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R Anderson and K Stein

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Computerised decision support systems in order communication for diagnostic, screening or monitoring test ordering: systematic reviews of the effects and cost-effectiveness of systems

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Abstract

Computerised decision support systems in order communication for diagnostic, screening or monitoring test ordering: systematic reviews of the effects and cost-effectiveness of systems

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Background: Order communication systems (OCS) are computer applications used to enter diagnostic and therapeutic patient care orders and to view test results. Many potential benefits of OCS have been identified including improvements in clinician ordering patterns, optimisation of clinical time, and aiding communication processes between clinicians and different departments. Many OCS now include computerised decision support systems (CDSS), which are information systems designed to improve clinical decision-making. CDSS match individual patient characteristics to a computerised knowledge base, and software algorithms generate patient-specific recommendations.

Objectives: To investigate which CDSS in OCS are in use within the UK and the impact of CDSS in OCS for diagnostic, screening or monitoring test ordering compared to OCS without CDSS. To determine what features of CDSS are associated with clinician or patient acceptance of CDSS in OCS and what is known about the cost-effectiveness of CDSS in diagnostic, screening or monitoring test OCS compared to OCS without CDSS.

Data sources: A generic search to identify potentially relevant studies for inclusion was conducted using MEDLINE, EMBASE, Cochrane Controlled Trials Register (CCTR), CINAHL (Cumulative Index to Nursing and Allied Health Literature), DARE (Database of Abstracts of Reviews of Effects), Health Technology Assessment (HTA) database, IEEE (Institute of Electrical and Electronic Engineers) *Xplore* digital library, NHS Economic Evaluation Database (NHS EED) and EconLit, searched between 1974 and 2009 with a total of 22,109 titles and abstracts screened for inclusion.

Review methods: CDSS for diagnostic, screening and monitoring test ordering OCS in use in the UK were identified through contact with the 24 manufacturers/suppliers currently contracted by the National Project for Information Technology (NpfIT) to provide either national or specialist decision support. A generic search to identify potentially relevant studies for inclusion in the review was conducted on a range of medical, social science and economic databases. The review was undertaken using standard systematic review methods, with studies being screened for inclusion, data extracted and quality assessed by two reviewers. Results were broadly grouped according to the type of CDSS intervention and study design where possible. These were then combined using a narrative synthesis with relevant quantitative results tabulated.

Results: Results of the studies included in review were highly mixed and equivocal, often both within and between studies, but broadly showed a beneficial impact of the use of CDSS in conjunction with OCS over and above OCS alone. Overall, if the findings of both primary and secondary outcomes are taken into account, then CDSS significantly improved practitioner performance in 15 out of 24 studies (62.5%). Only two studies covered the cost-effectiveness of CDSS: a Dutch study reported a mean cost decrease of 3% for blood tests orders (€639) in each of the intervention clinics compared with a 2% (€208) increase in control clinics in test costs; and a Spanish study reported a significant increase in the cost of laboratory tests from €41.8 per patient per annum to €47.2 after

implementation of the system.
Limitations: The response rate from the survey of manufacturers and suppliers was extremely low at only 17% and much of the feedback was classified as being commercial-in-confidence (CIC). No studies were identified which assessed the features of CDSS that are associated with clinician or patient acceptance of CDSS in OCS in the test ordering process and only limited data was available on the cost-effectiveness of CDSS plus OCS compared with OCS alone and the findings highly specific. Although CDSS appears to have a potentially small positive impact on diagnostic, screening or monitoring test ordering, the majority of studies come from a limited number of institutions in the USA.
Conclusions: If the findings of both primary and secondary outcomes are taken into account then CDSS showed a statistically significant benefit on either process or practitioner performance outcomes in nearly two-thirds of the studies. Furthermore, in four studies that assessed adverse effects of either test cancellation or delay, no significant detrimental effects in terms of additional utilisation of health-care resources or adverse events were observed. We believe the key current need is for a well designed and comprehensive survey, and on the basis of the results of this potentially for evaluation studies in the form of cluster randomised controlled trials or randomised controlled trials which incorporate process, and patient outcomes, as well as full economic evaluations alongside the trials to assess the impact of CDSS in conjunction with OCS versus OCS alone for diagnostic, screening or monitoring test ordering in the NHS. The economic evaluation should incorporate the full costs of potentially developing, testing, and installing the system, including staff training costs.
Study registration: Study registration 61.

Contents

Glossary and list of abbreviations

Glossary

Algorithm A process for carrying out a complex task broken down into simple decision and action steps. Often assists the requirements analysis process carried out before programming.

Applicability The extent to which the results of a study or review can be applied to the target population in practice.

Appraisal of evidence Formal assessment of the quality of research evidence and its relevance to the clinical question according to predetermined criteria.

Bias Systematic errors in the design and execution of a study which may lead to an over- or underestimation of the 'true' effect of a treatment or intervention.

Blinding The practice of keeping the investigators or patients in a study ignorant of the group to which a participant has been assigned or of the population from which the participant has come from. The purpose of 'blinding' is to protect against bias.

Computerised decision support systems (CDSS) An active knowledge system, which uses two or more items of patient data to generate case-specific advice.

Clinical effectiveness How well a drug, procedure, device or package of care works to produce good outcomes for patients.

Clinical trial Research study conducted with patients, usually to evaluate a new drug, device or procedure. Each trial is designed to answer scientific questions and to find better ways to treat individuals with a specific disease. See also randomised controlled trial.

Cochrane Library The Cochrane Library consists of a regularly updated collection of evidence-based medicine databases including the Cochrane Database of Systematic Reviews. The Cochrane Library is available on CD-ROM and on the Internet.

Computerised tomography A technique whereby X-rays are used to map the inside of the body.

Confidence interval This helps us assess the likely effect of an intervention by describing the range of possible effects that are consistent with the results of a study (or a combination of studies). A wide confidence interval indicates a lack of certainty or precision about the true size of the clinical effect and is seen in studies with too few patients. Where confidence intervals are narrow they indicate more precise estimates of effects and a larger sample of patients studied. We usually interpret a 95% confidence interval as the range of effects within which we are 95% confident that the true effect lies.

Confounding factor Something that introduces uncertainty and bias into an observed outcome, complicating interpretation of the result.

Control group A group of patients recruited into a study that receives no treatment, a treatment of known effect, or a placebo in order to provide a comparison for a group receiving an experimental treatment, such as a new procedure.

Controlled clinical trial A study that includes some form of a control group that is not randomised.

Diagnostic work-up The process of making a diagnosis through tests, clinical history and clinical judgement.

Effectiveness The extent to which a specific procedure or device, when used under usual or everyday conditions, does what it is intended to do.

Electronic patient record A computer-based clinical data system designed to replace paper patient records.

Extrapolation The application of research evidence based on studies of a specific population to another population with similar characteristics.

Heterogeneity The term is used in meta-analysis and systematic reviews when the results or estimates of effects from separate studies seem to have different magnitude or even different sign or direction. Differences in the interventions, patient populations, outcome measures, definition of variables and duration of follow-up of the studies included in the analysis create problems of non-compatibility. See also homogeneity.

Homogeneity This means that the results of studies included in a systematic review are similar and there is no evidence of heterogeneity. Results are usually regarded as homogeneous when differences between studies could reasonably be expected to occur by chance.

Inclusion criteria See selection criteria.

Intention to provide or communicate information Analyses of a clinical trial where patients are analysed according to the group to which they were initially randomly allocated, regardless of whether or not they dropped out, fully complied with the treatment, or cross over and received the alternative treatment.

Knowledge base A store of knowledge represented explicitly so that a computer can search and reason with it automatically; often uses a clinical coding system to label the concepts.

Knowledge-based system (expert system) A computer decision support system with an explicit knowledge base and separate reasoning program that uses this to give advice or interpret patient data.

Methodological quality The extent to which a study has conformed to recognised good practice in the design and execution of its research methods.

Non-experimental study A study based on participants selected on the basis of their availability, with no attempt having been made to avoid problems of bias.

Objective measure A measurement that follows a standardised procedure which is less open to subjective interpretation by potentially biased observers or study participants.

Pre–post study A study design which measures outcomes in one group of people, first before, and then after, an intervention is given or initiated.

Probability How likely an event is to occur, for example how likely a treatment or intervention will alleviate the symptom.

Prognostic factor Patient or disease characteristics which influence the course of a particular condition. In a randomised trial to compare two treatments, chance imbalances in prognostic factors that influence patient outcomes are possible, especially if the size of the study is fairly small. In terms of analysis these prognostic factors become confounding factors.

***p*-value** If a study is done to compare two treatments, then the p-value is the probability of obtaining the results, or something more extreme, if there really was no difference between treatments. By convention, where the value of p is below 0.05 (i.e. $< 5\%$) the result is seen as statistically significant.

Randomised controlled trial A trial in which people are randomly assigned to two (or more) groups: one (the experimental group) receiving the treatment that is being tested, and the other (comparison or control group) receiving an alternative treatment, a placebo, or no treatment. The two groups are followed-up to compare differences in outcomes between the two groups.

Reliability Reliability refers to a method of measurement that consistently gives the same results.

Sample A part of the study's target population from which the participants of the study will be recruited. If participants are drawn in an unbiased way from a particular population, the results can be generalised from the sample to the population as a whole.

Selection criteria Explicit criteria used in systematic reviews to decide which studies should be included and excluded from consideration as potential sources of evidence.

Standard deviation A measure of the spread, scatter or variability of a set of measurements.

Validity Assessment of how well a tool or instrument measures what it is intended to measure.

List of abbreviations

ABG	arterial blood gas
ALT	alanine aminotransferase
ANA	antinuclear antibody
ARB	angiotensin receptor blocker
ASCC	Additional Supply and Capacity service Contract
AST	aspartate aminotransferase
CBA	cost–benefit analyses
CCA	cost–consequence analyses
CCT	controlled clinical trial
CDSS	computerised decision support system
CEA	cost-effectiveness analyses
CFU	Connecting for Health
CI	Confidence interval
CIC	commercial-in-confidence
CK	creatine kinase
CPOE	computerised physician order entry
CPP	controlled pre–post study
CRCT	cluster randomised controlled trial
CRD	Centre for Reviews and Dissemination
CT	computerised tomography
CUA	cost–utility analyses
CVR	coronary vascular risk
DRG	diagnostic-related group
HIV	human immunodeficiency virus
ICD-9	*International Classification of Diseases*, Ninth Edition
ICU	intensive care unit
IT	information technology
ITS	interrupted time series
LDL	low-density lipid
MRI	magnetic resonance imaging
NSAID	non-steroidal anti-inflammatory drug
NPfIT	National Project for Information Technology
OCS	order communication system
PACS	picture archiving and communication system
RCT	randomised controlled trial

RF	rheumatoid factor	SME	small to medium-sized enterprise
SD	standard deviation	STD	sexually transmitted disease
SHA	Strategic Health Authority	UPP	uncontrolled pre–post study

All abbreviations that have been used in this report are listed here unless the abbreviation is well known (e.g. NHS), or it has been used only once, or it is a non-standard abbreviation used only in figures/tables/appendices, in which case the abbreviation is defined in the figure legend or in the notes at the end of the table.

Executive summary

Background

Order communication systems (OCS) [termed Computerised Physician Order Entry (CPOE) systems in the USA] are computer applications used to enter diagnostic and therapeutic patient care orders, for example laboratory test requests or prescriptions, and to view test results. Many potential benefits of OCS have been identified. These include improvements in clinician ordering patterns, optimisation of clinical time, and aiding communication processes between clinicians and different departments. These systems have the potential to automate the clinical test ordering process and to improve the quality and safety of patient care.

Many OCS now include computerised clinical decision support systems (CDSS), which are information systems designed to improve clinical decision-making. CDSS match individual patient characteristics to a computerised knowledge base, and software algorithms generate patient-specific recommendations. Health-care practitioners or patients can manually enter patient data into the computer system, or alternatively, and increasingly commonly, electronic medical records can be queried for patient data retrieval. Computer-generated recommendations are delivered to the clinician through the electronic medical record, by pager, or through printouts, which may be placed in a patient's paper notes. These systems provide several modes of decision support, including alerts of critical values, reminders of overdue preventative health tasks (including laboratory or radiology imaging tests), advice for drug prescribing, critiques of existing health-care orders, and suggestions around various care issues. The implementation of CDSS is time-consuming, complex and costly.

Objectives

The objectives of this report were to address the following questions:

1. Which CDSS in OCS for diagnostic, screening, or monitoring test ordering are currently in use within the UK, and what are their main characteristics and their intended/actual scope of use?
2. What is the impact of CDSS in OCS for diagnostic, screening or monitoring test ordering compared to OCS without CDSS on process outcomes, patient outcomes and adverse events/safety?
3. What features of CDSS are associated with clinician or patient acceptance of CDSS in OCS?
4. What is known about the cost-effectiveness of CDSS in diagnostic, screening or monitoring test OCS compared to OCS without CDSS?

Methods

Study question one: CDSS for diagnostic, screening and monitoring test ordering OCS currently in use or being implemented in the UK were identified through contact with the 24 manufacturers/suppliers currently contracted by the National Project for Information Technology [NpfIT (service category 2.20)] to provide either national or specialist decision support. Manufacturers were contacted by e-mail and asked to stipulate whether their specific system was currently in use or being implemented in the UK. They were additionally asked to state the number and at which sites their CDSS were installed. Where they considered this data to be commercial-in-confidence (CIC) they were asked to state this, but at least respond as to whether the CDSS was currently deployed in the UK. Non-responders to the survey were followed-up twice, at two weekly intervals.

Study questions two, three and four: A generic search to identify potentially relevant studies for inclusion in the three systematic reviews was conducted on a range of medical, social science and economic databases between 1974 and 2009; with a total of 22,109 titles and abstracts screened for inclusion. The following study designs were included:

- randomised controlled trials (RCTs)
- cluster randomised controlled trials (CRCTs)
- controlled clinical trials with a contemporaneous control group (CCTs)
- interrupted time series (ITS)
- controlled and uncontrolled pre–post studies (CPP and UPP).

In addition, for the systematic review of economic evaluations and cost–comparison studies, full cost-effectiveness analyses , cost–utility analyses, cost–consequence analyses, and cost–comparison studies were included. The intervention of interest was CDSS, which for the purpose of the reviews was defined as 'an active knowledge system that uses two or more items of patient data to generate patient-specific assessments or recommendations that are then presented to clinicians for consideration'. For studies to be included in review questions two and four, the CDSS had to be compared to the use of an OCS alone, whereas for review question three, a comparison with OCS alone was not necessarily required for inclusion. To be eligible for inclusion all studies needed to have been conducted either with health-care workers in practice or training, or patients undergoing testing for diagnostic, screening or monitoring purposes. Studies in which the CDSS had not been evaluated in a clinical setting were excluded. Likewise, studies in which the system: (1) only provided summaries of patient information (i.e. no specific test ordering or test interpretative advice was provided); (2) gave aggregate feedback on groups of patients without individual assessment; (3) only provided computer-aided instruction (i.e. provided generic rather than patient-specific advice); or (4) was used in image analysis were excluded.

Outcomes for review question two included objective measures of process of care, for example, test volumes, rates of compliance with CDSS-based guidelines, patient outcomes, and adverse events. Studies which only reported the diagnostic accuracy of the CDSS compared to a gold standard (such as a diagnosis reached by the clinician without use of the CDSS) (i.e. sensitivity and specificity) were excluded. For review question three, the outcome of interest was acceptability of CDSS to clinicians or patients and for review question four the cost-effectiveness of the CDSS plus OCS versus OCS alone.

The reviews were undertaken using standard systematic review methods, with studies being screened for inclusion, data extracted and quality assessed by two reviewers. Results were broadly grouped for each question according to the type of CDSS intervention and study design where possible. These were then combined using a narrative synthesis with relevant quantitative results tabulated.

Results

Study question 1: Which CDSS in OCS for test ordering are currently in use within the UK, and what are their main characteristics and their intended/actual scope of use?

The response rate from the survey of manufacturers and suppliers under the additional Supply and Capacity contract (ASCC) was extremely low at only 17%, with only four manufacturers providing any type of feedback. All of this was classified as being CIC, and therefore did little to provide any information on the current deployment of CDSS within the NHS.

Study question 2: What is the impact of CDSS in OCS for diagnostic, screening or monitoring test ordering compared to OCS without CDSS on process outcomes, patient outcomes and adverse events/safety?

Twenty-four studies reported in 23 publications met the inclusion criteria for the review. These consisted of seven CRCTs (29%), four RCTs (17%), two non-randomised controlled trials (8%), one randomised crossover trial (4%), two ITS studies (8%), one controlled pre–post study (CPP, 4%), and seven uncontrolled pre–post studies (UPP). Duration of follow-up varied widely with a median of 7 months (range: 2–72).

In terms of the study settings, 17 (71%) of the studies were conducted in the USA, followed by two (8%) each conducted in the UK and Spain, with the remaining three studies conducted in France, the Netherlands and Belgium (4% each) respectively. Of the 17 studies conducted in the USA, 12 had been undertaken at three large academic centres that are well renowned for being 'leaders' at the forefront of CDSS and OCS development and implementation: the Wishard Memorial Hospital, Indianapolis, IN; Brigham and Women's Hospital, Boston, MA; and the Vanderbilt University Medical Centre. The systems used within these centres are all home-grown, and sharply focused on specific wards or units, and/or display a technical novelty side to their investigation. Only two studies were conducted within the UK. Both of

these were focused on specific patient groups, namely screening patients for hyperlipidemia, and those being assessed for or undergoing liver transplantation. Both of these studies and therefore the systems assessed were relatively old with the studies published in 1994 and 1996 respectively.

There was considerable heterogeneity between the identified studies in terms of the type of CDSS assessed, the settings in which the studies were conducted, the patient populations, whether the studies focused on the impact of the CDSS on a single type of laboratory or imaging test order or on multiple tests and the study designs. All the studies focused upon the decision to order a test, its appropriateness and timing. No studies were identified that addressed the results reporting process within CDSS, with the provision of context specific interpretative comments to help interpretation of test results by clinicians.

However, the studies could broadly be grouped into those assessing: (1) the impact of presenting test charges ($n = 3$); (2) previous test results ($n = 2$); (3) reminders to undertake preventative care measures or laboratory test medication monitoring ($n = 10$); (4) studies that displayed restricted lists of test orders ($n = 2$); and (5) those in which the CDSS provided a recommendation ($n = 7$).

The results of the studies were generally highly mixed and equivocal, often both within and between studies, but broadly showed a beneficial impact of the use of CDSS in conjunction with OCS over and above OCS alone. Overall, if the findings of both primary and secondary outcomes are taken into account, then CDSS significantly improved practitioner performance in 15 out of 24 studies (62.5%), including:

- one of three studies (33.33%) assessing the impact of the display of costs
- one of the two studies (50%) assessing the impact of the display of previous test results
- six of the 10 studies (60%) examining the use of reminders
- one of the two studies (50%) that used the display of previous test results
- and two of the seven studies (28.6%) that assessed the impact of the display of recommendations.

Four studies also assessed the impact of test cancellation or delay on potential adverse events. There were no significant differences between treatment groups in any of these four trials in terms of extra health-care utilisation by patients or adverse events. Therefore the impact of cancelling either costly or redundant tests on adverse outcomes currently appears to be negligible.

Study question 3: What features of CDSS are associated with clinician or patient acceptance of CDSS in order communication systems?

A total of 31 papers were screened for relevance for this question. However, none met the inclusion criteria. It was therefore not possible to address this question in this assessment.

Study question 4: What is known about the cost-effectiveness of CDSS in diagnostic, screening or monitoring test order communication systems compared to order communication systems without CDSS?

Only two studies met the inclusion criteria, both of which were cost–comparison analyses. These were contained within studies of the impact of CDSS plus OCS versus OCS alone which had been included in the review for question 2. One of the studies, conducted in the Netherlands, focused on a cost–comparison between the use of CDSS that showed an optimal but restricted list of blood tests versus OCS alone (unrestricted lists), while the other, conducted in Spain, focused on the cost impact of using CDSS guideline recommendations in the management of patients with hyperliperdemia. Both of the studies found the use of CDSS plus OCS versus OCS alone had no significant impact on test costs.

The Dutch study reported a mean cost decrease of 3% for blood tests orders (€639) in each of the intervention clinics compared with a 2% (€208) increase in control clinics in test costs. However, this difference failed to reach conventional levels of statistical significance. The Spanish study reported a significant increase in the cost of laboratory tests from €41.8 per patient per annum to €47.2 after implementation of the system.

Conclusions

Review question 1: Although a survey of manufacturers and suppliers under the ASCC was undertaken to establish the present deployment or implementation of CDSS within the NHS, the survey response rate was extremely low at only 17%. Most of the very limited data provided by contractors was designated as being CIC and

therefore it was not possible to address the question of which CDSS are currently being used within the NHS in this assessment by this method.

Review question 2: The findings from the review on the impact of CDSS plus OCS versus OCS alone are mixed and equivocal. Overall, if the findings of both primary and secondary outcomes are taken into account then CDSS showed a statistically significant benefit on either process or practitioner performance outcomes in nearly two-thirds of the studies. Furthermore, in four studies that assessed adverse effects of either test cancellation or delay, no significant detrimental effects in terms of additional utilisation of health-care resources or adverse events were observed. However, none of the studies assessed patient outcomes such as complications, disease progression or quality of life, and therefore it is unclear whether the use of CDSS either for curtailing unnecessary or redundant tests, or increasing the appropriateness of tests and their timing has any potential impact on health-care outcomes that are relevant to patients. Also, although CDSS appears to have a potentially small positive impact on diagnostic, screening or monitoring test ordering, the majority of the studies come from a limited number of institutions in the USA with 'home-grown' systems, and it is unclear how well these results would extrapolate to the current NHS situation in which 'off the shelf' systems are being installed. Furthermore, it should be noted that the studies included in this review ranged in year of publication from 1980 to 2009; with 10 of the studies published within the last 4 years. Therefore, potentially the older systems evaluated in this review will now be obsolete, and many of the systems will have been changed and upgraded in light of the constant changes in the demand for different technologies.

Review question 3: No studies were identified which assessed the features of CDSS that are associated with clinician or patient acceptance of CDSS in OCS in the test ordering process. This question therefore could not be addressed in this review.

Review question 4: Given the very limited data available on the cost-effectiveness of CDSS plus OCS compared with OCS alone, and the highly specific indications in which both of the identified studies were undertaken, it is not possible to extrapolate findings to the wider context in which diagnostic, screening or monitoring test ordering occurs within the NHS. It is therefore not possible to comment on the likely cost-effectiveness of CDSS within OCS as they would be implemented and used within a wider NHS clinical setting at this time.

Suggested research priorities

There is a need to establish which CDSS in OCS are currently being piloted, implemented or already deployed within the NHS and the type of systems (e.g. hospital or laboratory information systems) with which they interface. A comprehensive survey of individual Strategic Health Authorities, user sites, primary care trusts, Connecting for Health via their IT investment survey, pathology services, the Royal Colleges of Pathologists, and Radiologists is therefore warranted to establish which systems are in place or likely to be implemented within the context of the NpfIT. The results of such a survey would hopefully inform system commissioners as to the best manner in which to conduct a rigorous evaluation of the CDSS within OCS that are already being implemented or currently 'rolled out'.

Currently there is very little evidence from the UK on the impact of CDSS in OCS compared to OCS alone, and no evidence on the impact of 'off the shelf' CDSS which are of relevance to the NpfIT and the NHS. There is therefore a need to establish whether there is any 'grey' literature available from NHS Trusts that have already implemented OCS as this would be potentially of use in informing how to design and implement evaluation studies of CDSS within OCS within the NHS.

We believe the key current need is for a well designed and comprehensive survey, and on the basis of the results of this potentially for evaluation studies in the form of CRCTs or RCTs which incorporate process, and patient outcomes, as well as full economic evaluations alongside the trials to assess the impact of CDSS in conjunction with OCS versus OCS alone for diagnostic, screening or monitoring test ordering in the NHS. The economic evaluation should incorporate the full costs of potentially developing, testing, and installing the system, including staff training costs.

Study registration

This study is registered as 61.

Chapter 1
Background

Accurate and efficient diagnostic procedures are paramount in optimising patient management and use of health-care resources. If a correct diagnosis is not made patients may receive inaccurate information regarding their prognosis, may undergo inappropriate medical treatment, or the correct treatment may be withheld. This can result in less than optimal outcomes, both in terms of the clinical management of patients and the use of health-care resources. Furthermore, following the use of different tests to establish a diagnosis, further tests are often required to monitor disease progression, or to screen for the presence of other risk factors or concomitant disease.

To reach a diagnosis or manage a patient, a clinician may choose to order one or more medical tests. In this sense, 'diagnostic test' refers to any procedure that tries to confirm or identify the presence or absence of a patients' symptoms or signs or alteration in a patient's condition. This includes laboratory measurements, e.g. biochemistry, haematology, bacteriology, imaging, and invasive procedures. There are a number of factors which may influence a clinician's decision to order a test including:

- a patient's medical history, signs and symptoms
- therapeutic and prognostic factors, such as deciding on an appropriate course of treatment
- patient-related factors such as demographics or patient preference
- factors related to both the individual clinician and health-care organisation.[1]

A recent systematic review of reasons and context for test ordering by clinicians highlighted that the majority of factors associated with test ordering were clinician related, including level of clinical experience, confidence in their clinical judgement, speciality, and working patterns. Availability of tests, type of health-care organisation (salaried health-care professionals vs fee for service approach), and size of the primary care practice were also found to influence test requesting patterns.[1] This review therefore highlights the fact that clinician test ordering behaviour is influenced by a multitude of interactive factors, and therefore may be difficult to standardise as it will depend not only on the nature of clinical consultation, but also on the individual clinician working within a specific organisational environment. Many potential benefits of order communication systems (OCS) (termed Computerised Physician Order Entry or CPOE systems in the USA) in hospitals have been identified. These include improvements in clinician ordering patterns, optimisation of clinical time, and aiding communication processes between clinicians and different departments.[2–5] These systems have the potential to automate the clinical test ordering process and to improve the quality and safety of patient care.[6–9] Many OCS now include computerised decision support systems (CDSS). These incorporate features such as decision support mechanisms, including alerts of critical values, reminders of overdue preventative health tasks, (including laboratory or radiology imaging tests), built-in alerts, rule-based prompts, advice for drug prescribing, critiques of existing health-care orders, and suggestions for various care issues. However, as a number of reviews have highlighted CDSS do not always improve clinical practice. In a recent review of computer-based systems, (including but not restricted to just CDSS) of 100 randomised controlled trials (RCTs) assessing a wide range of indications for OCS and CDSS use (diagnosis, reminder systems, disease management systems, and drug-dosing or prescribing systems), most [62/97 (64%)] significantly improved practice in some way, but 36% did not.[10] Furthermore, there is relatively little sound scientific evidence available to explain why some systems succeed and some systems fail.

Computerised decision support systems in health care are information systems designed to improve clinical decision making, and by and large are intended to support health-care workers in the normal course of their duties, assisting in tasks that rely on the manipulation of data and knowledge. Although there is no consensus on the definition of a CDSS, the definition used in three systematic reviews conducted at McMaster University, Hamilton, ON, Canada[9–11] is an:

> active knowledge systems which use two or more items of patient data to generate case-specific advice.[9–11]

Computerised clinical decision support systems match characteristics of an individual patient to a computerised knowledge base, with software algorithms used to generate patient-specific recommendations. Clinicians, health-care staff or patients can manually enter patient characteristics into the computer system, or alternatively electronic medical records can be queried for retrieval of patient characteristics. Computer-generated recommendations are then delivered through the electronic medical record, by pager, e-mail, or through printouts placed in a patient's paper chart. Additionally, CDSS can be used to check the potential duplication of services and highlight test orders that should be considered when one order is placed ('corollary' orders).

A large proportion of orders processed through order communication systems are for pathology and imaging services. The use of laboratory services for diagnostic testing has increased in many health-care jurisdictions around the world.[12–14] The Healthcare Commission report '*Getting results: Pathology services in acute and specialist trusts*', highlights the fact that in the UK pathology is the largest diagnostic service in the number of requests it meets annually (175 million), in expenditure (£1.8B in 2005–6 and 5.1% of the total budget of NHS Trusts) and in the proportion of clinical decisions that it affects (reputedly over 70%).[15] Moreover the number of requests for biochemistry, haematology and microbiology tests continues to increase, and there is also an increase in the number of tests requested per sample. The report also highlights that in 2005 while tests were generally completed more quickly that in 2003, there was still considerable variation between laboratories in test turn around times. Additionally, many non-urgent tests were being completed more quickly than in 2003, raising the question of whether improved turnaround results in clinical benefits that may justify additional marginal costs.

In the test ordering process there are two distinct aspects to order communication systems:

1. Test requesting – the process of making a request to a diagnostic service.
2. Results reporting – the process of electronic reporting of results to the clinician.

Figure 1 outlines the flow of information in the test requesting and reporting process and the stages in which CDSS and OCS can have an impact.

In the test ordering process the use of CDSS in OCS has the potential to: reduce the number of redundant tests that are ordered; ensure necessary tests are performed at the correct intervals by prompting clinicians; ensure tests appropriate to the specific clinical circumstances are ordered; and correct sampling procedures for the tests that are ordered.

In the results reporting process the potential impact of CDSS in OCS with intelligent feedback lies in the provision of context-specific interpretative comments to help the clinician with the interpretation of test results (either alone or in addition to those provided by pathology or imaging services), and provide advice on the best course of action given a specific result, e.g. to undertake further investigations and the timing of such tests.

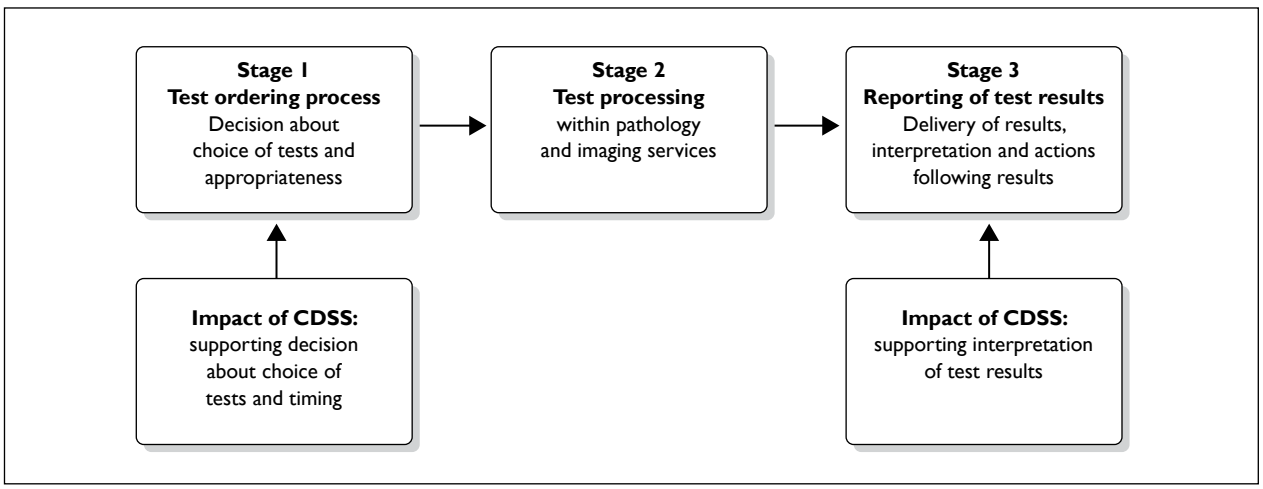

FIGURE 1 *Information flow in order communication.*

Types of order communication and CDSS

Order communication systems vary in their level of sophistication with a distinction between systems which provide only knowledge support, those which provide audit feedback on aggregated data, and those which provide real-time decision support embedded in the clinical process. OCS can vary in at least four different ways, which have the potential to impact on any benefits and costs associated with the system:

1. Functions of the system. There are at least four important dimensions along which systems can differ:
   i. only order tests versus order and display past/current results
   ii. ordering/result display alone versus system with knowledge support (e.g. an electronic laboratory handbook for browsing) versus system with decision support
   iii. with or without a regular audit report on the number and type of tests ordered by the user
   iv. location of the access points: fixed access points versus mobile computers
   v. patient identification aids: none versus bar coding versus other identification such as radio frequency identification tags.
2. Scope of the orders covered:
   i. orders for tests from one single laboratory versus
   ii. for all laboratories versus
   iii. for laboratories plus imaging and electrocardiograms, etc.
   iv. versus for all tests and therapies and drugs versus
   v. all orders integrated into full electronic patient record.
3. Purpose of the tests ordered:
   i. test ordering for preventive care or screening versus
   ii. diagnostic purposes versus
   iii. monitoring of long-term conditions and drug dosing (e.g. insulin, warfarin).
4. Aim of the advice offered by system:
   i. to increase appropriate use of tests versus
   ii. to decrease over use of tests.

Additionally, as the systematic review including a meta-analysis and meta-regression by Kawamoto and colleagues[16] highlights, other specific system features may be related to the success or failure of the CDSS in significantly improving clinical practice. In their review, which included 70 studies comparing 71 relevant comparisons, 15 decision support features whose importance had been repeatedly suggested in the literature as having an impact on the effects of CDSS were assessed using univariate analyses for each selected feature to determine whether or not it had a statistically or clinically significant impact on clinical practice. The authors did not report how a 'significant impact on clinical practice' was defined within the review. Nor did it appear that the included studies reported a significant improvement in practice using the same definition. The presence or absence of each of the 15 features within a system were then used as predictors of system success or failure in terms of having a significant impact using multiple regression models. The 15 features assessed in the review are listed in *Table 1*. Further explanatory variables to account for decision support subject matter (acute vs non-acute care) and two indicators for the study setting (academic vs non academic, and outpatient vs inpatient care) were also entered into the regression models. The authors found that four system features were independent predictors of improved clinical practice: automatic provision of decision support as part of clinician workflow, provision of recommendations rather than just assessments, provision of decision support at the time and location of decision making, and computer-based decision support.[16] However, the odds ratios for the two most important predictors identified by the authors, namely automatic provision of decision support as part of clinician workflow, and provision of recommendations rather than just assessments, were implausibly high with associated very wide confidence intervals (CIs). As the authors acknowledge these two features that were included in the multivariate model may have had a significant effect in the regression model due to model over-fitting.[16]

Additionally, as well as CDSS systems varying in their degree of sophistication, location of access points and timeliness and mode of feedback, and the information system in which they are located (Laboratory/Radiology Information Systems; Hospital Information Systems, or GP Practice Systems), CDSS also vary in the reasoning methods used to generate advice and the source of the information from which advice is generated. A typology of six types of reasoning methods for decision tools was described by Liu and colleagues.[72] This categorised the reasoning methods as either (1) Bayesian methods, (2) logistic regression extensions of Bayes' theorem, (3) based on discrimination rules, (4) clinical algorithms, (5) expert systems or (6) machine learning methods.

TABLE 1 *Fifteen features of clinical decision support systems assessed by Kawamoto and colleagues[16]*

Features and sources[a]
General system features
Integration with charting or order entry system to support workflow integration.[17–21]
± Use of computer to generate the decision support.[b,22–31]
Clinical–system interaction features
± Automatic provision of decision support as part of clinician workflow.[18,19,32–41]
No need for additional clinician data entry.[17,32,33,36,42–6]
Request documentation of the reason for not following CDSS recommendations.[42,45–8]
± Provision of decision support at time and location of decision making.[5,20,22,23,25,31,35,37–41,44,49–51]
Recommendations executed by noting agreement.[24,46,47,52]
Communication content features
± Provision of a recommendation, not just an assessment.[45,49,53]
Promotion of action rather than inaction.[36,39,54]
Justification of decision support via provision of reasoning.[17,47,54,55]
Justification of decision support via provision of research evidence.[29,34,54,55]
Auxiliary features
Local user involvement in development process.[5,18,45,54–62]
Provision of decision support results to patients as well as providers.[25,63–7]
CDSS accompanied by periodic performance feedback.[34,40,50,54,60,68]
CDSS accompanied by conventional education.[28,50,69–71]

a Reviews or primary studies in which the authors suggested the feature was important for CDSS effectiveness.
b Feature not relevant to the scope of the current review; ± system feature found to be an independent predictor of system success.

Bayesian methods

Bayes' theorem describes how the probability that an individual has a disease (known as the pre-test or prior probability) changes when the result of a diagnostic test is obtained (post-test probability), dependent on the performance characteristics of the test. Bayes' theorem can be extended to combine multiple pieces of diagnostic information, with the post-test probability obtained from the first test acting as the prior probability for the next test. However, this approach, known as naive Bayes, has been shown to give over-optimistic predictions when individual test results are not independent due to the double counting of diagnostic information.

Logistic regression extensions of Bayes' theorem

The problem of double counting of diagnostic information is removed by using logistic regression models that account for correlations between the different pieces of diagnostic information. In this method the links between Bayes' theorem and logistic regression models can be fitted by re-expressing the theorem using 'weights of evidence' or log likelihood ratios to account for the correlations.[73] Adjustments for correlations between diagnostic items are made by estimating a beta parameter for each test, which either increases or decreases the likelihood ratio for the test. Bivariate and multivariate model fitting approaches can then be used to remove redundant symptoms and select those to keep in the final model.

Discrimination rules

Discrimination rules use standard statistical methods to produce a rule that can be used to discriminate between individuals on the basis of symptoms or test results, and to allocate them to the group to which they are most likely to belong, for example, diseased versus non-diseased. These methods rely on producing predictions from

either logistic regression models or discriminant functional analyses to predict membership of two or more groups. The application of logistical regression in this instance differs in two important ways from that applied to Bayes' theorem. Firstly, there is no direct way of altering predictions to allow for differences in pre-test probabilities, and secondly, there is no quantification of the uncertainty around group allocation.

Clinical algorithms

An algorithm is a process for carrying out a complex task which is broken down into a series of simple decision and action steps.[74] Clinical algorithms can either be represented as paper-based flowcharts or as computer programs. These algorithms have a number of limitations including the need to have all the data specified in the algorithm available, space restrictions if the algorithm is paper based, and the practical difficulties of breaking down many clinical problems into a set of discrete decisions that can then be represented in computer language. Optimal clinical algorithms can be developed using statistical methods known as classification and regression trees.

Expert systems

An expert system is a computer program that simulates human thought processes 'to provide the kind of problem analysis and advice that the expert might provide'.[74]

Machine learning

Machine learning can either be supervised or unsupervised. In supervised learning the system is provided with a sample of input data and the content designated on how to identify and classify patterns within the data. In unsupervised learning the system is provided with data, but is left to identify patterns without external assistance using a form of cluster analysis. There are a number of different types of machine learning methods, including decision trees, artificial neural networks and genetic algorithms. For all methods, internal weights within the system are adjusted during training until a pre-specified performance level is attained. Limitations of these systems include the fact that although experts can evaluate a decision tree generated by a machine system, the system cannot often provide understandable reasons for the advice it generates. Furthermore experts can rarely evaluate the reasoning behind the classifiers generated by neural networks and genetic algorithms as these systems are 'black boxes'.

Evaluation of CDSS

Wyatt and Spiegelhalter describe a systematic approach to laboratory and field testing of CDSS, suggesting that the final stages should include evaluation of effects on health-care processes and patient outcomes.[75] However, if a CDSS is to have an ultimate impact on health-care processes or patient outcomes then acceptance of the system and usage rates must be high. User acceptance and satisfaction with a CDSS is therefore highly important; if users are satisfied they are likely to modify their behaviour to use the system to their advantage, but if they are not then they will either not use the system or will use it in a suboptimal manner.[76]

A literature review by Ohmann and colleagues, which focused on user satisfaction with computer-based systems, highlights the fact that satisfaction is a complex interplay between both system-dependent and system-independent factors.[77] System-dependent factors include 'satisfaction with the content of the CDSS' and 'satisfaction with the interface of the system', whereas system-independent factors include personal factors, such as 'computer anxiety' and 'attitudes towards computers' as well as organisational factors, including the environment in which the system is used.

In terms of system-dependent factors acceptance of CDSS depends on a number of factors including:

- time taken to get access to the CDSS
- time taken to use the CDSS
- conceptual complexity of the CDSS (which affects ease of understanding and usage)
- number of data items to collect (if the data are not already available in electronic patient records)
- ease of data entry
- ease of interpreting the results (numbers, probabilities, graphs, advice, etc.)
- perceived applicability of the CDSS knowledge base to the clinician's own patients.

Although it is recognised that system-independent factors are additionally likely to impact on user acceptance of CDSS, it is necessary to assess what features of CDSS are likely to make the system more or less acceptable to clinicians or patients

when developing prototypes and final versions of the system, as ultimately acceptance of the system will impact on usage rates, and may influence both process and patient outcomes. Thus during the development stage as highlighted in the review by Kawamoto and colleagues[16] it may be important to involve local users in the development process, as ultimately they will be the system users, and may be able to provide useful feedback on the different functionalities of the system as the development phase progresses.

Figure 2 adapted from Sim and colleagues, highlights the complex interplay between the knowledge source that underpins the CDSS, the CDSS characteristics, the information delivery and the clinical work context.[55]

Current service provision

The National Programme for Information Technology (NpfiT) is a 10-year programme that will procure, develop and implement modern, integrated information technology (IT) infrastructure and systems for all NHS organisations, and was originally described as one of the world's biggest IT projects projected to cost £6.2B. However due to the complexity and delays in completing the project, in 2006 a report from the National Audit Office suggested that spending on the NpfiT would actually reach £12.4B by the year 2014.[78]

The key elements of the programme are:

- The NHS Care Records Service, with a record for each individual patient, which can be accessed securely by both the patient and health-care providers.
- Choose and Book, an electronic booking service aiming to give patients a greater choice of hospital or clinic and more convenience in the date and time of their appointment.
- A system for Electronic Transmission of Prescriptions, to make GP prescribing and dispensing safer and easier.
- A national network for the NHS (N3), providing IT infrastructure and broadband connectivity to meet all NHS computing needs.

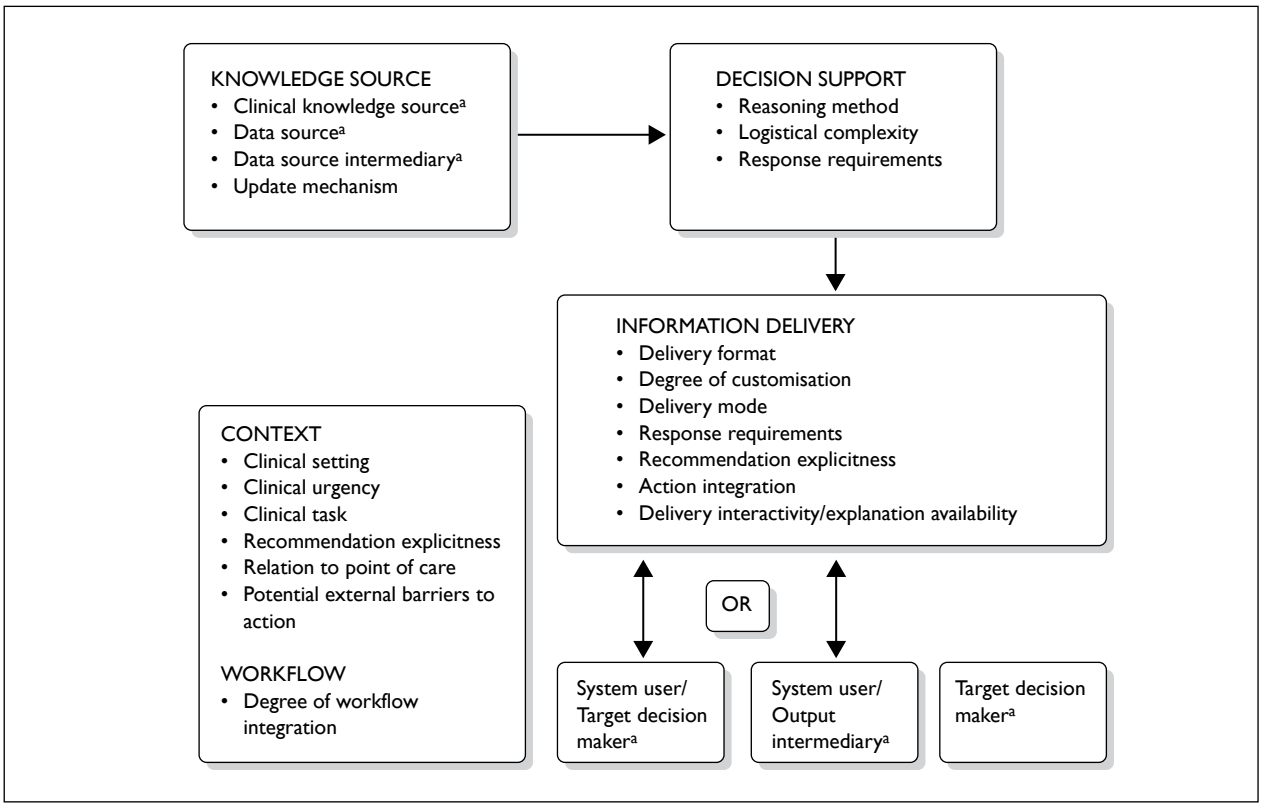

FIGURE 2 *Overview of CDSS and the interplay with the context in which it is used. a denotes human and possible human roles.*

- Picture Archiving and Communications System (PACS) to capture, store and distribute static and moving medical images.
- The Quality and Management and Analysis System giving GP practices and primary care trusts objective evidence and feedback on the question of care delivered to patients.
- NHS e-mail, including a directory service for the NHS.

Originally the agency responsible for delivering the NpfIT was NHS Connecting for Health (CFH), with a number of core contractors employed to deliver specific aspects of the programme at either a national or regional level. *Table 2* below shows the original core contractors and the services which they were responsible for delivering.

However, accountability for the delivery of the programme was transferred to Strategic Health Authorities (SHAs) in April 2007, as part of the NpfiT Local Ownership Programme. Currently programme activity is split into three programmes for IT, each of which is hosted by the SHAs and has a Local Service Provider. These are comprised of:

- London Programme for IT (LpfiT) for which the local service provider is BT.
- North Midlands and East (NME) Programme for IT (NMEPfIT) for which the local service provider is Computer Sciences Corporation. This covers the six SHAs: East Midlands SHA, East of England SHA, North East SHA, North West SHA, West Midlands SHA and Yorkshire and Humberside SHA.
- Southern Programme for IT which covers three SHAs: South Central SHA, South East Coast SHA and South West SHA.

Furthermore, an Additional Supply and Capacity service Contract (ASCC) was established for specific technical aspects of the project in recognition of the fact that the original NpfIT contract was likely to require additional capability and capacity over and above that of the original contractors. Additional Supply and Capacity Service contractors were established to provide specialist knowledge, skills and services not currently or readily available from the existing NpfIT suppliers at either the local, regional, pan-SHA or national level. In relation to the provision of decision support (Service Category 2.20), 24 additional suppliers were contracted, 12 at the national level and 12 at the level of small to medium-sized enterprises (SMEs). These additional 24 decision support suppliers along with the core contractors formed the basis of the sampling frame used to identify which CDSS in OCS are currently either in use or being implemented in the UK. A list of these suppliers is given in *Table 3*.

Up-to-date information (current as of 1 July 2009) regarding the deployment of the different key elements of the NpfIT project by the three programmes for IT and the service providers

TABLE 2 *NpfIT core contractors and system functionality to be delivered*

Contract	Area	Company	Duration
NHS Care Records Service – NASP	National	BT	10 years
NHS Care Records Service – LSP	North East	CSC	10 years
NHS Care Records Service – LSP	Eastern	CSC	10 years
NHS Care Records Service – LSP	London	Capital Care Alliance (BT)	10 years
NHS Care Records Service – LSP	North West and West Midlands	CSC	10 years
NHS Care Records Service – LSP	Southern	The Fujitsu Alliance	10 years
N3	National	BT	7 years
Choose and book	National	Atos Origin	5 years
NHS Mail	National	Cable and Wireless	10 years

BT, British Telecommunications; CSC, Computer Science Corporation; LSP, Local Service Providers responsible for the delivery of a range of IT services in a Cluster of Strategic Health Authorities; NASP, National Application Service Providers responsible for delivery of core national applications.

is available at www.connectingforhealth.nhs.uk/newsroom/statistics/deployment/commsrep.pdf. However it should be noted that this does not include data on deployment of CDSS, although does provide minimal information on the deployment of OCS.

TABLE 3 *Additional suppliers contracted under the ASCC for decision support*

National
AGFA Healthcare (UK) Ltd
Atos Origin
British Telecommunications plc
Cerner Ltd
CSE Servelec Ltd
FileTek UK Ltd
Fujitsu Services Ltd
ISoft plc
Perot Systems Europe Ltd
Siemens plc
Steria Ltd [formerly known as Xansa (UK) Ltd]
TATA Consultancy Services Ltd
Specialist SME
Adastra Software Ltd
ALERT Life Sciences Computing, SA
Oasis Medical Solutions Ltd (formerly known as Capula Healthcare Ltd)
CAS Services Ltd (formerly known as Clinical Solutions Ltd)
CSW Group Ltd
Egton Medical Information Systems Ltd
Infermed Ltd
Map of Medicine (formerly known as Informa UK Ltd)
Plain Healthcare
Sowerby Centre for Health Informatics at Newcastle Ltd
Stalis Ltd

Chapter 2

Scope of the technology assessment

Aims and objectives

The purpose of this report was to assess:

1. Which CDSS in OCS for test ordering are currently in use within the UK, and what are their main characteristics and their intended/actual scope of use?
2. What is the impact of CDSS in OCS for diagnostic, screening or monitoring test ordering compared to OCS without CDSS on process outcomes, patient outcomes and adverse events/safety?
3. What features of CDSS are associated with clinician or patient acceptance of CDSS in OCS?
4. What is known about the cost-effectiveness of CDSS in diagnostic, screening or monitoring test OCS compared to OCS without CDSS?
5. In order to address the questions specified, the assessment was comprised of:
   i. A survey of the 24 manufacturers/suppliers currently contracted by NpfIT to provide either national or specialist SME decision support systems, NHS CFH, eHealth Strategy Board, 'Informing Health Care', the Healthcare Commission,[15] NHS Purchasing Suppliers, and the NHS Supply Chain.
   ii. Two linked systematic reviews to assess, firstly, the impact of CDSS in OCS for diagnostic, screening or monitoring test ordering compared to OCS without CDSS on process and patient outcomes, and secondly, to examine what specific features of CDSS may be associated with clinician or patient acceptance of the system.
   iii. A systematic review of economic evaluations and cost-comparison studies of CDSS in diagnostic, screening or monitoring test OCS compared to OCS CDSS.

Interventions

The report assesses CDSS in OCS for diagnostic, screening or monitoring test ordering compared to OCS without CDSS evaluated in a clinical setting.

For the purpose of this assessment a CDSS is defined as:

> an active knowledge system which uses two or more items of patient data to generate patient-specific assessments or recommendations that are then presented to clinicians for consideration.[9–11]

Studies in which a CDSS has not been evaluated in a clinical setting are not included. Additionally, studies in which the OCS: (1) only provides summaries of patient information (i.e. no specific test ordering or test interpretation advice); (2) provides feedback on groups of patients without individual assessment; (3) only provides computer-aided instruction (i.e. provides generic rather than patient specific advice); or (4) is used in image analysis are not included.

Population

Studies which include health-care workers (e.g. physicians, nurses, dentists, psychiatrists, physiotherapists) in practice or training, or patients undergoing testing for diagnostic, screening or monitoring purposes in a primary or secondary care setting are included.

Relevant comparators

CDSS in OCS are compared with OCS without CDSS.

Outcomes

Study question two:

Studies which report an objective measure of process of care, e.g. test volumes, compliance with guidelines implemented via the CDSS, appropriateness of the test(s) ordered, patient outcomes, or adverse events, are included. Studies which only report the diagnostic accuracy of the CDSS compared to a gold standard (such

as a diagnosis reached by the clinician without use of the CDSS) (i.e. sensitivity and specificity) are excluded. These studies are excluded as the outcome of interest is the impact of CDSS in conjunction with OCS for test ordering, rather than the accuracy of CDSS compared with a clinician in providing a correct clinical diagnosis.

Study question three:

Outcomes that were included were clinician or patient self-reported acceptability of the CDSS. Acceptability was defined according to the definitions used in the primary studies.

Study question 4:

Studies which reported the cost-effectiveness of CDSS are included.

Study designs

For study questions two and three randomised, cluster randomised, and non-randomised trials with a contemporaneous control group, interrupted time series (ITS), and controlled and uncontrolled pre–post studies (CPPs and UPPs) are included. In addition for review question three cross sectional and longitudinal surveys and qualitative studies are also included. For review question four, the systematic review of economic evaluations, cost–comparison studies, full cost-effectiveness analyses (CEA), cost–utility analyses (CUA) and cost–consequence analyses (CCA) are included.

Publication language and status

A full English language text copy of the study has to be available for it to be included. Studies which are reported in abstract form only and where no further information is available were excluded. Foreign language papers were also excluded.

Overall aims and objectives of assessment

This assessment aimed to establish which CDSS in OCS for test ordering were currently in use or being implemented in the UK, and the main characteristics and intended/actual scope of their use. The assessment also reviews the evidence on the impact of CDSS in OCS, the specific CDSS features which may be associated with clinician or patient acceptance of the system, and the cost-effectiveness of CDSS in OCS compared to OCS alone through three linked systematic reviews. Additionally, through drawing together the evidence on the impact of CDSS on clinical processes and patient outcomes, and the likely cost-effectiveness of CDSS, systems for which future primary research would be of benefit will be identified.

Chapter 3

Methods to address the questions

Study question 1: identification of CDSS in OCS for diagnostic, screening and monitoring test ordering currently in use within the UK

Computerised decision support systems in diagnostic, screening and monitoring test OCS currently in use or being implemented within the UK were identified through contact with the 24 manufacturers/suppliers currently contracted by NpfIT (service category 2.20) to provide either national or specialist SME decision support. Manufacturers were contacted by e-mail and asked to stipulate whether their specific system was currently being piloted, in use or being implemented in the UK. They were additionally asked to state the number and at which sites their CDSS was installed. Where they considered this data to be commercial-in-confidence (CIC) they were asked to state this, but at least respond as to whether the CDSS was currently deployed in the UK. Non-responders to the survey were followed-up twice, at two weekly intervals.

In addition, NHS CFH, the Healthcare Commission,[15] NHS Purchasing Suppliers, and the NHS Supply Chain were contacted. These contacts did not yield any additional information.

Generic methods for the conduct of reviews to assess the impact, acceptability and cost-effectiveness of CDSS systems in test order communication systems

Standard systematic review methods following the guidance on the conduct of systematic reviews published by the Centre for Reviews and Dissemination (CRD)[79] was used to undertake the reviews of the impact, acceptability, and cost-effectiveness of CDSS. The generic methods for the conduct of the reviews are outlined below with the specific inclusion criteria for each of the reviews, data extracted, and methods of synthesis for each outlined for the specific review questions in turn.

Identification of relevant studies

A generic search to identify potentially relevant studies for inclusion in the three reviews was conducted. This was used to identify relevant clinical, cost-effectiveness and cost–comparison studies indexed on the following medical and social science databases between 1974 (the year of publication of the first article to evaluate the effect of a CDSS on clinician performance by De Dombal and colleagues)[80] and 2008: The searches were then updated in April 2009.

- MEDLINE
- EMBASE
- Cochrane Controlled Trials Register (CCTR)
- CINAHL (Cumulative Index to Nursing and Allied Health Literature)
- DARE (Database of Abstracts of Reviews of Effects)
- Health Technology Assessment (HTA) database
- IEEE (Institute of Electrical and Electronic Engineers) *Xplore*
- NHS Economic Evaluation Database (NHS EED)
- EconLit.

No study design filters were applied to the search strategy.

The literature searches retrieved 22,109 unique references after de-duplication. All references were managed using REFERENCE MANAGER, software version 11. Full details of the search strategies are presented in Appendix 1. In addition, bibliographies of all included studies were checked to identify further relevant studies.

Selection of primary studies for the reviews

Relevant studies were identified in two stages. One reviewer screened titles and abstracts returned by the database searches, and a random 20% of these

were checked for agreement by a second reviewer. Cohen's unweighted κ-statistic for disagreements at the title/abstract screening stage between reviewers was 0.89, indicating a good level of agreement. The full texts of any references that were considered relevant by either reviewer were obtained where available. The relevance of each paper was assessed according to the criteria set out below for each review question. Any discrepancies between the reviewers were resolved by recourse to the papers, and if necessary a third reviewer was consulted. All duplicate papers were double-checked and excluded. The extent of disagreements between reviewers for study inclusion in the reviews was again quantified using Cohen's unweighted κ-statistic with an agreement level of 0.91 between reviewers.[81] Further bibliographic details of excluded studies, along with reasons for their exclusion are detailed in Appendix 2.

Data extraction and quality assessment processes

Data were extracted from the included studies using a standardised data extraction form developed for each of the reviews. The quality of the individual studies was assessed according to study design by one reviewer and checked for accuracy by a second. RCTs, cluster randomised controlled trials (CRCTs), controlled clinical trials (CCTs), and CPPs and UPPs were assessed according to methodological criteria listed in the up-dated CRD Report 4;[79] ITS studies were assessed according to criteria specified by the Cochrane Effective Practice and Organisation of Care (EPOC) Group;[82] economic evaluations were assessed using the Consensus on Health Economic Criteria list questions developed by Evers and colleagues.[83]

The main criteria assessed according to study design are outlined below.

RCTs, CRCTs and CCTs

The assessment of internal validity was examined: the methods of randomisation (RCTs and CRCTs), the handling of potential confounders (baseline imbalance, cointervention), blinding of assessors and data analysts, the rate of attrition and the appropriateness of data analyses. In addition, for CRCTs whether the analysis took clustering into account was also examined.

ITS

In line with the quality assessment criteria suggested by the EPOC Group for ITS studies,[82] quality assessment criteria focused on whether the intervention was independent of other changes over time, whether sufficient data points were presented to enable reliable statistical inference and whether a formal test for trend was presented. Additionally, the reliability of the primary outcome measure, whether the intervention was likely to affect the methods of data collection, blinding of outcome assessors, and rates of attrition were assessed.

Controlled and uncontrolled pre–post studies

Assessment of validity for both controlled and uncontrolled pre–post studies was undertaken by assessing the adequacy of baseline details, rates of attrition and the appropriateness of data analyses (i.e. whether analyses were conducted on the basis of the 'intention to provide or communicate information').

Study question 2: What is the impact of CDSS in OCS for diagnostic, screening or monitoring test ordering compared to OCS without CDSS on process and patient outcomes?

Inclusion and exclusion criteria

The inclusion and exclusion criteria to select studies for the review on the impact of CDSS in OCS on process and patient outcomes were the same as those outlined in Chapter 2, for the participants, interventions, relevant comparators, outcomes and study designs.

Data extraction strategy

Data were extracted on the study setting, clinician and patient characteristics (where reported), study design and methods, intervention and comparator systems, area of impact, CDSS characteristics, including the presence or absence of the 14 relevant features of CDSS identified as being potentially related to system success by Kawamoto and colleagues,[16] and outcomes. Outcomes were summarised using descriptive summary statistics, including proportions (with 95% CIs) for categorical variables and mean [standard deviation (SD)] for continuous variables.

Data synthesis

Due to considerable heterogeneity between the studies, in terms of the type of CDSS evaluated, the output format of the CDSS, study designs and setting, and outcomes assessed, results were first broadly grouped according to the intervention (i.e. the type of information provided by the CDSS, for example, the display of test costs, corollary orders, or advice/recommendations). Studies within each broad intervention group were then further grouped according to study design. Due to the heterogeneity between studies results were therefore combined using a narrative synthesis[84,85] with key demographic data for each study and relevant quantitative results tabulated. All data extraction tables are presented in Appendix 3.

Study question 3: What features of CDSS are associated with clinician or patient acceptance of CDSS in OCS?

Inclusion and exclusion criteria

Inclusion criteria for eligible studies were the same as those specified in Chapter 2, for study participants. Inclusion criteria for the interventions were also the same as those listed in Chapter 2, apart from a comparator system, i.e. an OCS without CDSS was not required for studies to be eligible for inclusion. The study outcomes that were included were clinician or patient self-reported acceptability of the CDSS. Acceptability was defined according to the definitions used in the primary studies. Study designs that were included were the same as those used to address review question 2 (i.e. RCTs, CRCTs, CCTs, ITS, CPPs and UPPs) but in addition cross sectional and longitudinal surveys, and qualitative studies were also eligible for inclusion.

Data extraction strategy

The data extracted included the study setting; clinician and patient characteristics; study methods; intervention and comparator systems (where applicable); self-reported rates/scores of clinician or patient acceptability of the CDSS; and CDSS characteristics including where reported, time taken to obtain the CDSS, time taken to use the CDSS, methods of system reasoning, CDSS knowledge base, number of data items to collect (if the data are not already available in electronic patient records), ease of data entry, ease of interpreting results and perceived applicability of the CDSS knowledge base to the clinician's own patients. All data on clinician or patient acceptance of the CDSS were summarised using appropriate descriptive summary measures including proportions (with 95% CIs) for categorical variables.

Data synthesis

Due to considerable heterogeneity between the studies, in terms of the type of CDSS evaluated, the output format of the CDSS, study designs and setting, and outcomes assessed, results were first broadly grouped according to the intervention (i.e. the type of information provided by the CDSS, for example, the display of test costs, recommendations, or restricted lists). Where studies incorporated a second subsidiary CDSS intervention the study was grouped according to the primary outcome and aim of evaluating the CDSS, with the secondary outcome also reported within this category. Studies within each broad intervention group were then further subgrouped according to study design. Due to the heterogeneity between studies results were combined using a narrative synthesis[84,85] with key demographic data for each study and relevant quantitative results tabulated.

Studies were grouped according to the type of CDSS system with key data on acceptability and specific system features presented in tables. Results were then combined using a narrative synthesis.[84,85] Differences in rates/scores of acceptability between studies were explored narratively by recourse to differences in the study setting, and CDSS characteristics.

Study question 4: What is the cost-effectiveness of CDSS in diagnostic, screening or monitoring test OCS compared to OCS without CDSS?

Inclusion and exclusion criteria

The inclusion and exclusion criteria for the systematic review of economic evaluations and cost–comparison studies were identical to those specified in Chapter 2, apart from the study design criteria. For the review, full CEA, CUA, cost–benefit analyses (CBA), CCA, and cost–comparison studies

were included. Economic evaluations that only reported average cost-effectiveness ratios were only eligible for inclusion if incremental ratios could be calculated from the available published data.

Data extraction strategy

Data on study setting, clinician and patient characteristics (where reported), intervention, comparators, and outcomes were tabulated. In addition data were extracted on the study design (CEA, CUA or cost-analysis), model type or trial based study, research question, perspective, time horizon, discounting, main costs included, and sensitivity analyses.

Methods of data synthesis

Studies results were presented narratively and where possible key results presented in tables. Differences in the cost-effectiveness of CDSS in comparison with OCS alone were explored narratively by considering differences in the setting, type of tests ordered, type of CDSS and OCS, perspective, time horizon and methods of discounting.

Chapter 4
Survey results

The results from the survey of manufacturers and suppliers under the ASCC was extremely low at only 17%, with only four manufacturers providing any type of feedback. All of this was classified as being CIC and therefore does little to provide any information on the current deployment or implementation of CDSS within the NHS at the present time. For this reason and due to the lack of information provided the results of the survey are not presented within the main text of the report, but are presented in Appendix 4.

Chapter 5

Systematic reviews of the impact and acceptability of CDSS

Aims

1. To summarise existing published research evidence on the impact of CDSS in OCS for diagnostic, screening or monitoring test ordering compared with OCS alone on process, patient outcomes, and adverse events.
2. To examine what can be gleaned from the existing research evidence on the specific features of CDSS that are likely to be associated with clinician or patient acceptance of systems.

This chapter therefore firstly presents the results from the literature searches outlined in Chapter 3, Identification of relevant studies, undertaken to identify potentially relevant studies for the three reviews, followed by:

3. the results from the systematic review to assess the impact of CDSS with OCS versus OCS alone on process, patient outcomes and adverse events and
4. the results from the systematic review to examine what specific features of CDSS are likely to be associated with acceptance of the system.

Quantity and quality of research available for reviews

A total of 22,109 titles and abstracts were screened for inclusion in the three reviews to assess: (1) the impact of CDSS in OCS for diagnostic, screening, or monitoring test ordering; (2) the features of CDSS associated with clinician or patient acceptance of CDSS in OCS; and (3) the cost-effectiveness of CDSS compared to OCS without CDSS. Of the titles and abstracts screened 130 were ordered as full papers and assessed in detail. Two papers were unavailable at the time of the assessment. Of the full papers screened 95 related to the impact of CDSS on processes of care, patient outcomes or adverse events; 31 papers related to the acceptability of CDSS features to clinicians and patients; and four papers related to the cost-effectiveness of different CDSS. The overall process of study selection is shown in *Figure 3*.

In total, therefore, 24 studies reported in 23 publications met the inclusion criteria for the review of the impact of CDSS in OCS versus OCS alone on process, patient outcomes, and adverse events.[29,32,48,50,57,86–100] Two of these studies also reported limited cost–comparison data between CDSS in conjunction with OCS versus OCS alone and were included in the systematic review of economic evaluations.[96,98] No studies were identified that met the inclusion criteria to address study question 3, on the specific features of CDSS that may be associated with physician or patient acceptance of the system.

Study question 2: What is the impact of CDSS in OCS for diagnostic, screening or monitoring test ordering compared to OCS without CDSS on process and patient outcomes?

Due to the considerable heterogeneity between the studies, in terms of the type of CDSS evaluated, the output format of the CDSS, study designs and settings, and outcomes assessed, the review of the impact of CDSS in OCS is presented as follows:

- Overview of the quantity and quality of the included studies and CDSS characteristics.
- Review of the evidence for studies assessing the impact of the CDSS presenting:
  - test charges (i.e. the costs the patient would pay on that day for the specific tests ordered)
  - previous test results (i.e. as physicians wrote an order for a specific test the patients previous test results for that test or set of previous tests results were displayed)
  - reminders (i.e. reminders to undertake preventative patient care measures, order

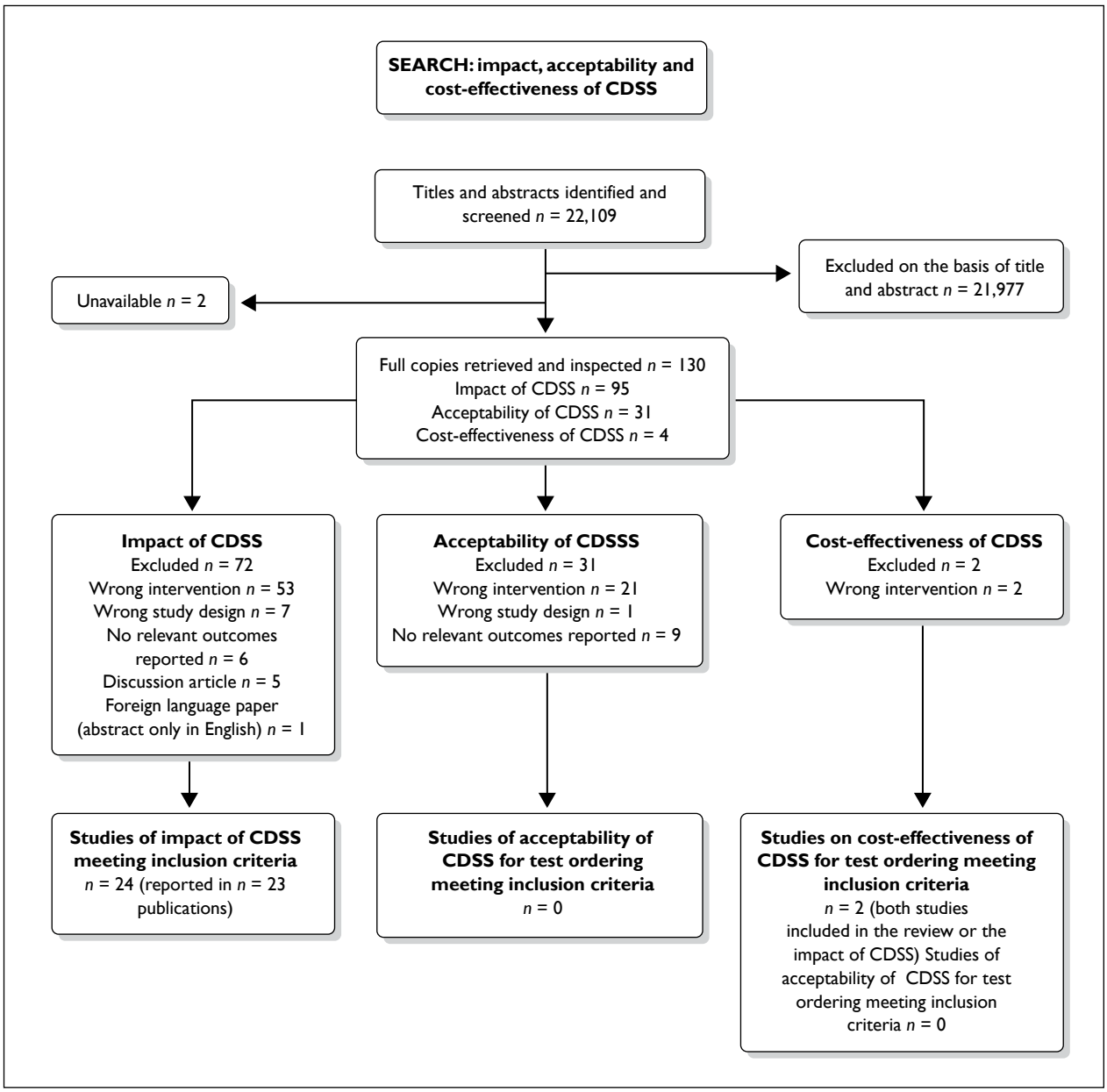

FIGURE 3 *Process of study selection for the three reviews.*

appropriate laboratory tests for medication monitoring, reminders regarding tests that may be redundant within that specific time interval, and reminders for appropriate guidelines for laboratory or radiological test ordering)

– restricted lists (i.e. restriction on the ordering of multiple laboratory tests simultaneously with or without limits on forward ordering)
– recommendations [i.e. guideline based recommendations for appropriate screening or monitoring intervals, referral for an MRI (magnetic resonance imaging) or CT (computerised tomography) scan, or the number of tests conducted per patient/day based on the CDSS recommendations].

For each intervention, text and summary tables are presented on:

- the quantity and quality of the studies
- the study characteristics (summary table)
- CDSS characteristics (text and summary table)

- the study results
- an overview of the impact of the CDSS intervention(s).

Overview of the quantity and quality of the research available

A total of 24 studies reported in 23 publications met the inclusion criteria.[29,32,48,50,57,86–101] The results from two RCTs, one assessing the impact of the display of test charges on clinical laboratory test orders and the other the impact on radiological test volumes conducted at the same institution, were reported together in one paper by Bates and colleagues.[101] Two further studies included in the review of the impact of CDSS in OCS also reported limited cost–comparison data and were therefore also included in the review of the cost-effectiveness of CDSS in OCS compared to OCS alone.[96,98]

As previously stated there was considerable heterogeneity between the identified studies in terms of the type of CDSS assessed, the settings in which the studies were conducted, the patient populations, whether the studies focused on the impact of the CDSS on a single type of laboratory or imaging test order or on multiple tests and study designs. The nomenclature used to attempt to group the studies is therefore highly simplistic, as a limited number of studies assessed the impact of multiple interventions. However, in grouping the studies the predominant CDSS intervention, for example the display of restricted test order lists, was chosen for the grouping. This means that the results of these studies are more likely to be confounded from concomitant interventions than is readily apparent from rudimentary methods used to devise the study groupings.

Overall, in total, the 24 studies could broadly be grouped into those that assessed the impact of the display of test charges ($n = 3$),[86,101] those that displayed patients previous test results ($n = 2$),[88,89] those that provided reminders ($n = 10$),[24,29,48,87,91–94,102,103] studies that displayed restricted lists of test orders ($n = 2$),[95,96] and those in which the CDSS provided a recommendation ($n = 7$).[29,32,48,50,57,86–101] A summary of the type of CDSS intervention by the number of studies and study design is displayed in *Table 4*.

Across the 24 studies, seven CRCTs (29%),[24,32,48,50,86,90,91] four RCTs (17%),[92,97,101] two non-randomised controlled trials (8%),[57,88] one randomised crossover trial (4%),[29] two ITS studies (one with a AB-AB-AB design) (8%),[93,95] one CPP study (4%),[96] and seven UPP studies (29%)[87,89,94,98–100,104] were identified. Duration of follow-up varied widely with a median of 7 months (range: 2–72). Sixty-five per cent of studies described funding from the public sector,[24,29,48,86,89–92,94–97,101] 13% stated funding was from the private sector,[50,57,98] while 22% did not report the funding source.[32,87,93,99,100] Developers of the CDSS software were also outcome evaluators in 62.5% of the studies,[24,29,48,86,88,89,91–93,95,96,99,101,104] were evaluators in part (collaboration) in one study (8%),[90] and were not involved in the system evaluation in 29% of the studies.[50,57,87,94,97,98,105]

TABLE 4 *Summary of CDSS interventions by number of studies and design*

Study design	CRCT	RCT	CCT	X-over	ITS	CPP	UPP	Total
Intervention group								
Display of test charges	1	2	–	–	–	–	–	3
Previous test results	–	–	1	–	–	–	1	2
Display of reminders	4	1	1	1	1	–	2	10
Restricted test lists	–	–	–	–	1	1	–	2
Recommendations	2	1	–	–	–	–	4	7
Total	**7**	**4**	**2**	**1**	**2**	**1**	**7**	**24**

CCT, controlled clinical trial; X-over, randomised crossover trial.

In terms of the study settings, of the 24 studies the majority (17, 71%) were conducted in the USA,[23,28,47,86–91,94–96,98,103] followed by two (8%) each conducted in the UK[32,99] and Spain.[7,98] The remaining three studies were conducted in France (4%),[93] the Netherlands (4%),[96] and Belgium (4%) respectively.[100] Of the studies conducted in the USA, 12 of the 17 studies had been undertaken at one of three specific sites: four studies were conducted at the Wishard Memorial Hospital, Indianapolis, IN, or at one or their outpatient centres;[24,29,48,86] five had been conducted at the Brigham and Women's Hospital, Boston, MA;[88,91,92,101] and three had been conducted at the Vanderbilt University Medical Center.[89,95,104] Across the 24 studies, eight were conducted in a primary care setting,[32,50,57,86,90,94,96,98] one was conducted in both a primary and secondary outpatient care setting,[91] two were conducted in secondary care outpatients,[29,97] 11 were conducted in secondary care inpatients,[24,48,87,88,92,95,99–101,104] one was conducted in a secondary care intensive care unit (ICU),[89] and one in an accident and emergency department.[93]

In relation to the patients indication(s) for undergoing either laboratory or radiological test imaging, the majority of the studies ($n = 10$) included patients with a mixture of diagnoses that were unspecified.[24,29,48,86,87,90–92,94,97] Two studies included only medical or surgical patients,[101] and one included patients undergoing testing for suspected rheumatic disease.[88] The focus of a further three studies were test specific, and so included patients undergoing arterial blood gas (ABG) laboratory testing,[89] serum magnesium level testing,[95] or a range of blood tests[96] respectively. Of the remaining studies, one included patients with a diagnosis of diabetes mellitus,[57] three included patients with hyperlipidemia,[32,50,98] two included patients undergoing assessment or liver transplantation,[101,102] and two included patients in which radiological imaging was indicated.[93,104]

The outcomes reported reflected the intended impact of the CDSS and included test volumes,[32,50,86,88,89,95,96,98,99,101,104,105] test costs,[86,97,99,101], compliance with reminders,[24,29,48,90,91,94] compliance with recommendations,[97,104] guideline compliance,[87,93] and order appropriateness in terms of test frequency.[57,92] Only four studies reported potential adverse effects of test cancellations.[86,92,101] Additionally, all the studies focused on the decision to order a laboratory or imaging test, rather than on the impact of CDSS on the interpretation of test results. Of the 24 included studies, six were focused more broadly on patient management, and included the ordering or appropriateness of pharmacological prescriptions, vaccinations or health-care advice. Therefore only limited outcomes in terms of the impact of CDSS on laboratory test rates or appropriateness were reported in these studies.[24,29,48,50,97,98]

As well as the studies being heterogeneous in terms of the type of CDSS assessed, the settings, patient groups and study designs, the year in which they were undertaken and published also varied considerably. Of the 24 eligible studies, one was published in the period 1980–4, two in 1990–4, eight in 1995–9, three in 2000–4 and 10 in 2004–9.

While the year of study publication can only act as a proxy for the year(s) in which the research was conducted, it can be postulated, particularly in terms of the older CDSS, that these systems may now be obsolete, or will have been upgraded and changed considerably with further technological development in clinical settings. Many of the older studies may therefore now not be of direct relevance to CDSS that are currently available, and greater weight should be given to the more recently published studies that have assessed technologies that are still available or may have undergone limited changes. A summary of the number of studies identified by year is displayed in *Figure 4* and a summary of study characteristics of the 24 identified studies in *Table 5*.

Study quality

As can be expected from the heterogeneity of the identified studies, the level of reporting and study quality was highly variable. Across the studies the median length of follow-up was 7 months, but this ranged dramatically, from 2 months to 72 months. An assessment of study quality is provided in each specific section of the report according to CDSS intervention type.

Overview of the CDSS characteristics according the 15 features of CDSS suggested by Kawamoto and colleagues[16] as having a potential impact on CDSS effectiveness

An overview of the CDSS characteristics from the 24 studies postulated by Kawamoto and colleagues[16] as having a potential impact on the effectiveness of the CDSS is displayed in *Figure 5*. The figure depicts 14 of the characteristics, but

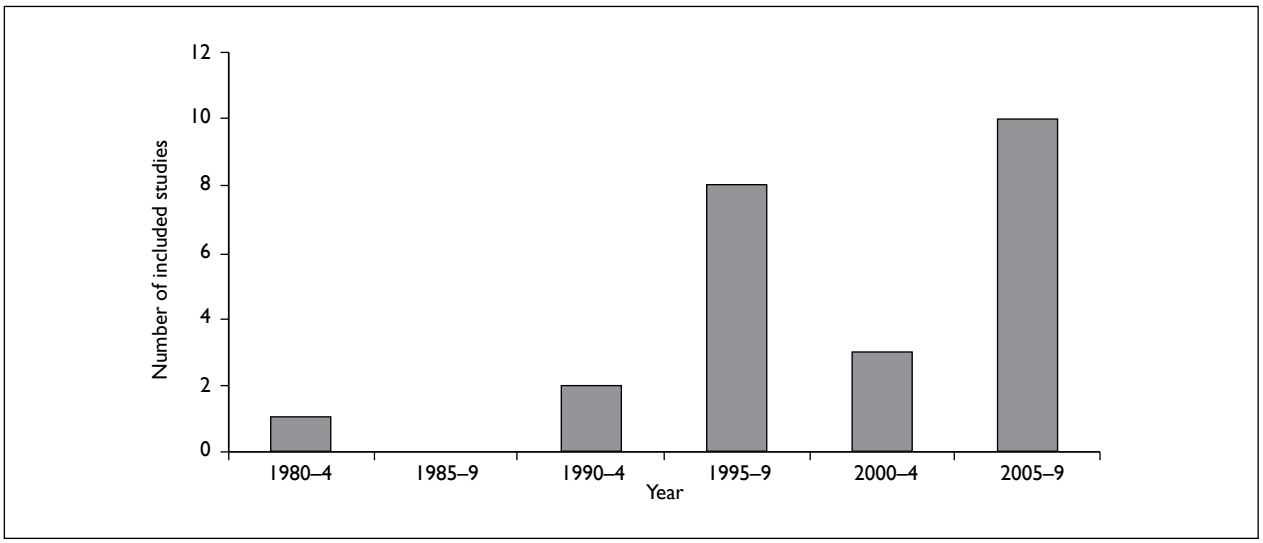

FIGURE 4 *Number of included studies by year.*

omits the use of a computer to generate the decision support, as this formed part of the inclusion criteria by which studies were selected for inclusion in the review, and therefore is not relevant to the current review scope.

As can be seen from *Figure 5* all the studies were integrated with charting or OCS to support workflow integration, provided automatic decision support as part of the clinician workflow, and provided support at the time and location of decision-making. In the majority of studies (79%, 19/24) there was no need for additional data entry by the clinician. Again in the majority of studies (67%, 16/24) the CDSS did not request documentation for not following the recommendations (where these were made), and in 83% (20/24) of studies there was no need for the clinician to execute any recommendations by noting agreement.

Only 38% (9/24) of studies provided a recommendation with the rest displaying either test charges, previous test results, reminders, or displaying restricted test ordering lists. In the majority of studies (79%, 19/24) it was not reported whether the CDSS output would be likely to promote action by the clinician rather than inaction (for example, suggesting a different course of action or test if appropriate rather than suggesting that the test order was cancelled). Additionally in 88% (21/24) of studies no justification of the CDSS output was provided either by recourse to the provision of CDSS reasoning or the research evidence on which this was based.

Local users of the CDSS were involved in the development process in only 17% (4/24) of the studies, with the majority of studies (63%, 15/24) not involving the health-care professionals who would ultimately use the system either in the development or piloting of the system. None of the studies provided decision support results to patients as well as clinicians, and only 8% (2/24) of the studies provided periodic performance feedback to clinicians. Additionally, only 4% (1/24) of the studies provided concomitant conventional education alongside use of the CDSS.

Studies assessing the impact of the display of test charges

Quantity and quality of the studies

The impact of the display of test charges on the number of laboratory and radiology test orders was assessed in one CRCT and two RCTs reported in two publications.[86,101] In all three trials, the objective was to reduce the number of tests that were ordered. The CRCT, by Tierney and colleagues[86] was conducted in the outpatient General Medicine Practice of the Regenstrief Health Centre, Indianapolis, IN, USA (the primary outpatient facility for the Wizard Memorial

TABLE 5 *Summary of the included studies by CDSS intervention*

Study ID	Intervention type	Specific CDSS	Study design	Country in which study was conducted	CDSS primary users	N primary results based on	Health-care setting	Patient condition(s)	Test indication
Tierney (1990)[86]	***Display of test charges***	Home-grown (Wishard Memorial Hospital)	CRCT	USA	Physicians	125 physicians	Primary care	Mixed	D
Bates (1997)[101]		Home-grown (Brigham and Women's Hospital)	2 RCTs	USA	Physicians	Laboratory trial *n* = 7090 patients Radiology trial *n* = 17,381 patients	Secondary care (inpatients)	Medical and surgical	NR
Solomon (1999)[88]	***Display of previous test results***	Home-grown (Brigham and Women's Hospital)	CCT	USA	Physicians	225 physicians	Secondary care (inpatients)	Rheumatic disease	D
Bansal (2001)[89]		Home-grown (Vanderbilt University Medical Centre)	UPP	USA	Physicians	6 ICUs	Secondary care (ICU)	Mixed (ABG test indicated	D and M
Overhage (1996)[48]	***Reminders***	Home-grown (Wishard Memorial Hospital)	CRCT	USA	Physicians	78 physicians	Secondary care (inpatients)	Mixed	S
Overhage (1997)[24]		Home-grown (Wishard Memorial Hospital)	CRCT	USA	Physicians	86 physicians	Secondary care (inpatients)	Mixed (general medicine)	M
Palen (2006)[90]		Clinical Information System (IBM, CO)	CRCT	USA	Physicians	207 physicians	Primary care	Mixed	M
Matheny (2008)[91]		Home-grown (Brigham and Women's Hospital)	CRCT	USA	Physicians	1922 patients	Primary care and secondary care (outpatients)	Mixed	M
Bates (1999)[92]		Home-grown (Brigham and Women's Hospital)	RCT	USA	Physicians	11,586 patients	Secondary care (inpatients)	Mixed	NR
O'Connor (2005)[57]		Epic Systems	CCT	USA	Physicians	122 patients	Primary care	Diabetes	M
McDonald (1980)[29]		Home-grown (Wishard Memorial Hospital)	Randomised crossover trial	USA	Residents, interns, nurses, clinicians	31 physicians	Secondary care (outpatients)	Mixed	NR
Carton (2002)[93]		NR	ITS (AB-AB-AB design	France	Physicians	6434 imaging tests	Secondary care (A & E)	Mixed (radiological imaging indicated)	D and S
Abboud (2006)[87]		INVISION®, (Siemens Medical Solutions, PA)	UPP	USA	Physicians	275 patients	Secondary care (paediatric inpatients)	Mixed (paediatric inpatients)	M
Steele (2005)[94]		NR	UPP	USA	Physicians	19,076 patients	Primary care	Mixed	M

Study ID	Intervention type	Specific CDSS	Study design	Country in which study was conducted	CDSS primary users	N primary results based on	Health-care setting	Patient condition(s)	Test indication
Rosenbloom (2005)[95]	***Restricted lists***	WizOrder (Vanderbilt University Medical Centre)	ITS	USA	Physicians, nurses, practitioners, medical students	194,192 patients	Secondary care (inpatients)	Mixed (serum magnesium test indicated)	M
Poley (2007)[96]		NR (Home-grown)	CPP	Netherlands	Physicians	134 practices	Primary care	Mixed (blood test indicated)	NR
Hobbs (1996)[32]	***Recommendations***	Primed (Wolfson Research Laboratories, University of Birmingham, UK)	CRCT	UK	Physicians	25 practices	Primary care	Hyperlipidemia	S
Cobos (2005)[50]		NR	CRCT	Spain	Physicians	2221 patients	Primary care	Hyperlipidemia	S and M
Apkon (2005)[97]		DSIT tool Problem-Knowledge Couplers (PKC Corp, VT)	RCT	USA	Physicians	1902 patients	Secondary care (outpatients)	Mixed	S and M
Bassa (2005)[98]		NR	UPP	Spain	Physicians	500 patients	Primary care	Hyperlipidemia	S and M
Sanders (2001)[104]		WizOrder (Vanderbilt University Medical Centre)	UPP	USA	Physicians, nurses, receptionists, medical students	1446 physicians	Secondary care (inpatients)	Head or brain CT or MRI indicated	D, S and M
Nightingale (1994)[99]		Home-grown (Wolfson Computer Laboratory, Queen Elizabeth Hospital, Birmingham, UK)	UPP	UK	Physicians	1487 patients	Secondary care (inpatients)	Patients undergoing assessment or liver transplantation	D, S and M
Boon-Falleur (1995)[100]		Computer Laboratory, Queen Elizabeth Hospital, Birmingham, UK)	UPP	Belgium	Physicians	217 patients	Secondary care (inpatients)	Patients undergoing assessment or liver transplantation	D, S and M

D, diagnostic; M, monitoring; NR, not reported; S, screening.

Hospital). In the CRCT the physician was the unit of randomisation, with 121 physicians with a total of 8392 patient visits during the intervention period included.[86] The trial consisted of a 14-week pre-intervention period, a 26-week intervention, and a 26-week post-intervention period conducted simultaneously from January 1988. The trial included all patients and visits to physicians, whether scheduled or unscheduled. It also included all outpatient diagnostic tests (i.e. all laboratory and radiological imaging studies) but excluded 24-hour electrocardiographic monitoring, treadmill exercise testing, and endoscopic procedures.[86] The specific CDSS evaluated was not reported, but as the primary care practice was associated with the Wishard Memorial Hospital, it can be postulated to be part of the 'home-grown/in-house' OCS and CDSS developed specifically for use at this site. Physicians in both the intervention and control groups entered all their orders for tests through a computer workstation. The CDSS intervention in the trial consisted of the display of the charge the patient (or the insurer) would pay for the current test when ordered and the total charges for all tests ordered for that patient on that day. Additional fees (e.g. for the interpretation of test results) were not included.

The two simultaneously conducted RCTs by Bates and colleagues[101] were undertaken on all medical and surgical inpatients at Brigham and Women's Hospital, Boston, MA, USA. The trials consisted of an assessment of the impact of the display of test charges on laboratory and radiological imaging test orders (length of trial follow-up 4 and 7 months respectively). The patient was the unit of randomisation in the trials, with 7090 patients included in the laboratory trial, and 17,381 in the radiology trial. Therefore physicians could treat both intervention and control group patients, therefore contamination was a risk thereby potentially reducing the effect size of any potential benefits of the CDSS. The trials were conducted between February and October 1994. The trials

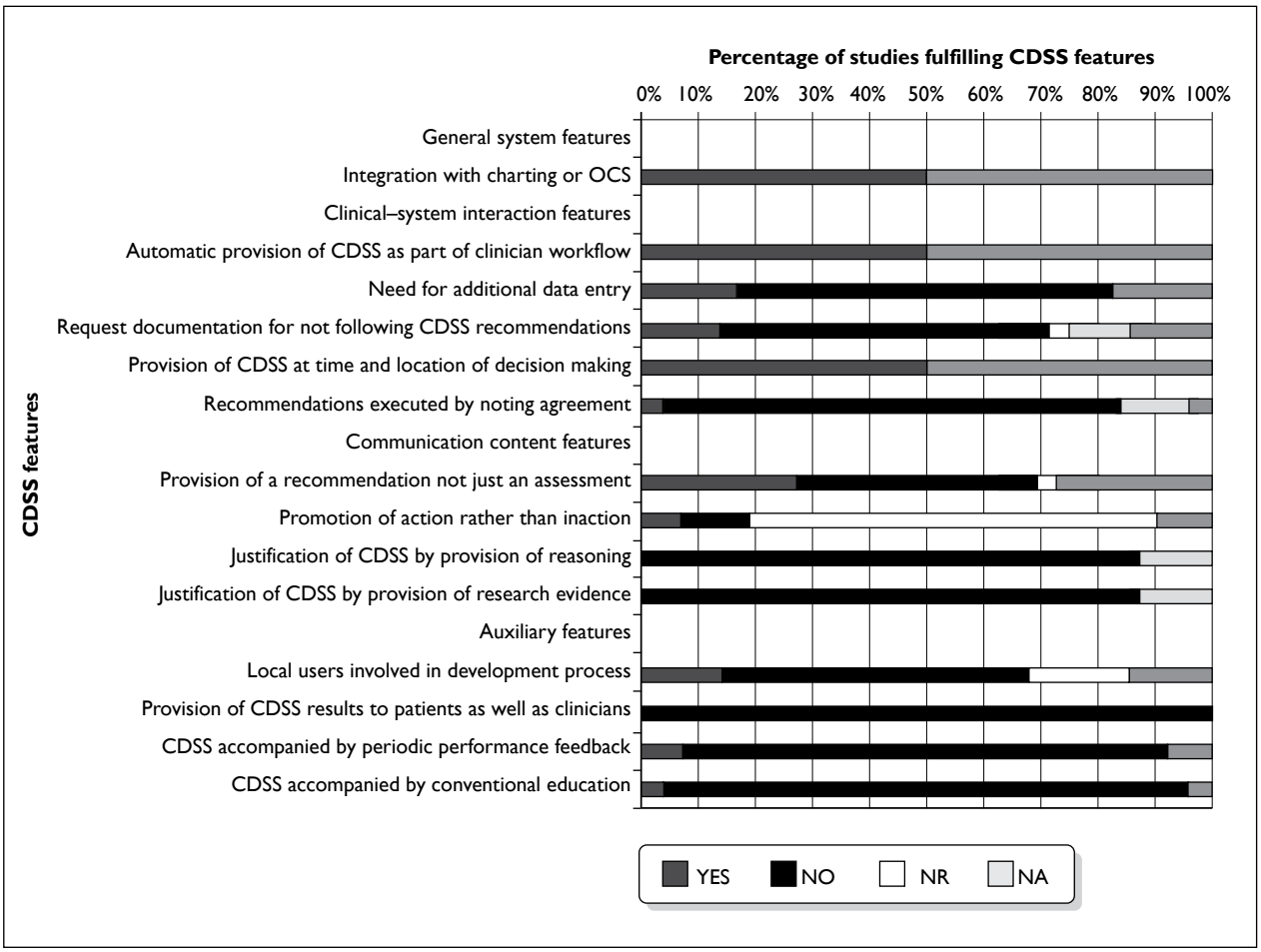

FIGURE 5 *Overview of the CDSS characteristics of the included studies. NA, not applicable; NR, not reported.*

included all laboratory test orders and the 35 most frequently ordered imaging tests. Charges for the remainder of the radiological tests were not displayed. Physicians could enter test orders for patients though the OCS, with individual and total test charges for each patient order displayed to physicians in the intervention group. Alternatively during the trial periods, specimens could be obtained and sent directly to the laboratory. Therefore the number of tests ordered during the trials was less than the number performed. For the laboratory and radiological trials respectively only 53% and 74% of tests performed had a corresponding computer order. Again, the specific CDSS assessed was not reported, but would appear to be part of the home-grown/in-house OCS and CDSS developed by Brigham and Women's Hospital. A summary of the study characteristics from the trials is displayed in *Table 6*.

Outcomes

Process outcomes

The areas of impact in the test ordering process assessed in all three trials were test volume and costs.[86,101] These included the number of tests ordered per visit/admission,[86,101] charges for tests per visit/admission,[86,101] and total hospital charges per admission.[101]

Adverse effects of test cancellation

All three trials assessed and reported the impact of the display of test charges on the subsequent decision by the physician on the basis of the display of test costs to order or cancel the indicated test(s) and the potential associated adverse effects. [86,101] Tierney and colleagues[86] assessed patients' use of other resources and their health outcomes through assessing the number of hospitalisations, visits to the accident and emergency department, and outpatient visits during both the trial intervention period, and a 26-week post-intervention follow-up. Bates and colleagues[101] assessed the length of patients hospital stay in both the laboratory and radiology trials.

Study quality

The methods of randomisation and whether allocation concealment was attained was not reported in any of the three trials.[86,101] Trial eligibility criteria were adequately specified and sufficient details of physician/patient baseline characteristics were reported. In all three trials baseline characteristics were balanced between treatment groups, indicating that the method of randomisation, while not specified, was probably appropriate. Blinding of physicians as in all trials of CDSS plus OCS to treatment allocation was not possible, and it was unclear whether outcome assessors were blinded. Moreover, as the unit of randomisation was the patient in the two trials by Bates and colleagues[101] contamination bias may be present. This could potentially lead to an underestimation of the impact of the CDSS. Data analyses to account for clustering by physician in the trial by Tierney and colleagues[86] was adequate and appropriate. Data analyses were only conducted on an 'intention to provide or communicate information' basis in the two trials by Bates and colleagues.[101] However, the rate of attrition (3.2%) was low in the trial by Tierney and colleagues[86] and therefore failure to conduct the analysis on an 'intention to provide or communicate information' basis is unlikely to impact significantly on the results attained.

CDSS characteristics

A summary of the key characteristics, including the 14 features of CDSS proposed by Kawamoto and colleagues[16] as predictors of system success or failure are displayed in *Table 7*. The specific CDSS, as stated in Quantity and quality of the studies was not reported in any of the trials, but in the trial by Tierney and colleagues[86] would appear to be the home-grown/in-house OCS and CDSS developed by the Wishard Memorial Hospital, Indianapolis, IN, USA. In the two trials by Bates and colleagues[101] the CDSS again appears to be a home-grown/in-house system, this time developed specifically by Brigham and Women's Hospital, Boston, MA, USA for use at this site.

The CDSS reasoning methods were not reported in any of the three trials.[86,101] Both systems used laboratory and radiological test costs as the system information source, and the display of test costs as the output format.[86,101] The time to complete the CDSS was only reported in the trial by Tierney and colleagues[86] with physicians in the intervention group taking an average of 11.5 seconds for test ordering, compared with 10 seconds taken by physicians in the control group. None of the trials describe any form of user training prior to implementation of the CDSS.[86,101]

In relation to the 14 features of CDSS proposed by Kawamoto and colleagues[16] the CDSS in all three trials was integrated as part of the OCS, did not require additional data entry by the physician, and provided output automatically as part of

TABLE 6 *Study characteristics of studies assessing display of test charges*

Study ID	Setting/ country	Study design	Number of sites	Intervention (I)/Comparison (C)	Study description	Area of impact	Outcomes	
							Process outcomes	Adverse effects of test cancellation
Tierney (1990)[86]	Outpatient physicians, Wishard Memorial Hospital, USA	CRCT	1	(I) OCS + CDSS: test charges displayed (C) OCS alone	Physicians (n = 121) were randomly allocated into intervention and control groups. Trial conducted over a 26-week period with 8392 patients with n = 4254 intervention group and n = 4138 control group	Test volume and costs	Number of tests ordered per visit Charges for tests ordered per visit (US$) Number of tests (scheduled visit) Number of tests (unscheduled visit) Charges for tests ordered (scheduled visit) (US$) Charges for tests ordered (unscheduled visit) (US$) Number of tests ordered per visit (post-intervention period) Charges for tests ordered per visit (post-intervention period) (US$)	Number of hospitalisations Number of A&E visits Number of outpatient visits
Bates (1997)[101]	Medical and surgical inpatients, Brigham and Women's Hospital, USA	2 RCTs	1	(I) OCS + CDSS: laboratory and radiology test charges displayed (C) OCS alone	Two RCTs including laboratory and radiological imaging tests. Patients n = 7090 laboratory tests (n = 3536 intervention group and n = 3553 control group) and n = 17,381 imaging tests (n = 8728 intervention group and n = 8653 control group) randomised to intervention and control groups. Trials conducted over 4 and 7 months	Test volume and costs	Number of tests ordered per admission Number of tests performed per admission Charges for tests ordered per admission (US$) Charges for tests performed per admission (US$) Total hospital charges (US$)	Length of patient stay (days)

TABLE 7 *Summary of the CDSS characteristics in studies assessing the impact of the display of test charges*

Study ID	Tierney (1990)[86]	Bates (1997)[101]
CDSS characteristics		
1. Name of CDSS (if any)	NR	NR
2. CDSS reasoning methods	NR	NR
3. CDSS knowledge base	Test costs	Test costs
4. Information used in CDSS	Costs of biochemical and radiology tests	Costs of biochemical and radiology tests
5. Time to complete CDSS (minutes)	11.5 seconds compared with 10 seconds in control group	NR
6. CDSS output format	Display of test costs	Display of test costs
7. Is a description of pilot testing with users prior to implementation provided?	Yes	No
8. Is user instructional training at the time of implementation described?	No	No
General system features		
9. Is the CDSS integrated with charting or OCS to support workflow integration?[a]	Yes	Yes
Clinician–system interaction features		
10. Is automatic provision of CDSS output provided as part of clinician workflow?[a]	Yes	Yes
11. Is there a need for additional data entry by the clinician other then the specification of which test orders?[a]	No	No
12. Does the CDSS request documentation of the reason for not following CDSS recommendations?[a]	NA	NA
13. Does CDSS provide output at the time and location of decision making?[a]	Yes	Yes
14. Are the CDSS recommendations executed by the clinician noting agreement?[a]	NA	NA
Communication content features		
15. Does the CDSS provide a recommendation rather than just an assessment?[a]	No	No
16. Does the CDSS promote action rather than inaction?[a]	NR	NR
17. Does the CDSS justify the output of provision of reasoning?[a]	NA	NA
18. Does the CDSS justify the output by provision of research evidence?[a]	NA	NA
Auxiliary features		
19. Were the local users involved in the CDSS development process?[a]	No	NR
20. Is the CDSS output provided to patients as well as clinicians?[a]	No	No
21. Does the CDSS provide periodic summaries of performance feedback?[a]	No	No
22. Is the CDSS used in conjunction with conventional education?[a]	No	No

NA, not applicable; NR, not reported.
a Features of CDSS proposed by Kawamoto and colleagues (2005) as predictors of system success or failure.[16]

the consultation workflow.[86,101] No reasons were required to be documented by the system for not following CDSS recommendations, as only test and total test charges were displayed, and therefore no specific recommendations to order or cancel specific tests were provided by the system. Again, as only test charges were displayed rather than specific recommendations, there was no need for these to be justified by recourse to either the system reasoning methods or the provision of research evidence supporting the recommendations.

It was unclear whether local system users were directly involved in the CDSS development. The data provided by the CDSS was used by the physician alone, and did not appear to provide period summaries of performance feedback. In all three trials the CDSS output information appeared to be used alone, and was not combined in conjunction with educational information regarding the charges for specific tests, and the indications for test ordering.[86,101]

Results

Process outcomes

In the CRCT by Tierney and colleagues[86] during the 14-week pre-intervention period there were no significant differences between the intervention and control groups in the number of tests ordered per visit [intervention group: 1.8 (SD: 0.9); control group: 1.7 (SD: 0.8)], or the total charges for tests per visit [intervention group: US$54.7 (SD: 28); control group: US$54.8 (SD: 22)]. During the 26-week trial intervention period, significantly fewer tests (–14%) were ordered per patient visit by intervention group physicians compared to those in the control group [intervention group: 1.6 (SD: 0.7) tests per patient; control group: 1.8 (SD: 0.9); % difference: –14; $p < 0.005$]. Correspondingly patient test charges were –13% (US$6.7), significantly lower in the intervention group relative to those in the control group [intervention group: US$45.1 (SD: 22.0); control group: US$51.8 (SD: 22.0); % difference: –13; $p < 0.05$].

Analyses of data by physician status [residents ($n = 99$); faculty ($n = 22$)] indicated that residents in the intervention group ordered 15.0% fewer tests than the residents in the control group [intervention group: 1.6 (SD: 0.7); control group: 1.9 (SD: 0.9); % difference: –15.0; $p < 0.005$], resulting in a 13.0% (US$7.1 per visit) reduction in test charges [intervention group: US$45.9 (SD: 22.0); control group: US$53.0 (SD: 22.2); % difference: –13.0; $p < 0.05$]. However, while faculty members in the intervention group ordered 7.9% fewer tests than those in the control group [intervention group: 1.4 (SD: 0.60); control group: 1.50 (SD: 0.70); % difference: –8.0; $p > 0.05$] this was not significantly different between the groups. Corresponding test charges per visit, while lower (–11.0%) in the intervention group [$41.8 (SD: 23.0)] were also not significantly different from those in the control group [US$47.1 (SD: 21.3); $p > 0.05$]. Differences in the size of the reduction in the number of tests ordered between resident and faculty physicians may reflect differences between the two physician groups in baseline test ordering rates, where it was observed in the pre-intervention period that facility physicians ordered 17% less tests [intervention group: 1.5 (SD: 0.6); control group: 1.5 (SD: 0.7)] than residents [intervention group: 1.9 (SD: 1.0); control group: 1.8 (SD: 0.80)]. Therefore it can be posited that the incremental effect of displaying test charges on test ordering rates may be smaller when test ordering rates are lower, or that the display of test charges lowers residents test ordering rates bringing closer to those observed by faculty members.

Further separate analyses of scheduled visits (return appointments and appointments for new patients) which constituted 80% of appointments during the intervention phase, versus unscheduled visits, indicated that physicians in the intervention group ordered 16.8% fewer tests than those in the control group during scheduled visits [intervention group: 1.6 (SD: 0.8); control group: 1.9 (SD: 0.9); % difference: –17; $p < 0.01$]. This equated to a significant 15.3% reduction (US$8.2) in test charges per visit [intervention group: US$45.3 (SD: 22.8); control group: US$53.4 (SD: 23.0); % difference: –15.3; $p < 0.01$]. Likewise, for unscheduled visits, physicians in the intervention group ordered significantly (–11.4%) fewer tests [1.2 (SD: 0.7)] compared to the control group, [1.3 (SD: 0.9)] which resulted in a significant [–9.7% (US$3.8)] reduction in charges per visit [intervention group: US$35.6 (SD: 21.3); control group: US$39.9 (SD: 25.1); % difference: –9.7; $p < 0.05$]. Differences in test ordering rates between scheduled and unscheduled visits may reflect the fact that for scheduled visits physicians' habits and practice patterns may be the main factors in decision to order tests, whereas for unscheduled visits, patients' symptoms and clinical condition may dominate decisions about testing.

Post-intervention follow-up

Further data on 74 physicians ($n = 39$ intervention group; $n = 35$ control group) who remained in

the practice during the 19-week post-intervention period were collected in order to assess any lasting effects of the intervention. During the pre-intervention period, there were no statistically significant differences in test ordering rates between the physicians in the intervention group who remained in the practice and control [1.8 (SD: 0.9) vs 1.8 (SD: 0.9)] tests per visit respectively. However, during the intervention period, physicians in the intervention group ordered 17.6% fewer tests than the control group [intervention group: 1.6 (SD: 0.7) vs control group: 1.9 (SD: 1.0); % change: –17.6%; $p < 0.05$]; resulting in a significantly [14.7% (US$7.9)] lower charges per visit [intervention group: US$45.8 (SD: 22.1) vs control group: US$53.7 (SD: 24.8); $p = 0.08$]. During the post-intervention period, physicians in the intervention group ordered only 7.7% fewer tests [1.7 (SD: 0.8) vs 1.8 (SD: 0.9); $p > 0.05$] per visit. The lasting effect on charges was even weaker. Charges for tests ordered by physicians in the intervention group was only 3.5% (US$1.8 per visit) lower than test charges ordered by control group physicians [US$48.3 (SD: 22.6) vs US$50.0 (SD: 21.7) respectively; $p > 0.05$]. This indicates that there was little evidence of any learning effect from the intervention of the display of test charges during the intervention period.

Adverse effects of test cancellation

To assess whether any potential cost savings resulting from the intervention were potentially offset by increases in patients' use of other resources or worse outcomes, the number of hospitalisations, emergency room visits, and visits to the General Medicine Practice and all other outpatient clinics were recorded for all patients who attended the practice during the intervention phase, and follow-up throughout the 26-week post-intervention period. There were no significant differences in the number of hospitalisations between patients in the intervention and control groups [0.2 (SD: 0.6) vs 0.2 (SD: 0.6)], emergency room visits [1.0 (SD: 1.7) vs 1.00 (SD: 1.7)] or outpatient visits [4.3 (SD: 3.4) vs 4.3 (SD: 3.4)] respectively.

In both the laboratory and radiological imaging test order trials conducted by Bates and colleagues[101] patients groups were well balanced with respect to age, gender, race, insurer, hospital service at admission and diagnostic-related group (DRG) at baseline. In the laboratory test order trial, during the 4-month intervention period, there were no significant differences between intervention and control groups for the mean number of tests ordered per admission [intervention group: 25.6 (SD: 38.0); control group: 26.8 (SD: 43.4); % differences: –4.5; $p = 0.074$]. Correspondingly there were also no significant differences in charges for tests ordered per admission between the two groups [intervention group: US$739 (SD: 1129); control group: US$771 (SD: 1310); % difference: –4.2; $p = 0.97$]. The mean values for the number of tests performed as opposed to ordered and their associated costs per admission, while higher in both groups than the number of tests performed, were not significantly different between groups, with the mean number of tests performed being –5.4% lower in the intervention group [intervention: 46.9 (SD: 79.2); control group: 49.6 (SD: 94.4); % change: –5.4%; $p = 0.87$]; and the costs being –4.9% lower in this group [intervention group: US$1423 (SD: 2730); control group: US$1496 (SD: 3147); % change: –4.9%; $p = 0.89$]. This translated into a US$73 reduction in the costs for tests performed per admission between the intervention and control groups. Multiple linear regression analyses that adjusted for age, gender, race, admission service, and DRG weight also showed no significant differences for the number of laboratory tests that were ordered and performed per admission [intervention group: 25.7 (SD: 0.6); control group: 26.6 (SD: 0.6); % change: –3.4%; and intervention group: 47.4 (SD:1.1); control group: 49.1 (SD: 1.1); % change: –3.3%, for the number of tests ordered and performed respectively]. Charges for tests ordered and performed in the analyses were correspondingly not significantly different between groups [intervention group: US$743 (SD: 17); control group: US$766 (SD: 17); % difference: –3.0 and intervention group: US$1440 (SD: 37); control group: 1478 (SD: 38); % change: –2.6% respectively].

For the radiological imaging test trial, during the 7-month intervention period the differences between the intervention and control groups were smaller than for the clinical laboratory test trial. The number of tests ordered and performed per admission were nearly identical between groups {[intervention group: 1.8 (SD: 4.4); control group: 1.8 (SD: 4.7); % change: 0; $p = 0.13$] and [intervention group: 1.5 (SD: 3.6); control group: 1.5 (SD: 4.1); % change: 0; $p = 0.10$ respectively]}. Correspondingly, there were only minor insignificant changes in both the costs for tests ordered and those performed. The costs for tests ordered per admission only decreased by –0.4% [intervention group: US$275 (SD: 688); control group: US$276 (SD: 737); % change: –0.4; $p = 0.10$], whilst those for tests performed increased by 2.3% [intervention group: US$220 (SD: 473); control group: US$215 (SD: 515); % change:

+2.3%; $p = 0.03$]. Multiple linear regression analyses again adjusting for age, gender, race, admission service, and DRG weight also showed no significant differences for the number of tests ordered [intervention group: 1.9 (SD: 0.04); control group: 1.9 (SD: 0.04); % change: +0.5] and tests performed [intervention group: 1.6 (SD: 0.03); control group: 1.6 (SD: 0.03): % change: +0.6]. Again, due to insignificant differences between the groups in the number of tests ordered and performed, there were no significant differences between groups for the costs of tests ordered [intervention group: US$296 (SD: 7.0); control group: US$296 (SD: 7.1); % change: 0] or performed [intervention group: US$234 (SD: 4.7); control group: US$228 (SD: 4.8);% change: +2.6].

Adverse effects of test cancellation

Comparison of the total length of hospital stay between groups in both the laboratory and radiological imaging test trials showed no significant differences between groups in either of the trials. The median length of stay in both groups in the laboratory trial was 4 days (range: 2–7), and in the radiology trial was 3 days in both groups (range: 2–7 and 2–6) for the intervention and control groups respectively.

Summary of studies assessing the impact of the display of test charges

Process outcomes

Three trials, including a total of 32,863 patients assessed the impact of the display of test charges on the number of tests ordered. In both studies the aim was to reduce the number of tests ordered and their associated charges. Both studies were conducted in the USA, with one conducted in outpatients at a general medicine practice,[86] and the other two conducted on medical and surgical inpatients.[101] The duration of follow-up across the trials ranged from 4 to 14 months (including the post-intervention follow-up undertaken in the CRCT by Tierney and colleagues).[86] Two of the trials focused predominantly on the effects of the display of test charges on laboratory test orders,[86,101] while the other focused on radiological imaging test orders.[101] Results across the three trials were equivocal. The trial by Tierney and colleagues[86] conducted in outpatients found a significant decrease (–14.3%) in the number of tests ordered per patient visit in the intervention group [1.6 (SD: 0.7)] compared to the control group [1.8 (SD: 0.9)]. Corresponding patient test charges were also significantly lower in the intervention group [US$45.1 (SD: 22.0)] compared to the control group [(US$51.8 (SD: 22.0)]. However, the reduction in the number of tests ordered and the subsequent charges to patients, appeared to be driven more by the reduction in the number of tests ordered by residents physicians as opposed to faculty physicians, for whom it was observed that baseline test ordering rates were lower. It would therefore appear that the display of test costs may be differentially effective in reducing the number of test orders and their corresponding costs according to baseline ordering rates. Furthermore, additional post-intervention follow-up indicated that the effect of displaying test charges may be relatively transient, as there were no significant differences between intervention and control physicians in the number of tests ordered in this period.

Contrary to the results of the CRCT by Tierney and colleagues,[86] Bates and colleagues[101] found no significant impact of the display of test costs on either the number of laboratory or radiological imaging tests ordered between intervention and control groups per patient admission. Correspondingly there were no significant differences in either of the trials in test costs between the intervention and control groups. A summary of the results of the process outcomes for the three trials is displayed in *Table 8*.

Adverse effects of test cancellation

In all three trials there were no significant differences in the patient outcomes of number of hospitalisations, emergency room visits, visits to the General Medicine Practice or other outpatient clinics,[85] or length of hospital stay.[101] Therefore it would appear that any potential cost savings achieved in the trials resulting from a reduction in the number of tests performed were not offset by increases in patient's use or other resources of worse outcomes. A summary of the results of patient outcomes for the trials is displayed in *Table 9*.

Studies assessing the impact of display of previous test results

Quantity and quality of the studies

Two studies, one CCT and one UPP study assessed the impact of the display of previous test results on subsequent test order volumes.[88,89]

TABLE 8 *Summary of process outcomes for studies assessing the impact of the display of test charges*

Study ID	**Tierney (1990)[86]**		**Bates (1997) (laboratory test trial)[101]**		**Bates (1997) (radiological imaging trial)[101]**	
Study design	CRCT		RCT		RCT	
Intervention	OCS alone	OCS + CDSS	OCS alone	OCS + CDSS	OCS alone	OCS + CDSS
N	59	62	3554	3536	8653	8728
Process outcomes						
Number of tests ordered per visit/ admission	1.8 ± 0.9	1.6 ± 0.7	26.8 ± 43.4	25.6 ± 37.9	1.76 ± 4.68	1.76 ± 4.43
% difference between groups	–14		–4.5		0	
p-value for difference between groups	$p < 0.005$		$p = 0.074$		$p = 0.13$	
Charges for tests ordered per visit/ admission (US$)	51.8 ± 22.0	45.1 ± 22.0	771 ± 1310	739 ± 1129	276 ± 737	275 ± 688
% difference between groups	–13		–4.2		–0.4	
p-value for difference between groups	$p < 0.05$		$p = 0.97$		$p = 0.1$	
Number of tests (scheduled visit)	1.9 ± 0.9	1.6 ± 0.8				
% difference between groups	–16.8					
p-value for difference between groups	$p < 0.01$					
Charges for test ordered (scheduled visit) (US$)	53.4 ± 23	45.3 ± 22.8				
% difference between groups	–15.3					
p-value for difference between groups	$p < 0.01$					
Number of tests (unscheduled visit)	1.3 ± 0.9	1.2 ± 0.7				
% difference between groups	–11.4					
p-value for difference between groups	$p < 0.05$					
Charges for test ordered (unscheduled visit) (US$)	39.4 ± 25.1	35.6 ± 21.3				
% difference between groups	–9.7					
p-value for difference between groups	$p < 0.05$					
N	35	39				
Number of tests ordered per visit (post-intervention period)	1.8 ± 0.9	1.7 ± 0.8				

continued

TABLE 8 *Summary of process outcomes for studies assessing the impact of the display of test charges (continued)*

Study ID	Tierney (1990)[86]		Bates (1997) (laboratory test trial)[101]		Bates (1997) (radiological imaging trial)[101]	
% difference between groups	–7.7					
p-value for difference between groups	$p > 0.05$					
Charges for tests ordered per visit (post-intervention period) (US$)	50.0 ± 21.7	48.3 ± 22.6				
% difference between groups	–3.5					
p-value for difference between groups	$p > 0.05$					
Number of tests performed per admission			49.6 ± 94.4	46.9 ± 79.2	1.53 ± 4.1	1.5 ± 3.6
% difference between groups			–5.4		0	
p-value for difference between groups			$p = 0.87$		$p = 0.10$	
Charges for test ordered per admission (US$)			1496 ± 3147	1423± 2730	215 ± 515	220 ± 473
% difference between groups			–4.9		+2.3	
p-value for difference between groups			$p = 0.89$		$p = 0.03$	

a Reported as the mean (SD).

The CCT conducted by Solomon and colleagues[88] was carried out at the Brigham and Women's Hospital, Boston, MA, USA, and was focused on reducing unnecessary serological testing in the diagnosis of suspected systemic rheumatic disease.[88] The trial was conducted over a 10-month period, with the intervention and control groups formed according to the indication for test(s) ordered. All physicians ordering a rheumatoid factor (RF) or antinuclear antibody (ANA) test for the suspected indications of rheumatoid arthritis, systemic lupus erythematosus, primary systemic sclerosis, mixed connective tissue disease, or Sjögren's syndrome were assigned to the intervention group. All test orders for RF or ANA for the suspected indications of systemic vasculitis and cryoglobulinemia, or a complement test for any condition during the study period were assigned to the control group. Therefore, during the trial physicians were exposed to both the intervention and control conditions. Tests were selected as target tests for the trial on the basis that estimates of the test's sensitivity and specificity for each of the suspected indications existed in the literature. The CDSS intervention required physicians to state their estimate of the pre-test probability of disease in the patient. The CDSS then calculated the post-test positive and negative predictive values, based on the physician's estimated pre-test probability. These calculations were based on sensitivity and specificity values abstracted from relevant literature.[106–112] During the 10-month trial 71 physicians wrote test orders for 99 patients in the intervention group, while 154 physicians wrote orders for 236 patients in the control group. The two groups were well balanced in terms of both physician (age, gender, postgraduate year, department) and patient (age, gender, length of hospital stay, total hospital charges) baseline characteristics.

The UPP study conducted by Bansal and colleagues[89] aimed to assess the impact of a computer-based intervention on ABG usage in an ICU setting. The study was conducted at

TABLE 9 *Summary of adverse effects of test cancellation for studies assessing the impact of the display of test charges*

Study ID	Tierney (1990)[86]		Bates (1997) (laboratory test trial)[101]		Bates (1997) (radiological imaging trial)[101]	
Intervention	OCS alone	OCS + CDSS	OCS alone	OCS + CDSS	OCS alone	OCS + CDSS
N	5962	62	3554	3536	8653	8728
Patient outcomes[a]						
Number of hospitalisations/ patient	0.2 ± 0.6	0.2 ± 0.6				
p-value for difference between groups	$p > 0.05$					
Number of emergency room visits/patient	1.0 ± 1.7	1.0 ± 1.7				
p-value for difference between groups	$p > 0.05$					
Number of outpatient visits/ patient	4.3 ± 3.4	4.3 ± 3.4				
p-value for difference between groups	$p > 0.05$					
Length of hospital stay (days)[b]			4 (2.7)	4 (2.7)	3 (2–6)	3 (2–7)
p-value for difference between groups			$p > 0.05$		$p > 0.05$	

a Reported as the mean (SD).
b Reported as median (range).

Vanderbilt University Medical Centre, Nashville, TN, USA, and included six conditions managed in ICU (trauma, general surgery, medical, cardiac, burn and neurology). The study was conducted over a 12-week period, consisting of a 5-week pre-intervention and a 7-week intervention period. There were no restrictions on the ordering of ABG tests during the pre-intervention period (OCS alone).

During the intervention the CDSS provided the user with a graphical display of the patient's previous ABG values; pO_2 pCO_2, HCO_3, O_2 saturation, pH, and FiO_2. All values, except O_2 saturations, reflected previous ABGs performed during the patient's current hospitalisation. In addition cointervention educational text was provided alongside the graphical display of results and test ordering was limited to within 24 hours so no multi-day orders were allowed. The default (pre-populated) response was to cancel the order. However, the final decision to test or not was left to the user's discretion. *Table 10* displays a summary of the key characteristics of both studies.

Outcomes

Process outcomes

The area of impact in the test ordering process assessed in both studies was test volumes, although only limited outcomes were reported in both studies.[88,89] Solomon and colleagues[88] assessed the number of cancelled test orders, and the number of positive tests for known rheumatic disease, while Bansal and colleagues[89] examined the number of ABG test orders both pre- and post-intervention.

Adverse effects of test cancellation

Neither of the studies assessed any potential adverse effects of test cancellation.[88,89]

Study quality

In both studies adequate eligibility criteria were specified, and detailed baseline characteristics were provided in the study by Solomon and colleagues[88] that indicated the two study groups were well balanced at baseline in terms of both physician and patient characteristics. However, only details on the CDSS users were reported by Bansal and colleagues[89] with no details on patient characteristics provided. It is therefore unclear

TABLE 10 *Study characteristics of studies assessing display of previous test results*

Study ID	Setting /country	Study design	Number of sites	Intervention (I)/ Comparison (C)	Study description	Area of impact	Outcomes	
							Process outcomes	Adverse effects of test cancellation
Solomon (1999)[88]	Inpatients, Brigham and Women's Hospital, Boston, MA, USA	CCT	1	(I) OCS + CDSS: CDSS required physicians to enter their estimate of the pre-test probability of disease and the sensitivity and specificity of the test ordered. CDSS then calculated +ve and –ve predictive values based on the values for test sensitivity and specificity derived from a literature review. (C) OCS alone (no +ve and –ve predicative values displayed)	Trial conducted over a 10-month period. Study intervention and control groups were formed according to the type of test ordered. Intervention tests included all RF or ANA tests for the suspected indications of rheumatoid arthritis, systemic lupus erythematosus, primary systemic sclerosis, mixed connective tissue disease, or Sjögren's syndrome. Control tests included RF or ANA for systemic vasculitis and cryoglobulinemia, or a complements level for any condition. Over the 10-month trial 71 physicians wrote test orders for 99 patients in the intervention group and 154 physicians wrote orders for 236 patients in the control group	Test volume	Number of tests cancelled Number of positive tests for known rheumatic disease	NR
Bansal (2001)[89]	Inpatients, Vanderbilt University Hospital, Nashville, TN, USA	UPP	1 (6 ICUs)	(I) OCS + CDSS: Baseline: OCS alone (no previous test results or limits on forward ordering) (I) OCS + CDSS: graphical display of patients previous ABG results; educational text and tests ordering limited to within 24-hours	Study consisted of 12 weeks; 5 weeks pre-intervention and 7 weeks intervention period. Intervention implemented on 6 ICUs. Number of ABG test requested per week compared in pre- and intervention periods	Test volume	Number of ABG test orders pre- and post-intervention	NR

NR, not reported.

whether differences in patient characteristics between the pre- and post-intervention periods may have potentially confounded study results.

In the study by Solomon and colleagues[88] physicians were exposed to both the intervention and control conditions. This has the potential to impact on the study results through contamination, with learning through exposure to the intervention condition impacting on test ordering behaviour in the control condition. The impact of this, if any, would potentially be to underestimate the impact of the CDSS intervention.

In both studies the tests used to conduct the statistical analyses were appropriate, and greater than 80% of physicians/patients were included in the follow-up assessment. However, it is unclear in the study by Bansal and colleagues[89] whether analyses were conducted on an 'intention to provide or communicate information' basis. In both studies there were therefore a number of factors that may have biased the results and the results should be interpreted in light of these.

CDSS characteristics

The specific CDSS evaluated were the home-grown/in-house OCS and CDSS developed by Brigham and Women's Hospital, Boston, MA, USA, and Vanderbilt University Hospital, Nashville, TN, USA, in the studies by Solomon and colleagues[88] and Bansal and colleagues[89] respectively. The CDSS in the study by Solomon and colleagues[88] used naive Bayesian methods of reasoning, with the physician's pre-test probability of disease as the system input information. The CDSS output format were post-test positive and negative predictive values based on values for each specific indication for test sensitivity and specificity derived from a review of the literature. The CDSS reasoning methods were not reported by Bansal and colleagues,[89] but the system input information included six previous test ABG input parameters (ABG values; pO_2 pCO_2, HCO_3, O_2 saturation, pH, and FiO_2); the results of these were presented to the system user as a graphical display.

Neither of the studies reported the time needed to use the CDSS, or pilot testing with users prior to implementation, but instructional training was provided to users in the study by Solomon and colleagues.[88] In both of the studies the CDSS was integrated with OCS, and CDSS output was provided as part of the physician workflow, providing output at the time and location of decision making. The study by Solomon and colleagues[88] required the input of additional information by the physician in the form of a pre-test probability of disease. Neither of the studies required a reason to be documented for not following the CDSS output, as only previous test results were displayed, and therefore no specific recommendations to order or cancel specific tests were provided by the system. It was unclear in both studies whether the display of previous test results were likely to promote action rather than inaction on the part of the physician.[88,89] Additionally, it would appear that local system users were not directly involved in the CDSS development process of either system. The data provided by the CDSS was used by the physician alone, and did not appear to provide period summaries of performance feedback.

In the study by Solomon and colleagues[88] the previous test results appeared to be used alone, while in the study by Bansal and colleagues[89] they were combined with educational text regarding the interpretation of previous ABG results, and limitations on further test ordering within the consecutive 24-hour period. A summary of the key CDSS characteristics for each study is displayed in *Table 11*.

Results

Process outcomes

In the CCT by Solomon and colleagues[88] during the 10-month trial period significantly more test orders [11 out of 99 tests (11%)] were cancelled compared to those in the control group [1 out of 236 (0.4%); $p = 0.001$]. There were no associations between the physicians' pre-test probability estimates and whether the test was cancelled ($p = 0.59$). Additionally, only 43 of the 335 test orders (13%) yielded positive results, but from these only four patients (1%) were given new diagnoses of rheumatic disease.

Results from the UPP study by Bansal and colleagues[89] showed no significant differences in the number of ABG test orders placed pre- and post-intervention (376 and 387 respectively; $p = 0.09$).

Summary of studies assessing the impact of the display of previous test results

Only two studies, one CCT and one UPP study, assessed the impact of the display of previous test results on subsequent test ordering.[88,89] Both studies reported only very limited results, and were focused upon specific test types, namely RF and ANA,[88] and ABG.[89] It is therefore difficult to know the extent

TABLE 11 *Summary of the CDSS characteristics in studies assessing the impact of the display of previous test results*

Study ID	Solomon (1999)[88]	Bansal (2001)[89]
CDSS characteristics		
1. Name of CDSS (if any)	NR[b]	NR[c]
2. CDSS reasoning methods	NBM	NR
3. CDSS knowledge base	Sensitivity and specificity values abstracted from the literature	NR
4. Information used in CDSS	Pre-test probability estimates	6 previous ABG results (pO_2, pCO_2, HCO_3, pH, FiO_2, O_2 saturations
5. Time to complete CDSS (minutes)	NR	NR
6. CDSS output format	Post test +ve and -ve predictive values	Graphical display of previous test results
7. Is a description of pilot testing with users prior to implementation provided?	No	No
8. Is user instructional training at the time of implementation described?	Yes	No
General system features		
9. Is the CDSS integrated with charting or OCS to support workflow integration?[a]	Yes	Yes
Clinician–system interaction features		
10. Is automatic provision of CDSS output provided as part of clinician workflow?[a]	Yes	Yes
11. Is there a need for additional data entry by the clinician other then the specification of which test orders?[a]	Yes	No
12. Does the CDSS request documentation of the reason for not following CDSS recommendations?[a]	No	No
13. Does CDSS provide output at the time and location of decision making?[a]	Yes	Yes
14. Are the CDSS recommendations executed by the clinician noting agreement?[a]	No	Yes
Communication content features		
15. Does the CDSS provide a recommendation rather than just an assessment?[a]	No	No
16. Does the CDSS promote action rather than inaction?[a]	No	No
17. Does the CDSS justify the output of provision of reasoning?[a]	No	No
18. Does the CDSS justify the output by provision of research evidence?[a]	No	No
Auxiliary features		
19. Were the local users involved in the CDSS development process?[a]	NR	Yes
20. Is the CDSS output provided to patients as well as clinicians?[a]	No	No
21. Does the CDSS provide periodic summaries of performance feedback?[a]	No	No
22. Is the CDSS used in conjunction with conventional education?[a]	No	No

NBM, naive Bayesian methods; NR: not reported.
a Features of CDSS proposed by Kawamoto and colleagues (2005) as predictors of system success or failure.[16]
b Home-grown system from Brigham and Women's Hospital.
c Home-grown system from Vanderbilt University Medical Centre.

to which the results from these studies could be extrapolated to a wider context in which a broader spectrum of tests were being ordered.

Results between the two studies were contradictory, with the CCT by Solomon and colleagues[88] showing a significant increase (11.1%) in the number of tests cancelled in the intervention group compared to the control group (0.42%) despite the fact that the same physicians ordered tests for both intervention and control patients. The UPP study by Bansal and colleagues, in contrast, found no significant differences in the number of ABG test orders between the pre- and post-intervention periods. A summary of the results from both studies is displayed in *Table 12*.

Studies assessing the impact of the display of reminders

Quantity and quality of the studies

The impact of the display of reminders was assessed in 10 studies:[24,29,48,57,87,90–94]

- four CRCTs, two published by Overhage and colleagues in 1996 and 1997,[24,48] one by Palen and colleagues,[90] one by Matheny and colleagues[91]
- one RCT undertaken by Bates and colleagues[92]
- one CCT by O'Connor and colleagues[57]
- one randomised crossover trial by McDonald and colleagues[29]
- one ITS study with an AB-AB-AB design by Carton and colleagues[93] and
- two UPP studies by Steele and colleagues and Abboud and colleagues.[87,94]

Across the studies, nine of the 10 were conducted in the USA,[24,29,48,57,87,90–92,94] while the remaining study was conducted in France.[93] Of those undertaken in the USA, three studies were undertaken at the Wishard Memorial Hospital, Indianapolis, IN,[24,29,48] two of which were undertaken in an inpatient setting[24,48] and one in an outpatient setting.[29] Two studies were conducted at the Brigham and Women's Hospital, and associated community and outpatient clinics,[91,92] one of which included inpatients and the other outpatients. Of the remaining four studies undertaken in the USA, three were undertaken in an outpatient setting (group-model managed care organisation, Kaiser Permanente; Health Partners Medical Group, MN; and Sam Sandos Family Health Clinic, Denver Health respectively)[57,90,94] and one was undertaken in a paediatric inpatient population at Cincinnati Children's Hospital Medical Centre, OH.[87] Of these nine studies, one assessed compliance with reminders to undertake preventative care measures,[48] seven assessed compliance with reminders to undertake appropriate laboratory testing,[24,29,57,87,90,91,94] and one examined compliance with reminders about redundant tests.[92] The focus in three of the studies, the two CRCTs by Overhage and colleagues[2,48] and the randomised crossover trial by McDonald and colleagues[29] was on both reminders to order medication, screening, and other health-care procedures. In these three studies

TABLE 12 *Summary of process outcomes for studies assessing the impact of the display of previous test results*

Study ID	**Solomon (1999)[88]**		**Bansal (2001)[89]**	
Study design	CCT		UPP	
Intervention	OCS alone	OCS + CDSS	OCS alone	OCS + CDSS
			Pre-	Post-
N	154	71	NR	NR
Process outcomes				
Number of cancelled tests (*n* %)	11 (11))	1 (0.4)		
p-value[a]	$p = 0.001$			
Number of ABG test orders (*n*)			376	387
p-value[b]			$p = 0.09$	

NR, not reported.
a Difference between groups.
b Difference in values pre- and post-intervention.

therefore only limited results were presented for laboratory test ordering alone.

The one study conducted in France, was undertaken in two accident and emergency departments, and assessed the impact of reminders to undertake the most appropriate radiological tests across all the physicians involved in the study.[93] This study therefore assessed the impact of reminders on the number of tests that complied with guideline recommendations.[93] A summary of study characteristics from the eight studies that assessed the impact of reminders is displayed in *Table 13*.

The two CRCTs conducted by Overhage and colleagues[24,48] were both conducted on six inpatient medical wards (three intervention and three control) at the Wishard Memorial Hospital, Indianapolis, IN, USA. Both of the trials therefore used the site-specific home-grown Regenstrief Medical Record System which interfaced with two CDSS that appear to have been developed specifically for the trials.[24,48] The first trial published in 1996 included 78 physicians treating 1622 patients (821 intervention group and 801 control group) on one of the six wards.

During the 6-month trial period, wards were randomised to either receive or not receive preventative care measure recommendations provided by the CDSS. Any patient who had at least one preventative care recommendation was eligible for inclusion in the intervention group. The preventative care recommendation reminders were based on 22 preventative care measures from the US Preventive Services Task Force recommendations, and included vaccination measures, prescription of prophylactic medication, as well as laboratory screening test reminders.[113] Only 10 of the 22 preventive care recommendations were related to the use of laboratory testing and therefore of relevance to the present review. Data on these 10 were therefore extracted and presented, and included: (1) cervical cytology, (2) mammography, (3) thyrotropin screen, (4) hepatitis B screen, (5) screening urinalysis, (6) cholesterol test, (7) human immunodeficiency virus (HIV) screen, (8) 24-hour urine protein test, (9) sickle cell screen, and (10) sexually transmitted disease (STD) screen.

While the trial groups were well balanced in terms of age, gender, ethnic origin, and primary discharge diagnosis, data were presented only for the overall trial groups, not just patients who received laboratory test preventative care recommendations. It should therefore be noted that there may be potential baseline imbalances within the intervention and control groups, which could bias the results for these specific outcomes from this trial.

In the second trial, published in 1997, 86 physicians were randomised (45 intervention group and 41 control group) to receive or not receive reminders to order suggested corollary tests or medications needed to detect or ameliorate adverse effects to any one of the selected 87 trial tests or treatments. Standard reference texts[114] and drug package inserts were used to identify 87 trial target orders (76 drugs and 11 tests) that were paired with one or more corollary orders. For example, aminoglycoside prescribing was paired with peak and trough aminoglycoside levels, and warfarin with prothrombin time. The CDSS then issued a reminder during the 6-month trial period to intervention physicians when any of the 87 target orders were placed, to consider ordering the linked corollary tests or medications. When suggesting corollary orders, the CDSS took into account the status of the order (a new order or a revision of an old order); the time elapsed since the last time the order being suggested was written; and whether any orders for a new equivalent item had already been written.

Physicians were free to accept or reject the suggested corollary orders. All inpatients who had at least one order written that triggered a suggested corollary order were eligible for trial inclusion, with 814 patients included in the intervention group and 872 in the control group. Again, groups were well balanced at baseline between the two groups in terms of age, gender, ethnic group, and primary diagnostic group. However, as the trial considered compliance with reminders to order both corollary medications and laboratory tests, again only the data for compliance with the ordering of laboratory tests was extracted and is presented. Therefore, as patient sociodemographic data were presented for the overall trial groups (not by type of order) then it is again possible that there were baseline differences between the intervention and control groups that may potentially confound the results for the laboratory outcomes of interest.

The CRCT by Palen and colleagues[90] like the trial by Overhage and colleagues[24] also focused upon the impact of reminders when ordering medications on compliance with guidelines for laboratory test monitoring. The trial, conducted

TABLE 13 *Study characteristics of studies assessing reminders*

Study ID	Setting/ Country	Study design	Number of sites	Intervention (I)/ Comparison (C)	Study description	Area of impact	Outcomes: Process outcomes	Outcomes: Adverse effects of test cancellation
Overhage (1996)[48,a]	Inpatient general medicine ward, Wishard Memorial Hospital, Indianapolis, IN, USA	CRCT	1 (6 independent medical services within the ward)	(I) OCS + CDSS: reminders to physicians to undertake preventative care measures (11 measures included laboratory tests) (C) OCS alone (reminders suppressed)	Services were randomly allocated to intervention and control groups (n = 78 physicians; n not reported by group). The trial was conducted over a 6-month period including 1622 patients (n = 821 intervention group; n = 801 control group)	Reminder compliance	Compliance with reminders for preventative care measures	NR
Overhage (1997)[24,b]	Inpatient general medicine ward, Wishard Memorial Hospital, Indianapolis, IN, USA	CRCT	1 (6 independent medical services within the ward)	(I) OCS + CDSS: reminders about recommended corollary test orders (C) OCS alone (reminders suppressed)	Services were randomly allocated to intervention (n = 45 physicians) or control (n = 41 physicians) groups. The trial was 6-month duration including 1686 patients (n = 814 intervention; n = 872 control)	Reminder compliance	Rate of 24-hour compliance for the 18 most common laboratory test corollary orders	NR
Palen (2006)[90]	Outpatients, group-model managed care organisation (Kaiser Permanente), USA	CRCT	16	(I) OCS + CDSS: reminders to physicians ordering medication for concomitant laboratory test orders (C) OCS alone (reminders suppressed)	Physicians were randomly allocated into intervention (n = 104) or control groups (n = 103). The trial was conducted over a 12-month period and included 26,586 patients (intervention n = 14,376; control n = 12,210) prescribed one of the 34,242 prescriptions for one or more of the 25 target prescriptions	Reminder compliance	Compliance with recommended laboratory monitoring tests Compliance with recommended tests by gender and medication type	NR

continued

TABLE 13 *Study characteristics of studies assessing reminders (continued)*

Study ID	Setting/ Country	Study design	Number of sites	Intervention (I)/ Comparison (C)	Study description	Area of impact	Outcomes	
							Process outcomes	Adverse effects of test cancellation
Matheny (2008)[91]	Partners Healthcare system (including Brigham and Women's Hospital, Massachusetts General Hospital, and a number of community hospitals and outpatient clinics)	CRCT	20	(I) OCS + CDSS: reminders to physicians to order a test (C) OCS alone (reminders suppressed)	Physicians were randomly allocated into intervention (n = 145) or control groups (n = 158). The trial was conducted over a 6-month period and included 1922 patients (intervention n = 924; control n = 998) on at least one of the 15 target study medications for whom no laboratory monitoring test had been conducted in the previous year	Reminder compliance	Number of appropriate laboratory tests ordered when overdue within 14 days	NR
Bates (1999)[92]	All inpatients Brigham and Women's Hospital, USA	RCT	1	(I) OCS + CDSS: reminders to physicians about redundant tests (C) OCS alone (reminders suppressed)	Patients were randomly allocated into intervention (n = 5700) and control groups (n = 5886). The trial was conducted over a 15-week period and included 5059 instances of the target tests (n = 2478 intervention group; n = 2581 control group)	Order appropriateness Hospital costs (estimated total annual saving)	Proportion of tests cancelled Proportion of test performed after reminder Proportion of tests performed earlier than test-specific intervals Proportion of justified overrides of reminders Charge saving associated with reminders for redundant tests	Adverse effects of test cancellation (new abnormal results for the same test performed within 3 days of cancellation)

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Study ID	Setting/ Country	Study design	Number of sites	Intervention (I)/ Comparison (C)	Study description	Area of impact	Outcomes	
							Process outcomes	Adverse effects of test cancellation
McDonald (1980)[29]	Outpatients, Wishard Memorial Hospital, Indianapolis, IN, USA	Randomised crossover trial	1	(I) OCS + CDSS: reminders to physicians to order a test (S1) (either with or without bibliographic citations supporting the reminders (S2) (C) OCS alone (reminders suppressed)	Study consisted of 15 weeks; 5 weeks control period; 5 weeks of S1 and 5 weeks of S2. 31 care providers were randomly allocated to each condition and assessed in the three treatment cross-over I	Reminder compliance	Compliance with reminders to order a test(s)	NR
O'Connor (2005)[57]	Outpatients with an established diagnosis of diabetes, HealthPartners Medical Group, MN, USA	CCT	2	(I) OCS + CDSS: prompts and reminders. Prompts were included when a patient had no HbA_{1C} test within 6 months, no urine microalbuminiuria test within 1 year, had blood pressures of ≥130/85 mm Hg, LDL levels of ≥130 mg/dL, HbA_{1C} levels of ≥8% or no aspirin use if aged 40 years or older (C) OCS alone	Frequency of tests for glycated haemoglobin and low-density lipoprotein were compared at baseline and three time points over 5-year follow-up between the intervention (*n*=57 patients) and control clinic (*n*=65 patients) which used a common diabetes care guideline	Order appropriateness (appropriate test frequency)	Number of HbA_{1C} tests Number of LDL cholesterol tests Percentage of patients having at least two HbA_{1C} tests, one LDL test, or two HbA_{1C} and one LDL test	NR
Carton (2002)[93]	Accident and emergency department physicians treating patients with an indication for radiological imaging tests, Boulogne and Rennes, France	ITS (AB-AB-AB design)	2	(I) OCS + CDSS: reminders displaying the appropriate guideline recommendations for radiological imaging tests (Baseline) OCS alone (reminders suppressed)	Study consisted of 6 months; three control periods and three intervention periods run alternately with no delay between periods. A total of 15,086 patients were seen during the study, with 6869 radiological examinations undertaken	Guideline compliance	Number of requests complying with guideline recommendations Type of requests not complying with guideline recommendations Most frequent requests not complying with guideline recommendations	NR

continued

TABLE 13 *Study characteristics of studies assessing reminders (continued)*

Study ID	Setting/ Country	Study design	Number of sites	Intervention (I)/ Comparison (C)	Study description	Area of impact	Outcomes	
							Process outcomes	Adverse effects of test cancellation
Steele (2005)[96]	Outpatient physicians, Sam Sandos Family Health Clinic, Denver Health, CO, USA	UPP	1	(I) OCS + CDSS: reminders to physicians for drug–laboratory interactions for potential drug induced hypokalemia; hyperkalemia; nephrotoxicity; thrombocytopenia or hepatotoxicity. Physicians were also alerted to rule-associated laboratory test orders	Baseline (17 weeks): No reminders were displayed to physicians. Intervention period (21 weeks): Reminders were displayed for drug-laboratory test interactions and associated laboratory test orders. A total of 19,076 patients were seen during the intervention period, with 9274 prescriptions triggering an alert. Differences between the number of laboratory test orders pre- and during the intervention period were compared	Compliance with reminders for drug–laboratory interactions	Number of rule associated laboratory tests ordered: no alert displayed Number of rule associated laboratory tests ordered: alert displayed Number of rule associated laboratory tests ordered: 'abnormal labs' message displayed Number of rule associated laboratory tests ordered: 'no labs' message displayed	NR
Abboud (2006)[87]	Paediatric inpatients, Cincinnati Children's Hospital Medical Centre, OH, USA	UPP	1	(I) OCS + CDSS: reminders about corollary order blood tests for patients receiving aminoglycosides (Baseline) OCS alone (reminders suppressed)	Study consisted of 6 months; 3 months pre-intervention and 3 months post-intervention. The number of orders for aminoglycosides during study period was 336 (159 pre- and 177 post-intervention)	Guideline compliance	Number of courses of aminoglycosides with appropriate laboratory test monitoring. Frequency of therapeutic, toxic, subtherapeutic, or toxic and subtherapeutic laboratory values during courses of therapy	NR

LDL, low-density lipid; NR, not reported.

a Results only extracted for preventative care measures which required laboratory or radiology tests, the number of patients reported at baseline refers to all patients included in the trial not just those undergoing laboratory/radiology tests.

b Results only extracted for 24-hour compliance rates for the 18 most common corollary orders involving laboratory tests, the number of patients reported at baseline refers to all patients included in the trial not just those with test orders triggering suggested corollary laboratory test orders.

at 16 primary care sites within the group model managed care organisation Kaiser Permanente, included 207 physicians (104 intervention group and 103 control group) who ordered 34,242 prescriptions for study medication for 26,586 different patients during the 12-month trial period. Physicians were randomised to receive or not receive non-intrusive drug–laboratory reminders for 25 selected medications within the OCS. This information was specific for the individual medication and presented guidelines for appropriate baseline monitoring. The 25 medications chosen were selected based on the presence of US Food and Drug Administration (FDA) black box warnings, published clinical guidelines, and the potential for adverse clinical consequences related to lack of monitoring.

The guideline recommendations for laboratory test monitoring for each medication were developed from information presented in national and internal clinical guidelines, and through discussion with physicians, pharmacists, and clinician leaders within the health-plan group. These guidelines then formed the basis for the reminders that were presented via the CDSS, which was implemented within the existing proprietary system (Clinical Information System) that was developed in collaboration with IBM (Boulder, CO).

For each of the 25 target medications, prescribing data from the 12-month trial period were analysed to assess whether appropriate laboratory tests had been completed within either 2 weeks after the medication order or had been 'recently performed'. 'Recently performed' tests were defined as those completed within 180 days before medication dispensing or 2 weeks after dispensing. Physicians were defined as having followed the laboratory monitoring guideline if results of completed laboratory tests were available for review within these time frames (i.e. 180 days pre-dispensing and 2 weeks post-dispensing).

Matheny and colleagues[91] in their CRCT also assessed the impact of reminders on appropriate laboratory monitoring of maintenance therapy with a focus on the monitoring of potassium, creatinine, liver function, thyroid function, and therapeutic drug levels for appropriate medications. The specific medications assessed were selected for inclusion in the reminder system based on (1) prevalence of their use, and (2) potential morbidity associated with failure to perform appropriate laboratory monitoring. These were based on evidence-based guidelines that were reviewed for routine medication monitoring.[115–118] The specific 15 target drugs included in the system were:

- non-steroidal anti-inflammatory drugs (NSAIDs)
- angiotensin receptor blockers (ARBs)
- metformin
- potassium supplements
- potassium sparing diuretic
- thiazide diurectic
- angiotensin-converting enzyme inhibitors
- HMG (3-hydroxy-3-methyl-glutaryl)-CoA reductase inhibitors (statins)
- thyroxine
- carbamazapine
- ciclosporin
- phenobarbital
- phenytoin
- proc-NAPA
- valproate.

The interval chosen for appropriate monitoring was annual, and therefore the trial included all outpatients (total $n = 1922$; 924 intervention group and 998 control group) seen during the 6-month study period on one or more of the 15 target study drugs for at least 365 days for which no relevant laboratory monitoring tests were conducted in the preceding year. The two groups were reasonably well matched in terms of age, gender, race and insurance status, and these factors were included in the analytic model to assess appropriate laboratory testing rates. Physicians from the Partners Healthcare system, which included two academic teaching hospitals (Brigham and Women's Hospital and Massachusetts General Hospital), and a number of community hospitals and outpatient clinics were randomised from a total of 20 sites, either to receive reminders ($n = 145$ physicians) or for reminders to be suppressed ($n = 158$). The two physician trial groups were well balanced at baseline in terms of both age and gender.

The RCT conducted by Bates and colleagues,[92] 'a randomised trial of a computer-based intervention to reduce utilization of redundant laboratory tests', was undertaken at Brigham and Women's Hospital, Boston, MA, USA and included 5,700 inpatients in the intervention group and 5,886 in the control group admitted during the study period (between 28 June and 30 October 1994). Thirteen specific tests were chosen as appropriate candidates for redundant reminders either because they were commonly ordered or because the marginal cost of performing the test was high. The specific candidate tests were chemistry-20 profiles;

urinalyses; urine, sputum and stools cultures; serum digoxin, tobramycin, aminophylline, vancomycin, and gentamicin levels; *Clostridium difficile* cultures;[119] and fibrin split products.

Test-specific intervals within which a second test was considered redundant, were based on a review of the literature, and evaluated retrospectively by applying them to a random sample of patients.[120] 'Target tests' were defined as tests repeated earlier than the test-specific interval, which for all tests except fibrin split products were 20 hours. The test specific interval for fibrin split products was 8 hours. For digoxin and aminophylline levels, reminders were sent only if the first test result was within the reference range. A patient admission formed the unit of randomisation with physicians entering orders for both intervention and control patients using the home-grown site-specific Brigham and Women's Hospital OCS.

In the intervention group, if a test had previously been ordered within its test-specific interval, the physician received a reminder that the test had been performed recently or was pending, and the result given if available. For the control group, redundancy was determined in the same way, but the reminder was suppressed. In the intervention group, when a reminder was delivered, the default response was to cancel the test. Physicians could override a reminder, but were required to choose from a menu of reasons for the override. For technical reasons, checking for redundancy was performed only for tests ordered from the main OCS screens and not for tests ordered using order sets or templates. Consequently, of the redundant laboratory tests performed, only 44% had an associated computer order. In total the trial included 5059 admissions (2478 in the intervention group and 2581 in the control group) who had at least one of the specified target tests within the 15-week trial period, with 13,425 study tests ordered in the intervention group versus 13,847 in the control group. Both groups were well matched at baseline in terms of age and gender. No details on sociodemographic data for the physicians were reported, or the number involved in the trial.

The randomised crossover trial by McDonald and colleagues,[29] like the two CRCTs conducted by Overhage and colleagues,[24,48] was undertaken at the Wishard Memorial Hospital, Indianapolis, IN, USA. However, the trial was undertaken in an outpatient population, and the CDSS system used, although part of the site-specific hospital system, is unlikely to be comparable to that assessed in the other trials due to considerable differences in the years in which the studies were conducted. It should also be noted that as the trial was conducted in 1980 the CDSS is likely now to be obsolete, and not of direct relevance to service providers needing to implement CDSS within the NHS at the present time.

The aim of this trial was to assess whether the CDSS that was designed to detect and remind physicians about clinical events that might need corrective action significantly increased response rates to events. The trial, which included 31 care providers (interns, residents and practice nurses) lasted 15 weeks: 5 weeks control period (no reminders sent); 5 weeks study period 1 (S1) and 5 weeks study period 2 (S2). During S1 care providers were sent reminders about the detected conditions alone, and during S2 were sent reminders plus bibliographic citations supporting the reminders. The correct action to the reminder was predetermined and compliance assessed. The three study periods, were presented in six possible temporal sequences, with care providers randomly assigned to a sequence. No information on patient sociodemographic status or presenting conditions was reported.

O'Connor and colleagues[57] undertook a 5-year longitudinal study (CCT) to assess whether implementation of an electronic medical record with CDSS or the medical record system alone improved the process or outcomes of care in patients with an established diagnosis of diabetes mellitus. The trial was conducted in two clinics at the HealthPartners Medical Group, MN, USA and included all patients with a diagnosis of diabetes at study baseline (1996) in both clinics. The clinic that the patient attended was then identified in 1998 and 2000 based on administrative data. Patients were only eligible for inclusion in the analyses if they attended their original study clinic in all 3 years, with a total of 57 patients included in the intervention group and 65 in the control group. Patient baseline characteristics were well balanced between the two clinics in terms of age, gender, and Charlson comorbidity score.[121] As modified by Deyo and colleagues,[122] and Rush and colleagues.[123] No sociodemographic data on the physicians participating in the trial were presented, but physicians in both clinics participated in the same diabetes-related care improvement activities within the medical group over the trial period. Similarly, both clinics had access to diabetes specific registries, in-clinic diabetes teaching nurses for patient education, and a common diabetes clinical

guideline developed by the Institute for Clinical Systems Improvement (www.icsi.org/).

The CDSS used was a commercial system developed by Epic Systems (Madison, WI) that provided reminders to physicians when a patient had no HbA_{1C} test within 6 months, no urine microalbuminiuria test within 1 year, had blood pressures of ≥ 130/85 mmHg, low-density lipid (LDL) levels of ≥ 130 mg/dL, HbA_{1C} levels of ≥ 8%, or no aspirin use if aged 40 years or older. The reminders were displayed on screen, but a response to them was not obligatory. In the control group the reminders were suppressed. The electronic medical record system used a Windows interface and a Visual Basic (Microsoft Corp, Redmond, Washington, DC, USA) operating system linked to laboratory test results and pharmacy databases.

The process of care measures included the number of HbA_{1C} tests and LDL cholesterol tests conducted for patients in each clinic in 1996, 1998, and 2000. Additional process measures assessed whether patients met minimum thresholds for HbA_{1C} and LDL testing. Specifically, three threshold measures assessed whether the patient had at least two HbA_{1C} tests per annum; at least one LDL test per year; or at least two HbA_{1C} and one LDL test. Intermediate outcome measures included glycemic and lipid control, as assessed by HbA_{1C} and LDL test values in each of the three study years.

The only study conducted outside the USA was undertaken by Carton and colleagues,[93] and aimed to assess the impact of guidelines on medial imaging referral practice in two hospital accident and emergency departments, the Hospital Ambroise Pare, Boulonge-Billancourt and Hospital de Pontchaillous, Rennes, France. The study was an ITS with an AB-AB-AB design, with the intervention implemented with three control periods and three intervention periods running alternatively over 6 months, with no delay between periods, and each period 1 month in length. The study included all physicians working in either emergency department who ordered a radiological examination within the study period. The number of physicians included in the study and details of their sociodemographic status were not reported. During intervention periods the CDSS displayed the appropriate guideline recommendation on screen for the patient's indication; if the request did not conform to the guidelines, confirmation was requested before submitting the request. The request could still be fulfilled even if it was not in agreement with the guidelines. During the control periods, radiological requests were recorded, but no reminder displayed.

The CDSS knowledge base was written by the Collège des Enseignants de Radiologie de France (French Society of Radiologists) based on the results of a review of the literature, existing guidelines and the expertise of all the societies of radiologists and clinicians. During the study period a total of 15,086 patients were seen in the two departments, with 6,434 radiological requests recorded. Of these, 743 (11%) were discarded from the analysis because the radiological examination and/or clinical context had been profoundly changed by hand. The primary outcome measure was the number of requests complying with the guideline reminders, and secondary outcomes being the type of requests not in compliance.

The primary focus of the pre–post study by Steele and colleagues[94] was on medication ordering, and drug–laboratory interactions. The primary outcome measure was therefore the number of medication orders cancelled after a reminder for a drug–laboratory interaction was displayed. The secondary outcome measures were the number of times the indicated laboratory test(s) were ordered once a reminder had been displayed, the number of associated test(s) ordered when an 'abnormal labs' message was displayed, and the number of appropriate test(s) ordered when a 'no labs' reminder was given. The study was conducted at the Sam Sandos Family Health Clinic, Denver Health outpatient primary care clinics, Denver, CO, USA. The study consisted of a 17-week pre-intervention period, and a 21-week intervention period, with a total of 19,076 patients seen during this 9-month period. This provided a total of 54,206 patient visits with medications ordered on 17,444 (32%) of visits. The rule processed on 49% of all medication orders during the entire study period. During the post-intervention period, a reminder was displayed to the care provider for 11.8% (1,093 out of 9,274) of the times the rule processed. Among these reminders, 5.6% were for only 'missing laboratory values', 6.0% were for only 'abnormal laboratory values', and 0.2% were for both types of reminders. This means that there were 14,297 medication orders across the study period where the rule was triggered, but it did not meet the criteria to display a reminder. All provider staff were allowed to enter medication orders, including physicians, allied health-care providers (nurse practitioners, physician assistants), and residents. No further information was reported on

health-care provider demographics. All registered patients were eligible for inclusion in the study.

The CDSS was developed in collaboration with Thomson Micromedex and Siemens Medical Solutions, and used commercially available rules developed in Ardex Syntax language as Medical Logic Modules, which were then modified to meet local needs. The study focused upon rules that were determined as being the most appropriate to addressing patient safety in an outpatient setting. The rules covered the following five areas:

1. potential drug-induced hyperkalemia (covering interactions with captopril, lisinopril, spironolactone, and enalapril)
2. hypokalemia (covering interactions with chlorthalidone, furosemide, hydrochlorothiazide, metolazone and ethacrynic acid)
3. thrombocytopenia (covering interactions with ranitidine)
4. elevated creatinine levels (covering interactions with amiloride, chlorthalidone, enalapril, furosemide, hydrochlorothiazide, lisinopril, metolazone and spironolactone)
5. elevated transaminase (covering interactions with atorvastatin, citalopram, fluoxetine, paroxetine, rosiglitazone and sertaline).

For each drug–laboratory interaction, rules were written identifying medications, routes of administration, and abnormal laboratory threshold levels for inclusion in the rule. The laboratory cut-off values for triggering a reminder were the same as for the Denver Health abnormal laboratory reference ranges. In addition, a determination was made for each medication as to whether a reminder should be provided for an abnormal laboratory value only, an abnormal or missing laboratory value, or whether despite an association with a laboratory abnormality, no reminder would be displayed. In response to reminders, CDSS users could decide to order, revise or delete the medication order. They could also order any rule-associated laboratory tests. Users did not need to respond to the reminder, but needed to select 'Continue' to proceed with the drug ordering session.

In the 17-week pre-intervention period, the rules were turned on in the background, but no reminders were displayed to users. Baseline ordering behaviour was then compared in a pre-post design with ordering behaviour during the 21-week intervention period.

The UPP study conducted by Abboud and colleagues[87] was undertaken in paediatric inpatients at the Cincinnati Children's Hospital Medical Centre, Cincinnati, OH, USA. The study consisted of a 3-month pre-intervention period followed by a 3-month intervention period, with a total study duration of 6 months. The study was specifically aimed at assessing the impact of a CDSS corollary order for aminoglycoside laboratory blood monitoring levels in all patients who received aminoglycosides for 4 or more days duration during the study period, as this was identified as being suboptimal at study baseline. This interval was chosen by investigator consensus as the minimum duration of therapy that would require monitoring of aminoglycoside levels. The CDSS was developed and implemented in the existing hospital information system (INVISION®, Siemens Medical Solutions, Malven, PA, USA).

During the intervention phase, immediately after placement of an order for aminoglycosides, the physician was reminded to check peak, trough, peak and trough, or random blood levels for the drug prescribed. This could be undertaken during the same session as the prescribing session. During the pre-intervention phase no reminders were presented on screen.

The study included 159 courses of antibiotic therapy of 4 or more days duration ($n = 125$ patients) in the pre-intervention phase, and 177 ($n = 150$ patients) in the intervention phase. No specific patient demographics were reported, but groups were well matched in the pre- and post-intervention phases in terms of the number of courses of aminoglycosides prescribed, total number of laboratory results obtained, and the number of laboratory results per patient. For the analyses, all antibiotic levels ordered were utilised in assessing the response to the reminder, but only true peak and trough levels were used to assess toxicity and subtherapeutic values. These were defined according the hospital laboratory guidelines, with peak and trough levels further divided into toxic or subtherapeutic. In the study a peak level was predefined as a level obtained 50–120 minutes after drug administration, and a trough defined as being obtained 0–120 minutes prior to drug administration.

Outcomes

Process outcomes

The area of impact in the test ordering process assessed in six of the studies was reminder

compliance,[24,29,48,90,91,94] while two studies assessed compliance with guideline recommendations,[87,93] and two assessed order appropriateness.[57,92] The outcomes assessed in the six studies which assessed reminder compliance included rates of compliance with reminders to undertake preventative care measures,[48] and appropriate laboratory tests for drug monitoring.[24,29,90,91,94] In the two studies that examined compliance with guideline recommendations, the outcomes included the number of requests that complied with recommendations,[93] and the number of courses of drug therapy with appropriate laboratory test monitoring.[87] Outcomes in the two studies that assessed order appropriateness included the proportion of tests that were cancelled or performed after a reminder, the proportion of tests performed earlier than specified test-specific intervals,[92] and the number of HbA_{1C}, and of LDL cholesterol tests performed.[56]

Adverse effects of test cancellation

Only the RCT by Bates and colleagues[92] assessed potential adverse effects associated with test cancellation as advocated by the reminders. These were defined as new abnormal results for the same test performed within 3 days of the original test cancellation.

Study quality

Controlled studies

Study quality was generally reasonable apart from in the randomised crossover trial by McDonald and colleagues[29] in which the methods were very poorly reported. The method of randomisation was adequate in the four CRCTs,[24,48,90,91] and the RCT conducted by Bates and colleagues,[92] but unclear in the randomised crossover trial by McDonald and colleagues.[29] It was therefore unclear whether true randomisation was carried out. Adequate study eligibility criteria were reported in the four CRCTs,[24,48,90,91] the RCT,[92] and the CCT,[57] but again were lacking in the trial by McDonald and colleagues.[29]

Only partial baseline details on the physicians and patients included in the two trials conducted by Overhage[24,48] and the RCT by Bates and colleagues[92] were reported, and again this information was lacking in the trial by McDonald and colleagues.[29] However, where this information were reported it does appear that intervention and control groups were reasonably well balanced in terms of baseline prognostic factors.[24,48,57,90,92] The exception to this was the CRCT conducted by Matheny and colleagues,[91] in which baseline imbalances in terms of patients' gender, age and insurance status were adjusted for in the analyses. Only the CCT by O'Connor and colleagues[57] administered any cointerventions, and these were similar between the two treatment groups. Care provider blinding to treatment allocation, as expected with this type of intervention was not attained in any of the trials. Data analyses were appropriate in three of the CRCTs,[24,48,91] and the RCT,[92] but clustering was not taken into account in the analyses in the CRCT by Palen and colleagues.[90] Again due to lack of adequate reporting it was unclear whether the analyses undertaken by McDonald and colleagues[29] were appropriate. Apart from the CRCT by Overhage and colleagues,[48] analyses in all of the trials was undertaken on an 'intention to provide or communicate information' basis. All the trials attained a > 80% follow-up of patients.

Uncontrolled studies

The uncontrolled studies consisted of an ITS study by Carton and colleagues[93] and two UPP studies by Steele and colleagues[94] and Abboud and colleagues.[87] The studies were of variable quality. In the ITS it was unclear whether the intervention was independent of other secular changes over time which may have confounded the results. Moreover, the AB-AB-AB employed is likely to have confounded results due to intervention carry over effects into the control periods. The effect of this if any, would be to underestimate the effects of the CDSS intervention. Additionally, although there were an adequate number of data points collected to allow for reliable statistical analysis, no formal tests for trends were undertaken. On a more positive note, the method of data collection was reliable and unlikely to be affected by the intervention, and outcome assessment was blinded. Furthermore, there was a low rate of attrition with > 80% of episodes of care included in the follow-up assessment.[93] In the pre–post study by Steele and colleagues[94] adequate, although limited study eligibility criteria were reported for both health-care providers and patients. However, no further sociodemographic information were reported on the health-care providers in the study. Detailed sociodemographic information on all patients seen during the study period were reported, but this was not reported separately for pre- and intervention periods. It is therefore unclear whether any differences in patient socio-demographics between the two study periods could have potentially biased the results obtained. All statistical analyses undertaken were appropriate,

with analysis conducted on an 'intention to provide or communicate information' basis. Overall, the study was reasonably well designed and conducted, with the results likely to be robust. The study by Abboud and colleagues[87] was of a somewhat poor methodological quality. Although study eligibility criteria were adequately specified, no baseline sociodemographic data on either the patients or physicians involved in the study were presented. This means that differences in patient baseline characteristics between the pre- and post-intervention periods could potentially confound the results. Data analyses were appropriate and conducted on an 'intention to provide or communicate information' basis, with > 80% of episodes of care included in the analyses.

CDSS characteristics

A summary of the key characteristics of the CDSS used in the 10 studies are displayed in *Table 14*. The specific CDSS used in the studies were only reported in four of the studies,[57,87,90,94] but in the two CRCTs by Overhage and colleagues[24,48] and the study by McDonald and colleagues[29] would appear to be the home-grown/inhouse OCS and CDSS developed by Wishard Memorial Hospital, Indianapolis, IN, USA. Likewise, in the CRCT by Matheny and colleagues[91] and the RCT by Bates and colleagues[92] the system would again appear to one of the site specific ones, this time belonging to Brigham and Women's Hospital, Boston, MA, USA. In the four studies that reported the systems used, the CRCT undertaken by Palen and colleagues[90] used a study-specific CDSS (Clinical Information System) developed in collaboration with IBM (Boulder, CO, USA) that was implemented within the existing Kaiser Permanente proprietary system; the CCT by O'Connor and colleagues[57] used what appears to be a commercially available diabetes mellitus-specific CDSS developed by Epic Systems (Madison, WI, USA); and the two pre–post studies by Steele and colleagues[94] and Abboud and colleagues[87] used study-specific CDSS that were developed in collaboration with Thomson Micromedex and Siemens Medical Solutions using commercially available Medical Logical Modules modified to meet the needs of the Denver Health laboratory,[94] and a CDSS developed by INVISION®, Siemens Medical Solutions, Malven, PA, USA that was then implemented within the existing hospital information system.[87] The CDSS used in the ITS by Carton and colleagues[93] was not reported.

In the four studies that reported the CDSS reasoning methods, these were all based on discrimination rules.[24,48,91,94] Where reported the CDSS knowledge base was based upon either reviews of the literature,[92,93] guidelines,[48] standard reference books, and drug packet inserts,[24] or existing database information.[94] The CDSS output in all studies was the display of reminders.

In relation to the 14 features of CDSS proposed by Kawamoto and colleagues[16] the CDSS was not reported as being piloted with users prior to implementation in any of the 10 studies, but user instructional training at the time of implementation was reported in four.[57,90,92,100] The CDSS in all 10 studies was integrated as part of the OCS, and provided output automatically as part of the consultation workflow. Only in the UPP study by Carton and colleagues was there a need for additional data entry by the physician,[93] and only in this study and the CRCT by Overhage and colleagues[48] was a reason requested for not following the CDSS reminders. None of the studies required the user to note agreement with the reminder before implementation. The study by O'Connor and colleagues[57] was the only one in which a recommendation rather than just a reminder was issued. In none of the studies was the reminder justified by recourse to the CDSS reasoning methods or evidence upon which these were based. Additionally, it would appear that local system users were only involved in the CDSS development process in the study by Steele and colleagues.[94] The data provided by the CDSS was used by the physician alone, and in all studies did not appear to provide periodic summaries of performance feedback. Two studies, those by O'Connor and colleagues[57] and Abboud and colleagues[87] both combined CDSS implementation with concomitant coeducation of users. None of the other studies deployed any concomitant cointerventions.

Results

Process outcomes

In the first CRCT by Overhage and colleagues[48] there were no significant differences between intervention and control physicians in compliance with suggested preventative laboratory testing guidelines for cervical cytology screening, mammography, thyrotropin screen, hepatitis B screen, urinalysis, cholesterol testing, human immunodeficiency virus (HIV) screening, 24-hour urine protein testing, sickle cell screening or screening for STDs. Of note in this trial, no further significant differences were observed in compliance with reminders for preventive care measures

between intervention and control physicians for either recommendations to undertake vaccinations or for the prescription of prophylactic medication.[48] A summary of the specific results from the trial by laboratory test type is displayed in *Table 15*.

In the second CRCT, also conducted by Overhage and colleagues[24] only relevant data on 24-hour compliance rates for the 18 most common laboratory test corollary orders were presented separately and were of relevance to the current assessment. The overall trial results indicate that the display of reminders had a significant effect on the number of corollary orders placed, with compliance rates of 46.3% in the intervention group compared with 21.9% in the control group for immediate compliance with test orders ($p < 0.0001$). The data on compliance with the ordering of common laboratory tests supports there being a significant effect of reminders on corollary test ordering, with compliance rates being higher in the intervention group than the control for every type of test order. The increase in compliance with suggested corollary orders ranged from 7.1% to 72.6% according to the type of laboratory test suggested, in the intervention group compared to the control. A specific breakdown of compliance rates by trial group and suggested laboratory test order is given in *Table 16*.

In contrast to the results of the CRCT by Overhage and colleagues,[24] Palen and colleagues[90] found no significant differences between intervention and control group physicians in the overall rate of compliance with ordering the recommended laboratory monitoring tests for patients prescribed one or more of the 25 target study medications. Laboratory monitoring was performed within the recommended guidelines 56.6% of the time (10,494 of 18,556 index dispensings) in the intervention group compared with 57.1% of the time (8957 of 15,686 index dispensings) in the control group ($p = 0.31$). Analysis of guideline compliance rates by patient gender also showed no significant differences between the intervention and control groups.

Male patients who had medication orders placed by intervention group physicians had a laboratory monitoring rate of 57.5% compared with 58.5% for control physicians ($p = 0.18$). The comparative percentages for female patients were 55.7% and 55.9% respectively ($p = 0.82$). Compliance rates with guidelines for laboratory monitoring for individual medications varied from 0.0% to 93.7%. A summary of compliance rates for each of the 25 individual medications is shown in *Table 17*. Although the overall results showed no significant difference between the two groups, this was not true across all individual medications. In the four drugs in which a statistically, or borderline statistically, significant difference was observed, the improvement in monitoring rates favoured the patients of physicians in the intervention group. The laboratory monitoring rates among patients prescribed medications by the intervention group compared with control group was 52.8% versus 46.0% for colchicine ($p = 0.05$), 71.2% versus 62.3% for gemfibrozil ($p = 0.003$), 42.9% versus 0.0% for methotrexate ($p = 0.03$), and 75.7% versus 73.9% for statins ($p = 0.05$).

Likewise, Matheny and colleagues[91] also found no significant differences between intervention and control group physicians in the overall rate of compliance with ordering the recommended laboratory monitoring tests for one or more of the 15 study target drugs in patients who had not received a laboratory monitoring test in the previous year. Rates of appropriate laboratory monitoring within 14 days of an office visit ranged from 12.5% for therapeutic drug levels to 64% for potassium levels. A summary of compliance rates for each of the 15 individual medications is shown in *Table 18*. The authors postulated that the impact of reminders in the intervention group was small due to the already high rates of appropriate laboratory monitoring of patients. In the study medication-laboratory monitoring non-compliance ranged from 1.6% (21/1330) for potassium supplementation to 6.3% (1287/20,376) for statin use.

Bates and colleagues[92] reported 939 apparently redundant laboratory tests ordered over the 4-month trial period, including 437 (47%) in the intervention group. In this group, suggestions to cancel the test were accepted 69% (300 out of 437 tests) of the time, and therefore 31% of reminders were overridden. The rate of actual performance of the redundant test orders was significantly reduced in the intervention group, being 27% (117) compared to the 51% (257) observed in the control group, and therefore there was an absolute difference in the proportion of redundant tests performed of 24% ($p < 0.001$). Of note, the rate of test performance for tests that would have received a reminder was reasonably low at 51% in the control group. A pre–post comparison of the number of target tests performed earlier than the test specific interval comparing the 4 months

TABLE 14 *Summary of the CDSS characteristics in studies assessing the impact of the display of reminders*

Study ID	Overhage (1996)[48]	Overhage (1997)[24]	Palen (2006)[90]	Matheny (2008)[91]	Bates (1999)[92]	McDonald (1980)[29]	O'Connor (2005)[57]	Carton (2002)[93]	Steele (2005)[94]	Abboud (2006)[87]
CDSS characteristics										
1. Name of CDSS (if any)	NR	NR	Clinical Information System[a]	NR (Brigham and Women's Hospital)	NR	NR[b]	Epic Systems	NR	NR[c]	INVISION®
2. CDSS reasoning methods	DR	DR	NR	DR	NR	NR	NR	NR	DR	NR
3. CDSS knowledge base	Guidelines (US Preventive Services Task Force Recommendations)	Standard reference books, drug package inserts and local practice guidelines	Published and internal guidelines, and expert opinion	Guidelines	Test-specific intervals based on a review of the literature	NR	NR	Guidelines based on a review of the literature and clinician expertise	Commercially available Medical Logic Modules developed and adapted to meet local needs	NR
4. Information used in CDSS	NR	NR	Medication related alerts for baseline laboratory monitoring tests	Time interval from previously ordered test	Published and internal guidelines and expert opinion	NR	NR	NR	Biochemical tests	Test orders
5. Time to complete CDSS (minutes)	NR	NR	NR	NR	NR	NR	NR	1 min	NR	NR
6. CDSS output format	R	R	R	R	R	R	R	R	R	R
7. Is a description of pilot testing with users prior to implementation provided?	No	No	No	No	No	No	No	No	No	No
8. Is user instructional training at the time of implementation described?	No	No	Yes	No	Yes	No	Yes	No	No	Yes

Study ID	Overhage (1996)[48]	Overhage (1997)[24]	Palen (2006)[90]	Matheny (2008)[91]	Bates (1999)[92]	McDonald (1980)[29]	O'Connor (2005)[57]	Carton (2002)[93]	Steele (2005)[94]	Abboud (2006)[87]
General system features										
9. Is the CDSS integrated with charting or OCS to support workflow integration?[d]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Clinician–system interaction features										
10. Is automatic provision of CDSS output provided as part of clinician workflow?[d]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
11. Is there a need for additional data entry by the clinician other than the specification of which test orders?[d]	No	No	No	No	No	No	No	Yes	No	No
12. Does the CDSS request documentation of the reason for not following CDSS recommendations?[d]	No	No	No	No	No	No	No	Yes	No	No
13. Does CDSS provide output at the time and location of decision making?[d]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
14. Are the CDSS recommendations executed by the clinician noting agreement?[d]	No	No	No	No	No	No	No	No	No	No

continued

TABLE 14 *Summary of the CDSS characteristics in studies assessing the impact of the display of reminders (continued)*

Study ID	Overhage (1996)[48]	Overhage (1997)[24]	Palen (2006)[90]	Matheny (2008)[91]	Bates (1999)[92]	McDonald (1980)[29]	O'Connor (2005)[57]	Carton (2002)[93]	Steele (2005)[94]	Abboud (2006)[87]
Communication content features										
15. Does the CDSS provide a recommendation rather than just an assessment?[d]	NR	No	No	Yes	No	No	Yes	No	No	No
16. Does the CDSS promote action rather than inaction?[d]	No	NR	NR	Yes	NR	NR	Yes	NR	No	NR
17. Does the CDSS justify the output of provision of reasoning?[d]	No	No	No	No	No	No	No	No	NR	No
18. Does the CDSS justify the output by provision of research evidence?[d]	No	No	No	No	No	No	No	No	No	No

continued

Study ID	Overhage (1996)[48]	Overhage (1997)[24]	Palen (2006)[90]	Matheny (2008)[91]	Bates (1999)[92]	McDonald (1980)[29]	O'Connor (2005)[57]	Carton (2002)[93]	Steele (2005)[94]	Abboud (2006)[87]
Auxiliary features										
19. Were the local users involved in the CDSS development process?[d]	No	No	No	No	No	No	No	No	Yes	No
20. Is the CDSS output provided to patients as well as clinicians?[d]	No	No	No	No	No	No	No	No	No	No
21. Does the CDSS provide periodic summaries of performance feedback?[d]	No	No	No	No	No	No	No	No	No	No
22. Is the CDSS used in conjunction with conventional education?[d]	No	No	No	No	No	No	Yes	No	No	Yes

DR, discrimination rules; NR, not reported; R, reminder.
a Clinical Information System, IBM, CO.
b Home-grown system from Wishard Memorial Hospital.
c CDSS developed in collaboration with Thomson Micromedex and Siemens Medical Solutions.
d Features of CDSS proposed by Kawamoto and colleagues (2005) as predictors of system success or failure[16].

TABLE 15 *Summary of compliance with reminders for preventive laboratory testing measures from the trial by Overhage and colleagues (1996)[48]*

Intervention	**OCS alone**		**OCS + CDSS**		
Preventive laboratory test	*n*	Compliance (%)	*n*	Compliance (%)	*p*-value
Cervical cytology study	329	2.8	323	2.8	0.41
Mammography	131	1.5	125	5.6	0.08
Thyrotropin screen	118	9.3	112	16.1	0.12
Hepatitis B screen	92	2.2	88	8.0	0.08
Screening urinalysis	75	34.7	68	32.4	0.77
Cholesterol test	58	13.8	70	14.3	0.94
HIV Screen	43	9.3	44	4.6	0.38
24-hour urine protein test	23	4.4	24	25.0	0.05
Sickle cell screen	14	0.0	22	9.0	0.25
STD screen	6	16.7	2	50.0	0.35

STD, sexually transmitted disease.

TABLE 16 *Summary of 24-hour compliance rates for the 18 most common corollary laboratory tests suggested in the trial by Overhage and colleagues (1997)[24]*

Intervention		**OCS alone**	**OCS + CDSS**	
	Total (*n*)	**%**	**%**	**Compliance increase (%)**
Suggested test order (compliance) (%)				
Serum creatinine	1209	41.2	48.3	7.1
Serum electrolytes	1034	70.9	87.0	16.2
Glycosylated HbA_{1C}	821	7.4	23.7	16.3
Activated partial thromboplastin time	615	59.6	89.2	29.7
SGPT (ALT)	569	1.9	12.6	10.8
SGOT (AST)	467	0	7.1	7.1
Capillary glucose	446	4.4	30.8	26.7
Blood cell profile	382	51.4	80.5	29.0
Stool occult blood test	374	12.1	60.9	48.9
Prothrombin time	320	45.5	64.6	19.1
Theophylline level	270	46.5	75.9	29.4
Platelet count	236	15.1	70.0	54.9
Reticulocyte count	205	11.4	19.7	8.3
Fe-TIBC	149	0	12.6	12.6
Vancomycin	143	65.2	90.7	25.6
Phenytoin level	140	38.4	73.1	34.8
A-V blood gas	123	0	72.6	72.6
Gentamicin level	118	75.9	90.0	14.1

ALT, alanine aminotransferase; AST, aspartate aminotransferase; A-V, arterial-venuous; Fe, iron; SGOT, serum glutamic oxaloacetic transaminase; SGPT, serum glutamate pyruvic transaminase; TIBC, total iron binding capacity.

TABLE 17 *Summary of compliance rates for guidelines with laboratory test monitoring by individual target medications from Palen and colleagues (2006)*[89]

Medication	OCS alone[a]	OCS + CDSS[a]	*p*-value[b]
ACE inhibitors	2729 (47.5)	3099 (47.0)	0.681
Allopurinol	355 (61.1)	429 (57.6)	0.31
Carbamazepine	119 (35.3)	153 (34.6)	0.91
Colchicine	400 (46.0)	411 (52.8)	0.05
Digoxin	178 (48.9)	242 (55.0)	0.22
Diuretic	4270 (45.6)	5384 (44.0)	0.11
Gemfibrozil	454 (62.3)	569 (71.2)	0.003
Isoniazid	36 (19.4)	33 (15.2)	0.64
Losartan potassium	433 (52.7)	506 (52.0)	0.84
Metformin hydrochloride	940 (7.6)	1098 (67.7)	0.14
Methotrexate	9 (0.0)	7 (42.9)	0.03
Niacin	36 (47.2)	34 (67.7)	0.084
Phenytoin sodium	52 (25.0)	83 (32.5)	0.35
Pioglitazone hydrochloride	63 (93.7)	76 (92.1)	0.73
Potassium chloride	1291 (57.8)	1623 (54.3)	0.06
Rifampincin	6 (50.0)	7 (14.3)	0.20
Statins	4245 (73.9)	4717 (75.7)	0.05
Valproic acid	70 (38.6)	85 (36.5)	0.79
Total	15,686	18,556	0.79

ACE, angiotensin converting enzyme.
a Data are given as number (% monitored) unless otherwise indicated.
b Chi-squared test.

immediately preceding the trial and results from the 15-week study period, indicated that during the preceding period, 20.5% of target tests were performed earlier than the specific intervals. During the study period this was significantly lower in the intervention group at 18.5% ($p = 0.004$) but not in the control group (19.6%; $p = 0.19$). Additionally, in the 4-month period preceding the intervention, there were 4.84 target tests per admission, compared with 4.24 during the study period in the intervention group and 4.28 in the control group ($p < 0.0001$).

Adverse effects of test cancellation

To determine whether the cancellation of a test had potentially adverse effects new abnormal results for the same test performed with 3 days of cancellation was conducted. Chemistry-20 profiles were excluded from the analysis due to high probability of an abnormal result on at least one of the tests in the panel. Of the remaining 225 accepted reminders, 119 (53%) were followed by another test of the same type within 72 hours; 55 (24%) of these were abnormal. Only 10 (4%) of these had not been preceded by a similar abnormal result within 24 hours before the cancelled test, and two were duplicate orders for the same patient. Therefore only 8 (4%) of the tests provided new information.

Process outcomes

McDonald and colleagues[29] reported limited results from their randomised crossover trial for test ordering alone. These indicated the presentation of reminders (either with or without supporting bibliographic citations) significantly increased compliance with test ordering in both residents and interns. These increased from 20% and 9% during the control phase in which reminders were suppressed to 49% and 38% during their presentation for each of the groups respectively. The presence of reminders had no significant effect on the test ordering behaviour of nurse clinicians with compliance rates of 15% and 24% in each trial condition.

Results from the CCT by O'Connor and colleagues[57] in outpatients with diabetes showed that the number of HbA_{1C} tests performed per patient per year in the intervention clinic increased significantly relative to the number of HbA_{1C} tests

TABLE 18 *Summary of compliance rates for reminders for laboratory test monitoring by individual target medications from Matheny and colleagues (2008)[91]*

Medication-laboratory reminder	Visits (*n*)	Visits with laboratory overdue (*n*; %)	Laboratory ordered when overdue (*n*; %)	Odds Ratio (adjusted) (95% CI)	*p*-value
NSAID-Cr					
OCS + CDSS	8487	442 (5.2%)	150 (33.9%)	1.24 (0.71 to 2.15)	0.457
OCS alone	9307	428 (4.6%)	136 (31.8%)		
ARB-Cr					
OCS + CDSS	751	31 (4.1%)	17 (54.8%)	0.24 (0.04 to 1.34)	0.104
OCS alone	832	27 (3.2%)	17 (63.0%)		
Metformin-Cr					
OCS + CDSS	857	20 (2.3%)	7 (35.0%)	0.53 (0.05 to 5.34)	0.594
OCS alone	781	16 (2.1%)	6 (37.5%)		
K Supplement-K					
OCS + CDSS	579	12 (2.1%)	7 (58.3%)	0.91 (0.03 to 24.44)	0.956
OCS alone	751	9 (1.2%)	5 (55.5%)		
K Sparing Diuretic-K					
OCS + CDSS	761	19 (2.5%)	13 (68.4%)	0.82 (0.12 to 5.60)	0.836
OCS alone	875	28 (3.2%)	17 (60.7%)		
Thiazide Diuretic-K					
OCS + CDSS	1997	62 (3.1%)	40 (64.5%)	1.30 (0.63 to 2.67)	0.473
OCS alone	2508	89 (3.5%)	46 (51.7%)		
ACE Inhibitor-K					
OCS + CDSS	2279	119 (5.2%)	57 (47.9%)	1.00 (0.43 to 2.30)	0.993
OCS alone	2790	80 (2.9%)	40 (50.0%)		
Statin-ALT					
OCS + CDSS	9441	613 (6.5%)	291 (47.5%)	0.89 (0.43 to 1.81)	0.740
OCS alone	10935	674 (6.2%)	358 (53.1%)		
Thyroxine-TSH					
OCS + CDSS	897	38 (4.2%)	22 (57.9%)	1/19 (0.40 to 3.53)	0.747
OCS alone	1233	44 (3.6%)	25 (56.8%)		
Therapeutic level[a]					
OCS + CDSS	514	16 (3.1%)	2 (12.5%)	0.55 (0.03 to 8.94)	0.677
OCS alone	755	26 (3.4%)	4 (15.4%)		

ACE, angiotensin converting enzyme; ALT, alanine aminotranferase; Cr, chromium; K, potassium; TSH, thyroid stimulating hormone.

a Represents the aggregated reminders for therapeutic monitoring for carbamazapine, ciclosporin, phenobarbital, phenytoin, Proc-NAPA, valproate.

in the comparison clinic at both 2-year ($p < 0.04$) and 4-year follow-up ($p < 0.001$) after the CDSS was introduced. In the first year of the introduction of the system (1996) 1.67 HbA_{1C} tests were performed per patient in the 12-month period in the intervention clinic, with this increasing to 2.2 in 1998 and 2.46 in 2000. The comparative figures for the control clinical were 1.75, 1.83 and 1.63 for the years 1996, 1998, and 2000 respectively. Therefore while an increase in the number of tests performed was observed in the intervention clinic, a comparable rise was not observed in the control clinic. There were no significant effects of any other covariates in the model (patient age,

gender and baseline Charlson comorbidity score) observed. For the number of LDL cholesterol tests performed, the number increased in both clinics from 1996 (0.54 in the intervention clinic vs 0.49 in the control clinic), through 1998 (0.87 in the intervention clinic vs 0.59 in the control clinic) to 2000 (1.45 in the intervention clinic vs 0.92 in the control clinic). However there were no significant differences in LDL cholesterol test rates between the clinics ($p = 0.33$ and $p = 0.19$) for the years 1998 and 2000 respectively. Again there were no significant interactions in the model for any of the covariates.

Results of the third model which tested whether the proportion of patients who met both the HbA_{1C} and LDL testing thresholds increased with time and by clinic showed the proportion increased significantly from 1996 (29.8 for the intervention clinic vs 30.8 in the control clinic) to 1998 (57.9 for the intervention clinic vs 46.2 in the control clinic (between time points; < 0.05) and showed an even greater increase between 1996 and 1998 in the intervention clinic (70.2), but remained stable in the control clinic (46.2) (between time points; $p < 0.01$). There was no significant difference between the intervention and control clinics for the time period of 1996 to 1998 ($p = 0.27$), but due to the increase in the proportion of patients meeting the criteria in the intervention clinic between 1998 and 2000 was significantly different ($p = 0.03$).

There were no significant differences between clinics for the outcome of HbA_{1C} values either for the time period of 1996 (7.80 for the intervention clinic vs 7.35 for the control clinic) to 1998 (7.90 for the intervention clinic vs 7.26 for the control clinic) ($p = 0.10$) nor the period 1998 to 2000 (7.71 for the intervention clinic vs 7.11 for the control clinic) ($p = 0.27$). The only significant effect involving covariates showed that older patients had lower HbA_{1C} values. There were too few patients with LDL cholesterol level measurements throughout the two follow-up periods for the data to produce reliable statistical estimates. Therefore these data were not analysed.

Carton and colleagues[93] in their ITS study to assess the effects of CDSS on radiology referral practice compared with a set of guidelines in two French accident and emergency departments, found a small but significant decrease in the proportion of requests that did not conform to the guideline from 33% when the guidelines were inactive to 27% when recommendations were active ($p < 0.0001$). However, there were considerable differences between the two hospitals in the number of requests that did not conform to the guidelines, with 353 (18%) of requests not conforming in hospital A compared to 1693 (35%) in hospital B ($p < 0.0001$). The three most common examinations (abdominal plain radiographs, chest radiographs and CT of the brain) represented more than 90% of all examinations not in agreement with the guidelines. When considering each of these examinations separately, approximately 76.5% of abdominal plain radiographs, 24.9% of chest radiographs and 15.8% of CT examinations did not conform to guidelines. Overall, the requests from junior practitioners more frequently disagreed with recommendations than those from senior practitioners (30.8% vs 24.0% respectively; $p < 0.0001$). Additionally, analyses of the number of requests not conforming with the guidelines by temporal period (i.e. change from intervention period one to control period one) showed an increase on each of the three successive occasions when the recommendations were switched off: from 27.5% to 29.8% (relative increase of 8.4%), from 27.0% to 37.8% (relative increase of 40%), and from 26.0% to 26.9% (relative increase of 3.5%) indicating that there did not appear to be a learning effect regarding guideline appropriate test ordering that carried through into the control periods.

Results from the pre–post study by Steele and colleagues[94] showed that comparison of the pre- and post-intervention periods for medication orders for which no reminder was displayed showed no significant differences in the percentage of time the provider ordered the drug rule associated laboratory test (17.0% during pre-intervention period vs 16.2% during the post-intervention period; $p = 0.38$). This indicates that there was no trend to increased laboratory test ordering during the post-intervention period.

In contrast there was a significant increase during the intervention period that the rule associated laboratory test was ordered when an alert was displayed, from 347 (38.5%) during the pre-intervention period to 559 (51.1%) in the intervention period (% change: +32.73; p-value <0.0001).

In the UPP study conducted by Abboud and colleagues[87] there were 336 courses of aminoglycoside therapy prescribed for 4 or more days duration in 275 patients (1.2 courses per patient). In total there were 548 laboratory results obtained (2.0 per patient). However of these,

114 results (20.8%) did not meet the predefined criteria for a peak or trough level, resulting in 434 analysed laboratory results. In the pre- and post-intervention periods there were no significant differences between the number of aminoglycoside prescriptions with appropriate laboratory test monitoring: 128 (80.5%) vs 146 (82.5%) for each time period respectively ($p > 0.05$). Additionally, there were no significant differences observed in the frequency in which patients had all therapeutic levels [$n = 94$ (84.7%) in the pre-intervention phase vs $n = 100$ (80.0%) in the post-intervention phase]; any toxic level [$n = 9$ (8.1%) in the pre-intervention phase vs $n = 15$ (12.0%) in the post-intervention phase]; or any subtherapeutic levels [$n = 8$ (7.2%) in the pre-intervention phase vs $n = 7$ (5.6%) in the post-intervention phase].

Summary of studies assessing the impact of the display of reminders

Process outcomes

Ten studies, including four CRCTs,[24,48,90,91] one RCT,[92] one CCT,[57] one randomised crossover trial,[29]one ITS with an AB-AB-AB design,[93] and two UPP studies[87,94] assessed the impact of the display of reminders. Across the studies nine of the 10 were conducted in the USA,[24,29,48,57,87,90–92,94] and assessed the impact of the reminders on compliance to undertake preventative care measures[48], laboratory test ordering for medication monitoring,[24,29,57,87,90,91,94] or the ordering of redundant tests.[92] Two of the studies were either undertaken on specific patient groups, namely those with diabetes,[57] or assessed one specific drug (aminoglycosides).[87] All the rest of the studies assessed the impact on the monitoring of a number of different pre-specified drugs or test orders.

The final study, which was conducted in France, assessed the impact of reminders on compliance with guidelines for radiology imaging referral. Results from the one CRCT that assessed compliance with reminders to undertake preventative care measures suggests that contrary to findings in an outpatient setting, these had no impact on increasing compliance with guidelines for undertaking preventative laboratory screening in patients in an inpatient setting, as there were no significant differences between the intervention and control groups observed.[93]

In relation to compliance with guidelines for undertaking suggested laboratory monitoring for pre-specified drugs, the results across the studies were mixed and equivocal. Of the six studies reviewed, the CRCT by Overhage and colleagues,[24] the pre–post study by Steele and colleagues,[94] and the randomised crossover trial by McDonald and colleagues[29] all reported a significant impact of the display of reminders on compliance with undertaking the necessary laboratory tests. However, in the trial by McDonald and colleagues[29] this impact was limited only to physicians and did not extend to nurse practitioners. In the other three studies, the two CRCTs by Palen and colleagues[90] and Matheney and colleagues[91] and the pre–post study by Abboud and colleagues,[87] reminders did not significantly improve compliance with suggested laboratory test monitoring across a range of different pharmacological therapeutic interventions in both primary and secondary care settings.

Again, the impact of the display of reminders on compliance with guidelines for laboratory test monitoring in patients with diabetes was mixed in the CCT by O'Connor and colleagues.[57] Reminders had a significant impact on the number of patients undergoing HbA_{1C} tests, but no significant impact on the number of LDL cholesterol tests undertaken. Likewise, there were mixed effects on the proportion of patients meeting both the HbA_{1C} and LDL testing thresholds, with no significant differences between intervention and control groups observed at 2-year follow-up, but a significant impact in favour of the intervention group observed at 4-year follow-up. In terms of actual HbA_{1C} values there were no significant differences observed at either time point between patients in the intervention and control groups. Thus suggesting that while reminders may have some impact (dependent on the test type) on the number of tests undertaken, this does not translate into actual clinical differences that may impact on the patient's disease process and management.

Results from the one RCT by Bates and colleagues[92] assessing the impact of reminders about redundant tests, suggested that these have a significantly positive impact on the number of redundant test orders placed, with a 27% absolute reduction in rates observed between the intervention and control groups. This did not appear to have adverse effects in terms of there being new abnormal results that would have provided new information from the cancelled redundant test, and therefore potentially impacted upon patient care outcomes.

Likewise, the ITS by Carton and colleagues[93] found the display of reminders had a small but significant impact on the number of radiology imaging referrals that conformed to guidelines, with an increase from 66.8% compliance without reminders to 73.1% with reminders. A summary of the results of the eight studies which assessed the impact of the display of reminders on compliance with preventative care measures or laboratory medication monitoring is displayed in *Table 19*, while the results for the impact of reminders on redundant laboratory tests and compliance with radiology referral guidelines is displayed in *Table 20*.

Studies assessing the impact of the display of restricted lists

Quantity and quality of the studies

Assessment of the display of restricted lists was examined in one ITS study by Rosenbloom and colleagues[95] and one CPP study by Poley and colleagues.[96] The study by Poley and colleagues[96] also included a cost-comparison analyses, the results of which are reported in Chapter 6, Systematic review of economic evaluations. Both studies targeted specific tests, with the ordering of serum magnesium level tests being the subject of the ITS by Rosenbloom and colleagues[95] and blood test ordering targeted by Poley and colleagues.[96] The area of impact in the test ordering process targeted in both studies was therefore test volumes.[95,96] The ITS by Rosenbloom and colleagues[95] was conducted on 30 of the 33 inpatient wards at the Vanderbilt University Hospital, Nashville, TN, USA over a 6-year period (1 January 1998 to 31 December 2003). The specific CDSS evaluated was the WizOrder Care Provider Order Entry System, a home-grown system developed by the medical centre. The system assessed in the study was a non-commercialised form of the software code used at the hospital. All patients admitted to any ward where the CDSS was implemented over the study period were eligible for inclusion; with a total of 194,192 patients admitted. The CDSS users were all physicians, nurse practitioners or medical students working within the specific wards. No further data on CDSS user sociodemographic variables were presented.

The study consisted of three different CDSS intervention protocols that were implemented sequentially over the study period. The Vanderbilt University Medical Centre Resource Utilization Committee firstly identified two 'normal' ranges for serum magnesium test results that were considered appropriate. One was based on the institutional laboratory's statistically normal range, 1.5–2.5 mg/dL, and other represented a 'physiologically appropriate' range (i.e. serum magnesium was unlikely to directly cause clinical sequelae if within this range) of 1.0–3.9 mg/dL. These were then implemented within the CDSS, with changes to the three different interventions made based on the results of the previous intervention.

At study baseline (1 January 1998 to 4 December 1999), no protocols were in place restricting the frequency, context or volume of serum magnesium test ordering. The first CDSS intervention (implemented from 5 December 1999 to 21 March 2000), targeted all open-ended laboratory and radiology orders, with tests scheduled more than 72 hours into the future flagged, and users prompted to consider discontinuing the order. The second intervention, which was implemented from 20 June 2000 to 30 November 2001, was also a broad-based CDSS intervention, that globally addressed the ordering of multiple laboratory tests simultaneously. The specific tests addressed were magnesium, calcium, and phosphorus.

The intervention included a graphical display of patients' recent serum magnesium, calcium, and phosphorus test results, educational material outlining indications for magnesium testing, and test interpretation. This intervention also limited orders to one test per order (i.e. no recurrent testing was possible). CDSS users could bypass the intervention only by ordering magnesium testing from disease-specific order sets or by specifically ordering a single magnesium test (rather than recurrent testing) from the standard OCS. The third intervention, implemented from 1 December 2001 to 31 December 2003, focused only on the ordering of magnesium tests. This intervention included a graphical display of patients' most recent serum magnesium result, and a graphical display of a calculated corrected magnesium value. Test volumes were also limited to one test per order. In addition users had to enter a reason for testing after reviewing a list of indications. CDSS users could bypass the intervention by ordering magnesium tests from a disease-specific order set. Both of the second and third interventions implemented therefore included a concomitant CDSS intervention, such as the display of

TABLE 19 *Summary of process outcomes for studies assessing the impact of the display of reminders on compliance with preventative care measures or laboratory medication monitoring*

Study ID	**Overhage (1996)[48]**		**Overhage (1997)[24]**		**Palen (2006)[90]**		**Matheny (2008)[91]**		**McDonald (1980)[29]**		**O'Connor (2005)[57]**		**Steele (2005)[94]**		**Abboud (2006)[87]**	
Study design	CRCT		CRCT		CRCT		CRCT		Randomised x-over trial		CRCT		UPP		UPP	
	OCS alone	OCS + CDSS	OCS alone	OCS + CDSS	OCS alone	OCS + CDSS	OCS alone	OCS + CDSS	OCS alone	OCS + CDSS	OCS alone	OCS + CDSS	OCS alone	OCS + CDSS	OCS alone	OCS + CDSS
													Pre-	Post-	Pre-	Post-
n	821	801	814	872	14,376	12,210	924	998	31		57	65	19.076[a]		159	177
Compliance with suggested preventative screening tests	NS															
24-hour compliance with suggested laboratory corollary orders (%)	46.3		46.3	21.9												
p-value[b]			$p < 0.0001$													
Compliance with suggested laboratory monitoring tests (%)					56.6	57.1	NR overall by group	NR overall by group	Resident: 20% Interns: 9% Nurses: 15%	49% 38% 24%			38.5	51.1	80.5	82.5
p-value[b]					$p = 0.31$		$p > 0.05$						$p < 0.0001$		$p > 0.05$	
Number of HbA1c tests performed per patient year											1.7 22.2 2.5	1.8 1.8 1.6				
Baseline:																
2-year follow-up																
4-year follow-up																

Study ID	Overhage (1996)[48]	Overhage (1997)[24]	Palen (2006)[90]	Matheny (2008)[91]	McDonald (1980)[29]	O'Connor (2005)[57]		Steele (2005)[94]	Abboud (2006)[87]
p-value						$p < 0.04$			
2-year follow-up						$p < 0.001$			
4-year follow-up									
Number of LDL cholesterol tests performed per patient year						0.54	0.49		
						0.87	0.59		
						1.45	0.92		
Baseline:									
2-year follow-up									
4-year follow-up									
p-value			$p = 0.33$			$p = 0.33$			
2-year follow-up			$p = 0.19$			$p = 0.19$			
4-year follow-up									
Proportion of patients meeting both HbA_{1C} and cholesterol tests thresholds						29.8	30.8		
						57.9	46.2		
						70.2	46.2		
Baseline:									
2-year follow-up									
4-year follow-up									

continued

TABLE 19 *Summary of process outcomes for studies assessing the impact of the display of reminders on compliance with preventative care measures or laboratory medication monitoring (continued)*

Study ID	Overhage (1996)[48]	Overhage (1997)[24]	Palen (2006)[90]	Matheny (2008)[91]	McDonald (1980)[29]	O'Connor (2005)[57]	Steele (2005)[94]	Abboud (2006)[87]
p-value				$p < 0.05$		$p < 0.05$		
2-year follow-up				$p < 0.01$		$p < 0.01$		
4-year follow-up								

NR, not reported; x-over, crossover trial.
a patient number not reported separately for pre-and post-intervention periods.
b difference between study groups.

TABLE 20 *Summary of process outcomes for studies assessing the impact of the display of reminders on redundant laboratory test orders and compliance with radiology referral guidelines*

Study ID	**Bates (1999)[92]**		**Carton (2002)[93]**	
Study design	RCT		ITS	
Intervention	OCS alone	OCS + CDSS	OCS alone	OCS + CDSS
n	5700	5886	6869	
Number of redundant test orders (*n*; %)	437 (47)	502 (53)		
Difference between groups in proportion of redundant tests performed (%)	24			
p-value[a]	$p < 0.001$			
% requests not complying with radiology referral guidelines			26.9	33.2
p-value[a]			$p < 0.0001$	

a Difference between groups

educational material, and were not limited to just the use of test restrictions. Follow-up within the study was conducted at 11 months, 27 months; 47 months and 72 months.[95]

The CPP study by Poley and colleagues[96] was conducted in 134 primary care practices in the Netherlands, with the study consisting of a 6-month pre-intervention period and a 6-month post-intervention period. The total length of study follow-up was therefore 12 months. The study included 234 primary care physicians (159 in the intervention group and 75 in the control group), with study inclusion criteria including submission of greater than 80% of blood test orders to one of the 27 laboratories participating in the study, and use of one of three information systems (Elias, MicroHIS, or Promedico) for which the CDSS was developed. There were no statistically significant differences in baseline sociodemographic variables either between physicians in the intervention and control groups, or between physicians in the intervention group and national figures on physicians from the Netherlands Institute for Health Services Research. The CDSS was comprised of an optimal but restricted list of blood tests based on recommendations for blood test ordering for the patient's indication, selected by the physician based on guidelines from the Dutch College of General Practitioners (http://nhg.artsennet.nl/). The GP could adhere to the proposed list or add or remove tests from the list as appropriate. Additionally, the GPs were not obliged to use the CDSS. The specific CDSS developed was a study specific system, that is available (in Dutch only) from the authors, and is integrated with the three OCS specified above as in the study.[96] A summary of the study characteristics from the two studies is displayed in *Table 21*.

Outcomes

Process outcomes

The area of impact in the test ordering process assessed in both studies were test volumes.[95,96] As both studies assessed the impact of CDSS on specific test types, these included test volumes pertaining to either serum magnesium test orders or the volume of blood test orders placed. The specific outcomes reported were weekly instances of serum magnesium test orders,[95] number of magnesium test orders per patient admission, reported magnesium test results,[95] the proportion of either calcium or phosphorus tests ordered concurrently with magnesium test orders,[95] the number of laboratory request forms submitted,[96] and the number of tests per order form.[96] Additionally, as previously stated, Poley and colleagues[96] also reported a cost-comparison for the development and implementation of the CDSS, compared to OCS alone, the results of which are reported in Chapter 6, Systematic review of economic evaluations.

Adverse effects of test cancellation

Neither of the studies reported any potential adverse effects of using the tests advocated by the restricted lists only.[95,96]

Study quality

In both studies, study eligibility criteria were adequately reported,[95,96] and groups were balanced in terms of sociodemographic variables

TABLE 21 *Study characteristics of studies assessing restricted lists*

Study ID	Setting/ country	Study design	Number of sites	Intervention (I)/ Comparison (C)	Study description	Area of impact	Outcomes	
							Process outcomes	Adverse effects of test cancellation
Rosenbloom (2005)[95]	Inpatients, Vanderbilt University Hospital, Nashville, TN, USA	ITS	1 (30 out of 33 inpatient wards)	Three different interventions were implemented sequentially. Baseline: no restrictions in place on frequency, context or volume of magnesium test ordering. (I) OCS + CDSS (time 1): targeted all open-ended laboratory and radiology orders; tests scheduled >72 hours into the future flagged, and user prompted to consider discontinuing order (time 2): targeted magnesium, calcium and phosphorus tests; display of previous test results and educational material displayed; test orders limited to one test per order (no recurrent testing possible) (time 3): targeted magnesium tests; display of previous test results and corrected magnesium values; test orders limited to one test per order; user had to enter a reason for test ordering.	Study conducted over a 6-year period January 1998 to December 2003 with 194,192 patients admitted during this period. All patients admitted to any hospital unit where the CDSS was implemented who required one of the indicated tests were eligible for inclusion. Follow-up was conducted at 23 months, 27 months, 47 months and 72 months	Test volumes	Weekly rates of serum magnesium test orders Number of magnesium test orders per patient Reported magnesium test results Number of calcium tests ordered concurrently with serum magnesium tests Number of phosphorus tests ordered concurrently serum magnesium tests	NR

Study ID	Setting/ country	Study design	Number of sites	Intervention (I)/ Comparison (C)	Study description	Area of impact	Outcomes	
							Process outcomes	Adverse effects of test cancellation
Poley (2007)[96]	Outpatient practices throughout the Netherlands	CPP	134	(I) OCS + CDSS: optimal, but restricted list of blood (C): OCS alone	Study consisted of 12-months; 6-months pre-intervention period where physicians ordered blood tests from an unrestricted list. 6-month intervention period where optimal but restricted list of blood tests were displayed for the patients suspected indication in the intervention group (n = 87 physicians). No restriction were placed on lists in control group (n = 47 physicians)	Test volumes	Number of laboratory request forms submitted Number of tests per order form	NR

at baseline in the pre–post study by Poley and colleagues.[96] In both studies the intervention appeared to be implemented independently of other changes in the study period, which is of particular import in the ITS study conducted by Rosenbloom and colleagues,[95] and in the study by Poley and colleagues was controlled for by use of a separate group that were not exposed to the CDSS intervention.[96] In both studies therefore, steps were taken to limit bias from exposure to other concomitant interventions or independent secular changes over time.

The intervention could not influence the methods of data collection in either of the studies, and the primary outcome measure of the number of test orders was reliable.[95,96] In the ITS study by Rosenbloom and colleagues[95] sufficient data points over time were reported for reliable statistical inference, and formal tests for trends were conducted.[95] In both studies statistical analyses were appropriate, and in the controlled pre–post study by Poley and colleagues comparisons of pre- and post-intervention periods, and between group comparisons were conducted.[96] However, data were not analysed on an 'intention to provide or communicate information' basis in this study, and the rate of attrition in the intervention group (23%) was reasonably high. This has the potential to bias the results, and no sensitivity analyses were conducted to explore differences between study completers, and those who dropped out.[96] In the ITS study by Rosenbloom and colleagues[95] analyses were conducted for all instances of test ordering, and results are therefore unlikely to be biased.

CDSS characteristics

A summary of the CDSS characteristics in both studies is displayed in *Table 22*. In the ITS by Rosenbloom and colleagues[95] the specific CDSS evaluated was the WizOrder Care Provider Order Entry System, a home-grown/inhouse system from Vanderbilt University Medical Centre. In this particular study a non-commercialised form of the software code was implemented. The CDSS used in the controlled pre–post study by Poley and colleagues was not reported, but a Dutch language version of the CDSS is available on request from the authors. Neither of the studies reported the CDSS reasoning methods, but the information used in the CDSS appeared to the normal reference ranges for serum magnesium test results in the study by Rosenbloom and colleagues[95] and information from the relevant guideline in the study by Poley and colleagues.[96]

In both studies the output format was primarily restricted lists, but also included restrictions on forward ordering, a graphical display of previous test results, and education material as concomitant interventions at different phases of the ITS by Rosenbloom.[95] Neither of the studies reported the time to complete the CDSS, or whether pilot testing and user training were provided prior to implementation. Both the CDSS were integrated with OCS and provided output at the time and location of decision making. Neither of the systems required the additional input of information. Additionally as output was limited to the display of restricted lists only and no specific recommendations were provided, the user was not required to document a reason for not following the CDSS recommendations. It was unclear in both studies whether the display of restricted lists was likely to promote action rather than inaction on the part of the physician. The data provided by the CDSS was used by the physician alone, and did not appear to provide periodic summaries of feedback performance.

Results

Process outcomes

In the ITS study by Rosenbloom and colleagues[95] at baseline when no intervention was in place the weekly rate of new serum magnesium test requests was 539. This decreased significantly to 380 per week after implementation of the first CDSS intervention ($p = 0.001$) (which targeted all open-ended laboratory and radiology orders; flagged tests scheduled >72 hours into the future and prompted the user to discontinue the order), increased significantly to 491 per week after the second intervention ($p < 0.001$) (which targeted magnesium, calcium and phosphorus tests; provided the display of previous test results and educational material, and limited tests to one per order, i.e. no recurrent testing was possible) and then decreased significantly to 276 per week after the third intervention ($p < 0.001$) (which targeted magnesium tests alone; displayed previous test results and corrected test values, limited test orders to one test per order; and prompted the user for a reason for the test ordering). Predicated upon this, the net serum magnesium test orders per patient followed a similar trend. CDSS users ordered a baseline mean of 0.87 test instances per admitted patient on all study wards. This decreased significantly to 0.59 net instances per patient with the first intervention ($p < 0.001$), increased significantly to 0.87 per patient after the second intervention ($p = 0.001$), and decreased

TABLE 22 *Summary of the CDSS characteristics in studies assessing the impact of restricted lists*

Study ID	**Rosenbloom (2005)[95]**	**Poley (2007)[96]**
CDSS characteristics		
1. Name of CDSS (if any)	WizOrder Care Provider Order Entry System[a]	NR
2. CDSS reasoning methods	NR	NR
3. CDSS knowledge base	Serum magnesium test results cut-offs	Guidelines
4. Information used in CDSS	NR	NR
5. Time to complete CDSS (minutes)	NR	NR
6. CDSS output format	Restricted lists	Restricted lists
7. Is a description of pilot testing with users prior to implementation provided?	No	No
8. Is user instructional training at the time of implementation described?	No	No
General system features		
9. Is the CDSS integrated with charting or OCS to support workflow integration?[b]	Yes	Yes
Clinician–system interaction features		
10. Is automatic provision of CDSS output provided as part of clinician workflow?[b]	Yes	Yes
11. Is there a need for additional data entry by the clinician?[b]	No	No
12. Does the CDSS request documentation of the reason for not following CDSS recommendations?[b]	No	No
13. Does CDSS provide output at the time and location of decision making?[b]	Yes	Yes
14. Are the CDSS recommendations executed by the clinician noting agreement?[b]	No	No
Communication content features		
15. Does the CDSS provide a recommendation rather than just an assessment?[b]	No	No
16. Does the CDSS promote action rather than inaction?[b]	NR	NR
17. Does the CDSS justify the output of provision of reasoning?[b]	No	No
18. Does the CDSS justify the output by provision of research evidence?[b]	No	No
Auxiliary features		
19. Were the local users involved in the CDSS development process?[b]	NR	No
20. Is the CDSS output provided to patients as well as clinicians?[b]	No	No
21. Does the CDSS provide periodic summaries of performance feedback?[b]	No	No
22. Is the CDSS used in conjunction with conventional education?[b]	No	No

NR, not reported.
a Home-grown system from Vanderbilt University Medical Centre.
b Features of CDSS proposed by Kawamoto and colleagues (2005) as predictors of system success or failure.[16]

significantly to 0.39 per patient after the third intervention ($p = 0.003$). There were no significant trend changes in net requests per patient with any of the interventions. At the end of the study period, the expected rate of magnesium testing had dropped to 0.41 requests per patient. Overall, magnesium serum testing was ordered on 21% of all admitted patients at baseline, and had dropped to 14% at the end of the study period. During all periods of the study, 14% of serum magnesium results fell outside the laboratory normal range, and 0.4% of results fell outside the physiologically acceptable range; there was no change in these rates with any of the interventions.

During the baseline period, 33% of orders for calcium testing were entered simultaneously with orders for serum magnesium testing. This did not change immediately upon implementation of the first intervention, but had dropped significantly over time to 23% prior to implementation of the second intervention ($p < 0.001$). Concurrent magnesium and calcium test ordering then increased significantly to 37% after implementation of the second intervention ($p < 0.001$), and then dropped significantly to 25% following implementation of the third ($p < 0.001$). During the baseline period, 48% of phosphorous test orders were entered simultaneously with orders for magnesium serum testing. This increased significantly to 80% with the implementation of the second CDSS intervention ($p < 0.001$), and then decreased significantly to 47% with implementation of the third ($p < 0.001$).

In the controlled pre–post study by Poley and colleagues[96] there was a significant decrease in the number of tests requested per order form between groups in the post-intervention period ($p < 0.001$). In the CDSS plus OCS group 5.9 (SD 1.5) tests were requested per form in the pre-intervention period compared with 5.5 (SD 1.4) requested with implementation of the CDSS [change within group: –0.4 (SD 0.7)]. This compared with 5.8 (SD 1.3) ordered in the pre-intervention period in the control group, and 5.8 (SD 1.3) in the post-intervention period [mean change within group: –0.01 (SD 0.4)] to give a significant difference between groups of –0.38 (95% CI –0.61 to –0.16) in the number of requests ordered per form.

However, there was no significant effect upon the number of laboratory request forms submitted with implementation of the CDSS. The mean number of forms submitted in the OCS plus CDSS group in the pre-intervention period was 358 (SD 174) compared with 356 (SD 177) with implementation of the system. The change of –2 (SD 53) forms between the pre- and post-intervention periods was not significant. Likewise, there were no significant differences between the number of forms submitted in either period between the intervention and control groups, with a mean change between groups of –7 forms (95% CI –26 to 11). In the control group 376 (SD 194) forms were submitted in the pre-intervention period, and 382 (SD 208) in the post-intervention period [change within group: +6 (SD 52)].

Summary of studies assessing the impact of the display of restricted lists

Two studies, one ITS study conducted on inpatients in the USA, and one CPP study conducted in general practice in the Netherlands assessed the impact of the display of restricted lists. The aim in both of the studies was to limit unnecessary test orders, and therefore the outcomes of interest were test volumes. Both of the studies focused on specific test types with Rosenblooom and colleagues[95] focusing primarily on serum magnesium test orders, and as secondary outcomes calcium and phosphorus test instances. Poley and colleagues[96] targeted a range of blood tests.

Results from the ITS by Rosenbloom and colleagues,[95] generally showed a significant reduction from baseline in mean weekly requests for serum test orders, from 539 at baseline, to 380 after the implementation of the first intervention, and 277 after the third. Paradoxically, there was a significant increase in test order rates after implementation of the second intervention to 491. Net requests of magnesium test orders per patient also followed this trend. Concurrent calcium and phosphorus test ordering with serum magnesium tests also showed a similar pattern, both decreasing significantly from baseline after implementation of the first intervention, increasing significantly after introduction of the second, and then decreasing significantly after the third. Overall, therefore, it would appear in this study that while the CDSS had the potential to regulate and limit unnecessary serum magnesium test ordering, other concomitant CDSS interventions may interact with this aim, and have the potential to paradoxically increase test ordering rates.

Limited results from the CPP study by Poley and colleagues[96] indicated that implementation of an optimal but restricted list of blood tests within

the CDSS did not significantly decrease the mean number of laboratory request forms over and above the use of OCS alone. However, there was a small (–0.38) but significant decrease noted in the number of test requests per form in favour of the intervention group. No results were reported for the overall number of blood tests conducted. A summary of the results of the two studies is displayed in *Table 23*.

Studies assessing the impact of the display of recommendations

Quantity and quality of the studies

The effect of the CDSS providing a recommendation was assessed in seven studies;[32,50,97–100,104] two CRCTs published by Hobbs and colleagues[32] and Cobos and colleagues[50] respectively; one RCT conducted by Apkon and colleagues;[97] and four pre–post studies undertaken by Bassa and colleagues,[98] Sanders and colleagues,[104] Nightingale and colleagues[99] and Boon-Falleur and colleagues.[100]

Across the studies, two each were conducted in the UK,[32,99] Spain,[50,98] and the USA,[97,104] with the remaining study being undertaken in Belgium.[100] Three of the studies which all focused on the management of hypercholesterolaemia were undertaken in primary care settings,[32,50,98] (one from the UK,[32] and two from Spain)[50,98] while of the remaining four studies conducted in a secondary care setting, one assessed the impact of CDSS recommendations on the number of health-care opportunities fulfilled in terms of the number of laboratory and radiology screening tests undertaken,[97] one examined the impact on test ordering patterns of neuroradiology head imaging studies,[104] while the further two studies assessed the impact on the number of laboratory test requests in patients either being assessed for or having undergone a liver transplantation.[99,100] The RCT which assessed the impact of recommendations on the number of laboratory and radiology screening test opportunities undertaken was conducted in the USA at two military treatment facilities[97] and reported the number of health-care opportunities fulfilled for a wide range of health problems including vaccinations, pharmacological treatments, smoking cessation, and diet and exercise counselling. As only the number of opportunities fulfilled, in terms of laboratory test screening and back pain imaging were of relevance to the current review, only data on these outcomes were extracted and are reported. A summary of study characteristics from the seven studies that assessed the impact of recommendations is displayed in *Table 24*.

The first CRCT which assessed the impact of the provision of recommendations was undertaken in 25 primary care practices (21 intervention and 4 control) in Birmingham, UK, by Hobbs and colleagues.[32] The aim of the 9-month trial, which included a 3-month historical baseline control period and a 6-month intervention period, was to examine the effect of CDSS on the management of hyperlipidaemia in patients not previously diagnosed with the problem. The primary outcome of interest in relation to this review was lipid test rates between intervention and control groups, although changes in prescribing and referral practices were also reported. The CDSS used was the Primed system designed for use in general practice by Wolfson Research Laboratories, University of Birmingham, UK. The software was a rule-based system, which provided an initial screening prompt for capture of patient sociodemographic and cardiovascular risk factor data. This also included the input of the patients' current cholesterol level. The patients' coronary risk score was then displayed on screen, with a score greater than 10 being in the top quintile for risk of a coronary event within the next 5 years.

Based on the risk score, the CDSS provided advice on patient management, with the rules underpinning the recommendations derived from a protocol developed by a lipid specialist. Overall, the trial was subject to high rates of attrition with eight clusters (seven intervention and one control) withdrawing (the total number of physicians within the trial was not reported). Furthermore, only limited results were reported, and all comparisons were analysed as a change from the 3-month baseline period, rather than as between group comparisons, thus limiting their utility in assessing the effects of the CDSS in conjunction with OCS compared to OCS alone.

The second non-inferiority CRCT conducted by Cobos and colleagues[50] in general practices in Spain (mainly drawn from the Catalonia region) aimed to assess the cost-effectiveness of CDSS for adapted recommendations based on guidelines from the European Society of Cardiology and other societies for Hypercholesterolemia Management.[124] The 12-month pragmatic trial,

TABLE 23 *Summary of process outcomes for studies assessing the impact of the display of restricted lists*

Study ID	**Rosenbloom (2005)[95]**				**Poley (2007)[96]**			
Study design	ITS				Controlled pre–post			
Intervention	Baseline	Int 1	Int 2	Int 3	OCS alone		OCS + CDSS	
					Pre-	Post-	Pre-	Post-
N (practices in analyses)	NR	NR	NR	NR	47	47	87	87
Process outcomes								
Mean instances of weekly serum magnesium test orders	539	380	491	277				
p-value between periods	–	0.001	<0.001	<0.001				
Net instances of magnesium test orders per patient	0.9	0.6	0.9	0.4				
p-value between periods	–	<0.001	0.001	0.003				
Proportion of calcium tests ordered concurrently with serum magnesium tests (%)	33	23	37	25				
p-value between periods	–	<0.001	<0.001	<0.001				
Proportion of phosphorus tests ordered concurrently serum magnesium tests (%)	48	NR	80	47				
p-value between periods	–	NR	<0.001	<0.001				
Mean number of laboratory request forms (*n*; SD)					376 ± 194	382 ± 208	358 ± 174	356 ± 177
Change within group (*n*; SD)					+6 ± 52		–2 ± 53	
Mean difference in change between groups (*n*; 95% CI)					–7 (–26 to 11)			
Number of test requests per order form (*n*; SD)					5.8 ± 1.3	5.8 ± 1.35	5.9 ± 1.5	5.5 ± 1.4
Change within group (*n*; SD)					–0.01 ± 0.4		–0.39 ± 0.7	
Mean difference in change between groups (*n*; 95% CI)					–0.38 (–0.61 to –0.16)			

NR, not reported.

included 44 practices (22 in the intervention group and 22 in the usual care group) with a total of 2191 patients (1046 in the intervention group and 1145 in the usual care group) with

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TABLE 24 *Study characteristics of studies assessing recommendations*

Study ID	Setting/ country	Study design	Number of sites	Intervention (I)/ Comparison (C)	Study description	Area of impact	Outcomes	
							Process outcomes	Adverse effects of test cancellation
Hobbs (1996)[32,a]	Outpatients in 25 practices, Birmingham, UK	CRCT	25	Baseline: OCS alone in all 25 practices (I) OCS + CDSS: recommendations on patient management (C) OCS alone: (no recommendations)	Practices were randomly allocated to intervention (n = 21) and control (n = 4) groups. Study comprised a 3-month baseline period in both groups where OCS alone was used, followed by a 6-month intervention period	Test volumes	Lipid test rates Number of patients receiving a full lipid profile (cholesterol, fasting triglyceride and HDL)	NR
Cobos (2005)[50]	Outpatients with hypercholesterolemia in 44 practices in Spain (mainly the Catalonia region)	CRCT	44	(I) OCS + CDSS: recommendations on therapy, frequency of follow-up visits, and laboratory tests. (C) OCS alone (no recommendations)	General practices were randomly allocated to intervention (n = 22 physicians; n = 1046 patients) or control (n = 22 physicians; n = 1145 patients) groups. Trial conducted over a 12- month period	Test volumes	Number of lipid assessments per visit Number of AST/ ALT tests per visit Number of CK tests per visit	NR
Apkon (2005)[97,b]	Outpatients at two military treatment hospitals, Ireland Army Community Hospital and Clinic, Fort Knox, KT, and Mayport Branch Health Clinic, Mayport, FL, USA	RCT	2	(I) OCS + CDSS: patients entered medical histories into appropriate Coupler. This information was used by CDSS to provide recommendation for 24 health-care measures (screening/prevention and acute/chronic disease management) (C) OCS alone (no Coupler or recommendation provided)	Patients were randomly allocated to intervention (Coupler) (n = 936) or control group (n = 966). Patients follow-up at 60 days to assess the 'quality of care' as defined by the number of opportunities for prevention/screening or acute/chronic disease management fulfilled	Compliance with recommendations Resource consumption	Number of health-care opportunities fulfilled within 60 days of index visit Laboratory test resource consumption within 60 days of index visit Diagnostic imaging test resource consumption within 60 days of index visit	NR

continued

TABLE 24 *Study characteristics of studies assessing recommendations (continued)*

Study ID	Setting/ country	Study design	Number of sites	Intervention (I)/ Comparison (C)	Study description	Area of impact	Outcomes	
							Process outcomes	Adverse effects of test cancellation
Bassa (2005)[98,c]	Outpatients with hypercholesterolemia, Vila Olimpica Primary Health Care Centre, Barcelona, Spain	UPP	1	Baseline: OCS alone (no recommendations (I) OCS + CDSS: recommendations on therapy, frequency of follow-up visits, and laboratory tests	Study consisted of 12-month pre-intervention period (OCS alone) and 12-month intervention period, with 500 patients included over both periods	Test volumes	Number of lipid profile tests carried out pre- and post intervention	NR
Sanders (2001)[104]	Inpatients;, Vanderbilt University Hospital, Nashville, TN, USA	UPP	1	Baseline: OCS alone (I) OCS + CDSS: recommendations to physicians for ordering an MRI of the brain or a CT of the head.	Study consisted of 17 weeks: 9-week pre-intervention and 8-week intervention. 742 orders were made pre-intervention and 704 during the intervention period	Test volumes	Number of tests ordered pre-and post- intervention Number of orders complying with the recommendation	NR

Study ID	Setting/ country	Study design	Number of sites	Intervention (I)/ Comparison (C)	Study description	Area of impact	Outcomes	
							Process outcomes	Adverse effects of test cancellation
Nightingale (1994)[99]	Inpatients, Supraregional Liver Unit, The Queen Elizabeth Hospital, Birmingham, UK	UPP	1	Baseline: OCS alone (no management protocol in place) (I) OCS + CDSS: recommendations for tests to be performed the following day based on latest test results and patient clinical categories	Study consisted of 2-year period; 1-year pre-intervention and 1-year intervention. Total patients (N = 1487; n = 654 pre-intervention and n = 833 intervention period)	Test volumes	Total number of tests requested per patient day Number of out of hours tests requested per patient day Direct laboratory costs per patient day Number of plasma urea and electrolyte tests, liver function tests, bone profile, calcium and other tests requested per patient day	NR
Boon-Falleur (1995)[100,d]	Inpatients, Paediatric Liver Transplantation Unit, Cliniques Universitaires St. Luc, Universite Catholique de Louvain, Brussels, Belgium	UPP	1	Baseline: OCS alone (no management protocol in place) (I) OCS + CDSS: recommendations for tests to be performed the following day based on latest test results and patient clinical categories	Study consisted of 12 months: 6-month pre-intervention and 6-month intervention period. Total patients (N = 2041; n = 1,153 pre-intervention and n = 888 intervention period)	Test volumes	Number of tests per patient (assessment protocols) Number of tests per patient (transplant protocols) Mean number of urgently requested tests per patient	NR

ALT, alanine aminotransferase; AST, aspartate aminotransferase; CK, creatine kinase; NR, not reported.
a No between group comparison conducted and specific figures for pre- and post-intervention data not reported.
b Results only extracted for laboratory and radiology test screening.
c Results extracted on the number of laboratory tests conducted pre- and post-intervention.
d CDSS assessed the same as that developed by Nightingale and colleagues[99] (multilingual version developed and used in Belgium).

a diagnosis of hypercholesterolemia. This was defined as a pre-treatment total cholesterol concentration > 200 mg/dL, and < 400 mg/dL. Patients who lacked a baseline lipid profile were excluded from all analyses. Patient groups were well matched at baseline in terms of age, gender, mean BMI, and other concomitant risk factors for hypercholesterolemia. No sociodemographic data on the physicians participating in the trial was reported.

The CDSS was based on adapted algorithms that were implemented in the intervention group and withheld in the usual care group that issued recommendations on therapy, frequency of follow-up visits, and laboratory tests according to the patient's cardiovascular risk factors LDL-C goals. Physicians were free to either adopt or ignore the CDSS recommendations. Adherence to the guideline was monitored by the CDSS and a reason requested in case of any discrepancy between the treatment recommended and prescribed. A concomitant intervention, of the provision of items such as table cloths and fridge magnets with relevant promotional messages was also undertaken in intervention group practices, but withheld in the usual care practices. Only data on the number of laboratory test analyses were extracted and are therefore reported in this review.

Like the trial conducted by Hobbs and colleagues[32] this study was subject to a high rate of missing post-baseline data with 26% of the intervention group and 28% of the control group having no post-baseline lipid profile. Additionally, only 59% of the intervention group and 47% of the usual care group had a follow-up of 9 months or more. However, appropriate sensitivity analyses to missing data (no post-baseline assessment and < 9 months follow-up) were conducted. Among patients lost to follow-up after the first (baseline) visit no change in lipids or coronary vascular risk (CVR) was assumed. This assumption was then tested in two different analyses, one including patients with at least one post-baseline assessment (per protocol analysis) and patients with a length of follow-up of at least 9 months.

The RCT conducted at the Ireland Army Community Hospital and Clinic, Fort Knox, KT, USA, and the Mayport Branch Health Clinic, Mayport, FL, USA, within two military treatment facilities by Apkon and colleagues[97] aimed to assess the impact of the use of CDSS on quality of patient care. This was defined as the total percentage of any of 24 health-care quality process measures (opportunities to provide evidence-based care) that were fulfilled within 60 days of a patients' index visit. The trial measured and reported a wide range of health-care opportunities, but as only the results of those that have an impact on laboratory testing or radiology imaging rates are relevant to the present review, only data for these outcomes were extracted and reported.

A total of seven outcomes were deemed relevant to this review:

1. cervical cancer screening
2. screening for *Chlamydia*
3. colorectal cancer screen
4. lipid level testing
5. back pain imaging
6. screening for diabetes using glycosylated haemoglobin levels
7. screening for lipid abnormalities.

In addition laboratory test resource and diagnostic test imaging consumption were reported.

These were calculated from the Centers for Medicare and Medicaid Services 2003 fee schedule using the relative value unit conversion rate of US$36.8. The 60-day trial included 4639 health-care opportunities (2374 in the intervention group and 2265 in the control group) among study patients at their index visit. Patient characteristics were reasonably well balanced at baseline in terms of age, gender, and type of visit (acute, established, routine, wellness or other). However, as data were reported by trial group rather than by patient indication, it is possible that there were baseline imbalances between the two groups which could potentially bias results. No sociodemographic data or the number of physicians involved in the trial were stated.

The CDSS intervention which used the DSIT Problem-Knowledge Couplers (PKC Corp, Burlington, VT, USA) involved the use of a number of 'Couplers' which were available for a wide range of preventive and acute/chronic disease management needs. Patients entered data into the Coupler appropriate for their complaint, or when no condition-specific Coupler was appropriate, a generic medical history and screening Coupler, prior to seeing the physician. This took approximately 20 minutes. Physicians treating intervention group patients could enter additional information before reviewing Coupler outputs outlining investigation or treatment options. Patients in the control group had no exposure

to Couplers. In total there were 667 health-care opportunities (325 in the intervention group and 342 in the control group) from the seven of relevance to this review.

Of the four pre–post studies, the first conducted by Bassa and colleagues[98] was undertaken at the Vila Olimpica Primary Health Care Centre, Barcelona, Spain and included 500 patients randomly selected from the Primary Health Care centre database with hypercholesterolemia. These patients had a median age of 67 years, 65.8% (329/500) were female, 18% had a concomitant diagnosis of diabetes mellitus (90/500), 16.6% (83/500) were current smokers, and 52.4% (262/500) had a sedentary lifestyle. In terms of the number of cardiovascular risk factors per patient at baseline in the study, 4.4% (22/500) had none, 34.8% (174/500) had one, 53.4% (267/500) had two, and 7.4% (37/500) had more than two. The number of physicians involved in the study or sociodemographic data on them were not reported.

The aim of the study was to assess the impact in terms of effectiveness and costs of CDSS and to implement a practice guideline for patient management. The study was carried out over a 2-year period, with 1-year pre-implementation of the CDSS and 1-year post-implementation. The CDSS recommendations were based on the Sociedad Española de Medicina de Familia y Comunitania's clinical guidelines for dyslipidemia management and cost-effectiveness data published in a meta-analysis.[125,126] Based on the patient's data (personal history of cardiovascular disease, cardiovascular risk factors, and lipid profile), the CDSS established the therapeutic objectives in terms of LDL cholesterol levels and issued testing, therapeutic and follow-up recommendations for the patient. Physicians were free to accept or decline the recommendations, but were prompted for a reason when they declined. The recommendations included dietary treatment, lipid-lowering drugs, monitoring of hepatic and muscular enzymes and a recommended date for the follow-up visit. As only data on the number of lipid-profile tests conducted and their costs are of relevance to the present review only these data were abstracted and are reported. Data associated with the mean cost of undertaking laboratory assessment tests and the data sources and method used to calculate these are reported in Chapter 6, Systematic review of economic evaluations.

The second pre–post study undertaken by Sanders and colleagues[104] was conducted at the Vanderbilt University Medical Centre, Nashville, TN, USA, using a module specifically designed for use in the University-specific WizOrder entry system. The study consisted of a 9-week control (pre-intervention) period and an 8-week intervention phase. The aim of the study was to assess the effects of guidelines implemented within the CDSS for the ordering of neurological head imaging studies on test ordering patterns and guideline compliance.

All physicians, nurses, medical students and receptionists who entered an order via the system for one or more head CT or brain MRI scans during the study period were eligible for inclusion in the study, with a total of 1446 orders included in the analyses (742 pre-implementation and 704 post-implementation). To develop the CDSS a list of common indications for ordering an imaging examination of the head or brain was created based on prior free text indications at the time of order entry, historical *International Classification of Diseases*, Ninth Edition (ICD-9) coding data and local clinical guidelines for the tests. These were then mapped to ICD-9 codes, and for each indication, the most appropriate imaging test determined.

The CDSS required input of the patients' acuity and indication by the user and provided a recommended test (head CT without contrast; head CT with contrast; head CT with and without contrast; brain MRI without contrast; and brain MRI with and without contrast). If a suggestion was given, this choice was defaulted. The user was able to override the recommendation and select any of the listed studies, but had to type the reason for doing so. If no indication for requesting the test was given by the user or 'other' was chosen, no CDSS recommendation was provided. Analyses were then conducted between study periods to evaluate changes in the distribution of test ordering patterns.

The last two pre–post studies were both conducted in secondary care settings involving patients either being assessed for, or undergoing, liver transplantation.[99,100] The first of the two studies, by Nightingale and colleagues[99] was undertaken in adult patients at the Supraregional Liver Unit, The Queen Elizabeth Hospital, Birmingham, UK. The study aimed to assess the effects of a CDSS protocol management system on the number of tests, costs, and the appropriateness of laboratory investigations requested. The study consisted of a 1-year pre-implementation phase during which 654 patients were assessed, and a 1-year post CDSS implementation phase during which 833 patients were assessed. Patient categories in terms

of the numbers undergoing initial assessment, reassessment, transplant, post-transplantation or being an emergency were fairly well matched between the two study periods. No socio-demographic data on the physicians involved in the study or their numbers were reported. The study specific CDSS was developed by Wolfson Computer Laboratories at the hospital, and aimed to implement the unit's existing investigation protocols developed by senior clinicians. These were based on information regarding the category of the patient's clinical state (e.g. assessment, transplant) and the use of the latest test results to propose the laboratory investigations to be performed on the following day. The system was based upon a combination of static and dynamic rules. Static rules were those that applied to all patients with a certain classification for a certain number of days, and dynamic rules were those which used the results of previous laboratory results to determine which investigations to propose. Once the physician had viewed the proposed tests they were free to accept or modify them as required.

The same CDSS as used in the study by Nightingale and colleagues[99] was adapted to a multilingual version and exported for use at the Paediatric Liver Transplantation Unit, Cliniques Universitaires Saint-Luc, Université catholique de Louvai, Brussels, Belgium by Boon-Falleur and colleagues.[100] This study, like that by Nightingale and colleagues,[99] aimed to assess the impact of the system on the number of laboratory tests performed pre-implementation and post-implementation. However, this study only included paediatric inpatients who were undergoing either a pre-transplant assessment protocol ($n = 183$; 32 pre-intervention and 151 post-intervention) or transplant protocol ($n = 34$; 10 pre-implementation and 24 post-implementation). No sociodemographic data on the patients in either study period were reported, and so it is not possible to comment on whether there were systematic differences in the patient populations in the pre- and post-intervention periods that may potentially confound the results. Likewise, no socio-demographic data on the physicians or the number involved in the study were reported.

The pre-implementation phase consisted of a 6-month period, but the length of post-intervention assessment was not reported. Additionally, the results were reported according to the number of tests per patient, rather than the number of tests per patient per day, which potentially confounds length of stay with number of tests, and is not an appropriate outcome measure.

Outcomes

Process outcomes

The area of impact in the test ordering process assessed in all seven studies were test volumes.[32,50,97–100,104] Additionally, the RCT by Apkon and colleagues[97] and the UPP study by Sanders and colleagues[104] also assessed compliance with guidelines for laboratory or imaging test protocols. As three of the studies, by Hobbs and colleagues,[32] Cobos and colleagues[50] and Bassa and colleagues,[98] assessed the impact of CDSS on hypercholesterolemia testing rates (either in patients diagnosed with the conditions or as a screening procedure in previously undiagnosed patients), the specific outcomes in these studies included lipid profile test rates,[32,50,98] number of patients receiving full lipid profile tests, (cholesterol, fasting triglyceride and HDL),[32] and the number of aspartate aminotransferase/alanine aminotransferase (AST/ALT) and creatine kinase (CK) tests per visit.[50] The RCT by Apkon and colleagues[97] assessed the number of health-care opportunities fulfilled within 60 days of the patients' index visit, so not only did this study report compliance with recommended laboratory/imaging recommendations, but also the number of tests completed between the intervention and control groups. The study also reported outcomes on the resources used in terms of both laboratory and imaging tests.[97] The pre–post study by Sanders and colleagues[104] being the only study to assess the impact of guidelines implemented within CDSS for CT/MRI head imaging protocols reported both the number of imaging tests ordered both pre- and post-implementation of the CDSS, but also the number of test orders that complied with guideline recommendations. The two pre–post studies that were undertaken in adult and paediatric liver transplantation patients by Nightingale and colleagues[99] and Boon-Falleur and colleagues[100] both reported changes in test volumes,[99,100] as well as additionally the number of out of hours requests,[99] number of specific tests requested for plasma urea and electrolyte, liver function, bone profile, and calcium levels,[99] number of urgently requested tests,[100] and laboratory costs per patient day.[99]

Adverse effects of test cancellation

None of the seven studies reported any adverse effects of not following the CDSS recommendations.[32,50,97–100,104]

Study quality

Controlled studies

In the CRCT by Hobbs and colleagues[32] and the RCT by Apkon and colleagues[97] the methods of randomisation were not stated, and it was also unclear whether allocation concealment were attained in these trials. Additionally, in the RCT by Apkon and colleagues[97] contamination may have occurred, as physicians treated both intervention and control group patients, and therefore any 'learning effect' from use of the CDSS Coupler may have passed onto the control group. The effect of this if any would be to underestimate the treatment effect in the Coupler intervention group. Additionally the results of this RCT are likely to be confounded by the completion of a 20 minute patient-completed computer-based questionnaire. In contrast, the CRTC by Cobos and colleagues[50] was properly randomised and took clustering into account in both the design and analysis. Eligibility criteria, baseline details and baseline similarity between groups were attained in both the CRCT by Cobos and colleagues[50] and RCT by Apkon and colleagues.[97] However, only partial details were presented on trial eligibility by Hobbs and colleagues,[32] and no sociodemographic data on participants were reported. It was therefore unclear whether groups were balanced at baseline. As can be expected in CDSS trials, physicians were not blinded to treatment allocation, and it was unclear whether outcome assessors were blinded. Data analysis were appropriate in the trials by Cobos and colleagues[50] and Apkon and colleagues,[97] and greater than 80% follow-up was attained in both trials. However, only Cobos and colleagues[50] undertook their analyses on an 'intention to provide or communicate information' basis. In the trial by Hobbs and colleagues[32] little detail regarding the analyses were reported, but no between group comparisons or specific point estimates were given. The few results reported, were reliant on differences between pre- and post-intervention rates, and were therefore not appropriate.

Uncontrolled studies

Study eligibility criteria were adequately reported by Bassa and colleagues,[98] Sanders and colleagues,[104] and Nightingale and colleagues,[99] but were only partially reported in the study by Boon-Faulleur and colleagues.[100] Baseline details were fully reported in only one of the four studies, that by Nightingale,[99] were partially reported in a further two by Bassa and colleagues[98] and Sanders and colleagues,[104] but no details were given in the paper by Boon-Faulleur and colleagues.[100] In relation to this it was impossible to tell whether there were potential differences in patient baseline characteristics between the pre- and post-intervention phases that may potentially confound the study results. Data analyses were appropriate in three of the studies,[98,99,104] but only conducted on an 'intention to provide or communicate information' basis in the studies by Sanders and colleagues[104] and Nightingale and colleagues.[99] Both of these studies additionally achieved a greater than 80% follow-up rate. In the study by Boon-Falleur and colleagues[100] the analyses were unclear, and the presentation of the results by the number of tests per patient rather than the number of tests per patient day confounds the length of hospital stay with the number of tests. The results of this study should therefore be interpreted with caution.

CDSS characteristics

A summary of the key characteristics of the CDSS used in the seven studies is displayed in *Table 25*. The specific CDSS used was only reported in three of the studies,[32,97,104] these included the DSIT tool Problem-Knowledge Couplers (PKC Corp, Burlington, VT, USA) implemented within the existing Military Health System's electronic medical system (Composite Healthcare System),[97] the Primed system developed specifically for use in patients with hyperlipidemia in a primary care setting by Wolfson Research Laboratories, University of Birmingham, UK,[32] and the WizOrder entry system, the home-grown/in-house system from Vanderbilt University Medical Center, Nashville, TN, USA.[104] In the other studies, three of the other four CDSS appeared to have been developed and implemented specifically for the sites and specialities in which it was used (in two studies screening for hyperlipidemia[50,98] and in the third for the assessment and management of patients undergoing liver transplantation).[99] This CDSS was developed again by Wolfson Research Laboratories, University of Birmingham, UK, and adapted to a multilingual version for use in the study by Boon-Falleur and colleagues,[100] again for the management of liver transplantation patients.

In three of the seven studies the CDSS reasoning methods were discrimination rules,[32,99,100] and in a further two clinical algorithms.[50,98] Reasoning methods were not clear in the remaining two studies.[97,104] The CDSS knowledge base was either expert opinion,[32,99,100] clinical guidelines,[98,104] or a combination of prior indications at the time of order entry, historical ICD-9 coding data and guidelines.[104] The information used in the

TABLE 25 *Summary of the CDSS characteristics in studies assessing the impact of the display of recommendations*

Study ID	Apkon (2005)[97]	Hobbs (1996)[32]	Cobos (2005)[50]	Bassa (2005)[98]	Sanders (2001)[104]	Nightingale (1994)[99]	Boon-Falleur (1995)[100]
CDSS characteristics							
1. Name of CDSS (if any)	DSIT tool Problem-Knowledge Couplers[a]	Primed system[b]	NR	NR	WizOrder[c]	NR[b]	NR[b]
2. CDSS reasoning methods	NR	DR	CA	CA	NR	DR	DR
3. CDSS knowledge base	NR	Expert opinion (protocol developed by lipid specialist)	Recommendations of the European Society of Cardiology and other societies for Hypercholesterolemia Management	SEMFYC (Sociedad Española de Medicina de Familia y Comunitania's) clinical guidelines for dyslipidemia management and cost-effectiveness data published in a meta-analysis	Prior free indications at the time of order entry, historical ICD-9 coding data and local published guidelines	Expert opinion	Expert opinion
4. Information used in CDSS	Patients entered their medical histories into the appropriate Coupler tool for their complaint	Sociodemographic details; CV risk factors; cholesterol level	History Biochemical laboratory test results (number of items NR)	History of CV disease; CV risk factors and lipid profile	Acuity and indication	NR	NR (signs; symptoms; history, biochemical test results)
5. Time to complete CDSS (minutes)	30	NR	NR	NR	NR	NR	NR
6. CDSS output format	R	R	R	R	R	R	R
7. Is a description of pilot testing with users prior to implementation provided?	No	No	No	No	No	No	No
8. Is user instructional training at the time of implementation described?	No	Yes	No	No	No	Yes	No

Study ID	Apkon (2005)[97]	Hobbs (1996)[32]	Cobos (2005)[50]	Bassa (2005)[98]	Sanders (2001)[104]	Nightingale (1994)[99]	Boon-Falleur (1995)[100]
General system features							
9. Is the CDSS integrated with charting or OCS to support workflow integration?[a]	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Clinician–system interaction features							
10. Is automatic provision of CDSS output provided as part of clinician workflow?[a]	Yes	Yes	Yes	Yes	Yes	Yes	Yes
11. Is there a need for additional data entry by the clinician other then the specification of which test orders?[a]	No	Yes	No	No	No	Yes	Yes
12. Does the CDSS request documentation of the reason for not following CDSS recommendations?[a]	?	NR	Yes	Yes	Yes	No	No
13. Does CDSS provide output at the time and location of decision making?[a]	Yes	Yes	Yes	Yes	Yes	Yes	Yes
14. Are the CDSS recommendations executed by the clinician noting agreement?[a]	No	No	No	No	No	No	No
Communication content features							
15. Does the CDSS provide a recommendation rather than just an assessment?[a]	Yes	Yes	Yes	Yes	Yes	Yes	Yes

continued

TABLE 25 *Summary of the CDSS characteristics in studies assessing the impact of the display of recommendations (continued)*

Study ID	Apkon (2005)[97]	Hobbs (1996)[32]	Cobos (2005)[50]	Bassa (2005)[98]	Sanders (2001)[104]	Nightingale (1994)[99]	Boon-Falleur (1995)[100]
16. Does the CDSS promote action rather than inaction?[a]	?	NR	NR	NR	NR	NR	NR
17. Does the CDSS justify the output of provision of reasoning?[a]	No	No	No	No	No	No	No
18. Does the CDSS justify the output by provision of research evidence?[a]	No	No	No	No	No	No	No
Auxiliary features							
19. Were the local users involved in the CDSS development process?[a]	No	No	No	NR	Yes	Yes	No
20. Is the CDSS output provided to patients as well as clinicians?[a]	No	No	No	No	No	No	No
21. Does the CDSS provide periodic summaries of performance feedback?[a]	No	No	No	No	Yes	Yes	No
22. Is the CDSS used in conjunction with conventional education?[a]	No	No	No	No	No	No	No

CA, clinical algorithm; DR, discrimination rules; NR, not reported; R, recommendations; ?, unclear.
a PKC Corp, Burlington, VT, USA.
b Home-grown system from Wolfson Research Laboratories, University of Birmingham, UK.
c Home-grown system from Vanderbilt University Medical Centre, Nashville, TN, USA.

CDSS was the patient's medical history in one RCT which patients entered themselves into the appropriate Coupler,[97] CV risk factors coupled with either cholesterol level or lipid profile in three studies,[32,50,98] acuity and indication in the pre–post study assessing the impact of CDSS implemented guidelines for radiological imaging in one study,[104] and not reported in the remaining two studies.[99,100] In these two studies it would, however, appear to have been based on the patients condition, history, and results of any previous laboratory tests.[99,100] The CDSS outputs in all the studies was the display of recommendations. Only the RCT by Apkon and colleagues[97] reported the length of time to complete the CDSS Coupler which was 20 minutes and patient completed. In relation to the 14 features of CDSS proposed by Kawamoto and colleagues[16] as being important to the success or failure of a CDSS, the CDSS was not reported as being piloted with users prior to implementation in any of the seven studies, and user instructional training was provided in only one.[32] In all seven studies the CDSS was integrated as part of the OCS, and provided output automatically as part of the consultation workflow. In three of the studies there was a need for additional data entry by the physician,[32,99,100] while in a further study this was optional.[97] Additionally, in three studies there was a need for documentation for not following the CDSS recommendations,[50,98,104] however, none of the studies required the physician to note agreement with the recommendations in order for these to be implemented. In none of the studies was a recommendation justified by recourse to the CDSS reasoning methods or evidence upon which these were based. Additionally it would appear that local users were directly involved in the CDSS development process in only two of the studies.[100,104] The data provided by the CDSS was used by the physician alone, and only in two studies was periodic performance feedback provided.[99,104] None of the studies deployed any concomitant educational cointerventions.

Results

In the CRCT by Hobbs and colleagues[32] which assessed the impact of CDSS on screening patients with previously undiagnosed hyperlipedmia no point estimates for pre- and post-implementation rates of lipid test rates were reported. Likewise, no between group comparisons were conducted. The authors stated that in the 9-month post-implementation period the mean rate of testing was 4.4 tests/1000 population/month. This rate was not significantly different from the pre-intervention phase. However, the authors stated that there was a significant increase in the number of patients receiving a full lipid profile in the intervention phase, and a decrease in those having only a partial investigation compared with the baseline period ($p < 0.05$). Again the exact figures were not reported.

Similarly, in the 1-year CRCT conducted by Cobos and colleagues[50] there were no significant differences between the treatment and usual care groups ($n = 1046$ and 1145 respectively) in the number of lipid assessments conducted per patient visit. This was 1.8 in the intervention group compared with 1.8 in the control group ($p = 0.298$). However, there was a significant increase in the number of patients receiving AST/ALT tests per visit in the intervention group, 1.4 compared to the control group, 1.3 ($p = 0.033$). No significant differences were observed in the number of CK tests performed per patient visit, with 0.54 and 0.24 conducted in the intervention and control groups respectively ($p = 0.053$).

The 60-day trial undertaken by Apkon and colleagues[97] to assess the impact of CDSS Coupler recommendations on the number of health-care opportunities fulfilled 60-days after the patient's initial index visit, showed no statistically significant differences between the treatment groups in terms of any of the seven opportunities related to laboratory or imaging tests screening. A break down of the number of opportunities fulfilled in each group by opportunity type is displayed in *Table 26*.

However, the authors reported a statistically significant increase in median laboratory test resource consumption in the intervention group of US$43 (range: 0–144) compared to the usual care group, US$31 (range: 0–139) ($p = 0.04$). No differences were observed between the two groups in terms of diagnostic test imaging consumption, with these being US$31 (range: 0–148) and US$29 (range: 0–127) in the intervention and control groups respectively ($p = 0.26$).

Bassa and colleagues[98] from their 2-year pre–post study on the effects of the implementation of guidelines for the treatment of patients with hypercholesterolmia implemented via CDSS, reported no significant differences in the number of lipid tests carried out in the pre-and post-implementation phases of the study. At baseline a total of 773 tests were conducted per annum compared with 763 post-intervention ($p = 0.59$).

TABLE 26 *Summary of the number of health-care opportunities completed by treatment group and type of opportunity*

Opportunity type	OCS + Coupler (*n* = 325)	OCS alone (*n* = 342)	Difference between groups
Cervical cancer	26/95 (27.4%)	22/98 (22.4%)	$p = 0.47$
Chlamydia	22/73 (30.1%)	19/64 (29.7%)	$p = 0.90$
Colorectal cancer	4/32 (12.5%)	2/58 (3.4%)	$p = 0.15$
Lipids	13/49 (26.5%)	18/48 (37.5%)	$p = 0.32$
Back pain imaging	4/4 (100%)	2/2 (100%)	NA
Diabetes – glycosylated haemoglobin	3/6 (50%)	1/3 (33.3%)	$p = 0.48$
Lipid abnormalities	12/66 (18.2%)	11/69 (15.9%)	$p = 0.81$

NA, not available.

In the 17-week pre–post study by Sanders and colleagues[104] examining the effects of implementation of a guideline for ordering head or brain imaging studies, there was a small significant decrease in the number of imaging tests ordered after implementation of the CDSS. This fell from 742 tests ordered in the pre-implementation phase to 704 tests post-intervention ($p = 0.048$). Compliance with ordering the CDSS recommended tests however, was still fairly low at only 60%.

The two pre–post studies by Nightingale and colleagues[99] and Boon-Falleur and colleagues[100] assessing the impact of CDSS recommendations for adult and paediatric inpatients pre- and post-liver transplantation protocols showed slightly disparate results. In the 2-year study by Nightingale and colleagues[99] there was a significant (17%) overall reduction in the number of tests requested per patient day from 8.5 (SD 3.6) pre-intervention to 7.0 (SD 3.5) with the implementation of the protocols ($p < 0.001$). This reduction was consistent across all patient categories apart from patients undergoing routine reassessment in which an insignificant reduction from 4.8 (SD 2.7) to 3.7 (SD 2.7) tests per patient day was observed, and those undergoing an annual post-transplant review in which an insignificant 12% reduction in the number of tests ordered from 7.4 (SD 4.1) to 6.6 (SD 2.9) per patient day was observed. Additionally, there was an increase in the number of tests ordered for patients with emergency acute hepatic failure of 17%, from 6.7 (SD 3.8) at baseline to 7.8 (SD 4.0) per patient day post-implementation. A summary of the changes in the number of tests ordered per patient per day by patient category is displayed in *Table 27*.

The implementation of the CDSS protocols resulted in a significant 48% decrease in the number of out of hours tests requested per patient day, from a pre–post baseline of 0.31 to a post-intervention number of 0.16 ($p < 0.001$). Likewise, the median number of plasma urea and electrolyte tests ($p < 0.05$), bone profile tests ($p < 0.001$), and calcium tests ($p < 0.005$) were all significantly reduced. However, there was no significant reduction in the number of liver function tests conducted, and a minor non-significant increase in the number of others tests undertaken. The overall reduction in the number of tests conducted was reflected in direct laboratory costs per patient days with a significant 28% reduction observed ($p < 0.001$).

Results of the study by Boon-Falleur and colleagues[100] in contrast to those of Nightingale and colleagues[99] showed a 13% increase in the number of tests ordered per patient stay for patients undergoing pre-treatment assessment protocols. The authors did not state whether this was statistically significantly different from the number of tests ordered prior to implementation of the system. Interestingly, the largest increase in test orders (46%) was observed in the 'other test' category which consisted of special chemistry, serology, nuclear medicine and bacteriology tests, suggesting that more specialised diagnostic tests were requested more frequently after introduction of the CDSS. A summary of the number and type of tests ordered for patients undergoing assessment protocols pre- and post-implementation of the CDSS is displayed in *Table 28*.

In contrast to patients undergoing an assessment protocol, there was a 27% decrease observed in the number of tests requested per patient stay for

TABLE 27 *Total number of tests requested per patient day by patient category by Nightingale and colleagues (1994)[99]*

Patient category	Pre-[a]	Post-[a]	% change	Student's *t*-statistic
Initial assessment	7.1 (2.9)	5.4 (3.0)	–25	5.23[b]
Reassessment (routine)	4.8 (2.7)	3.7 (2.7)	–22	1.92
Reassessment (problem)	7.7 (2.1)	6.3 (2.3)	–19	2.67[c]
Transplant	11.0 (2.8)	9.6 (3.3)	–13	3.37[b]
Post-transplant (problem)	7.8 (2.5)	6.9 (2.3)	–11	2.62[c]
Post-transplant (t tube removal)	6.6 (4.0)	5.0 (2.1)	–25	2.41[d]
Post-transplant (annual review)	7.4 (4.1)	6.6 (2.9)	–12	1.73
Emergency (acute hepatic failure)	6.7 (3.8)	7.8 (4.0)	+17	1.37
Emergency (acute problem – chronic disease)	11.1 (4.2)	8.0 (4.1)	–28	2.57[d]
Other	6.2 (4.3)	5.5 (4.1)	–11	0.73
Total	**8.5 (3.6)**	**7.0 (3.5)**	**–17**	**8.10[b]**

a Mean (standard deviation) values.
b $p < 0.001$.
c $p < 0.01$.
d $p < 0.05$.

those undergoing a transplant protocol, from 1047 pre-implementation of the system, to 768 post-implementation. This was most marked for the 'other test' category in which a 33% decrease in the number of tests ordered was observed. Again the authors did not state whether this decrease from baseline levels was statically significant. There was also a 44% decrease in the number of urgently requested tests per patient from 65 per patient prior to CDSS implementation to 36 post-implementation.

Summary of studies assessing the impact of the display of recommendations

The effect of the CDSS providing a recommendation was assessed in seven studies;[32,50,97–100,104] two CRCTs,[32,50] one RCT,[97] and four pre–post studies.[98–100,104] Study quality was variable and only limited results were reported in one of the CRCTs by Hobbs and colleagues[32] and in the RCT by Apkon and colleagues.[97]

In the three studies that focused on the impact of the CDSS providing recommendations for the management of patients with hyperlipidemia, there was no significant effect in terms of increasing lipid test rates.[32,50,98] However, there was some limited impact in two, of increasing either the number of patients receiving a full lipid profile,[32] or receiving an AST/ALT test.[50] However, to what degree these marginal increases would translate into improved management of patients with hyperlipidemia is unclear.

Likewise, the one RCT that assessed the impact of recommendations provided by a CDSS Coupler on the number of patient health-care opportunities fulfilled showed no significant benefit in terms of the number of either laboratory or diagnostic screening imaging tests undertaken compared with usual care.[97] In fact, there was a significant increase in laboratory test resource consumption compared with the usual care group.

In the one UPP study that assessed the impact of CDSS guideline recommendations conducted by Sanders and colleagues[104] a small but significant reduction in the number of head or brain imaging studies was observed. However, despite this reduction compliance with the tests indicated by the guideline recommendations remained relatively low at only 60%.[104]

TABLE 28 *Total number of tests requested per patient stay by test type for patients undergoing an assessment protocol by Boon-Falleur and colleagues (2005)[100]*

Test category			
Number of tests per patient stay: pre-treatment assessment protocols	**Pre- (*n* = 32)**	**Post- (*n* = 151)**	Δ%
General chemistry	46	53	+15
Virology	22	18	–18
Haematology and coagulation	23	30	+30
Others	13	19	+46
Total	**106**	**120**	**+13**
Number of tests per patient stay: transplant protocols	**Pre- (*n* = 10)**	**Post- (*n* = 24)**	Δ%
General chemistry	368	273	–26
Virology	70	49	–30
Haematology and coagulation	345	268	–22
Others	264	178	–33
Total	**1047**	**768**	**–27**

Overall the results of the studies by Nightingale and colleagues[99] and Boon-Falleur and colleagues[100] conducted in specialist liver transplant centres showed that the implementation of guideline protocols for patient management may have differential effects according to the patient group. Overall, there tended to be a significant decrease in the number of laboratory tests ordered, the number of out of hours tests requested, and a reduction in laboratory costs. However, as appropriate levels of testing are driven by the patients' condition and disease stage there were some increases observed in test requesting in certain patient groups. This was most pronounced in the study by Boon-Falleur and colleagues[100] in which a 13% increase in the number of laboratory tests ordered in patients undergoing an initial assessment protocol was observed. A summary of the results from the studies assessing the impact of the display of recommendations is given in *Table 29*.

Study question 3. What features of CDSS are associated with clinician or patient acceptance of CDSS in order communication systems?

A total of 31 papers were screened for relevance to address the above question, however, none of these finally met the inclusion criteria. For the majority of these this was due to the fact that studies had assessed the acceptability of the overall CDSS for both pharmaceutical ordering as well as laboratory and imaging test ordering. Therefore it was not possible to discern the acceptability of the system to physicians for test ordering alone from these studies. A list of the 31 excluded studies and their reasons for exclusions are displayed in Appendix 2.

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TABLE 29 *Summary of process outcomes for studies assessing the impact of the display of recommendations*

Study ID	**Hobbs (1996)[32,a]**		**Cobos (2005)[50,a]**		**Apkon (2005)[97,b]**		**Bassa (2005)[98]**		**Sanders (2001)[104]**		**Nightingale (1994)[99]**		**Boon-Falleur (1999)[100]**	
Study design	CRCT		CRCT		RCT		UPP		UPP		UPP		UPP	
	OCS alone	OCS + CDSS	OCS alone	OCS + CDSS	OCS alone	OCS + CDSS	OCS alone	OCS + CDSS	OCS alone	OCS + CDSS	OCS alone	OCS + CDSS	OCS alone	OCS + CDSS
Process outcomes							Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
N	21	4	22	22	325	342	500	404	NR	NR	654	833	42	175
Lipid test rates[c]	4.4	4.4												
p-value[d]	$p > 0.05$													
Number of patients receiving a full lipid profile	NR	NR												
p-value[d]	$p < 0.05$													
Number of lipid assessments/ patient visit			1.8	1.89										
p-value[e]			$p = 0.298$											
Number of AST/ALT tests/patient visit			1.4	1.3										
p-value[e]			$p = 0.033$											
Number of CK tests/ patient visit			0.5	0.2										
p-value[e]			$p = 0.053$											
Number of health-care opportunities fulfilled					NR	NR								
p-value[e]					$p > 0.05$									

continued

TABLE 29 *Summary of process outcomes for studies assessing the impact of the display of recommendations (continued)*

Study ID	Hobbs (1996)[32,a]	Cobos (2005)[50,a]	Apkon (2005)[97,b]		Bassa (2005)[98]		Sanders (2001)[104]		Nightingale (1994)[99]		Boon-Falleur (1999)[100]	
Laboratory test resource consumption (US$)			43 (range: 0–144)	31 (range: 0–139)								
p-value[e]			$p = 0.04$									
diagnostic test imaging consumption (US$)			31 (range: 0–148)	29 (range: 0–127)								
p-value[e]			$p = 0.26$									
Lipid test rates (annum)					773	763						
p-value[d]					$p = 0.59$							
Number of imaging tests orders							742	704				
p-value[d]							$p = 0.048$					
Number of laboratory tests/									8.5 ± 3.6	7.0 ± 3.5		
patient day												
p-value[d]									$p < 0.001$			
Number of laboratory out of hours requests/ patient day									0.32	0.16		
p-value[d]									$p < 0.001$			
Process outcomes											Pre-	Post-
Number of laboratory tests/ patient stay (assessment protocol)											106	120

Study ID	Hobbs (1996)[32,a]	Cobos (2005)[50,a]	Apkon (2005)[97,b]	Bassa (2005)[98]	Sanders (2001)[104]	Nightingale (1994)[99]	Boon-Falleur (1999)[100]	
p-value[d]							NR	
Number of laboratory tests/ patient stay (transplant protocol)							1047	768
p-value[d]							NR	

NR, not reported.
a denotes number of clusters.
b denotes number of health-care opportunities in patients presenting with any one of the seven outcomes of relevance to this review.
c denotes per 1000 population/month.
d *p*-value calculated as the change in mean from baseline not the differences between groups.
e *p*-value calculated for differences between treatment groups.

Chapter 6

Systematic review of economic evaluations

Aim

To summarise existing published research evidence on both the costs and cost-effectiveness of CDSS in conjunction with OCS for diagnostic, screening or monitoring test ordering compared with OCS alone, with particular emphasis on the potential generalisability of previous studies to the current NHS policy and clinical context.

Methods

Search strategy

The generic search strategy used to identify relevant studies for inclusion in the three reviews is described in the section Identification of relevant studies, Chapter 3, and the search strategy documented in Appendix 1.

Study selection criteria

Apart from the study design criteria, the inclusion and exclusion criteria as outlined in Chapter 3 were identical to those for question two, the review of studies to assess the impact of CDSS in OCS versus OCS alone for diagnostic, monitoring or screening test ordering. For this review full CEA, CUA, CBA, CCA, and cost–comparison studies were eligible for inclusion. Economic evaluations that only reported the average cost-effectiveness ratios were also eligible for inclusion provided the incremental ratios could be calculated from the available published data. Based on the above inclusion/exclusion criteria, initial study selection was made on the basis of titles and abstracts from the search results by one reviewer, and a random 20% of these checked, unblinded by a second reviewer.

Data extraction strategy

Data were extracted by one reviewer and checked for accuracy by a second. Data extraction was limited by data availability in many studies. Relevant results were tabulated alongside the data for the main review to address the impact of CDSS in conjunction with OCS versus OCS alone (study question 2) and are presented in Appendix 3.

Quality assessment strategy

Both of the included identified studies primarily assessed the impact of CDSS plus OCS versus OCS alone, and were reported alongside evaluations of the impact of CDSS on process and patient outcomes. Therefore the reported cost comparisons were reported as secondary outcomes. Due to this the methodological quality of the studies was assessed according to the criteria for each study design outlined for question two, rather than by specific criteria for studies of economic evaluations. The methodological quality of both of the identified studies is previously discussed under the section including the review by Poley and colleagues[96] (Chapter 5, Studies assessing the impact of the display of restricted lists) and the review by Bassa and colleagues[98] (Chapter 5, Studies assessing the impact of the display of recommendations).

Results

As previously stated only two studies met the inclusion criteria, both of which were cost analyses.[96,98] A full description of both of the studies is reported in Chapter 5 in the sections Studies assessing the impact of the display of restricted lists and Study question 3. What features of CDSS are associated with clinician or patient acceptance of CDSS in order communication systems? on the impact of CDSS plus OCS versus OCS alone. One of the studies by Poley and colleagues[96] was conducted in the Netherlands, while the second study by Bassa and colleagues[98] was conducted in Spain. The perspective taken in both studies was the societal level.[96,98] The first study was a CPP study by Poley and colleagues[96] conducted in 134 primary care practices including 234 primary care physicians (159 in the intervention group and 75 in the control group) which aimed to evaluate the cost analyses of a computer-based CDSS for ordering blood tests in a primary care setting compared with OCS alone.[96] The study consisted of a 6-month pre-intervention period and a 6-month post-intervention period. The CDSS comprised an optimal but restricted list of blood tests based on recommendations for blood test ordering for the patient's indication, selected by the physician

based on guidelines from the Dutch College of General Practitioners (http://nhg.artsennet.nl/). Minimum, maximum and base-case intervention costs (comprising the costs of both developing and installing the CDSS) were calculated. Development costs comprised: (1) personnel costs for reviewing 83 different guidelines for possible recommendations on blood tests, (2) writing the content, programming the software, testing prototypes, writing an explanatory leaflet about the CDSS, and writing instructions for installation and use. A summary of the minimum, maximum and base-case interventions costs is displayed in *Table 30*.

The minimum, base-case and maximum costs for installing the CDSS per practice were therefore €502, €670 and €839. As the CDSS was ultimately installed in 118 practices the total minimum and maximum estimate of the costs of developing and installing the CDSS was €41,000 and €48,000 respectively, with a base-case estimate of €44,000.

As the cost of laboratory requests depended on (1) the number of blood samples obtained and (2) the number and type of laboratory tests performed, data on the number of blood samples and blood tests performed in the pre-intervention and post-intervention phases were obtained from the laboratories. Costs were calculated by multiplying the number of blood samples and the number of tests by their unit costs. All unit costs were obtained from the national list of charges established by the Dutch Board for Health Care Tariffs (year 2003). The cost for obtaining a blood sample was set at €11.50, with the cost per test varying from €1.47 to €33.19 depending on the type of test. In addition to these costs (which included the cost of materials, laboratory personnel, and housing) the salary costs of a clinical chemist or medical microbiologist were included.

As previously stated in the review of studies on the impact of CDSS in OCS for diagnostic, screening or monitoring test ordering on process or patient outcomes, there was a significant decrease in the intervention group in the number of tests per order form (–6%) compared to the control group (+0%) ($p = 0.001$). This in combination with the type of laboratory blood test ordered and performed

TABLE 30 *The minimum, maximum and base-case intervention costs of developing and installing the CDSS in each practice from Poley and colleagues (2007)[96]*

	Minimum estimate		Base-case estimate		Maximum estimate	
	Hours	**Costs (€)**	**Hours**	**Costs (€)**	**Hours**	**Costs (€)**
Developing the CDSS						
Writing CDSS content	108	3000	138	4000	168	5000
Expert meeting	228	9000	228	9000	228	9000
Software programming	480	15,000	560	17,000	640	19,000
Testing prototypes	64	2000	64	2000	64	2000
Writing instructions	400	12,000	400	12,000	400	12,000
Subtotal	1280	41,000	1390	44,000	1500	48,000
Costs per practice (n = 118)		349		377		405
Installing CDSS; performed by:						
Our team (n = 90 practices)	463	15,000	1048	30,000	1634	46,000
Physician (n = 8)	26	1000	33	1000	41	1000
Colleague physician (n = 20)	54[a]	2000	74[a]	3000	94[a]	4000
Subtotal	542	18,000	1155	35,000	1769	51,000
Costs per practice (n = 118)		153		293		434
Total	1821	59,000	2545	79,000	3268	99,000
Total costs per practice (n = 118)		**502**		**670**		**839**

resulted in an insignificant mean cost decrease of 3% (€639) in the intervention group in the post-intervention phase, compared with a 2% (€208) increase in the control group ($p = 0.09$). Thus the CDSS yielded a mean cost saving of €847 per practice per 6 months (i.e. €639 plus €208).

The break-even point at which savings on laboratory costs exceeded the intervention costs was therefore reached after 5 months. Sensitivity analysis using the best-case scenario (upper limit of the 95% CI of the difference in laboratory cost requests; i.e. yearly savings of €3,669 per practice) and the minimum estimate of the intervention costs (€502 per practice) indicated intervention costs would be offset by savings as early as 2-months post-intervention implementation. Sensitivity analysis using the worst-case scenario (lower limit of the 95% CI of the difference in laboratory cost requests; i.e. increase of €282 per practice and the maximum estimate of the intervention costs (€838 per practice per year) indicated intervention costs would not be outweighed by savings on laboratory costs.

The second UPP study by Bassa and colleagues[98] which assessed the impact on the effectiveness and costs of a practice guideline implemented through CDSS for the management of patients with hypercholesterolemia in a primary care setting, reported cost data pre- and post-implementation of the CDSS for pharmacological treatment, and laboratory tests. Only very minimal data were reported. The specific tests assessed were lipid profile and safety analyses (transaminases and muscular enzymes). These were costed using the Soikos database of health-care costs,[127] with €0.46 for total cholesterol, €2 for LDL, €3 for HDL, €4 for triglycerides, €15 of CK, €1 for serum glutamic oxaloacetic transaminase, and €1 for serum glutamic pyruvic transaminase respectively. Despite the fact that there were no significant differences in the number of lipid profile tests conducted in the pre- and post-intervention periods (773 pre-intervention and 763 post-intervention, there was a significant increase in laboratory costs per patient from €41.8 per annum in the pre-implementation phase to €47.2 post-intervention [difference: +5.4 (95%: 2.0; 8.7) $p = 0.0017$]. The authors reported that this was due to a significantly higher number of safety analyses conducted in the post-intervention phase compared to the pre-intervention phase (803 compared with 734 respectively). However, overall patient treatment costs were reduced by a total of €78.4 per patient in the 1-year post-intervention phase mainly due to a decrease in the number of patients treated pharmacologically.

Chapter 7
Discussion and conclusions

Statement of principal findings

Study question 1: Which CDSS in OCS for test ordering are currently in use in the UK?

As stated in Chapter 4, the response rate from the survey of the 24 manufacturers and suppliers commissioned under the ASCC to provide CDSS support and functionality within the systems currently being deployed in the NHS was extremely disappointing, at 17%. The results have therefore been included in an Appendix rather than reported in the main body of the report as we do not consider them to be informative. Where any responses were received these were generally classified as being commercially sensitive data, and did little to elucidate which CDSS are currently either being trialled, deployed or implemented within the NHS.

Further contact with NHS CFH, the Healthcare Commission,[15] NHS Purchasing Suppliers, and the NHS Supply Chain was made. However, as the contractual level is now managed at the individual SHA level, through the ASCC, no further useful information was gained as NHS Purchasing Suppliers and the NHS Supply Chain are not involved in this deployment.

Due to the time constraints of the assessment it was not possible to make contact with individual SHAs and PCTs to ascertain whether they are currently implementing CDSS and OCS as part of the NPfIT, and which systems if any they are implementing. It was therefore not possible within this assessment to ascertain which CDSS are currently being used within the NHS.

Study question 2: What is the impact of CDSS in OCS for diagnostic, screening or monitoring test ordering compared to OCS without CDSS on process and adverse events?

This section discusses the principal finding from the 24 studies that assessed the impact of CDSS in conjunction with OCS compared to OCS alone for test ordering. In the main body of the report the results from the studies have been discussed under the nominal categories according to predominant type of CDSS intervention(s). This section therefore follows the same format with the principal findings for (1) studies assessing the impact of the display of test costs ($n = 3$), (2) those assessing the impact of the display of previous test results ($n = 2$), (3) studies assessing the impact of reminders ($n = 10$), (4) studies assessing the effects of restricted test lists($n = 2$), and (5) those assessing the impact of recommendations ($n = 7$) presented.

Impact of the display of test charges

Evidence from one CRCT by Tierney and colleagues[86] and two RCTs by Bates and colleagues[101] both conducted in the USA, to support there being an impact of the display of laboratory or radiological imaging test charges on test volumes and costs is equivocal.

Two of the trials focused predominantly on the effects of the display of test charges on laboratory test orders,[86,101] while the other focused on radiological imaging test orders.[101] The CRCT by Tierney and colleagues[86] showed a statistically significant decrease in the number of tests ordered per patient visit in the intervention group compared to the control group. Corresponding patient test charges were significantly lower in the intervention group relative to the control group.[86] However, post-intervention follow-up indicated the effect of the display of test charges may be transient, and there may be little learning effect from their previous display as no significant differences in test ordering rates were observed between the groups in this period. In contrast to the results of the CRCT,[86] in the two RCTs by Bates and colleagues there were no significant differences between treatment groups in either the laboratory or radiological imaging RCTs on either test volumes or costs per patient admission.[101]

Impact of the display of previous test results

The impact of the display of previous test results was assessed in one CCT by Solomon and colleagues[88] and one UPP study by Bansal and

colleagues.[89] Both studies were conducted in the USA. The CCT focused on the reduction of reducing unnecessary serological testing in the diagnosis of suspected systemic rheumatic disease, and also included the interpretation of future test results,[88] while the focus of the pre–post study was on reducing ABG usage in an ICU setting. This study also included the provision of educational text and limitations on 24-hour multiple test ordering.[89]

Again, results between the two studies were contradictory. In the CCT by Solomon and colleagues[88] significantly more test orders (11%) were cancelled in the intervention group compared to the control group (0.42%). Whereas in the UPP study by Bansal and colleagues[89] there were no significant differences between the number of ABG test orders placed pre- and post- intervention (376 and 387 respectively).

Impact of the display of reminders

The impact of the display of reminders was assessed in 10 studies:[24,29,48,57,87,90–94] four CRCTs; two by Overhage and colleagues in 1996 and 1997,[24,48] one by Palen and colleagues,[90] and one by Matheny and colleagues; [91] one RCT undertaken by Bates and colleagues,[92] one CCT by O'Connor and colleagues,[57] one randomised crossover trial by McDonald and colleagues,[29] one ITS study with an AB-AB-AB design by Carton and colleagues,[93] and two UPP studies by Steele and colleagues and Abboud and colleagues.[87,94] Nine of the 10 studies were conducted in the USA,[24,29,48,57,87,90–92,94] while the remaining study was conducted in France.[93]

Nine studies assessed the impact of reminders; one for compliance to undertake preventative care measures,[48] seven for reminders to undertake appropriate laboratory test ordering for medication monitoring,[24,29,57,87,90,91,94] and one for reminders regarding the ordering of redundant laboratory tests.[92] Two of the studies were undertaken on specific patient groups, namely those with diabetes[57] or assessed specific drug monitoring of aminoglycosides.[87] The remaining five studies all assessed the impact of reminders on the monitoring of pre-specified study specific target medications.[24,29,90,91,94] The remaining study assessed the impact of reminders based on guidelines for radiology imaging referral practice.[93]

Results across the studies were mixed and equivocal. The one CRCT by Overhage and colleagues[24] assessing compliance with reminders to undertake laboratory or imaging preventative care measures in an inpatient setting showed no significant differences between treatment groups.[48] The results from the seven studies that assessed reminders to undertake appropriate laboratory test ordering for medication monitoring were also mixed, both between and within studies.[24,29,57,87,90,91,94] Among the seven studies, one CRCT by Overhage and colleagues and one pre–post study by Steele and colleagues,[24,94] showed a statistically significant benefit with the display of reminders in terms of compliance to undertake appropriate laboratory tests for medication ordering. In the randomised cross-over trial by McDonald and colleagues conducted in a mixed outpatient population,[29] and the CCT by O'Connor and colleagues[57] conducted in patients with diabetes, results were inconsistent. McDonald and colleagues[29] found a significant impact on compliance rates for medication laboratory test monitoring in physicians but not in nurse practitioners. In the CCT by O'Connor and colleagues reminders had a beneficial impact on the number of diabetic patients undergoing HbA_{1C} tests, but no significant impact on the number of LDL cholesterol tests undertaken.[57] In terms of HbA_{1C} values observed in the study, there were no significant differences between intervention and control groups at either 2- or 4-year follow-up, suggesting that while reminders may have some impact (dependent on the test type) on the number of tests undertaken, this does not necessarily translate into actual clinical differences that may impact on the patient's disease process and management. None of the other three studies, (two CRCTs and a pre–post study)[87,90,91] showed there to be any significant benefit with the display of reminders for compliance with recommended medication laboratory test monitoring.

In contrast, the RCT by Bates and colleagues[92] which assessed the impact of reminders for redundant laboratory test orders showed a statistically significant reduction in test ordering between the intervention and control groups (27% versus 51% respectively); and therefore an absolute difference in the proportion of redundant tests performed between the groups of 24% in favour of the intervention group. Likewise, the ITS by Carton and colleagues[93] found the display of reminders had a small but statistically significant impact on the number of radiology imaging referrals that conformed to guidelines, with an increase from 66.8% compliance without reminders to 73.1% with reminders.

Impact of the display of restricted lists

One ITS by Rosenbloom and colleagues[95] and one CPP study by Poley and colleagues[96] assessed the impact of the display of restricted lists.[95,96] The ITS was conducted in the USA and the pre–post study in the Netherlands. The former study focused primarily on the restriction of the ordering of serum magnesium tests, with calcium and phosphorus test instances as secondary outcomes, whilst the latter study targeted a range of blood tests.[96] Both studies showed that in general the use of restricted lists significantly reduced test volumes, although the ITS highlighted the complexity of the implementation of CDSS and how unexpected effects due to part(s) of the CDSS intervention may occur.

In this study, two of the three CDSS interventions reduced test ordering rates, but an increase in test volumes was noted after implementation of the second of the three interventions. The CDSS was then amended, and a significant reduction in the volume of test orders was observed. Results from the controlled pre–post study showed a small (–0.38) but statistically significant decrease in the number of test requests per form with implementation of the CDSS, but no differences in the number of laboratory request forms submitted compared to OCS alone.[96]

Impact of the display of recommendations

The effects of CDSS recommendations were assessed in seven studies: two CRCTs by Hobbs and colleagues,[32] and Cobos and colleagues;[50] one RCT by Apkon and colleagues;[97] and four pre–post studies by Bassa and colleagues,[98] Sanders and colleagues,[104] Nightingale and colleagues,[99] and Boon-Falleur and colleagues.[100] The CRCT by Hobbs and colleagues[32] and the pre–post study by Nightingale and colleagues[99] were both conducted in the UK; the two studies by Apkon and colleagues[97] and Sanders and colleagues[104] were undertaken in the USA; the studies by Cobos and colleagues[50] and Bassa and colleagues[98] were conducted in Spain, while the study by Boon-Falleur and colleagues[100] was undertaken in Belgium. Overall, the results both within and between studies were mixed and equivocal. All three studies focusing on the provision of recommendations for the management of patients with hyperlipidemia (Hobbs and colleagues,[32] Cobos and colleagues[50] and Bassa and colleagues[98]) showed no significant beneficial impact in terms of increasing lipid test rates. However, there was some limited impact in two of the studies on increasing either the number of patients receiving a full lipid profile,[32] or receiving an AST/ALT test.[50] Likewise, the RCT by Apkon and colleagues that assessed the impact of recommendations provided by a CDSS Coupler on the number of patient health-care opportunities fulfilled showed no significant benefit in terms of the number of either laboratory or diagnostic screening imaging tests undertaken compared with usual care.[97] However, there was a significant increase in laboratory test resource consumption compared with the usual care group.

In one UPP study by Sanders and colleagues assessing the impact of CDSS guideline recommendation for undertaking head or brain imaging scans,[104] a small but statistically significant reduction in the number of imaging studies was observed, with a decrease from 742 scans undertaken pre-implementation of the CDSS to 704 after implementation. However, despite this reduction compliance with the tests indicated by the guideline recommendations remained relatively low at only 60%.[104]

Overall the results of the two pre–post studies by Nightingale and Boon-Falleur implementing guideline protocols for the management of liver transplant patients,[99,100] were somewhat mixed, but tended to show a significant decrease in the number of laboratory tests ordered,[99,100] the number of out of hours tests requested,[99] and a reduction in laboratory costs.[99] However, as appropriate levels of testing are driven by the patients' condition and disease stage there were some increases observed in test requesting in certain patient groups in both studies. This was most pronounced in the study by Boon-Falleur and colleagues[100] in which a 13% increase in the number of laboratory tests ordered in patients undergoing an initial assessment protocol was observed, but a 27% reduction in test orders for those undergoing transplant protocols was shown.

Study question 3. What features of CDSS are associated with clinician or patient acceptance of CDSS in OCS?

No studies were identified which met the inclusion criteria on the acceptability of CDSS to physicians or patients and therefore it was not possible to address this question within the context of this review.

Study question 4: What is the cost-effectiveness of CDSS in diagnostic, screening or monitoring test OCS compared to OCS without CDSS?

Only two studies met the inclusion criteria, both of which were cost-comparison analyses,[96,98] although some limited cost data were also reported in the three trials that assessed the impact of the display of test charges by Tierney and collegues[86] and the two RCTs by Bates and colleagues[101] which are included in the review of the impact of CDSS plus OCS versus OCS alone for test ordering. None of these three trials met the inclusion criteria for the systematic review of economic evaluations of CDSS and were therefore not included in this section. Of the two included cost-comparison analyses the one by Poley and colleagues was conducted alongside a CPP study,[96] and the one by Bassa and colleagues alongside a UPP study.[98] A full description of both of the studies is reported in Chapter 5, Studies assessing the impact of the display of recommendations and Study question 3. What features of CDSS are associated with clinician or patient acceptance of CDSS in order communications systems – on the impact of CDSS plus OCS versus OCS alone. Both studies found that the impact of CDSS plus OCS versus OCS alone had no significant impact on test costs.

Analyses conducted alongside the CPP study by Poley and colleagues found a mean cost decrease of 3% for blood tests orders (€639) in each of the intervention clinics compared with a 2% (€208) increase in the control clinics in test costs. However, this difference failed to reach conventional levels of statistical significance.[96] Likewise, the analysis conducted alongside the UPP study by Bassa and colleagues found a significant increase in the cost of laboratory tests (triglycerides, CK, serum glutamic oxaloacetic transaminase, and serum glutamic pyruvic transaminase) from €41.8 per patient per annum to €47.2 post implementation of the intervention. However, overall, patient treatment costs were reduced by a total of €78.4 per patient in the 1-year post-intervention phase, mainly due to a decrease in the number of patients treated pharmacologically.

Discussion

There is a growing body of research evidence which has examined the impact of CDSS in OCS versus OCS alone for diagnostic, screening or monitoring tests purposes on process outcomes and adverse events, although this lags far behind the volume of literature on the use of CDSS for medication ordering. This review identified 24 empirical studies which have examined the impact of CDSS plus OCS on test rates or compliance with guidelines for laboratory or radiological test imaging published between 1980 and 2009, with 10 of these published in the last 4 years.

However, there are a number of limitations to the evidence-base reviewed. All the 24 identified studies focused upon the decision to order a test, its appropriateness and timing. No studies were identified that addressed the results reporting process with the provision of context specific interpretative comments to help clinicians with the interpretation of the test results, and provide advice on the best course of action given a specific test result, for example to undertake further investigations and the timing of such tests. Moreover, only two of the 24 included studies, those by Bansal and colleagues[89] and Rosenbloom and colleagues,[95] assessed CDSS with a number of different functions, such as limitations on forward ordering of tests, the display of educational text, graphical display of recent test results and calculated correct test results. The remainder of the included studies tended to focus on one specific CDSS function, e.g. display of test charges, reminders, the display of restricted lists or recommendations. While it is useful to evaluate these single CDSS functions alone, in order to assess their impact prior to potentially incorporating them in a system with multiple functions, it limits the external validity of the results of these studies, as the majority of CDSS within OCS are likely to be multi-functionality systems, which may address issues such as corollary order sets, recommendations, the display of previous test results, and interpretative comments for results reporting, as well as the facility for medication ordering. Therefore, the results of these studies may do little to elucidate how multi-functional CDSS may actually be used by health-care professionals and perform in practice once implemented in a clinical setting.

Furthermore, of the 24 studies identified, 17 were conducted within the USA, [23,28,47,86–91,94–96,98,103] and of these 17, 12 were undertaken in three large academic centres which are well renowned for being 'leaders' at the forefront of CDSS and OCS development and implementation. Four studies had been conducted at the Wishard Memorial Hospital, Indianapolis, IN, or at one of their

outpatient centres,[24,29,48,86] five at the Brigham and Women's Hospital, Boston, MA,[88,91,92,101] and three at the Vanderbilt University Medical Center, Nashville, TN.[89,95,104] The systems used within these centres are all home-grown, and sharply focused on specific wards or units, and/or display a technical novelty side to their investigation. Additionally, in all 12 studies the system developers were also the evaluators. The results from these studies are potentially likely to be more biased in finding a significant benefit in favour of CDSS plus OCS use versus OCS use alone, as the systematic review by Garg and colleagues[10] highlights that studies in which the authors also developed and evaluated the CDSS were approximately three times more likely to show a beneficial effect in terms of CDSS use than when the authors were not the developers (74% success vs 28% success respectively). Additionally, it highlights the complexity of the development, implementation and use of CDSS which can be highly context specific and as Ash and colleagues[103] highlight can be highly dependent upon the organisational context, support for the system by both management and staff, and people with the specialist knowledge and skills who are able to develop systems that are likely to have a beneficial effect upon clinical practice. This means that systems that developers need to have a strong insight into the clinical process which they are attempting to address, and highlights the fact that systems that may have a beneficial impact on practice in some wards, units or hospitals may not do so when transferred into a different environmental context.

Only two studies were conducted within the UK.[32,99] Both of these were focused on specific groups, namely people being screened for hyperlipidemia,[32] and those being assessed for or undergoing liver transplantation.[99] Additionally, both of the studies, and therefore the systems, are relatively old with the studies having been published in 1994 and 1996 respectively.[32,99]

The implications of the evidence-base reviewed are threefold; first, it is very difficult to extrapolate the findings from studies conducted in the USA to the UK, as the health-care system is generally insurance based, and 'baseline' rates of laboratory testing or radiological imaging tend to be more than twice that observed within the NHS. Second, reliance on results from an evidence-base where 50% of the studies have been conducted within three known leading academic institutions is problematic, and may be more biased in terms of finding a statistically significant effect for CDSS use than would be observed in everyday general clinical practice. Furthermore in today's NHS these home-grown systems may be of little value, as 'off the shelf' systems have greater potential for wider deployment application.[103]

Third, of the 24 studies identified,[24,29,32,48,50,57,86–101,104] only 10 were published within the period of 2004–9,[50,57,87,90,91,94–98] with the remaining 13 studies being published either within or prior to 1999. It can therefore be postulated that many of these systems, particularly in terms of the older CDSS may now be obsolete or have been totally upgraded or updated with the further technological developments that are occurring rapidly within the growth and development of CDSS. Greater weight should therefore be given to the results of the studies that have been published more recently in which the technologies are still potentially available and may have undergone limited changes.

In terms of the findings of this review, as previously stated the findings were mixed and equivocal, often both within and between studies, which is not surprising given the heterogeneity between the study settings, patient indications, outcome assessed and the different types of CDSS evaluated. Overall, if the findings of both primary and secondary outcomes are taken into account then CDSS significantly improved practitioner performance in 15 out of 24 studies (62.5%),[24,29,32,50,57,86,88,92–96,99,100,104] including one of three studies (33.3%) assessing the impact of the display of costs,[86,101] one of the two studies (50%) assessing the impact of the display of previous test results,[99,89] six of the 10 studies (60%) examining the use of reminders,[24,29,48,57,87,90–94] one of the two studies (50%) that displayed previous test results,[95,96] and five of the seven studies (71.4%) that assessed the impact of the display of recommendations.[32,50,97–100,104]

Four studies also assessed the impact of test cancellation or delay on potential adverse events.[86,92,101] There were no significant differences between treatment groups in any of the four trials in terms of extra health-care utilisation by patients or adverse events. Therefore the impact of cancelling either costly or redundant tests on adverse outcomes currently appears to be negligible. Overall therefore it would appear that the implementation of CDSS in conjunction with OCS versus OCS alone for test ordering shows no evidence of harm even in studies in which the aim was primarily to reduce the rate of test ordering.

Due to the heterogeneity between studies it is very difficult to conclude why some CDSS are successful in terms of either decreasing laboratory or imaging test rates, or increasing test rates to the appropriate specified standards. In terms of the three system features that were found to be independent predictor of improved clinical practice by Kawamoto and colleagues[16] (automatic provision of CDSS output provided as part of clinician workflow; output at the time and location of decision making; and provision of a recommendation rather than just an assessment), there were few differences between the 24 studies, apart from in the provision of recommendations. All 24 studies provided automatic CDSS output as part of the clinician workflow and at the time and location of decision making. However, only seven of the studies provided a recommendation, of which five of seven found that the CDSS recommendations had a significant positive impact on either a primary or secondary outcome measure.[32,50,99,100,104]

With respect to the CDSS developers also being the outcome evaluators compared to independent evaluators assessing system impact, a less pronounced effect was observed in this review than that shown in the systematic review by Garg and colleagues.[10] In this review when system developers were also the evaluators a statistically significant positive impact of the CDSS on either a primary or secondary outcome measure was observed in 67% of the studies,[24,29,86,88,92,93,95,96,99,104] compared with 43% when the evaluator was not the developer.[57,94,105] These figures show a slightly different distribution to those found by Garg and colleagues who found a 74% success rate when the authors were also the system evaluator versus a 28% success rate when the evaluation was undertaken independently.[10]

It is often posited in the literature that studies of a less rigorous methodological design, such as CCTs, controlled and uncontrolled pre–post studies are more likely to be biased in terms of finding a significant effect. When an interaction between study design and a significant or non-significant effect in terms of the impact of the CDSS was assessed no such interaction was observed. Nor was there any interaction between year of study publication and a significant or non-significant impact of CDSS on process outcomes or practitioner performance.

Strengths and limitations of the assessment

The strengths of this assessment lie in the review of the impact of CDSS on process and patient outcomes. Extensive searches were undertaken, although restricted to English language articles, and studies included that reported any relevant outcome on the impact of CDSS on laboratory or radiological imaging included, even if this was not the primary aim of the study. The systematic review searches were updated in April 2009, and should therefore provide a comprehensive up-to-date review of the evidence available.

However, there are a number of limitations in the assessment. Firstly, although manufacturers and suppliers under the ASCC were contacted regarding the deployment or implementation of their CDSS within the NHS the response rate despite of follow-up was extremely low at 17%. Most of the information supplied by them was also classified as being CIC and therefore is not useful. We were therefore unable to address this question as set out in the original report protocol.

Secondly, in terms of the systematic review of the impact of CDSS plus OCS versus OCS alone on process and patient outcomes, the identified studies were so heterogeneous in terms of the settings, patient indications and CDSS assessed that any pooling of studies was not possible. This has meant that, while studies have been broadly grouped according to the type of CDSS intervention, the review has been presented on a study-by-study basis, rather than as a complete synthesis of the results for each type of intervention. This makes the interpretation of the results of the studies somewhat more complex, challenging and ultimately of less value to decision makers in the NHS. Furthermore, due to heterogeneity between the studies, particularly in terms of study design, we were unable to use formal meta-regression techniques to investigate the impact of the presence or absence of different CDSS features on the study results obtained. Additionally it should be noted that many of the studies identified were published a number of years ago, with only 10 of the 24 studies included in the review published post 2004. Therefore many of the CDSS evaluated within the review may now be obsolete and no longer used in practice or have been upgraded or changed in response to the rapid

changes taking place within pathology practice and the implementation of CDSS and OCS.

No studies were identified which have addressed the question of what features of CDSS are associated with clinician or patient acceptance of CDSS in OCS. As previously stated, this was due to the fact that while 31 studies were identified that had examined the acceptability of CDSS to physicians, the focus of these was generally on the ordering of medications, and results for laboratory or radiological test ordering were either not reported at all or not reported separately. These studies were therefore outside the scope of the current assessment.

The systematic review of economic evaluations is severely limited, and includes only two studies neither of which were conducted within the UK. Both of these were cost comparisons that compared the use of CDSS plus OCS versus OCS alone, and were focused on specific indications, namely blood test ordering and the management of patients with hypercholesterolemia. One of the studies reported only very limited results. It was therefore difficult to extrapolate the results of these studies to the wider context in which test ordering generally occurs, and on the basis of such limited evidence makes it impossible to comment on the cost-effectiveness of CDSS as they would be implemented and used in a wider clinical setting within OCS in the NHS.

Conclusions

Review question 1: Although a survey of manufacturers and suppliers under the ASCC was undertaken to establish the present deployment or implementation of CDSS within the NHS, the survey response rate was extremely low at only 17%. Most of the very limited data provided by contractors was designated as being CIC and therefore it was not possible to address the question of which CDSS are currently being used within the NHS in this assessment.

Review question 2: The findings from the review on the impact of CDSS plus OCS versus OCS alone are mixed and equivocal. Overall, if the findings of both primary and secondary outcomes are taken into account then CDSS showed a significant benefit on either process or practitioner performance outcomes in 15 out of 24 studies (62.5%). Additionally in four studies that assessed adverse effects of either test cancellation or delay, no significant detrimental effects in terms of patients extra utilisation of health-care resources or adverse events were observed. However, none of the studies assessed patient outcomes such as complications, disease progression or quality of life, and therefore it is unclear whether the use of CDSS either for curtailing unnecessary or redundant tests, or increasing the appropriateness of tests and their timing has any potential impact on health-care outcomes that are relevant to patients. Furthermore, although CDSS appears to have a potentially small positive impact on diagnostic, screening or monitoring test ordering, the majority of the included studies come from a limited number of institutions in the USA with home-grown systems, and it is unclear how well these results would extrapolate to the current NHS situation in which 'off the shelf' systems are being installed

Review question 3: No studies were identified which assessed the features of CDSS that are associated with clinician or patient acceptance of CDSS in OCS. This question was therefore not addressed within the context of this review.

Review question 4: Given the very limited data available on the cost-effectiveness of CDSS plus OCS compared with OCS alone, and the highly specific indications in which both of the identified studies were undertaken, it is not possible to extrapolate the findings of these studies to the wider context in which diagnostic, screening or monitoring test ordering occurs within the NHS. It is therefore not possible to comment on the likely cost-effectiveness of CDSS within OCS as they would be implemented and used within a wider NHS clinical setting.

Research recommendations

There is a need to establish which CDSS in OCS are currently being piloted, implemented or already deployed within the NHS and the type of systems, e.g. hospital or laboratory information systems, with which they interface. A comprehensive survey of individual SHAs, user sites, primary care trusts, CFH via their IT investment survey, pathology services, the Royal Colleges of Pathologists, and Radiologists is therefore warranted to establish which systems are in place or likely to be implemented within the context of the NpfIT. The results of such a survey would hopefully inform system commissioners as

to the best manner in which to conduct a rigorous evaluation of the CDSS within OCS that are already being implemented or currently 'rolled out'.

Currently there is very little evidence from the UK on the impact of CDSS in OCS compared to OCS alone, and no evidence on the impact of 'off the shelf' CDSS which are of relevance to the NpfIT and the NHS. There is therefore a need to establish whether there is any 'grey' literature available from NHS Trusts that have already implemented OCS as this would be potentially of use in informing how to design and implement evaluation studies of CDSS within OCS within the NHS.

We believe the key current need is for a well designed and comprehensive survey, and on the basis of the results of this potentially for evaluation studies in the form of CRCTs or RCTs which incorporate process, and patient outcomes, as well as full economic evaluations alongside the trials to assess the impact of CDSS in conjunction with OCS versus OCS alone for diagnostic, screening or monitoring test ordering in the NHS. The economic evaluation should incorporate the full costs of potentially developing, testing, and installing the system, including staff training costs.

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The views expressed in this report are those of the authors and not necessarily those of the NHS R&D HTA Programme. Any errors are the responsibility of the authors.

About PenTAG

The Peninsula Technology Assessment Group (PenTAG) is part of the Institute of Health Service Research at the Peninsula Medical School. PenTAG was established in 2000 and carries out independent health technology assessments for the UK HTA Programme, systematic reviews and economic analyses for the NICE Centre for Public Health Excellence, and systematic reviews as part of the Cochrane Collaboration Heart Group, as well as for other local and national decision-makers. The group is multi-disciplinary and draws on individuals' backgrounds in public health, health services research, computing and decision analysis, systematic reviewing, statistics and health economics. The Peninsula Medical School is a school within the Universities of Plymouth and Exeter. The Institute of Health Research is made up of discrete, but methodologically related research groups, across which health technology assessment is a strong and recurring theme.

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Appendix 1
Search strategy

CDSS Search strategies

Ovid MEDLINE
Current: Ovid MEDLINE 1950 to July Week 1 2008. Search Date: 9 July 2008. Update 2 April 2009.

Set number	Search term	Number of hits returned
1	(computer* or microcomputer* or electronic* or automat* or web).tw.	305,363
2	computers/or microcomputers/	57,081
3	(remind* or alert* or notif*).ti,ab.	32,570
4	(screen* or monitor* or feedback).ti,ab.	641,672
5	((diagnos$or screen$or monitor$) and (order$or test$or laborator$or endoscop$or imag$)).tw.	507,094
6	(order$and test$).tw.	80,981
7	1 or 2	331,025
8	3 or 4 or 5 or 6	1,038,072
9	7 and 8	57,217
10	3 or 5 or 6	600,044
11	exp Unnecessary Procedures/	1622
12	exp Reminder Systems/	1216
13	exp Decision Support Techniques/	55,089
14	decision making, computer-assisted/or diagnosis, computer-assisted/or therapy, computer-assisted/or drug therapy, computer-assisted/	20,401
15	exp Physician's Practice Patterns/	26,391
16	"Laboratory Techniques and Procedures"/sn, ut [Statistics & Numerical Data, Utilization]	695
17	exp Medical Records Systems, Computerized/or Medical Records/	43,823
18	exp Diagnostic Tests, Routine/	4736
19	Point-of-Care Systems/	3448
20	"Diagnostic Techniques and Procedures"/	1230
21	(decision adj2 support).tw.	4112
22	or/11–21	154,807
23	9 and 22	6962
24	Clinical Laboratory Information Systems/	1530
25	Decision Support Systems, Clinical/	2482
26	Medical Order Entry Systems/	476
27	order$communicat$system$.tw.	8
28	(decision adj2 support adj2 system$).tw.	1683
29	24 or 25 or 26 or 27 or 28	5480
30	artificial intelligence/	10,687
31	"neural networks (computer)"/	10,704
32	30 or 31	20,047

33	10 and 32	2141
34	(expert system$or neural network$or artificial intellig$or bayes$).tw.	23,684
35	10 and 34	3075
36	(CDSS or OCS or CPOE or (order adj entry)).tw.	3339
37	(diagnos$or screen$or monitor$).tw.	1,639,950
38	36 and 37	506
39	(case reports or comment or congresses or editorial or historical article or interview or letter or news).pt.	2,596,968
40	(animals not humans).sh.	3,235,272
41	39 or 40	5,763,459
42	23 or 29 or 33 or 35 or 38	15,318
43	42 not 41	14,264
44	43	14,264
45	limit 44 to (english language and yr="1974 – 2008")	12,926
46	35 not 45	500

EMBASE

17 July 2008 Current: EMBASE 1980 to 2008 Week 28.

1. (computer* or microcomputer* or electronic* or automat* or web).tw.

2. computer/or computer system/or microcomputer/

3. (remind* or alert* or notif*).ti,ab.

4. (screen* or monitor* or feedback).ti,ab.

5. ((diagnos$or screen$or monitor$) and (order$or test$or laborator$or endoscop$or imag$)).tw.

6. (order$and test$).tw.

7. 1 or 2

8. 3 or 4 or 5 or 6

9. 7 and 8

10. unnecessary procedure/

11. reminder system/

12. computer assisted diagnosis/

13. computer assisted drug therapy/

14. clinical practice/

15. medical record/

16. laboratory/

17. medical information system/or medical record/

18. hospital information system/

19. electronic medical record/

20. information system/

21. "point of care testing"/

22. diagnostic approach route/

23. diagnostic procedure/

24. computer assisted therapy/

25. medical informatics/

26. medical order/

27. decision making/

28. (decision adj2 support).tw.

29. Feedback System/

30. 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28 or 29

31. 9 and 30

32. order$communicat$system$.tw.

33. (decision adj2 support adj2 system$).tw.

34. decision support system/

35. computerized physician order entry/

36. 32 or 33 or 34 or 35

37. artificial intelligence/

38. Artificial Neural Network/

39. (expert system$or neural network$or artificial intellig$or bayes$).tw.

40. Expert System/

41. 37 or 38 or 39 or 40

42. 9 and 41

43. (CDSS or OCS or CPOE or (order adj entry)).tw.

44. (diagnos$or screen$or monitor$).tw.

45. 43 and 44

46. 31 or 36 or 42 or 45

47. (book or editorial or letter or press or release).pt.

48. ((animal or nonhuman) not human).sh.

49. 47 or 48

50. 46 not 49

51. 50

52. limit 51 to (english language and yr="1974 – 2008")

Total pr-dedupluication = 8928

CINAHL

20 July 2008 CINAHL – 1982 to date (NAHL)

DIALOG DATASTAR web version

Set number		Search term		Number of hits returned
1	CINAHL – 1982 to date	(computer$4 OR microcomputer$4 OR electronic$4 OR automat$4 OR web).TI,AB.	unrestricted	39,999
2	CINAHL – 1982 to date	Computers-and-Computerization.DE.	unrestricted	4232
3	CINAHL – 1982 to date	Microcomputers.W..DE.	unrestricted	944
4	CINAHL – 1982 to date	(remind$4 OR alert$4 OR notif$4).TI,AB.	unrestricted	6097
5	CINAHL – 1982 to date	(screen$4 OR monitor$4 OR feedback).TI,AB.	unrestricted	57,895
6	CINAHL – 1982 to date	(diagnos$4 OR screen$4 OR monitor$4).TW. AND (order$4 OR test$4 OR laborator$4 OR endoscop$4 OR imag$4).TW.	unrestricted	161,729
9	CINAHL – 1982 to date	order$4.TI,AB. AND test$4.TI,AB.	unrestricted	4842
10	CINAHL – 1982 to date	1 OR 2 OR 3	unrestricted	42,332
11	CINAHL – 1982 to date	4 OR 5 OR 6 OR 9	unrestricted	199,115
12	CINAHL – 1982 to date	10 AND 11	unrestricted	8748
13	CINAHL – 1982 to date	Reminder-Systems.DE.	unrestricted	622
14	CINAHL – 1982 to date	Decision-Making-Computer-Assisted.DE. OR Diagnosis-Computer-Assisted.DE. OR Therapy-Computer-Assisted.DE. OR Drug-Therapy-Computer-Assisted.DE.	unrestricted	2687
15	CINAHL – 1982 to date	Computers-and-Computerization.DE.	unrestricted	4232
17	CINAHL – 1982 to date	15	various	3557
19	CINAHL – 1982 to date	15 NOT 17	various	675
20	CINAHL – 1982 to date	Management-Information-Systems#.DE.	unrestricted	1257
21	CINAHL – 1982 to date	Clinical-Information-Systems#.DE.	unrestricted	9766

22	CINAHL – 1982 to date	Diagnostic-Tests-Routine.DE.	unrestricted	528
24	CINAHL – 1982 to date	(decision$2 ADJ support$2).TI,AB.	unrestricted	885
25	CINAHL – 1982 to date	Patient-Record-Systems#.DE.	unrestricted	5325
26	CINAHL – 1982 to date	Artificial-Intelligence#.DE.	unrestricted	1771
27	CINAHL – 1982 to date	Neural-Networks-Computer#.DE.	unrestricted	210
29	CINAHL – 1982 to date	(expert ADJ system$2 OR neural ADJ network$2 OR artificial ADJ intellig$5 OR bayes$4).TI,AB.	unrestricted	815
30	CINAHL – 1982 to date	13 OR 14 OR 19 OR 20 OR 21 OR 22 OR 24 OR 25 OR 26 OR 27 OR 29	various	17,394
31	CINAHL – 1982 to date	12 AND 30	various	1571
32	CINAHL – 1982 to date	Electronic-Order-Entry.DE.	unrestricted	637
33	CINAHL – 1982 to date	Decision-Support-Systems-Clinical.DE.	unrestricted	707
34	CINAHL – 1982 to date	(order$2 ADJ communicat$5 ADJ system$2). TI,AB.	unrestricted	2
35	CINAHL – 1982 to date	(decision$2 ADJ support$2 ADJ system$2). TI,AB.	unrestricted	306
36	CINAHL – 1982 to date	32 OR 33 OR 34 OR 35	unrestricted	1434
37	CINAHL – 1982 to date	(CDSS OR OCS OR CPOE OR order ADJ entry).TI,AB.	unrestricted	732
38	CINAHL – 1982 to date	(diagnos$4 OR screen$4 OR monitor$4). TI,AB.	unrestricted	125,575
39	CINAHL – 1982 to date	37 AND 38	unrestricted	77
40	CINAHL – 1982 to date	31 OR 39	various	1620
41	CINAHL – 1982 to date	PT=CASE-STUDY OR PT=CEU OR PT=COMMENTARY OR PT=EDITORIAL OR PT=LETTER	unrestricted	323,950
42	CINAHL – 1982 to date	40 NOT 41	various	1471
1.	SEARCH:	(computer$4 OR microcomputer$4 OR electronic$4 OR automat$4 OR web).TI,AB.		
2.	SEARCH:	Computers-and-Computerization.DE.		
3.	SEARCH:	Microcomputers.W..DE.		
4.	SEARCH:	(remind$4 OR alert$4 OR notif$4).TI,AB.		
5.	SEARCH:	(screen$4 OR monitor$4 OR feedback). TI,AB.		
6.	SEARCH:	(diagnos$4 OR screen$4 OR monitor$4). TW. AND (order$4 OR test$4 OR laborator$4 OR endoscop$4 OR imag$4). TW.		
7.	SEARCH:	order$4.TI,AB. AND test$4.TI,AB.		
8.	SEARCH:	1 OR 2 OR 3		
9.	SEARCH:	4 OR 5 OR 6 OR 7		
10.	SEARCH:	8 AND 9		
11.	SEARCH:	Reminder-Systems.DE.		
12.	SEARCH:	Decision-Making-Computer-Assisted. DE. OR Diagnosis-Computer-Assisted. DE. OR Therapy-Computer-Assisted.DE. OR Drug-Therapy-Computer-Assisted.DE.		
13.	SEARCH:	Computers-and-Computerization.DE.		
14.	SEARCH:	13 (restricted to 1987-current)		
15.	SEARCH:	13 NOT 14		
16.	SEARCH:	Management-Information-Systems#.DE.		

17.	SEARCH:	Clinical-Information-Systems#.DE.
18.	SEARCH:	Diagnostic-Tests-Routine.DE.
19.	SEARCH:	(decision$2 ADJ support$2).TI,AB.
20.	SEARCH:	Patient-Record-Systems#.DE.
21.	SEARCH:	Artificial-Intelligence#.DE.
22.	SEARCH:	Neural-Networks-Computer#.DE.
23.	SEARCH:	(expert ADJ system$2 OR neural ADJ network$2 OR artificial ADJ intellig$5 OR bayes$4).TI,AB.
24.	SEARCH:	11 OR 12 OR 15 OR 16 OR 17 OR 18 OR 19 OR 20 OR 21 OR 22 OR 23
25.	SEARCH:	10 AND 24
26.	SEARCH:	Electronic-Order-Entry.DE.
27.	SEARCH:	Decision-Support-Systems-Clinical.DE.
28.	SEARCH:	(order$2 ADJ communicat$5 ADJ system$2). TI,AB.
29.	SEARCH:	(decision$2 ADJ support$2 ADJ system$2). TI,AB.
30.	SEARCH:	26 OR 27 OR 28 OR 29
31.	SEARCH:	(CDSS OR OCS OR CPOE OR order ADJ entry).TI,AB.
32.	SEARCH:	(diagnos$4 OR screen$4 OR monitor$4). TI,AB.
33.	SEARCH:	31 AND 32
34.	SEARCH:	25 OR 33
35.	SEARCH:	PT=CASE-STUDY OR PT=CEU OR PT=COMMENTARY OR PT=EDITORIAL OR PT=LETTER
36.	SEARCH:	34 NOT 35
		TOTAL CINAHL pre de-dup: 1471

Cochrane Library

Cochrane Library Edition 2008:3 – online

Date searched: 20 July 2008

NOTE: search excluded EMBASE and Pubmed references as searched separately

Total: SRs: 420

CENTRAL: 540

HTA: 150

NHS EED: 103

DARE: 22

Set number	Search term	Number of hits returned
#1	(computer* or microcomputer* or electronic* or automat* or web):ti,ab	12,133
#2	MeSH descriptor Computers explode all trees	717
#3	(remind* or alert* or notif*):ti,ab	2559
#4	(screen* or monitor* or feedback):ti,ab	33,706
#5	((diagnos* or screen* or monitor*) and (order* or test* or laborator* or endoscop* or imag*)):ti,ab	19,057

#6	(order* and test*):ti,ab	6492
#7	(#1 OR #2)	12,413
#8	(#3 OR #4 OR #5 OR #6)	49,173
#9	(#7 AND #8)	3291
#10	(#3 OR #5 OR #6)	26,784
#11	MeSH descriptor Unnecessary Procedures explode all trees	78
#12	MeSH descriptor Reminder Systems explode all trees	360
#13	MeSH descriptor Decision Support Techniques explode all trees	2981
#14	MeSH descriptor Decision Making, Computer-Assisted explode all trees	2021
#15	MeSH descriptor Drug Therapy, Computer-Assisted explode all trees	101
#16	MeSH descriptor Physician's Practice Patterns explode all trees	996
#17	MeSH descriptor Laboratory Techniques and Procedures explode all trees with qualifier: SN	175
#18	MeSH descriptor Medical Records Systems, Computerized explode all trees	190
#19	MeSH descriptor Medical Records explode all trees	1490
#20	MeSH descriptor Diagnostic Tests, Routine explode all trees	231
#21	MeSH descriptor Point-of-Care Systems explode all trees	192
#22	MeSH descriptor Diagnostic Techniques and Procedures, this term only	78
#23	(decision support):ti,ab	728
#24	(#11 OR #12 OR #13 OR #14 OR #15 OR #16 OR #17 OR #18 OR #19 OR #20 OR #21 OR #22 OR #23)	8756
#25	(#9 AND #24)	476
#26	(order* communicat* system*):ti,ab	40
#27	(expert system* or neural network* or artificial intellig* or bayes*):ti,ab	1255
#28	(CDSS or OCS or CPOE or (order entry)):ti,ab	457
#29	(#9 OR #23 OR #25 OR #26 OR #27 OR #28)	5528
#30	"accession number" NEAR pubmed	316,701
#31	"accession number" near2 embase	51,982
#32	(#30 OR #31)	368,683
#33	(#29 AND NOT #32)	

EconLit (EconLit)

EconLit (EconLit)

Via: First Search, 1969 to present

Search Date: 23 July 2008

Monthly; Last update: 18 July 2008

Set number	Search term	Number of hits returned
#1	de: computers or de: computer and ln= "english"	7809
#2	kw: decision and kw: support and kw: systems and ln= "english"	384
#3	su= "Introductory Material"	2089
#4	ti: remind* or su= "alert* or notif*" or ab: remind* or su= "alert* or notif*"	193
#5	ti: remind* or su= "alert* or notif*" or ab: remind* or su= "alert* or notif*"	193
#6	ti: screen* or su= "monitor* or feedback" and ab: screen* or su= "monitor* or feedback"	225
#7	(ti: diagnos* or ti: screen* or ti: monitor*) and (su= "order* or test* or laborator* or endoscop* or imag*") and (ab: diagnos* or ab: screen* or ab: monitor*) and (su= "order* or test* or laborator* or endoscop* or imag*")	0

#8	(ti: diagnos* or ti: screen* or ti: monitor*) and (ti: order* or ti: test* or ti: laborator* or ti: endoscop* or ti: imag*) and (ab: diagnos* or ab: screen* or ab: monitor*) and (ab: order* or ab: test* or ab: laborator* or ab: endoscop* or ab: imag*)	38
#9	(ti: order* and ti: test*) or (ab: order* and ab: test*)	2554
#10	(ti: remind* or su= "alert* or notif*" or ab: remind* or su= "alert* or notif*") or (ti: remind* or su= "alert* or notif*" or ab: remind* or su= "alert* or notif*") or (ti: screen* or su= "monitor* or feedback" and ab: screen* or su= "monitor* or feedback") or ((ti: diagnos* or ti: screen* or ti: monitor*) and (ti: order* or ti: test* or ti: laborator* or ti: endoscop* or ti: imag*) and (ab: diagnos* or ab: screen* or ab: monitor*) and (ab: order* or ab: test* or ab: laborator* or ab: endoscop* or ab: imag*)) or ((ti: order* and ti: test*) or (ab: order* and ab: test*))	2991
#11	(de: computers or de: computer and ln= "english") and ((ti: remind* or su= "alert* or notif*" or ab: remind* or su= "alert* or notif*") or (ti: remind* or su= "alert* or notif*" or ab: remind* or su= "alert* or notif*") or (ti: screen* or su= "monitor* or feedback" and ab: screen* or su= "monitor* or feedback") or ((ti: diagnos* or ti: screen* or ti: monitor*) and (ti: order* or ti: test* or ti: laborator* or ti: endoscop* or ti: imag*) and (ab: diagnos* or ab: screen* or ab: monitor*) and (ab: order* or ab: test* or ab: laborator* or ab: endoscop* or ab: imag*)) or ((ti: order* and ti: test*) or (ab: order* and ab: test*)))	17
#12	ti: comput* or ab: comput*	13,200
#13	(ti: remind* or su= "alert* or notif*" or ab: remind* or su= "alert* or notif*") or (ti: remind* or su= "alert* or notif*" or ab: remind* or su= "alert* or notif*") or (ti: screen* or su= "monitor* or feedback" and ab: screen* or su= "monitor* or feedback") or ((ti: diagnos* or ti: screen* or ti: monitor*) and (ti: order* or ti: test* or ti: laborator* or ti: endoscop* or ti: imag*) and (ab: diagnos* or ab: screen* or ab: monitor*) and (ab: order* or ab: test* or ab: laborator* or ab: endoscop* or ab: imag*)) or ((ti: order* and ti: test*) or (ab: order* and ab: test*)) and (ti: comput* or ab: comput*)	158
#14	(de: computers or de: computer and ln= "english") and ((ti: remind* or su= "alert* or notif*" or ab: remind* or su= "alert* or notif*") or (ti: remind* or su= "alert* or notif*" or ab: remind* or su= "alert* or notif*") or (ti: screen* or su= "monitor* or feedback" and ab: screen* or su= "monitor* or feedback") or ((ti: diagnos* or ti: screen* or ti: monitor*) and (ti: order* or ti: test* or ti: laborator* or ti: endoscop* or ti: imag*) and (ab: diagnos* or ab: screen* or ab: monitor*) and (ab: order* or ab: test* or ab: laborator* or ab: endoscop* or ab: imag*)) or ((ti: order* and ti: test*) or (ab: order* and ab: test*))) or ((ti: remind* or su= "alert* or notif*" or ab: remind* or su= "alert* or notif*") or (ti: remind* or su= "alert* or notif*" or ab: remind* or su= "alert* or notif*") or (ti: screen* or su= "monitor* or feedback" and ab: screen* or su= "monitor* or feedback") or ((ti: diagnos* or ti: screen* or ti: monitor*) and (ti: order* or ti: test* or ti: laborator* or ti: endoscop* or ti: imag*) and (ab: diagnos* or ab: screen* or ab: monitor*) and (ab: order* or ab: test* or ab: laborator* or ab: endoscop* or ab: imag*)) or ((ti: order* and ti: test*) or (ab: order* and ab: test*)) and (ti: comput* or ab: comput*))	170
#15	ti: decsion* n3 support* or ab: decsion* n3 support* or kw: decsion* n3 support*	0
#16	ti: decision* n3 support* or ab: decision* n3 support* or kw: decision* n3 support*	936
#17	(ti: decision* n3 support* or ab: decision* n3 support* or kw: decision* n3 support*) AND (ti: medical* or ab: medical* or kw: medical*)	11
#18	(ti: decision* n3 support* or ab: decision* n3 support* or kw: decision* n3 support*) AND su= "hospitals"	0
#19	(ti: decision* n3 support* or ab: decision* n3 support* or kw: decision* n3 support*) AND kw: hospital	15
#20	(ti: decision* n3 support* or ab: decision* n3 support* or kw: decision* n3 support*) AND (ti: medical* or ab: medical* or kw: medical*) or ((ti: decision* n3 support* or ab: decision* n3 support* or kw: decision* n3 support*) AND kw: hospital)	21
#21	(ab: CDSS or ab: OCS or ab: CPOE or ab: order w entry) or (ti: CDSS or ti: OCS or ti: CPOE or ti: order w entry)	59
#22	ab: CDSS	12
#23	(ab: point and ab: care) and de: hospital	11

Appendix 2
Excluded studies

Study question 2: What is the impact of CDSS in OCS for diagnostic, screening or monitoring test ordering compared to order communication systems without CDSS on process and patient outcomes?

Study ID	Reason for exclusion
Ali (2005)[128]	No test order outcomes
Anonymous (2002)[129]	No OCS alone at baseline
Anonymous (1999)[130]	No OCS alone at baseline
Anton (2009)[131]	Overview of system; no outcome data reported
Augstein (2007)[132]	No OCS alone (continuous glucose monitoring system versus monitoring system plus CDSS); no test outcomes
Ayanian (2008)[133]	No CDSS or OCS
Bernstein (1994)[134]	No CDSS; no evaluation; discussion of development of system
Berry (2006)[135]	No CDSS; cross sectional survey
Bindels (2004)[136]	OCS + CDSS in both groups; randomised to provide recommendations for different test ordering between the groups
Blaser (2006)[137]	Discussion article (no evaluation)
Braham (1987)[138]	No CDSS; audit and feedback of test costs to physicians for tests ordered; aggregate data only
Cannon-Wagner (2002)[139]	No CDSS; no test ordering outcomes
Chambers (1989)[140]	No CDSS
Christensen-Szalanski (1982)[141]	Comparator not OCS alone
Chu (2004)[142]	No CDSS; no OCS alone at baseline; system not used for test ordering
Chu (2001)[143]	Discussion article on CDSS and OCS (no evaluation)
Colombet (2004)[144]	Discussion article on development of system and study design for evaluation (no evaluation reported)
Colombet (2003)[145]	Focus group conducted on CDSS using scenarios in a non-clinical setting
Connelly (1996)[146]	No OCS alone comparator; audit
Connelly (1996)[147]	Discussion article; no evaluation
Connelly (1995)[148]	OCS + CDSS compared with no OCS at baseline
Cordero (2004)[149]	Evaluates implementation of OCS + CDSS versus no OCS
de Wilde (1996)[150]	No OCS at baseline; all orders entered on paper
Demakis (2000)[151]	Comparator not OCS alone; both groups CDSS
Emerson (2001)[152]	No CDSS
Fihn (1994)[153]	No CDSS; no test outcomes (scheduling of return visits)
Fitzmaurice (2000)[154]	Comparator not OCS alone
Fordham (1990)[67]	CDSS + OCS not compared to CDSS alone; system is a manual audit for producing reminders
Fransen (2004)[155]	No evaluation
Georgiou (2007)[156]	Whole system analysis; not just CDSS in OCS versus OCS alone

Glasgow (2005)[157]	No CDSS
Groopman (1992)[158]	No CDSS (OCS alone)
Guss (2008)[159]	No CDSS
Harpole (1997)[54]	CDSS plus CS (standard) versus CDSS plus OCS (amended); no OCS alone comparator
Harris (1990)[160]	No CDSS
Hasman (1993)[161]	No evaluation of CDSS
Hetlevik (1999)[162]	Not test ordering
Hetlevik (1998)[163]	CDSS not compared with OCS alone
Holleman (1996)[164]	No CDSS; health summaries and test results created manually pre-patient visit
Hwang (2002)[3]	No CDSS just OCS
Kern (2007)[165]	No CDSS; not compared to OCS alone; cross-sectional study
Kinney (2003)[166]	Diagnostic accuracy study
Koide (1995)[167]	Japanese language article (abstract only in English)
Kuperman (1999)[52]	Comparator not OCS alone
Litzelman (1993)[47]	CDSS in OCS requiring response to alert from clinicians versus CDSS in OCS not requiring response (CDSS versus CDSS)
Lobach (1996)[40]	Effect of an audit programme for monitoring physician guideline adherence rates. Data feedback on aggregate patient group not individual patients
Maass (2008)[168]	CDSS plus OCS versus OCS alone not compared
Mantha (2005)[169]	Cross sectional study (no pre, just post)
Martens (2006)[170]	No CDSS; no test outcomes (prescribing behaviour)
McPhee (1989)[65]	No CDSS all patient records searched and audit
McPhee (1991)[27]	CDSS with OCS not compared to OCS alone
Modai (1998)[171]	CDSS implemented at the same time as OCS; no pre-implementation data reported
Mutimer (1992)[172]	No OCS in pre-implementation phase
Nam (2007)[173]	OCS alone no CDSS
Neilson (2004)[174]	No CDSS
Nicholls (2008)[51]	No CDSS
Nilasena (1995)[175]	Comparator not OCS alone; outcomes for laboratory test/referral rates are pooled between the two groups and analysed as a post intervention change from baseline
Ornstein (1995)[176]	No CDSS; audit of preventive care services (including screening) appropriate to age and gender, only aggregate data reported
Patkar (2006)[177]	CDSS used on hypothetical cases
Payne (2003)[178]	No CDSS (OCS alone)
Perkins (2008)[179]	Discussion article
Pham (2008)[180]	No CDSS: not test ordering
Piva (2009)[181]	No CDSS: not test ordering
Rosenthal (2006)[182]	Only frequency of system use reported pre- and post-addition of CDSS
Stair (1998)[183]	No pre-and post-assessment
Studnicki (1993)[184]	No CDSS
Subramanian (2004)[102]	CDSS versus CDSS; no OCS comparator
Thompson (2004)[68]	No CDSS just OCS alone
Tierney (1993)[185]	CDSS + OCS compared to no OCS
Valenstein (1995)[186]	Survey on accuracy of tests orders transmitted to the laboratory
van Wijk (2001)[187]	Compares two different CDSS + OCS with each other
Vashitz (2007)[188]	Not CDSS with OCS; reminders sent to physicians via a hard copy every 4 months

Study question 3: What features of CDSS are associated with clinician or patient acceptance of CDSS in order communication systems?

Study ID	Reason for exclusion
Aarts (2004)[189]	Not test ordering (prescribing); no acceptability outcome measure
Ahearn (2003)[190]	No CDSS; no acceptability outcome measure
Alberdi (2000)[191]	Not test ordering; no CDSS; no acceptability outcome measures
Asaro (2005)[192]	No CDSS; no acceptability outcome measure
Ash (2007)[193]	Not test ordering
Ash (2003)[194]	Not test ordering
Aydin (1998)[195]	OCS not CDSS
Banet (2006)[196]	OCS + CDSS in both groups; randomised to provide recommendations for different test ordering between the groups therefore no evaluation of OCS alone at baseline
Bindels (2003)[197]	CDSS not used for test ordering; no acceptability outcomes; no evaluation
Bonnevie (2005)[198]	No acceptability outcome measure
Bossen (2007)[199]	Not CDSS within OCS (stand alone internet CDSS – ISABEL); no acceptability outcomes
Briggs (2005)[200]	OCS not CDSS
Callen (2007)[201]	No acceptability outcomes; not evaluation of implementation of CDSS
Campbell (2006)[202]	No acceptability rates reported
Doolan (2003)[7]	No acceptability rates reported
Fung (2008)[203]	OCS without CDSS; orders for laboratory tests completed using paper forms
Gandhi (2005)[204]	No acceptability rates reported
Grundmeier (1999)[205]	Attitudes towards future addition of CDSS to OCS
Jaspers (2008)[206]	CDSS in OCS not used for test ordering; no acceptability outcomes
Kailajarvi (2000)[207]	No CDSS; focus groups used to discuss general usefulness of alerts/reminders (not test ordering specific)
Krall (2002)[208]	No CDSS; not used for test ordering; no acceptability outcomes
Krall (2001)[209]	OCS not CDSS
Lee (1996)[210]	Not test ordering
Martens (2006)[170]	Not test ordering
Murff (2001)[211]	No test ordering results, evaluation on number of preventive care recommendations flagged.
Nilasena (1995)[175]	No test ordering results, evaluation on number of preventive care recommendations
Rapley (2005)[212]	Not conducted in a clinical setting; diagnostic accuracy outcomes
Ridderikhoff (1999)[213]	No acceptability outcomes
Rosenbloom (2004)[214]	Not test ordering; no acceptability outcome measure
Short (2004)[215]	CDSS in OCS not used for test ordering; no acceptability outcomes
Sittig (2006)[105]	CDSS in OCS not used for test ordering; no acceptability outcomes

Study question 4: What is known about the cost-effectiveness of CDSS in diagnostic, screening or monitoring test order communication systems compared to order communication systems without CDSS?

Study ID	Reason for exclusion
Barnett (1999)[216]	Not CDSS compared with CDSS plus OCS; only comparison of methods for obtaining cost data reported
Ohsfeldt (2005)[217]	No CDSS

Appendix 3

Data extraction tables

Studies assessing the display of test charges (*n* = 3)

Study demographics

Author; year; study ID: Tierney (1990)[86]

Title: The effect on test ordering of informing physicians of the charges for outpatient diagnostic tests

Country: USA

Specific setting: General Medicine Practice of the Regenstrief Health Center, Indianapolis, IN, USA (The centre is the primary outpatient facility for Wishard Memorial Hospital) and provides primary care to more than 12,000 patients

Study objectives: To assess the effects of informing physicians of the charges for outpatient diagnostic tests on test ordering practices

Health-care setting: Primary care

If secondary care, academic status of the hospital: Academic Primary Care Centre

Health-care system: USA (Medicare; Medicaid; commercial insurance; Hospital's programme for indigent patients; no health insurance coverage)

Study design: RCT (14-week pre-intervention period; 26-week intervention period; 19-week post-intervention period)

Number of sites: 1

Funding source: Public sector

Was evaluator of tool also its developer? Unclear

System users

	Intervention group	**Control group**
CDSS user(s)	Physicians	Physicians
Pre-intervention period (14 weeks)		
Physicians (*n*)	62	59
Residents (*n*)	51	48
Faculty (*n*)	11	11
Intervention period (26 weeks)		
Physicians (*n*)	62	59
Residents (*n*)	51	48
Faculty (*n*)	11	11
Post-intervention period (19 weeks)		
Physicians (*n*)	39	35
Residents (*n*)	32	26
Faculty (*n*)	7	9
Practitioners (*n*) in analysis:		
Pre-intervention period	121	
Intervention period	74	
Post-intervention period	74	

Inclusion criteria: Physicians using OCS with or without CDSS for laboratory or radiological test ordering for all outpatient visits within the study period

Exclusion criteria: NR

Patient baseline demographics[a]

Inclusion criteria: All outpatients attending for either scheduled or unscheduled visits at the practice within the study period

Exclusion criteria: NR

	Intervention group	**Control group**
Pre-intervention period (14 weeks)		
N	3511	3362
Visits (*n*)	5229	5040
Intervention period (26 weeks)		
N	4254	4138
Visits (*n*)	7800	7457
Post-intervention period (19 weeks)		
N	2784	2806
Visits (*n*)	4461	4259

a No further baseline details were reported on study participants.

Interventions

Intervention: OCS plus CDSS (display of test charges). The computer displayed the charge the patient (or insurer) would pay for the current test and total charges for all tests ordered for the patient on that day. Physicians were then given the option of cancelling the test(s) or continuing with the order. The charges displayed were the hospital's current charges to the patients or their insurance carriers; additional fees (e.g. for interpretation of the roentrogenograms) were not included. Tests included all laboratory and imaging studies; 24-hour electrocardiographic monitoring tests, treadmill exercise testing, and endoscopic procedures were excluded

During the pre-intervention period and post-intervention period no messages about test charges appeared when tests were ordered

Comparator: OCS alone (no display of test charges)

Concomitant interventions: NA

CDSS tool

Name of CDDS (if any)	NR
CDSS reasoning method	NR
CDSS knowledge base	Hospital test costs
Did study use training set and test set data?	Training set: NR Test set: NR

For training set data complete the following:

Design	NR	
Target decision	NR	
Sample characteristics:	**Intervention**	**Control**
Sample size (*n*)	NR	NR
Age (mean; range)	NR	NR
Gender (*n* male; *n* female)	NR	NR
Disease type	NR	NR

For test set data complete the following:

Properties of test set data	NR
Test centre	NR
Target decision	NR

Other CDSS information

1. Information used in CDSS [number of items; signs; symptoms; history; biochemical tests (list)]	NR; costs of biochemical and radiology tests
2. Time to complete the CDSS (minutes)	NR

3. CDSS output format: (score; probability graph; advice, etc).	Display of test costs
4. Is a description of pilot testing with users prior to implementation provided?	No
5. Is user instructional training at the time of implementation described?	No
6. Is the CDSS integrated with charting or OCS to support workflow integration?	Yes
7. Is automatic provision of CDSS output provided as part of clinician workflow?	Yes
8. Is there a need for additional data entry by the clinician?	No
9. Does the CDSS request documentation of the reason for not following CDSS recommendations?	No
10. Does CDSS provide output at the time and location of decision making?	Yes
11. Are the CDSS recommendations executed by the clinician noting agreement?	No
12. Does the CDSS provide a recommendation rather than just an assessment?	No
13. Does the CDSS promote action rather than inaction?	NR
14. Does the CDSS justify the output by provision of reasoning?	No
15. Does the CDSS justify the output by provision of research evidence?	No
16. Were local users involved in the CDSS development process?	No
17. Is the CDSS output provided to patients as well as clinician?	No
18. Does the CDSS provide periodic summaries of performance feedback?	No
19. Is the CDSS used in conjunction with conventional education?	No

Outcome measures

Outcome 1: Mean number of tests ordered per visit

Outcome 2: Mean charges for tests ordered per visit

Outcome 3: Mean number of tests ordered per scheduled visit

Outcome 4: Mean number of tests ordered per unscheduled visit

Outcome 5: Mean charges for tests ordered per scheduled visit

Outcome 6: Mean charges for tests ordered per unscheduled visit

Outcome 7: Mean number of tests ordered per visit in post-intervention period

Outcome 8: Mean charges for tests ordered per visit in post-intervention period

Outcome 9: Number of hospitalisations per patient in the intervention and post-intervention period

Outcome 10: Number of emergency room visits per patient in the intervention and post-intervention period

Outcome 11: Number of outpatient visits per patient in the intervention and post-intervention period

Total length of follow-up: 40 weeks; 26 weeks for the intervention period (14 weeks pre-intervention period and 26 weeks post-intervention period)

Follow-up assessment times: Baseline (end of pre-intervention period); 26 weeks (post-intervention); and 52 weeks (end of post-intervention period)

Rate of attrition at each follow-up time: Baseline (end of pre-intervention period): 4/125 (n = 121; 3.2% attrition); end of intervention period: 51/125 (n = 74; 40.8% attrition); end of post-intervention period: 51/125 (n = 74; 40.8% attrition)

Methods of statistical analysis: For each physician the mean number of tests ordered and the mean charge for tests per patient visit was calculated separately for each study period (pre-intervention, intervention, and post-intervention). The analysis was weighted by the reciprocal of the sum of the variance within and between physicians. Weighted analysis of covariance was used to compare differences between groups in the intervention period, with each physician's pre-intervention mean entered as a covariate. All two-tailed p-values < 0.05 were considered statistically significant. Rates of hospitalisations, emergency room visits and outpatient visits were compared using the Wilcoxon rank-sum test

Results: mean ± SD

Outcome 1: Mean number of tests ordered per visit

Intervention	**OCS + CDSS (costs – US$)**	**OCS alone**	**% difference**	***p*-value**
All physicians	1.56 ± 0.72	1.82 ± 0.90	–14.3%	$p < 0.005$
Residents	1.60 ± 0.73	1.89 ± 0.93	–15.3%	$p < 0.005$
Faculty	1.39 ± 0.64	1.51 ± 0.71	–7.9%	$p > 0.05$

Outcome 2: Mean charges for tests ordered per visit

Intervention	**OCS + CDSS (costs – US$)**	**OCS alone**	**% difference**	***p*-value**
All physicians	45.13 ± 21.98	51.81 ± 21.99	–12.9%	$p < 0.05$
Residents	45.90 ± 21.9	52.99 ± 22.21	–13.4%	$p < 0.05$
Faculty	41.84 ± 23.01	47.12 ± 21.28	–11.2%	$p > 0.05$

Outcome 3: Mean number of tests ordered per scheduled visit

Intervention	**OCS + CDSS (costs – US$)**	**OCS alone**	**% difference**	***p*-value**
All physicians	1.59 ± 0.75	1.91 ± 0.94	–16.8%	$p < 0.01$

Outcome 4: Mean number of tests ordered per unscheduled visit

Intervention	**OCS + CDSS (costs – US$)**	**OCS alone**	**% difference**	***p*-value**
All physicians	1.17 ± 0.67	1.32 ± 0.94	–11.4%	$p < 0.05$

Outcome 5: Mean charges for tests ordered per scheduled visit

Intervention	**OCS + CDSS (costs – US$)**	**OCS alone**	**% difference**	***p*-value**
All physicians	45.26 ± 22.79	53.43 ± 22.97	–15.3%	$p < 0.01$

Outcome 6: Mean charges for tests ordered per unscheduled visit

Intervention	**OCS + CDSS (costs – US$)**	**OCS alone**	**% difference**	***p*-value**
All physicians	35.55 ± 21.32	39.38 ± 25.10	–9.7%	$p < 0.05$

Outcome 7: Mean number of tests ordered per visit in post-intervention period

Intervention	**OCS + CDSS (costs – US$)**	**OCS alone**	**% difference**	***p*-value**
All physicians	1.67 ± 0.77	1.81 ± 0.9	–7.7%	$p > 0.05$

Outcome 8: Mean charges for tests ordered per visit in post-intervention period

Intervention	**OCS + CDSS (costs – US$)**	**OCS alone**	**% difference**	***p*-value**
All physicians	48.28 ± 22.55	50.04 ± 21.73	–3.5%	$p > 0.05$

Outcome 9: Number of hospitalisations per patient in the intervention and post-intervention period

Intervention	**OCS + CDSS**	**OCS alone**	***p*-value**
Number of hospitalisations/patient	0.19 ± 0.62	0.17 ± 0.55	$p > 0.05$

Outcome 10: Number of emergency room visits per patient in the intervention and post-intervention period

Intervention	**OCS + CDSS (costs – US$)**	**OCS alone**	***p*-value**
Number of emergency room visits/patient	1.03 ± 1.73	1.00 ± 1.74	$p > 0.05$

Outcome 11: Number of outpatient visits per patient in the intervention and post-intervention period

Intervention	**OCS + CDSS (costs – US$)**	**OCS alone**	***p*-value**
Outpatient visits/patient	4.30 ± 3.39	4.30 ± 3.44	$p > 0.05$

Authors' conclusions: In the 14 weeks before the trial, the number of tests orders and the average charges for test per patient visit were similar for the intervention and control groups. During the trial displaying the charges for diagnostic tests significantly reduced the number and cost of tests ordered, especially for patients with scheduled visits. The effect of this intervention did not persist after it was discontinued

Methodological assessment criteria (Tierney) (1990)[86]

1. Is the study properly randomised?	Unclear
2. Is allocation of treatment concealed?	Unclear
3. Were the study eligibility criteria specified?	Yes
4. Are adequate baseline details presented?	Yes
5. Are groups similar at baseline?	Yes

6. Are any baseline imbalances adequately adjusted for in the analysis?	NA
7. Are similar cointerventions administered?	NA
8. Are physician's blinded to treatment allocation?	No
9. Are outcome assessors blinded?	Unclear
10. Are data analyses appropriate?	Yes
11. Is analysis conducted on an 'intention to provide or communicate' information basis?	No
12. Are greater than 80% of physicians/patients included in the follow-up assessment?	Yes
13. Are the conclusions supported by the results?	Yes
Comments: None	

Study demographics

Author; year; study ID: Bates (1997)[101]

Title: Does the computerised display of charges affect inpatient ancillary test utilisation?

Country: USA

Specific setting: Brigham and Women's Hospital, Boston, MA, USA (720-bed tertiary care hospital)

Study objectives: To assess whether the computerised display of charges for clinical laboratory or radiological tests affects physician-ordering behaviour

Health-care setting: Secondary care (medical and surgical I inpatients)

If secondary care, academic status of the hospital: Teaching hospital

Health-care system: Medicare; HMO; private insurance; uninsured

Study design: 2 RCTs

Number of sites: 1 (720-bed hospital)

Funding source: Public sector

Was evaluator of tool also its developer? Yes

System users (both RCTs)

	Intervention group	**Control group**
CDSS user(s)	Physician	Physician
Practitioners (*n*)	NR	NR
Practitioners (*n*) in analysis	NR	NR

a No further baseline details were reported on study physicians.

Inclusion criteria: All physicians using OCS with or without CDSS for laboratory or radiological test ordering on the medical or surgical wards during the study period. The clinical laboratory study period was 4 months (February to May 1994) and Radiology study period was 7 months (April to October 1994)

Exclusion criteria: NR

Patient baseline demographics

Inclusion criteria: All inpatients who were admitted to the medical or surgical wards during and discharged before the last day of the study periods

Exclusion criteria: NR

Clinical laboratory trial

	Intervention group	**Control group**
N	3536	3554
Age (years) (mean; SD)	55.3 ± 17.8	54.7 ± 17.7
Gender (Male, *n*; %)	1847 (49.4)	1732 (48.7)
Service (*n*; %)		
Medical	2081 (55.7)	1952 (55.9)

Surgical	1658 (44.3)	1602 (45.1)
DRG weight[a,b]	1.09 (0.76–1.97)	1.07 (0.76–1.97)
White (*n*; %)	2690 (71.9)	2574 (72.4)
Medicare, HMO, or private insurance (*n*; %)	3242 (86.7)	3088 (68.9)
Length of stay (days)[b]	4 (2–7)	4 (2–7)
Radiology trial		
N	8728	8653
Age (mean; SD)	54.0 ± 17.9	53.2 ± 17.9
Gender (Male, *n*; %)	3894 (44.6)	3877 (44.8)
Service (*n*; %)		
Medical	4194 (52.0)	4099 (51.9)
Surgical	3874 (48.0)	3799 (48.1)
DRG weight[a,b]	1.02 (0.76–1.96)	1.02 (0.75–1.89)
White (*n*; %)	6388 (73.2)	6329 (73.1)
Medicare, HMO, or private insurance (*n*; %)	7611 (87.2)	7545 (87.2)
Length of stay (days)[b]	3 (2–7)	3 (2–6)

a DRG indicates diagnosis related group.

b Medians; ranges (in parentheses) are 25% and 75% quartiles.

Interventions

Intervention: OCS plus CDSS (display of test charges). For the laboratory test trial the costs for 19 commonly ordered laboratory tests were displayed. Other less frequently ordered laboratory tests were entered from other checkbox screens or via textual input. This was used to parse a coded test name. The coded test name and test charge were then displayed. For the radiological procedures, charges for 35 of the most frequently ordered tests were displayed at the time of ordering. Charges for the remainder of the radiological tests were not displayed. In both trials, in addition to the display of charges, a 'cash register' window that showed physicians the sum of the total charges for the tests during the ordering session was displayed. Charges that were displayed were the hospital's charges to the patients or their insurers for the tests only; other charges (e.g. for interpretation of radiographs) were not displayed.

Comparator: OCS alone

Note: During the study periods tests could still be ordered directly from the laboratory thus by-passing the use of the OCS. Additionally, radiological studies that were performed in the operating room (6.3% of all radiological studies) or in the emergency department (10% of all studies) were not ordered via OCS. Therefore in the study periods only 53% of the laboratory tests performed and 74% of the radiology tests performed had a corresponding computer order.

Concomitant interventions: NA

CDSS tool

Name of CDDS (if any)	NR
CDSS reasoning method	NR
CDSS knowledge base	Hospital test costs
Did study use training set and test set data?	Training set: NR Test set: NR

For training set data complete the following:

Design	NR
Target decision	NR

Sample characteristics:	***Intervention***	***Control***
Sample size (*n*)	NR	NR
Age (mean; range)	NR	NR
Gender (*n* male; *n* female)	NR	NR
Disease type	NR	NR

For test set data complete the following:

Properties of test set data	NR
Test centre	NR
Target decision	NR

Other CDSS information

1. Information used in CDSS [number of items; signs; symptoms; history; biochemical tests (list)]	NR; biochemical and radiology test orders
2. Time to complete the CDSS (minutes)	NR
3. CDSS output format: (score; probability graph; advice; etc.)	Display of test costs
4. Is a description of pilot testing with users prior to implementation provided?	No
5. Is user instructional training at the time of implementation described?	No
6. Is the CDSS integrated with charting or OCS to support workflow integration?	Yes
7. Is automatic provision of CDSS output provided as part of clinician workflow?	Yes
8. Is there a need for additional data entry by the clinician?	No
9. Does the CDSS request documentation of the reason for not following CDSS recommendations?	No
10. Does CDSS provide output at the time and location of decision making?	Yes
11. Are the CDSS recommendations executed by the clinician noting agreement?	No
12. Does the CDSS provide a recommendation rather than just an assessment?	No
13. Does the CDSS promote action rather than inaction?	NR
14. Does the CDSS justify the output by provision of reasoning?	No
15. Does the CDSS justify the output by provision of research evidence?	No
16. Were local users involved in the CDSS development process?	Unclear
17. Is the CDSS output provided to patients as well as clinician?	No
18. Does the CDSS provide periodic summaries of performance feedback?	No
19. Is the CDSS used in conjunction with conventional education?	No

Outcome measures

Outcome 1: Mean number of tests ordered per admission

Outcome 2: Mean number of tests performed per admission

Outcome 3: Mean charges for tests ordered per admission

Outcome 4: Mean charges for tests performed per admission

Outcome 5: Mean length of patient stay (days)

Outcome 6: Mean total hospital charges

Total length of follow-up: Clinical laboratory trial – 4 months; radiology trial – 7 months

Follow-up assessment times: Clinical laboratory trial – 4 months; radiology trial – 7 months

Rate of attrition at each follow-up time: NA

Methods of statistical analysis: Results for the number of tests and charges were reported as medians (with 25% and 75% quartiles) and as means (SDs). Univariate comparisons between intervention and comparator groups were made with Wilcoxon rank-sum statistic or *t*-tests. Multiple linear regression analysis were performed adjusting for age, gender, race, primary insurer, and DRG weight

Results

Outcome 1: Mean number of tests ordered per admission

Clinical laboratory trial[a]

Intervention	**OCS + CDSS (costs – US$)**	**OCS alone**	**Δ (%)**	***p*-value**[b]
N in analysis	3739	3554	–	–
	25.6 ± 37.9	26.8 ± 43.4	–4.5	0.74; 0.21
	15 (6–31)	15 (6–31)		

Radiology trial[a]				
N in analysis	8728	8653	–	–
	1.76 ± 4.43	1.76 ± 4.68	0	0.13; 0.95
	0 (0–2)	0 (0–2)		

a Results reported as mean ± SD with medians with 25th and 75th percentiles in parentheses.

b First *p*-value by Wilcoxon rank-sum test; second *p*-value by *t*-test.

Outcome 2: Mean number of tests performed per admission

Clinical laboratory trial[a]				
Intervention	**OCS + CDSS (costs – US$)**	**OCS alone**	**Δ (%)**	***p*-value**[b]
N in analysis	3739	3554	–	–
	46.9 ± 79.2	49.6 ± 94.4	–5.4	0.87; 0.18
	25 (13–50)	24 (13–52)		
Radiology trial[a]				
N in analysis	8728	8653	–	–
	1.53 ±3.58	1.53 ± 4.06	0	0.06; 0.99
	0 (0–1)	0 (0–1)		

a Results reported as mean ± SD with medians with 25th and 75th percentiles in parentheses.

b First *p*-value by Wilcoxon rank-sum test; second *p*-value by *t*-test.

Outcome 3: Mean charges for tests ordered per admission ($)

Clinical laboratory trial[a]				
Intervention	**OCS + CDSS (costs – US$)**	**OCS alone**	**Δ (%)**	***p*-value**[b]
N in analysis	3739	3554	–	–
	739 ± 1129	771 ± 1310	–4.2	0.97; 0.25
	392 (151–907)	399 (149–883)		
Radiology trial[a]				
N in analysis	8728	8653	–	–
	275 ± 688	276 ± 737	-0.4	0.10; 0.88
	0 (0–266)	0 (0–209)		

a Results reported as mean ± SD with medians with 25th and 75th percentiles in parentheses.

b First *p*-value by Wilcoxon rank-sum test; second *p*-value by *t*-test.

Outcome 4: Mean charges for tests performed per admission

Clinical laboratory trial[a]				
Intervention	**OCS + CDSS (costs – US$)**	**OCS alone**	**Δ (%)**	***p*-value**[b]
N in analysis	3739	3554	–	–
	1423 ± 2730	1496 ± 3147	–4.9	0.89; 0.29
	649 (309–1409)	565 (305–1463)		
Radiology trial[a]				
N in analysis	8728	8653	–	–
	220 ± 473	215 ± 515	+2.3	0.03; 0.50
	0 (0–266)	0 (0–200)		

a Results reported as mean ± SD with medians with 25th and 75th percentiles in parentheses.

b First *p*-value by Wilcoxon rank-sum test; second *p*-value by *t*-test.

Outcome 5: Mean length of patient stay (days)

Clinical laboratory trial[a]

Intervention	**OCS + CDSS (costs – US$)**	**OCS alone**	**Δ (%)**	***p*-value**
N in analysis	3536	3363	–	–
	6.25 ± 0.11	6.50 ± 0.11	–3.8	NS
Radiology trial[a]				
N in analysis	8728	8653	–	–
	5.97 ± 0.07	5.86 ± 0.07	+1.9	NS

a Adjusted by age, diagnosis related group weight, race, service, and insurance status.

Outcome 6: Mean total hospital charges ($)

Clinical laboratory trial[a]

Intervention	**OCS + CDSS (costs – US$)**	**OCS alone**	**Δ (%)**	***p*-value**
N in analysis	3536	3363	–	–
	16,298 ± 318	16,734 ± 326	–2.6	NS
Radiology trial[a]				
N in analysis	8728	8653	–	–
	16,842 ± 264	16,417 ± 267	+2.6	NS

a Adjusted by age, diagnosis related group weight, race, service, and insurance status.

Authors' conclusions: The computerised display of charges had no statistically significant effect on the number of clinical laboratory tests or radiological procedures ordered or performed, although small trends were present for clinical laboratory tests. More intensive interventions may be needed to affect physician test utilisation

Methodological assessment criteria (Bates) (1997)[101]

1. Is the study properly randomised?	Unclear
2. Is allocation of treatment concealed?	Unclear
3. Were the study eligibility criteria specified?	Yes
4. Are adequate baseline details presented?	Yes
5. Are groups similar at baseline?	Yes
6. Are any baseline imbalances adequately adjusted for in the analysis?	NA
7. Are similar cointerventions administered?	NA
8. Are physician's blinded to treatment allocation?	No
9. Are outcome assessors blinded?	Unclear
10. Are data analyses appropriate?	Yes
11. Is analysis conducted on an 'intention to provide or communicate information' basis?	Yes
12. Are greater than 80% of physicians/patients included in the follow-up assessment?	Yes
13. Are the conclusions supported by the results?	Yes

Comments: contamination likely as patients are the unit of randomisation and physicians treated patients in both groups (with and without test costs displayed). Trials may lack power to detect any differences between the two groups as only 53% of the laboratory tests performed and 74% of the radiology tests performed had a corresponding computer order.

Studies assessing the impact of display of previous test results (*n* = 2)

Study demographics

Author; year; study ID: Solomon (1999)[88]

Title: A computer-based intervention to reduce unnecessary serologic testing

Country: USA

Specific setting: Brigham and Women's Hospital, Boston, MA, USA

Study objectives: To assess whether physicians would reduce their use of unnecessary serologic tests if provided with information on the likelihood that a antinuclear antibody (ANA), rheumatoid factor (RF), or complement level test would change their estimate of disease

Health-care setting: Secondary care (inpatients)

If secondary care, academic status of the hospital: NR

Health-care system: NR

Study design: CCT

Number of sites: 1 (720-bed hospital)

Funding source: Public sector

Was evaluator of tool also its developer? Yes

System users

	Intervention group	**Control group**	***p*-value**
CDSS user(s)	Physician	Physician	
Practitioners (*n*)	71	154	
Age (year) (mean; SD)	30 ± 4	30 ± 4	0.5
Gender (Female, %)	28	36	0.2
Postgraduate year (%)[a]			
First	65	52	
Second	13	27	
Third	16	14	
Fourth	5	7	0.08
Department (%)[a]			
Medicine	86	82	
Surgery	2	7	
Neurology	7	8	
Obstetrics-gynaecology	5	3	0.2

a Percentages may not sum due to rounding (reported by authors).

b Calculated from chi-squared tests for categorical data and Wilcoxon rank sum tests for ordinal data.

Practitioners (*n*) in analysis		NA	NA

Inclusion criteria: All physicians ordering an RF or ANA test for the suspected indications of rheumatoid arthritis, systemic lupus erythematosus, primary systemic sclerosis, mixed connective tissue disease, or Sjögren's syndrome during the 10-month study period (September 1996 to June 1997) were assigned to the intervention group. All physicians ordering an RF or ANA for the suspected indications of systemic vasculitis and cryoglobulinemia, or a complement test for any condition during the study period were assigned to the control group

Exclusion criteria: When multiple orders for the same test for the same patient during one calendar day were made, only the last order was included

Patient baseline demographics

Inclusion criteria: All inpatients with an order written for an ANA, RF or complement level test during the 10-month study period

Exclusion criteria: NR

Patient characteristics	**Intervention group**	**Control group**	***p*-value[a]**
N	99	236	
Age (year) (mean; SD)	55 ± 19	54 ± 17	0.7

Gender (female) (%)	66	66	1.0
Length of stay (days)[b]	6 (3,12)	6 (3,11)	0.9
Total charges (US$)[b]	13,415 (7636; 27,951)	13,217 (7337; 25,634)	0.6
Died in hospital (*n*)	4	6	0.4

a Calculated from chi-squared tests for categorical data and Wilcoxon rank-sum tests for ordinal data.

b Median (25%; 75%).

Interventions

Intervention: OCS plus CDSS. The CDSS required the physician to enter into the computer their estimate of the pre-test probability of disease. The CDSS then calculated the positive and negative post-test predictive values based on estimates of the sensitivity and specificity of each test derived from the literature

Comparator: OCS alone

Concomitant interventions: NA

CDSS tool

Name of CDDS (if any)	NR (home-grown system Brigham and Women's Hospital)
CDSS reasoning method	Naive Bayesian methods
CDSS knowledge base	Sensitivity and Specificity values abstracted from the literature
Did study use training set and test set data?	Training set: NR Test set: NR

For training set data complete the following:

Design	NR	
Target decision	NR	
Sample characteristics:	Intervention	Control
Sample size (*n*)	NR	NR
Age (mean; range)	NR	NR
Gender (*n* male; *n* female)	NR	NR
Disease type	NR	NR

For test set data complete the following:

Properties of test set data	
Test centre	NR
Target decision	NR

Other CDSS information

1. Information used in CDSS [number of items; signs; symptoms; history; biochemical tests (list)]	1; pre-test probability estimate
2. Time to complete the CDSS (minutes)	NR
3. CDSS output format: (score; probability graph; advice; etc.)	Positive and negative predictive values (post-test)
4. Is a description of pilot testing with users prior to implementation provided?	No
5. Is user instructional training at the time of implementation described?	Yes
6. Is the CDSS integrated with charting or OCS to support workflow integration?	Yes
7. Is automatic provision of CDSS output provided as part of clinician workflow?	Yes
8. Is there a need for additional data entry by the clinician?	Yes
9. Does the CDSS request documentation of the reason for not following CDSS recommendations?	No
10. Does CDSS provide output at the time and location of decision making?	Yes
11. Are the CDSS recommendations executed by the clinician noting agreement?	No
12. Does the CDSS provide a recommendation rather than just an assessment?	No

13. Does the CDSS promote action rather than inaction?	No
14. Does the CDSS justify the output by provision of reasoning?	No
15. Does the CDSS justify the output by provision of research evidence?	No
16. Were local users involved in the CDSS development process?	NR
17. Is the CDSS output provided to patients as well as clinician?	No
18. Does the CDSS provide periodic summaries of performance feedback?	No
19. Is the CDSS used in conjunction with conventional education?	No

Outcome measures

Outcome 1: Number of tests cancelled

Outcome 2: Yield of positive tests for known or new rheumatic disease

Total length of follow-up: 10 months (September 1996 to June 1997)

Follow-up assessment times: 10 months

Rate of attrition at each follow-up time: 348 patients had a ANA, RF or complement test ordered, of these 13 duplicate orders were excluded. *N* = 335 tests (attrition rate = 3.7%)

Methods of statistical analysis: Chi-squared tests and Wilcoxon rank-sum tests for univariate analysis

Results

Outcome 1: Number of tests cancelled

	OCS + CDSS	**OCS alone**	***p*-value**
N in analysis	99	236	–
Number of tests cancelled *n* (%)	11 (11.1%)	1 (0.42%)	$p = 0.001$

Outcome 2: Yield of positive tests for known or new rheumatic disease

The charts of 43 patients with positive tests were reviewed to determine whether the positive test yielded a new diagnosis of a rheumatic condition. 26/43 of the positive tests were in patients with known rheumatic disease. Only 4/43 new diagnosis of rheumatic disease were made, which account for 1.2% of all tests ordered

Authors' conclusions: The computer-based intervention resulted in a small but statistically significant decrease in orders for AAN and RF levels by 10%. Further reductions without clinical harm are probably possible, since the yield of testing for new rheumatic diseases was low

Methodological assessment criteria Solomon (1999)[88]

1. Were the study eligibility criteria specified?	Yes
2. Are adequate baseline details presented?	Yes
3. Are groups similar at baseline?	Yes
4. Are any baseline imbalances adequately adjusted for in the analysis?	NA
5. Are similar cointerventions administered?	NA
6. Are physician's blinded to treatment allocation?	No
7. Are outcome assessors blinded?	No
8. Are data analyses appropriate?	Yes
9. Is analysis conducted on an 'intention to provide or communicate' information basis?	Yes
10. Are greater than 80% of physicians/patients included in the follow-up assessment?	Yes
11. Are the conclusions supported by the results?	Yes

Comments: None

Study demographics

Author; year; study ID: Bansal (2001)[89]

Title: A computer-based intervention on the appropriate use of ABG

Country: USA

Specific setting: Vanderbilt University Medical Center, Nashville, TN, USA (630-bed hospital with 31,000 admissions per year)

Study objectives: To evaluate the impact of a computer-based intervention on ABG usage in an intensive care setting

Health-care setting: Secondary care (ICUs)

If secondary care, academic status of the hospital: University

Health-care system: NR

Study design: Pre–post

Number of sites: 1 (six ICUs; trauma; general surgery; medical; cardiac; burn; neurology)

Funding source: Public sector

Was evaluator of tool also its developer? Yes

System users

CDSS user(s)[a]	Physicians'; respiratory therapists; nurses; medical receptionists
Practitioners (*n*)	NR

Orders entered by user type at baseline

User type[a]	***n***	%
Ancillary staff	24	1.8%
Physicians	366	28.0%
Other users	8	0.6%
Nurses	813	62.0%
Respiratory therapists	80	6.1%

a Staff who were not MD had the ability to enter verbal or written orders from physicians.

Inclusion criteria: All users with the authority to enter orders via the OCS during the study period

Exclusion criteria: NR

Patient baseline demographics

Inclusion criteria: All patients on the six ICUs; (trauma; general surgery; medical; cardiac; burn; neurology) who had a ABG test ordered during the study period[a]

Exclusion criteria: NR

a No further data on patient baseline demographics was reported.

Interventions

Intervention: OCS plus CDSS. CDSS provided the ordering clinician with educational text alongside a graphical display of the patient's previous ABG values (pO_2, pCO_2, HCO_3, pH, FiO_2) and O2 saturations. Advanced ordering of ABG tests was also limited to within 24 hours so no multiday orders were allowed. The default response was to cancel the order, but the final decision regarding the test order was left to the user's discretion

Comparator: OCS alone (pre-intervention)

Concomitant interventions: NA

CDSS tool

Name of CDDS (if any)	NR (home-grown system Vanderbilt University Medical Center)
CDSS reasoning method	NR
CDSS knowledge base	NR
Did study use training set and test set data?	Training set: No Test set: No

For training set data complete the following:

Design	NR

Target decision	NR
Sample characteristics:	
Sample size (*n*)	NR
Age (mean; range)	NR
Gender (*n* male; *n* female)	NR
Disease type	NR
For test set data complete the following:	
Properties of test set data	NR
Test centre	NR
Target decision	NR
Other CDSS information	
1. Information used in CDSS [number of items; signs; symptoms; history; biochemical tests (list)]	Six previous ABG results (pO_2, pCO_2, HCO_3, pH, FiO_2 O2 saturations
2. Time to complete the CDSS (minutes)	NR
3. CDSS output format: (score; probability graph; advice; etc.)	Graphs
4. Is a description of pilot testing with users prior to implementation provided?	No
5. Is user instructional training at the time of implementation described?	No
6. Is the CDSS integrated with charting or OCS to support workflow integration?	Yes
7. Is automatic provision of CDSS output provided as part of clinician workflow?	Yes
8. Is there a need for additional data entry by the clinician?	No
9. Does the CDSS request documentation of the reason for not following CDSS recommendations?	No
10. Does CDSS provide output at the time and location of decision making?	Yes
11. Are the CDSS recommendations executed by the clinician noting agreement?	Yes
12. Does the CDSS provide a recommendation rather than just an assessment?	No
13. Does the CDSS promote action rather than inaction?	No
14. Does the CDSS justify the output by provision of reasoning?	No
15. Does the CDSS justify the output by provision of research evidence?	No
16. Were local users involved in the CDSS development process?	Yes
17. Is the CDSS output provided to patients as well as clinician?	No
18. Does the CDSS provide periodic summaries of performance feedback?	No
19. Is the CDSS used in conjunction with conventional education?	No

Outcome measures

Outcome 1: Number of ABG test orders placed pre- and post-intervention

Total length of follow-up: 12 weeks (pre-intervention 5 weeks; post-intervention 7 weeks). Study period: 1 November 2000 to 23 January 2001

Follow-up assessment times: 12 weeks

Rate of attrition at each follow-up time: NA

Methods of statistical analysis: ANOVA and linear regression analysis

Results

Outcome 1: Number of ABG test orders placed pre- and post-intervention

Pre-intervention (*n*)	**Post-intervention (*n*)**	***p*-value**
376	387	$p = 0.09$

Authors' conclusions: Study did not demonstrate significant change. Longer study periods are therefore needed. The impact could be improved in the future by targeting physician users and tailoring the intervention to specific workflow patterns of high utilisation units

Methodological assessment criteria (Bansal) (2001)[89]	
1. Were the study eligibility criteria specified?	Yes
2. Are adequate baseline details presented?	Partial
3. Are similar cointerventions administered in both study periods?	No
4. Are data analyses appropriate?	Yes
5. Is analysis conducted on an 'intention to provide or communicate information' basis?	Unclear
6. Are greater than 80% of physicians/patients included in the follow-up assessment?	Yes
7. Are the conclusions supported by the results?	Yes

Comments: The numbers presented in the abstract for change in the number of test orders placed pre- and post-intervention do not tally with those presented in the text on page 34. It is unclear whether the post-intervention results reported in both the abstract and text (p. 34) pertain to just the implemented units or all units together. Numbers reported for outcome 1 are taken from the abstract

Studies assessing the impact of the display of reminders (*n* = 10)

Study demographics

Author; year; study ID: Overhage (1996)[48]
Title: Computer reminders to implement preventive care guidelines for hospitalised patients
Country: USA
Specific setting: Wishard Memorial Hospital, Indianapolis, IN, USA
Study objectives: To determine if computer reminders increase the provision on inpatient preventive care
Health-care setting: Inpatient general medicine ward
If secondary care, academic status of the hospital: Teaching hospital
Health-care system: NR
Study design: CRCT
Number of sites: 1; 6 independent medical services within the ward (3 intervention; 3 control)
Funding source: Public sector
Was evaluator of tool also its developer? Yes

System users

	Intervention group	**Control group**
CDSS user(s)	Physician	Physician
Practitioners (*n*)	78 (24 unique teams of physicians and medical students rotated through the 6 medical services)	
If the CDSS user is a doctor, complete *n* for the following:	NR	NR
Consultant (attending)		
Registrar (chief resident)		
SHO (resident)		
HO (intern)		

Practitioners (n) in analysis ***74***

Inclusion criteria: NR

Exclusion criteria: Physicians who rotated through the service more than once and could not be assigned to the same study status (i.e. intervention or control were excluded in the analysis)

Patient baseline demographics

Inclusion criteria: All patients admitted to the inpatient general medicine ward during the study period for whom the computer generated at least one preventive care recommendation

Exclusion criteria: Data from patients who were (1) admitted before the study began, (2) discharged after the study period, (3) had already been hospitalised during the study period or (4) remained in the hospital less than 18 hours were excluded from the analysis

	Intervention group	**Control group**
N	821	801
Age (years) (mean; SD)	51 ± 18	51 ± 18
Gender (% male)	50%	50%
White ethnic group (%)	50.1%	48.4%
Primary discharge diagnosis (%)		
Chest pain, angina, MI	7.6%	8.1%
Pneumonia	5.7%	6.7%
Congestive heart failure	4.8%	4.9%
Pancreatitis	3.0%	3.6%
Asthma	3.6%	3.6%
Gastrointestinal bleeding	3.3%	3.6%
Diabetic ketoaciodosis	3.0%	3.1%

Abdominal pain	1.0%	3.1%
Diabetes mellitus	2.2%	2.8%

Interventions

Intervention: OCS plus reminders for preventive care measures. Twenty-two preventive care measures from the US Preventive Services Task Force recommendations were developed and presented for each patient to physicians as reminders on printed daily reports for each patient and also in the OCS used for all order writing. These were the only reminders that were active during the study period. The preventive care actions included: (1) cervical cytology study; (2) pneumococcal vaccination; (3) aspirin; (4) oestrogen treatment; (5) calcium treatment; (6) ophthalmologic referral; (7) mammography; (8) thyrotropin screen; (9) hepatitis B screen; (10) rubella screen; (11) screening urinalysis; (12) cholesterol test; (13) pregnancy test; (14) HIV screen; (15) ACE inhibitor; (16) heparin prophylaxis; (17) 24-hour urine protein test; (18) sickle cell screen; (19) cholesterol treatment; (20) screening electrocardiogram; (21) beta-blocker; (22) STD screen

Note: only data on (1) cervical cytology study; (2) mammography; (3) thyrotropin screen; (4) hepatitis B screen; (5) screening urinalysis; (6) cholesterol test; (7) HIV screen; (8) 24-hour urine protein test; (9) Sickle cell screen; (10) screening electrocardiogram; (11) STD screen impact on test volumes/rates and are therefore extracted

Comparator: OCS alone without reminders

Concomitant interventions: NA

CDSS tool

Name of CDDS (if any)	NR
CDSS reasoning method	Discrimination rules
CDSS knowledge base	US Preventive Services Task Force Recommendations (Guidelines)
Did study use training set and test set data?	Training set: Yes Test set: NR

For training set data complete the following:

Design	Retrospective test against data from 1000 medical inpatients	
Target decision	NR	
Sample characteristics:	Intervention	Control
Sample size (*n*)	NR	NR
Age (mean; range)	NR	NR
Gender (*n* male; *n* female)	NR	NR
Disease type	NR	NR

For test set data complete the following:

Properties of test set data	NR
Test centre	Same as for training set
Target decision	NR

Other CDSS information

1. Information used in CDSS [number of items; signs; symptoms; history; biochemical tests (list)]	NR
2. Time to complete the CDSS (minutes).	NR
3. CDSS output format: (score; probability graph; advice; etc.)	Reminders
4. Is a description of pilot testing with users prior to implementation provided?	No
5. Is user instructional training at the time of implementation described?	No
6. Is the CDSS integrated with charting or OCS to support workflow integration?	Yes
7. Is automatic provision of CDSS output provided as part of clinician workflow?	Yes
8. Is there a need for additional data entry by the clinician?	No
9. Does the CDSS request documentation of the reason for not following CDSS recommendations?	No
10. Does CDSS provide output at the time and location of decision making?	Yes
11. Are the CDSS recommendations executed by the clinician noting agreement?	No
12. Does the CDSS provide a recommendation rather than just an assessment?	No

13. Does the CDSS promote action rather than inaction?	NR
14. Does the CDSS justify the output by provision of reasoning?	No
15. Does the CDSS justify the output by provision of research evidence?	No
16. Were local users involved in the CDSS development process?	No
17. Is the CDSS output provided to patients as well as clinician?	No
18. Does the CDSS provide periodic summaries of performance feedback?	No
19. Is the CDSS used in conjunction with conventional education?	No

Outcome measures

Outcome 1: Compliance with reminders for preventive care measures

Total length of follow-up: 6 months (beginning 26 October 1992)

Follow-up assessment times: 6 months

Rate of attrition at each follow-up time: During the study period 1929 patients received care during 2595 hospitalisations. Data were eliminated from 973 hospitalisations (38%) because (1) the patient was admitted before the study began (n = 76), (2) the patient was discharged after the study ended (n = 95), (3) the patient had already been hospitalised once during the study (n = 412), (4) the patient remained in hospital less than 18 hours (n = 226), (5) other (n = 164) (unspecified). After exclusions data from 1622 hospitalisations remained

Methods of statistical analysis: Results for individual preventive care measures and all measures combined were analysed using the Kleinman β-binomial model. A 2-tailed p-value ≤ 0.05 was considered significant

Results

Outcome 1: Compliance with reminders for preventative care measures

Preventive Care Action	**OCS + CDSS (alerts)**		**OCS alone**		***p*-value**
	N	Compliance (%)	*N*	Compliance (%)	
Cervical cytology study	323	2.8	329	2.8	$p = 0.41$
Mammography	125	5.6	131	1.5	$p = 0.08$
Thyrotropin screen	112	16.1	118	9.3	$p = 0.12$
Hepatitis B screen	88	8.0	92	2.2	$p = 0.08$
Screening urinalysis	68	32.4	75	34.7	$p = 0.77$
Cholesterol test	70	14.3	58	13.8	$p = 0.94$
HIV screen	44	4.6	43	9.3	$p = 0.38$
24-hour urine protein test	24	25.0	23	4.4	$p = 0.05$
Sickle cell screen	22	9.0	14	0.0	$p = 0.25$
Screening electrocardiogram	13	0.0	14	21.4	$p = 0.08$
STD screen	2	50.0	6	16.7	$p = 0.35$

HIV, human immunodeficiency virus; STD, sexually transmitted disease.

Authors' conclusions: Using a moderately intensive intervention we were unable to increase the provision of preventive care during hospitalisations. The physicians providing care during the hospitalisations were not the patients' primary care physicians which proved to be an important barrier

Methodological assessment criteria (Overhage) (1996)[48]

1. Is the study properly randomised?	Yes
2. Did the analysis take clustering into account?	Yes
3. Were the study eligibility criteria specified?	Yes
4. Are adequate baseline details presented?	Partial
5. Are groups similar at baseline?	Yes
6. Are any baseline imbalances adequately adjusted for in the analysis?	NA
7. Are similar cointerventions administered?	NA
8. Are physician's blinded to treatment allocation?	No
9. Are outcome assessors blinded?	Unclear

10. Are data analyses appropriate?	Yes
11. Is analysis conducted on an 'intention to provide or communicate information' basis?	No
12. Are greater than 80% of physicians/patients included in the follow-up assessment?	Yes
13. Are the conclusions supported by the results?	Yes
Comments: None.	

Study demographics

Author; year; study ID: Overhage (1997)[24]

Title: A randomised trial of 'corollary' to prevent errors of omission

Country: USA

Specific setting: Wishard Memorial Hospital, Indianapolis, IN, USA

Study objectives: To determine if automated, guideline-based reminders to physicians provided as they wrote orders could reduce errors of omission to order tests or treatments needed to monitor/ameliorate the effects of other tests or treatments

Health-care setting: Inpatient general medicine ward

If secondary care, academic status of the hospital: Teaching hospital

Health-care system: NR

Study design: CRCT

Number of sites: 1; 6 independent medical services within the ward (3 intervention; 3 control)

Funding source: Public sector

Was evaluator of tool also its developer? Yes

System users

	Intervention group	**Control group**
CDSS user(s)	Housestaff physician	Housestaff physician
Practitioners (*n*)	45	41
If the CDSS user is a doctor, complete *n* for the following:	NR	NR
Consultant (attending)		
Registrar (chief resident)		
SHO (resident)		
HO (intern)		
Practitioners (*n*) in analysis	45	41

Inclusion criteria: All housestaff physicians who received five or more suggestions for corollary orders during the study period (October 1992 to April 1993)

Exclusion criteria: Housestaff physicians who received fewer than five suggestions about corollary orders were excluded from the analysis. Additionally, data from physicians who rotated through the service more than once and could not be assigned to the same study status (i.e. intervention or control) were excluded from all rotations after the physician's original study status changed. Data on suggested orders that occurred when physicians' and patients' study status differed were also excluded

Patient baseline demographics

Inclusion criteria: All inpatients who had at least one order written that triggered a suggestion for a corollary order during the study period

Exclusion criteria: NR

	Intervention group	**Control group**
N	814	872
Age (years) (mean; SD)	54 ± 18	53 ± 18
Gender (Male; %)	45	51
White ethnic group (%)	50	49

Problem list (%)		
Hypertension	5.2	5.6
Heart failure	3.4	3.2
Diabetes mellitus	3.0	3.0
Chest pain	3.5	2.9
Pneumonia	2.5	2.7
Urinary tract infection	2.4	2.2
Anaemia	2.4	2.2
Gastrointestinal tract infection	1.9	1.7
Diabetic ketoacidosis	0.6	0.5

Interventions

Intervention: OCS plus CDSS (suggested corollary orders linked to trigger orders). Eighty-seven target orders (76 drugs and 11 tests) were identified that could be paired with one or more corollary orders. Examples of the target orders identified were (1) heparin infusion; (2) IV fluids; (3) insulin (all kinds); (4) oral hypoglycaemic agents; (5) narcotics (class II); (6) nonsteroidals; (7) aminoglycosides; (8) vancomycin intravenously; (9) warfarin; (10) amphotericin B; (11) angiotensin-converting enzyme inhibitions; (12) choloramphenicol; (13) air contrast barium enema; (14) isoniazid; (15) potassium supplements; (16) pulmonary artery catheter; (17) ventilator orders; and (18) vasopressin drip

Each time one of the target orders was placed, the CDSS suggested that the other linked corollary orders be considered. When suggesting orders the CDSS took into account, the status of the order (a new order or a revision of an old order); the time elapsed since the last time the order being suggested was written; and whether any orders for a new equivalent item had already been written. Physicians were free to accept or reject the suggested corollary orders

Note: only data on 24-hour suggested laboratory test corollary orders is extracted, as the main reported results are a combination of all orders (i.e. both pharmaceutical and laboratory orders) and therefore do not report laboratory/radiology orders separately (extracted data taken from *Table 16*, page 54)

Comparator: OCS alone (no suggested corollary orders)

Concomitant interventions: NA

CDSS tool

Name of CDDS (if any)	NR
CDSS reasoning method	Discrimination rules
CDSS knowledge base	Standard reference text books, drug package inserts and local practice guidelines
Did study use training set and test set data?	Training set: No Test set: No

For training set data complete the following:

Design	NR	
Target decision	NR	
Sample characteristics:	Intervention	Control
Sample size (*n*)	NR	NR
Age (mean; range)	NR	NR
Gender (*n* male; *n* female)	NR	NR
Disease type	NR	NR

For test set data complete the following:

Properties of test set data	NR
Test centre	NR
Target decision	NR

Other CDSS information

1. Information used in CDSS [number of items; signs; symptoms; history; biochemical tests (list)]	NR
2. Time to complete the CDSS (minutes)	NR

3. CDSS output format: (score; probability graph; advice; etc.)	Suggested corollary orders
4. Is a description of pilot testing with users prior to implementation provided?	No
5. Is user instructional training at the time of implementation described?	No
6. Is the CDSS integrated with charting or OCS to support workflow integration?	Yes
7. Is automatic provision of CDSS output provided as part of clinician workflow?	Yes
8. Is there a need for additional data entry by the clinician?	No
9. Does the CDSS request documentation of the reason for not following CDSS recommendations?	No
10. Does CDSS provide output at the time and location of decision making?	Yes
11. Are the CDSS recommendations executed by the clinician noting agreement?	No
12. Does the CDSS provide a recommendation rather than just an assessment?	Yes
13. Does the CDSS promote action rather than inaction?	NR
14. Does the CDSS justify the output by provision of reasoning?	No
15. Does the CDSS justify the output by provision of research evidence?	No
16. Were local users involved in the CDSS development process?	No
17. Is the CDSS output provided to patients as well as clinician?	No
18. Does the CDSS provide periodic summaries of performance feedback?	No
19. Is the CDSS used in conjunction with conventional education?	No

Outcome measures

Outcome 1: 24-hour compliance rates for the 25 most common corollary orders (only data on laboratory test orders extracted)

Outcome 2: Length of hospital stay

Outcome 3: Total inpatient charges

Total length of follow-up: 6 months (beginning October 1992)

Follow-up assessment times: 6 months

Rate of attrition at each follow-up time: NA

Methods of statistical analysis: General estimating equation models and *t*-tests were used to analyse the immediate 24-hour and hospital stay compliance with suggested collory orders. *T*-tests were used to assess differences between the intervention group and comparator group for length of hospital stay and costs, and *t*- and chi-squared tests were used to assess baseline differences between groups

Results

Outcome 1: 24-hour compliance rates for the 25 most common corollary orders (only data on laboratory test orders extracted)

Suggested order	Total orders	OCS +CDSS compliance (%)	OCS alone compliance (%)	Compliance increase (%)
Serum creatinine	1209	48.28%	41.18%	7.10%
Serum electrolytes	1034	87.03%	70.86%	16.18%
Glycosylated HbA_{1C}	821	23.71%	7.39%	16.32%
Activated partial thromboplastin time	615	89.21%	59.56%	29.65%
Serum glutamic pyruvic transaminase (alanine aminotransferase)	569	12.63%	1.87%	10.76%
Serum glutamic oxaloacetic transaminase (aspartate aminotransferase)	467	7.14%	0.00%	7.14%
Capillary glucose	446	30.77%	4.41%	26.36%
Blood cell profile	382	80.46%	51.44%	29.02%
Stool occult blood test	374	60.94%	12.09%	48.85%
Prothrombin time	320	64.57%	45.52%	19.05%
Theophylline level	270	75.89%	46.51%	29.38%
Platelet count	236	70.00%	15.09%	54.91%

Reticulocyte count	205	19.66%	11.36%	8.29%
Fe-TIBC	149	12.64%	0.00%	12.64%
Vancomycin	143	90.74%	65.17%	25.57%
Phenytoin level	140	73.13%	38.36%	34.78%
A-V blood gas	123	72.60%	0.00%	72.60%
Gentamicin level	118	90.00%	75.86%	14.14%

Authors' conclusions: This study demonstrates that physician workstations, linked to a comprehensive electronic medical record, can be an efficient means for decreasing errors of omissions and improving adherence to practice guidelines

Methodological assessment criteria (Overhage) (1997)[24]

1. Is the study properly randomised?	Yes
2. Did the analysis take clustering into account?	Yes
3. Were the study eligibility criteria specified?	Yes
4. Are adequate baseline details presented?	Partial
5. Are groups similar at baseline?	Yes
6. Are any baseline imbalances adequately adjusted for in the analysis?	NA
7. Are similar cointerventions administered?	NA
8. Are physician's blinded to treatment allocation?	No
9. Are outcome assessors blinded?	Unclear
10. Are data analyses appropriate?	Yes
11. Is analysis conducted on an 'intention to provide or communicate information' basis?	Yes
12. Are greater than 80% of physicians/patients included in the follow-up assessment?	Yes
13. Are the conclusions supported by the results?	Yes

Comments: None

Study demographics

Author; year; study ID: Palen (2006)[90]

Title: Evaluation of laboratory monitoring alerts within a computerized physician order entry system for medication orders

Country: USA

Specific setting: Kaiser Permanente group-model managed care organisation with more than 350,000 members

Study objectives: To evaluate if computerised non-intrusive reminders presented during OCS for medications would increase physicians' compliance with guidelines for laboratory monitoring at initiation of therapy

Health-care setting: Primary care

If secondary care, academic status of the hospital: NA

Health-care system: Group-model managed care organisation (Kaiser Permanente)

Study design: CRCT

Number of sites: 16

Funding source: Public sector

Was evaluator of tool also its developer? In part

System users

	Intervention group	**Control group**
CDSS user(s)	Physician	Physician
Practitioners (*n*)	104	103

If the CDSS user is a doctor, complete *n* for the following:	Primary-care physicians	Primary-care physicians
Consultant (attending)		
Registrar (chief resident)		
SHO (resident)		
HO (intern)		
Practitioners (*n*) in analysis	104	103

Inclusion criteria: NR

Exclusion criteria: NR

Patient baseline demographics

Inclusion criteria: All patients must have (1) been a health plan member for at least 180 days before and 14 days after drug dispensing, (2) received the drug dispensing between 1 November 2002, and 31 October 2003, (3) not received a dispensing of that drug within the previous 180 days (i.e. the drug dispensing was the index dispensing), and (4) had the drug order by a physician in the control or intervention study group

Exclusion criteria: NR

	Intervention group	**Control group**	***p*-value**
N Index Dispensings	14,084	12,502	–
Age (median; 5th and 95th percentile)	64 (40; 85)	64 (40; 84)	0.90
Age at dispensing (mean; SD; range)	63.20 ± 13.98 (range: 18; 89)		
Gender (female: *n*; %)	7523 (53.4%)	–6853 (54.8%)	0.22
Prescribed 1 medication (*n*; %)	20,433 (76.9%)	–	
Prescribed 2 medications (*n*; %)	4903 (18.4%)	–	
Prescribed 3–6 medications (*n*; %)	1250 (4.7%)	–	

Interventions

Intervention: OCS plus CDSS. All physicians had a 'custom formulary' of medications loaded into their OCS. In addition to this list, an additional field contained information specific to recommended laboratory monitoring for the selected study medications. This information was specific for the individual medication and presented guidelines for appropriate baseline and on-going monitoring. The selected study medications (25) were: angiotensin-converting enzyme inhibitors (captopil, lisinopril); angiotensin-II receptor blocker (losartan potassium); antiarrhythmic (digoxin); antiinfective agents (isoniazid, rifampin); antigout (allopurinol, colchicine); cholesterol-lowering (atorvastatin calcium, gemfibrozil, lovastatin, niacin, simvastatin); diurectics (bumetanide, furosemide, hydrochlorothiazide, spironolactone, triamterene/hydrochlorothiazide); hyperglycemics (methotrexate, pioglitazone); and neurologica (carbamazepine, phenytoin sodium, valproic acid). At the end of the study period prescribing data for study medications was analysed to assess if appropriate laboratory tests had been completed within either 2 weeks after the medication order or had been 'recently performed'. 'Recently performed' tests were defined as those completed within 180 days before medication dispensing and 2 weeks after dispensing. Physicians were defined as having followed the laboratory monitoring guideline if results of completed laboratory tests were available for review in EMR within these time frames (i.e. 180 days pre-dispensing and 2 weeks post-dispensing)

Comparator: OCS alone. Physicians received the standard list of medications loaded into their custom formularies

Concomitant interventions: NA

CDSS tool

Name of CDDS (if any)	Clinical Information System; IBM; Boulder, CO, USA
CDSS reasoning method	NR
CDSS knowledge base	Published guidelines and internal clinical guidelines; expert physician and clinical pharmacist opinion
Did study use training set and test set data?	Training set: NR Test set: NR

For training set data complete the following:

Design	NR

Target decision	NR	
Sample characteristics:	Intervention	Control
Sample size (*n*)	NR	NR
Age (mean; range)	NR	NR
Gender (*n* male; *n* female)	NR	NR
Disease type	NR	NR

For test set data complete the following:

Properties of test set data	NR
Test centre	NR
Target decision	NR

Other CDSS information

1. Information used in CDSS [number of items; signs; symptoms; history; biochemical tests (list)]	Medication related alerts for baseline laboratory monitoring tests
2. Time to complete the CDSS (minutes)	NR
3. CDSS output format: (score; probability graph; advice; etc.)	Alert
4. Is a description of pilot testing with users prior to implementation provided?	No
5. Is user instructional training at the time of implementation described?	Yes
6. Is the CDSS integrated with charting or OCS to support workflow integration?	Yes
7. Is automatic provision of CDSS output provided as part of clinician workflow?	Yes
8. Is there a need for additional data entry by the clinician?	No
9. Does the CDSS request documentation of the reason for not following CDSS recommendations?	No
10. Does CDSS provide output at the time and location of decision making?	Yes
11. Are the CDSS recommendations executed by the clinician noting agreement?	No
12. Does the CDSS provide a recommendation rather than just an assessment?	No
13. Does the CDSS promote action rather than inaction?	NR
14. Does the CDSS justify the output by provision of reasoning?	No
15. Does the CDSS justify the output by provision of research evidence?	No
16. Were local users involved in the CDSS development process?	No
17. Is the CDSS output provided to patients as well as clinician?	No
18. Does the CDSS provide periodic summaries of performance feedback?	No
19. Is the CDSS used in conjunction with conventional education?	No

Outcome measures

Outcome 1: Compliance with recommended laboratory monitoring tests

Outcome 2:.Compliance with recommended laboratory monitoring tests by patient gender

Outcome 3:.Compliance with recommended laboratory monitoring tests by medication

Total length of follow-up: 12 months (1 November 2002 to 31 October 2003)

Follow-up assessment times: 12 months

Rate of attrition at each follow-up time: NA

Methods of statistical analysis: Chi-squared test was used to compare differences in laboratory monitoring rates between groups, by drug or drug class and by gender

Results

Outcome 1: Compliance with recommended laboratory monitoring tests

Intervention	**OCS + CDSS (alerts)**	**OCS alone**	**Difference between groups[b]**
N in analysis	18,556	15,686	–
Compliance rates (*n*: %)	10,494 (56.6%)	8957 (57.1%)	$p = 0.31$

Outcome 2: Compliance with recommended laboratory monitoring tests by patient gender

Intervention	**OCS + CDSS (alerts)**	**OCS alone**	**Difference between groups**
Compliance rates in males (%)	57.5% 58.5%	58.5%	$p = 0.18$
Compliance rates in females (%)	55.7%	55.9%	$p = 0.82$

Outcome 3: Compliance with recommended laboratory monitoring tests by medication[a]

Medication	**All dispensings**	**Intervention**	**Control**	***p*-value[b]**
ACE inhibitors	5828 (47.2%)	3099 (47.0%)	2729 (47.5%)	0.681
Allopurinol	784 (59.2%)	429 (57.6%)	355 (61.1%)	0.31
Carbamazepine	272 (34.9%)	153 (34.6%)	119 (35.3%)	0.91
Colchicine	811 (49.6%)	411 (52.8%)	400 (46.0%)	0.05
Dogoxin	420 (52.4%)	242 (55.0%)	178 (48.9%0	0.22
Diuretic	9654 (44.7%)	5384 (44.0%)	4270 (45.6%)	0.11
Gemfibrozil	1023 (67.3%)	569 (71.2%)	454 (62.3%)	0.003
Isoniazid	69 (17.4%)	33 (15.2%)	36 (19.4%)	0.64
Losartan pottassium	939 (52.3%)	506 (52.0%)	433 (52.7%)	0.84
Metformin hydrochloride	2038 (69.0%)	1098 (67.7%)	940 (7.6%)	0.14
Methotrexate	16 (18.7%)	7 (42.9%)	9 (0.0%)	0.03
Niacin	70 (57.1%)	34 (67.7%)	36 (47.2%)	0.084
Phenytoin sodium	135 (29.6%)	83 (32.5%)	52 (25.0%)	0.35
Pioglitaone hydrochloride	139 (92.8%)	76 (92.1%)	63 (93.7%)	0.73
Potassium chloride	2914 (55.8%)	1623 (54.3%)	1291 (57.8%)	0.06
Rifampin	13 (30.8%)	7 (14.3%)	6 (50.0%)	0.20
Statins	8962 (74.9%)	4717 (75.7%)	4245 (73.9%)	0.05
Valproic acid	155 (37.4%)	85 (36.5%)	70 (38.6%)	0.79
Total	34,242	18,556	15,686	0.79

a Data are given as number (% monitored) unless otherwise indicated.

b Chi-squared test.

Authors' conclusions: As OCS becomes more prevalent, additional research is needed to determine effective decision support tools. These findings then should be communicated to the developers and users of computerised medical record systems

Methodological assessment criteria (Palen) (2006)[90]

1. Is the study properly randomised?	Yes
2. Did the analysis take clustering into account?	No
3. Were the study eligibility criteria specified?	Partial
4. Are adequate baseline details presented?	Yes
5. Are groups similar at baseline?	Yes
6. Are any baseline imbalances adequately adjusted for in the analysis?	NA
7. Are similar cointerventions administered?	NA
8. Are physician's blinded to treatment allocation?	No
9. Are outcome assessors blinded?	Unclear
10. Are data analyses appropriate?	Partial
11. Is analysis conducted on an 'intention to provide or communicate information' basis?	Yes
12. Are greater than 80% of physicians/patients included in the follow-up assessment?	Yes
13. Are the conclusions supported by the results?	Yes

Comments: No ICC reported in design and clustering by physician was not taken into account in the analysis (unit of analysis was patient–drug therapy combination)

Study demographics

Author; year; study ID: Matheny (2008)[91]

Title: A randomised trial of electronic clinical reminders to improve medication laboratory monitoring

Country: USA

Specific setting: Partners Healthcare system (including Brigham and Women's Hospital, Massachusetts General Hospital, and a number of community hospitals and outpatient clinics)

Study objectives: To assess the impact of electronic reminders delivered to primary care physicians on rates of appropriate routine medication laboratory monitoring

Health-care setting: Outpatient clinics (4 community health centres, 9 hospital-based clinics, 7 off-site practices)

If secondary care, academic status of the hospital: Academic teaching

Health-care system: NR

Study design: CRCT

Number of sites: 20 (10 intervention, 10 control)

Funding source: Public sector

Was evaluator of tool also its developer? Yes

System users

	Intervention group	**Control group**
CDSS user(s)	Physician	Physician
Practitioners (*n*)	145	158
If the CDSS user is a doctor, complete n for the following:	NR	NR
Consultant (attending)		
Registrar (chief resident)		
SHO (resident)		
HO (intern)		
Age (mean; SD)	40.5 (11.1)	40.6 (11.2)
Female (%)	90 (62.1)	93 (58.8)

Inclusion criteria: All physicians using OCS with a patient on one of the 15 target study medications for at least 365 days in which no relevant laboratory monitoring test had been undertaken. The study target medications were selected for inclusion due to (1) the prevalence of their use; (2) potential morbidity associated with failure to perform appropriate laboratory monitoring, and were based on a review of evidence based guidelines for routine medication laboratory monitoring. The 15 target medications included: (1) non-steroidal anti-inflammatory drugs (NSAIDs); (2) angiotensin receptor blockers (ARB); (3) metformin; (4) potassium supplements; (5) potassium sparing diuretic; (6) thiazide diurectic; (7) angiotensin-converting enzyme inhibitors; (8) HMG-CoA reductase inhibitors (statins); (9) thyroxine; (10) carbamazapine; (11) ciclosporin; (12) phenobarbital; (13) phenytoin; (14) proc-NAPA; and (15) valproate. Laboratory monitoring focused on tests for potassium, creatinine, liver function, thyroid function, and therapeutic levels as appropriate for the other medications

Exclusion criteria: NR

Patient baseline demographics

Inclusion criteria: All outpatients seen during the 6-month study period (1 Janary 2004 to 30 June 2004) on one or more of the 15 target study for at least 365 days for which no relevant laboratory monitoring tests were conducted in the preceding year

Exclusion criteria: NR

Patient characteristics	**Intervention group**	**Control group**	***p*-value**
N	924	998	–
Age (mean, yr, SD)	60.2 (14.3)	60.2 (14.6)	0.996
Female (%)	530 (57.4)	605 (60.6)	0.150
Race (%)			
White	509 (55.1)	596 (59.7)	0.042
African American	107 (11.6)	82 (8.2)	0.041
Hispanic	153 (16.6)	66 (6.6)	<0.001
Other	30 (3.2)	43 (4.3)	0.234

Unknown	125 (13.5)	211 (21.1)	<0.001
Insurance (%)			
Medicare	326 (35.3)	328 (32.9)	0.268
Medicaid	126 (13.6)	74 (7.4)	<0.001
Private	447 (48.4)	579 (58.0)	<0.001
Self-pay	25 (2.7)	17 (1.7)	0.160
Interventions			
Intervention: OCS with reminder generated if patient was on one or more of the study target medications for at least 365 days and there was no relevant laboratory test for that medication within that timeframe			
Comparator: OCS with reminder suppressed			
Concomitant interventions: NA			
CDSS tool			
Name of CDDS (if any)		NR (Brigham and Women's Hospital)	
CDSS reasoning method		DR	
CDSS knowledge base		Test-specific monitoring intervals of 1 year were based on a review of the literature.	
Did study use training set and test set data?		Training set: NR Test set: NR.	
For training set data complete the following:			
Design		NR	
Target decision		NR	
Sample characteristics:		Intervention	Control
Sample size (*n*)		NR	NR
Age (mean; range)		NR	NR
Gender (*n* male; *n* female)		NR	NR
Disease type		NR	NR
For test set data complete the following:			
Properties of test set data		NR	
Test centre		NR	
Target decision		NR	
Other CDSS information			
1. Information used in CDSS [number of items; signs; symptoms; history; biochemical tests (list)]			1; time interval from previously ordered test
2. Time to complete the CDSS (minutes)			NR
3. CDSS output format: (score; probability graph; advice; etc.)			Reminder
4. Is a description of pilot testing with users prior to implementation provided?			No
5. Is user instructional training at the time of implementation described?			No
6. Is the CDSS integrated with charting or OCS to support workflow integration?			Yes
7. Is automatic provision of CDSS output provided as part of clinician workflow?			Yes
8. Is there a need for additional data entry by the clinician?			No
9. Does the CDSS request documentation of the reason for not following CDSS recommendations?			No
10. Does CDSS provide output at the time and location of decision making?			Yes
11. Are the CDSS recommendations executed by the clinician noting agreement?			No
12. Does the CDSS provide a recommendation rather than just an assessment?			Yes
13. Does the CDSS promote action rather than inaction?			Yes
14. Does the CDSS justify the output by provision of reasoning?			No

15. Does the CDSS justify the output by provision of research evidence?	No
16. Were local users involved in the CDSS development process?	Unclear
17. Is the CDSS output provided to patients as well as clinician?	No
18. Does the CDSS provide periodic summaries of performance feedback?	No
19. Is the CDSS used in conjunction with conventional education?	No

Outcome measures

Outcome 1: Number of appropriate laboratory tests ordered when overdue within 14 days

Total length of follow-up: 6 months (1 January 2004 to 30 June 2004)

Follow-up assessment times: 6 months

Rate of attrition at each follow-up time: NA

Methods of statistical analysis: All reminders for therapeutic drug level monitoring were aggregated into one category for analyses. Multivariable logistic regression models were used to assess the impact of the reminder system on rates of appropriate laboratory monitoring with adjustment for patient age, gender, race and insurance status as well as provider age and gender. GENMOD procedure within SAS was used to account for clustering of patients by surgery site

Results

Outcome 1: Number of appropriate laboratory tests ordered when overdue within 14 days

Medication-laboratory reminder	Visits (*n*)	Visits with laboratory overdue (*n*; %)	Laboratory ordered when overdue (*n*; %)	Odds Ratio (adjusted) (95% CI)	*p*-value
NSAID-Cr					
OCS + CDSS	8487	442 (5.2%)	150 (33.9%)	1.24 (0.71 to 2.15)	0.457
OCS alone	9307	428 (4.6%)	136 (31.8%)		
ARB-Cr					
OCS + CDSS	751	31 (4.1%)	17 (54.8%)	0.24 (0.04 to 1.34)	0.104
OCS alone	832	27 (3.2%)	17 (63.0%)		
Metformin-Cr					
OCS + CDSS	857	20 (2.3%)	7 (35.0%)	0.53 (0.05 to 5.34)	0.594
OCS alone	781	16 (2.1%)	6 (37.5%)		
K Supplement-K					
OCS + CDSS	579	12 (2.1%)	7 (58.3%)	0.91 (0.03 to 24.44)	0.956
OCS alone	751	9 (1.2%)	5 (55.5%)		
K Sparing Diuretic-K					
OCS + CDSS	761	19 (2.5%)	13 (68.4%)	0.82 (0.12 to 5.60)	0.836
OCS alone	875	28 (3.2%)	17 (60.7%)		
Thiazide Diuretic-K					
OCS + CDSS	1997	62 (3.1%)	40 (64.5%)	1.30 (0.63 to 2.67)	0.473
OCS alone	2508	89 (3.5%)	46 (51.7%)		
ACE Inhibitor-K					
OCS + CDSS	2279	119 (5.2%)	57 (47.9%)	1.00 (0.43 to 2.30)	0.993
OCS alone	2790	80 (2.9%)	40 (50.0%)		
Statin-ALT					
OCS + CDSS	9441	613 (6.5%)	291 (47.5%)	0.89 (0.43 to 1.81)	0.740
OCS alone	10935	674 (6.2%)	358 (53.1%)		
Thyroxine-TSH					
OCS + CDSS	897	38 (4.2%)	22 (57.9%)	1/19 (0.40 to 3.53)	0.747
OCS alone	1233	44 (3.6%)	25 (56.8%)		

Therapeutic level[a]					
OCS + CDSS	514	16 (3.1%)	2 (12.5%)	0.55 (0.03 to 8.94)	0.677
OCS alone	755	26 (3.4%)	4 (15.4%)		

a Represents the aggregated reminders for therapeutic monitoring for carbamazapine, ciclosporin, phenobarbital, phenytoin, proc-NAPA and valproate.

Authors' conclusions: High rates of appropriate baseline laboratory monitoring were identified, and electronic reminders did not significantly improve these monitoring rates. Future studies should focus on settings with lower baseline adherence rates and alternate drug–laboratory combinations

Methodological assessment criteria Matheny (2008)[91]

1. Is the study properly randomised?	Yes
2. Did the analysis take clustering into account?	Yes
3. Were the study eligibility criteria specified?	Yes
4. Are adequate baseline details presented?	Yes
5. Are groups similar at baseline?	No
6. Are any baseline imbalances adequately adjusted for in the analysis?	Yes
7. Are similar cointerventions administered?	NA
8. Are physician's blinded to treatment allocation?	No
9. Are outcome assessors blinded?	Unclear
10. Are data analyses appropriate?	Yes
11. Is analysis conducted on an 'intention to provide or communicate information' basis?	Yes
12. Are greater than 80% of physicians/patients included in the follow-up assessment?	Yes
13. Are the conclusions supported by the results?	Yes

Comments: None

Study demographics

Author; year; study ID: Bates (1999)[92]

Title: A randomised trial of a computer-based intervention to reduce utilization of redundant laboratory tests

Country: USA

Specific setting: Brigham and Women's Hospital, Boston, MA, USA

Study objectives: To determine the degree to which reminders for apparently redundant laboratory tests affects (1) the number of tests ordered, (2) the number of test performed, (3) to evaluate what proportion of overrides of reminders are justified, (4) whether the cancellation of tests resulted in adverse effects for patients, and (5) to assess the charge savings and potential for additional savings associated with giving reminders for apparently redundant tests

Health-care setting: Secondary care (all inpatients)

If secondary care, academic status of the hospital: NR

Health-care system: NR

Study design: RCT

Number of sites: 1 (720-bed hospital)

Funding source: Public sector

Was evaluator of tool also its developer? Yes

System users

	Intervention group	**Control group**
CDSS user(s)	Physician	Physician
Practitioners (*n*)	NR	NR

If the CDSS user is a doctor, complete n for the following:	NR	NR
Consultant (attending)		
Registrar (chief resident)		
SHO (resident)		
HO (intern)		
Practitioners (*n*) in analysis	NR	NR

Inclusion criteria: All physicians using OCS during the study period to order any one of the following 13 tests: chemistry-20 profiles; aminophyilline level; digoxin level; vancomycin level; gentamicin level; tobramycin level; amikacin level; urinalysis; urine culture; stool culture; sputum culture; *Clostridium difficile* toxin assay or fibrin split products. Test were chosen as candidates for redundant reminders as they were either commonly ordered or because the marginal cost of performing the test was high. Additionally, there needed to be published literature or clinical consensus about how often the tests should be performed. The interval in which a test was considered redundant was 20 hours in most instances. During the study period physicians could order tests through the OCS or by sending specimens directly to the laboratory in a labelled envelope, without using the OCS

Exclusion criteria: NR

* Note: 56% of redundant test performed did not have a computer order and 50% of tests with a computer order were not screened for redundancy because they were ordered as part of an order set

Patient baseline demographics

Inclusion criteria: All inpatients during the 4-month period between 28 June and 30 October, 1994, excluding 3 weeks from 27 July 1994 to 16 August 1994

Exclusion criteria: NR

	Intervention group	**Control group**
All admissions in study period (*n*)	5700	5886
Age (mean; SD)	38.7 ± 24.6	39.2 ± 24.8
Gender (female %)	65	66
Medical condition(s)	NR	NR
Total number of tests	131,563	132,068
Number of study tests	13,425	13,847
Admissions with ≥ 1 study test (*n*)[a]	2478	2581
Age (mean; range)	50.0 ± 22.0	50.9 ± 2.0
Gender (female %)	59	59
Medical condition(s)	NR	NR

a Compared to the entire sample patients with ≥ 1 study test were older and more frequently male.

Interventions

Intervention: OCS with alert if test had previously been ordered within its test-specific interval. Previous test results were displayed where available. Checking for redundancy was only performed for tests ordered from the main order entry screens and not for tests ordered using order sets or templates (tools that allow many orders to be entered at once). When a reminder was delivered the default response was to cancel the test

Comparator: OCS with reminder suppressed

Concomitant interventions: NA

CDSS tool

Name of CDDS (if any)	NR
CDSS reasoning method	NR
CDSS knowledge base	Test-specific intervals within which a second test was considered redundant were based on a review of the literature. They were evaluated retrospectively by applying them to a random sample of patients from an earlier study. This information and clinical evaluation was used to select the intervals used in the study
Did study use training set and test set data?	Training set: NR Test set: NR

For training set data complete the following:

Design	NR

Target decision	NR	
Sample characteristics:	Intervention	Control
Sample size (*n*)	NR	NR
Age (mean; range)	NR	NR
Gender (*n* male; *n* female)	NR	NR
Disease type	NR	NR

For test set data complete the following:

Properties of test set data	NR
Test centre	NR
Target decision	NR

Other CDSS information

1. Information used in CDSS [number of items; signs; symptoms; history; biochemical tests (list)]	1; time interval from previously ordered test
2. Time to complete the CDSS (minutes)	NR
3. CDSS output format: (score; probability graph; advice; etc.)	Reminder
4. Is a description of pilot testing with users prior to implementation provided?	No
5. Is user instructional training at the time of implementation described?	No
6. Is the CDSS integrated with charting or OCS to support workflow integration?	Yes
7. Is automatic provision of CDSS output provided as part of clinician workflow?	Yes
8. Is there a need for additional data entry by the clinician?	No
9. Does the CDSS request documentation of the reason for not following CDSS recommendations?	Yes
10. Does CDSS provide output at the time and location of decision making?	Yes
11. Are the CDSS recommendations executed by the clinician noting agreement?	No
12. Does the CDSS provide a recommendation rather than just an assessment?	No
13. Does the CDSS promote action rather than inaction?	No
14. Does the CDSS justify the output by provision of reasoning?	Yes
15. Does the CDSS justify the output by provision of research evidence?	No
16. Were local users involved in the CDSS development process?	Unclear
17. Is the CDSS output provided to patients as well as clinician?	No
18. Does the CDSS provide periodic summaries of performance feedback? (yes; no; unclear)	No
19. Is the CDSS used in conjunction with conventional education?	No

Outcome measures

Outcome 1: Proportion of reminders accepted

Outcome 2: Proportion of test performed after reminder

Outcome 3: Proportion of tests performed earlier than test-specific intervals

Outcome 4: Proportion of justified overrides of reminders by specific test

Outcome 5: Adverse effects of test cancellation (new abnormal results for the same test performed within 3 days of cancellation)

Outcome 6: Charge savings associated with reminders for redundant tests

Total length of follow-up: 4 months from 28 June to 30 October 1994. Data were also collected from the preceding 4-month period to assess any changes in the overall frequency of test ordering

Follow-up assessment times: 4 months

Rate of attrition at each follow-up time: NA

Methods of statistical analysis: Comparisons between intervention and control group and between different time periods made using Student's *t*-test for continuous variables and chi-square test for categorical variables. Annual charge savings estimated by multiplying the 1994 charges for each test by the number of test cancelled, and annualised to 1 year. Statistical significance set at $p < 0.05$ (two sided)

Results

Outcome 1: Proportion of reminders accepted

Intervention	**OCS + CDSS (reminders)**	**OCS alone**	**Difference between groups**
N in analysis	437	502[a]	–
	300 (69%)	NA[b]	

a Tests that would have received reminders.

b Not applicable.

Outcome 2: Proportion of test performed after reminder

Intervention	**OCS + CDSS (reminders)**	**OCS alone**	**Difference between groups**
N in analysis	437	502[a]	
	117 (27%)	257 (51%)	$p < 0.0001$

a Tests that would have received reminders.

Outcome 3: Proportion of tests performed earlier than test-specific intervals (change from baseline)

Baseline (both groups)	**OCS + CDSS (reminders)**	**OCS alone**	**Difference from baseline**
20.5%	18.5%	19.6%	$p = 0.004$[a]
			$p = 0.19$[b]

a Change from baseline in OCS + CDSS group.

b Change from baseline in OCS alone group.

Outcome 4: Proportion of justified overrides of reminders by specific test

Test	Number ordered	Number of overrides	Override justified
Urinalysis	136	46 (34%)	26 (57%)
Chemistry-20 profile	113	38 (34%)	24 (63%)
Urine culture	110	25 (23%)	3 (12%)
Sputum culture	39	10 (26%)	2 (20%)
Stool culture	15	7 (47%)	0 (0%)
Other	24	11 (46%)	1 (9%)
Total	437	137 (31%)	56 (41%)

Outcome 5: Adverse effects of test cancellation (new abnormal results for the same test performed within 3 days of cancellation): Chemsitry-20 profiles were excluded from the analysis due to high probability of an abnormal result on at least one of the tests in the panel. Of the remaining 225 accepted reminders, 119 (53%) were followed by another test of the same type within 72 hours; 55 (24%) of these were abnormal. Only 10 (4%) of these had not been preceded by a similar abnormal result within 24 hours before the cancelled test, and two were duplicate orders for the same patient. Therefore only 8(4%) of tests provided new information

Outcome 6: Charge savings associated with reminders for redundant tests (1994) rates: US$35,000

Authors' conclusions: Reminders about orders for apparently redundant laboratory tests are effective when delivered. However, the overall effect was limited because many tests were performed without corresponding computer orders, and many orders were not screened for redundancy

Methodological assessment criteria (Bates) (1999)[92]

1. Is the study properly randomised?	Yes
2. Is allocation of treatment concealed?	Yes
3. Were the study eligibility criteria specified?	Yes
4. Are adequate baseline details presented?	Partial
5. Are groups similar at baseline?	Yes
6. Are any baseline imbalances adequately adjusted for in the analysis?	NA
7. Are similar cointerventions administered?	NA
8. Are physician's blinded to treatment allocation?	No
9. Are outcome assessors blinded?	Yes
10. Are data analyses appropriate?	Yes

11. Is analysis conducted on an 'intention to provide or communicate information' basis?	Yes
12. Are greater than 80% of physicians/patients included in the follow-up assessment?	Yes
13. Are the conclusions supported by the results?	Yes

Comments: contamination likely as patients are the unit of randomisation and physicians both received reminders/had reminders suppressed at the same time

Study demographics

Author; year; study ID: O'Connor (2005)[57]

Title: Impact of an electronic medical record on diabetes quality of care

Country: USA

Specific setting: HealthPartners Medical Group; Minnesota (Multi-specialty medical group that provided care to 175,000 adults in 18 clinics in 1996)

Study objectives: To assess whether implementation of an Electronic Medical Record (EMR) in a primary care clinic significantly improves process of care [appropriate frequency of testing for HbA_{1C} and low-density lipoprotein (LDL)] or intermediate outcomes of care (change in HbA_{1C} and LDL levels) for adults with diabetes mellitus

Health-care setting: Primary care

If secondary care, academic status of the hospital: NA

Health-care system: NR

Study design: CCT

Number of sites: 2

Funding source: Private Sector (HealthPartners Medical Group)

Was evaluator of tool also its developer? No

System users

	Intervention group	**Control group**
CDSS user(s)	Physician	Physician
Practitioners (*n*)	4 or 5	NR
If the CDSS user is a doctor, complete *n* for the following:	NR	NR
Consultant (attending)		
Registrar (chief resident)		
SHO (resident)		
HO (intern)		
Practitioners (*n*) in analysis	NR	NR

Inclusion criteria: NR

Exclusion criteria: NR

Patient baseline demographics

Inclusion criteria: All adult patients (> 18 years) with an established diagnosis of diabetes at study baseline (1996) in both clinics. Patients were classified as having diabetes if in calendar year 1994 they had either (1) 1 or more inpatient or 2 or more outpatient ICD-9 codes for diabetes or (2) filled a prescription for a diabetes-specific drug (insulins, sulfonylureas, metformin, thiazolidinediones, alpha-glucosidase inhibitors, medlitinides). The clinic that each patient attended was identified in 1996, 1998 and 2000 based on number of visits and administrative data. Patients were included in the analysis only if they attended their original study clinical in all 3 study years and were still alive and enrolled in HealthPartners Medical Group on 31 December 2000

Exclusion criteria: NR

Patient characteristics	**Intervention group**	**Control group**	***p*-value**
N	57	65	
Age (years) (mean; SE)	60.6 ± 1.62	59.4 ± 1.72	$p = 0.34$
Gender (male, %)	54.4	58.5	$p = 0.65$
Charlson < 2 (%)[a]	73.7	75.4	$p = 0.97$
Charlson = 2 (%)[a]	15.8	15.4	–

Charlson > 2 (%)[a]	10.5	9.2	–

a Charlson comorbidy score was based on the method of Charlson and colleagues[121] and modified by Deyo and colleagues[122] and Rush and colleagues.[123]

Interventions

Intervention: OCS plus CDSS (prompts and reminders). Prompts were included when a patient had no HbA_{1C} test within 6 months, no urine micoalbuminiuria test within 1 year, had blood pressures of ≥130/85 mmHg, LDL levels of ≥130 mg/dL, HbA_{1C} levels of ≥8% or no aspirin use if aged 40 years or older

Comparator: OCS alone

Concomitant interventions: Other diabetes-related care improvement activities (both clinics)

CDSS tool

Name of CDDS (if any)	Epic Systems
CDSS reasoning method	NR
CDSS knowledge base	NR
Did study use training set and test set data?	Training set: NR Test set: NR

For training set data complete the following:

Design	NR	
Target decision	NR	
Sample characteristics:	Intervention	Control
Sample size (*n*)	NR	NR
Age (mean; range)	NR	NR
Gender (*n* male; *n* female)	NR	NR
Disease type	NR	NR

For test set data complete the following:

Properties of test set data	
Test centre	NR
Target decision	NR

Other CDSS information

1. Information used in CDSS [number of items; signs; symptoms; history; biochemical tests (list)]	NR
2. Time to complete the CDSS (minutes)	NR
3. CDSS output format: (score; probability graph; advice; etc.)	Prompts and Reminder
4. Is a description of pilot testing with users prior to implementation provided?	No
5. Is user instructional training at the time of implementation described?	Yes
6. Is the CDSS integrated with charting or OCS to support workflow integration?	Yes
7. Is automatic provision of CDSS output provided as part of clinician workflow?	Yes
8. Is there a need for additional data entry by the clinician?	No
9. Does the CDSS request documentation of the reason for not following CDSS recommendations?	No
10. Does CDSS provide output at the time and location of decision making?	Yes
11. Are the CDSS recommendations executed by the clinician noting agreement?	No
12. Does the CDSS provide a recommendation rather than just an assessment?	Yes
13. Does the CDSS promote action rather than inaction?	Yes
14. Does the CDSS justify the output by provision of reasoning?	No
15. Does the CDSS justify the output by provision of research evidence?	No
16. Were local users involved in the CDSS development process?	No
17. Is the CDSS output provided to patients as well as clinician?	No
18. Does the CDSS provide periodic summaries of performance feedback?	No

19. Is the CDSS used in conjunction with conventional education? Yes

Outcome measures

Outcome 1: Number of HbA_{1c} tests in each study clinic in years 1996, 1998, and 2000

Outcome 2: Number of LDL cholesterol tests in each study clinic in years 1996, 1998, and 2000

Outcome 3: Percentage of patients having at least two HbA_{1c} tests, one LDL test, or two HbA_{1c} and one LDL test in each study clinic in 1996, 1998 and 2000

Outcome 4: Mean HbA_{1c} test values in each study clinic in years 1996, 1998, and 2000

Total length of follow-up: 4 years

Follow-up assessment times: Baseline (1996), 2 years (1998) and 4 years (2000)

Rate of attrition at each follow-up time: For the outcome of mean HbA_{1c} test values in each study clinic in years 1996, 1998 and 2000, 11 in the intervention group and 15 in the comparison group

Methods of statistical analysis: Generalised linear models were used to assess whether the independent variables of electronic medical record (EMR) use and study year (1996, 1998 and 2000) were predictors of the number of tests performed, the proportion of patients with the recommended number of tests in a given year, and changes in test values. Patient age, gender and Charlson comorbidity score were entered as covariates into the model. In all models the unit of analysis was the patient, and the covariance structure among the repeated measures unspecified

Results

Outcome 1: Number of HbA_{1c} tests in each study clinic in years 1996, 1998, and 2000[a]

Year	**OCS + CDSS**	**OCS alone**	**Time by EMR *p*-value**
N in analysis	57	65	–
1996	1.67	1.75	–
1998	2.20	1.83	0.04
2000	2.46	1.63	0.001

a Results adjusted for age, gender and Charlson comorbidity score.

Outcome 2: Number of LDL cholesterol tests in each study clinic in years 1996, 1998, and 2000[a]

Year	OCS + CDSS	OCS alone	Time by EMP *p*-value
N in analysis	57	65	–
1996	0.54	0.49	–
1998	0.87	0.59	0.33
2000	1.45	0.92	0.19

a Results adjusted for age, gender and Charlson comorbidity score.

Outcome 3: Percentage of patients having at least two HbA_{1c} tests, one LDL test, or two HbA_{1c} and one LDL test in each study clinic in 1996, 1998 and 2000[a]

	OCS + CDSS	**OCS alone**	**Time by EMP *p*-value**
N in analysis	57	65	–
Test			
≥2 HbA_{1c} tests			
1996	47.4	55.4	–
1998	73.7	63.1	0.09
2000	78.9	53.9	0.002
≥1 LDL test			
1996	42.1	46.2	–
1998	68.4	55.4	0.12
2000	84.2	72.3	0.12
≥2 HbA_{1c} and 1 LDL test			
1996	29.8	30.8	–
1998	57.9	46.2	0.27
2000	70.2	46.2	0.03

a Results adjusted for age, gender and Charlson comorbidity score.

Outcome 4: Mean HbA_{1C} test values in each study clinic in years 1996, 1998, and 2000[a]

	OCS + CDSS	OCS alone	Time by EMP *p*-value
N in analysis	46	50	–
1996	7.80	7.35	–
1998	7.90	7.26	0.10
2000	7.71	7.11	0.27

a Predicted least squares mean adjusted for age, gender and Charlson comorbidity score.

Authors' conclusions: EMR (with CDSS) led to an increased number of HbA_{1C} and LDL tests but not to better metabolic control as evidence by patients HbA_{1C} test values. If EMRs are to fulfil their promise as care improvement tools, improved implementation strategies and more sophisticated clinical decision support may be needed

Methodological assessment criteria (O'Connor) (2005)[57]

1. Were the study eligibility criteria specified?	Yes
2. Are adequate baseline details presented?	Yes
3. Are groups similar at baseline?	Yes
4. Are any baseline imbalances adequately adjusted for in the analysis?	NA
5. Are similar cointerventions administered?	Yes
6. Are physician's blinded to treatment allocation?	No
7. Are outcome assessors blinded?	Unclear
8. Are data analyses appropriate?	Yes
9. Is analysis conducted on an 'intention to provide or communicate information' basis?	Yes
10. Are greater than 80% of physicians/patients included in the follow-up assessment?	Partial (outcome measure dependent)
11. Are the conclusions supported by the results?	Yes

Comments: Small number of patients (*n* = 122)

Study demographics

Author; year; study ID: McDonald (1980)[29]

Title: Physicians response to computer reminders

Country: USA

Specific setting: Wishard Memorial Hospital, Indianapolis, IN, USA

Study objectives: To assess whether a medical record system designed to detect and remind physicians about clinical events that might need corrective action significantly increases response rates to such events

Health-care setting: Secondary care (all outpatients)

If secondary care, academic status of the hospital: NR

Health-care system: NR

Study design: Randomised crossover trial

Number of sites: 1

Funding source: Public Sector

Was evaluator of tool also its developer? NR

System users

	Intervention group 1	Intervention group 2	Control group
N	31	31	31
CDSS user(s)	Interns (*n* = 9)	Interns (*n* = 9)	Interns (*n* = 9)
	Residents (*n* = 17)	Residents (*n* = 17)	Residents (*n* = 17)
	Nurse practitioners (*n* = 5)		Nurse practitioners (*n* = 5)
N in analysis	31	31	31

Inclusion criteria: Interns, Residents, and Practice Nurses of the General Medicine Clinic involved in the diagnosis, and management of patients in the 15-week study period

Exclusion criteria: NR

Patient baseline demographics

Inclusion criteria: NR

Exclusion criteria: NR

Patient characteristics	**Intervention group**	**Control group**	***p*-value**
N	NR	NR	–
Age (mean; SD)	NR	NR	NR
Gender (female, %)	NR	NR	NR

Interventions

Intervention: OCS plus CDSS (reminders). Study consisted of 15 weeks; 5 weeks of control period (C); 5 weeks of study period 1 (S1) and five weeks of study period 2 (S2). During S1 care providers were sent reminders about the detected conditions alone, and during S2 were sent reminders plus bibliographic citations supporting the reminders. The 3 intervention periods, C, S1 and S2 could be presented in six possible temporal orders

Comparator: Control conditions with no reminders sent to care providers

Concomitant interventions: NA

CDSS tool

Name of CDDS (if any)	NR (home-grown system Wishard Memorial Hospital)
CDSS reasoning method	NR
CDSS knowledge base	NR
Did study use training set and test set data?	Training set: NR Test set: NR

For training set data complete the following:

Design	NR		
Target decision	NR		
Sample characteristics:	Intervention 1	Intervention 2	**Control**
Sample size (*n*)	NR	NR	NR
Age (mean; range)	NR	NR	NR
Gender (*n* male; *n* female)	NR	NR	NR
Disease type	NR	NR	NR

For test set data complete the following:

Properties of test set data	
Test centre	NR
Target decision	NR

Other CDSS information

1. Information used in CDSS [number of items; signs; symptoms; history; biochemical tests (list)]	NR
2. Time to complete the CDSS (minutes)	NR
3. CDSS output format: (score; probability graph; advice; etc.)	Reminders
4. Is a description of pilot testing with users prior to implementation provided?	No
5. Is user instructional training at the time of implementation described?	No
6. Is the CDSS integrated with charting or OCS to support workflow integration?	Yes
7. Is automatic provision of CDSS output provided as part of clinician workflow?	Yes
8. Is there a need for additional data entry by the clinician?	No
9. Does the CDSS request documentation of the reason for not following CDSS recommendations?	No
10. Does CDSS provide output at the time and location of decision making?	Yes
11. Are the CDSS recommendations executed by the clinician noting agreement?	No
12. Does the CDSS provide a recommendation rather than just an assessment?	No

13. Does the CDSS promote action rather than inaction?	NR
14. Does the CDSS justify the output by provision of reasoning?	No
15. Does the CDSS justify the output by provision of research evidence?	No
16. Were local users involved in the CDSS development process?	No
17. Is the CDSS output provided to patients as well as clinician?	No
18. Does the CDSS provide periodic summaries of performance feedback?	No
19. Is the CDSS used in conjunction with conventional education?	No

Outcome measures

Outcome 1: Compliance with reminders to order a test

Total length of follow-up: 15 weeks

Follow-up assessment times: 15 weeks

Rate of attrition at each follow-up time: NR

Methods of statistical analysis: A variance-stabilising transformation and *F*-root transformation. Data from S1 and S2 periods were analysed together, as differences in compliance with reminder rates were not different between the two periods (S1 + S2/2)

Results

Outcome 1: Compliance with reminders to order a test

	OCS + CDSS	**OCS alone**	***p*-value**
Resident			
Events detected (*n*)	725	374	–
Compliance with reminder (%)	49.0%	20.0%	$p < 0.001$
Intern			
Events detected (*n*)	226	108	–
Compliance with reminder (%)	38.0%	9.0%	$p < 0.017$
Nurse clinician			
Events detected (*n*)	289	89	–
Compliance with reminder (%)	24.0%	15.0%	Not statistically significant

Authors' conclusions: Reminders significantly increased care providers response rate (in terms of test orders and treatment changes) to clinical events that might need corrective action

Methodological assessment criteria (McDonald) (1980)[29]

1. Is the study properly randomised?	No
2. Were the study eligibility criteria specified?	No
3.. Are adequate baseline details presented?	No
4. Are groups similar at baseline?	Unclear
5. Are any baseline imbalances adequately adjusted for in the analysis?	Unclear
6. Is the 'wash out' period adequate?	No
7. Are physician's blinded to treatment allocation?	No
8. Are outcome assessors blinded?	No
9. Are data analyses appropriate?	Unclear
10. Is analysis conducted on an 'intention to provide or communicate information' basis?	Yes
11. Are greater than 80% of physicians/patients included in the follow-up assessment?	Yes
12. Are the conclusions supported by the results?	Partial

Comments: Very small number of participants ($n = 31$) in a sequential crossover trial. Potential for temporal effects due to learning through completing periods S1 and S2 before control condition

Study demographics

Author; year; study ID: Carton (2002)[93]

Title: Assessment of radiological referral practice and effect of computer-based guidelines on radiological requests in two emergency departments

Country: France

Specific setting: Hopital Ambroise Pare, Boulogne-Billancourt and Hopital de Pontchaillou, Rennes, France

Study objectives: To assess medical emergency radiology referral practice compared with a set of French guidelines and to measure the efficiency of computer-based guidelines on unnecessary medical imaging

Health-care setting: Secondary care (A&E)

If secondary care, academic status of the hospital: Teaching

Health-care system: NR

Study design: ITS (AB-AB-AB design)

Number of sites: 2

Funding source: NR

Was evaluator of tool also its developer? Yes

System users

CDSS user(s)	Physician
Practitioners (*n*)	NR
If the CDSS user is a doctor, complete *n* for the following:	NR
Consultant (attending)	
Registrar (chief resident)	
SHO (resident)	
HO (intern)	
Practitioners (*n*) in analysis	NR

Inclusion criteria: All physicians working in the emergency departments of either two hospitals who ordered a radiological examination within the study period. Study was conducted over 6 months between June and November 1998. Three control periods and three intervention periods were run alternately with no delay between periods; each period was about 1-month long

Exclusion criteria: NR

Patient baseline demographics

Inclusion criteria: All patients for who a radiological examination was ordered during the study period in either emergency department

Exclusion criteria: NR

Number of patients seen in emergency departments (*n*)	15,086
Number of documented radiological requests (*n*)	6434
Number of requests excluded (*n*;%)[a]	743 (11)

a 743 (11%) requests were excluded from analysis because the radiological examination and/or clinical context had been profoundly altered by hand.

Interventions

Intervention: OCS with CDSS (reminders displaying the appropriate guideline recommendation). The guidelines were written by the Collège des Enseignants de Radiologie de France (French Society of Radiologists) based on the results of a review of the literature, existing guidelines and the expertise of all the societies of radiologists and clinicians. During the control periods, radiological requests were recorded but no action taken. During intervention periods, reminders displayed on screen the appropriate recommendations for the given clinical context

Comparator: NA

Concomitant interventions: NA

CDSS tool

Name of CDDS (if any)	NR
CDSS reasoning method	NR
CDSS knowledge base	Guidelines based on a review of the literature, existing guidelines and the clinician expertise

Did study use training set and test set data?	Training set: NR Test set: NR	
For training set data complete the following:		
Design	NR	
Target decision	NR	
Sample characteristics:		
Sample size (*n*)	NR	
Age (mean; range)	NR	
Gender (*n* male; *n* female)	NR	
Disease type	NR	
For test set data complete the following:		
Properties of test set data		NR
Test centre		NR
Target decision		NR
Other CDSS information		
1. Information used in CDSS [number of items; signs; symptoms; history; biochemical tests (list)]		NR
2. Time to complete the CDSS (minutes)		1 minute
3. CDSS output format: (score; probability graph; advice; etc.)		Reminder
4. Is a description of pilot testing with users prior to implementation provided?		No
5. Is user instructional training at the time of implementation described?		No
6. Is the CDSS integrated with charting or OCS to support workflow integration?		Partial
7. Is automatic provision of CDSS output provided as part of clinician workflow?		Yes
8. Is there a need for additional data entry by the clinician?		Yes
9. Does the CDSS request documentation of the reason for not following CDSS recommendations?		Yes
10. Does CDSS provide output at the time and location of decision making?		Yes
11. Are the CDSS recommendations executed by the clinician noting agreement?		No
12. Does the CDSS provide a recommendation rather than just an assessment?		Yes
13. Does the CDSS promote action rather than inaction?		NR
14. Does the CDSS justify the output by provision of reasoning?		No
15. Does the CDSS justify the output by provision of research evidence?		No
16. Were local users involved in the CDSS development process?		No
17. Is the CDSS output provided to patients as well as clinician?		No
18. Does the CDSS provide periodic summaries of performance feedback?		No
19. Is the CDSS used in conjunction with conventional education?		No

Outcome measures

Outcome 1: Number of radiography requests complying with guideline recommendations

Outcome 2:.Type of radiography requests not complying with guideline recommendations

Outcome 3: Most frequent radiography requests not complying with guideline recommendations

Outcome 4: Number of radiography requests not complying with guideline recommendations by control and intervention periods

Total length of follow-up: 6 months between June and November 1998

Follow-up assessment times: 6 months

Rate of attrition at each follow-up time: 743/6434 (11%) requests were excluded from analysis because the radiological examination and/or clinical context had been profoundly altered by hand

Methods of statistical analysis: comparison of the distribution of categorical variables was made using Pearson chi-squared test. All *p*-values were two-tailed, with values lower than 5% considered significant

Results

Outcome 1: Number of radiography requests complying with guideline recommendations

	Centre A (*n*; %)	Centre B (*n*; %)	Total (*n*; %)
In agreement	1657 (82.4)	3166 (65.2)	4823 (70.2)
Not in agreement	353 (17.6)	1693 (34.8)	2046 (29.8)

Outcome 2: Type of radiography requests not complying with guideline recommendations

Radiography	Total (*n*)	(%)[a]	(%)[b]
Abdominal plain radiographs	861	42.1	76.5
Chest radiographs	891	43.5	24.9
CT of the brain	162	7.9	15.8
Others	132	6.5	11.6
Total	2046	100	29.8

a Percentage of total examinations that were not in agreement with guideline.

b Percentage of examinations that were not in agreement with guideline for a given radiography.

Outcome 3: Most frequent radiography requests not complying with guideline recommendations

Clinical context	***n* (%)**
Chest radiographs for systematic entry check-up	611 (29.9)
Abdominal plain radiographs or abdominal ultrasonography for abdominal pain	398 (19.4)
Chest radiographs for acute bronchitis	145 (7.1)
CT of the brain for a first epileptic fit, without fever or neurological symptoms	83 (4.1)
Abdominal plain radiographs for diarrhoea	82 (4.0)
Abdominal plain radiographs for constipation	68 (3.3)
Radiograph of the ribs for minor thoracic trauma	44 (2.2)
Others[a]	615 (30.1)

a Represents 54 different requests that were not in agreement with guidelines, each with a frequency of under 2%.

Outcome 4: Number of radiography requests not complying with guideline recommendations by control and intervention periods

The proportion of requests not conforming to guidelines increased on each of three success occasions when the recommendations displayed on screen were switched off: from 27.5% to 29.8% (relative increase of 8.4%), from 27.0% to 37.8% (relative increase of 40%), and from 26.0% to 26.9% (relative increase of 3.5%)

Authors' conclusions: While the computer provided advice that was tailored to the needs of individual patients concurrent with care, the effect of the intervention was weak. However, our study identified the few situations that were responsible for the majority of unnecessary radiological requests

Methodological assessment criteria (Carton) (2002)[93]

1. Is the intervention independent of other changes over time?	Unclear
2. Are there sufficient data points to enable reliable statistical inference?	Yes
3. Does the analysis include a formal test for trend?	No

4. Is the intervention unlikely to affect data collection?	Yes
5. Is the assessment of primary outcome blinded?	Yes
6. Are greater than 80% of physicians/patients/episodes of care included in the follow-up assessment?	Yes
7. Is the primary outcome measure reliable?	Yes
Comments: AB-AB-AB design and therefore it is possible that intervention effects were carried over into the control periods. No tests for trends were conducted	

Study demographics

Author; year; study ID: Steele (2005)[94]

Title: The effect of automated alerts on provider ordering behaviour in an outpatient setting

Country: USA

Specific setting: Sam Sandos Family Health Clinic, Denver Health outpatient primary-care clinics, Denver, CO, USA

Study objectives: To assess the effects of implementation of OCS with CDSS providing automated alerts on medication errors related to drug–laboratory interactions in an outpatient primary care setting

Health-care setting: Primary care

If secondary care, academic status of the hospital: NA

Health-care system: Mixed (Medicaid; Medicare; private/commercial; uninsured)

Study design: Pre–post

Number of sites: 1

Funding source: Public sector

Was evaluator of tool also its developer? No

System users

CDSS user(s)[a]	Physicians, allied health providers (nurse practitioners, physician assistants), residents
Practitioners (*n*)	NR

a No further baseline details were reported on study physicians.

Inclusion criteria: All users who entered medication orders during the study period

Exclusion criteria: NR

Patient baseline demographics

Inclusion criteria: All registered patients were eligible for inclusion

Exclusion criteria: NR

	N	%
N	19,076	100.0%
Age (mean)	25.3	–
Gender (female)	12,241	64.2%
Ethnic group		
African American	514	2.7%
Caucasian	2081	10.9%
Hispanic	15,708	82.3%
Other	773	4.1%
Insurance		
Medicare	8049	42.2%
Medicaid	1249	6.5%
Private/commercial	1174	6.2%
Uninsured	7832	41.1%
Other	772	4.0%

Interventions

Intervention: OCS plus CDSS. The CDSS used commercially available rules developed by Thomson Micromedex as Medical Logic Modules (MLM) and modified them to meet local needs. The rules chosen focused upon those appropriate to addressing patient safety in an outpatient setting and covered the following five areas: (1) medication use that can lead to hyperkalemia, (2) hypokalemia, (3) nephrotoxicity, (4) thrombocytopenia, and (5) heptic inflammation. In addition a determination was made for each medication as to whether an alert should be provided for (1) an abnormal laboratory value only; (2) either an abnormal laboratory value or a missing laboratory value, or (3) no alert displayed. The laboratory cut-off values for triggering an alert were the same as the Denver Health abnormal laboratory reference ranges

In response to the alerts, providers could decide to keep, revise or delete the medication order. They could also order any rule associated laboratory tests

Comparator: OCS alone (pre-intervention)

Concomitant interventions: NA

CDSS tool

Name of CDDS (if any)	NR (developed in collaboration with Thomson Micromedex and Siemens Medical Solutions)
CDSS reasoning method	Discrimination rules
CDSS knowledge base	Commercially available Medical Logic Modules developed by Thomson Micromedex and then adapted to meet local needs
Did study use training set and test set data?	Training set: No Test set: No

For training set data complete the following:

Design	NR
Target decision	NR
Sample characteristics:	
Sample size (*n*)	NR
Age (mean; range)	NR
Gender (*n* male; *n* female)	NR
Disease type	NR

For test set data complete the following:

Properties of test set data	NR
Test centre	NR
Target decision	NR

Other CDSS information

1. Information used in CDSS [number of items; signs; symptoms; history; biochemical tests (list)]	Biochemical tests
2. Time to complete the CDSS (minutes)	NR
3. CDSS output format: (score; probability graph; advice; etc.)	Alert
4. Is a description of pilot testing with users prior to implementation provided?	No
5. Is user instructional training at the time of implementation described?	No
6. Is the CDSS integrated with charting or OCS to support workflow integration?	Yes
7. Is automatic provision of CDSS output provided as part of clinician workflow?	Yes
8. Is there a need for additional data entry by the clinician?	No
9. Does the CDSS request documentation of the reason for not following CDSS recommendations?	No
10. Does CDSS provide output at the time and location of decision making?	Yes
11. Are the CDSS recommendations executed by the clinician noting agreement?	No
12. Does the CDSS provide a recommendation rather than just an assessment?	Yes
13. Does the CDSS promote action rather than inaction?	NR
14. Does the CDSS justify the output by provision of reasoning?	No

15. Does the CDSS justify the output by provision of research evidence?	No
16. Were local users involved in the CDSS development process?	Yes
17. Is the CDSS output provided to patients as well as clinician?	No
18. Does the CDSS provide periodic summaries of performance feedback?	No
19. Is the CDSS used in conjunction with conventional education?	No

Outcome measures

Outcome 1: Percentage of time rule associated laboratory test ordered: no alert displayed

Outcome 2: Percentage of time rule associated laboratory test ordered: alert displayed

Outcome 3: Percentage of time rule associated laboratory test ordered: 'abnormal labs' message displayed

Outcome 4: Percentage of time rule associated laboratory test ordered: 'no labs' message displayed

Total length of follow-up: 9 months (pre-intervention 17 weeks; post-intervention 21 weeks). Study period: 1 August 2002 to 30 April 2003

Follow-up assessment times: 9 months

Rate of attrition at each follow-up time: NA

Methods of statistical analysis: Fisher's exact test or generalised estimating equations

Results

Outcome 1: Percentage of time rule associated laboratory test ordered: no alert displayed[a]

Pre-intervention (*n*; %)	**Post-intervention (*n*; %)**	**% change**	***p*-value**
1042 (17)	1322 (16.20)	–4.71	0.38

a There was no significant change in the % time provider ordered the rule associated laboratory test pre- and post-intervention indicating there was no trend to increased laboratory test ordering during the study period.

Outcome 2: Percentage of time rule associated laboratory test ordered: alert displayed

Pre-intervention (*n*;%)	**Post-intervention (*n*;%)**	**% change**	***p*-value**
347 (38.50)	559 (51.10)	32.73	<0.0001

Outcome 3: Percentage of time rule associated laboratory test ordered: 'abnormal labs' message displayed

Pre-intervention (*n*;%)	**Post-intervention (*n*;%)**	**% change**	***p*-value**
152 (33.80)	240 (41.70)	23.37	0.0771

Outcome 4: Percentage of time rule associated laboratory test ordered: 'no labs' message displayed

Pre-intervention (*n*;%)	**Post-intervention (*n*;%)**	**% change**	***p*-value**
198 (43.0)	331 (62.0)	44.19	<0.001

Authors' conclusions: Providers will adhere to alerts and will use this information to improve patient care. Specifically, in response to drug–laboratory interaction alerts, providers will significantly increase the ordering of laboratory tests

Methodological assessment criteria (Steele) (2005)[94]

1. Were the study eligibility criteria specified?	Yes
2. Are adequate baseline details presented?	Partial
3. Are similar cointerventions administered in both study periods?	NA
4. Are data analyses appropriate?	Yes
5. Is analysis conducted on an 'intention to provide or communicate information' basis?	Yes
6. Are greater than 80% of physicians/patients included in the follow-up assessment?	Yes
7. Are the conclusions supported by the results?	Yes

Comments: None

Study demographics

Author; year; study ID: Abboud (2006)[87]

Title: Impact of workflow-integrated corollary orders on aminoglycoside monitoring in children

Country: USA

Specific setting: Cincinnati Children's Hospital Medical Center, Cincinnati, OH, USA (423-bed tertiary care children's hospital with over 700,000 total patient visits per annum)

Study objectives: To assess the impact of an electronic workflow-integrated aminoglycoside corollary order in paediatric patients

Health-care setting: Secondary care (paediatric inpatients)

If secondary care, academic status of the hospital: NR

Health-care system: NR

Study design: Pre–post

Number of sites: 1 (423 bed hospital)

Funding source: NR

Was evaluator of tool also its developer? No

System users

CDSS user(s)[a]	Physicians
Practitioners (*n*)	NR

a No further baseline details were reported on study physicians.

Inclusion criteria: All users who entered aminoglycosides medication orders for 4 or more days duration during the study period (October 2003 to March 2004)

Exclusion criteria: NR

Patient baseline demographics

Inclusion criteria: All patients who received aminoglycosides for 4 or more days duration during the study period

Exclusion criteria: NR

	Baseline period (September 2003 to November 2003)	**Intervention period (January 2004 to March 2004)**	***p*-value**
Courses of antibiotic therapy ≥ 4 days	159	177	n.s
Total number of patients:	125	150	n.s
1 course of therapy	101	128	n.s
2 courses of therapy	19	19	n.s
3 courses of therapy	4	2	n.s
≥4 courses of therapy	1	1	n.s
Courses of antibiotic therapy/ patient	1.3	1.2	n.s
Total number of laboratory results obtained	262	286	n.s
Laboratory results analysed based on predefined criteria (% of total)[a]	215 (82.1%)	219 (76.6%)	n.s
Laboratory results per antibiotic course (range)	1.6 (0–9)	1.6 (0–8)	n.s
Laboratory results per patient (range)	2.1 (0–11)	1.9 (0–10)	n.s

n.s, not statistically significant.

a Laboratory values were analysed only if obtained at predefined peak (obtained 50–120 minutes after drug administration) or trough (obtained 0–120 minutes prior to drug administration) times.

Interventions

Intervention: OCS plus CDSS (corollary order). For all aminoglycoside orders of 4 or more days duration, CDSS prompted the physician in whether they were interested in checking peak, trough, peak and trough or random blood level for the drug being prescribed as well as the date and time when they wanted the blood sample obtained

Comparator: OCS alone (pre-intervention)

Concomitant interventions: NA

CDSS tool

Name of CDDS (if any)	INVISION®, Siemens Medical Solutions, Malvern, PA, USA
CDSS reasoning method	NR
CDSS knowledge base	NR
Did study use training set and test set data?	Training set: No Test set: No

For training set data complete the following:

Design	NR
Target decision	NR
Sample characteristics:	
Sample size (*n*)	NR
Age (mean; range)	NR
Gender (*n* male; *n* female)	NR
Disease type	NR

For test set data complete the following:

Properties of test set data	NR
Test centre	NR
Target decision	NR

Other CDSS information

1. Information used in CDSS [number of items; signs; symptoms; history; biochemical tests (list)]	Test order
2. Time to complete the CDSS (minutes)	NR
3. CDSS output format: (score; probability graph; advice; etc.)	Prompt
4. Is a description of pilot testing with users prior to implementation provided?	No
5. Is user instructional training at the time of implementation described?	Yes
6. Is the CDSS integrated with charting or OCS to support workflow integration?	Yes
7. Is automatic provision of CDSS output provided as part of clinician workflow?	Yes
8. Is there a need for additional data entry by the clinician?	No
9. Does the CDSS request documentation of the reason for not following CDSS recommendations?	No
10. Does CDSS provide output at the time and location of decision making?	Yes
11. Are the CDSS recommendations executed by the clinician noting agreement?	No
12. Does the CDSS provide a recommendation rather than just an assessment?	No
13. Does the CDSS promote action rather than inaction?	NR
14. Does the CDSS justify the output by provision of reasoning?	No
15. Does the CDSS justify the output by provision of research evidence?	No
16. Were local users involved in the CDSS development process?	No
17. Is the CDSS output provided to patients as well as clinician?	No
18. Does the CDSS provide periodic summaries of performance feedback?	No
19. Is the CDSS used in conjunction with conventional education?	Yes

Outcome measures

Outcome 1: Number of courses of aminoglycosides with appropriate laboratory test monitoring

Outcome 2: Frequency of therapeutic, toxic, subtherapeutic, or toxic and subtherapeutic laboratory values during courses of therapy

Total length of follow-up: 6 months (3 months pre- and 3 months post-intervention). Study period: October 2003 to March 2004

Follow-up assessment times: 6 months

Rate of attrition at each follow-up time: NA

Methods of statistical analysis: Categorical data were analysed using descriptive statistics and chi-square tests. Continuous parametric data were analysed by *t*-tests and non-parametric data by Mann-Whitney rank-sum test. *p*-Values <0.05 were considered statistically significant

Results

Outcome 1: Number of courses of aminoglycosides with appropriate laboratory test monitoring

	Pre-intervention (n; %)	**Post-intervention (n; %)**	***p*-value**
N in analysis	159	177	–
	128 (80.5%)	146 (82.5%)	n.s

n.s, not statistically significant at the p < 0.05 level.

Outcome 2: Frequency of therapeutic, toxic, subtherapeutic, or toxic and subtherapeutic laboratory values during courses of therapy

	Pre-intervention (n; %)	**Post-intervention (n; %)**	***p*-value**
***N* in analysis**	111	125	–
All therapeutic levels	94 (84.7%)	100 (80.0%)	$p = 0.44$
Any toxic levels	9 (8.1%)	15 (12%)	$p = 0.44$
Any subtherapeutic levels	8 (7.2%)	7 (5.6%)	$p = 0.81$
Both toxic and sub-therapeutic levels	0	3 (2.4%)	$p = 0.29$

Authors' conclusions: The introduction of a computerised corollary order for aminoglycoside blood level monitoring tests did not significantly improve laboratory monitoring rates, nor did it result in a reduction in the rate of either toxic or subtherapeutic levels. However, aminoglycoside corollary orders may have an important role in institutions where pharmacists are not actively involved in monitoring therapy

Methodological assessment criteria (Abboud) (2006)[87]

1. Were the study eligibility criteria specified?	Yes
2. Are adequate baseline details presented?	No
3. Are similar cointerventions administered in both study periods?	NA
4. Are data analyses appropriate?	Yes
5. Is analysis conducted on an 'intention to provide or communicate information' basis?	Yes
6. Are greater than 80% of physicians/patients included in the follow-up assessment?	Yes
7. Are the conclusions supported by the results?	Yes

Comments: None

Studies assessing the impact of the display of restricted lists (*n* = 2)

Study demographics

Author; year; study ID: Solomon (1999)[88]

Title: A computer-based intervention to reduce unnecessary serologic testing

Country: USA

Specific setting: Brigham and Women's Hospital, Boston, MA, USA

Study objectives: To assess whether physicians would reduce their use of unnecessary serologic tests if provided with information on the likelihood that an antinuclear antibody (ANA), rheumatoid factor (RF), or complement level test would change their estimate of disease

Health-care setting: Secondary care (inpatients)

If secondary care, academic status of the hospital: NR

Health-care system: NR

Study design: CCT

Number of sites: 1 (720-bed hospital)

Funding source: public sector

Was evaluator of tool also its developer? Yes

System users

	Intervention group	**Control group**	***p*-value[b]**
CDSS user(s)	Physician	Physician	
Practitioners (*n*)	71	154	
Age (year) (mean; SD)	30 ± 4	30 ± 4	0.5
Gender (female, %)	28	36	0.2
Postgraduate year[a] (%)			
First	65	52	
Second	13	27	
Third	16	14	
Fourth	5	7	0.08
Department (%)[a]			
Medicine	86	82	
Surgery	2	7	
Neurology	7	8	
Obstetrics-gynaecology	5	3	0.2

a Percentages may not sum due to rounding (reported by authors).

b Calculated from chi-squared tests for categorical data and Wilcoxon rank-sum tests for ordinal data.

Practitioners (*n*) in analysis	NA	NA	

Inclusion criteria: All physicians ordering an RF or ANA test for the suspected indications of rheumatoid arthritis, systemic lupus erythematosus, primary systemic sclerosis, mixed connective tissue disease, or Sjögren's syndrome during the 10-month study period (September 1996 to June 1997) were assigned to the intervention group. All physicians ordering an RF or ANA for the suspected indications of systemic vasculitis and cryoglobulinemia, or a complement test for any condition during the study period were assigned to the control group

Exclusion criteria: When multiple orders for the same test for the same patient during one calendar day were made, only the last order was included

Patient baseline demographics

Inclusion criteria: All inpatients with an order written for an ANA, RF or complement level test during the 10-month study period

Exclusion criteria: NR

Patient characteristics	**Intervention group**	**Control group**	***p*-value[a]**
N	99	236	
Age (year) (mean; SD)	55 ± 19	54 ± 17	0.7

Gender (female) (%)	66	66	1.0
Length of stay (days)[b]	6 (3,12)	6 (3,11)	0.9
Total charges (US$)[b]	13,415 (7636; 27,951)	13,217 (7337; 25,634)	0.6
Died in hospital (*n*)	4	6	0.4

a Calculated from chi-squared tests for categorical data and Wilcoxon rank-sum tests for ordinal data.

b Median (25%; 75%).

Interventions

Intervention: OCS plus CDSS. The CDSS required the physician to enter into the computer their estimate of the pre-test probability of disease. The CDSS then calculated the positive and negative post-test predictive values based on estimates of the sensitivity and specificity of each test derived from the literature

Comparator: OCS alone

Concomitant interventions: NA

CDSS tool

Name of CDDS (if any)	NR (home-grown system Brigham and Women's Hospital)
CDSS reasoning method	Naive Bayesian methods
CDSS knowledge base	Sensitivity and Specificity values abstracted from the literature
Did study use training set and test set data?	Training set: NR Test set: NR

For training set data complete the following:

Design	NR	
Target decision	NR	
Sample characteristics:	Intervention	Control
Sample size (*n*)	NR	NR
Age (mean; range)	NR	NR
Gender (*n* male; *n* female)	NR	NR
Disease type	NR	NR

For test set data complete the following:

Properties of test set data	
Test centre	NR
Target decision	NR

Other CDSS information

1. Information used in CDSS [number of items; signs; symptoms; history; biochemical tests (list)]	1; pre-test probability estimate
2. Time to complete the CDSS (minutes)	NR
3. CDSS output format: (score; probability graph; advice; etc.)	Positive and negative predictive values (post-test)
4. Is a description of pilot testing with users prior to implementation provided?	No
5. Is user instructional training at the time of implementation described?	Yes
6. Is the CDSS integrated with charting or OCS to support workflow integration?	Yes
7. Is automatic provision of CDSS output provided as part of clinician workflow?	Yes
8. Is there a need for additional data entry by the clinician?	Yes
9. Does the CDSS request documentation of the reason for not following CDSS recommendations?	No
10. Does CDSS provide output at the time and location of decision making?	Yes
11. Are the CDSS recommendations executed by the clinician noting agreement?	No
12. Does the CDSS provide a recommendation rather than just an assessment?	No

13. Does the CDSS promote action rather than inaction?	No
14. Does the CDSS justify the output by provision of reasoning?	No
15. Does the CDSS justify the output by provision of research evidence?	No
16. Were local users involved in the CDSS development process?	NR
17. Is the CDSS output provided to patients as well as clinician?	No
18. Does the CDSS provide periodic summaries of performance feedback?	No
19. Is the CDSS used in conjunction with conventional education?	No

Outcome measures

Outcome 1: Number of tests cancelled

Outcome 2: Yield of positive tests for known or new rheumatic disease

Total length of follow-up: 10 months (September 1996 to June 1997)

Follow-up assessment times: 10 months

Rate of attrition at each follow-up time: 348 patients had a ANA, RF or complement test ordered, of these 13 duplicate orders were excluded. *N* = 335 tests (attrition rate = 3.7%)

Methods of statistical analysis: Chi-squared tests and Wilcoxon rank-sum tests for univariate analysis

Results

Outcome 1: Number of tests cancelled

	OCS + CDSS	**OCS alone**	***p*-value**
N in analysis	99	236	–
Number of tests cancelled *n* (%)	11 (11.1%)	1 (0.42%)	$p = 0.001$

Outcome 2: Yield of positive tests for known or new rheumatic disease

The charts of 43 patients with positive tests were reviewed to determine whether the positive test yielded a new diagnosis of a rheumatic condition. 26/43 of the positive tests were in patients with known rheumatic disease. Only 4/43 new diagnosis of rheumatic disease were made, which account for 1.2% of all tests ordered

Authors' conclusions: The computer-based intervention resulted in a small but statistically significant decrease in orders for AAN and RF levels by 10%. Further reductions without clinical harm are probably possible, since the yield of testing for new rheumatic diseases was low

Methodological assessment criteria Solomon (1999)[88]

1. Were the study eligibility criteria specified?	Yes
2. Are adequate baseline details presented?	Yes
3. Are groups similar at baseline?	Yes
4. Are any baseline imbalances adequately adjusted for in the analysis?	NA
5. Are similar cointerventions administered?	NA
6. Are physician's blinded to treatment allocation?	No
7. Are outcome assessors blinded?	No
8. Are data analyses appropriate?	Yes
9. Is analysis conducted on an 'intention to provide or communicate information' basis?	Yes
10. Are greater than 80% of physicians/patients included in the follow-up assessment?	Yes
11. Are the conclusions supported by the results?	Yes

Comments: None

Study demographics

Author; year; study ID: Bansal (2001)[89]

Title: A computer-based intervention on the appropriate use of arterial blood gas

Country: USA

Specific setting: Vanderbilt University Medical Center, Nashville, TN, USA (630-bed hospital with 31,000 admissions per year)

Study objectives: To evaluate the impact of a computer-based intervention on ABG usage in an intensive care setting

Health-care setting: Secondary care (ICUs)

If secondary care, academic status of the hospital: University

Health-care system: NR

Study design: Pre–post

Number of sites: 1 (6 ICUs; trauma; general surgery; medical; cardiac; burn; neurology)

Funding source: Public sector

Was evaluator of tool also its developer? Yes

System users

CDSS user(s)[a]	Physicians; respiratory therapists; nurses; medical receptionists	
Practitioners (*n*)	NR	
Orders entered by user type at baseline		
User type[a]	*n*	%
Ancillary staff	24	1.8%
Physicians	366	28.0%
Other users	8	0.6%
Nurses	813	62.0%
Respiratory therapists	80	6.1%

a Staff who were not medical doctors had the ability to enter verbal or written orders from physicians.

Inclusion criteria: All users with the authority to enter orders via the OCS during the study period

Exclusion criteria: NR

Patient baseline demographics

Inclusion criteria: All patients on the six ICUs (trauma; general surgery; medical; cardiac; burn; neurology) who had a ABG test ordered during the study period[a]

Exclusion criteria: NR

a No further data on patient baseline demographics was reported.

Interventions

Intervention: OCS plus CDSS. CDSS provided the ordering clinician with educational text alongside a graphical display of the patient's previous ABG values (pO_2, pCO_2, HCO_3, pH, FiO_2) and O_2 saturations. Advanced ordering of ABG tests was also limited to within 24 hours so no multiday orders were allowed. The default response was to cancel the order, but the final decision regarding the test order was left to the user's discretion

Comparator: OCS alone (pre-intervention)

Concomitant interventions: NA

CDSS tool

Name of CDDS (if any)	NR (home-grown system Vanderbilt University Medical Center)
CDSS reasoning method	NR
CDSS knowledge base	NR
Did study use training set and test set data?	Training set: No Test set: No
For training set data complete the following:	
Design	NR
Target decision	NR

Sample characteristics:		
Sample size (*n*)	NR	
Age (mean; range)	NR	
Gender (*n* male; *n* female)	NR	
Disease type	NR	
For test set data complete the following:		
Properties of test set data	NR	
Test centre	NR	
Target decision	NR	
Other CDSS information		
1. Information used in CDSS [number of items; signs; symptoms; history; biochemical tests (list)]		Six previous ABG results (pO_2, pCO_2, HCO_3, pH, FiO_2, O_2 saturations
2. Time to complete the CDSS (minutes)		NR
3. CDSS output format: (score; probability graph; advice; etc.)		Graphs
4. Is a description of pilot testing with users prior to implementation provided?		No
5. Is user instructional training at the time of implementation described?		No
6. Is the CDSS integrated with charting or OCS to support workflow integration?		Yes
7. Is automatic provision of CDSS output provided as part of clinician workflow?		Yes
8. Is there a need for additional data entry by the clinician?		No
9. Does the CDSS request documentation of the reason for not following CDSS recommendations?		No
10. Does CDSS provide output at the time and location of decision making?		Yes
11. Are the CDSS recommendations executed by the clinician noting agreement?		Yes
12. Does the CDSS provide a recommendation rather than just an assessment?		No
13. Does the CDSS promote action rather than inaction?		No
14. Does the CDSS justify the output by provision of reasoning?		No
15. Does the CDSS justify the output by provision of research evidence?		No
16. Were local users involved in the CDSS development process?		Yes
17. Is the CDSS output provided to patients as well as clinician?		No
18. Does the CDSS provide periodic summaries of performance feedback?		No
19. Is the CDSS used in conjunction with conventional education?		No

Outcome measures

Outcome 1: Number of ABG test orders placed pre- and post-intervention

Total length of follow-up: 12 weeks (pre-intervention 5 weeks; post-intervention 7 weeks). Study period: 1 November 2000 to 23 January 2001

Follow-up assessment times: 12 weeks

Rate of attrition at each follow-up time: NA

Methods of statistical analysis: ANOVA (analysis of variance) and linear regression analysis

Results

Outcome 1: Number of ABG test orders placed pre- and post-intervention

Pre-intervention (*n*)	**Post-intervention (*n*)**	***p*-value**
376	387	$p = 0.09$

Authors' conclusions: Study did not demonstrate significant change. Longer study periods are therefore needed. The impact could be improved in the future by targeting physician users and tailoring the intervention to specific workflow patterns of high utilisation units

Methodological assessment criteria (Bansal) (2001)[89]

1. Were the study eligibility criteria specified?	Yes
2. Are adequate baseline details presented?	Partial
3. Are similar cointerventions administered in both study periods?	No
4. Are data analyses appropriate?	Yes
5. Is analysis conducted on an 'intention to provide or communicate information' basis?	Unclear
6. Are greater than 80% of physicians/patients included in the follow-up assessment?	Yes
7. Are the conclusions supported by the results?	Yes

Comments: The numbers presented in the abstract for change in the number of test orders place pre- and post-intervention do not tally with those presented in the text on page 34. It is unclear whether the post-intervention results reported in both the abstract and text (p 34) pertain to just the implemented units or all units together. Numbers reported for outcome 1 are taken from the abstract

Studies assessing the impact of recommendations (*n* = 7)

Study demographics

Author; year; study ID: Hobbs (1996)[32]

Title: A prospective controlled trial of computerized decision support for lipid management in primary care

Country: UK

Specific setting: Primary care; 25 practices covering a population of 150,000 in Birmingham, UK

Study objectives: To explore the uptake and effect in primary care of a computerised decision support system for the management of hyperlipidaemia

Health-care setting: Primary care

If secondary care, academic status of the hospital: NA

Health-care system: NHS

Study design: CRCT

Number of sites: 25 practices (21 intervention; 4 control)

Funding source: NR

Was evaluator of tool also its developer? No

System users

	Intervention group	**Control group**
CDSS user(s)	Physician	Physician
Practitioners (*n*)	NR	NR
If the CDSS user is a doctor, complete *n* for the following:	NR	NR
Consultant (attending)		
Registrar (chief resident)		
SHO (resident)		
HO (intern)		
Practitioners (*n*) in analysis	NR	NR

Inclusion criteria: NR

Exclusion criteria: Practices with previous experience of CDSS were excluded

Patient baseline demographics

Inclusion criteria: NR

Exclusion criteria: NR

	Intervention group	**Control group**
Age (mean; SD)	NR	NR
Gender (female %)	NR	NR

Interventions

Intervention: OCS with CDSS (Primed system) using the hyperlipidaemia decision support module

Comparator: OCS without CDSS

Concomitant interventions: NA

CDSS tool	
Name of CDDS (if any)	Primed system (Wolfson Research Laboratories, University of Birmingham)
CDSS reasoning method	Discrimination rules
CDSS knowledge base	Physician opinion (protocol developed by a lipid specialist)
Did study use training set and test set data?	Training set: NR Test set: NR

For training set data complete the following:

Design	[Consecutive; random; retrospective; unclear; other: (specify)]
Target decision	State

Sample characteristics:	**Intervention**	**Control**
Sample size (*n*)	NR	NR
Age (mean; range)	NR	NR
Gender (*n* male; *n* female)	NR	NR
Disease type	NR	NR
For test set data complete the following:		
Properties of test set data	NR	
Test centre	NR	
Target decision	NR	
Other CDSS information		
1. Information used in CDSS [number of items; signs; symptoms; history; biochemical tests (list)]		Sociodemographic details; cardiovascular risk factors; cholesterol level
2. Time to complete the CDSS (minutes)		NR
3. CDSS output format: (score; probability graph; advice; etc.)		Advice
4. Is a description of pilot testing with users prior to implementation provided?		No
5. Is user instructional training at the time of implementation described?		Yes
6. Is the CDSS integrated with charting or OCS to support workflow integration?		No
7. Is automatic provision of CDSS output provided as part of clinician workflow?		Yes
8. Is there a need for additional data entry by the clinician?		Yes
9. Does the CDSS request documentation of the reason for not following CDSS recommendations?		NR
10. Does CDSS provide output at the time and location of decision-making?		Yes
11. Are the CDSS recommendations executed by the clinician noting agreement?		No
12. Does the CDSS provide a recommendation rather than just an assessment?		Yes
13. Does the CDSS promote action rather than inaction?		NR
14. Does the CDSS justify the output by provision of reasoning?		No
15. Does the CDSS justify the output by provision of research evidence?		No
16. Were local users involved in the CDSS development process?		No
17. Is the CDSS output provided to patients as well as clinician?		No
18. Does the CDSS provide periodic summaries of performance feedback?		No
19. Is the CDSS used in conjunction with conventional education?		No

Outcome measures

Outcome 1: Lipid test rates

Outcome 2: Number of patients receiving a full lipid profile (cholesterol, fasting triglyceride and HDL)

Total length of follow-up: 9 months (3 months historical control period and 6 months intervention period

Follow-up assessment times: 9 months

Rate of attrition at each follow-up time: eight practices (three practices failed to record any data; three practices lost all collected data; one practice dropped out; data from one practice was lost in the post)

Methods of statistical analysis: Comparisons between pre- and intervention time for each practice was compared using paired *t*-tests and Wilcoxon tests. No between group comparisons were conducted with all analysis conducted as a change from baseline period

Results

Outcome 1: Lipid test rates

The mean rate of testing was 4.4 tests/1000 population/month. The authors report that rates of testing did not show any significant differences between the pre- and intervention period (actual figures not reported)

Outcome 2: Number of patients receiving a full lipid profile (cholesterol, fasting triglyceride and HDL)

The authors report there was a significant increase in the number of patients receiving a full lip profile in the study period and a decrease in those having only partial investigations ($\chi^2 = 49.5$; df = 3; $p < 0.05$) (actual figures not reported)

Authors' conclusions: Greater integration of CDSS software and practice based data handling systems is needed. The mode of data capture, and hence both the content and form of knowledge representation, in CDSS must take greater account of the primary care consultation process if such systems are to be of use to practitioners

Methodological assessment criteria (Hobbs) (1996)[32]

1. Is the study properly randomised?	Unclear
2. Did the analysis take clustering into account?	No
3. Were the study eligibility criteria specified?	Partial
4. Are adequate baseline details presented?	No
5. Are groups similar at baseline?	Unclear
6. Are any baseline imbalances adequately adjusted for in the analysis?	No
7. Are similar cointerventions administered?	NA
8. Are physician's blinded to treatment allocation?	No
9. Are outcome assessors blinded?	Unclear
10. Are data analyses appropriate?	No
11. Is analysis conducted on an 'intention to provide or communicate information' basis?	No
12. Are greater than 80% of physicians/patients included in the follow-up assessment?	No
13. Are the conclusions supported by the results?	Yes

Comments: attrition 8/25 clusters; no intraclass correlation reported in design and clustering does not appear to have been taken into account in analysis; no between group differences reported, analysis conducted as a change in pre- and post- intervention rates

Study demographics

Author; year; study ID: Apkon (2005)[97]

Title: A randomised outpatient trial of a decision-support information technology tool

Country: USA

Specific setting: Two military treatment facilities (Ireland Army Community Hospital and Clinic, Fort Knox, KY, USA and Mayport Branch Health Clinic, Mayport, FL, USA)

Study objectives: To conduct a RCT to evaluate the impact of the DSIT tool Problem-Knowledge Couplers within a computerised medical record on quality of care, and resource consumption

Health-care setting: Secondary care (all outpatients)

If secondary care, academic status of the hospital: NR

Health-care system: USA military treatment facilities

Study design: RCT

Number of sites: 2

Funding source: Public sector

Was evaluator of tool also its developer? No

System users

	Intervention group	**Control group**
CDSS user(s)	Physician	Physician
Practitioners (*n*)	NR	NR
If the CDSS user is a doctor, complete *n* for the following:	NR	NR
Consultant (attending)		
Registrar (chief resident)		
SHO (resident)		
HO (intern)		
Practitioners (*n*) in analysis	NR	NR

Inclusion criteria: All physicians treating patients at either the Ireland Army Community Hospital and Clinic, Fort Knox, KY, USA, or Mayport Branch Health Clinic, Mayport, FL, USA. No further inclusion criteria were reported

Exclusion criteria: NR

Patient baseline demographics

Inclusion criteria: Patients ≥18 years with scheduled appointments, who could speak and read English, were not scheduled for obstetric care, and who had no emergency medical condition and who had not completed a previous Coupler session

Exclusion criteria: NR

	Intervention group	**Control group**
Age (mean; SD)	34.4 ± 10.4	35.3 ± 11.0
Gender (female *n*; %)	593 (63.4)	587 (60.8)
Visit type (*n*: %)		
Acute	383 (40.9)	416 (43.1)
Established	47 (5.0)	27 (2.8)
Routine	365 (39.0)	375 (38.8)
Wellness	126 (13.5)	139 (14.4)
Other	15 (1.6)	9 (0.9)

Interventions

Intervention: OCS plus Coupler. Couplers were available for a wide range of preventive health-care needs and conditions or management of acute conditions. Patients completed the Coupler appropriate for their complaint, or when no condition-specific Coupler was appropriate, a generic history and screening Coupler. Physicians treating Coupler patients could enter additional information before reviewing Coupler outputs. Data only extracted on the seven outcomes using either laboratory tests or imaging

Comparator: OCS alone (usual care)

Concomitant interventions: NA

CDSS tool

Name of CDDS (if any)	DSIT tool Problem-Knowledge Couplers (PKC Corp, Burlington, VT, USA)
CDSS reasoning method	NR
CDSS knowledge base	NR
Did study use training set and test set data?	Training set: NR Test set: NR

For training set data complete the following:

Design	NR	
Target decision	NR	
Sample characteristics:	**Intervention**	**Control**
Sample size (*n*)	NR	NR
Age (mean; range)	NR	NR
Gender (*n* male; *n* female)	NR	NR
Disease type	NR	NR

For test set data complete the following:

Properties of test set data	NR
Test centre	NR
Target decision	NR

Other CDSS information

1. Information used in CDSS [number of items; signs; symptoms; history; biochemical tests (list)]	Patients entered their medical histories into the appropriate Coupler tool for their complaint
2. Time to complete the CDSS (minutes)	30

3. CDSS output format: (score; probability graph; advice; etc.)	Advice
4. Is a description of pilot testing with users prior to implementation provided?	No
5. Is user instructional training at the time of implementation described?	No
6. Is the CDSS integrated with charting or OCS to support workflow integration?	Yes
7. Is automatic provision of CDSS output provided as part of clinician workflow?	Yes
8. Is there a need for additional data entry by the clinician?	No, but physician could enter additional information if necessary
9. Does the CDSS request documentation of the reason for not following CDSS recommendations?	Unclear
10. Does CDSS provide output at the time and location of decision making?	Yes
11. Are the CDSS recommendations executed by the clinician noting agreement?	Unclear
12. Does the CDSS provide a recommendation rather than just an assessment?	Unclear
13. Does the CDSS promote action rather than inaction?	Unclear
14. Does the CDSS justify the output by provision of reasoning?	Unclear
15. Does the CDSS justify the output by provision of research evidence?	Unclear
16. Were local users involved in the CDSS development process?	No
17. Is the CDSS output provided to patients as well as clinician?	Unclear
18. Does the CDSS provide periodic summaries of performance feedback? (yes; no; unclear)	Unclear
19. Is the CDSS used in conjunction with conventional education?	No

Outcome measures

Outcome 1: Number of health-care opportunities fulfilled within 60 days of index visit (data extracted for laboratory and radiology test screening only)

Outcome 2: Laboratory test resource consumption within 60 days of index visit

Outcome 3: Diagnostic imaging test resource consumption within 60 days of index visit

Total length of follow-up: 60 days

Follow-up assessment times: 60 days

Rate of attrition at each follow-up time: 74.9% (77% intervention group; 72.9% control group). In intervention group 15.3% had missing/incomplete medical records at index visit, 6% had no health-care opportunity at index visit and 1.7% had missing/incomplete medical records for 60-day follow-up. In control group 16.8% had missing/incomplete medical records at index visit, 7.9% had no health-care opportunity at index visit and 2.5% had missing/incomplete medical records for 60-day follow-up

Methods of statistical analysis: Likelihood of health-care opportunities being fulfilled was compared using a Mantel-Haenszel chi-squared test of homogeneity, stratified by physician and adjusted for clustering by patient. Dollar values for laboratory and diagnostic imaging test resource consumption were taken from the Centers for Medicare and Medicaid Services 2003 fee schedule using a relative value unit conversion rate of US$36.7856. Where not coded in the Composite Healthcare System, Current Procedural Terminology codes were assigned for the midlevel service for each visit type. Differences in median resource use between groups was compared using Wilcoxon rank-sum of equality of distribution

Results

Outcome 1: Number of health care opportunities fulfilled within 60 days of index visit (data extracted for laboratory and radiology test screening only)

Opportunity type	OCS + Coupler	OCS alone	Difference between groups
Cervical cancer	26/95 (27.4%)	22/98 (22.4%)	$p = 0.47$
Chlamydia	22/73 (30.1%)	19/64 (29.7%)	$p = 0.90$
Colorectal cancer	4/32 (12.5%)	2/58 (3.4%)	$p = 0.15$
Lipids	13/49 (26.5%)	18/48 (37.5%)	$p = 0.32$
Back pain imaging	4/4 (100%)	2/2 (100%)	NA
Diabetes – glycosylated haemoglobin	3/6 (50%)	1/3 (33.3%)	$p = 0.48$
Lipid abnormalities	12/66 (18.2%)	11/69 (15.9%)	$p = 0.81$

NA, not available.

Outcome 2: Laboratory test resource consumption within 60 days of index visit			
Intervention	OCS + Coupler	OCS alone	Difference between groups
Median (interquartile range US$)	43 (0–144)	31 (0–139)	$p = 0.04$
Outcome 3: Diagnostic imaging test resource consumption within 60 days of index visit			
Intervention	OCS + Coupler	OCS alone	Difference between groups
Median (interquartile range US$)	31 (0–148)	29 (0–127)	$p = 0.26$
Authors' conclusions: The results provide no strong evidence to support the utility of this decision-support tool, but the study demonstrates the value of rigorous evaluation of decision-support information technology			
Methodological assessment criteria (Apkon) (2005)[97]			
1. Is the study properly randomised?			Unclear
2. Is allocation of treatment concealed?			Unclear
3. Were the study eligibility criteria specified?			Yes
4. Are adequate baseline details presented?			Yes
5. Are groups similar at baseline?			Yes
6. Are any baseline imbalances adequately adjusted for in the analysis?			NA
7. Are similar cointerventions administered?			NA
8. Are physician's blinded to treatment allocation?			No
9. Are outcome assessors blinded?			Unclear
10. Are data analyses appropriate?			Yes
11. Is analysis conducted on an 'intention to provide or communicate information' basis?			No
12. Are greater than 80% of physicians/patients included in the follow-up assessment?			No
13. Are the conclusions supported by the results?			Yes
Comments: contamination likely as patients are the unit of randomisation and physicians at both sites treatment Coupler and usual care groups			

Study demographics

Author; year; study ID: Bassa (2005)[98]

Title: Impact of a clinical decision support system on the management of patients with hypercholesterolemia in the primary health care setting

Country: Spain

Specific setting: Vila Olimpica Primary Health Care Centre, Barcelona, Spain

Study objectives: To assess the impact on the effectiveness and costs of a practice guideline implemented through a clinical decision support system for the management of patients with hypercholesterolemia in the primary health-care setting

Health-care setting: Primary care

If secondary care, academic status of the hospital: NA

Health-care system: Private model of management

Study design: Pre–post

Number of sites: One

Funding source: Private sector (Novartis Pharmaceuticals)

Was evaluator of tool also its developer? No

System users

CDSS user(s)[a]	Physicians
Practitioners (*n*)	NR

[a] No further baseline details were reported on study physicians.

Inclusion criteria: Physicians treating study eligible participants during the post-intervention study phase

Exclusion criteria: NR

Patient baseline demographics

Inclusion criteria: Patients with hypercholesterolemia randomly selected from the practice database

Exclusion criteria: NR

N	500
Age; median (IQR)	67 (14)
Gender (female, %)	329 (65.8%)
Diabetes mellitus (*n*; %)	90 (18%)
Current smoker (*n*; %)	83 (16.6%)
Sedentary lifestyle (*n*; %)	262 (52.4%)
Number of CVRFs	
None (*n*; %)	22 (4.4%)
One (*n*; %)	174 (34.8%)
Two (*n*: %)	267 (53.4%)
More than two (*n*; %)	37 (7.4%)

IQR, interquartile range; CVRF, cardiovascular risk factors.

Interventions

Intervention: OCS plus CDSS (recommendations). The CDSS recommendations were based on the SEMFYC clinical guidelines for dyslipidemia management and cost-effectiveness data published in a meta-analysis [Cobos and colleagues (1999)[218]]. Based on the patient's data (personal history of cardiovascular disease, cardiovascular risk factors, and lipid profile), the CDSS established the therapeutic objectives in terms of LDL and issued therapeutic and follow-up recommendations for the patient. The therapeutic recommendations included dietary treatment and lipid-lowering drugs. The follow-up recommendations included the monitoring of hepatic and muscular enzymes and a recommended date for the subsequent control visit

Physicians were free to accept or decline the recommendations issued by the CDSS, but were prompted for a reason when they declined

To estimate the costs in the pre- and post-intervention periods, the consumption of the following resources was considered: (1) the number of physician visits related to the management of hypercholesterolemia, (2) the number of laboratory assessments (lipid profile, transaminases, and muscular enzymes), (3) lipid-lowering drugs prescribed. The unit cost used for cost estimation were obtained from the SOIKOS database of health-care costs and were set to €12 for visits, €0.46 for total cholesterol, €2 for LDL, €3 for HDL, €4 for triglycerieds, €15 for creatine kinase, €1 for serum glutamic oxaloacetic transaminase, and €1 for serum glutamic pyruvic transaminase. Costs were estimated from the societal perspective (year of costing 2002)

Comparator: OCS alone (pre-intervention)

Concomitant interventions: NA

CDSS tool

Name of CDDS (if any)	NR
CDSS reasoning method	Clinical algorithm
CDSS knowledge base	SEMFYC clinical guidelines for dyslipidemia management and cost-effectiveness data published in a meta-analysis
Did study use training set and test set data?	Training set: NR Test set: NR

SEMFYC, Sociedad Española de Medicina de Familia y Comunitania's.

For training set data complete the following:

Design	NR
Target decision	NR
Sample characteristics:	
Sample size (*n*)	NR
Age (mean; range)	NR
Gender (*n* male; *n* female)	NR
Disease type	NR

For test set data complete the following:

Properties of test set data	NR
Test centre	NR
Target decision	NR

Other CDSS information

1. Information used in CDSS [number of items; signs; symptoms; history; biochemical tests (list)]	History of cardiovascular (CV) disease; CV risk factors and lipid profile
2. Time to complete the CDSS (minutes)	NR
3. CDSS output format: (score; probability graph; advice; etc.)	Recommendation
4. Is a description of pilot testing with users prior to implementation provided?	No
5. Is user instructional training at the time of implementation described?	No
6. Is the CDSS integrated with charting or OCS to support workflow integration?	Yes
7. Is automatic provision of CDSS output provided as part of clinician workflow?	Yes
8. Is there a need for additional data entry by the clinician?	No
9. Does the CDSS request documentation of the reason for not following CDSS 9?	Yes
10. Does CDSS provide output at the time and location of decision making?	Yes
11. Are the CDSS recommendations executed by the clinician noting agreement?	No
12. Does the CDSS provide a recommendation rather than just an assessment?	Yes
13. Does the CDSS promote action rather than inaction?	NR
14. Does the CDSS justify the output by provision of reasoning?	No
15. Does the CDSS justify the output by provision of research evidence?	No
16. Were local users involved in the CDSS development process?	NR
17. Is the CDSS output provided to patients as well as clinician?	No
18. Does the CDSS provide periodic summaries of performance feedback?	No
19. Is the CDSS used in conjunction with conventional education?	No

Outcome measures

Outcome 1: Number of lipid-profile tests carried out in pre- and post-intervention periods

Outcome 2: Mean costs of lipid profile and safety analyses (transaminases and muscular enzymes) tests carried out pre- and post-intervention periods

Total length of follow-up: 2 years (pre-intervention 1 year; post- intervention 1 year). Study period: October 1998 to October 2000

Follow-up assessment times: 2 years

Rate of attrition at each follow-up time: 19.2% (96/500 patients). None of the 96 patients had an LDL assessment after the beginning of the intervention. For 62 of these patients, the CDSS had recommended to carry out the following control after 1–5 years because they were low-risk. The remaining 36 patients (7.2% from initial sample) were lost to follow-up

Methods of statistical analysis: Difference in the pre- and post-intervention periods were compared using the McNemar test for dichotomous variables and the Wilcoxon test for continuous variables. Paired *t*-test was used to compare pre- and post-intervention cost data without any transformation

Results

Outcome 1: Number of lipid-profile tests carried out in pre- and post-intervention periods

Pre-intervention (*n*)	**Post-intervention (*n*)**	***p*-value**
773	763	$p = 0.59$

Outcome 2: Mean costs of lipid profile and safety analyses (transaminases and muscular enzymes) tests carried out pre- and post-intervention periods (euros)

Pre-intervention	**Post-intervention**	**Difference (95% CI)**	***p*-value[a]**
41.8	47.2	5.4 (2.0 to 8.7)	$p = 0.0017$

a Paired *t*-test.

Authors' conclusions: The results of the present study suggest that it is possible to optimise the efficiency of the management of hypercholesterolemia in standard practice by the implementation of a CDSS	
Methodological assessment criteria (Bassa) (2005)[98]	
1. Were the study eligibility criteria specified?	Yes
2. Are adequate baseline details presented?	Partial
3. Are similar cointerventions administered in both study periods?	NA
4. Are data analyses appropriate?	Yes
5. Is analysis conducted on an 'intention to provide or communicate information' basis?	No
6. Are greater than 80% of physicians/patients included in the follow-up assessment?	80% of patients included in follow-up
7. Are the conclusions supported by the results?	Yes
Comments: Very few relevant outcomes that could be extracted with only minimal data	

Study demographics

Author; year; study ID: Sanders (2001)[104]

Title: The effects on clinician ordering patterns of a computerized decision support system for neuroradiology imaging studies

Country: USA

Specific setting: Vanderbilt University Medical Center (630 bed academic hospital with approximately 31,000 admissions per year)

Study objectives: To evaluate the impact of computerised ordering guidelines on clinical (clinician) ordering patterns for neuroradiology imaging studies of the head

Health-care setting: Secondary care (inpatient)

If secondary care, academic status of the hospital: University

Health-care system: NR

Study design: Pre–post

Number of sites: One

Funding source: Public sector

Was evaluator of tool also its developer? Yes

System users

CDSS user(s)	Physicians; nurses; medical students; receptionists; other (unspecified)
Practitioners (*n*)	NR

Orders entered by user type at baseline

User type[a]	*n*	%
Medical doctor	617	83%
Nurse	102	14%
Receptionist	14	2%
Medical student	3	<1%
Other	6	1%
Total	742	100%

a Staff who were not medical doctors had the ability to enter verbal or written orders from physicians.

Inclusion criteria: All users who entered an order via WizOrder for one or more head CT or brain MRI imaging examinations on inpatients during the study period

Exclusion criteria: NR

Patient baseline demographics

Inclusion criteria: All inpatients who had a head CT or brain MRI imaging examination ordered via WizOrder in the study period[a]

Exclusion criteria: NR

a No further data on patient baseline demographics was reported.

Interventions

Intervention: OCS plus CDSS. A list of common indications for ordering an imaging examination of the head or brain was created and mapped to ICD-9 codes. For each indication, the most appropriate imaging test was determined. The CDSS required input of the patients' acuity and indication by the user and provided a recommended test (head CT without contrast; head CT with contrast; head CT with and without contrast; brain MRI without contrast; and brain MRI with and without contrast). If a suggestion was given, this choice was defaulted. The user was able to override the recommendation and select any of the listed studies but had to type the reason for doing so. If no indication for requesting the test was given by the user or 'other' was chosen, no CDSS recommendation was provided

Comparator: OCS alone (pre-intervention)

Concomitant interventions: NA

CDSS tool

Name of CDDS (if any)	WizOrder (home-grown system Vanderbilt University Medical Center)
CDSS reasoning method	NR
CDSS knowledge base	Prior free indications at the time of order entry, historical ICD-9 coding data and Local Medical Review Policy published guidelines
Did study use training set and test set data?	Training set: NR Test set: NR

For training set data complete the following:

Design	NR
Target decision	NR
Sample characteristics:	
Sample size (*n*)	NR
Age (mean; range)	NR
Gender (*n* male; *n* female)	NR
Disease type	NR

For test set data complete the following:

Properties of test set data	NR
Test centre	NR
Target decision	NR

Other CDSS information

1. Information used in CDSS [number of items: signs; symptoms; history; biochemical tests (list)]	4
2. Time to complete the CDSS (minutes)	NR
3. CDSS output format: (score; probability graph; advice; etc.)	Recommendation
4. Is a description of pilot testing with users prior to implementation provided?	No
5. Is user instructional training at the time of implementation described?	No
6. Is the CDSS integrated with charting or OCS to support workflow integration?	Yes
7. Is automatic provision of CDSS output provided as part of clinician workflow?	Yes
8. Is there a need for additional data entry by the clinician?	No
9. Does the CDSS request documentation of the reason for not following CDSS recommendations?	Yes
10. Does CDSS provide output at the time and location of decision making?	Yes
11. Are the CDSS recommendations executed by the clinician noting agreement?	No
12. Does the CDSS provide a recommendation rather than just an assessment?	Yes
13. Does the CDSS promote action rather than inaction?	NR
14. Does the CDSS justify the output by provision of reasoning?	No
15. Does the CDSS justify the output by provision of research evidence?	No
16. Were local users involved in the CDSS development process?	Unclear

17. Is the CDSS output provided to patients as well as clinician?	No
18. Does the CDSS provide periodic summaries of performance feedback?	No
19. Is the CDSS used in conjunction with conventional education?	No

Outcome measures

Outcome 1: Number of tests ordered pre- and post-intervention

Outcome 2: Number of orders complying with the recommendation

Total length of follow-up: 17 weeks (9 weeks pre-intervention, 8 weeks post-intervention) (study conducted between 30 September 2000 and 30 January 2001)

Follow-up assessment times: 17 weeks

Rate of attrition at each follow-up time: NA

Methods of statistical analysis: Chi-squared tests were performed to evaluated changes in the distribution of ordering patterns

Results

Outcome 1: Number of tests ordered pre-and post- intervention (by user type)

User type[a]	**Pre- (*n*; %)**	**Post- (*n*; %)**	***p*-value**
MD	617 (83%)	596 (85%)	NR
Nurse	102 (14%	84 (12%)	NR
Receptionist	14 (2%)	18 (3%)	NR
Medical student	3 (<1%)	3 (<1%)	NR
Other	6 (1%)	3 (<1%)	NR
Total	742 (100%)	704 (100%)	0.048

a Staff who were not MD had the ability to enter verbal or written orders from physicians.

Outcome 2: Number of orders complying with the recommendation

N in analysis	551
Orders complying with recommendation (*n*; %)	328 (60%)
Orders not complying with recommendation (*n*; %)	223 (40%)

Authors' conclusions: This study was successful in showing that a computerised implementation of guidelines for head and brain imaging studies influenced ordering patterns

Methodological assessment criteria (Sanders) (2001)[104]

1. Were the study eligibility criteria specified?	Yes
2. Are adequate baseline details presented?	Partial
3. Are similar cointerventions administered in both study periods?	NA
4. Are data analyses appropriate?	Yes
5. Is analysis conducted on an 'intention to provide or communicate information' basis?	Yes
6. Are greater than 80% of physicians/patients included in the follow-up assessment?	Yes
7. Are the conclusions supported by the results?	Yes

Comments: None

Study demographics

Author; year; study ID: Nightingale (1994)[99]

Title: Effects of a computerised protocol management system on ordering of clinical tests

Country: UK

Specific setting: Supraregional Liver Unit, The Queen Elizabeth Hosptial, Birmingham, UK

Study objectives: To assess the effects of a computerised protocol management system on the number, cost, and appropriateness of laboratory investigations requested

Health-care setting: Secondary and tertiary (inpatients)

If secondary care, academic status of the hospital: Teaching

Health-care system: NHS

Study design: Pre–post

Number of sites: 1

Funding source: NR

Was evaluator of tool also its developer? Yes

System users

CDSS user(s)[a]	Physicians
Practitioners (*n*)	NR

a No further baseline details were reported on study physicians.

Inclusion criteria: All physicians on the unit within the study period

Exclusion criteria: NR

Patient baseline demographics

Inclusion criteria: All patients admitted to the unit during the study period

Exclusion criteria: NR

N (%) of patients

Patient category	Pre-intervention	Post-intervention
Initial assessment	177 (27%)	153 (18%)
Reassessment (routine)	33 (5%)	67 (8%)
Reassessment (problem)	30 (5%)	45 (5.5%)
Transplant	106 (16%)	112 (13.5%)
Post-transplant (problem)	84 (13%)	112 (13.5%)
Post-transplant (t tube removal)	41 (6%)	48 (6%)
Post-transplant (annual review)	86 (13%)	146 (18%)
Emergency (acute hepatic failure)	39 (6%)	62 (7.5%)
Emergency (acute problem – chronic disease)	32 (5%)	19 (2%)
Other	26 (4%)	69 (8%)
Total	654 (100%)	833 (100%)

Interventions

Intervention: OCS plus CDSS. The CDSS used the latest available test results along with the clinical categories applicable to the patient to propose the test investigations to be performed on the following day. The system was based upon a combination of static and dynamic rules. Static rules were those that applied to all patients with a certain classification for a certain number of days, and dynamic rules were those which used the results of previous laboratory results to determine which investigations to propose

Once the physician had viewed the proposed tests they were free to accept or modify them as required

Comparator: OCS alone (pre-intervention)

Concomitant interventions: NA

CDSS tool

Name of CDDS (if any)	NR (home-grown system developed by the Wolfson Computer Laboratory, Queen Elizabeth Hospital, Birmingham, UK)

CDSS reasoning method	Discrimination rules	
CDSS knowledge base	Protocol developed by Senior Clinicians	
Did study use training set and test set data?	Training set: No Test set: No	
For training set data complete the following:		
Design	NR	
Target decision	NR	
Sample characteristics:		
Sample size (*n*)	NR	
Age (mean; range)	NR	
Gender (*n* male; *n* female)	NR	
Disease type	NR	
For test set data complete the following:		
Properties of test set data	NR	
Test centre	NR	
Target decision	NR	
Other CDSS information		
1. Information used in CDSS [number of items; signs; symptoms; history; biochemical tests (list)]		NR (signs; symptoms; history, biochemical tests)
2. Time to complete the CDSS (minutes)		NR
3. CDSS output format: (score; probability graph; advice; etc.)		Advice
4. Is a description of pilot testing with users prior to implementation provided?		No
5. Is user instructional training at the time of implementation described?		Yes
6. Is the CDSS integrated with charting or OCS to support workflow integration?		Yes
7. Is automatic provision of CDSS output provided as part of clinician workflow?		Yes
8. Is there a need for additional data entry by the clinician?		Yes
9. Does the CDSS request documentation of the reason for not following CDSS recommendations?		No
10. Does CDSS provide output at the time and location of decision making?		Yes
11. Are the CDSS recommendations executed by the clinician noting agreement?		No
12. Does the CDSS provide a recommendation rather than just an assessment?		Yes
13. Does the CDSS promote action rather than inaction?		NR
14. Does the CDSS justify the output by provision of reasoning?		No
15. Does the CDSS justify the output by provision of research evidence?		No
16. Were local users involved in the CDSS development process?		Yes
17. Is the CDSS output provided to patients as well as clinician?		No
18. Does the CDSS provide periodic summaries of performance feedback?		Yes
19. Is the CDSS used in conjunction with conventional education?		No

Outcome measures

Outcome 1: Total number of tests requested per patient day (pre- and post-intervention)

Outcome 2: Number of out of hours tests requested per patient day (pre- and post-intervention)

Outcome 3: Direct laboratory costs per patient day (pre- and post-intervention)

Outcome 4: Number of plasma urea and electrolyte tests, liver function tests, bone profile, calcium and other tests requested per patient day (pre- and post-intervention)

Total length of follow-up: 2 years (pre-intervention 1 year; post-intervention 1 year). Study period: January 1990 to December 1991

Follow-up assessment times: 2 years

Rate of attrition at each follow-up time: NA

Methods of statistical analysis: Comparison between pre- and post-intervention periods were made using 2-sample Student's *t*-tests or Mann-Whitney *U*-tests. Direct costs of laboratory tests were calculated by the methods of Broughton and Hogan[219]

Results

Outcome 1: Total number of tests requested per patient day (pre- and post-intervention)

Patient category	Pre-[a]	Post-[a]	% change	Student's *t*-statistic
Initial assessment	7.1 (2.9)	5.4 (3.0)	–25	5.23[d]
Reassessment (routine)	4.8 (2.7)	3.7 (2.7)	–22	1.92
Reassessment (problem)	7.7 (2.1)	6.3 (2.3)	–19	2.67[c]
Transplant	11.0 (2.8)	9.6 (3.3)	–13	3.37[d]
Post-transplant (problem)	7.8 (2.5)	6.9 (2.3)	–11	2.62[c]
Post transplant (t tube removal)	6.6 (4.0)	5.0 (2.1)	–25	2.41[b]
Post-transplant (annual review)	7.4 (4.1)	6.6 (2.9)	–12	1.73
Emergency (acute hepatic failure)	6.7 (3.8)	7.8 (4.0)	+17	1.37
Emergency (acute problem – chronic disease)	11.1 (4.2)	8.0 (4.1)	–28	2.57[b]
Other	6.2 (4.3)	5.5 (4.1)	–11	0.73
Overall	8.5 (3.6)	7.0 (3.5)	–17	8.10[d]

a Mean (standard deviation) values.

b $p < 0.05$.

c $p < 0.01$.

d $p < 0.001$.

Outcome 2: Number of out of hours tests requested per patient day (pre- and post-intervention)

Pre-intervention (*n*;%)	Post-intervention (*n*;%)	% change	*p*-value
0.31	0.16	–48	$p < 0.001$

Outcome 3: Direct laboratory costs per patient day (pre- and post-intervention)

Patient category	Pre-[a]	Post-[a]	% change	Mann-Whitney statistic
Initial assessment	2.54 (1.37–4.61)	2.46 (1.54–3.83)	–3	0.21
Reassessment (routine)	0.35 (0.21–0.94)	0.76 (0.21–1.94)	+117	1.38
Reassessment (problem)	1.67 (1.21–2.25)	0.83 (0.38–1.23)	–50	3.24[c]
Transplant	2.84 (1.94–4.18)	2.51 (1.86–3.42)	–12	1.46

Post-transplant (problem)	1.65 (1.03–2.37)	1.43 (0.78–1.90)	–13	2.44[b]
Post transplant (t tube removal)	1.16 (0.91–1.52)	0.72 (0.60–1.34)	–38	3.09[c]
Post-transplant (annual review)	1.29 (0.91–1.43)	0.86 (0.74–1.29)	–33	5.50[d]
Emergency (acute hepatic failure)	2.34 (0.91–3.77)	1.68 (0.60–2.56)	–28	1.74
Emergency (acute problem – chronic disease)	2.92 (1.93–5.59)	2.44 (0.92–3.49)	–16	1.20
Other	0.00 (0.00–1.16)	0.12 (0.00–1.19)	NR	0.10
Overall	1.79 (0.94–2.96)	1.29 (0.71–2.37)	–28	6.86[d]

a Median (interquartile range) values.

b $p < 0.05$.

c $p < 0.01$.

d $p < 0.001$.

Outcome 4: Number of plasma urea and electrolyte tests, liver function tests, bone profile, calcium and other tests requested per patient day (pre- and post-intervention)

Requests	**Pre-[a]**	**Post-[a]**	**% change**	**Mann-Whitney statistic**
Plasma urea and electrolytes	0.67 (0.42–0.95)	0.56 (0.33–0.83)	–16	2.32b
Liver function tests	0.60 (0.39–0.88)	0.50 (0.33–0.80)	–17	1.92
Bone profile	0.40 (0.17–0.67)	0.00 (0.00–0.10)	–100	18.4c
Calcium	0.50 (0.33–0.72)	0.07 (0.00–0.25)	–86	16.3c
Others	1.27 (0.50–2.67)	1.38 90.33–3.14)	+9	0.32

a Median (interquartile range) values.

b $p < 0.05$.

c $p < 0.001$.

Authors' conclusions: Use of the computerised protocol management system resulted in closer compliance with the protocols and a significant reduction in the overall level of requesting

Methodological assessment criteria (Nightingale) (1994)[99]

1. Were the study eligibility criteria specified?	Yes
2. Are adequate baseline details presented?	Yes
3. Are similar cointerventions administered in both study periods?	NA
4. Are data analyses appropriate?	Yes
5. Is analysis conducted on an 'intention to provide or communicate information' basis?	Yes
6. Are greater than 80% of physicians/patients included in the follow-up assessment?	Yes
7. Are the conclusions supported by the results?	Yes

Comments: None

Study demographics

Author; year; study ID: Boon-Falleur (1995)[100]

Title: A rule-based decision support application for laboratory investigations management

Country: Belgium

Specific setting: Paediatric Liver Transplantation Unit, Cliniques Universitaires Saint-Luc, Université catholique de Louvain, Brussels, Belgium

Study objectives: To assess the impact of a rule-based expert system for clinical laboratory investigations management in a paediatric liver transplantation unit

If secondary care, academic status of the hospital: University

Health-care system: NR

Study design: Pre–post

Number of sites: One

Funding source: NR

Was evaluator of tool also its developer? No

System users

CDSS user(s)[a]	Physicians
Practitioners (*n*)	NR

a No further baseline details were reported on study physicians.

Inclusion criteria: All physicians on the unit within the study period treating patients with either an assessment protocol or immediate post-transplant monitoring protocol

Exclusion criteria: NR

Patient baseline demographics[a]

Inclusion criteria: All patients admitted to the unit during the study period who were classified as managed by either an assessment protocol or immediate post-transplant monitoring protocol

Exclusion criteria: NR

a No further baseline details were reported on study patients.

Interventions

Intervention: OCS plus CDSS. The CDSS used the latest available test results along with the clinical categories applicable to the patient to propose the test investigations to be performed on the following day. The system was based upon a combination of static and dynamic rules. Static rules were those that applied to all patients with a certain classification for a certain number of days, and dynamic rules were those which used the results of previous laboratory results to determine which investigations to propose. The parameters evaluated by the rules were current patient status, current and previous test(s) results including trend analysis, and previous proposals. All patients classified according to the clinical categories as being eligible to be managed by either the assessment protocol or immediate post-transplant monitoring protocol were included in the study

Once the physician had viewed the proposed tests they were free to amend them by adding or removing requests from the proposed schedule

Comparator: OCS alone (pre-intervention)

Concomitant interventions: NA

CDSS tool

Name of CDDS (if any)	NR (home-grown system developed by the Wolfson Computer Laboratory, Queen Elizabeth Hospital, Birmingham, UK)
CDSS reasoning method	Discrimination rules
CDSS knowledge base	Protocol developed by senior clinicians
Did study use training set and test set data?	Training set: No Test set: No

For training set data complete the following:

Design	NR
Target decision	NR

Sample characteristics:			
Sample size (*n*)	NR		
Age (mean; range)	NR		
Gender (*n* male; *n* female)	NR		
Disease type	NR		
For test set data complete the following:			
Properties of test set data	NR		
Test centre	NR		
Target decision	NR		
Other CDSS information			
1. Information used in CDSS [number of items; signs; symptoms; history; biochemical tests (list)]	NR (signs; symptoms; history, biochemical tests)		
2. Time to complete the CDSS (minutes)	NR		
3. CDSS output format: (score; probability graph; advice; etc.)	Advice		
4. Is a description of pilot testing with users prior to implementation provided?	No		
5. Is user instructional training at the time of implementation described?	No		
6. Is the CDSS integrated with charting or OCS to support workflow integration?	Yes		
7. Is automatic provision of CDSS output provided as part of clinician workflow?	Yes		
8. Is there a need for additional data entry by the clinician?	Yes		
9. Does the CDSS request documentation of the reason for not following CDSS recommendations?	No		
10. Does CDSS provide output at the time and location of decision making?	Yes		
11. Are the CDSS recommendations executed by the clinician noting agreement?	No		
12. Does the CDSS provide a recommendation rather than just an assessment?	Yes		
13. Does the CDSS promote action rather than inaction?	NR		
14. Does the CDSS justify the output by provision of reasoning?	No		
15. Does the CDSS justify the output by provision of research evidence?	No		
16. Were local users involved in the CDSS development process?	No		
17. Is the CDSS output provided to patients as well as clinician?	No		
18. Does the CDSS provide periodic summaries of performance feedback?	No		
19. Is the CDSS used in conjunction with conventional education?	No		
Outcome measures			
Outcome 1: Number of tests per patient – assessment protocols (pre- and post-intervention)			
Outcome 2: Number of tests per patient – transplant protocols (pre- and post-intervention)			
Outcome 3: Number of urgently requested tests per patient (pre- and post-intervention)			
Total length of follow-up: Unclear (6 month pre-intervention baseline conducted between June and December 1993. Post-intervention from March 1994; length not reported)			
Follow-up assessment times: Unclear			
Rate of attrition at each follow-up time: NA			
Methods of statistical analysis: NR			
Results			
Outcome 1: Number of tests per patient – assessment protocols			
Test category	**Pre- (*n* = 32)**	**Post- (*n* = 151)**	Δ%
General chemistry	46	53	15%
Virology	22	18	–18%
Haematology and coagulation	23	30	30%
Others	13	19	46%

Total	106	120	13%
Outcome 2: Number of tests per patient – transplant protocols			
Test category	**Pre- (*n* = 10)**	**Post- (*n* = 24)**	Δ%
General chemistry	368	273	–26%
Virology	70	49	–30%
Haematology and coagulation	345	268	–22%
Others	264	178	–33%
Total	1047	768	–27%

Outcome 3: Number of urgently requested tests per patient (mean)

Pre-	**Post-**	Δ%
65.0	36	–44%

Authors' conclusions: The system was perceived by the clinicians as increasing the overall benefits in use of clinical resources, improving the laboratory data management, and saving time for the execution of laboratory ancillary tasks

Methodological assessment criteria (Boon-Falleur) (1995)[100]

1. Were the study eligibility criteria specified?	Partial
2. Are adequate baseline details presented?	No
3. Are similar cointerventions administered in both study periods?	NA
4. Are data analyses appropriate?	Unclear
5. Is analysis conducted on an 'intention to provide or communicate information' basis?	Unclear
6. Are greater than 80% of physicians/patients included in the follow-up assessment?	Unclear
7. Are the conclusions supported by the results?	Yes

Comments: Study quality and level of reporting is poor. The presentation of results by the number of tests per patient, rather than the number of tests per patient per day, confounds length of stay with number of tests. Length of stay is not reported and therefore it is not possible to assess whether this was similar between the groups of patients in the pre- and post-intervention periods. Results should be interpreted with caution

Appendix 4

Responses to survey by CDSS manufacturers/suppliers

Manufacturer/ Supplier	Specific CDSS	Deployed in UK	Currently being implemented in UK	Number of sites	Sites where deployed
National					
AGFA Healthcare (UK) Ltd	NR	NR	NR	NR	NR
Atos Origin	NR	NR	NR	NR	NR
British Telecommunications plc	NR	NR	NR	NR	NR
Cerner Ltd	NR	NR	NR	NR	NR
CSE Servelec Ltd	RiO Care Records System	Yes	Yes	46 NHS organisations and 2 commercial companies including primary and secondary care, and mental health and learning disabilities	Across London and the south-east
FileTek UK Ltd	NR	NR	NR	NR	NR
Epic Systems Ltd	NR	No	No	NR	NR
Fujitsu Services Ltd	NR	NR	NR	NR	NR
ISoft plc	NR	NR	NR	NR	NR
Perot Systems Europe Ltd	NR	NR	NR	NR	NR
Siemens plc	NR	NR	NR	NR	NR
Steria Ltd [formerly known as Xansa (UK) Ltd]	NR	NR	NR	NR	NR
TATA Consultancy Services Ltd	NR	NR	NR	NR	NR
Specialist SME					
Adastra Software Ltd	NR	NR	NR	NR	NR
ALERT Life Sciences Computing, SA	NR	No	Will be implemented in one private hospital run by Circle Health by end 2009 and expects to interface with PAS, Pathology, PACS, and pharmacy stock control systems	1	NR
Oasis Medical Solutions Ltd (formerly known as Capula Healthcare Ltd)	NR	NR	NR	NR	NR
CAS Services Ltd (formerly known as Clinical Solutions Ltd)	NR	NR	NR	NR	NR

CSW Group Ltd	NR	NR	NR	NR	NR
Egton Medical Information Systems Ltd	NR	NR	NR	NR	NR
Infermed Ltd	NR	NR	NR	NR	NR
Map of Medicine (formerly known as Informa UK Ltd)	NR	NR	NR		NR
Plain Healthcare	Odyssey FacetoFace	Yes	Unclear	NR	NR
Sowerby Centre for Health Informatics at Newcastle Ltd	NR				
Stalis Ltd	NR	NR	NR	NR	NR

NR, not reported.

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The HTA programme and the authors would like to know your views about this report.

The Correspondence Page on the HTA website (www.hta.ac.uk) is a convenient way to publish your comments. If you prefer, you can send your comments to the address below, telling us whether you would like us to transfer them to the website.

We look forward to hearing from you.

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