

The impact of health information technology on patient safety

Yasser K. Alotaibi, SBFM, ABFM, Frank Federico, RPh.

ABSTRACT

منذ نشر تقرير معهد الطب الأصلي (IOM) كان هناك تسارع في تطوير واعتماد تكنولوجيا المعلومات الصحية بدرجات متفاوتة من الأدلة حول تأثير تكنولوجيا المعلومات الصحية حول سلامة المرضى. ويهدف هذا المقال إلى مراجعة الأدلة العلمية المتاحة الحالية على تأثير تكنولوجيا المعلومات الصحية المختلفة على تحسين نتائج سلامة المرضى. نستنتج أن تكنولوجيا المعلومات الصحية تحسن سلامة المريض عن طريق الحد من أخطاء الدواء، والحد من ردود الفعل السلبية للأدوية، وتحسين الامتثال للمبادئ التوجيهية الممارسة. وينبغي أن لا يكون هناك شك في أن تكنولوجيا المعلومات الصحية هي أداة هامة لتحسين جودة الرعاية الصحية والسلامة. كما يتعين على منظمات الرعاية الصحية أن تكون انتقائية تستخدم فيها التكنولوجيا للاستثمار، كما تبين الأدبيات أن بعض التكنولوجيا لديها أدلة محدودة على تحسين نتائج سلامة المرضى.

Since the original Institute of Medicine (IOM) report was published there has been an accelerated development and adoption of health information technology with varying degrees of evidence about the impact of health information technology on patient safety. This article is intended to review the current available scientific evidence on the impact of different health information technologies on improving patient safety outcomes. We conclude that health information technology improves patient's safety by reducing medication errors, reducing adverse drug reactions, and improving compliance to practice guidelines. There should be no doubt that health information technology is an important tool for improving healthcare quality and safety. Healthcare organizations need to be selective in which technology to invest in, as literature shows that some technologies have limited evidence in improving patient safety outcomes.

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From the Continuous Quality Improvement and Patient Safety Department (Alotaibi), Medical Services General Directorate, Ministry of Defense, Riyadh, Kingdom of Saudi Arabia and the Department of Patient Safety (Federico), Institute for Health Care Improvement, Cambridge Massachusetts, United States of America.

Address correspondence and reprint request to: Dr. Yasser K. Alotaibi, Continuous Quality Improvement and Patient Safety Department, Medical Services General Directorate, Ministry of Defense, Riyadh, Kingdom of Saudi Arabia. E-mail: ykeotb@gmail.com
ORCID ID: orcid.org/0000-0001-8741-027X

Patient safety is a subset of healthcare and is defined as the avoidance, prevention, and amelioration of adverse outcomes or injuries stemming from the processes of health care.¹ In 1999 the Institute of Medicine's (IOM) report "To err is human" called for developing and testing new technologies to reduce medical error,² and the subsequent 2001 report "crossing the quality chiasm" called for using information technology as a key first step in transforming and changing the healthcare environment to achieve better and safer care.³

Healthcare information technology (HIT) has been defined as "the application of information processing involving both computer hardware and software that deals with the storage, retrieval, sharing, and use of health care information, data, and knowledge for communication and decision making".⁴

Health information technology includes various technologies that span from simple charting, to more advanced decision support and integration with medical technology. Health information technology presents numerous opportunities for improving and transforming healthcare which includes; reducing human errors, improving clinical outcomes, facilitating care coordination, improving practice efficiencies, and tracking data over time. Since the original IOM report was published, there has been an accelerated development and adoption of health information technology with varying degrees of evidence about the impact of health information technology on patient safety.

This review is intended to summarize the current available scientific evidence on the impact of different health information technologies on improving patient safety outcomes. This review might be useful for clinicians and healthcare policy makers when

making evidence based decisions on procurement and implementation of such technology to improve patient safety. This review considered studies that were conducted in the healthcare settings both inpatient and community setting, with an intervention of any of the following; electronic physician's orders (CPOE), clinical decision support (CDS), E-prescribing, electronic sign-out and hand-off tools, bar code medication administration (BCMA), smart pumps, automated medication dispensing cabinets (ADC), electronic medication administration record (eMAR), patient data management systems (PDMS), retained surgical items detectors, patient electronic portals, telemedicine, electronic incident reporting, and electronic medical record (EMR). Our primary outcomes of interest were patient safety, medical errors, adverse events, medication errors, adverse drug events, and mortality. The priority was given to systematic reviews, meta-analysis and randomized clinical trials. If such studies were not identified then other types of experimental studies or epidemiological study designs including; non-randomized controlled trials, quasi-experimental, before and after studies, prospective and retrospective cohort studies and case control studies.

Studies were excluded if they met any of the following criteria: high risk of bias, studies that were conducted in non-clinical settings, cointerventions with non-health information technology interventions, not evaluating patient safety outcomes, qualitative or narrative studies.

The search strategy was conducted to find both published and unpublished studies. The search strategy included Medline, Embase, Cochrane Database. Studies published until January 2017 were considered for inclusion in this review. Initial keywords used were: Electronic Medical Record (EMR), Electronic Physician's Order entry (CPOE), Clinical Decision Support (CDS), E-prescribing, Electronic Sign-out and Hand-off, Bar Code Medication Administration (BCMA), Closed Loop Medication Administration, Patient Data Management Systems (PDMS), Retained Surgical Items Detectors, Patient Electronic Portals, Telemedicine, Electronic Incident Reporting, Intelligent Infusion Devices, Smart Pump, Programmable Pump, Automated Medication Dispensing, medication error adverse events, adverse drug events, adverse drug reactions, patient safety, medical errors. Studies were assessed for methodological validity and risk of bias using the Cochrane methodology prior to inclusion in the review.

Electronic physician's orders and E-prescribing.

Computerized physician order entry entails the use of electronic or computer support to enter physician

orders including medication orders using a computer or mobile device platform.⁵ Computerized physician order entry systems were originally developed to improve the safety of medication orders, but more modern systems allow electronic ordering of tests, procedures, and consultations as well. Computerized physician order entry systems are usually integrated with a clinical decision support system (CDS), which acts as an error prevention tool through guiding the prescriber on the preferred drug doses, route, and frequency of administration. In addition, some CPOE systems may have the feature of prompting the prescriber to any patient allergies, drug-drug or drug-lab interactions or with sophisticated systems it might prompt the prescriber towards interventions that should be prescribed based on clinical guideline recommendation (example venous thromboembolism prophylaxis). A metaanalysis⁶ evaluating the effectiveness of CPOE to reduce medication errors and adverse drug events in hospitals found that the implementation of a COPE with clinical decision support resulted in significant reduction in medication errors (RR:0.46; 95% CI 0.31 to 0.71) and adverse drug reactions (RR: 0.47; 95% CI 0.35 to 0.60). Similarly, studies conducted in community based outpatient services showed comparable results in reducing medication errors.^{7,8} The use of hard-stops as a measure of forcing function and error prevention in CPOE systems has been studied and was found to be effective in changing prescribing errors. However, the use of hard-stops resulted in clinically important treatment delays.⁹

The use of a stand-alone CPOE without CDS does not seem to reduce medication errors. Studies that have evaluated the use of a basic CPOE system without a clinical decision support system showed that it did not improve overall patient safety or reduce medication errors.¹⁰ Published research demonstrates that COPE systems are one of the most rigorously evaluated health information technologies, with a high level of scientific evidence regarding the reduction of medication errors, but this benefit is only consistent when used in combination with a CDS system.

Clinical decision support. Clinical decision support provides the health care professional with information and patient-specific information. This information is intended to enhance the decision of the healthcare provider and is rationally filtered and presented to the healthcare professional at appropriate times. Clinical decision support includes a range of tools to enhance decision-making and the clinical workflow. These tools include notifications, alerts and reminders to care providers and patients, clinical guidelines, condition-

specific order sets, patient specific clinical summaries, documentation templates, investigation and diagnostic support, among other tools.¹¹ A Cochrane systematic review¹² concluded that the use of on screen reminders for physicians resulted in minor to modest improvements in process adherence, medication ordering, vaccination, laboratory ordering and clinical outcomes.

Physicians tend to frequently ignore alerts from clinical decision support systems. A study¹³ evaluated 18,115 drug alerts in the Boston area and found that 33% of alerts were ignored by the ordering physician. Several clinical trials^{14,15} have studied the effect of different CDS system modifications to improve physician's compliance to alerts and have found that "tiering" and "automation of alerts" resulted in improved physician's compliance to CDS alerts. A meta-analysis studied reasons for why some CDS systems succeed and improve patient outcomes and why others do not, and concluded that CDS systems which provided simple advice were less likely to succeed, while the odds of success were greater for CDS systems that demanded the healthcare provider to justify the reason when over-riding CDS advice. The odds of success were also better for CDS systems that provided advice simultaneously to patients and practitioners. In addition, CDS systems that were evaluated by their developer rather than third party developers were more likely to be successful.¹⁶ Published research demonstrates consistent high-quality evidence that CDS systems improve quality of care and patient safety but the results may vary with different system designs and implementation methods.

Electronic sign-out and hand-off tools. Sign-out or "hand-over" communication relates to the process of passing patient-specific information from one caregiver to another, from one team of caregivers to the next, or from caregivers to the patient and family for the purpose of ensuring patient care continuity and safety.¹⁷ Breakdown in handover of patient information has been found to be one of the leading root causes of sentinel events in the United States.¹⁸ Electronic sign-out applications are tools used as standalone or integrated with the electronic medical record to ensure a structured transfer of patient information during healthcare provider handoffs. Two systematic reviews^{19,20} evaluating outcomes of electronic tools supporting physician shift-to-shift handoffs concluded that most studies supported using an electronic tool with an improvement in the process of handover, fewer omissions of critical patient information and reduced handover time when using the electronic tool with few low-quality studies assessing patient outcome measures. The authors in both reviews also noted that a significant

number of the included studies were not well designed and further evaluation using rigorous study designs is needed.

Bar code medication administration. Bar code medication administration systems are electronic systems that integrate electronic medication administration records with bar code technology. These systems are intended to prevent medication error by ensuring that the right patient receives the right medication at the right time. Furthermore, there are varying levels of sophistication among existing barcode systems. For example, some software produces alerts when sound-alike or look-alike medications may be confused. Others provide clinical advisories for specific medications when scanned, and others may assist with documentation (namely, recording drug administration in the eMAR and other relevant clinical details).²¹

Our literature search did not find any randomized controlled clinical trials on the use of barcode medication administration or closed loop medication administration. The highest level of clinical evidence on this technology is based on observational or quasi-experimental studies. A systematic review of quasi-experimental studies²² found that bar code medication administration when integrated with electronic medication administration records may reduce medication administration errors by 50% to 80%. However, the systematic review did not elaborate on whether the included studies were evaluated for the quality of their methodology. The review also noted that there is a limited data on the use of barcode technology on pediatric and outpatient setting as most studies have been conducted in an inpatient adult setting. Another systematic review²¹ conducted a meta-analysis of studies involving BCMA which found that implementing BCMA resulted in an overall reduction in medication errors by 57% (OR=0.425, 95% CI: 0.28-0.65, $p<0.001$). However, this result should be interpreted with caution as studies involved in the meta-analysis had a high degree of heterogeneity. Although BCMA automates and improves documentation of medication administration, there is a moderate to weak clinical evidence on its efficacy in reducing medication errors. Further robust studies are needed to make a conclusion. Healthcare organizations also need to consider the impact of implementing BCMA on their workflows.

Smart pumps. Smart pumps are intravenous infusion pumps that are equipped with medication error-prevention software. This software alerts the operator when the infusion setting is set outside of pre-configured safety limits.²³ The only published

randomized controlled trial²⁴ on the impact of smart pumps on medication safety has shown that there was no statistical difference between activating the decision support feature on or off the smart pump. The authors had explained that this was likely in part due to poor compliance of healthcare providers to infusion practices. A systematic review of quasi-experimental studies²⁵ concluded that smart pumps may reduce programming errors but they do not eliminate such errors. The review also found that hard limits were more effective than soft limits in preventing medication errors. This was explained by the high override rate of soft limits. Further robust studies are needed to make a conclusion of the efficacy of smart pumps on reducing medication errors and improving patient's safety.

Automated medication dispensing technology. Automated dispensing cabinets (ADC) are electronic drug cabinets that store medication at the point of care with controlled dispensing and tracking of medication distribution. Automated dispensing cabinets were first used in hospitals in the 1980s, but have evolved over time to include more sophisticated software and digital interfaces to synthesize high-risk steps in the medication dispensing process. Automated medication dispensing cabinets have been successfully used as a medication inventory management tool that help in automating the medication dispensing process by minimizing the workload on the central pharmacy and keeping better track of medication dispensing and patient billing. The impact of ADC on patient's safety is limited, as there is only one published controlled trial,²⁶ which found that the use of ADC resulted in a 28% ($p < 0.05$) reduction in the rate of medication errors in a hospital critical care unit (RR: 0.7; NNT: 4). Detailed analysis revealed that most reduced errors were preparation errors. The automated dispensing system did not reduce errors causing harm. Automated dispensing cabinets seem to reduce medication preparation errors in critical care setting. Although the level of evidence is high, it is however only limited to critical care setting. Further controlled studies are needed to make a conclusion on the impact of ADC on medication safety in other settings.

Retained surgical items prevention technology. There are various technologies that are used to enhance the prevention of retained surgical items which include: bar coding and radiofrequency (RFID) tagging of surgical items. A systematic review²⁷ identified 3 studies that evaluated technologies preventing retained surgical items. One study was a randomized control trial on the use of barcode assisted sponge count technology which found that there was no difference between the

intervention group and the control group, but the time to conduct the count was significantly longer in the intervention. Another study evaluated the RFID tagging of surgical items and found statistically insignificant results. Currently, there is insufficient clinical evidence to recommend for or against the use of such technology. The use of such technologies must not be considered as a stand-alone procedure and must be supplementary to manual counts due to many reasons which include cost, confusion with older non-tagged devices, and wand technique with RF and RFID systems.²⁸

Patient electronic portals. A patient portal is a secure online application that provides patients access to their personal health information and 2-way electronic communication with their care provider using a computer or a mobile device.²⁹ Numerous studies³⁰⁻³² have shown that patient portals improve outcomes of preventive care and disease awareness and self-management. However, there is no evidence that they improve patient safety outcomes.

Telemedicine. Telemedicine is defined as the use of telecommunication technologies to facilitate patient to provider or provider to provider communication. Communication maybe synchronous with real-time 2-way video communication or asynchronous transmission of patient clinical information. In addition to communication, telemedicine may provide health information that is collected remotely from medical devices or personal mobile devices. This information may be used to monitor patients, track or change their behavior.³³

Synchronous telemedicine. Virtual visits are real-time 2-way audio/video communication between a healthcare provider and a patient. Numerous systematic reviews³⁴⁻³⁷ have studied the impact of virtual visits on patient outcomes in critical care, chronic disease care, and psychiatric care. All have showed that telemedicine is as effective as face to face care with regard to specific clinical outcomes but there is limited evidence regarding patient safety outcomes. An e-consultation is an electronic communication between the patient's primary care clinician and a specialist using a secure communication platform. This technology facilitates guidance from the specialist regarding the management of the patient without the need for referring the patient. There is limited evidence about the efficacy and safety of e-consults, but studies have shown that e-consults may reduce patient wait times for specialist appointments and opinions.^{38,39}

Remote patient monitoring. Studies evaluating community based Remote patient monitoring (telemonitoring)⁴⁰⁻⁴⁴ have shown that it improves

patient outcomes for certain chronic conditions including; heart failure, stroke, COPD, asthma and hypertension. Patient data management system (PDMS) are systems that automatically retrieve data from bedside medical equipment (namely patient monitor, ventilator, intravenous pump, and so forth). The data is subsequently summarized and restructured to aid healthcare providers in interpreting the data.⁴⁵ Recent advances in integration have allowed PDMS to be integrated with clinical decision support and the patient's electronic medical record. A systematic review⁴⁵ studied the clinical impact of PDMS and found that such systems increased the time spent on direct patient care by reducing the time spent on charting. In addition, PDMS systems reduced the occurrence of errors (medication errors, ventilator incidents, intravenous incidents, and other incidents). The review also found that 2 articles reported an improvement in clinical outcomes when a PDMS was integrated with a clinical decision support system. Research shows that telemedicine technology seems to improve clinical outcomes for certain medical conditions and, seems to enhance accessibility to healthcare services and foster patient-physician collaboration. Apart from the limited evidence on PDMS, the impact of telemedicine on patient safety does not seem to be very clear.

Electronic incident reporting. Electronic incident reporting systems are web-based systems that allow healthcare providers who are involved in safety events to voluntarily report such incidents. Such systems can be integrated with the electronic health record (EHR) to enable abstraction of data and automated detection of adverse events through trigger tools. Electronic incident reporting systems potentially have the following advantages; standardize reporting structure, standardize incident action workflow, rapid identification of serious incidents and trigger events, while automating data entry and analysis. Published research shows that healthcare organizations that have moved to an electronic reporting system have experienced a significant increase in reporting frequency.⁴⁶ Incident reporting systems may improve clinical processes, but there is little evidence that electronic reporting systems ultimately reduce medical errors.⁴⁷

Overall impact of EMR on patient safety. Numerous studies have considered the outcomes of implementing an electronic medical record on healthcare quality and patient safety, with a majority of studies showing favorable results. Although, some studies demonstrated negative outcomes which continues to evoke dispute. Campanella et al⁴⁸ published perhaps the largest and most recent metaanalysis on the impact of electronic

health records on healthcare quality and patient safety, which included 47 studies. The results favored the use of electronic medical records. The metaanalysis showed that organizations which implemented electronic health records had a 30% higher guideline adherence (RR= 1.33; 95% CI: 1.01 to 1.76; $p=0.049$), a reduction in medication errors by 54% (RR=0.46; 95% CI: 0.38 to 0.55; $p<0.001$) and a reduction in adverse drug reactions by 36% (RR=0.66; 95% CI: 0.44 to 0.99; $p=0.045$). The meta-analysis did not find any impact on overall mortality.

Discussion. There is substantial evidence that implementing an electronic medical record reduces medical errors and improves patient's safety. Computerized physician order entry and CDS are probably one of the most beneficial health information technologies for improving patient safety. In addition, ADC systems and PDMS seem to improve patient safety in critical care setting. Currently, there is insufficient evidence to reach a conclusion on patient safety outcomes for the following health information technologies; electronic sign-out and hand-off tools, smart pumps, bar-code medication administration, retained surgical items detectors, patient portals, telemedicine and electronic incident reporting. It is worth mentioning, that there is evidence that the aforementioned technologies seem to improve healthcare processes and non-safety outcomes Table 1 summarizes the evidence on various HIT technologies on patient safety.

Published studies on health information technology exhibit variation in outcomes between different organizations when using the same technology. This has been attributed in the literature to the operationalization of health information technology within the complex adaptive health care system. Sittig and Singh⁴⁹ suggested a conceptual socio-technical model that accounts for key factors which influence the success of health information technology interventions. The 8 dimensions of their model are human-computer interface, workflow and communication, clinical content, internal organizational policies, people, hardware and software, external factors and system measurement and monitoring. The first 3 domains have been found by the Joint Commission to lead to 80% of health information technology sentinel events and serious adverse events and the Joint Commission subsequently recommended actions to improve HIT by focusing on 3 areas: safety culture, process improvement, and leadership.⁵⁰ The ONC has also published a series of guides called the "SAFER guide", which addresses electronic health record safety in a variety of areas (<https://www.healthit.gov/safer/safer-guides>).

Table 1 - Summary of the evidence of Health Information Technology (HIT) on patient safety.

Health Information Technology	Summary of evidence
Computerized physician order entry (COPE)	Reduction in the rate of medication errors (only observed when integrated with CDS).
Clinical Decision support (CDS)	Improvement in process adherence, medication ordering, vaccination, lab ordering and clinical outcomes.
Electronic sign out/hand off tools	Improved handover process and fewer omissions of critical patient information. Weak evidence in reducing medical errors.
Bar code medication administration (BCMA)	Reduction in medication errors & adverse drug reactions. Reduction in mislabeled laboratory specimens.
Smart Pumps	Insufficient evidence on reduction of medication errors. Reduction in pump programming errors.
Patient Data management systems (PDMS)	Reduction in charting time, increasing the time spent on direct patient care and reducing the occurrence of errors.
Automated medication dispensing(ADC)	Reduction of medication errors in critical care units.
Retained surgical item detectors	No significant reduction in the rate of retained surgical items.
Patient Portals	Higher compliance to preventive medical services. Reduction of frequency of asthma attacks Improved patients' medication adherence, disease awareness, self-management of disease and patient satisfaction, No evidence on improving patient safety
Telemedicine - virtual visits	As effective as face to face care with regard to specific clinical outcomes. No evidence regarding patient safety outcomes.
Telemedicine - Telemonitoring	Improved clinical outcomes for patients with certain chronic disease e.g. CHF, COPD, Hypertension. No evidence regarding patient safety outcomes.
Electronic incident reporting	Significant increase in adverse event reporting frequency.
Overall Electronic Medical Record EMR	Improved Guideline adherence. Reduction in Medication errors. Reduction in Adverse drug reactions. No significant impact on mortality.

The authors of this review recommend a comprehensive framework for organizations looking to improve patient safety outcomes when using health information technology which includes the following:

1. **Health Information Governance.** Organizations must establish a health information oversight mechanism that includes leadership and relevant stakeholders. In addition, organizations need to ensure that their health information plan is coordinated with the organization's patient safety and risk management plan.

2. **Safety Risk Identification.** Organizations need to identify areas that health information technology might aid in improving patient safety namely, medication safety, guideline adherence, and so forth.

3. **Stake-Holder Involvement:** Stakeholders need to be involved in all phases of health information projects from planning and implementation until continuous improvement. The most important stakeholder must be the system end-user and process owner.

4. **Informed Decision:** Organizations need to review the cost effectiveness of suggested technologies, which includes conducting an evidence based decision and an evaluation of the current information technology infrastructure including software and hardware.

5. **Sufficient Training:** Organizations need to ensure that all relevant line staff receive sufficient training on the use of the proposed health information technology.

6. **Gradual Implementation:** Rolling out the technology in a gradual stepped approach is crucial to avoid disruption of current processes and systems.

7. **Continuous evaluation and monitoring of patient safety outcomes:** Organizations need to measure patient safety outcomes on a continuous basis especially during the initial implementation to ensure that the new technology achieves its intended outcome.

8. **Technology optimization:** Organizations need to modify and finetune the implemented technology based on user feedback and patient safety outcomes.

9. Regular technology updates: Organizations must ensure that health information technologies are continuously updated to comply with recent best clinical practices, regulatory standards, and technical stability.

Study limitations. We studied the impact of a broad array of health information technologies which yielded studies with heterogeneous methodologies and interventions. Other sources of variability in the reviewed studies could be due to different vendors, software, quality, usability, and settings of implementation. Most studies on health information technology were in English, and we limited our search as such, which might result in the exclusion of relevant international articles.

In conclusion, health information technology improves patient safety by reducing medication errors, reducing adverse drug reactions and improving compliance to practice guidelines. There should be no doubt that health information technology is an important tool for improving healthcare quality and safety, but healthcare organizations need to be selective in which technology to invest in, as literature shows that some technologies have limited evidence in improving patient safety outcomes.

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