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Going digital: a narrative overview of the clinical and organisational impacts of eHealth technologies in hospital practice

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Abstract

Objective. The aim of the present study was to determine the effects of hospital-based eHealth technologies on quality, safety and efficiency of care and clinical outcomes.

Methods. Systematic reviews and reviews of systematic reviews of eHealth technologies published in PubMed/Medline/Cochrane Library between January 2010 and October 2015 were evaluated. Reviews of implementation issues, non-hospital settings or remote care or patient-focused technologies were excluded from analysis. Methodological quality was assessed using a validated appraisal tool. Outcome measures were benefits and harms relating to electronic medical records (EMRs), computerised physician order entry (CPOE), electronic prescribing (ePrescribing) and computerised decision support systems (CDSS). Results are presented as a narrative overview given marked study heterogeneity.

Results. Nineteen systematic reviews and two reviews of systematic reviews were included from 1197 abstracts, nine rated as high quality. For EMR functions, there was moderate-quality evidence of reduced hospitalisations and length of stay and low-quality evidence of improved organisational efficiency, greater accuracy of information and reduced documentation and process turnaround times. For CPOE functions, there was moderate-quality evidence of reductions in turnaround times and resource utilisation. For ePrescribing, there was moderate-quality evidence of substantially fewer medications errors and adverse drug events, greater guideline adherence, improved disease control and decreased dispensing turnaround times. For CDSS, there was moderate-quality evidence of increased use of preventive care and drug interaction reminders and alerts, increased use of diagnostic aids, more appropriate test ordering with fewer tests per patient, greater guideline adherence, improved processes of care and less disease morbidity. There was conflicting evidence regarding effects on in-patient mortality and overall costs. Reported harms were alert fatigue, increased technology interaction time, creation of disruptive workarounds and new prescribing errors.

Conclusion. eHealth technologies in hospital settings appear to improve efficiency and appropriateness of care, prescribing safety and disease control. Effects on mortality, readmissions, total costs and patient and provider experience remain uncertain.

What is known about the topic? Healthcare systems internationally are undertaking large-scale digitisation programs with hospitals being a major focus. Although predictive analyses suggest that eHealth technologies have the potential to markedly transform health care delivery, contemporary peer-reviewed research evidence detailing their benefits and harms is limited.

What does this paper add? This narrative overview of 19 systematic reviews and two reviews of systematic reviews published over the past 5 years provides a summary of cumulative evidence of clinical and organisational effects of contemporary eHealth technologies in hospital practice. EMRs have the potential to increase accuracy and completeness of clinical information, reduce documentation time and enhance information transfer and organisational efficiency. CPOE appears to improve laboratory turnaround times and decrease resource utilisation. ePrescribing significantly reduces medication errors and adverse drug events. CDSS, especially those used at the point of care and integrated into workflows, attract the strongest evidence for substantially increasing clinician adherence to guidelines, appropriateness of disease and treatment monitoring and optimal medication use. Evidence of effects of eHealth technologies on discrete clinical outcomes, such as morbid events, mortality and readmissions, is currently limited and conflicting.

What are the implications for practitioners? eHealth technologies confer benefits in improving quality and safety of care with little evidence of major hazards. Whether EMRs and CPOE can affect clinical outcomes or overall costs in the absence of auxiliary support systems, such as ePrescribing and CDSS, remains unclear. eHealth technologies are evolving rapidly and the evidence base used to inform clinician and managerial decisions to invest in these technologies must be updated continually. More rigorous field research using appropriate evaluation methods is needed to better define real-world benefits and harms. Customisation of eHealth applications to the context of patient-centred care and management of highly complex patients with multimorbidity will be an ongoing challenge.

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Introduction

Considerable financial investment is currently being devoted in many countries to implementing potentially transformative eHealth technologies. For example, England has invested at least £12.8 billion in a National Program for Information Technology (NPfIT) for the National Health Service[1] and the Obama administration in the US has similarly committed to a US$34 billion eHealth investment in health care.[2,3] The eHealth market worldwide is predicted to reach US$308 billion by 2022.[4] Much of this expenditure has been directed towards digitising hospital practice. Queensland Health has embarked on an A$1.3 billion statewide campaign to digitise all its major public hospitals by 2020.[5] Such large-scale expenditure has been justified on the grounds that electronic medical records (EMRs), electronic prescribing (ePrescribing) and associated computerised provider (or physician) order entry systems (CPOE) and computerised decision support systems (CDSS) will help address the problems of variable quality and safety in modern health care, improve efficiency and contain rising healthcare costs.[5–9] However, the evidence base underpinning such claims remains uncertain.

The aim of the present study was to generate a narrative overview of systematic reviews and reviews of reviews of contemporary eHealth technologies that have assessed their effects on the quality, safety and resource utilisation of hospital-based health care delivery compared with traditional paper-based systems of care.

Methods

Scope of the overview

Given the wide spectrum of eHealth technologies, the foci of this review were those having two functions (with some inevitable overlap): (1) primary technology to enable the storage, retrieval and transmission of clinical data (EMRs); and (2) auxiliary technologies to support clinical decision making (CPOE, ePrescribing and CDSS). Technologies supporting remote care (Telehealth, Telemonitoring and similar) were excluded from the analysis, as were patient-focused interventions (patient-controlled EMRs, electronic messaging or education). Given the rapid evolution of eHealth technologies, we restricted the present review to reports published in the past 5 years to ensure relevance to current deliberations.

Search strategy, data sources and study selection

Established Cochrane-based systematic review principles were used to search for relevant systematic reviews and reviews of such reviews. We used the pre-specified PubMed Clinical Queries search string for 'electronic health record' (see Item S1, available as Supplementary Material to this paper) and 'article type = review' and 'publication date = last 5 years' filters to search PubMed, MEDLINE and Cochrane Library contents for reviews published in English-language journals, either in print or online, from 1 January 2010 to 31 October 2015. Additional searches were performed using PubMed Clinical Queries function (with 'systematic reviews' search filter) and relevant search terms for CPOE, ePrescribing and CDSS. The bibliographies of retrieved reviews were scrutinised to find additional reviews. Articles were screened for inclusion on the basis of: (1) reference to the study as being a systematic review or a review of systematic reviews by the authors within the title, abstract or text; and/or (2) evidence from the description of the methods that systematic review principles had been used in searching and appraising the evidence. Reviews that contained randomised trials and/or observational studies were included in the analysis. Studies were excluded if, for any of the four eHealth technologies: (1) they focused only on single disciplines (e.g. oncology, mental health), single class of investigations or medications or single vendor systems; (2) dealt primarily with implementation issues; or (3) were conducted exclusively or predominantly in non-hospital settings or in developing countries. A complete list of inclusion and exclusion criteria is provided in Item S2. All potentially suitable reviews were independently assessed for inclusion by two reviewers (JK and IAS) and agreement reached by consensus. A log of excluded studies and reasons for exclusion is available on request from the authors.

Quality of evidence

The methodological quality and risk of bias of each review was critically appraised using the Assessing the Methodological Quality of Systematic Reviews (AMSTAR; https://amstar.ca/Amstar_Checklist.php, verified 17 September 2015) tool for systematic reviews (Item S3). Reviews were rated as high quality on the basis of AMSTAR scores $\geq$8.

Data extraction and synthesis

Data from included reviews were abstracted using a standardised format by one reviewer (JK) and cross-checked by a second reviewer (IAS). In synthesising the data, the heterogeneity of reviews was too diverse in terms of eTechnologies and outcome measures to allow meta-analysis of pooled data and therefore a narrative synthesis was undertaken.

Outcome measures

The outcome measures, based on a typology of eHealth technology functions and effects developed by Black *et al.*,[6] are listed below.

1. For EMR alone, the benefits (compared with paper-based systems) were categorised as data security, legibility, accessibility, completeness, comprehensiveness, efficiency and secondary uses. The harms were categorised as paper persistence, patient disengagement, insecure data, increased time for data entry and increased costs.
2. For CPOE, the benefits were categorised as resource utilisation, indicated care, patient outcomes (all-cause mortality, disease-specific mortality, disease-specific events, symptom measures, quality of life scores (as stated by the authors)), cost savings and time savings. The harms were categorised as increased time to perform task, interruptions, increased costs and workarounds. Where reviews reported findings in the CPOE category that were related to orders for medications, we thought it more appropriate to place these in the ePrescribing category for analysis.
3. For ePrescribing, the benefits were categorised as surrogate outcomes (as stated by the authors), guideline adherence, safer prescribing, communication, patient outcomes (as listed above), resource and/or cost savings and time savings. The harms were categorised as patient harm (adverse drug-related events (ADEs) or mortality), increased time to perform task and increased costs.
4. For CDSS, the benefits were categorised as indicated care, guideline adherence, surrogate outcomes (as stated by the authors) and patient outcomes (as stated above). The harms were categorised as practitioner performance and patient outcomes. Although we anticipated many CDSS would be applied to CPOE and ePrescribing functions, we elected to retain them in the CDSS category in keeping with their primary intended function.

Estimates of effect related to outcome measures

Estimates of effect related to outcome measures were defined as: (1) qualitative measures, as stated by the authors (i.e. no, small (modest), moderate or large effect); (2) standardised effect size (ES), where an ES of 0.2 indicates a small effect, an ES of 0.5 indicates a moderate effect and an ES of 0.8 indicates a large effect; (3) relative risk (RR) or odds ratio (OR) for benefit (or harm); and (4) absolute risk reduction (ARR) or increase (ARI) for benefit or harm respectively.

Quality of evidence for each review

Where review authors assessed the quality of the primary studies using numerical scoring methods (expressed as mean quality scores for all studies) or rated the quality of evidence as high, moderate, low, or very low based on the Grades of Recommendation, Assessment, Development and Evaluation (GRADE) system,[10] these scores or ratings were reported.

Results

The search strategy retrieved 1197 abstracts for screening, of which 1139 were rejected, leaving 58 articles that were subject to full-text review. Of these, 21 articles were included in the overview (see Fig. 1), comprising 19 systematic reviews[7–9,11–26] and two reviews of systematic reviews.[6,27] In all, 18 of the 21 (85.7%) articles evaluated CDSS,[6–9,11–19,22–24,26,27] five (23.8%) evaluated data information retrieval and transfer,[6,9,20,25,27] six (28.6%) measured effects of CPOE[6,9,16,21,22,27] and three (14.3%) assessed ePrescribing.[6,16,25] Most articles evaluated more than one eHealth technology and nine of the 21 (42.9%) articles were rated as high quality.[6,8,9,15,18,19,20,21,24] A summary of evidence from the studies included and interpretive comments made by their authors are given in Appendix 1 for systematic reviews and in Appendix 2 for reviews of reviews, listed in descending level of quality (and in chronological order within each level); key findings from each type of review are presented below.

Electronic medical records

Systematic reviews

One low-quality review reported enhanced communication of information between providers and a 22% reduction in documentation time.[25] In a high-quality review, there was moderate-quality evidence of a 15% reduction in hospitalisations and small decreases in both the length of hospital stay and the number of patient visits to emergency departments as a result of electronically generated reports of investigations containing care recommendations.[20] The same review noted no improvement in timeliness of discharge summaries to primary care providers and no effects on disease-specific processes of care or clinical outcomes.[20] Two reviews, one low quality[23] and another high quality,[9] that examined in-hospital mortality showed no effects from EMR. However, EMRs that included electronic surveillance systems for monitoring patient deterioration were associated with a 15% reduction in in-hospital mortality.[9]

Reviews of reviews

In one high-quality review, there was limited evidence of improvement in data security, interpretability, accessibility, comprehensiveness and search and retrieval functions for secondary uses such as research.[6] One low-quality review noted modest effects of EMRs on information accuracy and completeness, with

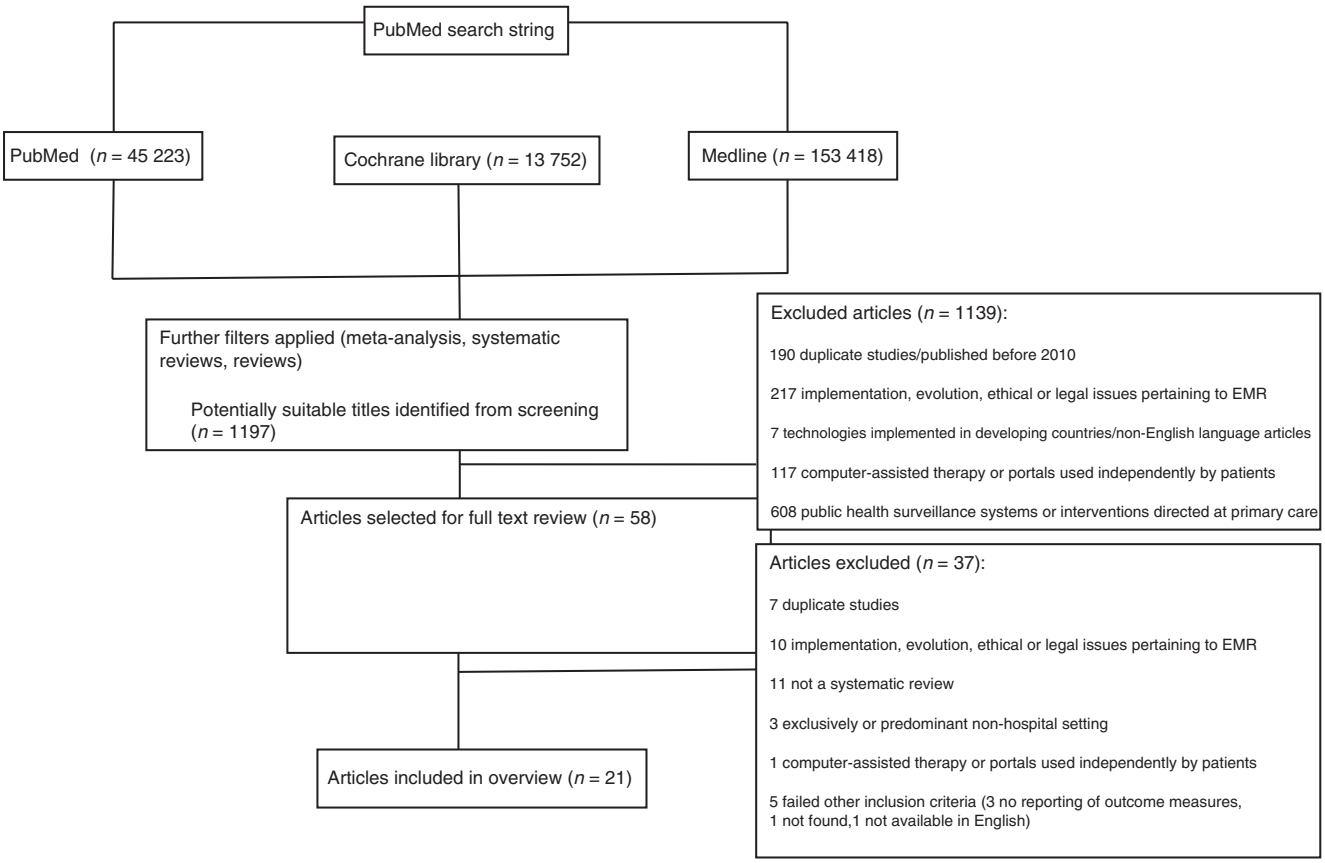

Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram of study selection. EMR, electronic medical records.

just over half the included studies reporting positive metrics for data storage, retrieval and transfer.[27] There were also trends towards improved organisational efficiency and greater use of health information exchange technology.[6,27] Although there were varying levels of sophistication and functionality across home-developed and commercial systems, time efficiency depended on the skills of end-users.[6]

Computerised provider order entry

Systematic review

One high-quality review reported no effects of CPOE on hospital mortality or length of stay.[9]

Reviews of reviews

In one low-quality review, positive feedback was reported for CPOE in two-thirds of 287 studies, but there was no effect on clinical performance or overall costs.[27] In a high-quality review of 53 reviews, modest effects were seen on turnaround times for processing and delivering laboratory investigation, as well as on practitioner performance.[6] The same review noted small time and cost savings overall, but there was also evidence of increased time to interact with CPOE systems in order to address alerts and override or confirm orders, leading to interruptions and work-arounds at the point of care.[6]

ePrescribing

Systematic reviews

One high-quality review quantified the benefits of ePrescribing as a 54% decrease in medication errors and a 53% decrease in ADEs,[21] whereas the corresponding reductions seen in a low-quality review were 54% and 34% respectively.[25] However, a twofold risk of new prescribing errors (e.g. concurrent submission of duplicate orders) was reported in two of 16 studies, which could potentially be disruptive to work flows but, to date, has not been associated with patient harm.[21]

Review of reviews

One high-quality review reported moderate evidence of improvement in organisational efficiency, more accurate communication between prescribers and pharmacists, and limited evidence of decreased turnaround times in supplying stock to wards and filling discharge prescriptions.[6] The same review reported limited to moderate evidence of reductions in medication errors and ADEs, increases in more appropriate prescribing, greater guideline adherence, improvement in disease outcomes and savings on cost and resource use.[6] However, these benefits came at the cost of introducing alert fatigue and inadvertent selection of incorrect type and dosage of medications.[6]

Computerised decision support systems

Systematic reviews

Multiple CDSS were described with variable levels of sophistication with regard to inputs, targeted goals and prompts and inference mechanisms. High-quality reviews showed moderate evidence (more than 50% of primary studies were positive) of improvements in processes of care[15] and appropriateness of test ordering.[24] In one review there was moderate-quality evidence of a 42% increase in preventive care services and a 72% increase in ordering or completion of recommended clinical investigations, and high-quality evidence of a 57% increase in adherence to treatment guidelines.[17] However, the same review reported no effects on mortality, ADEs, length of stay or clinician confidence in patient care.[17] In contrast, in another high-quality review, morbid events were reduced by 18% across a range of clinical conditions,[8] whereas in a third high-quality review, in-hospital mortality was reduced by 17%, which was just below statistical significance ($P = 0.05$).[9] One low-quality review reported a two-fold increase in adherence to clinical recommendations, a 42% increase in the use of preventive care services and a 57% increase in the appropriate use of medical treatments, in association with a 12% decrease in the incidence of morbid events.[22] However, this same review noted that, in the presence of alert fatigue, adherence to advice decreased by 63%.[22] Another low-quality review noted moderate effects in reducing inappropriate diagnostic imaging and modest reductions in overall use, but also slight increase (~7%) in failure to order appropriate tests when indicated.[23] Other low-quality reviews noted evidence of less ordering of redundant tests[7,11,26] (up to 18% less[11]), increased use of alerts and reminders[12,13] and diagnostic and medication dosing aids,[13] improved processes of care,[12,14] lower costs,[14] a 33% greater adherence to guidelines[25] and a 60% decrease in turnaround times.[26] With regard to chronic disease management, one low-quality review reported improved management of diabetes only,[12] whereas in another review, management of other chronic diseases, such as ischaemic heart disease,[18] hypertension and chronic obstructive pulmonary disease, also benefited.[13] Various reviews showed more significant optimisation of the use of high-risk drugs in certain patient subgroups, such as those receiving insulin,[16] vitamin K antagonists,[15] antibiotics and anti-rejection drugs.[19]

Reviews of reviews

One high-quality review noted evidence of improved delivery of indicated care[6] and guideline adherence,[6] whereas a low-quality review[27] noted increased use of alerts and reminders.

Discussion

The present narrative overview provides an update on the cumulative evidence of clinical and organisational effects of contemporary eHealth technologies in hospital practice. The current evidence base is limited for EMR simply as a data storage, retrieval and transfer platform, and for CPOE. In contrast, ePrescribing and CDSS have attracted greater research interest, probably because these systems have the greatest potential to directly and significantly affect patient care and outcomes. However, the overall quality of evidence is low, with only nine of 21 reviews being rated as high quality. Moreover, the results of different reviews, even those ostensibly studying the same question, yield somewhat inconsistent results, which may reflect, in part, the heterogeneity of the populations studied, technologies analysed and outcomes measured. Positive effects in many reviews are often small to moderate in magnitude and based on low- to moderate-quality evidence. There is very limited and conflicting evidence of the effects of eHealth technologies on patient-important clinical outcomes, such as morbid events, mortality and unplanned readmissions. Measures of hospital bed use, equity of access, resource utilisation, patient satisfaction or quality of life measures, or provider satisfaction and perceived ease of use, were rarely, if ever, reported. Although some reviews made mention of overall costs, data relating to cost-effectiveness remains sparse and is no doubt explained by the complexity of measuring direct and indirect costs of development and implementation of eHealth technologies over a period of time sufficiently long enough to allow adequate evaluation.

Study strengths and limitations

The present overview provides a current synopsis of the evidence of effect of currently available eHealth technologies that may assist project groups in developing business cases for local design and implementation. Strengths include a comprehensive search for systematic reviews and reviews of reviews from the literature and an assessment of their quality using a validated appraisal instrument. Detailed information on study characteristics, process and outcome measures according to four categories of technology functions, and interpretive comments, were extracted from each review, enabling readers to better assess relevant intervention effects.

Limitations relate to inadequate indexing of eHealth technologies in the literature, although the search method was one developed and endorsed by PubMed and it is unlikely that sentinel articles were missed. The scope of the present review was restricted to articles published in the past 5 years, which may have led to oversight of effective technologies that have withstood the test of time, although many reviews included individual studies dating back more than two decades. We did not search grey literature from websites or other sources given the potential for bias in reports not subject to peer review. We only assessed clinical and organisational effects devoid of any consideration of contextual issues around implementation, which may have affected the results. We concede overviews, by aggregating results from multiple primary studies, can only generate estimates of 'average' effects that may totally obscure highly positive results in individual trials. In addition, reviews rarely distinguished between studies that evaluated eHealth technologies as before–after 'brownfield' designs (i.e. an existing hospital converting from paper-based to computerised systems) or comparative 'greenfield' designs (newly built computerised hospitals or units compared with concurrent or historical controls). However, our aim was to generate effect estimates that were broadly generalisable.

Our categorisation of results of some reviews into CPOE, ePrescribing or CDSS could be regarded as arbitrary, but overlap of these functions was, at times, unavoidable and our choice of category was explained. There is the also the potential for over-emphasising the findings of particular reviews (and their included

primary studies) by including multiple reviews and reviews of reviews that duplicate the same studies multiple times. However, adopting this approach affords the opportunity for noting consistency in, and hence potential robustness of, the findings of different reviews performed by different authors. Although we were unable to assess the quality of individual trials in every review, we did cite the methods and results used to conduct such assessments whenever reported by review authors, and the AMSTAR quality criteria we used to appraise the reviews take account of whether such assessments had been undertaken. We were unable to pool data across all reviews, but reported quantitative results for those reviews that undertook meta-analyses. Many evaluations were conducted in large academic institutions by potentially conflicted developers of the eHealth technologies, which raises the potential for information and publication bias leading to overestimation of benefits, with most reviews making no mention of potential harms. Where review authors tested for such bias, we have reported their findings.

Implications for clinical practice

The authors have been involved in the recent digitisation of a large tertiary adult hospital in Brisbane that incorporates all four eHealth functions mentioned above. Presenting a synthesis of evidence of effects helped inform clinicians' and managers' views of the benefits (and harms) of digitisation, and assisted in gaining hospital-wide acceptance for such a major transformational change.

This overview suggests EMRs have the potential to increase the accuracy and completeness of clinical information and to reduce documentation time. Improvements in information transfer and organisational efficiency may translate into reduced hospitalisations, emergency visits and redundant test requests. Whether EMRs in the absence of auxiliary support systems affect clinical outcomes or overall costs remains unclear. Similarly, although CPOE appears to improve laboratory turnaround times, this is offset by increased interaction times, workflow interruptions and workarounds. Neither EMR nor CPOE has been shown to reduce mortality, length of hospital stay or overall costs.

There is reasonably strong evidence that ePrescribing significantly reduces medication errors and ADEs and may further increase patient safety and organisational efficiency with reminders relating to significant drug interactions that may otherwise be missed. Eliminating illegible handwriting and inappropriate dose prescribing by physicians, and improving communication with pharmacists, are proven benefits. However, there is potential for alert fatigue and duplication or wrong selection of medication type and dosage.

Evidence for improving processes and quality of care that affect clinical outcomes is currently strongest for CDSS, especially those used at the point of care and integrated well into workflows. Reviews have shown that such systems substantially increase clinician adherence to guidelines, appropriateness of disease and treatment monitoring and optimal use of medications. However, customisation of CDSS applications to the context of patient-centred care and management of highly complex patients with multimorbidity remains an ongoing challenge.

Conclusion

This overview of recently published systematic reviews of eHealth technologies may help inform decisions to invest in eHealth technologies in hospitals throughout Australia. Overall, eHealth technologies, especially ePrescribing and CDSS, appear effective in improving health care processes and outcomes across diverse settings using both commercially and locally developed systems.

eHealth technologies are evolving rapidly and much is still to be learned as to how these tools should be designed and used in ways that optimise their effectiveness. Evaluation methodologies most suited to assessing benefits and harms of these technologies, in both quantitative and qualitative terms, need to be deployed and refined over time. More rigorous field research targeting hospitals undergoing digital transformation, and performed by independent, multidisciplinary research groups, is required to narrow the gap between theorised potential benefits of eHealth technologies and empirically demonstrated real-world improvements in patient care and outcomes and efficient use of resources.

Competing interests

None declared.

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Appendix 1. Summary of findings from systematic reviews included in the present analysis

ADEs, adverse drug events; AMI, acute myocardial infarction; AMSTAR, Assessing the Methodological Quality of Systematic Reviews; CDSS, computerised decision support systems; 95% CI, 95% confidence interval; CMV, cytomegalovirus; COPD, chronic obstructive pulmonary disease; CPOE, computerised physician order entry; CPP, controlled pre-post; CT, controlled trial; CXR, chest X-ray; ED, emergency department; EHR, electronic health record; EMR, electronic medical records; ES, effect size; GRADE, Grades of Recommendation, Assessment, Development and Evaluation; HIT, health information technology HIS, health information systems; ICU, intensive care unit; INR, International Normalised Ratio; ITS, interrupted time series; LOS, length of stay; MD, mean difference; MRI, magnetic resonance imaging; N/a, not available; ORs, odds ratios; QOL, quality of life; RCT, randomised control trial; RR, relative risk; SBP, systolic blood pressure; SMD, standardised mean differences; TIA, transient ischaemic attack; UPP, uncontrolled pre-post

Study	Study characteristics	Brief summary of main outcomes	Quality appraisal	Outcome measures	Data information retrieval, transfer (EMR)	CPOE	ePrescribing	CDSS	Authors' interpretative comments
Ontario Health Technology Assessment Series,[20] 2013	11 studies published up to April 2012 examining effects of eTools for health information exchange in the context of care coordination for individuals with chronic disease in the community 4 RCTs, 1 non-RCT, 5 case control studies and 1 case series Majority in US hospital out-patients (8 studies); 1 study each from Australia, The Netherlands and UK	Evidence that the right e-tools in the right environment and context can significantly impact health services utilisation Doubts over the ability of eTools with care coordination capabilities to independently improve quality of out-patient care (due to inefficiencies in the healthcare system)	AMSTAR 10/11 Authors used GRADE criteria[10] to determine quality of evidence	2 studies examined impact of eTools on hospitalisations, 1 examined LOS and readmissions, 3 examined ED visits, 3 examined disease-specific clinical outcomes, 5 examined achievement of clinical indicators, 8 examined process of care indicators and 4 examined efficiency measures Effect estimates for primary and secondary outcomes were reported in most studies as the MD in outcomes; others used absolute risk difference or ORs	Moderate-quality evidence of 15% reduction in hospitalisations over 32 months follow-up (MD –0.03; 95% CI –0.05, –0.01), hospital LOS (MD –0.11; 95% CI –0.19, –0.03 days) and ED visits (MD –0.09; 95% CI –0.14, –0.04 visits per patient) following implementation of electronically generated reports with recommendations No effect on disease-specific outcomes for blood pressure, lipid or blood sugar control No effect on process of care measures No difference in proportion of primary care providers receiving discharge summaries within first week after discharge No effect on time or communication efficiencies	N/a	N/a	N/a	
Gillaizeau *et al.*[19] (2013)	42 trials published between 1996 and January 2012 comprising 40 RCTs and 2 controlled trials 15 studies reported on warfarin initiation and dose adjustment, 2 reported on anaesthetic agents, 10 evaluated insulin administration, 5 reported aminoglycoside antibiotics, 4 evaluated both theophylline and	Computerised advice for drug dosage has some benefits (e.g. ensuring appropriate serum concentrations for aminoglycoside antibiotics and improving the proportion of patients in whom plasma drug levels are within therapeutic range Physiological parameters more often within the desired range for oral anticoagulants and insulin	AMSTAR 10/11 Quality of studies was generally low, with high risk of bias due primarily to performance bias, lack of similar baseline characteristics and incomplete outcome data	Effect of computerised advice on drug dosage and patient outcomes compared with routine care (empiric dosing) RR was used for dichotomous variables; SMD for continuous variables	N/a	N/a	N/a	Fewer side effects for aminoglycosides (nephrotoxicity: RR 0.67; 95% CI 0.42, 1.06) and anti-rejection drugs (CMV infections: RR 0.90; 95% CI 0.58, 1.40) Increased target peak serum concentrations (SMD 0.79; 95% CI 0.46, 1.13) Increased proportion of patients with aminoglycoside plasma drug concentrations within	High heterogeneity between studies

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Study	Study characteristics	Brief summary of main outcomes	Quality appraisal	Outcome measures	Data information retrieval, transfer (EMR)	CPOE	ePrescribing	CDSS	Authors' interpretative comments
	anti-rejection drugs, 1 study each evaluated antidepressants and gonadotropins Majority in US inpatients; few in outpatient settings							therapeutic range after 2 days (RR 4.44; 95% CI 1.94, 10.13) Improvement in percentage of time spent within target INR for warfarin (SMD (+0.19; 95% CI 0.06, 0.33) or within target glucose range for hypoglycaemic drsugs (SMD +1.27; 95% CI 0.56, 1.98) Decreased time to achieve stabilisation for oral anticoagulants (SMD –0.56; 95% CI –1.07, –0.04) Decreased rate of venous thromboembolism in anticoagulated patients (rate ratio 0.68; 95% CI 0.49, 0.94) No effect on mortality or other clinical adverse events for insulin, anaesthetic agents and anti-rejection drugs	
Moja *et al.*[8] (2014)	Meta-analysis of 28 RCTs published up to January 2014; 16 trials assessing effect on mortality, 9 trials assessing effect on morbidity Majority in US in-patients	New-generation CDSSs integrated with EHRs do not affect mortality but may moderately improve morbidity outcomes	AMSTAR 10/11	Morbidity (e.g. occurrence of illness, progression of diseases and number of hospitalisations) and mortality outcomes	N/a	N/a	N/a	No significant effect on mortality Reduction in disease morbidity (RR 0.82; 95% CI 0.68, 0.99) 17/28 (60%) trials reporting economic outcomes show CDSS no better than non-CDSS interventions in reducing or containing costs	Most studies underpowered and of too short duration to prove or exclude an effect on mortality, raising the possibility of a Type 2 error High risk of bias across 7 (39%) studies and unclear risk of bias for 10 (56%) studies
Nuckols *et al.*[21] (2014)	Meta-analysis of 16 studies published between January 2007 and September 2013 comprising 3 comparator studies and 13 pre–post studies Majority in US and UK inpatients	Implementing CPOE is associated with >50% decline in ADEs and medication errors	AMSTAR 10/11	6 studies addressed ADEs in addition to medication errors; 15 studies assessed CPOE systems Primary outcome was preventable ADEs; secondary outcome was medication errors (prescribing, transcribing, dispensing or administration) with potential to or actually did cause harm Pooled analyses of	N/a	N/a	Benefits: pooled data analysis showed reduced ADEs (RR 0.47; 95% CI 0.31, 0.71) and medication errors (RR 0.46; 95% CI 0.35, 0.60). Harms: 2/16 studies (12%) indicated new medication errors may have been created (RR 2.08; 95% CI 1.84, 2.34), such as concurrent submission of duplicate orders due	N/a	Considerable heterogeneity in study results for primary (($I^2 = 69\%$) and secondary outcome (($I^2 = 99\%$). Studies using pharmacist order review reported greater effectiveness than studies using more comprehensive event detection methods. including formal medical record review, incident reporting tools

				medication errors with sensitivity analyses according to intervention design and implementation, context and study methods Random effects model for meta-analyses for ADEs and medication errors			to order sets, although no reports of increased risk of ADEs		Higher baseline rates of medication errors predicted greater reductions with CPOE No significant differences found between commercial vs home-grown systems, sophistication of CDSS, hospital-wide vs limited implementation and US vs non-US studies
Nieuwlaat *et al.*[15] (2011)	33 RCTs published up to January 2010 on effects of CDSS on: management of vitamin K antagonists (14), insulin (6), theophylline/ aminophylline (4), aminoglycosides (3), digoxin (2) and lignocaine (1) Majority in US in-patients	CDSSs can improve process of care for therapeutic drug monitoring and dosing, specifically insulin and vitamin K antagonist dosing No convincing evidence of improvement in patient outcomes	AMSTAR 9/11 Methodological quality of trial was good (median quality score 7.9/10)	Effect of CDSS on processes of care or patient outcomes for therapeutic drug monitoring and dosing Studies were classified as positive (benefit) or negative (harm) or no effect, with effect defined as >50% of relevant outcomes showing a statistically significant difference In some trials the components of the primary outcome were evaluated	N/a	N/a	N/a	18/30 (60%) trials showed improvement for process of care and 4/19 (21%) for patient outcomes 6/12 (50%) trials showed improvement in vitamin K antagonist dosing and time in therapeutic range by 6.1% ($P = 0.03$) Patient outcomes were improved in 1/6 (17%) of these trials; 2/5 (40%) trials reported improvements in vitamin K antagonist initiation but not during maintenance No decrease in risk of major bleeding seen compared with control; 5/5 (100%) trials reported improved insulin dosing No effects seen with regard to aminoglycoside dosing, digoxin dosing or effect on multiple drug therapy issues	In terms of study quality, concealed study group allocation before randomisation and cluster randomisation were infrequent.
Anchala *et al.*[18] (2012)	10 articles published up to July 2011 comprising 7 RCTs and 3 cohort studies 5 studies reported outcomes on blood pressure	CDSS moderately enhanced secondary prevention measures in patients with heart disease CDSS associated with significant reduction	AMSTAR 9/11 (methodological quality of trial was good; mean quality score 7.8/10)	Effect of CDSS on prevention of cardiovascular disease, with subgroups of TIA/ stroke, heart failure, coronary artery	N/a	N/a	N/a	30% reduction in incidence of AMI (RR 0.70; 95% CI 0.59, 0.81) in 1 study of 1628 participants No effect on optimisation of therapy prescribed	Evidence of significant publication bias after assessing funnel plot for studies that reported effects of CDSS on management and

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Study	Study characteristics	Brief summary of main outcomes	Quality appraisal	Outcome measures	Data information retrieval, transfer (EMR)	CPOE	ePrescribing	CDSS	Authors' interpretative comments
	management, 1 on heart failure, 2 each on stroke and coronary heart disease Majority in US in-patients	in incidence of AMI in patients suffering from coronary artery disease No benefit in the management of hypertension		disease, and hypertension management Pooled data analysed for each outcome measure In studies analysing blood pressure management, a two-sample *t*-test tested MD in SBP between intervention and control groups A fixed-effects meta-analysis model applied to mean differences in SBP				for prevention of ischaemic or haemorrhagic stroke in one study (RR reduction of 16.8% (95% CI 13.1, 23.8) and 16.7% (95%CI 13.5, 22.9) respectively) No clinically relevant effect in reducing blood pressure	control of blood pressure Secular trends in care over the time gap between baseline and intervention periods, absence of optimal management of all relevant risk factors and very short follow-up of 6 months limit ability of studies to adequately assess role of CDSS in preventing coronary artery disease
Sahota *et al.*[12] (2011)	36 RCTs evaluating effect on process of care or patient outcomes of a CDSS used for acute medical care vs care provided without CDSS Studies published up to January 2010, majority in US, The Netherlands and UK in-patients	CDSS can improve chronic disease management of diabetes and preventive care; 10/36 (27.8%) articles examined meaningful patient outcomes and none showed significant reductions in patient morbidity or mortality, although 5/36 (13.9%) found small reductions in LOS	AMSTAR 8/11 Methodological quality was fair (mean score 6.4/10; 95% CI 5.7, 7.2)	Individual studies were rated positive, negative or no effect depending on whether there was any benefit or harm shown over the control group or there was a statistically significant improvement/harm in at least 50% of relevant outcomes. Processes reviewed included preventative care, chronic disease management, and therapeutic drug monitoring and dosing	N/a	N/a	N/a	4/5 (80%) trials showed improved diabetes management, 9/11 (82%) demonstrated improvement in processes of care with regard to alerts of possible drug interactions or reminders for preventive therapies such as vaccines Small improvement in lipid monitoring and treatment No benefits seen in trials targeting management of angina, myocardial infarction, heart failure, asthma or COPD	Magnitude of effects not determined (studies were simply tallied up in terms of the proportion with positive results)
Goldzweig *et al.*[24] (2014)	23 articles targeting use of radiological interventions published between 1995 and 2013: 3 RCTs, 7 time series studies and 13 pre–post studies 10 interventions targeted 'high-cost imaging', including MRI, CT and nuclear medicine tests; 4 targeted pulmonary CT angiography; 2 targeted CXR; 4 targeted multiple	Moderate-quality evidence using the GRADE criteria that EMR-based interventions can reduce inappropriate test ordering by a moderate amount and reduce utilisation by a small amount	AMSTAR 8/11 21/23 studies rated as providing moderate-quality evidence	Primary outcome was change in level of appropriateness Pooled analysis for appropriateness and utilisation were obtained from articles included	N/a	N/a	N/a	9/13 (69%) studies of test appropriateness reported moderate improvement (effect size 0.48, 95% CI –0.25 to 0.71) 6/13 (46%) studies reported small decrease in overall utilisation (effect size 0.13; 95% CI –0.23, –0.04)	Low quality evidence of greater effectiveness for interventions that include a 'hard stop' preventing clinicians from overriding a CDSS determination that a test order is inappropriate. Audit-and-feedback may be useful implementation tool, but data too sparse to draw conclusions Few data on potential harms of decision support tools to

	radiologic investigations; 3 targeted other radiological targets	Moderate-quality evidence using the GRADE criteria that EMR-based interventions can reduce inappropriate test ordering by a moderate amount and reduce utilisation by a small amount							reduce inappropriate radiology test ordering
Thompson *et al.*[9] (2015)	45 studies published up to July 2013: 5 described EMR, 11 described CPOE, 17 described CDSSs, 6 described surveillance systems and 6 described electronic medication reconciliation tools Majority in US in-patients	No substantial effects on mortality (ICU mortality or 90-day mortality), hospital LOS or costs	AMSTAR 8/11	Effects of eHealth technologies in the in-patient and ICU on mortality, LOS and cost Evidence on the goals of HIT providing improvement in the quality, safety and efficiency of care while reducing disparities, engaging patients and families in their care, promoting health, improvement in care coordination and promoting privacy and security of records Pooled analyses used random effects models in calculating odds ratios or mean differences	No effect of EMR on mortality in hospital or ICU settings Surveillance systems reduced in-hospital mortality (OR 0.85; 95% CI 0.76, 0.94) Most studies that assessed costs (8/14) reported some decrease in costs	No effect of CPOE on mortality or hospital LOS	N/a	CDSS associated with marginally significant reduction in mortality (OR 0.83; 95% CI 0.69, 1.00); no effect on hospital LOS	Costs unable to be quantitatively evaluated due to study heterogeneity; cost effectiveness was not evaluated Significant study heterogeneity and small clinical effects Lack of effect attributable to the small number of studies, method of EMR implementation, interpretation of correct use of EMRs and analytical methods
Roshanov *et al.*[7] (2011)	35 qualitative studies searched up to January 2010: 2 systemic reviews, 12 RCTs, 1 CT, 20 review articles Majority in US hospital clinics	Some evidence that CDSSs can modify practitioner test-ordering behaviour in terms of reducing test ordering rates	AMSTAR 7/11 Most individual studies had good methodological quality (median quality score 8/10)	Studies of effectiveness of CDSS intervention effects were considered 'positive' if they showed a statistically significant improvement in at least 50% of diagnostic process outcomes or pre-specified primary or secondary outcomes Magnitude of effect in each study was not determined by the authors	N/a	N/a	N/a	Benefits: 18/33 studies (55%) showed improved test-ordering behaviour, including 5/6 (83%) for diagnosis, 5/8 (63%) for appropriate disease treatment monitoring and 6/17 (35%) for appropriate disease monitoring for specific conditions (HbA1c, blood lipids, blood pressure, albumin : creatinine ratio, eye and foot health) 4 studies assessing reductions in test-ordering rates were all positive. 2 trials assessing reductions in cost of care and annual laboratory costs were positive	Sensitivity analysis showed no differences in reported success rates for diagnostic process outcomes Costs, user satisfaction and effect on workflow were rarely investigated or reported

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Study	Study characteristics	Brief summary of main outcomes	Quality appraisal	Outcome measures	Data information retrieval, transfer (EMR)	CPOE	ePrescribing	CDSS	Authors' interpretative comments
								Harms: alert burden noted in 8/35 studies (23%) of drug monitoring alerts with no improvement in patient outcomes	
Roshanov *et al.*[13] (2011)	55 RCTs of CDDS in chronic disease management published up to January 2010 Majority in US in-patients	CDSS significantly improve chronic disease management, alerting of pharmacists to drug interactions, reminders to physicians for preventative therapies and use of diagnostic and dosing aids Effects for each CDSS were considered positive (or negative) if they showed a statistically significant improvement (or harm) in at least 50% of relevant primary or secondary study outcomes	AMSTAR 7/11 Methodological quality of trials good (median score of 8/10)	CDSS effects on chronic disease management processes in regards to diabetes, hypertension, dyslipidaemia, asthma, COPD and cardiac care; effects on costs and process-related outcomes	N/a	N/a	N/a	25/55 trials (52%) demonstrated significant improvements in chronic disease management 11/36 (31%) trials that measured effect on non-major (surrogate) patient outcomes demonstrated benefits; 9/11 trials (82%) showed improvement in alerting pharmacists to possible drug interactions or giving reminders to physicians for preventative therapies 3/8 studies (37%) showed improvement in adherence to guidelines and algorithms 2/3 studies (66%) showed improvement in use of diagnostic aids 9/14 studies medication dosing aids (64%) of showed improvement in prescribing	Type 2 errors may be present due to summarising the evidence by vote counting. Effect sizes may be underestimated and results may also be affected by publication bias Some studies considered to show no effect found improvement on a minority of secondary or non-pre-specified clinical outcomes
Hemens *et al.*[14] (2011)	65 RCTs of CDSS published between 2004 and 2010; 59 assessed processes of care and 29 assessed patient outcomes	CDSS improved process of care measures In univariate analysis, CDSS not integrated with an EMR were more likely to	AMSTAR 7/11 Methodological quality of trials high, with median quality score of 8/10	Effect of CDSS on drug related process of care measures or patient outcomes compared with usual care.	N/a	N/a	N/a	Benefits: 38/59 studies (64%) assessing processes of care were positive 6/29 studies (21%) assessing clinical	Authors relied upon vote counting in obtaining an estimate of how often CDSS improved process or patient outcomes

	Majority in US in-patients	improve process of care outcomes compared with those with EMR linkage (16/20 (80%) vs 18/35 (51%) respectively; $P = 0.03$)		Features of studies or systems associated with improved process or patient measures CDSS classified as drug therapy management only or multifaceted CDSS depending on the complexity of the intervention Improvement was considered to have occurred where 50% or more of the selected outcomes showed a benefit with CDSS compared with control				outcomes were positive 8/15 trials (53%) reported that >70% respondents thought CDSS improved care 6/12 trials (50%) reported significantly decreased costs, 5/12 (41.7%) reported no change in costs and 1/12 (8%) reported increased costs Harms: 2/29 trials (7%) reported evidence of harm: high rate (40%) of clinically inappropriate reminders in one study; inappropriate redose of intraoperative prophylactic antibiotics	
Bright *et al.*[17] (2012)	148 RCTs published between 1976 and 2011 analysing effects of CDSS on clinical outcomes, health care processes, workload and efficiency, patient satisfaction, cost, provider use and implementation Majority in US in-patients	Both commercially and locally developed CDSS are effective at improving health care process measures across diverse settings, but evidence for clinical, economic, workload and efficiency outcomes remains sparse	AMSTAR 7/11 Authors used GRADE criteria to assess quality of evidence	Studies reported at least one of the following outcomes: clinical (LOS, morbidity, mortality, health-related QOL, and adverse events), health care process (recommended preventive care, investigation or treatment ordered or completed), user workload and efficiency (user knowledge, number of patients seen, clinician workload and efficiency), relationship centred (patient satisfaction), economic (cost and cost-effectiveness), or use and implementation by a health care provider	N/a	N/a	N/a	16/22 studies (73%) reported fewer morbid outcomes (RR 0.88; 95% CI 0.80, 0.96) based on moderate=quality evidence 25/43 studies (58%) reported increased use of preventative care services (OR 1.42; 95% CI 1.27, 1.58) based on high-quality evidence 20/29 studies (69%) reported improved ordering or completion of clinical investigations (OR 1.72; 95% CI 1.47, 2.00) based on moderate-quality evidence 46/67 studies (67%) reported improved adherence to treatment guidelines (OR 1.57; 95% CI 1.35, 1.82) based on high-quality evidence	Moderate-quality evidence from academic and community in-patient settings showing locally and commercially developed CDSS had lower treatment costs, total costs and reduced costs compared with control groups and other non-CDSS intervention groups

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Study	Study characteristics	Brief summary of main outcomes	Quality appraisal	Outcome measures	Data information retrieval, transfer (EMR)	CPOE	ePrescribing	CDSS	Authors' interpretative comments
								No significant effects of CDSS on mortality, adverse drug reactions, LOS or clinician knowledge or confidence in managing patient care based on low-quality evidence	
Goldzweig *et al.*[23] (2015)	23 studies published between 1995 and September 2014: 3 RCTs, 7 time series and 13 pre–post studies Majority in US in-patients	CDSS integrated with EMR can modestly improve appropriate use of diagnostic radiology and decrease overall use	AMSTAR 7/11	Effects of CDSS on appropriateness and overall use of diagnostic radiology	N/a	N/a	N/a	Benefits: 13/23 studies (56%) provided moderate-quality evidence that CDSS reduces inappropriateness (ES –0.49; 95% CI –0.71, –0.26) and reduces overall use (ES –0.13; 95% CI –0.23, –0.04) Harms: 1/4 studies (25%) reported an absolute 7.4% increase (from 1.9% to 9.3% of patients) in preoperative chest radiographies that were inappropriately not ordered; 1/4 (25%) revealed decreased ordering of urological tests (where 6/12 cases significantly influenced patient outcomes); and 2/4 studies (50%) reported physician dissatisfaction due to time constraints and perceived inefficiencies	Forcing functions to prevent health care providers from overriding CDSS for test ordering may be more effective in improving appropriateness of test requests
Main *et al.*[11] (2010)	24 clinical, cost-effectiveness and cost-comparison studies between 1974 and April 2009: 7 CRCTs, 4 RCTs, 2 NRCTs, 1 cross-over trial, 2 ITS studies, 1 CPP study and 7 UPP studies Majority in US and UK in-patients	Mixed results, but overall a beneficial effect of CDSS in conjunction with CPOE over and above CPOE alone No significant additional utilisation of healthcare resources or adverse events observed	AMSTAR 6/11	Number of test orders, costs and practitioner performance when CDSS applied to order communication for diagnostic, screening or monitoring test ordering compared with order communication without CDSS	N/a	N/a	N/a	Statistically significant decrease of 17.6% in mean (± s.d.) number of tests ordered per patient visit (1.6 ± 0.7 vs 1.9 ± 1.0) CDSS significantly improved practitioner performance in 15/24 studies (62.5%) No significant decrease in costs for blood test orders Mixed results for effect of CDSS recommendations and reminders	Difficult to conclude why some CDSS were successful in terms of either decreasing laboratory or imaging test rates due to the heterogeneity between studies Very limited data available on cost-effectiveness of CDSS

Nirantharakumar *et al.*[16] (2012)	2 RCTs, 8 reviews of before and after analyses, one case series and 3 observational descriptive studies from 1970 to 2010 Majority in US in-patients with diabetes and/or hyperglycaemia	Some evidence CPOE and CDSS may have a beneficial effect on care of in-patients with diabetes	AMSTAR 6/11	Outcome measures of benefits or harms related to glucose control, use of insulin, patient satisfaction, LOS and quality of diabetic care	N/a	N/a		Benefits: reduced use of sliding scale insulin and greater use of basal bolus insulin regimens in 3/4 studies (25%) 9/10 studies (90%) report a reduction using CPOE in patient-day-weighted mean blood sugar level with no mean increase in hypoglycaemic episodes Increased guideline adherence with more consistent and efficient prescription of insulin and oral hypoglycaemic drugs	No guarantee of uptake of electronic alerts Harms: increased testing rates for HBA1c
Campanella *et al.*[25] (2015)	Meta-analysis of 47 articles published between 1994 and 2013 Majority in US and UK in-patients	EMR systems, when properly implemented, can improve quality of health care, increase time efficiency and guideline adherence, and reduce medication errors and ADEs	AMSTAR 5/11	9 studies investigated relationship between EMR use and documentation time, 6 studies investigated association between EMR and guideline use, 24 studies evaluated medication errors, 7 studies evaluated ADEs and 8 studies investigated mortality Meta-analysis used random-effects model	Reduced documentation time (MD 22.4%; 95% CI 6.0%, 38.8%)	N/a	Fewer medication errors (RR 0.46; 95% CI 0.38, 0.55) Fewer ADEs (RR 0.66; 95% CI 0.44, to 0.99)	Improved guideline adherence (RR 1.33; 95% CI 1.01, 1.76) No effect on mortality	Large study heterogeneity (Q-test $P < 0.001$ and $I^2 = 80.8\%$) Information on technical items and procedures that shape the EMR software was not included in most studies
Fraccaro *et al.*[26] (2015)	No restriction on search date 20 reviews of CDSS with qualitative analysis of their effects on management of patients with multiple comorbidities Majority in European in-patients Most articles focused on medication use (10), clinical guidance (8) and diagnosis (6)	CDSS that systematise clinical practice guidelines without considering the interactions of different conditions and care processes may lead to unhelpful or harmful clinical actions	AMSTAR 5/11 Methodological quality of included studies was not measured	Analysis of CDSS targets, contextual information about patients, practitioners, services, decision maker(s), diseases and evaluation	N/a	N/a	N/a	Benefits: 1/3 studies (33%) of medication reconciliation maintained accuracy of medication reviews but decreased work turnaround time by 60% Good performance and positive judgements about system outcomes from surveys in 2 articles Harms: absence of patient-centred approach required more user time and effort in providing individualised care	Only one article used Health Level Seven linkage to enable interoperability in health care Need for more evidence about how both conditions and care processes interact; databases exist in EMRs but are underused Little data about continuity of care and none for self-management interventions Lack of rigorous evaluations of

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Study	Study characteristics	Brief summary of main outcomes	Quality appraisal	Outcome measures	Data information retrieval, transfer (EMR)	CPOE	ePrescribing	CDSS	Authors' interpretative comments
									effectiveness and usability in multimorbid patients, which may compromise patient safety Adoption of coding technologies (e.g. Systematized Nomenclature of Medicine Controlled Trial) linked with EMR can improve CDSS
Murphy[22] (2014)	Review including 1 meta-analysis (143 RCTs), 1 meta-regression analysis of 162 RCTs, 2 systematic reviews Majority in US in-patients	CDSS effective in improving clinical processes and outcomes in specific situations (e.g. adherence to surveillance guidelines) Characteristics that increased CDSS effectiveness included: (1) providing advice to both patients and practitioners; (2) requiring practitioners to supply reasons for overturning advice; and (3) evaluation of CDSS by clinicians	AMSTAR 4/11	CDSS effect on optimising preventive services processes and appropriate care processes	N/a	N/a	N/a	Benefits: automatic provision of decision support as part of work flow (OR 1.45–1.85), point of care advice (OR 1.35–1.78), integration with charting or order entry (OR 1.47–1.67) CDSS that presented advice in the CPOE interface were less likely to be effective than standard CDSS interfaces (OR 0.37; 95% CI 0.17, 0.80) Advice to providers and patients increased adherence to CDSS recommendations (OR 1.78–2.77) Higher rates of ordering or completing recommended preventive care service (OR 1.42; 95% CI 1.27, 1.58) and appropriate medical treatment (OR 1.57; 95% CI 1.35, 1.82) Decrease in morbidity (RR 0.88; 95% CI 0.80, 0.96) Harms: alert fatigue associated with reduced adherence to advice presented by CDSS at order entry interface (OR 0.37; 95% CI 0.17, 0.80)	Physician compliance with CDSS better when there is an outside incentive (e.g. time savings) Meta-regression analyses suggested bias when CDSS evaluated by their own developers (OR 4.35; 95% CI 1.66, 11.44), hence third-party evaluation is encouraged System user hostility at the point of care when using insistent CDSS alerts that are too sensitive and insufficiently specific

Appendix 2. Summary of findings from reviews of systematic reviews included in the present analysis

ADEs, adverse drug events; AMSTAR, Assessing the Methodological Quality of Systematic Reviews; CDSS, computerised decision support systems; CPOE, computerised physician order entry; EMR, electronic medical records; HIS, health information system

Reference	Study characteristics	Brief summary of main outcomes	Quality appraisal	Outcome measures	Data information retrieval, transfer (EMR)	CPOE	ePrescribing	CDSS	Authors' interpretative comments
Black *et al.*[6] (2011)	108 reviews published between 1997 and 2010: 53 reviews provided main empirical evidence base, 55 supplementary reviews provided context to the findings and their interpretation Majority in US in-patients	Beneficial effect of most eHealth technologies is often absent or, at best, only modest	AMSTAR 11/11 Individual studies were generally of substandard methodological quality, reporting and utility	11 studies assessed benefits and risks associated with EMRs; 3 assessed benefits associated with digital radiology; 8 assessed benefits and risks associated with CPOE; 28 assessed benefits and risks associated with ePrescribing; 8 evaluated benefits and risks associated with CDSS Pooled analyses were collected for each category and the evidence of benefit was rated as not assessed (n/a), none (+/–), weak (+), weak to moderate (+/++) and moderate (++)	Benefits: 8/11 studies (73%) reported weak evidence of organisational efficiency for the use of digital radiology Low to moderate evidence for improvements in data security in 1/11 studies (9%) studies, in 4/11 (36%), accessibility in 3/11 (27%), completeness in 4/11 (36%), comprehensiveness in 2/11 (18%) and efficiency in 9/11 (82%) Improved search and retrieval functions for secondary uses such as research in 2/11 studies (18%) Harms: increased time depending on end-user skill in 6/11 studies (54.5%) Insecure data and access issues due to system processes in 1/11 studies (9.1%)	Benefits: small effect on organisational efficiency Modest effect on time taken to process and deliver pathology or radiology results Moderate effects on improving practitioner performance Small improvements in resource utilisation in 5/8 studies (63%) and delivery of care in 7/8 studies (88%) Small cost savings in 4/8 studies (50%) and small time savings in 4/8 studies (50%) Harms: increased time to interact with systems in 3/8 studies (38%), increased interruptions in 3/8 studies (38%), workarounds noted in 1/8 studies (13%)	Benefits: moderate evidence for improving organisational efficiency Decreased turnaround time in 8/28 studies (29%); more accurate communication between prescribers and pharmacy in 5/28 studies (18%) Weak to moderate evidence of fewer medication errors and more optimal prescribing Weak to moderate evidence of improvement in surrogate outcomes (e.g. drug dosages, ADEs and disease control endpoints) in 25/28 (89%), guideline adherence in 16/28 (57%), safer prescribing in 17/28 (61%), communication in 5/28 (18%), patient outcomes in 9/28 (32%) and resource/cost savings in 10/28 (36%) Harms: some evidence of increased time and costs	Benefits: weak evidence for improved practitioner performance Increased provision of preventative care measures, disease-specific examinations or measures, corollary orders and decreased use of redundant care Improvement in delivery of indicated care in 13/17 studies (48%), guideline adherence in 11/17 (65%) and surrogate outcomes (e.g. increased immunisation rates, reduced resource utilisation, more timely diagnosis) in 13/17 (76%) No effect on patient outcomes in 17 studies Harms: impaired practitioner performance in 1/17 studies (6%) Inferior patient outcomes in 1/17 studies (6%)	Literature poorly referenced within bibliographic databases reflecting non-standard terminology and lack of consensus on a taxonomy of eHealth technologies Varying degrees of overlap between individual reviews and contradictory findings among reviews of the same primary studies Highly heterogeneous and complex nature of interventions makes consistency of findings difficult to detect Beneficial effect of EMR limited to a few academic clinical centres where systems were developed in-house, underwent extensive evaluation and continual improvements supported by strong sense of local ownership Evaluations gave little attention to risks and costs Promising systems, unless properly evaluated with results fed back into development, may not 'mature' to the extent needed to realise their potential when deployed in routine clinical settings

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Appendix 2. (*continued*)

Reference	Study characteristics	Brief summary of main outcomes	Quality appraisal	Outcome measures	Data information retrieval, transfer (EMR)	CPOE	ePrescribing	CDSS	Authors' interpretative comments
Lau *et al.*[27] (2010)	50 reviews from 1966 to 2008: 287 controlled studies of HIS across 8 countries Majority in US (38%) and UK (28%) Both hospital and non-hospital settings 9 reviews included meta-analysis of aggregate effects, 8 studies included summary statistics to describe aggregate effects	Some evidence for improved quality of care, which varied across topic areas HIS with CPOE and CDSS was effective in reducing medication errors, but not those for drug dosing in maintaining therapeutic target ranges HIS did not lead to significant improvement in resource utilisation, healthcare cost or health outcomes	AMSTAR 5/11: 31/50 studies assessed the methodological quality of included reviews	Measures covering medication management, preventative care, health conditions, data quality and various care processes and management The Infoway Benefits Evaluation Framework[A] was used to categorise the measures Vote-counting method in some reviews tallied the number of positive, neutral and negative studies based on significant differences between groups Studies with multiple measures were considered 'positive' if >50% of results improved significantly	Total of 180/287 (62.7%) positive studies, 9/287 (3.1%) negative studies and 98/287 (34.1) neutral studies Modest positive feedback on information accuracy in 55/72 (76.4%) and completeness in 25/41 studies (61.0%). Total of 313/575 positive studies (54.4%) by reported metrics, 244/575 neutral studies (42.4%) and 18/575 negative studies (3.1%)	N/a	Positive feedback for medication orders in 41/62 studies (66.1%); negative for 4/62 studies (6.5%) No difference in performance or practice standards or costs	Positive feedback for preventative care-reminders, alerts, feedback in 12/15 studies (80%) Positive user feedback for greater accessibility of alerts and orders in disease management in 4/5 studies (80%). 42/66 positive studies (63.6%) for reduction of medication errors in 11/13 positive studies (84.6%) for immunisation administration Mainly neutral feedback with regard to management of diabetes and hypertension. No benefit in prevention of adverse events	In many instances, studies were not designed and did not have sufficient power or duration to properly assess health outcomes Caution advised in interpreting findings because of wide variations in organisational contexts and how HISs were designed, implemented, used and perceived

[A]Lau F, Hagens S, Muttitt S. A proposed benefits evaluation framework for health information systems in Canada. *Healthc Q* 2007; 10: 112–6, 118.