Evaluating the impact of an integrated computer-based decision support with person-centered analytics for the management of asthma in primary care: a randomized controlled trial

Robyn Tamblyn, PhD1,2,3, Pierre Ernst, MD4, Nancy Winslade, PharmD5, Allen Huang, MD5, Roland Grad, MD6, Robert W. Platt, PhD2, Sara Ahmed, PhD1,3, Teresa Moraga, MSc3, Tewodros Eguale, MD, PhD2,3

ABSTRACT

Background Computer-based decision support has been effective in providing alerts for preventive care. Our objective was to determine whether a personalized asthma management computer-based decision support increases the quality of asthma management and reduces the rate of out-of-control episodes.

Methods A cluster-randomized trial was conducted in Quebec, Canada among 81 primary care physicians and 4447 of their asthmatic patients. Patients were followed from the first visit for 3–33 months. The physician control group used the Medical Office of the 21st century (MOXXI) system, an integrated electronic health record. A custom-developed asthma decision support system was integrated within MOXXI and was activated for physicians in the intervention group.

Results At the first visit, 9.8% (intervention) to 12.9% (control) of patients had out-of-control asthma, which was defined as a patient having had an emergency room visit or hospitalization for respiratory-related problems and/or more than 250 doses of fast-acting β-agonist (FABA) dispensed in the past 3 months. By the end of the trial, there was a significant increase in the ratio of doses of inhaled corticosteroid use to fast-acting β-agonist (0.93 vs. 0.69; difference: 0.27; 95% CI: 0.02–0.51; \( P = 0.03 \)) in the intervention group. The overall out-of-control asthma rate was 54.7 (control) and 46.2 (intervention) per 100 patients per year (100 PY), a non-significant rate difference of \(-8.7 (95\% \text{ CI: } -24.7, 7.3; P = 0.29)\). The intervention’s effect was greater for patients with out-of-control asthma at the beginning of the study, a group who accounted for 44.7% of the 5597 out-of-control asthma events during follow-up, as there was a reduction in the event rate of \(-28.4 \text{ per } 100 \text{ PY (95\% CI: } -55.6, -1.2; P = 0.04)\) compared to patients with in-control asthma at the beginning of the study \((-0.08 [95\% \text{ CI: } -10.3, 8.6; P = 0.86])\).

Discussion This study evaluated the effectiveness of a novel computer-assisted ADS system that facilitates systematic monitoring of asthma control status, follow-up of patients with out of control asthma, and evidence-based, patient-specific treatment recommendations. We found that physicians were more likely to use ADS for out-of-control patients, that in the majority of these patients, they were advised to add an inhaled corticosteroid or a leukotriene inhibitor to the patient’s treatment regimen, and the intervention significantly increased the mean ratio of inhaled corticosteroids to FABA during follow-up. It also reduced the rate of out-of-control episodes during follow up among patients whose asthma was out-of-control at the time of study entry. Future research should assess whether coupling patient-specific treatment recommendations, automated follow-up, and home care with comparative feedback on quality and outcomes of care can improve guideline adoption and care outcomes.

Conclusions A primary care-personalized asthma management system reduced the rate of out-of-control asthma episodes among patients whose asthma was poorly controlled at the study’s onset.

Trial Registration Clinicaltrials.gov Identifier: NCT00170248 http://clinicaltrials.gov/ct2/show/NCT00170248?term=Asthma&spn=McGill+University&state1=NA%3ACA%3AQC&rank=2

Key words: out-of-control; computer decision support; MOXXI; personalized medicine; RCT; asthma
INTRODUCTION
Asthma is a chronic condition that causes substantial morbidity.1–3 Chronic lung diseases, including asthma, cost Canadians an estimated $12 billion in 2010.4,5 The majority of these costs are related to poor disease control, due to under-using effective prophylactic therapies, inadequate monitoring of disease severity, and insufficient patient education.6 Evidence-based guidelines for asthma care recommend patient self-monitoring, as this enables patients to identify and manage mild exacerbations of their condition, which reduces their risk of hospitalization by 39%.7–14 Asthma guidelines also recommend the use of inhaled corticosteroids, as they improve symptoms and lung function15 and also reduce the likelihood of patient hospitalization16–18 and death.19 Although asthma guidelines are available internationally, few asthma patients receive evidence-based care, and, as a result, many patients suffer from inadequately controlled asthma.20–22

Primary care physicians provide the majority of asthma care.23,24 As these physicians are responsible for first-line prevention and management of multiple conditions in all age groups, keeping up-to-date with advances in clinical practice presents a considerable challenge. New and more efficient approaches to helping primary care physicians incorporate evidence-based guidelines into practice are needed; as evidenced by one study, even a decade after guideline dissemination, polled physicians knew only 60% of asthma treatment recommendations.25 Computerized decision support (CDS) systems have provided a new set of tools for incorporating evidence-based guidelines into practice by providing physicians with reminders and alerts for preventive care and disease management.26–33

CDS systems have been shown to improve preventive care and drug management through the use of reminders, but they have been less successful in evidence-based chronic disease management.34 The earliest randomized trials of CDS for asthma suffered from technical challenges.35 A subsequent trial, which used more advanced technology that enabled evidence-based guidelines to be seamlessly inserted into the workflow of the physician, also failed to show any benefit.36 Physicians found the recommendations too generic to be relevant to any specific patient, and adherence was <33% for most recommendations. Notably, when more patient-specific treatment recommendations were provided to community-based physicians in a non-computer-based intervention study, there was a significant reduction of asthma patient emergency room (ER) visits.37 A key feature of this intervention was labor-intensive weekly monitoring by hospital staff of patients with poorly controlled asthma and generation of customized recommendations for the physicians to improve patients’ asthma control. A recent study of pediatric clinics supports the importance of assisting physicians with monitoring their patients’ disease status.38 In this study, embedding asthma monitoring tools, alerts for assessment, and order sets within an electronic health record (EHR) significantly increased patients’ use of control medication and spirometry.

Prior research suggests that future asthma CDS systems need to facilitate asthma monitoring and follow-up of patients with out-of-control asthma and also offer physicians patient-specific recommendations.37,38 In this study, we developed a patient-specific asthma CDS management system that incorporated asthma surveillance through real-time monitoring, guideline-based treatment recommendations customized to asthma status, current medication, and follow-up management through an asthma home-care program. We tested the hypothesis that this personalized asthma management system would both increase the quality of asthma management and decrease the rate of out-of-control asthma, particularly for patients whose asthma was out of control at the start of follow-up and for physicians who were more regular users of the Medical Office of the 21st Century (MOXXI) system.

METHODS
Design overview and study population
A single-blind, cluster-randomized controlled trial was conducted to test the hypothesized benefits of CDS support for asthma management. The benefit of the intervention was assessed by comparing asthma patients of physicians who received asthma decision support (ADS) with asthma patients of physicians who were users of the MOXXI EHR system alone. The trial was conducted in a population of 81 primary care physicians and 4447 of their patients, from October 2006 to June 2009. This sample size was expected to demonstrate a reduction in the proportion of patients with poorly controlled asthma to 9% in the intervention group, assuming 48 physician clusters, 120 patients per physician, an intra-cluster correlation of 0.03, and Types I and II errors of 5% and 20%, respectively.

Family physicians in full-time, fee-for-service practices in Montreal or Quebec City were eligible for inclusion. Patients were eligible if they were aged 5 years or older, had a diagnosis of asthma (ICD9 code: 493), and were insured through the provincial drug plan. Patients with a diagnosis of chronic obstructive pulmonary disease (ICD9: 491, 492, 494, 496) were excluded. The study was reviewed and approved by McGill’s Institutional Review Board. All participating physicians and their patients gave written consent to be a part of the study. Parents gave written consent for any children under the age of 18.

Intervention and control group
The benefit of the intervention was assessed by comparing asthma patients of physicians who received ADS with asthma patients of physicians who received the MOXXI clinical information system alone. This approach was aimed at minimizing Hawthorne effects, arising from the intensive nature of practice intervention required to support computer-based systems in primary care. Comparison to physicians with no computerized intervention would likely result in an overestimation of the benefit of computer-based decision support for asthma management. Further, comparison to physicians with the same clinical information system provides a means by which information on prescriptions and disease profiles can be assessed in an equivalent way between intervention and control patients,
reducing biases related to differences in measurement sources.

**Basic and control intervention:** Physicians in both groups were regular users of the MOXXI EHR, which provided two critical features needed to successfully institute CDS: 1) MOXXI captures and codes clinical information so that it can be used to trigger CDS, for targeted patients, and generate patient-specific recommendations, and 2) it prepopulates each patient’s file with information on demographics, drugs, health problems, and medical visits from provincial health insurance databases at the Régie de l’assurance maladie Québec (RAMQ).39

**ADS intervention:** The ADS system uses Canadian consensus guidelines13,40 to address problems in asthma management – poor patient recognition of asthma control, underutilization of prophylactic therapy, lack of prescription of an action plan, and insufficient patient education and support for self-monitoring.21,41 The three components of the ADS system are integrated into the MOXXI EHR.

The dashboard alert (Figure 1) appears when a physician opens a patient’s electronic file, if the patient’s asthma was out of control, defined as the patient having had an ER visit or a hospitalization for respiratory-related problems in the past 3 months and/or the patient’s excess use (>250 doses dispensed) of fast-acting β-agonist (FABA) in the past 3 months. A patient’s asthma control status was determined dynamically, based on a daily retrieval of newly dispensed prescriptions and physician visit information from the RAMQ. The physician can click on the dashboard alert to open the patient’s asthma profile (Figure 2), which shows the details of their respiratory-related ER visits, dispensed FABA medication, home-monitoring results from specialized asthma nurses, if referred, and recommended changes in treatment.

**Decision support for evidence-based asthma management** (Figure 2) provides physicians with access to the Canadian guidelines and, most importantly, translation of the guidelines into assessment tools and recommendations for individual patients. The ADS can be accessed from a tab in the MOXXI EHR, for intervention physicians, or from the dashboard alert when it appears, for patients with out-of-control asthma. The ADS provides physicians with an asthma control checklist, tools to assess and manage environmental triggers, current medications, details of FABA use, and respiratory-related ER visits, all of which are retrieved from the MOXXI EHR. The physician can verify all the displayed information with the patient, use the asthma control checklist to update the patient’s asthma control status at the visit, and use the “update recommendations” button to receive revised treatment recommendations. Based on asthma control and current medication, patient-specific treatment recommendations are generated based on Canadian consensus guidelines.13,40 When a recommendation is selected, it automatically generates the required new prescription in the MOXXI EHR as well as the action plan appropriate for the current medication profile.

**Asthma home care and monitoring program** provides physicians with the option to refer their patients to asthma home care, in which specialized asthma nurses would monitor and support patients’ asthma control between visits. Based on dynamic analysis of the patients’ data, an automated triage algorithm triggers a recommendation for referral for patients with out-of-control asthma (Figure 1). Physicians can click on the dashboard alert toolbar to enroll the patient in asthma home care. If they feel the patient would benefit, physicians can also enroll a patient whose asthma is under control. The asthma nurse can use a web-based case management application integrated with ADS and the MOXXI EHR to keep track of patients, access their electronic records, complete tele-home monitoring visit reports, and communicate follow-up information to the referring physician. For patients whose asthma is out of control, the nurse would continue weekly monitoring until their asthma is brought under control and for 3 months thereafter.

Audit trails within the application were used to measure how physicians used the asthma decision-support application and the recommendations it generated.

**Randomization and blinding**

Physicians were randomized to either: 1) MOXXI with ADS or 2) MOXXI alone. Physicians were stratified by practice size, with groupings sufficient to maintain a minimum of two physicians within each stratum, and an equivalent number of physicians were randomized to ADS or the MOXXI system alone. An independent statistician who was blinded to physician identity carried out randomization. Patients, physicians, and research assistants involved in data collection and analysis were blinded to the study outcomes. Physicians randomly assigned to the intervention group were trained and had the ADS module activated in their MOXXI EHR.

Figure 1: The dashboard alert. An out-of-control alert based on ER visits for asthma and overuse of fast-acting β-agonists.
Outcomes and follow-up
Primary outcome: rate of out-of-control asthma episodes
An out-of-control episode was defined as a patient’s excessive use of fast-acting bronchodilators, an ER visit, or hospitalization for asthma (ICD9: 493) or a closely related respiratory condition (ICD9:490, 491, 496, 786, 786). Excessive use of fast-acting bronchodilators was included as an indicator, because it is associated with an increased risk of hospitalization and death from asthma42 and was defined as the dispensing of more than the equivalent of 250 doses of the most commonly prescribed FABA, salbutamol 100 mcg, to the patient in a 3-month period. Starting from the first visit to their physician, the patient’s control status was assessed for each 3-month period. Doses dispensed were calculated based on quantities recorded in dispensed prescriptions from the RAMQ. The maximum acceptable use of FABA was derived from guideline recommendations, which allow up to two inhalation doses per day and an additional six inhalation doses for three exercise episodes per week, for the prevention of exercise-induced symptoms.13

Secondary outcome: quality of asthma management
The inhaled corticosteroid to fast-acting β2-agonist ratio is a commonly used measure of quality of asthma care.43,44 The ratio of the number of doses of inhaled corticosteroids dispensed to the number of doses of FABA was calculated by summing the doses of dispensed prescriptions for inhaled corticosteroids and FABA during each 3-month period of follow-up. The mean of each 3-month ratio was then calculated for each patient for each 3-month follow-up window in which they were taking medications.

Statistical analysis
To test the hypothesis that ADS would reduce the rate of poor asthma control, we used Poisson regression within a generalized estimating equation framework to estimate the difference in out-of-control asthma event rates between the intervention and control groups. The numerator was the number of 3-month periods where the patient’s asthma was out of control. The denominator was the number of patient-months of follow-up, defined, for each patient, starting from the date of the first visit to the study physician post-randomization to the end of follow-up. A binary variable was used to represent the patient’s intervention group assignment, and the control group was used as the reference in the regression model. “Patient” was the unit of analysis, “physician” was the cluster, and an independent correlation structure and robust standard errors were used to account for dependence in outcomes among patients who had the same physician.45 To determine whether the effect of the intervention was greater in patients with out-of-control asthma, we conducted subgroup analyses by patient asthma control status at the start of follow-up. The same approach was used
to determine whether the intervention was more effective in the subgroup of physicians who were more regular MOXXI users. We added baseline patient and physician characteristics to control for any residual confounding resulting from imbalances in cluster randomization assignment. To test the hypothesis that there would be an improvement in the quality of asthma management, we used generalized estimating equation linear regression to estimate the difference in the mean inhaled corticosteroid to FABA ratio for each patient.

RESULTS
Overall, 81 physicians were randomized to the intervention and control groups (Figure 3). A total of 4447 patients in the practices of study physicians had a diagnosis of asthma, were covered by the provincial drug plan, and consented to participate. During 33 months of follow-up, eight physicians retired, moved, or dropped out of the study, along with their asthma patients \( n = 166 \), a slightly higher proportion in the control compared to the intervention group. All physicians and patients were included in the final analysis. The practice characteristics and electronic prescribing behavior of the intervention and control physicians, along with the patients, were similar (Table 1).

Overall, 30% of patients were between 5 and 45 years of age, 67% were female, and the mean household income was approximately $45,000 in both the intervention and control groups (Table 2). Over 90% of patients were prevalent cases who had a diagnosis of asthma before the start of the trial. Patients whose asthma was out of control at the first visit after randomization ranged from 9.8% (intervention) to 12.9% (control). The co-morbidity profile was similar in the intervention and control groups, as was the frequency of visits, hospitalization, and number of prescriptions in the year before the...
of the 81 physicians in the intervention and control groups

| Demographics | Control, N = 41 | Intervention, N = 40 |
|--------------|----------------|---------------------|
| Sex          |                |                     |
| Male         | 19 (46.3)      | 17 (42.5)           |
| Female       | 22 (53.7)      | 23 (57.5)           |
| Language     |                |                     |
| English      | 14 (34.1)      | 11 (27.5)           |
| French       | 27 (65.9)      | 29 (72.5)           |
| Practice experience (Years) | | |
| Less than 25 | 15 (36.5)      | 16 (40.0)           |
| 25 or more   | 26 (63.5)      | 24 (60.0)           |
| Practice characteristics | Mean | (SD) | Mean | (SD) |
| Annual practice size | 1317.9 (720.9) | 1484.5 (733.7) |
| Number of practice settings | 1.9 (1.1) | 1.9 (1.4) |
| Number of days worked/year | 196.5 (35.5) | 193.3 (47.9) |
| Number of patients/clinic day | 17.8 (6.8) | 18.7 (7.1) |
| Skill and use of the MOXXI software | Mean | (SD) | Mean | (SD) |
| Time to prescribe four drugs (Minutes) | 3.14 (1.03) | 2.97 (0.94) |
| Electronic Rx written/100 visits | 15.6 (13.3) | 16.8 (7.8) |

During the follow-up period, the 2273 patients in the intervention group made 15,614 visits, and in 2297 (14.7%) of these visits, their asthma was out-of-control (Figure 4). In 39.5% of visits for out-of-control asthma, compared to 5.3% of visits for in-control asthma, the physicians accessed the ADS system. For patients with out-of-control asthma, an increase in treatment was recommended in 69.8% of visits and referral to a specialist in 10.1%. In 20.1% of visits for out-of-control asthma, no recommendation was possible given the particular combination of medications used. The most frequent recommendations generated for patients with out-of-control asthma were to add an inhaled corticosteroid, a leukotriene inhibitor, or to increase the dose of the existing therapy (Table 3). In comparison, for patients with in-control asthma, the majority of recommendations (83.1%) were to maintain treatment and, in 6.7% of visits, to decrease treatment. In the intervention group, only 73 patients (3.2%) were referred to asthma home care; 41.1% of those referred versus 8.7% of those not referred had out-of-control asthma ($P < 0.001$).

The mean ratio of doses of inhaled corticosteroid use to FABA use was significantly higher in the intervention group (mean: 0.93) compared to the control group, indicating that there was a greater use of inhaled corticosteroids relative to FABAs among patients in the intervention group (mean: 0.69) (mean difference: 0.27, 95% CI: 0.02–0.51, $P = 0.03$) (Table 4). Higher ratios were evident in the intervention group in both patients who whose asthma was in control at the start of the study as well as those who whose asthma was out of control. The overall rate of out-of-control asthma events was 54.7/100 PY in the control group and 46.2/100 PY in the intervention group, a non-significant reduction in the multivariate adjusted rate of events in the intervention group of 8.7/100 PY (95% CI: -24.7, 7.3) (Table 4). When patients were stratified by asthma control status at entry, the intervention produced a significant reduction in the rate of out-of-control asthma events in patients whose asthma was out of control at the first visit (control: 222.1/100 PY compared to intervention: 192.4/100 PY; rate difference: -28.4, 95% CI: -55.6, -1.2; $P$-value: 0.04), but not in the patients whose asthma was in control at the start of follow-up. Of note, patients whose
Table 2: Characteristics of the 4447 patients in the intervention and control groups

| Demographics         | Control, N = 2174 N (%) | Intervention, N = 2273 N (%) |
|----------------------|-------------------------|-----------------------------|
| **Age at entry (Years)** |                         |                             |
| 5–18                 | 59 (2.7)                | 124 (5.5)                   |
| 19–45                | 594 (27.3)              | 635 (27.9)                  |
| 46–65                | 784 (36.1)              | 802 (35.3)                  |
| >65                  | 737 (33.9)              | 712 (31.3)                  |
| **Sex**              |                         |                             |
| Male                 | 717 (33.0)              | 731 (32.2)                  |
| Female               | 1457 (67.0)             | 1542 (67.8)                 |
| **Language**         |                         |                             |
| English              | 584 (26.9)              | 456 (20.1)                  |
| French               | 1590 (73.1)             | 1817 (79.9)                 |
| **Income** – Mean (SD) |                         |                             |
|                      | 45 103 (26 775)         | 45 807 (24 827)             |
| **Asthma status**    | N (%)                   | N (%)                       |
| Prevalent            | 1980 (91.1)             | 2121 (93.3)                 |
| Incident             | 194 (8.9)               | 152 (6.7)                   |
| **Asthma medication: year before entry** | | |
| No use               | 504 (23.2)              | 650 (28.6)                  |
| ≥ 1 asthma medications | 1670 (76.8)             | 1623 (71.4)                 |
| **Asthma control at entry** | | |
| In control           | 1894 (87.1)             | 2051 (90.2)                 |
| Out-of-control       | 280 (12.9)              | 222 (9.8)                   |
| **Comorbidity**      |                         |                             |
| Charlson index value at entry | | |
| 0                    | 1251 (57.5)             | 1332 (58.6)                 |
| ≥1                   | 923 (42.5)              | 941 (41.4)                  |
| Cardiac-related problems<sup>b</sup> | 274 (12.6)              | 297 (13.1)                  |
| Anxiety-related problems<sup>c</sup> | 322 (14.8)              | 309 (13.6)                  |
| **Healthcare use-year before entry – Mean (SD)** | | |
| Medical visits       |                         |                             |
| Total number of visits | 10.3 (11.3)             | 9.7 (9.3)                   |
| Mean % to study physician | 57.2 (29.8)             | 55.4 (29.2)                 |
| Total visits to respiratory specialists | 1.4 (4.7)              | 1.3 (4.9)                   |
| Prescriptions        |                         |                             |
| Total number of prescriptions | 64.4 (115.3)          | 58.6 (160.8)                |
| Mean % Rx by study physician | 51.1 (42.4)             | 50.2 (42.8)                 |
| Any hospitalization  |                         |                             |
| Yes                  | 375 (17.3)              | 358 (15.8)                  |
| No                   | 1799 (82.8)             | 1915 (84.2)                 |
| Respiratory-related hospitalization | | |
| Yes                  | 56 (2.6)                | 54 (2.5)                    |
| No                   | 2118 (97.4)             | 2216 (97.5)                 |

<sup>a</sup>Income data was obtained through RAMQ files; <sup>b</sup>cardiac-related problems included: ICD9 4139 (other and unspecified angina pectoris), 4279 (cardiac dysrhythmia, unspecified), 7865 (chest pain), 7851 (palpitations); <sup>c</sup>anxiety-related problems included: ICD9 in 7807 (malaise and fatigue), 7804 (dizziness and giddiness), 3009 (nonpsychotic mental disorder), 7840 (headache).
Physicians accessed the asthma decision support more often in patients with out-of-control asthma than patients with in-control asthma.

Table 3: Recommendations generated by the asthma decision support system for patients whose asthma was out-of-control by frequency

| Recommendation                                                                 | Frequency, N (%) |
|-------------------------------------------------------------------------------|------------------|
| Add fluticasone 125 mcg, 2 inhalations BID                                   | 260 (40.0)       |
| Add montelukast 10 mg PO daily                                               | 119 (18.3)       |
| Patient is at maximum dose, consider referring to a specialist               | 46 (7.1)         |
| Increase budesonide/formoterol; 200/6 mcg to 2 inhalations BID              | 41 (6.3)         |
| Increase fluticasone/salmeterol to 250/25 mcg, 2 inhalations BID            | 40 (6.2)         |
| Add long-acting β-agonist, salmeterol 50 mcg, 1 inhalation BID              | 23 (3.5)         |
| Change strength to fluticasone/salmeterol; 500/50 mcg Diskus500, 1 inhalation BID | 20 (3.1)       |
| Stop budesonide and start budesonide/formoterol; 200/6 mcg, 1 inhalation BID | 18 (2.8)         |
| Increase fluticasone/salmeterol; 125/25 mcg to 2 inhalations BID            | 15 (2.3)         |
| Stop fluticasone and long-acting β-agonist and start fluticasone/salmeterol; 250/25 mcg, 2 inhalations BID | 14 (2.2)         |
| Increase budesonide 200 mcg dose to 2 inhalations BID                        | 5 (0.7)          |
| Other                                                                         | 49 (7.5)         |
Table 4: The rate of out-of-control asthma events and the inhaled corticosteroid to FABA ratio in the follow-up period in the control and intervention group

|                          | Control, $N = 41$ MDs | Intervention, $N = 40$ MDs | GEE linear regression | P-value |
|--------------------------|-----------------------|-----------------------------|-----------------------|---------|
| Quality of asthma management | $N$                   | $N$                         | Mean difference in ratios | 95% CI  |         |
| Number using medication  | 1449                  | 1382                        |                       |         |         |
| Ratio inhaled steroids/FABAs – Mean (SD) | 0.69 (0.60)          | 0.93 (1.65)                | 0.27                  | 0.02, 0.51 | 0.034   |
| By asthma severity       |                       |                             |                       |         |         |
| Out-of-control at first visit | 0.53 (0.32)          | 0.68 (1.34)                | 0.16                  | −0.08, 0.405 | 0.198   |
| In control at first visit | 0.84 (0.75)          | 1.12 (1.84)                | 0.30                  | −0.048, 0.66 | 0.090   |
| Out-of-control event rate |                       |                             |                       |         |         |
|                           | $N$                   | $N$                         | Rate difference/100 PY | 95% CI  |         |
| Number of patients       | 2174                  | 2273                        |                       |         |         |
| Number of events         | 2940                  | 2657                        |                       |         |         |
| PY of follow-up          | 5368.7                | 5751.6                     |                       |         |         |
| Event rate/100 PY        | 54.7                  | 46.2                        | −8.7                  | −24.7, 7.3 | 0.29    |
| By asthma severity       |                       |                             |                       |         |         |
| Out-of-control at first visit |                   |                             |                       |         |         |
| Number of patients       | 280                   | 222                         |                       |         |         |
| Number of events         | 1455                  | 1048                        |                       |         |         |
| PY of follow-up          | 655.0                 | 544.7                       |                       |         |         |
| Event rate/100 PY        | 222.1                 | 192.4                       | −28.4                 | −55.6, −1.2 | 0.04    |
| In control at first visit |                       |                             |                       |         |         |
| Number of patients       | 1894                  | 2051                        |                       |         |         |
| Number of events         | 1485                  | 1609                        |                       |         |         |
| PY of follow-up          | 4713.7                | 5206.9                      |                       |         |         |
| Event rate/100 PY        | 31.5                  | 30.9                        | −0.08                 | −10.3, 8.6 | 0.86    |
Asthma was out of control at entry accounted for 44.7% of the 5597 out-of-control asthma episodes during follow-up, even though they represented only 11.3% of the 4447 asthma patients in the study. Indeed, there was a five-fold difference in the rate of events in this subgroup of patients with out-of-control asthma, compared to patients whose asthma was in control at the first visit. When the 73 patients who received asthma home care were excluded from the intervention group, to evaluate the effect of computerized decision-support alone, the effect of the intervention was even greater, reducing the overall rate of out-of-control asthma events by –13.3/100 patients (95% CI: –30.6, 4.1; P = 0.13), compared to the combined intervention, which reduced the rate by 8.7/100 patients. The magnitude of the benefit was even greater for patients whose asthma was out of control at the start of the intervention, reducing the rate of out-of-control asthma events by 36.9/100 (P = 0.01), compared to 28.4 for the combined intervention (P = 0.04). There was no difference in the effect of the intervention among physicians who were more regular users of the MOXXI system.

**DISCUSSION**

This study evaluated the effectiveness of a novel computer-assisted ADS system that facilitates systematic monitoring of asthma control status, follow-up of patients with out of control asthma, and evidence-based, patient-specific treatment recommendations. We found that physicians were more likely to use ADS for patients with out-of-control asthma; that in the majority of these patients, physicians were advised to add an inhaled corticosteroid or a leukotriene inhibitor to the patient’s treatment regimen; and that this intervention significantly increased the mean ratio of inhaled corticosteroid use to FABA use during follow-up. It also reduced the rate of out-of-control asthma episodes during follow-up among patients whose asthma was out of control at the time of study entry.

Similar to two prior studies, we found that practice interventions that enable asthma control monitoring improved use of control medication. A unique aspect of this study was that we used administrative claims data to conduct real-time monitoring of asthma status. Physicians found the alerts generated for patients with out-of-control asthma were particularly useful in identifying patients having difficulty managing their condition. This use of “smart-analytics,” whereby real-time point-of-care clinical data is used to monitor disease status is increasingly used in biomedical monitoring devices but has not been extended to the primary care environment.

A second feature of the ADS system was to provide patient-specific recommendations based on the patient’s current drug profile and control status. Designing these recommendations presented several challenges. The guidelines not only changed over the course of the trial, but they were also too generic to provide direction for specific patients. The guideline authors had to provide expert interpretation of what would be recommended for a patient with a particular combination of therapy and control status. Even then, no recommendations could be generated for medications used in one-fifth of the treatment episodes for patients with out-of-control asthma or in one-tenth of the treatment episodes for patients with in-control asthma. Guidelines are usually based on clinical trial results, but these populations often fail to represent usual practice. As a result, there is a growing shift to a “learning health care system” that can optimize treatment effectiveness through on-going analysis of care processes and outcomes.

Primary care physicians in this study were responsible for only one-half of their patients’ asthma management, and the effectiveness of the intervention may have been attenuated if they did not see themselves as the physician responsible for asthma management. It is only in the past decade that primary care physicians in Canada and the United States have assumed ownership and accountability for a defined population of patients through specific patient-physician agreements or capitated funding mechanisms. Unsurprisingly, in the absence of these agreements, there is ambiguity about who is responsible for the primary medical management of some patients. This is particularly true for patients with poorly controlled asthma, who often see many different physicians for urgent care. The additional time required for proactive monitoring of these patients is likely justified, as they account for the majority of ER visits and hospitalizations for asthma-related problems. In addition, our study showed that early detection and intervention was effective, and many jurisdictions, including Quebec, pay physicians an incentive fee to monitor these patients more closely. It is expected that clarifying primary medical management responsibility would not only increase physician engagement in implementing evidence-based care management for patient self-management and education, but would also improve care access and coordination. Accurate identification of the responsible physician would facilitate team-based primary care, integration of services (such as asthma home care), and a more substantive role for community pharmacists in providing care to asthma patients.

One limitation of this study is that we may have included patients who did not have asthma. While persons under the age of 5 and those with chronic obstructive lung disease were excluded, only a diagnosis of asthma was required for inclusion in the study. The impact of this misclassification would be equivalent in the intervention and control arms of the study. It would result in an over-estimation of asthma control in the population and would potentially dilute the impact of the intervention. This may be why the intervention had no impact in the population whose asthma was in control at study entry, as few experienced an out-of-control asthma episode during follow-up. In contrast, almost half of all out-of-control asthma episodes occurred in the group of patients whose asthma was out of control at study entry. This pattern is consistent with healthcare utilization in general; namely, a small proportion of patients account for a disproportionate share of the overall cost of healthcare.

In summary, we showed that a computer-assisted ADS system in primary care increased the quality of asthma management and reduced the rate of out-of-control asthma episodes for patients with poorly controlled asthma at study entry.
Future research should assess whether coupling patient-specific treatment recommendations, automated follow-up, and home care with comparative feedback on quality and outcomes of care, specialized support in adopting new approaches to treatment, and policies that support explicit physician-patient responsibilities/accountability and team-based primary care improve guideline adoption and care outcomes.

CONTRIBUTORS
RT, PE, NW, AH, RG, RWP, SA, and TE contributed to the conception and design, acquisition of data, drafted the article and critically revised it for important intellectual content. TM completed the data analysis. All authors approve the final version to be published.

FUNDING
This work was supported by the Canadian Institutes of Health Research and Canadian Health Infostructure Partnership Program of Health Canada

COMPETING INTERESTS
None.

REFERENCES
1. Vinicor F. Diabetes mellitus and asthma: “twin” challenges for public health and managed care systems. Am J Prev Med. 1998;14 (Suppl 3):87–92.
2. Wilkins K, Mao Y. Trends in rates of admission to hospital and death from asthma among children and young adults in Canada during the 1980s. Can Med Assoc J. 1993;148 (2):185–190.
3. Kelloway JS. A United States approach to the management of asthma in a managed care environment. Eur Respir Rev. 1996;6 (33):50–53.
4. Braman SS. The Global Burden of Asthma*. Chest. 2006;130:45–125.
5. The Conference Board of Canada. Lung Disease Imposes Major Costs on Canada’s Economy. News Release, March 15, 2012:12–96.
6. Krahn MD, Berka C, Langlois P, Detsky AS. Direct and Indirect Costs of Asthma in Canada, 1990. Can Med Assoc J. 1996;154 (6):821–831.
7. Booth A. Benefits of an individual asthma action plan. Pract Nurs. 2012;23:592–604.
8. Zemek RL, Bhogal SK, Ducharme FM. Systematic review of randomized controlled trials examining written action plans in children: what is the plan? Arch Pediatr Adolesc Med. 2008;162:157.
9. Bhogal S, Zemek R, Ducharme FM. Written action plans for asthma in children. Cochrane Database Syst Rev. 2006;3.
10. Gibson PG, Powell H. Written action plans for asthma: an evidence-based review of the key components. Thorax. 2004;59:94–99.
11. Boulet LP, Becker A, Berube D, Beveridge R, Ernst P; on behalf of the Canadian Asthma Consensus Group. Summary of recommendations from the Canadian Asthma Consensus Report, 1999. CMAJ Suppl. 2003;161.
12. Fitzgerald JM, Ernst P, Boulet LP, O’Byrne P. Measures of outcome. Evidence-Based Asthma Management. Hamilton, London: BC Decker Inc.; 2001:307–322.
13. Boulet LP, Bai TR, Becker A, et al. What is new since the last (1999) Canadian Asthma Consensus Guidelines? [comment]. Can Respir J. 2001;8 (Suppl A):3A–27A.
14. Gibson PG. Monitoring the patient with asthma: an evidence-based approach. [see comments.]. [Review] [72 refs]. J Allergy Clin Immunol. 2000;106:26–.
15. Lougheed MD, Leemiere C, Ducharme FM, et al. Canadian Thoracic Society 2012 guideline update: diagnosis and management of asthma in preschoolers, children and adults. Can Respir J. 2012;19:127–164.
16. Blais L, Suissa S, Boivin JF, Ernst P. First treatment with inhaled corticosteroids and the prevention of admissions to hospital for asthma. Thorax. 1998;53:1025–1029.
17. Blais L, Ernst P, Boivin JF, Suissa S. Inhaled corticosteroids and the prevention of readmission to hospital for asthma. Am J Respir Crit Care Med. 1998;158:126–132.
18. Suissa S, Ernst P, Kezouh A. Regular use of inhaled corticosteroids and the long term prevention of hospitalisation for asthma. Thorax. 2002;57:880–884.
19. Suissa S, Ernst P, Benayoun S, Baltzan M, Cai B. Low-dose inhaled corticosteroids and the prevention of death from asthma. New Engl J Med. 2000;343:332–336.
20. Licskai C, Sands T, Ong M, Paolatto L, Nicoletti I. Using a knowledge translation framework to implement asthma clinical practice guidelines in primary care. Int J Qual Health Care. 2012;24:538–546.
21. Chapman KR, Ernst P, Grenville A, Dewland P, Zimmerman S. Control of asthma in Canada: failure to achieve guideline targets. Can Respir J. 2001;8 (Suppl A):35A–40A.
22. Bateman ED, Boushey HA, Bousquet J, et al. Canadian Asthma Consensus Group. Summary of recommendations from the Canadian Asthma Consensus Report, 1999. CMAJ Suppl. 2003;161.
23. Wechsler ME. Managing asthma in primary care: putting new guideline recommendations into context. Mayo Clin Proc. 2009;84:707–717.
24. Yawn BP. The role of the primary care physician in helping adolescent and adult patients improve asthma control. Mayo Clin Proc. 2011;86:894–902.
25. Crim C. Clinical practice guidelines vs actual clinical practice: the asthma paradigm. Chest. 2000;118 (Suppl S):62S–64S.
26. Hunt DL, Haynes B, Hanna SE, Smith K. Effects of computer-based clinical decision support systems on physician performance and patient outcomes. A systematic review. JAMA. 1998;280:1339–1346.
27. Burack RC, Gimotty PA, George J, et al. Promoting screening mammography in inner-city settings: a randomized controlled trial of computerized reminders as a component of a
program to facilitate mammography. Med Care. 1994;32:609–624.
28. Frame PS, Zimmer JG, Werth PL, Hall WJ, Eberly SW. Computer-based vs manual health maintenance tracking. A controlled trial. Arch Fam Med. 1994;3:581–588.
29. McPhee SJ, Bird JA, Fordham D, Rodnick JE, Osborn EH. Promoting cancer prevention activities by primary care physicians. Results of a randomized, controlled trial. JAMA. 1991;266:538–544.
30. Turner RC, Peden JG Jr, O’Brien K. Patient-carried card prompts vs computer-generated prompts to remind private practice physicians to perform health maintenance measures. Arch Intern Med. 1994;154:1957–1960.
31. Rind DM, Safran C, Phillips RS, et al. Effect of computer-based alerts on the treatment and outcomes of hospitalized patients. Arch Intern Med. 1994;154:1511–1517.
32. Montgomery AA, Fahey T, Peters TJ, Macintosh C, Sharp DJ. Evaluation of computer based clinical decision support system and risk chart for management of hypertension in primary care: randomised controlled trial. Br Med J. 2000;320:686–690.
33. Shegog R, Bartholomew LK, Sockrider MM, et al. Computer-based decision support for pediatric asthma management: description and feasibility of the Stop Asthma Clinical System. Health Informatics J. 2006;12:259–273.
34. Roshanov PS, Misra S, Gerstein HC, et al. Computerized clinical decision support systems for chronic disease management: a decision-maker-researcher partnership systematic review. Implement Sci. 2011;6:92.
35. Eccles M, McColl E, Steen N, et al. Effect of computerised evidence based guidelines on management of asthma and angina in primary care: cluster randomised controlled trial. Br Med J. 2002;325:941–947.
36. Tierney WM, Overhage JM, Murray MD, et al. Can computer-generated evidence-based care suggestions enhance evidence-based management of asthma and chronic obstructive pulmonary disease? A randomized, controlled trial. Health Serv Res. 2005;40:477–498.
37. Kattan M, Crain EF, Steinbach S, et al. A randomized clinical trial of clinician feedback to improve quality of care for inner-city children with asthma. Pediatrics. 2006;117:e1095–e1103.
38. Bell LM, Grundmeier R, Localio R, et al. Electronic health record-based decision support to improve asthma care: a cluster-randomized trial. Pediatrics. 2010;125:e770–e777.
39. Tamblyn R, Huang A, Perreault R, et al. The medical office of the 21st century (MOXX): effectiveness of computerized decision-making support in reducing inappropriate prescribing in primary care. CMAJ. 2003;169:549–556.
40. Boulet LP, Becker A, Berube D, Beveridge R, Ernst P. Canadian Asthma Consensus Group. Can Med Assoc J. 1999;161:S1–S61.
41. Ernst P. Education of asthmatic patients. The Quebec experience. Revue Francaise D Allergologie et d Immunologie Clinique. 1998;38:784–788.
42. Spitzer WO, Suisse S, Ernst P, et al. The use of B-agonists and the risk of death and near death from asthma. N Engl J Med. 1992;326:501–506.
43. Global Initiative for Asthma. Global Strategy for Asthma Management and Prevention. 2014. http://www.ginasthma.org/local/uploads/files/GINA_Report_2014_Aug12.pdf. Accessed August 26, 2014.
44. Sin DD, Tu JV. Inhaled corticosteroids and the risk of mortality and readmission in elderly patients with chronic obstructive pulmonary disease. Am J Respir Crit Care Med. 2001;164:580–584.
45. Chuang JH, Hripcsak G, Jenders RA. Considering Clustering: A Methodological Review of Clinical Decision Support System Studies. Proc AMIA Symp. 2000;146–150.
46. Plaza V, Cobos A, Ignacio-Garcia JM, et al. [Cost-effectiveness of an intervention based on the Global INitiative for Asthma (GINA) recommendations using a computerized clinical decision support system: a physicians randomized trial]. Med Clin. 2005;124:201–206.
47. McCowan RGN. Lessons from a randomized controlled trial designed to evaluate computer decision support software to improve the management of asthma. Inform Health Soc Care. 2001;26:191–201.
48. Peters TE, Bhavaraju NC, Frei MG, Osorio I. Network system for automated seizure detection and contingent delivery of therapy. J Clin Neuropsychol. 2001;18:545–549.
49. Skledar SJ, Niccolai CS, Schilling D, et al. Quality-improve-ment analytics for intravenous infusion pumps. Am J Health Syst Pharm. 2013;70:680–686.
50. Institute of Medicine, Committee on the National Quality Report on Health Care Delivery, Corrigan J, et al. Envisioning the National Health Care Quality Report. Washington, DC: National Academy Press; 2001.
51. Institute of Medicine of the National Academies. Digital Data Improvement Priorities for Continuous Learning in Health and Health Care. Washington, D.C: The National Academies Press; 2013.
52. Hutchison B, Levesque JF, Strumpf E, Coyle N. Primary health care in Canada: systems in motion. Milbank Q. 2011;89:256–288.
53. Hutchison B, Glazier R. Ontario’s primary care reforms have transformed the local care landscape, but a plan is needed for ongoing improvement. Health Aff. 2013;32:695–703.
54. Hutchison B, Abelson J, Lavis J. Primary care in Canada: so much innovation, so little change. Health Aff. 2001;20:116–131.
55. Pham HH, Ginsburg PB. Unhealthy trends: the future of physi-cian services. Health Aff. 2007;26:1586–1598.
56. Walker S, Mason AR, Claxton K, et al. Value for money and the quality and outcomes framework in primary care in the UK NHS. Br J Gen Pract. 2010;60:e213–e220.
57. NHS Employers. Quality and Outcomes Framework guidance for GMS contract 2013/14. 1-3-2013. The NHS Confederation
62. Taylor EF, Machta RM, Meyers DS, Genevro J, Peikes DN. Enhancing the primary care team to provide redesigned care: the roles of practice facilitators and care managers. Ann Fam Med. 2013;11:80–83.

63. British Columbia Pharmacy Association. British Columbia Pharmacy Association (BCPhA) Clinical Service Proposal Asthma Consultation Service. British Columbia: British Columbia Pharmacy (BCPhA); 2013.

64. Buckley KN, Ryder SA. Asthma management in the community pharmacy setting in Ireland. Int J Clin Pharm. 2012;34:186.

65. Monheit AC. Persistence in health expenditures in the short run: prevalence and consequences. Med Care. 2003;41:III53–III64.

AUTHOR AFFILIATIONS

1Division of Clinical Epidemiology, McGill University Health Centre, Montreal, QC, Canada

2Department of Epidemiology, Biostatistics and Occupational Health, McGill University, Montreal, QC, Canada

3Clinical and Health Informatics Research Group, McGill University, Montreal, QC, Canada

4Centre for Clinical Epidemiology, Lady Davis Institute for Medical Research, Jewish General Hospital, McGill University, Montreal, QC, Canada

5Division of Geriatric Medicine, University of Ottawa, Ottawa, ON, Canada

6Herzl Family Practice Centre, Jewish General Hospital, Montreal, QC, Canada