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Review

Techniques to aid the implementation of novel clinical information systems: A systematic review

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ABSTRACT

Background: This systematic review identifies and evaluates techniques that aid the implementation of novel clinical information systems (CIS) within healthcare.
Methods: We searched electronic databases (MEDLINE, EMBASE, PsycINFO and HMIC Health Management Information Consortium). Desktop reviews for all potentially eligible studies were also conducted via reference lists and forward citation searches. 14,198 abstracts were identified through the initial electronic search. 63 articles were retained following title and abstract reviews, and submitted for full text evaluation. Of these, 18 papers met eligibility criteria.
Results: The 5 techniques that emerged from the review and that can assist CIS implementation were: system piloting, eliciting acceptance, use of simulation, training and education, and provision of incentives. These techniques were evaluated with a range of study endpoints (including system utilisation, clinical effectiveness, user satisfaction, attitudes towards system training, and attitudes towards implementation). Consideration of the clinical context in which the CIS was implemented was a consistent theme in the evidence-base.
Conclusions: Although some evidence is available for the effectiveness of the 5 implementation techniques found in this review, the variable endpoints and the non-comparable study designs mean that the evidencebase needs further developing. We discuss the potential role of simulation and clinical leadership, particularly in relation to surgeons, in CIS implementation and we propose practical advice for CIS implementation and evaluation within hospital settings.

1. Introduction

Since the early 1960s, clinical information systems (CIS) have been common within healthcare environments.[1] The term ‘clinical information system’ is generic; these systems, designed to support clinical processes and personnel, cover many different systems of relevance to surgeons and others – including electronic health records, picture archiving software, clinical prescription order entry software and more recently, dynamic forms of information provision such as clinical dashboards. CIS can improve the quality, safety and efficiency of patient care by providing easily accessible patient-related data and parameters for the continuous auditing and feedback on performance. To date, systematic reviews have shown that CIS can improve the quality of care. Benefits of CIS include enhanced surveillance and monitoring, reduction of medication errors, and improved information processing/communication by doctors to improve care processes and patient outcomes and reduce costs.[2–4]

Despite these positive features, wide implementation of CIS in hospitals has had limited success.[5,6] The failure rates of hospital IT systems are well documented, where delays and cancellations of software projects are reported to be endemic.[7] One example is the recent apparent failure of the UK's National Health Service Connecting For Health initiative, a project estimated to have cost in the region of £12 billion ($19.5 billion). Although the overall initiative did have some successes before being closed down by the incoming Government, the NHS National Programme for IT (NPfIT) was

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criticized, most notably in relation to failures to engage with clinicians during the initial design of systems.[8,9] Despite considerable investment of resources, problems associated with CIS implementation remain widespread, and new systems are often met with apathy or even hostility from doctors and nurses. This results in either low uptake or very partial implementation of these systems into clinical practice.[10] Furthermore, training staff to use novel CIS is a complex undertaking, which must address the varied skills of surgeons, physicians, nurses and managers or administrator users. The process of implementation may also increase workload as staff spend time learning a new system alongside their regular clinical tasks.

Current evidence suggests that, overall, CIS should be designed to accommodate clinical practice, rather than vice-versa. Clinical workflows and practice need to be carefully understood and used to shape the development of CIS in order that they do not impact negatively on clinical workflow.[11–14] Evidence also suggests that system design should involve clinicians, and recommends training on systems prior to implementation.[9–21] Less well understood, however, are the methods and techniques required to actually make the implementation of CIS 'successful' – defined in different ways across studies,[19,22–25] including how to maximize CIS utilization by healthcare users, how to engage clinical users, and how to assess CIS effectiveness, i.e. impact on clinical performance and processes.

The aim of this review was to identify the techniques that have been used to aid the implementation of CIS, and[19] to evaluate the impact that these techniques have had on the CIS implementation process.

2. Methods

2.1. Data sources and searches

An electronic database search was conducted using keywords and Medical Subject Headings (MeSH) in MEDLINE In-Process & Other Non-Indexed Citations and MEDLINE (1950 to July 2011), EMBASE Classic + EMBASE (1947 to July 2011), PsycINFO (1967 to July 2011) and HMIC Health Management Information Consortium. The review period began when electronic databases first became available, and the last publication examined was in March 2013. The search strategy for MEDLINE is presented in Appendix 1 (a similar strategy was used across the other databases, tailored as necessary). Reference lists and forward citation searches for all potentially eligible studies were also conducted.

2.2. Study selection and data extraction

We focussed on studies that directly assessed what impacts on the implementation process and its success. Studies considered eligible for the review contained:

i) a technique/strategy aimed at aiding the implementation process of a novel CIS within a healthcare context. This could include, for example, simulation techniques, information dissemination and staff training. The technique or strategy employed was required to be directly related to the CIS implementation.
ii) an evaluation of the technique, including primary data (e.g. observations, interviews, questionnaire data).

Risk of bias was assessed in line with recommended principles.[26] Papers that only described features of the design process, but not the implementation were excluded. Findings reported in the retrieved articles were recorded on a structured data extraction proforma for subsequent synthesis within evidence tables.

3. Results

3.1. Selected articles

The initial search yielded 14,198 abstracts. Two reviewers, with backgrounds in surgery and psychology independently reviewed 5% ($n = 750$) of the 14,198 abstracts for eligibility to establish inter-rater reliability. Agreement between the reviewers was high (Kappa = 0.77, $p < 0.001$). Screening based on article title and abstract resulted in 63 papers, which met inclusion criteria and were assessed in full text by the same independent reviewers. 18 papers were found to meet eligibility criteria and were included in the final evidence synthesis (Fig. 1).

3.2. Characteristics of included studies

The 18 articles that fulfilled the inclusion criteria are summarised in Table 1. The study designs and methods used were very diverse, ranging from informal approaches (such as engagement with users in training meetings[27]) and semi-structured methods (for instance *in situ* observations and medical record audits,[28–30] user feedback from training sessions,[31–34] interviews and surveys with clinical users[35–39]), to experimental approaches used in two of the retrieved studies (i.e. a prospective controlled study,[40] and a randomized crossover design[41]). Meta-analysis was therefore not feasible, as there were variable end-points and non-comparable study designs. The articles were therefore qualitatively reviewed and synthesised, and a number of firm general conclusions were drawn.

The studies were conducted in either (or both) primary and secondary care, but mainly in hospitals.[29,30,37–39,42] Two studies were specifically in emergency departments,[32,33] two in anaesthesia[40,41] and one each within oncology[43] and obstetrics.[31] Studies were also conducted in a primary care organisation,[28,36,38] nursing home,[35] and health maintenance organisation.[34] Finally, one study was conducted across both primary and secondary care settings.[44]

Most of the studies investigated the implementation of electronic health/patient records,[34,36,37,42,44] or clinical decision support systems.[31–33,40,41] Two of the studies focussed on telemedicine,[35,43] and one each for Computerised Physician Order Entry (CPOE),[30] electronic on-call packs,[27] electronic medication records,[29] and an electronic referral system.[38]

3.2.1. Implementation techniques and study endpoints

Table 2 provides an overview of the endpoints (subjective and objective) reported across studies in relation to the specific implementation techniques we found in these studies. Subjective user satisfaction with the system[27,31,33–36,42,43] and objective system utilisation (i.e., whether clinical staff actually used the system)[27,30,31,38,44] were the most salient endpoints. Five papers assessed surrogate measures of system effectiveness – including time to complete tasks on the CIS,[41] diagnostic accuracy using the CIS,[32,40] error rates using the CIS,[29] and perceived improvements in proficiency.[34] Further, one study assessed staff attitudes towards training,[34] and one study assessed staff attitudes towards system implementation.[37]

3.3. Techniques to aid CIS implementation

The key techniques to aid the implementation of CIS that were reported in the reviewed articles were *system piloting*,[27,28,35,36,38,39,43,44] *eliciting acceptance from users*,[30,31] *use of simulation*,[33,40,41] *training and education*,[29,32,34,37,42] and the *impact of incentives*.[30] Evidence on their effectiveness is summarised below:

3.3.1. System piloting

Eight papers specifically addressed system piloting. Six of these focussed upon user satisfaction with the system as the key indicator of successful CIS implementation,[27,35,36,38,43,44] while two articles investigated utilisation of CIS by healthcare staff,[38,44] and one assessed effectiveness via reduction in medication error rates.[28]

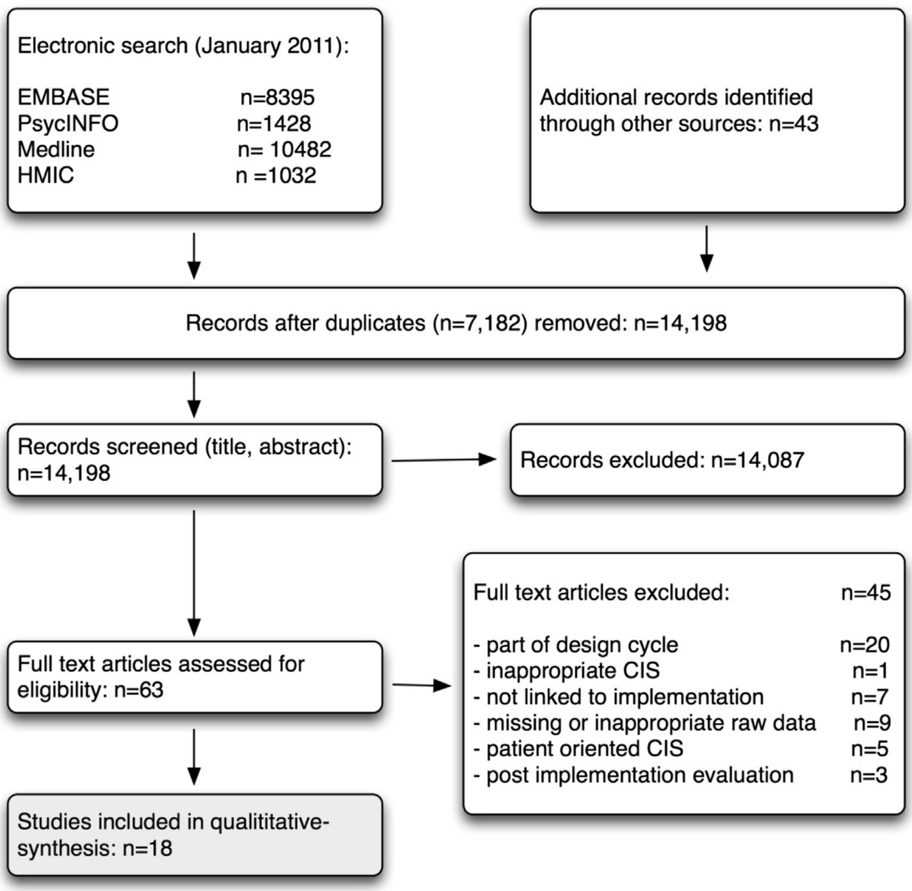

Fig. 1. Flow diagram for search strategy.

User satisfaction was on the whole positive in regards to CIS implementation,[27,38,43] with the exception of Dworkin et al.'s study where only 50% of staff were satisfied with the CIS.[36] One study prospectively assessed users' concerns and found a decrease over the duration of the pilot project (i.e., an improvement).[35] Satisfaction was typically assessed at one time point only, and thus comparisons between pre and post pilot implementation were not always feasible. However, in Armer et al.'s study, concerns about telemedicine were elicited prior to implementation, during implementation, and 12 months post-implementation, using multiple methods (e.g. interviews, observations, surveys). The authors noted that implementation is an ongoing process that varies over time, and thus recommended longitudinal evaluations.

Utilisation of CIS varied significantly between the two pilot studies identified in this review. Differences may be attributed to the type and scale of the care settings in which the pilot studies were conducted. Folz-Murphy et al. reported average levels of utilisation following the pilot with 48% of physicians actively using the system within a large-scale integrated healthcare system including a hospital, outpatient clinics and community-based clinics,[44] whereas Scott reported use within 80% of five general practices (i.e. in community settings) included in the pilot project.[38]

As denoted by markers of clinical effectiveness and improvements in medication error rates, Choi et al.'s pilot study indicated successful CIS implementation within the scope of their pilot-testing. For the authors, the decrease in error rates, combined with high levels of user satisfaction regarding the system were promising indicators of the success of their computerized order entry system.[28]

3.3.2. Eliciting users' acceptance

The importance of engaging closely with clinicians and overcoming user dissatisfaction was a key theme of Dagroso et al.'s research.[31] During the initial rollout phase of CIS implementation, clinicians identified problems with the CIS design and functionality, and expressed frustrations at how the design impeded their ability to use the application whilst seeing patients. Increasing user complaints lead the implementation team to question the feasibility of the system. Eventually, a formal announcement of dissatisfaction from clinical users lead to radical changes in system development. Receiving input from clinicians was therefore critical to the success of the programme. Techniques to increase acceptance included informing staff of system improvements, increasing awareness of the system, as well as promoting system use. After system changes, clinicians formally accepted the system. The effectiveness of these techniques was measured against system utilisation and an overall positive impact was found: reported utilisation increased by an average of 4% each month following attempts to foster acceptance. The highest level of system utilisation, reported at 17 months post-implementation, was 85%.

3.3.3. Simulation

Studies that combined simulation techniques with CIS implementation explored impact on clinical performance and processes. Berkenstadt et al. assessed anaesthesia residents' ability to diagnose and treat malignant hyperthemia using a point-of-care system.[40] They reported a positive effect of simulation techniques on clinical effectiveness, with significantly higher diagnostic accuracy in a group that used the novel electronic support system

(Mean = 21.5, Standard Deviation = 4.9) compared to controls who did not have the system (Mean = 15.5, Standard Deviation = 7.6; $p = 0.018$). Therefore, the point of care system improved the quality of treatment provided by the residents. In another study involving anaesthesia practitioners, Coopmans and Biddle evaluated the effect of computer-assisted decision making during simulated critical patient care events, by examining clinical accuracy (correct diagnosis and treatment) and speed of problem solving.[41] They found that the impact of a PDA was dependent on the clinical scenario used. Simple diagnostic decisions resulted in slower diagnosis and treatment decisions when using a PDA (21.33 s and 26.62 s, respectively) as compared to not using a PDA (13.48 s and 18.62 s, respectively). However, for more complicated (i.e. atypical) diagnostic decisions the opposite was found, with faster diagnosis and treatment when using the PDA (9.9 s and 12.53 s, respectively) than without using it (26.48 s and 29.84 s, respectively). Finally, Eley et al. aimed to provide clinical validation and assess user acceptance of a new decision support system via simulation.[33] In this study, approximately 87% of staff were positive about the system (including ease of use, high confidence using it, and high willingness to use it in their daily practice).

3.3.4. User Training and education

Findings on the impact of training on implementation were mixed.[29,32,34,37,42] Murphy et al. prospectively measured the impact of training on user acceptance,[42] and found that attitudes towards the system actually worsened significantly between pre-training (Mean = 3.62, Standard Deviation = 0.64) and post training (Mean = 3.30, Standard Deviation = 0.79; $p < 0.01$). This (surprising) decrease in acceptance was due to concerns over the length of time spent away from patient care and lack of physician 'buy in'. Three studies assessed training or education in relation to efficacy.[29,32,34] Kirshner et al. reported that one-to-one training resulted in advanced proficiency in the use of CIS.[34] Staff's self-perceived proficiency also increased following one-to-one training in 61.4% of clinicians. For a web-based triage decision support tool, Dong et al. found a trend towards improvements with additional training of nurse users.[32] Lemmetty et al. and Kirshner et al.'s studies assessed whether training in system usage improves users' satisfaction with the system – and overall, both studies found this to be the case.[34,37] In Kirshner et al.'s study one-to-one training methods were significantly preferred by clinicians above other teaching methods ($p < 0.001$). Lemmetty et al. compared attitudes towards implementation pre/post-training and reported a change in views from negative to positive in 48% of users who had negative views pre-training.[37]

3.3.5. Provision of incentives to users

One study assessed the impact of two incentives on implementation – small gifts and financial compensation for the time clinicians spent learning to use the new system.[30] Whereas small gifts had no effect, utilisation increased significantly from 35% to 57% when financial rewards were introduced ($p < 0.01$). Over time, however, financial rewards did not provide sustainable CIS use, as system utilisation dropped significantly within one month of withdrawal of the financial compensation scheme ($p < 0.01$).

4. Discussion

We systematically reviewed and evaluated techniques designed to aid successful CIS implementation. Defining what is a 'successful' CIS implementation proved to be a key component of our synthesis. Although the 'holy grail' is assumed to be actual system utilisation (and this, in turn, is really a process measure that should be ultimately linked to clinical outcomes), in terms of the key study endpoints cited in the literature, system utilisation featured in fewer papers than expected. Other measures of successful implementation that we found included user views/satisfaction, and staff attitudes towards training and implementation. The studies that specifically aimed to pilot a new technology described how 'successful' the process of CIS implementation was in a post-hoc manner, with lessons learned.

More objectively, clinical effectiveness was used as an index of successful implementation in a few studies, where the impact of CIS on clinical processes was assessed. Effectiveness was linked with completion of tasks on the CIS, diagnostic accuracy, and error rates. The simulation based evaluations[40,41,45,46] in particular demonstrated positive impacts on clinical effectiveness. This suggests a future avenue for further exploration: whereas simulation is currently used extensively in research and training on skills, especially in surgery, its potential as a valid environment for prospective testing of novel CIS is underutilised. We believe that this is a fruitful direction for the future, such that novel technologies can be tested and evaluated in immersive simulated environments that mimic real life (e.g., a simulated handover scenario, or a simulated OR with full team present[47]) and their impact on clinical work can be assessed in real time prior to implementation within time-pressurized and potentially high-risk acute hospital environments.

Surprisingly, only one study in this review reported on the impact of proactively engaging with and promoting acceptance amongst users.[31] This study aimed to bridge the gap between user dissatisfaction and satisfaction, by focussing on eliciting user acceptance and engagement with clinicians as a technique to aid CIS implementation. Here, the importance and implications of user dissatisfaction were made evidently clear, whereby formalized lack of support from clinicians forced the implementation team to question the feasibility of their implementation programme. User dissatisfaction was overcome through various techniques to engage with clinicians – including receiving input from clinicians in system development, informing them of system improvements, and raising awareness of the program more generally. The final successful end result was credited to "*the experienced project team that started listening to the users*" (p. 93).

4.1. Limitations

This review is limited by the nature of the search and also of the evidence that was assessed. The concept of 'implementation' of a novel CIS can be unclear in some studies, or it may have not been their primary aim, and hence studies could have been missed. Further, the reviewed studies were heterogeneous, reporting a range of endpoints and study designs, the vast majority of which did not evaluate implementation over time but only at a single time point. In the light of these limitations, future reviews should explore the option of focusing on a single CIS (e.g. electronic patient record) or on a single speciality (e.g. surgery) in an attempt to derive a more homogeneous evidence-base. Taking into account the broader healthcare informatics literature,[2,4,5] there is a gap between what is advocated in theory and what is evaluated in practice within healthcare. Firstly, whilst there are a number of recommendations about addressing real users' needs and actual utilisation, the reviewed studies tended to address the concept of user satisfaction cursorily by eliciting user ratings at one time point only. This practice means that longer-term implementation cannot be assessed – which is a major problem, since a study that employed a longitudinal design found that users' views actually improve over time,[31] whereas another study that evaluated the impact of financial incentives showed that over time such incentives are not sustainable.[30] Longitudinal designs like that employed by Armer et al.[35] should be used to truly capture doctors' and nurses' views and actual system usage over time.

Table 1
Characteristics of Included Studies.

Author(s), Year	Care setting, Country	Clinical information system	Implementation technique evaluated	Study endpoints (objective & self-reported measures assessed)	Study findings & observations
Abubakar, Williams & McEvoy,[27] 2005	Hospital, UK	Electronic on-call pack (PDA)	*System Piloting*	User Satisfaction (focus groups & surveys)	Implementation of a portable electronic on-call pack was piloted, during the first year of its development. Evaluation comprised qualitative (focus groups) and quantitative (questionnaire) components. Reported advantages of the system included faster access to information, ease of updating information and portability. Meetings raised concerns about confidentiality about identifiable patient information as well technical issues.
Armer, Harris & Dusold,[35] 2004	Nursing Home, USA	Telemedicine	*System Piloting*	User Satisfaction (surveys)	Examined users' concerns about and measured utilization of telemedicine during two time periods: pre-implementation and 12 months post-implementation. Self-reported 'concerns' decreased significantly post-implementation.
Choi, Jazayeri et al.,[28] 2004	Community Based Care Setting, Peru	Web based Nursing Order Entry System	*System Piloting*	Effectiveness (medication error rate)	Compared error rates between a system user group (intervention) and a control group that did not use the system. Post-introduction of the system, the intervention group showed a significant drop in error rates ($p = 0.0074$). No such drop was observed in the control group, where error rates were constant ($p = 0.66$). Users expressed satisfaction with the order entry system and ease of use.
Dworkin, Krall et al.,[36] 1998	Primary Care, USA	Electronic Medical Record (EMR)	*System Piloting*	User Satisfaction (surveys)	Evaluation of laptop computers to access existing comprehensive EMR in examination rooms. Surveys were conducted with clinicians pre- and post-implementation. Half of the 22 clinicians who participated in the study successfully adopted use of the system, by increasing their examination room time with patients by 25%. Problems cited by clinicians who did not adopt use of the system included equipment layout and function, battery issues and inadequate training.
Folz-Murphy, Partin et al.,[44] 1998	Integrated healthcare delivery system, USA	Ambulatory Medical Record System	*System Piloting*	System Utilization	Physicians who discontinued use of the system provided a better understanding of implementation problems. Factors affecting uptake involved design of the user interface, discomfort using the system in front of patients.
Kunkler, Rafferty et al.,[43] 1998	Oncology Centre, UK	Telemedicine	*System Piloting*	User Satisfaction (surveys)	A piloted tele-oncology system linked a cancer centre with a rural general hospital, involving patients, physicians, surgeons, radiologists and nursing staff, with the aim of providing oncological advice on non-clinic days. 18 video conferences were conducted, lasting a median 17 min each. A survey demonstrated patient and staff satisfaction and acceptance.
Scott,[38] 2009	GP Practices, UK	Electronic Referral System	*System Piloting*	System Utilization User Satisfaction (surveys)	Most (81%) urgent cancer referrals were processed within 1 h. Interviews showed that staff agreed that the use of a standardised electronic form was beneficial and also improved the quality of referral information sent to Consultants.
Weinhara, Stoicu-Tivadar & Dagres,[39] 2009	Hospital, Serbia	Electronic Medical Record (EMR)	*System Piloting*	User Satisfaction (surveys)	Higher satisfaction was associated with the visual cues of the system, flexibility, data retrieval, and reliability. Lower satisfaction was associated with speed and screen character size. Users expected the EMR would improve clinical documentation, consistency of health maintenance, access to patient data and research. Owing to favourable user satisfaction assessed via surveys, the EMR was deployed in other institutions. User feedback was utilised to guide future implementation and correct problems.
Dagroso, Williams et al.,[31] 2007	Obstetrics, USA	Clinical Decision Support System (CDSS)	*Eliciting Acceptance*	System Utilization User Satisfaction (surveys)	Clinicians exhibited dissatisfaction with the initial system, in relation to performance and functionality. Mandatory use of the system was suspended, modifications were made, training systems were developed and methods to foster acceptance were explored. Consequently, clinicians voted to accept the system for mandatory use.
Berkenstadt, Yusim et al.,[40] 2006	Anaesthesia, *Israel*	Decision Support System	*Simulation*	Effectiveness (error rate)	Compared anaesthesia residents' diagnoses and treatment of simulated patients, with and without the decision support system. Diagnostic scores were significantly higher ($p = 0.018$) for the system user group compared to the control group.
Coopmans & Biddle,[41] 2008	Surgery, USA	Computer Assisted Decision Making (CADM) System	*Simulation*	Effectiveness (diagnostic accuracy)	Evaluated effect of CADM on the accuracy and speed of problem solving by Certified Registered Nurse Anaesthetists during simulated critical patient care events. The time taken to diagnose and treat varied according to the simulated scenario. Use of the CADM took less time.

(*continued on next page*)

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Table 1 (*continued*)

Author(s), Year	Care setting, Country	Clinical information system	Implementation technique evaluated	Study endpoints (objective & self-reported measures assessed)	Study findings & observations
Eley, Hegney et al.,[33] 2005	Emergency Department (ED), Australia	Clinical Decision Support System (CDSS)	*Simulation*	User Satisfaction (interviews)	15 triage nurses underwent training and were tested on the application of the system via simulated scenarios (written, video and computerised). Interviews demonstrated positivity about the use of simulation as a training tool. Qualitative responses about the decision support system varied according to nurse's experience level. Experienced nurses felt the tool provided the 'right' answer; less experienced nurses reported that the system guided them through their decision making. Overall, the CDSS was regarded as a tool to adjunct and validate their triage rating. Concerns raised included universal applicability of the tool and 'role erosion' (over-reliance on CDSS).
Dong, Bullard et al.,[32] 2007	Emergency Department, Canada	Web-based triage decision support tool (eTRIAGE)	*Training and Education*	Effectiveness (comparison of reliability between study nurses)	Determined the impact of two different training schemes on system implementation. Agreement between study nurses and duty nurses using the eTRIAGE system was moderate to good, suggesting improvement with additional training.
Granlien & Hertzum,[29] 2009	Hospital, Denmark	Electronic Medication Record	*Training and Education*	Effectiveness (error rate)	Audits of the medical records showed that interventions significantly lowered the number of records that violated procedures. The positive results were achieved following multiple interventions, suggesting that positive associations with implementation wear off over time. Iterative approaches to implementation are recommended, combined with assessment of effectiveness.
Kirshner, Salomon & Chin,[34] 2003	Health Maintenance Organisation, USA	Electronic Medical Records, data retrieval and intranet based medical history	*Training and Education*	Satisfaction with Training (surveys) Perceived improvements in efficacy (surveys)	Assessed (i) level of improvement in CIS efficiency following one-on-one training, (ii) perceived value of one-on-one training compared to other teaching methods, and (iii) overall satisfaction with the training. The one-on-one training modality was significantly valued by clinicians above other methods ($p < 0.0001$).
Lemmetty, Hayrinen & Sundgren,[37] 1999	Hospital, Finland	Electronic Medical Records (EMR)	*Training and Education*	Satisfaction with Training (surveys)	Examined the professional competence in CIS users after training sessions in district/community hospitals. 52% of 138 respondents were positive towards the EMR implementation while 34% were negative. Following system training 48% of respondents changed their negative attitude to positive.
Murphy, Maynard & Morgan,[42] 1994	Hospital, USA	Patient Care Information System	*Training and Education*	User Satisfaction	Examined the impact of user computer-based training and system utilisation in self-reported satisfaction with system. Nurses' self-reported satisfaction with system improved significantly post-training and after using the system for 3 months.
Levick, Lukens & Stillman,[30] 2005	Hospital, USA	Computer Provider Order Entry (CPOE) System	*Incentives*	System Utilization	Physicians' utilization of the CPOE increased from 35% to 57% after an initial financial compensation program. Utilization declined to 42% after the first phase of the program, and then went on to increase to 54% after a second phase (longitudinal fluctuation).

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Table 2
Overview of study endpoints against implementation techniques: what is assessed?.

Implementation endpoints	Implementation techniques				
	System piloting	Eliciting acceptance	Simulation	Training & education	Incentives
User satisfaction	+[27] +[35] +[36] +[43] +[38] +[39]		+[33]	+[42]	
System utilisation	+[44] +[38]	+[31]			+[30]
Effectiveness			+[40] +[41]	+[32] +[29] +[34]	
Attitudes towards training				+[34] +[37]	
Attitudes towards implementation				+[37]	

4.2. Implications for implementation of novel systems

On the basis of our review, we suggest that system utilization, user acceptance, and the impact of CIS on clinical processes and performance are all important indicators of successful implementation, ideally investigated as part of an integrated framework. This points to a vast arena of potential future research that aims to positively influence end-users' views of novel CIS and translate them into in situ system utilisation. Although innovative collaborative initiatives are becoming hugely successful in helping to improve efficiency and effectiveness within other applied domains,[48] such standards remain to be successfully transferred to healthcare contexts. The challenge remains to successfully embed novel CIS into care settings without duplicating work for healthcare professionals and with the aim of improving standards and quality of patient care (and potentially also save millions in financial investment).

Further, we would argue that the role of clinical leadership, i.e., not simply clinical engagement, should be assessed and evaluated further in the context of novel CIS. Such leadership may take many facets – including clear specifications for the CIS design team, facilitation of system piloting within a clinical setting (which we found in this review is a technique that can foster system acceptance and usage), and finally a 'route' of communication between the clinical users and the technical developers. Clinical leadership has been shown to be instrumental in implementing interventions across the entire spectrum of healthcare[49–51] – here we propose that more could be made of it within the context of CIS.

Specifically in relation to surgeons, we propose that surgeons can and should be more engaged with the process of novel CIS implementation. Surgeons pride themselves as innovators – indeed a recent review directly linked surgeons' leadership potential with their ability to embrace and foster successful innovation within hospitals.[52] Recent years have seen multiple developments of electronic systems directly applicable to surgical patients or the OR context – including electronic whiteboards for the OR to improve safety, electronic systems to share information within the OR in complex cardiac procedures,[53] electronic checklists to enhance safety of care for cancer patients, electronic handover tools,[53,54] and 'black box' recording technologies to improve team performance in the OR.[55] Further, novel CIS is also relevant to surgeons from the point of view of clinical governance and audit procedures. Careful integration of novel systems within existing ones and implementation that takes into account user needs should facilitate electronic data gathering for audit/governance purposes (and thus minimize time-wasting). In the UK, ongoing auditing of the implementation of the WHO Surgical Safety Checklist currently occurring in many hospitals across the country is a good example of potential improvement with electronic applications. Beyond static audit, continuous monitoring of performance indicators (as determined by surgeons or OR teams) and feedback are increasingly being implemented[56] – again CIS can facilitate how individuals and teams monitor and improve their own performance and how they train their junior members.

Practically, we have produced recommendations that are based on the evidence and can help with successful development and implementation of novel CIS for healthcare (Box 1). These are intended to help improve the design and metrics of future studies but also, practically, to prevent major catastrophic failures of CIS within healthcare, which cost billions and create a culture of apathy and hostility towards technological innovation in hospitals. Scientific evaluation of the impact of these recommendations on how well CIS are implemented and used and what impact they have on

RECOMMENDATIONS FOR EVALUATING THE IMPLEMENTATION OF CLINICAL INFORMATION SYSTEMS IN HEALTHCARE SETTINGS

I. Longitudinal evaluation should be applied (pre-implementation, during implementation, post-implementation).

II. Simulation approaches should be considered to evaluate CIS impact prior to implementation within clinical environments

III. Assessment of impact of CIS should include individual-based impact (e.g. on clinical end-users' workload, stress) and team-based impact (e.g. on teamworking)

IV. Assessment of impact should include subjective endpoints (e.g. clinical end-users' views and perceptions) and objective system usage (during implementation and post-implementation)

V. End users should be engaged with the implementation process and take on leadership roles as necessary

Box 1. Recommendations for Implementation and evaluation of clinical information systems in healthcare settings.

safety is possible and should be routinely carried out. Well-designed, well-implemented and well-performing CIS can and should be the norm rather than the exception.

Ethical approval

Not applicable.

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Author contribution

Tanika Kelay: evidence synthesis, writing.
Sujatha Kesavan: manuscript revisions.
Ruth E. Collins: study design, data collection and extraction.
Jimmy Kyaw-Tun: data collection and extraction.
Benita Cox: study conceptualisation, manuscript revisions.
Fernando Bello: study conceptualisation, manuscript revisions.
Roger L. Kneebone: study conceptualisation, manuscript revisions.
Nick Sevdalis: study conceptualisation, study design, evidence synthesis, writing.

Conflicts of interest

None.

Appendix 1. Search strategy

	Step	Medline search strategy
Category A Information Systems	1	**(computer$ (MeSH) OR information system$ (MeSH) OR decision support system$ OR dashboard OR (wireless** adj **(technology OR system OR network))).ti,ab.**
	2	exp Computer Communication Networks/OR exp Management Information Systems/OR exp information systems
Category B Clinical Setting/Personnel	3	**(((acute OR primary OR secondary OR tertiary)** adj **care)** OR hospital OR infirmar* OR clinical OR nurs$ OR doctor$ OR physician$ OR patient$).ti,ab
	4	exp "Delivery of Health Care"/**(MeSH)**
Category C Clinical Information Systems	5	exp Telemetry **(MeSH)**/OR exp Telemedicine **(MeSH)**/OR exp Decision Support Systems, Clinical/OR exp Medical Order Entry Systems **(MeSH)**/OR ((electronic adj2 record$) OR telemetry **(MeSH)** OR telemedicine **(MeSH)** OR medical order entry **(MeSH)** OR clinical decision support system **(MeSH)** OR computeri$ed prescriber order entry system).ti,ab
Category D Implementation Technique	6	**exp *computer user training (MeSH)/OR exp *pilot projects (MeSH)/OR exp *evaluation studies (MeSH)/OR exp* information dissemination (MeSH)/OR exp** *Attitude to Computers **OR (train$ or pilot OR validat$ OR incentive* OR initiative OR simulat$ OR information dissemination OR champion or implement$).ti,ab. OR intervention.ti.**
	7	1 adj5 3
	8	2 and 4
	9	5 or 7 or 8
	10	6 and 9
Limits	11	**Limit 10 to (english language and humans)**

See Higgins et al.[26] for interpretation of terms used in search strategies.
Note: this is the search strategy used within the MEDLINE database – the searches within the EMBASE, PsycINFO, and HMIC databases were very similar, and are available upon request.

References

1. Staggers N, Thompson CB, Snyder-Halpern R. History and trends in clinical information systems in the United States. *Journal of Nursing Scholarship* 2001;**33**(1):75–81.
2. Chaudhry B, Wang J, Wu S, Maglione M, Mojica W, Roth E, et al. Systematic review: impact of health information technology on quality, efficiency, and costs of medical care. *Annals of Internal Medicine* 2006;**144**(10):742–52.
3. Bates DW, Leape LL, Cullen DJ, Laird N, Petersen LA, Teich JM, et al. Effect of computerized physician order entry and a team intervention on prevention of serious medication errors. *JAMA* 1998;**280**(15):1311–6.
4. Hayward GL, Parnes AJ, Simon SR. Using health information technology to improve drug monitoring: a systematic review. *Pharmacoepidemiology and Drug Safety* 2009;**18**(12):1232–7.
5. Willcocks LP, Lester S. Information technology: transformer or sink hole. In: Willcocks LP, Lester S, editors. *Beyond the IT productivity paradox*. Chichester, UK: Wiley; 1999. p. 1–30.
6. Blum MS, Cole C, Leviss J, Shabot MM, Weisenthal A, editors. *Advanced EMR implementations: practical experience from those who have been there*. *Proceedings of AMAIA Symposium 2003* 2003. [Washington, DC].
7. Kaplan B, Harris-Salamone KD. Health IT success and failure: recommendations from literature and an AMIA workshop. *Journal of the American Medical Informatics Association: JAMIA* 2009;**16**(3):291.
8. Cross M. Benefits of £12bn IT programme in NHS are "unclear," MPs say. *BMJ* 2007;**334**(7598):815.
9. House of Commons Committee of Public Accounts. *Department of health: the National Programme for IT in the NHS*. In *Twentieth Report of Session 2006-07. Report, together with formal minutes, oral and written evidence*. London: The Stationery Office Limited; 2007.
10. Willcocks L, Lester S. *Evaluating the feasibility of information technology, research*. Oxford: Oxford Institute of Information Management (Discussion paper DDP 93/1); 1993.
11. Campbell EM, Guappone KP, Sittig DF, Dykstra RH, Ash JS. Computerized provider order entry adoption: implications for clinical workflow. *Journal of General Internal Medicine* 2009;**24**(1):21–6.
12. Martin D. Managing integration work in an NHS electronic patient record (EPR) project. *Health Informatics Journal* 2007;**13**(1):47.
13. Berg M. Considerations for sociotechnical design: experiences with an electronic patient record in a clinical context. *International Journal of Medical Informatics* 1998;**52**(1–3):243.
14. Weerakkody G. CSCW-based system development methodology for health-care information systems. *Telemedicine and E-Health* 2003;**9**(3):273.
15. Adams GL. Effectiveness of prehospital wireless transmission of electrocardiograms to a cardiologist via hand-held device for patients with acute myocardial infarction (from the timely intervention in myocardial Emergency, northeast experience [TIME-NE]). *The American Journal of Cardiology* 2006;**98**(9):1160.
16. Mitchell E. A descriptive feast but an evaluative famine: systematic review of published articles on primary care computing during 1980-97. *Quality & Safety in Health Care* 2001;**322**(7281):279.
17. Dworkin LA, Krall M, Chin H, Robertson N, Harris J, Hughes J, editors. Experience using radio frequency laptops to access the electronic medical record in exam rooms. *Proceedings of Journal of the American Medical Informatics Association Symposium* 1999.
18. Kirshbaum MN. Are we ready for the electronic patient record? Attitudes and perceptions of staff from two NHS trust hospitals. *Health Informatics Journal* 2004;**10**(4):265.
19. Holleran K. Mobile technology in a clinical setting. *Journal of the American Medical Informatics Association* 2003;**2003**:863.
20. Patel VL. Impact of a computer-based patient record system on data collection, knowledge organization, and reasoning. *Quality & Safety in Health Care* 2000;**7**(6):569.
21. Wright P. How to limit clinical errors in interpretation of data. *Lancet* 1998;**352**(9139):1539.
22. Ahmad A, Teater P, Bentley TD, Kuehn L, Kumar RR, Thomas A, et al. Key attributes of a successful physician order entry system implementation in a multi-hospital environment. *Journal of the American Medical Informatics Association* 2002;**9**(1):16–24.
23. Bates DW, Kuperman GJ, Wang S, Gandhi T, Kittler A, Volk L, et al. Ten commandments for effective clinical decision support: making the practice of evidence-based medicine a reality. *Journal of the American Medical Informatics Association* 2003;**10**(6):523–30.
24. Koppel R, Metlay JP, Cohen A, Abaluck B, Localio AR, Kimmel SE, et al. Role of computerized physician order entry systems in facilitating medication errors. *JAMA* 2005;**293**(10):1197–203.
25. Sittig DF, Stead WW. Computer-based physician order entry: the state of the art. *Journal of the American Medical Informatics Association* 1994;**1**:108–23.
26. Higgins JP, Green SE. *Cochrane handbook for systematic reviews of interventions version 5.0.1 (updated September 2008)*. The Cochrane Collaboration. Available at: http://www.cochrane-handbook.org; 2008 [accessed June 1.06.10].
27. Abubakar I, Williams CJ, McEvoy M. Development and evaluation of a hand held computer based on-call pack for health protection out of hours duty: a pilot study. *BMC Public Health* 2005;**5**:35.
28. Choi SS, Jazayeri DG, Mitnick CD, Chalco K, Bayona J, Fraser HSF. Implementation and initial evaluation of a web-based nurse order entry system for

multidrug-resistant tuberculosis patients in Peru. *Studies in Health Technology & Informatics* 2004;**107**(Pt 1):202–6.
29. Granlien MS, Hertzum M. Implementing new ways of working: interventions and their effect on the use of an electronic medication record. In: *Proceedings of the ACM 2009 international conference on supporting group work* 2009. p. 321–30.
30. Levick D, Lukens HF, Stillman PL. You've led the horse to water, now how do you get him to drink: managing change and increasing utilization of computerized provider order entry. *Journal of Healthcare Information Management* 2005;**19**(1):70–5.
31. Dagroso D, Williams PD, Chesney JD, Lee MM, Theoharis E, Enberg RN. Implementation of an obstetrics EMR module: overcoming user dissatisfaction. *Journal of Healthcare Information Management* 2007;**21**(1):87–94.
32. Dong SL, Bullard MJ, Meurer DP, Blitz S, Holroyd BR, Rowe BH. The effect of training on nurse agreement using an electronic triage system. *Canadian Journal of Emergency Medicine* 2007;**9**(4):260–6.
33. Eley D, Hegney D, Wollaston A, Fahey P, Miller P, McKay M, et al. Triage nurse perceptions of the use, reliability and acceptability of the Toowoomba Adult Triage Trauma Tool (TATTT). *Accident & Emergency Nursing* 2005;**13**(1):54–60.
34. Kirshner M, Salomon H, Chin H. One-on-one proficiency training: an evaluation of satisfaction and effectiveness using clinical information systems. *AMIA Annual Symposium Proceedings/AMIA Symposium* 2003:366–70.
35. Armer JM, Harris K, Dusold JM. Application of the concerns-based adoption model to the installation of telemedicine in a rural Missouri nursing home. *Journal for Nurses in Staff Development - JNSD* 2004;**20**(1):42–9.
36. Dworkin LA, Krall M, Chin H, Robertson N, Harris J, Hughes J. Experience using radio frequency laptops to access the electronic medical record in exam rooms. *Proceedings/AMIA Annual Symposium* 1999:741–4.
37. Lemmetty K, Hayrinen K, Sundgren S. The impacts of informatics competencies and user training on patient information system implementation. *Studies in Health Technology & Informatics* 2009;**146**:646–51.
38. Scott K. The Swansea electronic referrals project. *Journal of Telemedicine & Telecare* 2009;**15**(3):156–8.
39. Weinhara M, Stoicu-Tivadar L, Dagres C. Early stage testing of user's satisfaction after implementation of a central electronic health record (EHR) system in Serbia. *Journal on Information Technology in Healthcare* 2009;**7**(2):127–33.
40. Berkenstadt H, Yusim Y, Ziv A, Ezri T, Perel A. An assessment of a point-of-care information system for the anesthesia provider in simulated malignant hyperthermia crisis. *Anesthesia & Analgesia* 2006;**102**(2):530–2.
41. Coopmans VC, Biddle C. CRNA performance using a handheld, computerized, decision-making aid during critical events in a simulated environment: a methodologic inquiry. *AANA Journal* 2008;**76**(1):29–35.
42. Murphy CA, Maynard M, Morgan G. Pretest and post-test attitudes of nursing personnel toward a patient care information system. *Computers in Nursing* 1994;**12**(5):239–44.
43. Kunkler IH, Rafferty P, Hill D, Henry M, Foreman D. A pilot study of tele-oncology in Scotland. *Journal of Telemedicine & Telecare* 1998;**4**(2):113–9.
44. Folz-Murphy N, Partin M, Williams L, Harris CM, Lauer MS. Physician use of an ambulatory medical record system: matching form and function. *Proceedings/AMIA Annual Symposium* 1998:260–4.
45. Sadideen H, Hamaoui K, Saadeddin M, Kneebone R. Simulators and the simulation environment: getting the balance right in simulation-based surgical education. *International Journal of Surgery* 2012;**10**(9):458–62.
46. Milburn JA, Khera G, Hornby ST, Malone PSC, Fitzgerald JEF. Introduction, availability and role of simulation in surgical education and training: review of current evidence and recommendations from the association of surgeons in training. *International Journal of Surgery* 2012;**10**(8):393–8.
47. Kneebone RL, Arora S, King D, Bello F, Sevdalis N, Kassab E, et al. Distributed Simulation – accessible immersive training. *Medical Teacher* 2010;**32**:65–70.
48. Killen C. *Enhancing practice: exploring innovation with technology in further education*. JISC, Higher Education Funding Council for England; 2012.
49. Lukas CV, Holmes SK, Cohen AB, Restuccia J, Cramer IE, Shwartz M, et al. Transformational change in health care systems: an organizational model. *Health Care Management Review* 2007;**32**(4):309–20.
50. Weiner B, Shortell S, Alexander J. Promoting clinical involvement in hospital quality improvement efforts: the effects of top management, board and physician leadership. *Health Services Research* 1997;**32**(4):491–510.
51. Firth-Cozens J, Mowbray D. Leadership and the quality of care. *Quality in Healthcare* 2001;**10**(Suppl. 2):113–7.
52. Suliman A, Klaber RE, Warren OJ. Exploiting opportunities for leadership development of surgeons within the operating theatre. *International Journal of Surgery* 2013;**11**:6–11.
53. Parush A, Kramer C, Foster-Hunt T, Momtahan K, Hunter A, Sohmer B. Communication and team situation awareness in the OR: implications for augmentative information display. *Journal of Biomedical Informatics* 2011;**44**:477–85.
54. Ryan S, O'Riordan JM, Tierney S, Conlon KC, Ridgway PF. Impact of a new electronic handover system in surgery. *International Journal of Surgery* 2011;**9**:217–20.
55. Guerlain S, Adams RB, Turrentine FB, Shin T, Guo H, Collins SR, et al. Assessing team performance in the operating room: development and use of a "black-box" recorder and other tools for the intraoperative environment. *Journal of the American College of Surgeons* 2005;**200**(1):29–37.
56. Benn J, Arnold G, Wei I, Riley C, Aleva F. Using quality indicators in anaesthesia: feeding back data to improve care. *British Journal of Anaesthesia* 2012;**109**(1):80–91.