysis. Proposals should be directed to guptas@smh.ca; to gain access, data requestors will need to sign a data access agreement.

AUTHORS' CONTRIBUTIONS

SG conceived of the study, oversaw all aspects of the study, and prepared the manuscript; CP contributed to the data cleaning, analysis, and interpretation; GA, DC, and SGo contributed to study design, recruitment, and manuscript revisions; SS, AK and LP contributed to study design and manuscript revisions; MM and GL contributed to study design, statistical analysis and interpretation, and manuscript revisions.

CONFLICT OF INTEREST STATEMENTS

Authors have no conflicts of interest to declare.

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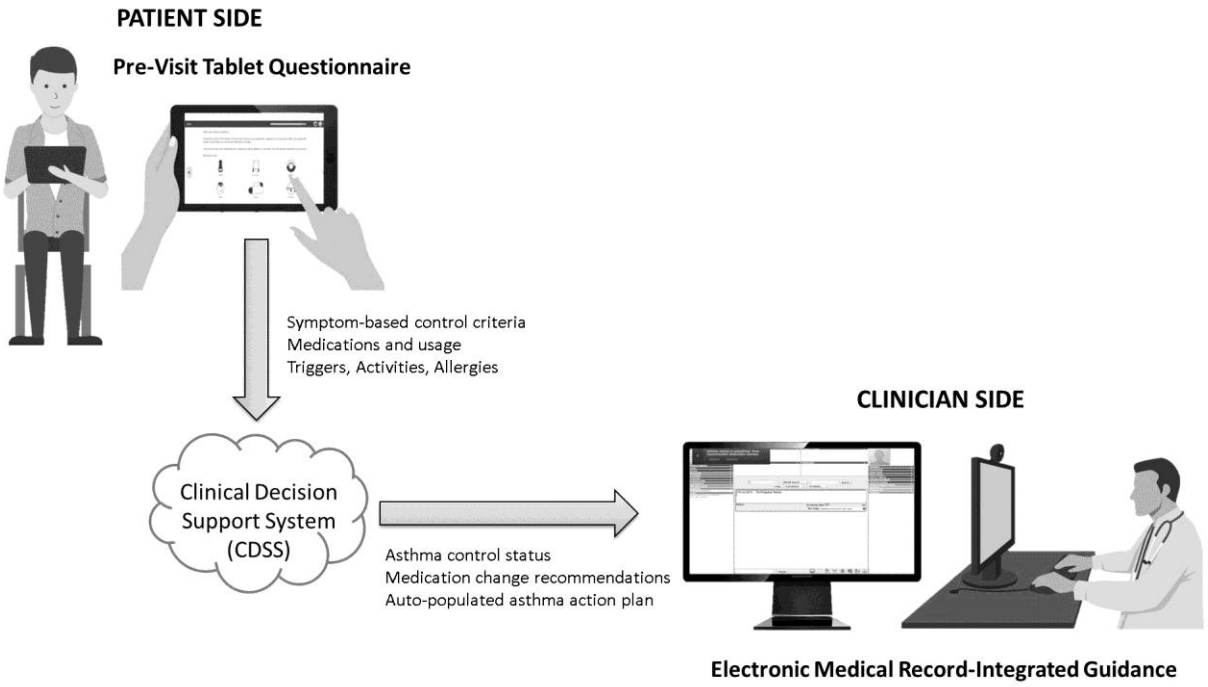
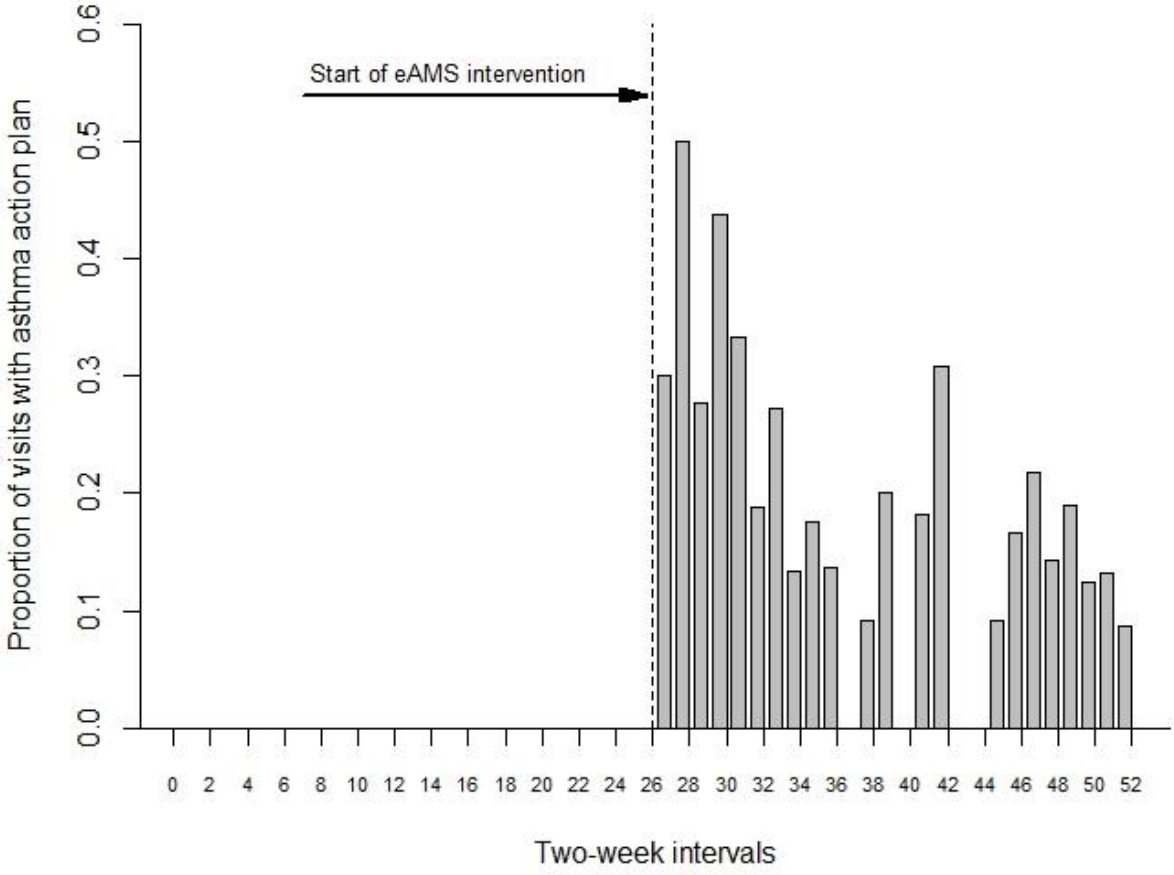
FIGURE LEGENDS

Figure 1. Electronic Asthma Management System (eAMS) Schematic. The eAMS started with a touch tablet patient questionnaire used in the clinic waiting room, which collected asthma symptoms according to Canadian guideline-recommended criteria; medications; and details required for asthma action plan personalization (patient-specific symptoms, activities, triggers, allergies). Next, these data were processed by an evidence-based computerized clinical decision support system in real time, and guidance regarding asthma control status, corresponding medication change recommendations, and an auto-populated, personalized asthma action plan were then integrated into the clinician-facing electronic medical record system.

Figure 2. Time Series Analysis. The proportion of asthma patient visits in which an asthma action plan was delivered, at each two week interval (baseline period - intervals 0-26; intervention period – intervals 26-52). The arrow indicates the period in which the Electronic Asthma Management System (eAMS) intervention was launched.


PATIENT SIDE
Pre-Visit Tablet Questionnaire
Symptom-based control criteria
Medications and usage
Triggers, Activities, Allergies
CLINICIAN SIDE
Clinical Decision Support System (CDSS)
Asthma control status
Medication change recommendations
Auto-populated asthma action plan
Electronic Medical Record-Integrated Guidance


Start of eAMS intervention
Proportion of visits with asthma action plan
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52
Two-week intervals

The Electronic Asthma Management System (eAMS) Improves Primary Care Asthma Management

Online Data Supplement

METHODS

Study Design, Setting, Population

Included clinics were academic family health teams (primary health teams including family physicians, nurses, and allied health members) which used the OSCAR electronic medical record (EMR) system (http://oscarcanada.org), were under a capitated funding model, and did not have asthma educators or respiratory therapists on site. Site principal investigators (GA, DC, SGo) sent invitations to all physicians and nurse practitioners (NPs) at each site. We identified asthma patients in the practices of all consented clinicians through a validated EMR search algorithm,[1] including: "asthma" in the cumulative patient profile (a standardized chart component which includes active and past medical history), use of the diagnostic billing code for asthma/allergic bronchitis (493) within the last 3 years [excluding patients in whom a COPD-related diagnostic billing code (491, 492, 496) had been used in the last 3 years]; and presence of "asthma" in any of the typed chart notes (algorithm-generated lists were vetted/modified by clinicians). We included asthma patients who were $\geq$ 16 years old, understood English, and had been on asthma medication in the prior 12 months (excluding patients who had been on a COPD medication in the prior year).[1] Asthma medications included: beclomethasone; budesonide; budesonide/formoterol; ciclesonide; fluticasone; fluticasone/salmeterol; formoterol; mometasone; mometasone/formoterol; salbutamol; salmeterol; and terbutaline sulfate (including all drug formulations, where applicable). COPD medications included medications used predominantly for COPD: tiotropium bromide and ipratropium bromide. [1] Note that 19 included patients were prescribed a long-acting muscarinic antagonist (tiotropium bromide) between the time they were identified as study candidates and the time they appeared for their first study visit, and were thus on a long-acting muscarinic antagonist at baseline (Table 1). Eligible patient lists were updated periodically throughout the study, to capture patients entering and leaving the included practices. Were excluded patients who were pregnant (due to lack of evidence for the most effective and safest therapeutic intensification regimen as part of an asthma action plan), or whom the physician deemed to have cognitive limitations (due to inability to use an asthma action plan) or a life expectancy of < 1 year (due to inability to capture adequate follow-up data). We excluded visits exclusively for administration of injection medication(s) (e.g. the flu shot). The study took place between August 1st, 2012 and July 31st, 2014.

Intervention

During the baseline period, all included clinicians were sent an email with access to the MacHealth/Ontario Lung Association AAP module (an accredited online educational module designed to teach primary care physicians how to complete an AAP, available at: https://machealth.ca/programs/asthma-action-plan/). We also provided clinicians with paper and .pdf copies of a blank AAP. This AAP was built through systematic evaluation of existing AAPs,[2] multiple stakeholder wiki-based collaborative editing, and usability optimization.[3, 4]

Intervention Implementation

The intervention user interface was developed with serial testing and feedback from the lead physicians at each of the three included sites. Study staff presented the eAMS to prescribers at the 3 sites in 3-4 presentations (at clinic rounds/meetings) held around the time of eAMS launch and 2-3 presentations delivered between 6-12 months after launch, at each site. All prescribers also received a pamphlet detailing eAMS features and were emailed a reminder to visit the study site, which included an online user guide, FAQs, a downloadable/printable brochure, site-specific educational videos, and a link to the online AAP module (see below).

Patient Questionnaire

All included patients were provided with the tablet questionnaire by a clinic staff member (e.g. receptionist) upon arrival for their appointment (i.e. before interacting with the clinician). Clinic staff used a database query or an automated patient tag in the registration system to identify the eligible patients. Patients who had completed the questionnaire within the prior month were not asked to repeat it, and those who had previously completed it more than one month prior were simply asked to confirm/edit prior responses.

CDSS

Upon opening the chart of any patient who had completed the questionnaire, clinicians received a notification alerting them to the patient's current asthma control status and prompting them to open the CDSS. If clinicians accessed the CDSS, they viewed the following information: screen 1 - a description of the patient's current control criteria and self-reported medication use; screen 2 - corresponding evidence-based medication escalation/de-escalation recommendations; screen 3 – corresponding AAP yellow zone medication recommendations; screen 4 - a pre-populated AAP (which could be text edited); and screen 5 - a reminder to book close follow-up and to provide the educational website URL (see below) (given that regular review and education are elements of a successful AAP intervention) (the website also included inhaler technique videos and a self-directed web-based asthma educational program). Recommended medications in each screen could be altered through drop-down lists. Accordingly, recommendations in each subsequent screen were determined dynamically based on information confirmed in each prior screen. If users progressed through at least one of these screens, a note was automatically written to the EMR chart documenting the patient's asthma control level, recommendations made by the CDSS, physician actions in response to each recommendation, and any new prescriptions required. If clinicians approved the AAP, it was sent to the chart in a .pdf format, for printing. Patients who had a personal health record (PHR) also automatically received an electronic copy of the AAP within their PHR. Patients also received the URL for a self-directed web-based asthma educational program (on a pre-printed post-it note added to the AAP and/or by email where available) (www.oscarasthma.ca).

Given that access to the eAMS was chart-based and not clinician-based, the CDSS was available for use by any clinician who happened to see an included patient [patients occasionally see clinicians other than their most responsive physician (MRP) for urgent issues]. In cases where a patient had completed the pre-visit questionnaire but the CDSS had not been opened or had been opened by a clinician other than the MRP, the MRP was prompted via an electronic message regarding the patient's current asthma status and asked to complete any remaining actions in the CDSS within 1 month (CDSS recommendations were kept active for 1 month after questionnaire completion, after which updated questionnaire responses were required).

CDSS logic was developed through a review of asthma guidelines,[5] systematic development of evidence-based rules for AAP auto-population,[6] and application of latest evidence to optimize the implementability of provided guidance.[7] The AAP populated by the eAMS was the same preference-based AAP as that described above in the baseline phase.

Aside from the tablet devices and the pre-printed sticky pads with the URL for the self-directed web-based asthma educational program, no additional resources were added to the clinics for the intervention.

Ongoing Feedback

Investigators also provided site leads with a monthly audit report detailing overall system usage, highlighting which clinicians had developed the most AAPs. This feedback was distributed to all participating physicians by site leads.

Data Collection

Primary care (GA, DC, AK, SGo) and respirology experts (SG, LPB) defined all data elements. Four trained reviewers performed electronic chart audit and entered data in a standardized electronic form (in Excel®). The form was refined for clarity and usability through three cycles of testing, each involving 20 visit reviews by each reviewer. Reviewers then independently abstracted data from 40 randomly selected visits to ensure agreement. We abstracted data for all outpatient visits and asthma-related telephone interactions by staff physicians, residents, nurse practitioners (NPs), NP students, or physician assistants (PAs) (i.e. prescribers). Abstracted data included visit time/date, presenting complaint, demographics, respiratory comorbidities, respiratory medications and any changes, previous diagnostic testing (spirometry and/or methacholine challenge), previous hospitalizations or emergency department (ED) visits for asthma, previous referrals/visits to respirologists/allergists (and their findings), clinician documentation of asthma control according to symptom-based Canadian guideline criteria (Table 1),[8] actual asthma control according to symptoms recorded in any place in the chart, provision of a written AAP, and all patient/clinician interactions with the eAMS (intervention period only).

Outcomes

The primary outcome was asthma action plan delivery, measured by the proportion of patients on a controller medication (inhaled corticosteroid, inhaled corticosteroid /long-acting beta agonist combination, and/or leukotriene receptor antagonist) who received a written AAP during the intervention period compared to the baseline period (cumulative proportion by patients and time series analysis by patient visits). Secondary outcomes included: the proportion of visits during which asthma control was assessed according to symptom-based criteria (and the proportion of patients who had asthma control assessed at least once) (patients were considered to have poor control if they met one or more guideline-based criterion for uncontrolled asthma based on review of the current and any prior visits within each corresponding look back period - (Table 1); and the proportion of visits during which controller therapy was escalated (i.e. a controller medication started/added/dose escalated) (and the proportion of patients who had at least one escalation). We calculated the proportion of rescue to controller medication prescriptions in each period. During the intervention period, we also measured the proportion of visits in which patients had good control in which a medication de-escalation was made; the proportion of patients in whom discussions about medication adherence took place, and system uptake.

Sample Size Calculation

Recommendations for a rigorous ITS design indicate that at least 10 pre- and 10 post-data points would be needed to achieve at least 80% power to detect a change (if the autocorrelation is > 0.4)[9]. As this was a novel intervention, there were no data on what the autocorrelation might be or what effect size the intervention was likely to produce. Therefore, we divided data into 26 2-week time points both before and after the intervention. Estimating an optimistic baseline AAP delivery rate of 11%[10], we would require only 15 time points in each phase for a power of 80% to detect a doubling in this rate to 22% with the intervention (a conservative estimate of effect size). Estimating a physician recruitment of 8 physicians across all sites, an average active practice size of 1000 patients per physician, a prevalence of physician-diagnosed asthma with asthma medication use within the last 12 months of 6.5%[11], and at least one eligible patient visit per year, we estimated that 520 eligible patients would be seen each year (approximately 20 visits per 2-week time period).

Analysis

We calculated interrater reliability using percent agreement among the 4 reviewers. We initially used a Fleiss' kappa to determine agreement. However, there were several variables for which there was perfect agreement, resulting in no variability and an inability to compute the kappa statistic. Thus, for consistency, we elected to report percent agreement across variables. We summarized baseline clinician and patient characteristics descriptively, using information from the first visit in patients with multiple visits. The intervention period included all visits that occurred while all components of the eAMS were active, in each respective clinic. We compared patient variables between periods with Fisher's exact/chi square tests and ANOVAs, as appropriate. All analyses were intention-to-treat; however we present additional "on-treatment" analyses for main outcomes. We compared all proportions between periods with the chi square test. The primary outcome (AAP delivery) measured the proportion of patients on an asthma controller medication for at least 1 visit in the relevant study period who received an AAP (excluding those who had received/reviewed an AAP in the last 6 months). In the ITS analysis, we used 26 consecutive 2-week time points to create a baseline model. For each time point, we calculated the proportion of visits by patients on an asthma controller medication (defined as above) associated with AAP delivery (excluding visits where an AAP had been received/reviewed in the prior 6 months). We compared outcomes rates in 26 consecutive 2-week intervals prior to the intervention to those in 26 consecutive 2-week intervals following the intervention, using an interventional autoregressive integrated moving average (ARIMA) model. Model checking examined autocorrelation and partial autocorrelation plots and the Augmented Dicky-Fuller test and Ljung-Box test.[12] We also fit a generalized estimating equation (GEE) model including all visits in the intervention period to examine the trend over time with regard to the outcome (this model did not adjust for any covariates and was tested using a one-sided test with a significance level of 0.05). In measuring asthma control assessment, we eliminated visits in which asthma control had been assessed within the prior 28 days (a standard lookback period for symptom-based asthma control assessment)[13]. In the measuring therapy escalation, we eliminated visits in which patients had had a controller medication escalated within the last three months (the typical duration of a therapeutic trial).[14] To account for individual and clinical risk factors as well as the longitudinal component, we used a generalized linear mixed model (GLMM) with a logit link to identify predictors of main outcomes (covariates tested are listed above) among patients seen in both the baseline and intervention periods. A random effect was included to account for within subject correlation (confidence intervals were bootstrapped). Analyses were performed using R Statistical Software (Version 3.4.0). Statistical significance was defined at a two-sided 0.05 level.

Table 1. Symptom-based criteria for assessing asthma control[8]

Criterion	Controlled	Uncontrolled
Daytime Symptoms *	<4 days/week	≥4 days/week
Night-time Symptoms*	<1 night/week	≥1 night/week
Physical Activity	Normal/No limitations	Restricted due to asthma in previous 3 months
Absenteeism	None	Missed work/school/other activities due to asthma in previous 3 months
Short-acting bronchodilator use*	<4 doses/week	≥ 4 doses/week

* Evaluated as an average of the prior 6 months

RESULTS

Table 2. Baseline Medications in Patients in Whom Asthma Control Could be Ascertained

Baseline Medications┼	Baseline Period (n=167)	Intervention Period (n=585)
Asthma Well Controlled, n (%)		
No controller therapy	0	180/257 (70.0%)
First line controller therapy (inhaled corticosteroid alone* and/or Leukotriene receptor antagonist)	0	45/257 (17.5%)
Inhaled corticosteroid with long-acting beta-agonist	1 (0.6%)	32/257 (12.5%)
Prednisone†	0	0
Asthma Poorly Controlled, n (%)		
No controller therapy	87 (52.1%)	149/328 (45.4%)
First line controller therapy (inhaled corticosteroid alone* and/or Leukotriene receptor antagonist)	41 (24.6%)	85/328 (25.9%)
Inhaled corticosteroid with long-acting beta-agonist	37 (22.2%)	94/328 (28.7%)
Prednisone†	1 (0.6%)	0

┼assessed at the first visit at which asthma control could be ascertained (by chart review), for each patient
* without concurrent use of a long-acting beta-agonist in a combination inhaler or as a separate inhaler
† includes only those patients using prednisone chronically

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