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Effects of eHealth on hospital practice: synthesis of the current literature

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Abstract

Objective. The transition to digital hospitals is fast-moving. Although US hospitals are further ahead than some others in implementing eHealth technologies, their early experiences are not necessarily generalisable to contemporary healthcare because both the systems and technologies have been rapidly evolving. It is important to provide up-to-date assessments of the evidence available. The aim of this paper is to provide an assessment of the current literature on the effects to be expected from hospital implementations of eHealth technologies.

Methods. A narrative review was conducted of systematic reviews investigating the effects of eHealth technologies (clinical decision support systems (CDSS), computerised provider order entry (CPOE), ePrescribing, electronic medical records (EMRs)) published between November 2015 and August 2017 and compared the findings with those of a previous narrative review that examined studies published between January 2010 and October 2015. The same search strategy and selection criteria were used in both studies.

Results. Of the seven relevant articles, three (42.9%) examined the effects of more than one eHealth system: only two (28.6%) studies were high quality, three (42.9%) were of intermediate quality and two (28.6%) were of low quality. We identified that EMRs are largely associated with conflicting findings. Previous reviews suggested that CPOE are associated with significant positive results of cost savings, organisational efficiency gains, less resource utilisation and improved individual performance. However, these effects were not investigated in the more recent reviews, and only mixed findings for communication between clinicians were reported. Similarly, for ePrescribing, later reviews reported limited evidence of benefits, although when coupled with CDSS, more consistent positive findings were reported.

Conclusion. This overview can help inform other hospitals in Australia and elsewhere of the likely effects resulting from eHealth technologies. The findings suggest that the effects of these systems are largely mixed, but there are positive findings, which encourage ongoing digital transformation of hospital practice.

What is known about the topic? Governments are increasingly devoting substantial resources towards implementing eHealth technologies in hospital practice with the goals of improving clinical and financial outcomes. Yet, these outcomes are yet to be fully realised in practice and conflicting findings are often reported in the literature.

What does this paper add? This paper extends a previous narrative review of systematic reviews and categorises the effects of eHealth technologies into a typology of outcomes to enable overall findings to be reported and comparisons to be made. In doings so, we synthesise 7 years of eHealth effects. Mixed results are largely reported for EMRs, with many

benefits being compromised by practices stemming from resistance to EMRs. Limited evidence of effectiveness exists for CPOE and ePrescribing. CDSS are associated with the most consistent positive findings for clinician- and hospital-level effects. We observed renewed interest in the literature for the effect of eHealth technologies on communication both between clinicians and with patients. Other new insights have emerged relating to effects on clinical judgement, changing practice and staff retention.

What are the implications for practitioners? eHealth technologies have the potential to positively affect clinical and financial outcomes. However, these benefits are not guaranteed, and mixed results are often reported. This highlights the need for hospitals and decision makers to clearly identify and act on the drivers of successful implementations if eHealth technologies are to facilitate the creation of new, more effective models of patient care in an increasingly complex healthcare environment.

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Introduction

eHealth technologies, including electronic medical records (EMR), computerised provider order entry (CPOE), ePrescribing and computerised decision support systems (CDSS), are promoted for their financial and clinical benefits. This has led eHealth to become central to many government agendas worldwide,[1] with 75% of US hospitals implementing EMRs.[2] However, negative unintended consequences are being increasingly reported, with clinicians using eHealth technologies in unanticipated ways.[3] Moreover, some clinicians resist using these systems[4] and develop workarounds compromising patient care.[5] This has prompted the US government to incentivise 'meaningful use' of eHealth technologies, but it is still uncertain how effective these incentives have been.

The transition to digital hospitals is fast moving. Although US hospitals are further ahead than some others in implementing eHealth technologies, their early experiences are not necessarily generalisable to contemporary healthcare because both the systems and technologies are rapidly evolving. This constantly changing environment, coupled with the heterogeneity in reported eHealth effects, means it is important to provide up-to-date assessments of the available evidence. The aim of this paper is to provide an assessment of the current literature on the effects to be expected from hospital implementations of eHealth technologies.[6] This paper provides the detailed background evidence for our recently published Deeble Institute Evidence Brief.[7]

Methods

Keasberry *et al*.[6] provided a narrative review of systematic reviews of the effects of EMR, CPOE, CDSS and ePrescribing published between 1 January 2010 and 31 October 2015. We update this review by replicating their search methods to review studies published from 1 November 2015 to 1 August 2017. We used the same search strategy, databases (PubMed, Medline, Cochrane) and inclusion and exclusion criteria as Keasberry *et al*.[6] As in that study, remote health and patient-focused eHealth systems were excluded, as were reviews: (1) pertaining to a single discipline, investigation, medicine or vendor; (2) focusing on implementation only; and (3) conducted predominantly in non-hospital settings or developing countries. (For the detailed search strategy used for PubMed as well as the complete list of the inclusion and exclusion criteria used in the present study, readers are referred to the supplementary material in Keasberry *et al*.[6])

Our search retrieved 563 articles. One author (RE) read all abstracts and coded them for inclusion and exclusion, whereas another author (ABJ) read and coded one-third of them. Due to high inter-rater reliability between the two authors' codes (Cohen's kappa 0.90), the first author's (RE) coding was used for all abstracts. Through this process, 39 articles were identified as potentially relevant for inclusion. Two authors (RE, ABJ) then conducted a full-text review of each article for inclusion or exclusion. Their assessments were highly similar (Cohen's kappa 0.84), with disagreements resolved by consensus. Through this process, seven articles were determined to be relevant. In four of the seven articles, the authors explicitly described their study as a systematic review. Three were not described as systematic reviews but were performed in a manner very similar to systematic reviews[8] and thus were included. The 32 full-text articles that were excluded are listed in Table S1, available as Supplementary Material to this paper. Fig. 1 depicts the final Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagram for inclusion and exclusion.

Each article was assessed for quality using AMSTAR (a measurement tool to assess systematic reviews).[9] In accordance with Long *et al*.,[10] an AMSTAR score $\geq$8 was determined to be a high quality review, a score of 4–7 was taken to indicate intermediate quality, and scores <4 were taken to indicate low quality.

The previous narrative review[6] acknowledged the heterogeneity of studies and opted to present the findings using a narrative synthesis. We follow that approach but also categorise the effects into a typology of outcome measures. Specifically, we adapted the typology of Black *et al*.,[11] which details the benefits and harms of CPOE, CDSS, ePrescribing and EMRs. For effects that reflect a range over a single dimension (e.g. cost-savings and costs, which reflect a range of financial effects), we used a single outcome category (e.g. costs) and coded effects as positive or negative if more than half the studies in a review reported positive or negative results respectively, in line with previous reviews.[12]

Fig. 2 illustrates the adapted typology of outcome measures.[11] According to the typology, EMRs are associated with benefits of accessibility, completeness, legibility, organisational efficiency, secondary use of data and considerations

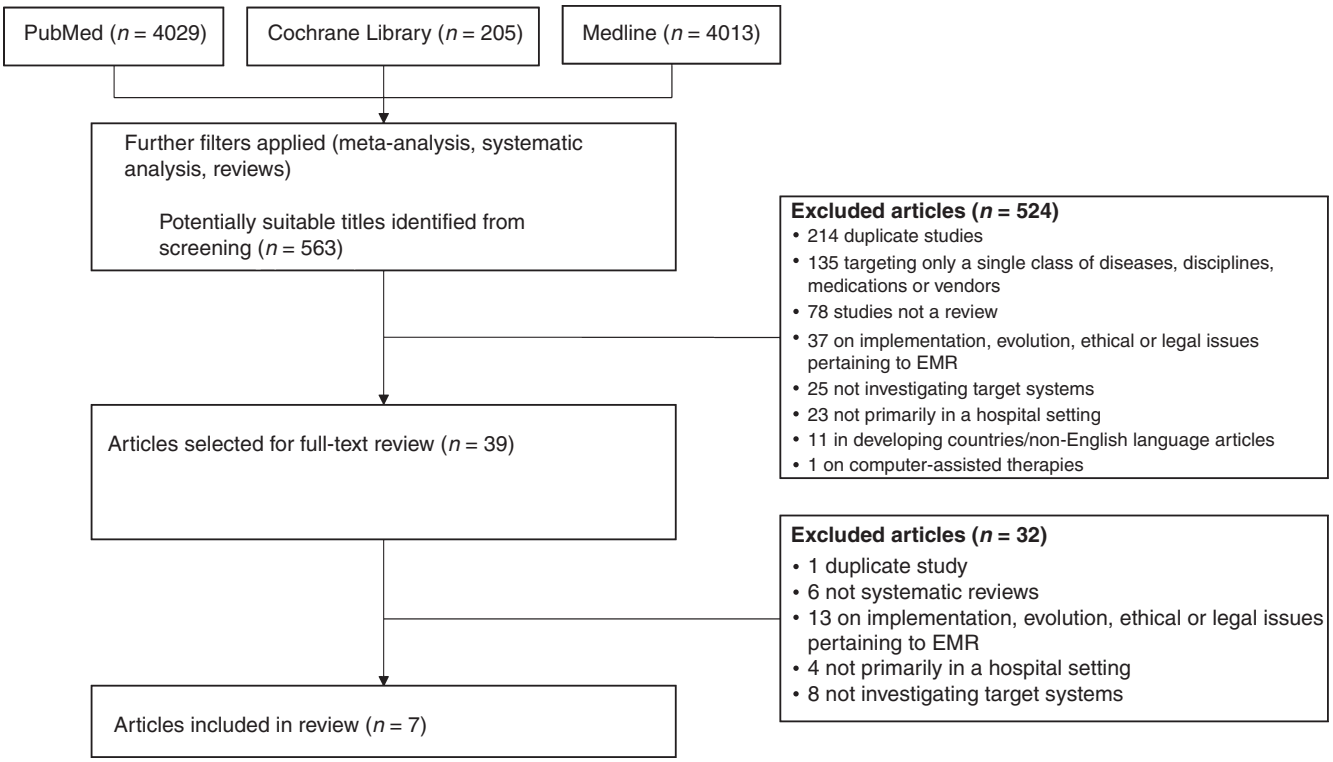

Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram of study selection. EMR, electronic medical record.

over data security, time, costs, communication with patients and paper persistence. CPOE are associated with improvements in resource utilisation, indicated care and patient outcomes, as well as issues related to workarounds, interruptions, cost and time delays. ePrescribing is associated with improvements in guideline adherence, safer prescribing and clinician communication, as well as considerations related to patient outcomes, time and costs. Finally, CDSS is associated with improvements in indicated care, guideline adherence, surrogate outcomes and considerations into patient outcomes and individual clinician performance.

We first categorised the effects reported in the narrative review[6] into the typology of outcome measures (Fig. 2) and identified any other emergent categories. Next, the effects reported in the updated studies were classified and compared with the findings reported in Keasberry *et al.*[6]

Results

Of the seven relevant articles, three (42.9%) examined the effects of more than one eHealth system:[3,5,12] CDSS were studied in six (85.7%) articles,[3,5,12–15] EMRs were studied in three (42.9%),[3–5] ePrescribing was studied in three (42.9%)[3,5,12] and CPOE was studied in two (28.6%).[3,5] Only two studies (28.6%) were high quality;[13,14] three (42.9%) were of intermediate quality[4,12,15] and two (28.6%) were of low quality.[3,5] The characteristics of the studies included are given in Appendix 1.

By way of contrast, the previous review by Keasberry *et al.*[6] identified 21 articles, most of which referenced multiple technologies. According to appendices 1 and 2 in Keasberry *et al.*,[6] four studies analysed the effects of multiple eHealth systems, five analysed EMRs, two investigated CPOE, four examined ePrescribing and 19 assessed CDSS.

The following sections detail the effects of each eHealth system and compare them with those reported by Keasberry *et al.*[6] Table 1 summarises the overall results.

Electronic medical records

Fourteen EMR effects were investigated in the updated review articles. Although eight of these effects were present in the previous review,[6] there were differences in valence (i.e. positive, negative, neutral or mixed) in the more recent articles. Overall, the updated results presents a more complex array of mixed and conflicting results when it comes to EMR benefits than reported previously.[6] For example, in the previous review completeness of information was improved by EMR,[6] yet the updated review found the opposite findings, with one low-quality study[3] and one intermediate-quality study[4] reporting negative results. Rathert *et al.*[4] reported that completeness of information (e.g. documentation of all relevant information of the patient's journey) in EMRs can be compromised with emotional and psychosocial information being overlooked as patients withhold relevant information due to their negative data security perceptions. Furthermore, Zheng *et al.*[3] identified that EMRs were not capable of recording all required health information. Similarly, data integrity was positive in the previous review,[6] yet an intermediate-quality study found mixed results reporting better-quality biomedical but poorer-quality psychosocial information in patient records.[4] The same study[4] highlighted the presence of

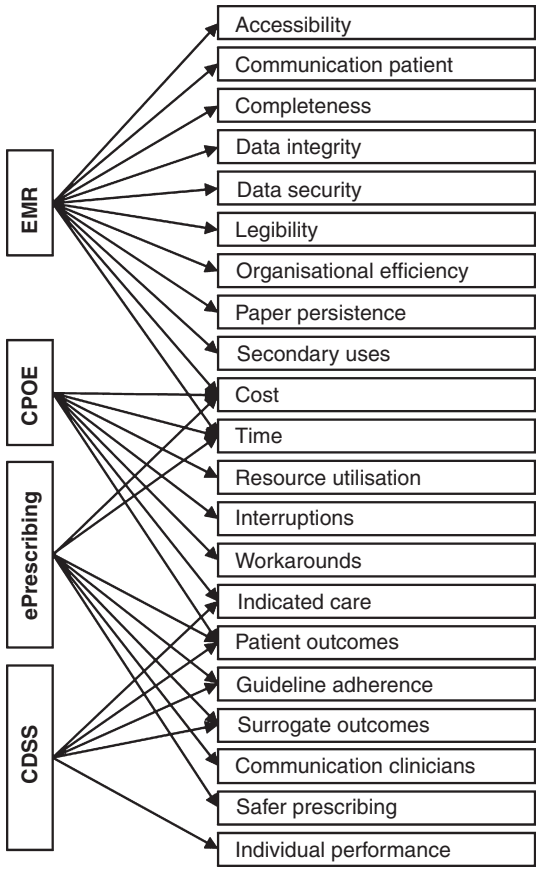

Fig. 2. Adapted typology of outcomes. CDSS, clinical decision support systems; CPOE, computerised provider order entry; EMR, electronic medical record.

unintended data entry errors compromising record quality, with similar findings reported by Zheng *et al*.[3]

The positive results in the previous review for costs, organisational efficiency, overall perception and mixed results for data security were all found to be either negative or mixed findings in the updated review, although these mostly arose from two low-quality articles[3,5] that only examined unintended consequences. These same studies also reported some additional negative results not reported previously, including guideline adherence, staff retention, clinician productivity, financial effects, organisational efficiency, changing practices and workarounds.[3] However, because these studies were specifically looking for unintended consequences, which are most likely to constitute undesirable effects,[5,16] they run the risk of ascertainment bias in overidentifying and overrating such effects compared with previous studies.

Communication was another effect not reported in Keasberry *et al*.[6] One intermediate-quality study reported mixed results for communication between clinicians and patients,[4] finding EMRs have changed the nature of patient encounters. The study identified that physicians need to actively maintain eye contact and recognise non-verbal cues while interacting with the EMR. On the upside, the same study reported that improved communication can result when physicians actively engage patients by showing them their own data using the EMR.[4]

Findings regarding patient outcomes painted a more complex picture compared with the previous review, which reported insufficient evidence.[6] Positive patient outcomes were found in an intermediate-quality study,[4] although negative findings were observed in a low-quality study investigating unintended consequences.[3] The former were attributed to EMRs facilitating clinician decision making,[4] whereas the latter derived from the unsafe use of EMRs with workarounds, continual copy and pasting, and clinician overreliance on the EMR.

Computerised provider order entry

Only two studies in our updated review examined the effect of CPOE. Both were of low quality, examined only unintended consequences and only examined CPOE in the presence of other eHealth systems. Both reviews focused only on one effect, communication among clinicians, with one review reporting mixed[3] and one reporting negative[5] findings. Although Zheng *et al*.[3] identified that CPOE use can facilitate proactive communication between clinicians, Kuziemsky *et al*.[5] found that errors in CPOE can result in miscommunication between clinicians.

Communication among clinicians was not reported in Keasberry *et al*.,[6] although their review identified other CPOE effects not examined in the recent studies, such as cost, individual clinician performance, interruptions, organisational efficiency, patient outcomes, resource utilisation, time and workarounds.

ePrescribing

Three studies investigated ePrescribing in the updated review, but all within the context of ePrescribing integrated with other EMR functions. Two studies were of low quality and investigated unintended consequences of eHealth,[3,5] and one study was of intermediate quality.[12] Only three effects were investigated: communication among clinicians, patient outcomes and safer prescribing. All three were investigated in the previous review and were found to be positive.[6] However, studies in the present review reported mixed, negative and neutral results for these three effects respectively.

With regard to communication among clinicians, Kuziemsky *et al*.[5] indicated that communication processes involving clinicians were negatively affected and that protocols needed to be put in place to ensure effective exchange of information. For patient outcomes, Zheng *et al*.[3] found mixed results, with some studies reporting a reduction in adverse drug events whereas others reported an increase. Moreover, Zheng *et al*.[3] found negative results for safer prescribing, whereas Nabovati *et al*.[12] reported no significant effect of ePrescribing on dangerous drug interactions and safer prescribing. However, when ePrescribing was paired with CDSS, more positive results were reported,[12] which are discussed in the following section.

Computerised decision support systems

Overall, six studies investigated CDSS, with two each being of low,[3,5] intermediate[12,15] and high quality.[13,14] In total, 12 effects were observed in the recent studies for CDSS. In intermediate- and high-quality reviews, positive effects were found for guideline adherence,[12,14] indicated care,[12–15] organisational efficiency,[14,15] clinicians' overall perceptions of the CDSS,[13–15] safer prescribing[12] and patient outcomes.[11,14,15] This is in

Table 1. Effects of clinical decision support systems (CDSS), computerised provider order entry (CPOE), electronic medical records (EMRs) and ePrescribing systems reported in the literature

Blank cells indicate that the effect has not been investigated for the specific eHealth system. +, positive effect; –, negative effect; +/–, mixed positive and negative effects; 0, no evidence of effect; +/0, mixed positive and neutral effects

Effects	January 2010–October 2015[A]				November 2015–August 2017 (Appendix 1)			
	CDSS	CPOE	EMR	ePrescribing	CDSS	CPOE	EMR	ePrescribing
Accessibility[B]	+		+					
Changing practice[D]					–		–	
Clinical judgement[D]					+			
Communication employees[B]			0	+		+/–	+/–	–
Communication patients[B]							+/–	
Completeness[B]			+				–	
Cost[B]	+/0	+	+	+/–	0		–	
Data integrity[B]			+		+		+/–	
Data security[B]			+/–				–	
Guideline adherence[B]	+			+/0	+		–	
Indicated care[B]	+				+			
Individual performance[B]	+/–	+		0			–	
Interruptions[B]	–	–						
Legibility[B]			+					
Organisational efficiency[B]	+	+	+	+	+		–	
Overall perception[C]	+		+		+		+/–	
Paper persistence[B]					–			
Patient outcomes[B]	+	0	0	+	+		+/–	+/–
Resource utilisation[B]	+	+						
Safer prescribing[B]	+			+	+			0
Secondary data uses[B]			+		+			
Staff retention or recruitment[D]							–	
Surrogate outcomes[B]	+			+				
Time[B]	–	+/–	+/–	+/–				
Workarounds[B]		–					–	

[A]Categorised into the typology based on the benefits reported in Keasberry *et al.*[6]
[B]Originally reported in Black *et al.*[11]
[C]Orginally reported in Keasberry *et al.*[6]
[D]Not identified in previous reviews, but found in the updated review.

agreement with findings in the previous review.[6] Other positive effects not reported previously[6] include improved data integrity and clinical judgment in one high-quality study.[14] In terms of data integrity, Dunn Lopez *et al.*[14] found significant improvements in the accuracy of information and the ability of clinicians to accurately interpret CDSS content.

In the previous review,[6] CDSS either reduced or had no effect on healthcare cost, but in the updated review no evidence was found of this effect. For example, Cook *et al.*[13] analysed CPOE integrated with CDSS by means of built-in infobuttons and found no significant difference in order costs compared with stand-alone CPOE. Two new negative effects of CDSS were found, with one low-quality review reporting changes in practice,[5] which can lead to risky workarounds, and another high-quality review reporting persistent use of paper forms.[14]

Discussion

This paper provides a contemporaneous account of the effects of eHealth technologies in hospital practice and classifies the effects into a typology of outcomes.[11] A broad range of effects was reported for CDSS and EMRs, whereas there was limited evidence for ePrescribing and CPOE, which were only investigated in conjunction with other eHealth technologies. The quality of most reviews was limited, with no high-quality reviews relating to CPOE, EMRs and ePrescribing. In contrast, high-quality reviews supported the positive effects of CDSS. The studies analysed were highly heterogeneous, which precluded attempts at meta-analysis, and, accordingly, results are only reported as a narrative synthesis

We found that the effects of EMRs were potentially not as straightforward as reported in the previous review,[6] with more mixed results apparent in the updated findings. This may be explained by the presence of more studies investigating unintended consequences in the present than previous review. However, when EMR systems were integrated with auxiliary technologies, such as ePrescribing and CDSS, more positive effects on patient outcomes and safer prescribing were obtained. In contrast with the previous review,[6] new effects were observed in the present review, including changing practice, clinical judgement and staff recruitment.

Study strengths and limitations

Because the present study used the approach of Keasberry *et al.*,[6] similar limitations exist, including the potential for reviews to be missed, although this is considered unlikely, omission of grey literature, although this has a higher risk of bias, and emphasis on effects devoid of consideration over behaviour and implementation factors. Although decisions over inclusion and exclusion of individual reviews were decided by researcher judgment, which could be potentially biased, the levels of inter-rater agreement for review selection were high. In terms of study strengths, although we followed Keasberry *et al.*[6] in limiting our

review to systematic reviews, we also included other reviews where their methods approximated systematic reviews to minimise bias and improve the completeness of findings. Like Keasberry *et al.*,[6] we used the AMSTAR criteria to judge the quality of reviews, but acknowledge ongoing discussions of the usefulness of AMSTAR and other quality criteria[17] specifically developed for application to evaluation studies of health informatics, such as STARE-HI (STAtement on the Reporting of Evaluation studies in Health Informatics).[18]

The effects reported by Keasberry *et al.*[6] and here in the updated review were classified according to the particular eHealth system being investigated and, where possible, to the typology of outcomes reported by Black *et al.*[11] This classification is both a strength and limitation. Classifying effects according to each system takes into account their different purposes and functions, thus conferring greater granularity to the findings. However, some of the studies that were analysed in the review looked at eHealth systems as a whole and did not attempt to clearly distinguish between the effects of separate systems. Therefore, subjectivity was involved when decomposing the effects according to the system. Still, classifying the benefits into a typology provided a way to visualise, compare and contrast the effects reported. We should also note that most studies within the reviews analysed examined the effects of eHealth in the US context, which therefore limits the generalisability to other jurisdictions. Given the rapid digital transformations taking place in Australian hospitals, more research on the effects and experiences of eHealth in this country is urgently needed.

Implications for clinical practice

Our findings can help hospitals and health authorities know what to expect from the implementation of EMRs and other major eHealth technologies. The authors have been involved in a statewide roll-out of an integrated eHealth system that includes all technologies of EMR, CPOE, CDSS and ePrescribing. The findings of the present study have been communicated to hospital and state health authorities and were considered helpful in identifying benefits and areas for improvement, as well as guiding future implementations and assessments at other sites.

In summary, it appears that optimisation of completeness and accuracy of information in eHealth systems can still be a challenge due to ineffective workarounds and user resistance. There is limited evidence to suggest that CPOE and EMRs directly improve clinical outcomes, but ePrescribing, when integrated with CDSS, does improve outcomes through safer prescribing behaviours. This updated review also highlights additional effects that hospitals should consider, including changing practice, clinical judgement and staff retention.

Conclusion

The present study can help inform other hospitals of the likely effects resulting from eHealth technologies (e.g. EMRs, CDSS, CPOE and ePrescribing). Overall results are encouraging for the ongoing digital transformation of hospital practice.

The findings in this review indicate that hospitals experience positive clinical and financial outcomes from implementing eHealth technologies, although increased attention is being given to unintended detrimental consequences, such as workarounds and paper persistence. Future research is needed to understand why these positive and negative effects occur. Improving governance structures and optimising the effective use of these eHealth technologies are two potential areas that should be investigated to minimise negative effects. Addressing these issues is of great importance for hospitals and decision makers, because successfully implementing eHealth will enable effective patient care in an increasingly complex environment.

Competing interests

None declared.

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References

1 Hruby GW, Matsoukas K, Cimino JJ, Weng C. Facilitating biomedical researchers' interrogation of electronic health record data: ideas from outside of biomedical informatics. *J Biomed Inform* 2016; 60: 376–84. doi:10.1016/j.jbi.2016.03.004

2 Gardner RM. Clinical information systems – from yesterday to tomorrow. *Yearb Med Inform* 2016; S62–S75. doi:10.15265/IYS-2016-s010

3 Zheng K, Abraham J, Novak LL, Reynolds TL, Gettinger A. A survey of the literature on unintended consequences associated with health information technology. *Yearb Med Inform* 2016; 13–29.

4 Rathert C, Mittler JN, Banerjee S, McDaniel J. Patient-centred communication in the era of electronic health records: what does the evidence say. *Patient Educ Couns* 2017; 100: 50–64. doi:10.1016/j.pec.2016.07.031

5 Kuziemsky CE, Randell R, Borycki EM. Understanding unintended consequences and health information technology: contribution from the IMIA Organizational and Social Issues Working Group. *Yearb Med Inform* 2016; 53–60. doi:10.15265/IY-2016-027

6 Keasberry J, Scott IA, Sullivan C, Staib A, Ashby R. Going digital: a narrative overview of the clinical and organisational impacts of eHealth technologies in hospital practice. *Aust Health Rev* 2017; 41: 646–64. doi:10.1071/AH16233

7 Eden R, Burton-Jones A, Scott I, Staib A, Sullivan C. The impacts of eHealth upon hospital practice: synthesis of the current literature. *Deeble Institue Evidence Brief* 2017; 16: 6.

8 Templier M, Pare G. A framework for guiding and evaluating literature reviews. *Comm Assoc Inform Syst* 2015; 37: 112–37.

9 Shea BJ, Grimshaw JM, Wells GA, Boers M, Andersson N, Hamel C, Porter AC, Tugwell P, Moher D, Bouter LM. Development of AMSTAR: a measurement tool to assess the methodological quality of systematic reviews. *BMC Med Res Methodol* 2007; 7: 10. doi:10.1186/1471-2288-7-10

10 Long L, Briscoe S, Cooper C, Hyde C, Crathorne L. What is the clinical effectiveness and cost-effectiveness of conservative interventions for tendinopathy? An overview of systematic reviews of clinical effectiveness and systematic review of economic evaluations. *Health Technol Assess* 2015; 19: doi:10.3310/hta19080

11 Black AD, Car J, Pagliari C, Anandan C, Cresswell K, Bokun T, McKinstry B, Proctor R, Majeed A, Sheikh A. The impact of eHealth on the quality and safety of health care: a systematic overview. *PLoS Med* 2011; 8: e1000387. doi:10.1371/journal.pmed.1000387

12 Nabovati E, Vakili-Arki H, Taherzadeh Z, Saberi MR, Medlock S, Abu-Hanna A, Eslami S. Information technology-based interventions to improve drug–drug interaction outcomes: a systematic review on features and effects. *J Med Syst* 2017; 41: 12. doi:10.1007/s10916-016-0649-4

13 Cook DA, Teixeira MT, Heale BSE, Cimino JJ, Del Fiol G. Context-sensitive decision support (infobuttons) in electronic health records: a systematic review. *J Am Med Inform Assoc* 2017; 24: 460–8. doi:10.1093/jamia/ocw104

14 Dunn Lopez K, Gephart SM, Raszewski R, Sousa V, Shehorn LE, Abraham J. Integrative review of clinical decision support for registered nurses in acute care settings. *J Am Med Inform Assoc* 2017; 24: 441–50. doi:10.1093/jamia/ocw084

15 Slovis BH, Nahass TA, Salmasian H, Kuperman G, Vawdrey DK. Asynchronous automated electronic laboratory result notifications: a systematic review. *J Am Med Inform Assoc* 2017; 24: 1173–83. doi:10.1093/jamia/ocx047

16 Kushniruk AW, Triola MM, Borycki EM, Stein B, Kannry JL. Technology induced error and usability: the relationship between usability problems and prescription errors when using a handheld application. *Int J Med Inform* 2005; 74: 519–26. doi:10.1016/j.ijmedinf.2005.01.003

17 Pollock M, Fernandes RM, Hartling L. Evaluation of AMSTAR to assess the methodological quality of systematic reviews in overviews of reviews of healthcare interventions. *BMC Med Res Methodol* 2017; 17: 48–61. doi:10.1186/s12874-017-0325-5

18 Talmon J, Ammenwerth E, Brender J, De Keizer N, Nykänen P, Rigby M. STARE-HI—Statement on reporting of evaluation studies in Health Informatics. *Int J Med Inform* 2009; 78: 1–9. doi:10.1016/j.ijmedinf.2008.09.002

19 Street RL, Makoul G, Arora NK, Epstein RM. How does communication heal: pathways linking clinician–patient communication to health outcomes. *Patient Educ Couns* 2009; 74: 295–301. doi:10.1016/j.pec.2008.11.015

Appendix 1. Summary of findings from systematic reviews from November 2015 to August 2017

AMSTAR (A Measurement Tool to Assess systematic Reviews) scores ≥8 indicate a high quality review, scores 4–7 indicate intermediate quality and scores <4 indicate low quality. ADE, adverse drug events; CDSS, clinical decision support systems; CPOE, computerised provider order entry; ED, emergency department; EMR, electronic medical record; HIS, health information systems; IT, information technology; LOS, length of stay; ME, medication errors; PC, patient-clinician; RCT, randomised control trials

Study	Study characteristics	Brief summary of main outcomes	Quality appraisal	Outcome measures	CDSS	CPOE	EMR	ePrescribing	Our interpretive comments
Cook *et al.*[13]	Identified 17 studies up to July 2015 examining effect of infobuttons on clinical practice and outcomes Studies performed in the US (16) and Argentina (1) Studies used randomised trials (3), non-random comparison (1), institution comparison (2), historical control (1), cross-sectional comparison (7) and cross-sectional with no comparison (1) methods	Infobuttons are generally perceived to be useful for decision making but there is no objective data on real benefits for clinicians or patients The extent of infobutton use is largely task dependent	AMSTAR 10/11	Usage User satisfaction Cost Clinical impact	3 studies reported that clinicians found answers using infobuttons >69% of the time, which enabled them to make more informed decisions (15–91% of the time) People generally had a favourable perception of infobuttons 1 study found no significant evidence for infobuttons reducing costs	N/A	N/A	N/A	The article suggests that infobuttons deserve more work because they have not been examined in detail yet
Dunn Lopez *et al.*[14]	Identified 28 studies from 2006 to 2013 examining the effect of CDSS on acute care nurses Studies performed in the US (19), Taiwan (4), Canada (3), Korea (1) and Netherlands (1) Studies used qualitative (5), quantitative (7), mixed (6), experimental (10) methods	Found CDSS generally led to positive outcomes and were largely viewed positively by clinicians	AMSTAR 8/11	Process outcomes (e.g. situation awareness, accuracy, overload, efficiency, process failure) Usability outcomes (e.g. satisfaction, usefulness, ease of learning) Patient outcomes (e.g. biomedical indicators, LOS) Clinician outcomes (e.g. critical thinking)	CDSS positively affected: • process improvements in 7/7 studies (subject (2) and information (1) accuracy, situational awareness (3), efficiency (2), errors (2)) • patient outcomes (2/2) • guideline adherence • critical thinking Studies found clinicians' overall perception of CDSS is positive (4/4) Mixed results for LOS Paper persistence was also identified	N/A	N/A	N/A	The article showed that the effects of CDSS on acute care nurse decision making were generally positive, but the study noted that this area of research was much less studied than physician use of CDSS and more work is needed

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Appendix 1. (*continued*)

Study	Study characteristics	Brief summary of main outcomes	Quality appraisal	Outcome measures	CDSS	CPOE	EMR	ePrescribing	Our interpretive comments
Nabovati *et al.*[12]	Identified 19 studies up to March 2014 examining the effect of IT-based interventions (e.g. CPOE or CDSS) on drug–drug interactions Studies performed in the US (12), Europe (4), Japan (1), Brazil (1) and Israel (1) Methods used: RCTs (5), non-RCTs (5), observational studies with controls (9)	Most studies examined surrogate outcomes (e.g. adherence to alerts) and found that IT-based systems had a positive effect, but there was insufficient research and evidence on beneficial clinical outcomes	AMSTAR 7/11	Clinical outcomes (patient outcomes) Surrogate outcomes (safer prescribing) Other outcomes (guideline adherence, indicated care)	Positive results were reported for guideline adherence (4/5), indicated care (1/1), safer prescribing (8/10) and patient outcomes (1/2)	N/A	N/A	The studies examining safer prescribing and patient outcomes found no significant results	The study referred to CDSS/CPOE, yet the details pertaining to CPOE were more indicative of ePrescribing because it examined the prescribing process, through prescribing, administering and monitoring Although most studies examined surrogate outcomes, we evaluated the study characteristics table reported and identified the actual effects investigated
Slovis *et al.*[15]	Identified 34 articles from 1980 to 2016 examining the effect of asynchronous notification systems	Asynchronous notifications were generally associated with positive outcomes, but it was challenging to find the balance between information provision and overload For notifications to be effective, they typically have to be used alongside other technology (flashing lights, pagers, telephone calls)	AMSTAR 6/11	Time to acknowledge result Time to provide care Quality of care	Studies reported largely positive results for CDSS improved: • endorsing results • patient outcomes • overall perception • secondary use • work efficiency • clinical awareness • indicated care • LOS	N/A	N/A	N/A	We view notification systems as a type of CDSS, but the study (p. 9) noted they were not sophisticated CDSSs and more work is needed on this front The study also noted that modern EMRs have these systems, and so could also be classified as (parts of) EMRs

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Study	Study characteristics	Brief summary of main outcomes	Quality appraisal	Outcome measures	CDSS	CPOE	EMR	ePrescribing	Our interpretive comments
Rathert *et al.*[4]	Identified 41 studies up to August 2015 examining effects of EMRs on PC communication Studies conducted in the US (28), UK (2), Australia (2), Canada (2), Israel (2), Denmark (1), Norway (1) and New Zealand (1) Studies used: observational (16), surveys (8), mixed (6), interviews (3), focus groups (3), randomised controlled trials (2), archival data (2), quasi experiment (1) methods	Largely found mixed results in the PC relationship as mapped onto the 'essential functions of PC communication framework'[19] Studies were of mixed quality, mostly exploratory, but overall the effects of EMRs depended on the physician Transfer of biomedical facts may be improving, but transfer of psychosocial details may be impaired	AMSTAR 4/11	Essential functions of PC communication: • fostering relationships • exchanging information • responding to emotions • managing uncertainty • making decisions • enabling self-management	N/A	N/A	Overall mixed results found for patient–clinician communication Studies investigated: fostering relationships (31), exchanging information (29), of which studies reported positive results for biomedical information quality and negative psychosocial information quality, decision making (8), uncertainty (6), emotions (4) The effect on communication was found to have mixed effects on data integrity, overall perceptions and positive results for patient outcomes	N/A	There was reference to self-management, but only in the patient portal context (out of the scope of the present review) The quality of studies also needs improving
Kuziemsky *et al.*[5]	Identified 18 studies from 2000 to 2015 examining unintended consequences of HIS from the perspective of organisational and social issues Studies performed in the US (12), Australia (1), Canada (1), Denmark (1), Israel (1), Netherlands (1) and Norway (1) Qualitative (16) and mixed-methods (2) approaches used	Developed a framework of considerations for studying unintended consequences with HIS Found that unintended consequences can occur because EMRs: • alter existing processes or enable new processes • can make work more collaborative • can be implemented in complex contexts	AMSTAR 3/11	Unintended consequences (typically negative)	Unintended consequences: changing work practices	Unintended consequences: communication and collaboration between clinicians	Unintended consequences: communication and collaboration between clinicians Found clinicians worked around EMRs due to work process changes	Unintended consequences: communication and collaboration between clinicians	The article largely focused on negative effects, because this is characteristic of literature on unintended consequences

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Study	Study characteristics	Brief summary of main outcomes	Quality appraisal	Outcome measures	CDSS	CPOE	EMR	ePrescribing	Our interpretive comments
Zheng *et al.*[3]	Identified 34 papers during 2014–15 that studied unintended consequences of health IT Studies conducted in the US (25), UK (3), Canada (2), Australia (1), Norway (1), Saudi Arabia (1) and Argentina (1) Quantitative (24), qualitative (8) and mixed methods (2) used	Compared with prior reviews: • unintended consequences have now been studied across more diverse health IT applications (not just CPOE) and hospital units (not just ED) • more studies used quantitative methods but not enough mixed methods • several new unintended effects consequences	AMSTAR 3/11	Patient safety Time efficiency and workflow Documentation quality, clinician performance, and quality of care Communication and coordination Workarounds Financial effects Staff attrition Privacy and confidentiality	Associated with unintended consequences: • patient safety effects: increased MEs	Associated with unintended consequence: • patient safety effects: increased MEs • communication and coordination effects: mixed findings for clinician communication	Associated with unintended consequence: • patient safety effects: increased MEs and clinical incidents • time efficiency and workflow effects: increased LOS, time taken for transfers and resource utilisation • documentation quality, clinician performance, and quality of care effects: negative results for guideline adherence, clinician productivity, completeness of information, clinician judgement • communication and coordination effects: mixed findings for clinician communication • detrimental workarounds negatively affecting data integrity • Financial effects: negative • staff attrition: negative • privacy and confidentiality: negative	Associated with unintended consequence: • patient safety effects: increased MEs and ADEs	The study reported EMR as a whole, but we decomposed the benefits into the relevant systems (i.e. CDSS, CPOE, ePrescribing). The article focused on largely negative effects, as this is characteristic of literature on unintended consequences