

# 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

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## 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  $\beta$ -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  $\beta$ -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% 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  $-28.4$  per 100 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% 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&spons=McGill+University&state1=NA%3ACA%3AQC&rank=2>

**Key words:** out-of-control; computer decision support; MOXXI; personalized medicine; RCT; asthma

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## INTRODUCTION

Asthma is a chronic condition that causes substantial morbidity.<sup>1–3</sup> Chronic lung diseases, including asthma, cost Canadians an estimated \$12 billion in 2010.<sup>4,5</sup> 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.<sup>6</sup> 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%.<sup>7–14</sup> Asthma guidelines also recommend the use of inhaled corticosteroids, as they improve symptoms and lung function<sup>15</sup> and also reduce the likelihood of patient hospitalization<sup>16–18</sup> and death.<sup>19</sup> Although asthma guidelines are available internationally, few asthma patients receive evidence-based care, and, as a result, many patients suffer from inadequately controlled asthma.<sup>20–22</sup>

Primary care physicians provide the majority of asthma care.<sup>23,24</sup> 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.<sup>25</sup> 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.<sup>26–33</sup>

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.<sup>34</sup> The earliest randomized trials of CDS for asthma suffered from technical challenges.<sup>35</sup> 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.<sup>36</sup> 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.<sup>37</sup> 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.<sup>38</sup> 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.<sup>37,38</sup> 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.

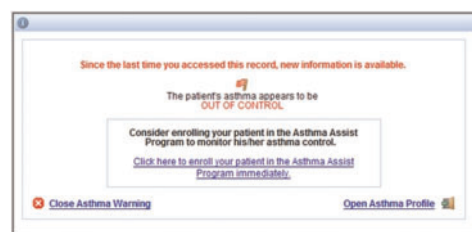
**Basic and control intervention:** Physicians in both groups were regular users of the MOXXI EHR, which provided two critical features needed to successfully institute CDS: 1) MOXXI captures and codes clinical information so that it can be used to trigger CDS, for targeted patients, and generate patient-specific 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 Quebec (RAMQ).<sup>39</sup>

**ADS intervention:** The ADS system uses Canadian consensus guidelines<sup>13,40</sup> 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.<sup>21,41</sup> 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  $\beta$ -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.<sup>13,40</sup> When a recommendation is*

**Figure 1: The dashboard alert. An out-of-control alert based on ER visits for asthma and overuse of fast-acting  $\beta$ -agonists.**



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 2: Decision support for evidence-based asthma management. Individualized treatment recommendations for out-of-control asthma based on a patient's current medication profile.

The screenshot displays a clinical decision support system interface for asthma management. The top navigation bar includes links for 'My Patients', 'My Practice', 'Monographs', and user information for 'Julia Morlec'. The main header shows the patient's name 'ARTHUR LAROCHE' and a status 'OUT OF CONTROL'. The interface is divided into several sections:

- Asthma Profile:**
  - 1. Please validate drugs and posologies:** A table showing current medications: FLOVENT DISKUS 100MCG (1 INH BID) and SALBUTAMOL 100MCG (1-2 INH).
  - 2. Respiratory-related ER Visits & Faba Medication Usage:** Checkboxes for 'Respiratory-related ER visits in the past 3 months: 1 visit(s)' and 'Dispensed FABA medications in the past 3 months: (Dose < 250)'.
  - 3. In the last week, the patient has:** A list of symptoms with checkboxes, including 'Trouble breathing on 4 or more days', 'Use of rescue inhaler 4 or more times', 'Awakened due to asthma', 'Unable to carry out usual activities', 'Missed school or work because of asthma', and 'Had an urgent medical visit for asthma'.
  - 4. Update:** A green checkmark and a button labeled 'Update Suggested Treatment'.
- Suggested Treatment:**
  - 5. Select Recommendation and Action Plan:** A list of recommendations with checkboxes, including 'ADD LABA SEREVENT DISKUS 50 1 INH BID.', 'STOP FLOVENT DISKUS & START ADVAIR DISKUS 100 1 INH BID.', 'INCREASE FLOVENT DISKUS DOSE & CHANGE STRENGTH TO 250 1 INH BID', and 'ADD LTN SINGULAIR 10MG PO QD.'. A green bar highlights 'Determining Drug: (FLOVENT DISKUS 100MCG 1 INH BID)'.
  - 6. Prescribe Fast Acting B Agonist (FABA) if needed:** Checkboxes for 'SALBUTAMOL MDI 100 1-2 INH AS NEEDED' and 'TERBUTALINE 500 1 INH AS NEEDED'.
  - 7. Asthma Home Care:** A link to 'Asthma Home Care Tool - Deactivated'.
  - 8. Apply Changes:** A green checkmark and buttons for 'Proceed with Changes' and 'Proceed with Changes And Print'.

### 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 asthma<sup>42</sup> 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.<sup>13</sup>

Secondary outcome: quality of asthma management

The *inhaled corticosteroid to fast-acting  $\beta$ 2-agonist ratio* is a commonly used measure of quality of asthma care.<sup>43,44</sup> 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

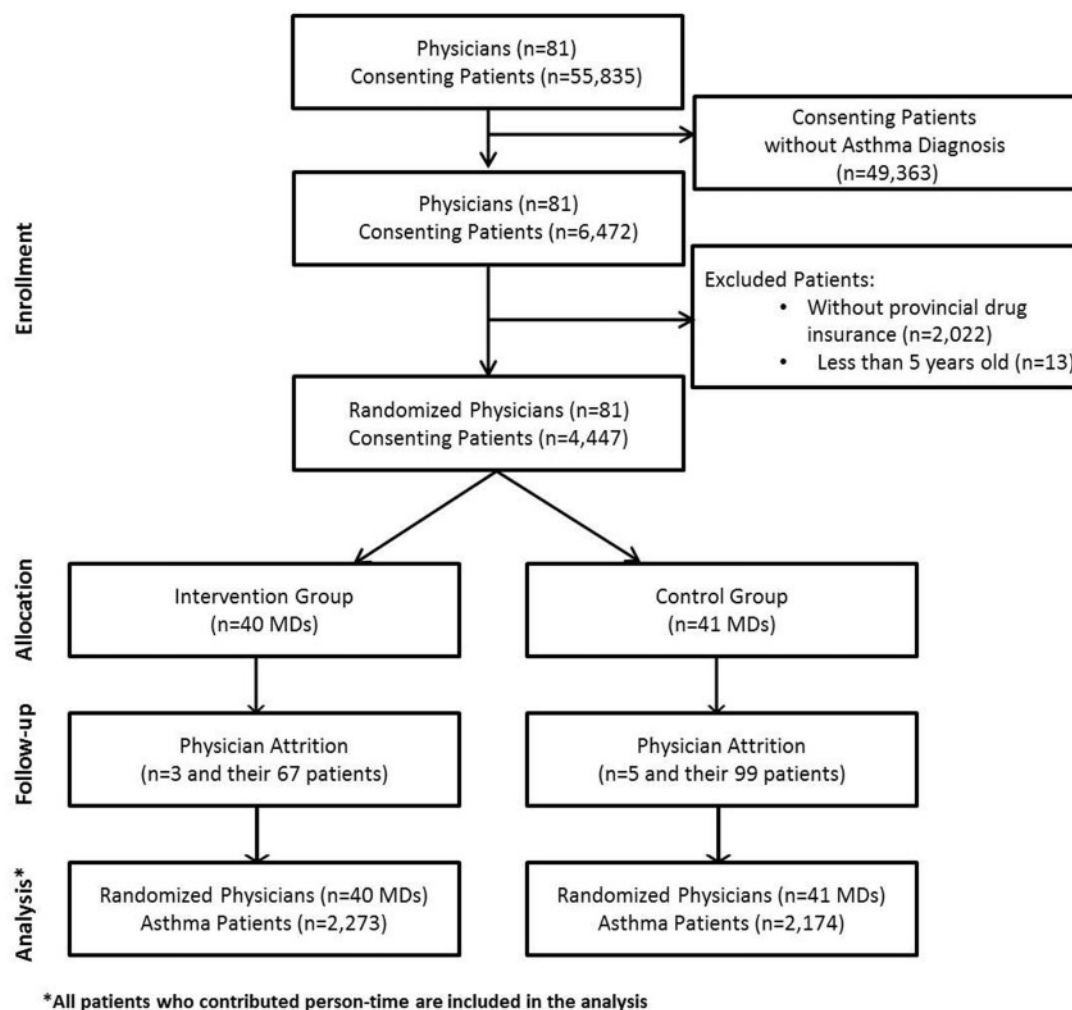
and FABA during each 3-month period of follow-up. The mean of each 3-month ratio was then calculated for each patient for each 3-month follow-up window in which they were taking medications.

### 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.<sup>45</sup> 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



**Figure 3: Consort diagram of physicians and patients eligible for the study.** Physicians and patients were included in this study if they met the criteria outlined in the “Methods” section. Physicians were stratified by practice size and then, along with their patients, were randomly assigned to either the intervention or control group.



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

Table 1: Characteristics of the 81 physicians in the intervention and control groups

	Control, <i>N</i> = 41		Intervention, <i>N</i> = 40	
Demographics	<i>N</i>	(%)	<i>N</i>	(%)
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)

patient's first visit after randomization. Of importance, the extent to which the study physicians managed their patients' medical care was also similar, where 55.4% (intervention) to 57.2% (control) of all medical visits and 50.2% (intervention) to 51.1% (control) of all drugs were managed by the patient's primary care physician.

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 whose asthma was in control at the start of the study as well as those 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, <i>N</i> = 2174 <i>N</i> (%)	Intervention, <i>N</i> = 2273 <i>N</i> (%)
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 <sup>a</sup> – Mean (SD)	45 103 (26 775)	45 807 (24 827)
Asthma status		
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).

Figure 4: Flow chart of the breakdown of visits of patients in the intervention group. Patients in the intervention group were categorized as having in-control or out-of-control asthma. Physicians accessed the asthma decision support more often in patients with out-of-control asthma than patients with in-control asthma.

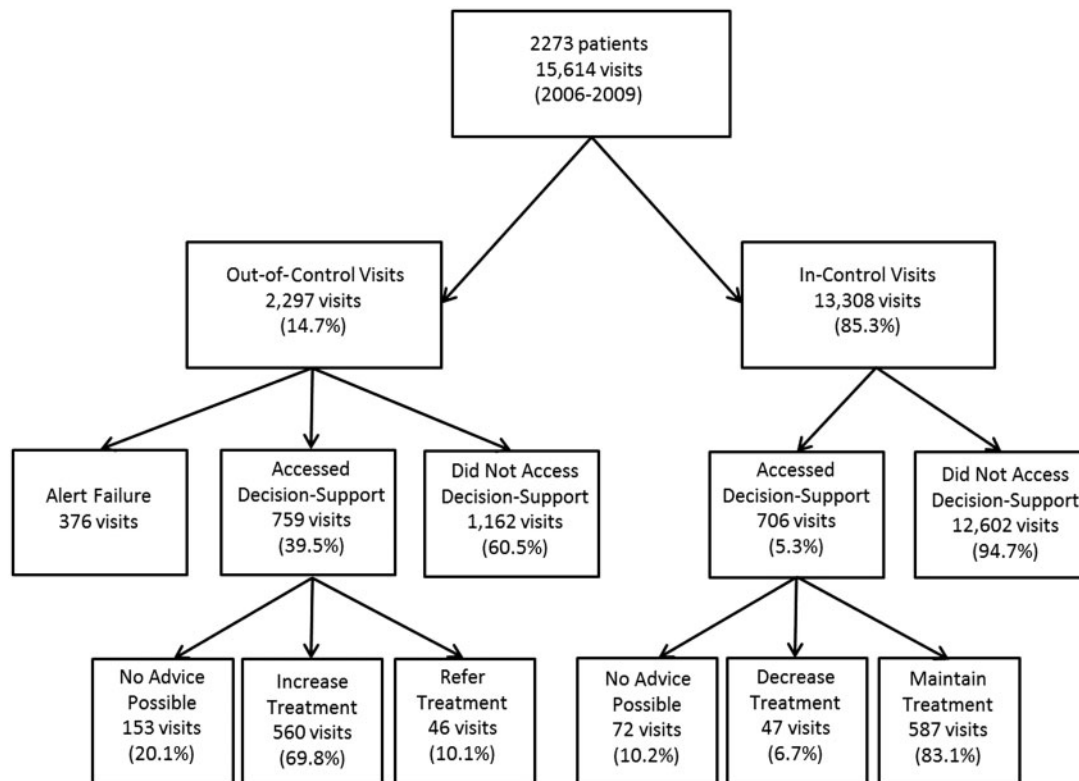


Table 3: Recommendations generated by the asthma decision support system for patients whose asthma was out-of-control by frequency

Recommendation	Frequency, <i>N</i> (%)
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 $\beta$ -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 $\beta$ -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 FABAs ratio in the follow-up period in the control and intervention group

	Control, <i>N</i> = 41 MDs	Intervention, <i>N</i> = 40 MDs	GEE linear regression	95% CI	<i>P</i> -value
Quality of asthma management	<i>N</i>	<i>N</i>	Mean difference in ratios		
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	Control, <i>N</i> = 41 MDs	Intervention, <i>N</i> = 40 MDs	GEE Poisson regression		
	<i>N</i>	<i>N</i>	Rate difference/100 PY	95% CI	<i>P</i> -value
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,<sup>46,47</sup> 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<sup>48,49</sup> 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.<sup>50,51</sup>

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<sup>52</sup> 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.<sup>53–55</sup> 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.<sup>14</sup> 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.<sup>20–22,37</sup> 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.<sup>56–58</sup> 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,<sup>59–62</sup> 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.<sup>63,64</sup>

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 health-care utilization in general; namely, a small proportion of patients account for a disproportionate share of the overall cost of healthcare.<sup>65</sup>

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.

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## COMPETING INTERESTS

None.

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