Computer decision support systems for asthma

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Article

Computer decision support systems for asthma: a systematic review

Patricia Matui1, Jeremy C Wyatt2, Hilary Pinnock1, Aziz Sheikh1 and Susannah McLean1

BACKGROUND: Increasing use of electronic health records offers the potential to incorporate computer decision support systems (CDSSs) to prompt evidence-based actions within routine consultations.

AIM: To synthesise the evidence for the use of CDSSs by professionals managing people with asthma.

MATERIALS AND METHODS: We systematically searched Medline, Embase, Health Technology Assessment, Cochrane and Inspect databases (1990 to April 2012, no language restrictions) for trials, and four online repositories for unpublished studies. We also wrote to authors. Eligible studies were randomised controlled trials of CDSSs supporting professional management of asthma. Studies were appraised (Cochrane Risk of Bias Tool) and findings synthesised narratively.

RESULTS: A total of 5787 articles were screened, and eight trials were found eligible, with six at high risk of bias. Overall, CDSSs for professionals were ineffective. Usage of the systems was generally low: in the only trial at low risk of bias the CDSS was not used at all. When a CDSS was used, compliance with the advice offered was also low. However, if actually used, CDSSs could result in closer guideline adherence (improve investigating, prescribing and issuing of action plans) and could improve some clinical outcomes. The study at moderate risk of bias showed increased prescribing of inhaled steroids.

CONCLUSIONS: The current generation of CDSSs is unlikely to result in improvements in outcomes for patients with asthma because they are rarely used and the advice is not followed. Future decision support systems need to align better with professional workflows so that pertinent and timely advice is easily accessible within the consultation.

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INTRODUCTION

The Global Initiative for Asthma estimates that 300 million people worldwide have asthma.1 Prevalence rates as high as 32% have been recorded in the United Kingdom and Australia,2 and the prevalence is increasing in many parts of the world.3–5 Despite evidence-based guidelines,1,6–9 there is consistent evidence that asthma is suboptimally controlled, resulting in unnecessary morbidity, loss of school and workdays, and high costs for countries.9–11 There are 250,000 asthma-related deaths each year.1

There are many reasons why guidelines are poorly implemented, including physician’s lack of knowledge or inertia of practice.12,13 As electronic health records are now the norm in many parts of the world,14,15 it is feasible to provide professionals with computer decision support systems (CDSSs) to prompt evidence-based actions within routine consultations, potentially improving professional adherence to guidelines.

Our systematic review aimed to synthesise the evidence for the use of CDSSs by professionals managing people with asthma. We were primarily interested in the effectiveness of CDSSs in improving patient outcomes, but also sought to investigate process measures of guideline adherence and practical usage of the system.

MATERIALS AND METHODS

Our protocol is registered with the PROSPERO international prospective register of systematic reviews (CRD 42012002412). We followed the methodology described in the Cochrane Handbook for Systematic Reviews of Interventions.16

Inclusion criteria

We used the PICOS (Participants, Intervention, Comparator, Outcomes, Study design) strategy for describing trials in which we were interested:

Participants. As this study is a review of the evidence, the study participants were de facto the health professionals using CDSSs who were caring for people with asthma—i.e., doctors, nurses and others (e.g., physiotherapists).

Intervention. We adopted Wyatt et al.’s definition of CDSSs as ‘active knowledge systems which use two or more items of patient data to generate case-specific advice’.17 Haynes and Wilczynski similarly described such systems as ‘information technology which matches characteristics of individual patients to a computerised knowledge base’, with software algorithms generating patient-specific information in the form of recommendations.18 There are various levels of sophistication for CDSSs, from reminders to enter specific data, prescribe certain drugs/vaccines or provide an asthma action plan, to a system retrieving patient asthma information from an electronic health-care record and providing a critique on the intended clinical action. Systems were included if they used patient data to generate case-specific asthma advice. Systems relating only to the task of asthma diagnosis or those exclusively providing patients with support for self-management were excluded.

Comparator. The comparator was ‘usual care’, specifically without the use of a CDSS.

Outcomes. Our primary interest was in the impact of CDSSs on clinical asthma control. In line with recommended guidelines,19 we included outcomes that reflected current control (including asthma-related quality of life) and frequency of asthma exacerbations (including frequency of the
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Facilitators

Stage

Barriers

Financial incentives

Guideline development

Perceived lack of credibility of guideline changes in treatment protocols

Smooth integration of software into electronic health record

Software development

Prototype does not work in practice

User-friendly design, easy (potentially automatic) access to relevant advice

Practical aspects of use of CDSS

Usability issues: too much non-specific information, difficulty activating CDSS, e.g., separate screen, long time to load, password protection

Relevant recommendations customised to clinical context

Process outcomes

Clinicians choose not to implement recommended changes

Measureable improvement in patients’ conditions

Health outcomes

Figure 1. Theoretical model showing how a computer decision support system can improve asthma outcomes.

Quality of reporting of trials

We assessed the risk of bias in each trial using the seven-criteria approach described in the Cochrane Handbook for Systematic Reviews of Interventions.16 Overall, each study was rated as follows: A: low risk of bias—no bias found; B: moderate risk of bias—one criterion for risk of bias; C: high risk of bias—more than one criterion for risk of bias.

Synthesis of results

We anticipated considerable heterogeneity in the populations studied, and in the interventions and the outcomes reported in the trials precluding meta-analysis of data. Instead, we planned to undertake a narrative synthesis based on our theoretical model of how such computer systems are expected to exert their effects (see Figure 1). The expectation is that, in a linked causal chain, CDSSs will impact process outcomes, which, in turn, will impact clinical outcomes. The theory underpinning their effectiveness is that relevant reminders and recommendations during a consultation will influence clinicians’ behaviour and thereby improve guideline adherence as measured by process outcomes (e.g. more rational ordering of investigations, prescribing of treatment and use of asthma action plans). Implementation of evidence-based practices will consequently be measureable in clinical outcomes for asthma patients, such as fewer exacerbations, emergency department attendances and hospitalisations.

RESULTS

Study selection

Figure 2 is the PRISMA flow diagram. From 5,787 titles, eight studies were selected,20–27 seven in English and one in Spanish.26 One study had two reports.24,28 None of the experts we contacted identified any additional eligible studies. We found nine ongoing and eight unpublished trials (Supplementary Appendix 2). We excluded a small group of studies from the early 1990s of computerised theophylline dose calculators because they addressed a specific problem in emergency care and have already been evaluated in a Cochrane review.29

Study characteristics

See Table 1 for details of study characteristics. Most studies were cluster randomised controlled trials20–26 in primary care in the UK21,25 or the Netherlands.23,24 Two studies randomised practices to receive a CDSS for asthma prescribing or a system for angina or cholesterol prescribing.21,24 The practices providing data on general practitioner’s asthma visits, emergency department asthma visits and asthma hospitalisations).

We were also interested in the process by which CDSSs might impact asthma control, both practical usage issues (e.g. the proportion of professionals who actually used the CDSS, the numbers of alerts issued and the impact on time within the consultation) as well as process measures reflecting enhanced guideline adherence (e.g. changes in treatment, in tests ordered and in the proportion of patients with asthma action plans).

Study design. All reports of randomised controlled trials of CDSSs used by health-care professionals for patients with asthma, in any language, published and unpublished, were eligible for inclusion. No other study designs were included.

Information sources and search strategy

We searched Medline, Embase, Cochrane Central Register of Controlled Trials, Health Technology Assessment and Inspec (engineering) databases from 1990 to April 2012 with the terms listed in Supplementary Appendix 1. We wrote to experts and authors of all included studies requesting additional relevant studies. We searched for ongoing and unpublished trials on the following websites: https://portal.nihr.ac.uk/Pages/NRRArchive.aspx, www.clinicaltrials.gov, www.controlled-trials.com and www.anzctr.org.au.

Study selection

Two authors (PM and SM) independently screened titles and abstracts, assessing them against the inclusion criteria. The full text of each potentially eligible paper was reviewed by both authors to decide whether the study should be included. Disagreements were resolved by discussion and, if necessary, arbitration of a third researcher (HP, AS or JCW).

Data collection and abstraction

Using a piloted data extraction form, PM and SM independently extracted the following data from included trials: country, setting, funding, study design, health-care professionals, patient population, features of the CDSS intervention, description of the control group, outcome measures and any adverse effects. Extraction tables were compared, and discussed with a third researcher (HP, AS or JW) arbitrating in the event of unresolved disagreement.

RESULTS

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angina and cholesterol prescribing were unaware that their (usual care) asthma prescribing data were control data for the parallel asthma study.

Six of the systems were integrated into an electronic health record:20,22–24,26,27 one was partly integrated21 and one was a stand-alone system.25 Five of the studies20,21,23,26,27 explicitly reported that the system gave prescribing advice and reminders. One system concentrated solely on the prescribing of inhaled corticosteroids to 44% of asthma patients (95% confidence interval [CI], 30–56%) in the intervention group, compared with 27% (95% CI, 14–47%) in the control group. In the trial by Bell et al.,20 there was a highly significant difference (P = 0.006) difference between the rate of prescribing inhaled corticosteroids in the subgroup of urban intervention practices compared with urban control practices. Urban and suburban practices were analysed separately in the cluster controlled trial because of marked baseline differences in patient population: the urban practices had more severe asthma.

Challenges in treatments. Eccles et al.,21 the only trial at low risk of bias, found no difference in asthma-related prescribing as a result of the intervention. Martens et al.,24 demonstrated an increase in the prescribing of inhaled corticosteroids to 44% of asthma patients (95% confidence interval [CI], 30–56%) in the intervention group, compared with 27% (95% CI, 14–47%) in the control group.

Changes in tests ordered. Eccles et al.,21 McCowan et al.,25 and Plaza et al.,26 all reported that the systems made no difference in the rates of ordering spirometry, X-rays, allergy tests or blood tests. Bell et al.,20 reported an increase in spirometry requests at intervention practices from 15 to 24%, whereas there was a decrease at control practices from 8 to 1%. In Kuilboer et al.,23 peak expiratory flow rate and spirometry tests were ordered more often in the intervention group, in patients over 11 years of age. In a four-arm trial, Tierney et al.,27 reported that between 39 and 50% of patients received the suggestion to obtain pulmonary function tests.

Risk of bias within studies
Table 2 lists the quality assessment: most studies were rated at high risk of bias. The study by Eccles et al.,21 was rated at low risk of bias and that by Martens et al.,24 at moderate risk of bias.

Effectiveness of CDSSs
The impact of CDSS on process, usage and clinical outcomes is detailed in Table 3. It was anticipated that usage and process outcomes would influence clinical outcomes as reflected in our model (Figure 1).

Practical aspects of CDSS use
In the study by Eccles et al.,21 the median number of activations of the system per practice was zero. In that by Kuilboer et al.,23 10,863 visits generated 10,532 decision support comments, but the doctor waited for the critique only 22% of the time, and then read only a third of them. In Tierney et al.’s study,27 doctors complied with a third of the systems’ suggestions. Bell et al.,20 reported that the CDSS was used 70% of the time. In the study by Fiks et al.,27 the vaccine alerts were only active during 27% of visits.

Process outcomes
Changes in tests ordered. Eccles et al.,21 McCowan et al.,25 and Plaza et al.,26 all reported that the systems made no difference in the rates of ordering spirometry, X-rays, allergy tests or blood tests. Bell et al.,20 reported an increase in spirometry requests at intervention practices from 15 to 24%, whereas there was a decrease at control practices from 8 to 1%. In Kuilboer et al.,23 peak expiratory flow rate and spirometry tests were ordered more often in the intervention group, in patients over 11 years of age. In a four-arm trial, Tierney et al.,27 reported that between 39 and 50% of patients received the suggestion to obtain pulmonary function tests.

Changes in treatments. Eccles et al.,21 the only trial at low risk of bias, found no difference in asthma-related prescribing as a result of the intervention. Martens et al.,24 demonstrated an increase in the prescribing of inhaled corticosteroids to 44% of asthma patients (95% confidence interval [CI], 30–56%) in the intervention group, compared with 27% (95% CI, 14–47%) in the control group. In the trial by Bell et al.,20 there was a highly significant difference (P = 0.006) difference between the rate of prescribing inhaled corticosteroids in the subgroup of urban intervention practices compared with urban control practices. Urban and suburban practices were analysed separately in the cluster controlled trial because of marked baseline differences in patient population: the urban practices had more severe asthma.

Kuilboer et al.,23 demonstrated a significant reduction in the prescribing of cromoglycate in a post hoc analysis. Plaza et al.,26 demonstrated a doubling of treatment conforming to guidelines, from 18 to 34% (P = 0.02). Vaccination rates increased in both arms of the Fiks trial with no significant differences.22 McCowan et al.,25 found no difference in asthma-related prescribing between the trial arms due to the intervention. Tierney et al.,27 reported on treatment suggestions for both asthma and chronic obstructive pulmonary disease. For example, across the four arms of the Tierney trial, between 5 and 9% of patients received the suggest-
| Author (country) | Study design | Participants and setting | Age (years) | Time scale | Intervention | Control |
|-----------------|--------------|--------------------------|-------------|------------|--------------|---------|
| Bell et al.²⁰ (USA) | Cluster RCT | 12 clusters: 12 primary care practices, 19,450 patients | 0–18 | 12 months | 6 months prior to study start clinicians participated in an educational programme, 12 months of intervention | CDSS embedded in an electronic health record (EHR) in the form of alerts and reminders based on expert asthma guidelines. This included a data entry tool, standardised documentation for asthma severity classification, standardised drug and spirometry order sets and an asthma control plan. There was also an educational programme for professionals. The control group experienced educational programme for professionals. It also had access to the data entry and all documentation tools but only passively, without alerts and reminders. |
| Eccles et al.²¹ (UK) | Cluster RCT with 2×2 incomplete block design | 60 clusters: 60 primary care practices, 1,129 patients | ≥ 18 | 24 months | 12 months baseline period, 12 months intervention | CDSS offered suggestions for management (including prescribing) depending on the chosen clinical scenario and requested the entry of relevant information. Controls received intervention for angina, while the asthma intervention group was the control from the angina group as a strategy to balance the Hawthorne effect. Described as routine care. |
| Fiks et al.²² (USA) | Cluster RCT | 20 clusters: 20 practices, 6,110 patients | 5–19 | 6 months | All intervention | CDSS was an EHR-based influenza vaccination alert system. Influenza vaccine alerts appeared prominently at the top of the computer screen in bold and highlighted text whenever the electronic health record was opened for a study subject who was due for this vaccine. Also a link was provided to simplify vaccine ordering. Described as usual care. |
| Kuilboer et al.²³ (The Netherlands) | Cluster RCT | 40 clusters: 32 primary care practices with a total of 40 GPs, each control practice with a mean of 4,933 control and 4,865 intervention patients | All | 10 months | 5 months baseline period, 5 months intervention | ‘AsthmaCritic,’ the CDSS, relied solely on the existing data in the EHR. Once data related to the visit was entered, the system evaluated whether the patient had asthma or COPD, reviewed the physician’s treatment of asthma and COPD, and generated feedback. In this way, the doctor made the decisions and the CDSS ‘critiqued’ these decisions. Described as usual care. |
| Martens et al.²⁴,²⁸ (The Netherlands) | Cluster RCT with an incomplete block design | 53 clusters, 14 practices with a total of 33 GPs | All | 12 months | 6 months intervention, 6 months data collection | CDSS was part of a computer-reminder system integrated into the EHR as a prescribing module. When the GP prescribed a drug the decision support system was activated and provided information specific to the patient (e.g., age and gender) and the prescribed drug. The GP was obliged to enter a diagnosis code which the CDSS would check and use to issue relevant reminders. One group that received prescription reminders for cholesterol-lowering drugs served as controls for the other group that received CDSS for antibiotics, asthma and COPD, and vice versa. |
| McCowan et al.²⁵ (UK) | Cluster RCT | 40 clusters: 40 practices, 477 patients | All | 6 months | No baseline data | ‘Asthma Crystal Byte’ was a stand-alone decision support system with management guidelines for asthma that aimed to improve the quality of the consultation. It included risk prediction software and printed asthma management plans. The control group had no knowledge of the intervention and had to report parallel data on the same number of patients as were recruited to the intervention group. |
ion to ‘start inhaled corticosteroids.’ However, only 11–30% of the physicians or pharmacists complied with this suggestion.

Clinical outcomes

Asthma symptoms. Three studies reported asthma symptoms. Eccles and coworkers\textsuperscript{10} reported that the CDSS had no effect on the validated Newcastle Asthma Symptoms Questionnaire (mean difference = −0.6 (95% CI, −2.1 to 0.9)).

Plaza et al.\textsuperscript{26} reported that asthma daytime symptoms, but not night-time symptoms, were significantly reduced in the intervention group compared with the control group (Wilcoxon P = 0.02). McCowan et al.\textsuperscript{25} reported no significant differences in asthma symptoms between the intervention and control groups (odds ratio 0.3, 95% CI, 0.03–3.3), although this study was underpowered.

Asthma-related quality of life. Three studies reported asthma-related quality of life. The study by Eccles et al.,\textsuperscript{21} a trial at low risk of bias, reported no effect on the validated Asthma Quality of Life Questionnaire. Plaza and coworkers\textsuperscript{32} reported low risk of bias, reported no effect on the validated Asthma quality of life using the Spanish version of the St George’s Respiratory Questionnaire and found significant improvement in all domains (activity P = 0.002, symptoms P = 0.003, impact P = 0.001). Tierney et al.\textsuperscript{27} used two different quality-of-life scales, but found a significant result only in one subdomain, possibly due to multiple testing.

Frequency of asthma exacerbations. Two studies reported exacerbation rates. In the study by Plaza et al.,\textsuperscript{26} exacerbation rates were not significantly different between the control and intervention groups: mean exacerbations, 1.3 (s.e. = 1.2) in the control group and 0.5 (s.e. = 0.3) in the intervention group (Wilcoxon P = 0.2). McCowan et al.\textsuperscript{25} reported that in the intervention group 12/147 patients had exacerbations compared with 57/330 in the control group: control patients were approximately twice as likely to experience an exacerbation as were intervention patients (odds ratio 0.4, 95% CI, 0.2–0.9, after adjustment for clustering). The denominators were different because of study dropouts.

Unscheduled health-care utilisation. McCowan et al.\textsuperscript{25} reported significantly fewer unscheduled general practitioner consultations in the intervention group in comparison with the control group (odds ratio 0.6, 95% CI, 0.4–0.95). Four studies reported no differences in the frequency of asthma-related visits to the general practitioner.\textsuperscript{20,22,23,26} Two studies reported no significant difference between the intervention and control groups in emergency department visits or hospitalisations. The absolute numbers were close to zero.

Table. 1. (Continued)

| Author (country)        | Study design      | Participants and setting                                                                 | Age (years) | Time scale | Intervention | Control |
|-------------------------|-------------------|-----------------------------------------------------------------------------------------|-------------|------------|--------------|---------|
| Plaza et al.\textsuperscript{26} (Spain) | Cluster RCT       | 20 clusters: 10 pulmonologists and 10 GPs, 198 patients                                 | ≥ 14        | 12 months 6 months baseline and 2 sessions of educational programme for clinicians, 12 months intervention | CDSS providing patient-tailored recommendations based on the GINA guidelines enabled clinicians to establish the severity of asthma according to the GINA classification, from relevant inputs such as PEFR, symptom frequency, quantity of corticosteroids and the clinician’s professional opinion. Then the CDSS would recommend medications according to the GINA guidelines. There were also education programmes for clinician and patients, teaching inhaler technique and general information about the condition of asthma. | The control group worked as normal but recorded additional data for comparison. |
| Tierney et al.\textsuperscript{27} (USA)  | 2 × 2 factorial randomisation of patients | 4 clusters: 4 hospital-based academic practices with 25 faculty general internists and over 100 internal medicine residents, 1 full-time and 9 part-time pharmacists, 706 patients | ≥ 18        | 36 months 28 months recruitment and baseline, 8 months intervention | CDSS generated care suggestions based on agreed guidelines. These include performing pulmonary function tests, giving influenza and pneumococcal vaccinations, prescribing advice and encouraging smoking cessation. These suggestions were presented on doctors’ workstations or were printed under a list of active medications that doctors received along with the patient’s paper chart when he/she presented for usual care. | Care suggestions were still generated by the CDSS but were not displayed to the physician or pharmacists caring for patients in the control group. |

Abbreviations: CDSS, computer decision support system; COPD, chronic obstructive pulmonary disease; GINA, The Global Initiative for Asthma; GP, general practitioner; RCT, randomised controlled trial.

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### Table 2. Risk of bias summary table

| Trial                  | Selection bias | Allocation concealment | Performance bias | Detection bias | Attrition bias | Selective reporting | Other bias | Quality   |
|------------------------|----------------|------------------------|------------------|---------------|---------------|---------------------|------------|-----------|
| Bell et al.            | Yes—there were ethnic differences between suburban and rural practices; however, clustering would have helped to control for this | No allocation concealment | Yes—there was no blinding for users | Unclear—no mention of blinding of outcome assessors | Unclear as to how many of the patients enrolled at each practice remained in the trial—pragmatic design, denominator quite flexible, withdrawals not reported. | Unclear—no pre-published protocol. | No         | C—high risk |
| Eccles et al.          | No—minimised by computerised randomisation of practices in a cluster design | No allocation concealment | No—GPs were acting as controls for the other block | No—data collectors were blinded to the status of practice | No—attrition rates were presented and balanced; there were 31 intervention practices and 29 control practices who completed the study and two withdrawals. | No—a pre-published protocol-outlined plan for data analysis and embedded case study and economic evaluation. | No         | A—low risk  |
| Fiks et al             | Unclear—no details of randomisation | No allocation concealment | Yes—no blinding, clinicians were aware that their software either did or did not have the alerts | Unclear—no mention of blinding of outcome assessors | No—attrition fairly balanced—no patients withdrew; however, there was fluctuation in the numbers of patients, as may be expected in such a large cohort. | Yes—flow diagram explains why patients dropped out or withdrew. No attrition at practice level. | No         | C—high risk |
| Kuilboer et al         | No—randomisation performed with a table of random numbers by a researcher who was blinded to the identity of practices | No allocation concealment | Yes—there was no blinding for GP users | Unclear—no mention of blinding of outcome assessors | No—flow diagram explains why patients dropped out or withdrew. No attrition at practice level. | Unclear—no pre-published protocol. | No         | C—high risk |
| Martens et al          | Unclear—no details of randomisation | Yes—GPs blinded as to whether they were assessed on treatment of cholesterol or asthma and COPD | No—GPs did not know that they were acting as controls for the other block | Unclear—no mention of blinding of outcome assessors | No—attrition was fairly balanced but resulted in the study being underpowered. Reasons for attrition were given. | Unclear—no pre-published protocol. | No         | B—moderate risk |
| McCowan et al          | No—randomisation using random number sequence and performed independently of the project administration team | No allocation concealment | Yes—there was no blinding of GPs | Unclear—no mention of blinding of outcome assessors | No—attrition was unbalanced and although most practices gave some reasons this resulted in the study being underpowered and intention-to-treat analysis was impossible due to insufficient information. | Unclear—no pre-published protocol. | No         | C—high risk |
| Plaza et al            | No—randomisation using SAS (statistics programme). Patients were recruited as they came for consultation | No allocation concealment | Unclear, not reported | Unclear—no mention of blinding of outcome assessors | No—clinician withdrawals reported (2/22) due to administrative problems, patient withdrawals also reported in diagram. | Unclear—no pre-published protocol. | No         | C—high risk |
| Tierney et al          | No—randomisation by flip coin, then switching to equal numbers of consultations per arm by a researcher blinded to allocation. | No allocation concealment | Yes—there was no blinding of GPs | Unclear—no mention of blinding of outcome assessors | No—flow diagram explains why patients dropped out or withdrew. Attrition appeared to be fairly balanced. | Yes—no pre-published protocol and post hoc analysis of power calculation. | No         | C—high risk |

Abbreviations: COPD, chronic obstructive pulmonary disease; GP, general practitioner.
| Study | Risk of bias | Practical aspects of CDSS use | Process outcomes | Clinical outcomes | Interpretation |
|-------|--------------|------------------------------|------------------|-------------------|----------------|
| Eccles et al. | Low | For both groups the median number of active interactions was zero. The number of alerts was approximately zero | No significant difference in drugs prescribed for asthma before and after introduction of CDSS. No significant difference in lung function assessment before and after OR 0.94 (0.67–1.33) | Overall effect of the CDSS on symptom score was non-significant: the parameter estimate from analysis of covariance of scale was –0.62 (95% CI is –2.12 to 0.88). No effect on quality of life was measured on the validated Juniper’s Asthma Quality of Life Questionnaire (AQLQ). No differences in GP visit rate; OR = 0.94 (0.81–1.08) | The design of this British study incorporated two arms, each controlling for the other. The study was a cluster design, with practices as the unit of randomisation. Practices investigating CDSS-driven care for angina provided usual care control data for the asthma CDSS care practices, and vice versa. In addition, the study was very large, with 62 practices across the UK, and so results should have been robust. This trial demonstrated very clearly that CDSS will not be used by clinicians if it is not integrated with their usual workflow. The median usage of the CDSS in this study was zero and there were no differences in consultation rates, process outcomes or clinical outcomes, which were carefully measured. |
| Martens et al. | Medium | GPs did not have a choice to decide if the CDSS was to be activated | 44% of the intervention group were prescribed according to the recommendations compared with 27% of the control group among patients with mildly persistent asthma | No clinical outcomes reported | This Dutch study consisted of 14 general practices in a cluster randomised controlled trial. As in the Eccles study, two arms of the study acted as controls for each other. One arm was given a CDSS to guide on antibiotic, asthma and COPD prescribing, and the other received CDSS for cholesterol prescribing. This design minimises the impact of performance bias and the Hawthorne effect and has therefore contributed to it being rated as only at moderate risk of bias. The study was underpowered (the actual variation was larger than values used to estimate study power), which may have contributed to the non-significant results. Although this US study was graded at high risk of bias, it did have a recognisable cluster design in which steps were taken to try to randomise the baseline differences of poverty and ethnicity in the different urban versus suburban practices. This study demonstrated that CDSS could improve the adherence to guidelines for prescribing, test ordering and use of asthma controller medication prescribed more often in urban intervention practices compared with urban control practices (P = 0.0068 and NSD in suburban practices. Increase in spirometry in intervention sites from 15 to 24% and decrease in control sites from 8 to 1% (P = 0.003). Number of asthma plans filed in suburban intervention practices increased compared with suburban controls (P = 0.03). NSD in urban practices | |
| Bell et al. | High | No difference between groups in the rate at which the CDSS was used (70% of the time during the intervention periods) | Controller medication prescribed more often in urban intervention practices compared with urban control practices (P = 0.0068 and NSD in suburban practices. Increase in spirometry in intervention sites from 15 to 24% and decrease in control sites from 8 to 1% (P = 0.003). Number of asthma plans filed in suburban intervention practices increased compared with suburban controls (P = 0.03). NSD in urban practices | No differences in GP visits | |
| Fiks et al. | High | Influenza vaccine alerts were active at only 27% of visits | Vaccination rates increased by 3.8% at control practices and by 4.8% at intervention sites | No differences in GP visits | This American study investigated the impact of CDSS for reminding clinicians to give children with asthma an influenza vaccination. The rate of increase in vaccination was not significantly different across the control and intervention groups as the rate increased in both groups. In interpreting this study it should be remembered that there are many influences on the uptake rate of vaccination, including whether a child is acutely unwell or not at the time they attend the clinic, and the health beliefs of the child and their parents. This trial provides some evidence of the effectiveness of CDSS in terms of its impact on guideline adherence. There were appreciable increases in the ordering of peak expiratory flow rates and spirometry. In addition, there was some evidence that doctors were more likely to change their prescribing of cromoglycate with the CDSS; however, there were no changes for the other drugs in the guideline (depropine, antihistamines and oral bronchodilators)—probably because the general practitioners rarely prescribed these drugs anyway. Also measured were changes in the coding of the record: doctors recorded more data in a more structured fashion. It was reported that only a third of the comments were read by doctors. The explanation for this may be that the CDSS provided asthma-related comments irrespective of the reason for the visit. |
| Kullberger et al. | High | The doctor waited for the result of the CDSS analysis in 22% of 0.863 visits. 10,532 comments were produced and 32% of these were read by doctors. The CDSS took on average 3.17 s to analyse the record. The median time spent by the doctor reading comments was 9 s (25th percentile = 4 s, 75th percentile = 48 s) | Some evidence for a decrease in cromoglycate prescriptions in one of four age brackets, but no other significant changes. More tests were ordered among the CDSS group, but this difference was not always significant | No differences in GP visits except in one of the four age brackets, but risk of multiple testing | This trial provides some evidence of the effectiveness of CDSS in terms of its impact on guideline adherence. There were appreciable increases in the ordering of peak expiratory flow rates and spirometry. In addition, there was some evidence that doctors were more likely to change their prescribing of cromoglycate with the CDSS; however, there were no changes for the other drugs in the guideline (depropine, antihistamines and oral bronchodilators)—probably because the general practitioners rarely prescribed these drugs anyway. Also measured were changes in the coding of the record: doctors recorded more data in a more structured fashion. It was reported that only a third of the comments were read by doctors. The explanation for this may be that the CDSS provided asthma-related comments irrespective of the reason for the visit. |
From an initial 46 UK practices who registered to undertake the trial only 12 control practices and 5 intervention practices completed the trial. A significant difference was found for the intervention practices had problems installing and using the software for the trial initiation. The CDSS was apparently partially effective in that there were significantly fewer exacerbations of asthma among intervention patients. However, the majority of outcomes (symptoms, inhaler technique and measurement of peak flow) were not statistically significantly different between control and intervention arms. This is on the basis of those who completed the trial; the data were not analysed by intention-to-treat analysis.

Table 3. (Continued)

| Study            | Risk of bias | Practical aspects of CDSS use                                                                 | Process outcomes                                                                 | Clinical outcomes                                                                 | Interpretation |
|------------------|--------------|-----------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|---------------------------------------------------------------------------------|----------------|
| McCowan et al.25 | High         | Usually less than 10 min to fill in the template and generate the advice according to a nested study | There was no difference in the proportions of patients in the different categories of maintenance prescribing according to the British asthma guidelines. No difference in PEFRs ordered. No difference in proportion with action plans. | Reported no significant differences in asthma symptoms between the intervention and control groups (odds ratio 0.31, 95% CI 0.03–3.32). | From an initial 46 UK practices who registered to undertake the trial only 12 control practices and 5 intervention practices completed the trial. A significant number from the intervention practices had problems installing and using the software for the trial initiation. The CDSS was apparently partially effective in that there were significantly fewer exacerbations of asthma among intervention patients. However, the majority of outcomes (symptoms, inhaler technique and measurement of peak flow) were not statistically significantly different between control and intervention arms. This is on the basis of those who completed the trial; the data were not analysed by intention-to-treat analysis. |
| Plaza et al.26    | High         | Not reported                                                                                   | 17.9 of control and 34% of intervention patients conformed to strict treatment guidelines (Wilcoxon P=0.0240). No difference in spirometry rates, X-rays allergy or blood tests | No difference in emergency department visits: OR = 0.37–0.395. | This Spanish study reported randomising groups (clusters) to either the intervention or the control arm. It was a small study with only 10 doctors in each arm. There were two components to the intervention: the CDSS and an asthma education programme for nurses based on the GINA guidelines. This study produced significant improvements in the measures of the St George's quality of life questionnaire. Daytime symptoms and exacerbations also improved but the majority of outcomes were not statistically significantly different between groups. As a result of multiple testing No difference in GP visits (P>0.05). |
| Tierney et al.27  | High         | 87–99% of consultations resulted in the generation of a suggestion; doctors complied with only 3%-37% of suggestions | 5–9% of patients received the suggestion to ‘start inhaled corticosteroids’. 11–0% of clinicians who received this suggestion adhered to it. Pulmonary function tests: 6% of the 39% in the control group and between 6 and 12% of 40–50% in the three intervention groups who received the suggestion adhered to it. | No difference in emergency department visits (P=0.0888). | This study had four arms: one control and three intervention. The intervention arms consisted of physician CDSS intervention, pharmacist CDSS intervention and both physician and pharmacist intervention. There were no significant differences between the four study groups in adherence to the care suggestions. However, the care suggestions were also generated for the control patients—only that they were on paper, not on the computer. Adherence to care suggestions for the control arm varied from 9 to 71%. Adherence to care suggestions for the physician and pharmacist arm was from 12 to 91%. Overall, there was no clear pattern. It may be presumed that as the adherence to suggestions was very variable and frequently less than 50% this may explain why no significant differences were found in the quality of life and asthma control questionnaires. |

Figures in brackets represent 95% confidence intervals. Abbreviations: CDSS, computer decision support system; CI, confidence interval; COPD, chronic obstructive pulmonary disease; GINA, The Global Initiative for Asthma; GP, general practitioner; NR, not reported; NSD, no significant difference; OR, odds ratio.
DISCUSSION

Main findings

We found eight relevant trials, four of which reported clinical measures of asthma control.21,25–27 The key finding was that CDDSSs for health-care professionals were ineffective in improving patient outcomes because the systems were rarely used21–23 and there was low compliance with the advice when it was issued.23,27 However, when systems are used, clinical outcomes can improve.20,25

Strengths and limitations of this study

A strength of this review is its robust search strategy. We used the Cochrane-suggested terminology for asthma and randomised controlled trials, and drew on our eHealth research group’s inclusive search terms for CDDSS.35 Nevertheless, we may have missed some relevant studies, and the list of ongoing trials suggests that more evidence may be available in due course.

In contrast to the methodology used by the recent McMaster group series of reviews in which improvement was considered to have occurred if >50% of the selected outcomes showed benefit,18,36–41 we report specific clinical, usage and process outcomes from each trial to explain why the systems were having an effect or not.

We did not perform a meta-analysis as populations and outcomes across trials were too heterogeneous. Descriptions of interventions were often poorly described, which may have limited our interpretation of the findings.

Interpretation of findings in relation to previously published work

Our review focuses on asthma as a clinically important area for CDDSSs. A crucial observation was that the systems were rarely used.13,21,22 Usage was not considered in the recent McMaster group’s meta-regression,35 although this is clearly fundamental to understanding the reasons for lack of effect, and should be a crucial focus for development if systems are to improve patient outcomes above the 15–31% impact on outcomes reported by the McMaster group in a series of reviews.36–41 Usage rate of the systems should be a core standard for reporting trials of CDDSSs.

The McMaster group’s meta-regression explored the features of CDDSSs associated with system ‘effectiveness’. They found (1) stand-alone programs, (2) advice directed at both health-care practitioners and patients, (3) requiring users to enter an explanation for any overrides of system recommendations and (4) developers’ involvement in trials to be associated with better patient outcomes. Poor integration (as in a stand-alone program), however, risks clinicians avoiding using the system as in Eccles et al.31 The issue, however, is complex as advice presented at the time of care does not always predict success, possibly because practitioners become overwhelmed by such integrated alerts that interrupt their workflow.43

Our recent analysis of recordings of general practice consultations emphasised the importance of the timing of alerts in the context of prescribing safety CDDSSs.44 The practitioner, negotiating with the patient, makes decisions regarding drugs and management throughout the consultation when information about allergies, sensitivities, interactions and guideline recommendations might be useful. Provision of information during the final computer-based task of generating the prescription can frustrate clinicians, who then override the alerts. Integration with workflow requires a detailed study of the consultation process.

Implications for future research, policy and practice

A detailed description of the CDDSS intervention under investigation is essential to providing insight into what promotes a well-used and effective system that can inform future development. Taxonomies and frameworks such as those described by Kawamoto et al.,45 Garg et al.46 or Berlin et al.47 may provide a suitable basis for a full description. Future research should substantiate our theoretical model (Figure 1), which we suggest as a possible useful framework. In terms of the logical chain from usage to process outcomes to clinical outcomes, Bell et al.20 demonstrated that usage rates have an impact on process outcomes, and Plaza et al.26 demonstrated the impact of process outcomes on health outcomes. However, we feel that further research is required to evidence this model more thoroughly.

Conclusions

Our review suggests that current CDDSSs are unlikely to result in improved outcomes in asthma because they are rarely used and the advice not followed. A key challenge in the future design of decision support systems lies in the better integration and alignment with professional workflows such that they are adopted into routine practice.

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We acknowledge the support of Lisette van den Beren (PM’s supervisor from Radboud University Nijmegen).

CONTRIBUTIONS

PM and SM, with AS, HP and JCW, wrote the protocol and undertook the searches, selection of studies and extraction of data. All authors contributed to the interpretation of the findings. PM and SM wrote the initial draft of the paper. All the authors contributed to and have approved the final text. SM is the study guarantor.

COMPETING INTERESTS

All authors have completed the ICMJE uniform disclosure form (www.icmje.org/doi/cool_disclosure.pdf). AS serves on the World Health Organization’s Health and Information Technology for Patient Safety Expert Working Groups and is an adviser to NHS Connecting for Health’s Evaluation Programme. He is a consultant to ALK and Phadia, and has received support from Napp, Pfizer and Chiesi for research advice. AS is Joint Editor-in-Chief of, and HP is an Associate editor of, the PCRJ; neither were involved in the editorial review of, nor the decision to publish, this article. HP has spoken for AstraZeneca, Boehringer Ingelheim, Chiesi, GlaxoSmithKline, Pfizer and Teva and undertaken advisory group work for Chiesi. The remaining authors declare no conflict of interest.

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3 Beasley R for the International Study of Asthma and Allergies in Childhood. The issue, however, is complex as advice presented at the time of care does not always predict success, possibly because practitioners become overwhelmed by such integrated alerts that interrupt their workflow.43

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All authors have completed the ICMJE uniform disclosure form (www.icmje.org/doi/cool_disclosure.pdf). AS serves on the World Health Organization’s Health and Information Technology for Patient Safety Expert Working Groups and is an adviser to NHS Connecting for Health’s Evaluation Programme. He is a consultant to ALK and Phadia, and has received support from Napp, Pfizer and Chiesi for research advice. AS is Joint Editor-in-Chief of, and HP is an Associate editor of, the PCRJ; neither were involved in the editorial review of, nor the decision to publish, this article. HP has spoken for AstraZeneca, Boehringer Ingelheim, Chiesi, GlaxoSmithKline, Pfizer and Teva and undertaken advisory group work for Chiesi. The remaining authors declare no conflict of interest.

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