Healthcare and the Effect of Technology:
Developments, Challenges and Advancements

Stefane M. Kabene
Ecole des Hautes Etudes en Santé Publique (EHESP), France

Medical Information Science Reference

MEDICAL INFORMATION SCIENCE REFERENCE
Hershey · New York

Director of Editorial Content:	Kristin Klinger
Director of Book Publications:	Julia Mosemann
Acquisitions Editor:	Lindsay Johnston
Development Editor:	Christine Bufton
Publishing Assistant:	Sean Woznicki
Typesetter:	Myla Harty
Production Editor:	Jamie Snavely
Cover Design:	Lisa Tosheff
Printed at:	Yurchak Printing Inc.

Published in the United States of America by
Medical Information Science Reference (an imprint of IGI Global)
701 E. Chocolate Avenue
Hershey PA 17033
Tel: 717-533-8845
Fax: 717-533-8661
E-mail: cust@igi-global.com
Web site: http://www.igi-global.com/reference

Library of Congress Cataloging-in-Publication Data

Healthcare and the effect of technology : developments, challenges, and advancements / Stefane M. Kabene, editor.
p. ; cm.
Includes bibliographical references and index.
Summary: "This book examines current developments and challenges in the incorporation of ICT in the health system from the vantage point of patients, providers, and researchers. The authors take an objective, realistic view of the shift that will result for patients, providers, and the healthcare industry in general from the increased use of eHealth services"--Provided by publisher.
ISBN 978-1-61520-733-6 (hardcover)
1. Medical informatics. 2. Medical telematics. 3. Medical technology. I. Kabene, Stefane M., 1956- [DNLM: 1. Medical Informatics Applications. 2. Electronic Health Records. 3. Telemedicine. W 26.5 H43445 2010] R858.H37 2010
610.285--dc22
2009054324

British Cataloguing in Publication Data
A Cataloguing in Publication record for this book is available from the British Library.

Chapter 2
The Effectiveness of Health Informatics

Francesco Paolucci
The Australian National University, Australia

Henry Ergas
Concept Economics, Australia

Terry Hannan
Australian College of Health Informatics, Australia

Jos Aarts
Erasmus University, Rotterdam, The Netherlands

ABSTRACT

Health care is complex and there are few sectors that can compare to it in complexity and in the need for almost instantaneous information management and access to knowledge resources during clinical decision-making. There is substantial evidence available of the actual, and potential, benefits of e-health tools that use computerized clinical decision support systems (CDSS) as a means for improving health care delivery. CDSS and associated technologies will not only lead to an improvement in health care but will also change the nature of what we call electronic health records (EHR). The technologies that "define" the EHR will change the nature of how we deliver care in the future. Significant challenges relating to the evaluation of these health information management systems relate to demonstrating their ongoing cost-benefit, cost-effectiveness, and effects on the quality of care and patient outcomes. However, health information technology is still mainly about the effectiveness of processes and process outcomes, and the technology is still not mature, which may lead to unintended consequences, but it remains promising and unavoidable in the long run.

INTRODUCTION

The Institute of Medicine (IOM) report, *To Err is Human: Building a Safer Health System* provides a landmark review of the functionality of modern health care delivery in the information and technology revolutions (Kohn, Corrigan & Donaldson, 2000). It concludes that health care is error-prone and costly, as a result of factors that include per-

DOI: 10.4018/978-1-61520-733-6.ch002

sistent major errors and delays in diagnosis and diagnostic accuracy, under/over-use of resources (e.g. excessive ordering or unnecessary laboratory tests), or inappropriate use of resources (e.g. use of outmoded tests or therapies) (Kohn, Corrigan & Donaldson, 2000). Health care is complex and there are few sectors that can compare to it in complexity as well as in the need for almost instantaneous information management and access to knowledge resources during clinical decision-making. An example of a comparable system of complex decision-making can be seen in air travel and is highlighted in the report on the factors contributing to the Tenerife air disaster on Sunday 17th, 1977. In the final summary on this disaster, Weick (1990) makes the following comments that could also be used to describe health care decision-making:

The Tenerife air disaster, in which a KLM 747 and a PanAm 747 collided with a loss of 583 lives, is examined as a prototype of system vulnerability to crisis. It is concluded that the combination of interruption of important routines among interdependent systems, interdependencies that become tighter, a loss of cognitive efficiency due to autonomic arousal, and a loss of communication accuracy due to increased hierarchical distortion, created a configuration that encouraged the occurrence and rapid diffusion of multiple small errors (Weick, 1990, pp. 593).

This major air disaster led to significant changes in air travel and reforms in the regulatory framework that have resulted in a higher level of safety and quality in this industry.

If we compare the changes that occurred in aviation to improvements in health care delivery following the *To Err Is Human* report (Kohn, Corrigan & Donaldson, 2000), which focused on documenting deaths due to medical errors in the U.S. health care system, then the changes have not been as significant. A number of studies have found evidence of a lack of improvement in health care delivery in the U.S. despite major public and private investments in technology. In 2005, Leape and Berwick (2005) reviewed the U.S. health delivery system five years after the IOM report was released. They found significant deficiencies and faults in nearly all aspects of health care delivery. For example, in patient diagnoses there remained significant errors in accuracy and delays. In attempts to evaluate a given diagnosis there were failures to employ appropriate tests (underuse), the continued use of outmoded tests or therapies (inappropriate use), and the failure to act on the results of tests or monitoring (ignoring medical alerts and reminders). In treatment protocols they reported significant errors in operations, surgical procedures, and tests. They also found evidence in the administration of medication, the continued administration of the wrong drugs, doses, and medications given to patients with a known allergy to the drug (also in Evans et al., 1998). Bates et al.(1994; 1997) and Rothschild et al., (2002) found the persistence of a high incidence of adverse drug events (ADE) and their associated costs during care delivery, and demonstrated a close relationship between the incidence of preventable ADE, costs and medical malpractice claims. Preventive care is also considered to be a significant area of health care where costs savings and better health outcomes can be delivered. Fries (1994) has estimated that healthcare cost savings of up to 70% can be achieved through the implementation of more effective preventive care measures. Other areas of healthcare information management that continue to impair healthcare delivery include persistent failures in communication, equipment failure, and other information systems failures.

It is well known that human beings in all lines of work make errors, and available data show that the health care sector is complex and error-prone resulting in substantial harm (Leape & Berwick, 2005). We also know that current and emerging technologies have the potential to provide significant improvements in healthcare delivery systems. Similar trends have occurred in aviation, which has also provided a guide as to where the focus of change should lie (Coiera, 2003).

In this chapter, the following questions are addressed:

- Can information technology and health information management tools improve the health care process, quality and outcomes, while containing costs?
- How do we assess the cost-effectiveness of health information technology?

This chapter will provide a historical perspective with examples of how information technologies, designed around computerised Clinical Decision Support Systems (CDSS), can facilitate the more accurate measurement of the healthcare delivery process, and have provided reproducible solutions for cost savings, improved patient outcomes, and better quality of care.

BACKGROUND: HISTORICAL PERSPECTIVE

The importance of clinical decision making (CDM) and its effects on outcomes in care have been well documented since the 1970s (Dick, Steen & Detmer, 1997; Kohn, Corrigan & Donaldson, 2000; Osheroff et al., 2006). The care process is now understood to function across complex environments involving the patient, primary care, prevention, in-hospital care, and sub-specialisation care. The information management interrelationships extend beyond the direct care process to research, epidemiology, planning and management, health insurance, and medical indemnity.

In 1976, McDonald discussed the key limitations of CDM in complex health information-rich environments, in particular by showing the failure of CDM to meet pre-defined standards of care, and concluded that computerised (electronic) decision support (CDSS) was an essential "augmenting tool" for CDM (McDonald, 1976). McDonald's research became a stimulus to the ongoing research in this domain of health care and revealed not only the benefits of CDSS in health care, but also how we can now begin to "measure the care processes" and evaluate what we do much more effectively.

In 2008 the importance of CDSS in health care was reconfirmed in a policy document prepared by the American Medical Informatics Association (AMIA) entitled *A Roadmap for National Action on Clinical Decision Support* (Osheroff et al., 2006). In the Executive Summary, the functions of CDSS in a modern health care system are clearly defined:

Clinical decision support provides clinicians, staff, patients or other individuals with knowledge and person-specific information, intelligently filtered or presented at appropriate times, to enhance health and health care. It encompasses a variety of tools and interventions such as computerized alerts and reminders, clinical guidelines, order sets, patient data reports and dashboards, documentation templates, diagnostic support, and clinical workflow tools. Clinical decision support has been effective in improving outcomes at some health care institutions and practice sites by making needed medical knowledge readily available to knowledge users (Osheroff et al., 2006, p.4).

Achieving desirable levels of patient safety, care quality, patient centeredness, and cost-effectiveness requires that the health system optimize its performance through consistent, systematic, and comprehensive application of available health-related knowledge – that is, through appropriate use of clinical decision support (Osheroff et al.,2006, p.4).

The knowledge we have from more than 25 years of research in clinical information management systems allows us to conclude that "information is care" (Leao, 2007). In the words of Tierney et al. (2007, p. 373), "although health care is considered a service profession, most of what clinicians do is manage information."

A number of studies support the centrality of CDSS in improving CMD and the overall health care delivery system. From the 1950s to 1970s the technology supporting medical laboratory procedures was evolving. There was a dramatic escalation in the number of procedures performed with a minimal change in the number of technical personnel to support the care process. During this time the number of personnel in hospitals numbered in the 100s or 1000s, yet the number of procedures was rising to the millions each year (Speicher, 1983). Even though the average cost of many of these laboratory procedures at that time (e.g. chest X-rays, full blood analysis) was less than $20 US, the overall decision making process was already very costly. The results of the study by Speicher (1983) provide supportive evidence to the earlier study by Johns and Blum (1979) that linked CDM to resource utilisation and ongoing data generation in clinical environments and found that within a set of four nursing units where the annual expenditure was $44 million U.S., there were, on average, 2.2 million clinical decisions per year, 6,000 per day, and six per patient per day.

A further example that linked CDM to compliance with care, clinical outcomes, and resource utilisation is that of immunization rates. In 1993 Gardner and Schaffner showed that vaccination rates for common illnesses such as influenza, pneumococcus, hepatitis B, and tetanus-diphtheria ranged from 10 to 40%. These are diseases where the vaccines have a clinical effectiveness ranging from 60 to 99% (Gardner & Schaffner, 1993). There are several cost and quality implications of these vaccination rates. From a quality perspective Gardner and Schaffner were able to correlate low vaccination rates with preventable deaths. A similar study by Tang, LaRosa, Newcomb, and Gorden (1999) demonstrated similar effects of immunisation rates on clinical outcomes.

Further historical evidence for the close relationship between CDM and outcomes of health care has been documented for a variety of parameters that measure healthcare processes. These include: the failure to comply with pre-defined standards of care, adverse drug event (ADE) detection, preventive healthcare procedures, health insurance claims management, and data acquisition for research (Bates et al., 1994; James, 1989; Tierney et al., 2007). To these factors can be added the significant cost inflation associated with the attempts to manage health care predominantly as a business or administrative organizational model. James (1989) analysed a range of common clinical scenarios for procedures such as cholecystectomy, prosthetic hip replacement, and transurethral resection of the prostate (TURP). He found a wide variation, not only in the care process amongst groups of clinicians within different health care institutions for standardised conditions, but also within each individual practitioner's activities. He also found that low quality leads directly to higher costs; he defines these costs that arise from an initial process failure and the resulting low quality output, as "quality waste" (i.e., resources that are consumed, in the form of scrap or repairs, when a unit of output fails to meet quality expectations - in clinical care this can represent death or short and long term morbidity). James also emphasises the importance of documentation in determining the quality of care. He states that fundamental elements for quality improvement are to eliminate inappropriate variation and document continuous improvement (i.e., measure what we do). This is not possible using essentially paper-based record systems for decision support. It has also been shown in the Harvard Medical Practice Study looking at negligence in medical care that paper-based record systems actually hide decision-making errors that promote poor clinical outcomes (Brennan et al., 1991).

ADE remains a significant reason for poor, and preventable, patient outcomes. In 1998, Cook, Woods, and Miller documented that 50% of ADEs are preventable and that they represent the highest incidence of medical deaths compared to motor vehicle accidents, breast cancer, and AIDS. These preventable events represent a cost of $17 to $29 billion U.S. per year. Bates et al. (1994) also demonstrated the costly nature of ADEs at the Brigham and Women's Hospital. All ADEs at that hospital cost $5.6 million U.S. and of these, preventable ADEs represented $2.6 million U.S. These figures excluded costs of injuries to patients, malpractice costs, and the costs of admissions due to ADE (Bates et al., 1994). The close relationship between ADEs and malpractice claims (outcomes) was demonstrated by Rothschild et al. (2002) and Studdert et al. (2006). These studies show that many of the added costs of these events were related to litigation and administrative costs and approximately 50% of the events were preventable.

Another factor contributing to the current status of health care delivery is the ability of clinicians to comply with pre-defined standards of care. For the three decades from 1979 to 1990, several studies demonstrated that the overall rate of what is done in routine medical practice that is based on published scientific research remained steady at between 10 to 20% (Ferguson, 1991; Williamson, Goldschmidt, & Jillson, 1979). In 2003 a RAND Corporation review revealed that, on average, patients received recommended care in only 54.9% of instances. While this reflects an improvement in compliance with care standards, it also indicates that around 45% of patients do not receive standardised care (Farley, 2005).

A final example that discusses the core principles of CDSS implementation is the Academic Model for Prevention and Treatment of HIV (AMPATH) in resource-poor Kenya (Tierney et al., 2007). This project saw the successful implementation of health information technologies based on electronic medical record (EMR) functionalities in a resource poor nation. The successful partnership now sees this EMR as the largest e-health system for developing nations and is implemented in more than 23 countries.

To obtain an extensive review of successes, difficulties, and an understanding of the complexity of information management in health, as well as how solutions can be found, we refer to the 25 year review of electronic medical record systems that focuses on CDSS in North America and Europe in the full issue of the International Journal of Medical Informatics in 1999 (see Editorial by Safran, 1999, pp. 155-156).

CLINICAL INFORMATION SYSTEMS AND CLINICAL DECISION SUPPORT SYSTEMS (CDSS) IN THE 21ST CENTURY: THE IMPACT ON HEALTH CARE QUALITY, COSTS, AND OUTCOMES

The statement "information (management) is care" (Tierney et al., 2007, p. 374) emphasises one of the core principals of health care, that is, everything a provider does with a patient involves the flow of information (e.g. clinical history, physical examination, orders for tests, instructions for care, follow-up). This process involves the collection, management, and reporting of data in readable formats to the provider, thereby facilitating the care process (Tierney et al., 2007).

Coiera (2003) also provides a clear description of where "clinical informaticians" fit into the care process:

Informaticians should understand that our first contribution is to see healthcare as a complex system, full of information flows and feedback loops, and we also should understand that our role is to help others 'see' the system, and re-conceive it in new ways (Coiera, 2003, p. xxii).

Any clinical decision support system(s) (CDSS) provides clinicians, staff, patients, or other individuals with knowledge and person-specific information, intelligently filtered or presented at appropriate times, to enhance health and health care (Coiera, 2003; Osheroff et al., 2006). CDSS encompass a variety of tools and interventions, such as computerized alerts and reminders, clinical guidelines, order sets, patient data reports and dashboards, documentation templates, diagnostic support, and clinical workflow tools.

The following four key functions have been defined for CDSS (Perreault & Metzger, 1999):

(1) **Administrative:** These systems provide support for clinical coding and documentation, authorization of procedures, and referrals.
(2) **Managing clinical complexity and details:** Keeping patients on research and chemotherapy protocols; tracking orders, referrals follow-up and preventive care. That is, complying with pre-defined standards of care.
(3) **Cost control:** This involves activities such as the monitoring of medication orders and avoiding duplicate or unnecessary tests.
(4) **Decision support:** These are complex information management systems that support clinical diagnosis and treatment plan processes; and that promote use of best practices, condition-specific guidelines, and population-based disease management.

Based on the existing evidence it is accepted that health information management systems centred on CDSS provide the most significant opportunity to improve health care delivery and management (Brennan et al., 2007). One could wonder why their use is not universal (Ford, Menachemi, Peterson & Huerta, 2009). A major barrier to CDSS implementation is clinician involvement in the development of the information management tools. We know that age, gender, and computer literacy are not significant factors in the use of computers in health care (Sands, 1999; Slack, 2001). Uptake of health information technologies is related to the efficiency and useability of the information management tools that CDSS deliver through the total e-health system. The current focus to provide solutions to the problem of clinician involvement relates to Computerized Provider Order Entry (CPOE) (Brennan et al., 2007). It is believed that CPOE will facilitate safe, effective care for patients by insuring that clinical care directions are communicated in a timely, accurate, and complete manner. The integration of clinical decision support functions with CPOE systems provides functionality that incorporates contemporary knowledge and best practice recommendations into the clinical management process. Additionally, by ensuring the quality, accuracy, and relevance of the decision logic integrated within CPOE systems, a guaranteed method for creating safe and effective practice is ensured. Brennan emphasises that CPOE is not a technology, rather it is a design (or redesign) of clinical processes that integrates technology to optimize provider ordering of medications, laboratory tests, procedures, etc. CPOE is distinguished by the requirement that the provider is the primary user. It is not the "electronification" of the paper record system in existing formats.

In summary the evidence to date indicates that the beneficial effects of health information technology on quality, efficiency, and costs of care can be found in three major areas (Chaudhry et al., 2006):

- increased adherence to guideline-based care,
- enhanced surveillance and monitoring, and
- decreased medication errors.

A recent overview of health information technology studies by Orszag (2008) from the US Congressional Budget Office (CBO) suggests, albeit with some qualifications, that a more comprehensive list of potential benefits from the use of HIT would include the following:

- Eliminating paper medical records – however, the CBO notes that these savings might not apply in very small practices that have low but relatively fixed costs related to medical records;
- Avoiding duplicated or inappropriate diagnostic tests – according to the CBO, some studies (e.g. Bates et al., 1998; Bates et al., 1994) suggest that electronic health records with a notice of redundancy could reduce the number of laboratory tests by about 6%;
- Reducing the use of radiological services - though the CBO notes that the evidence on this is weak. While studies (e.g. Harpole, Khorasani, Fiskio, Kuperman & Bates, 1997) show that HIT may ease the job of monitoring the use of radiological services, there is little evidence that it helps control costs;
- Promoting the cost-effective use of prescription drugs, particularly through decision support software and computerized provider order entry which prompts providers to use generic alternatives, lower-cost therapies, and cost-effective drug management programs (Mullett, Evans, Christenson & Dean, 2001);
- Improving the productivity of nurses and physicians – This has to be qualified, as one study found that when HIT was in use, nurses in hospitals saw reductions in the time required to document the delivery of care, but physicians saw increases in documentation time (Poissant, Pereira, Tamblyn, & Kawasumi, 2005). However, the CBO notes that the latter effect may reflect a short-run learning phase for doctors. Few studies have measured effects on physicians' efficiency in outpatient settings, and those that have show mixed results (Pizziferri et al., 2005).
- Reducing the length of hospital stays – HIT may reduce the average length of a hospital stay by speeding up certain hospital functions and avoiding costly errors (Mekhjian et al., 2002);
- General improvements in the quality of care through avoiding adverse drug events[1]; expanding exchanges of health care information thus reducing duplication of diagnostic procedures, preventing medical errors and reducing administrative costs; expanding the practice of evidence-based medicine[2]; and generating data for research on comparative effectiveness and cost-effectiveness of treatments. This benefit is also consistent with the results of an older literature review which found that HIT increased adherence to guideline- or protocol-based care (Chaudry et al., 2006). This increased quality of care would also be manifest in an associated decrease in malpractice claims, another prediction which is confirmed by a recent study (Virapongse et al., 2008).

Given the need for establishing the existing and ongoing benefits from investments in clinical information management technologies, it has been demonstrated that there are long-term financial benefits, in the form of an acceptable return on investment (ROI), in computerised provider order entry systems (Kaushal et al., 2006).

Despite these established benefits there remain many barriers to the widespread successful implementation of CDSS. Most of these are not technical. They relate to the design of information management tools and their acceptance by clinicians who have a long history of autonomy in health care (Beresford, 2008).

By contrast, the costs associated with implementation of HIT are:

- the initial fixed cost of the hardware, software, and technical assistance necessary to install the system;
- licensing fees;

- the expense of maintaining the system; and
- the "opportunity cost" of the time that health care providers devote to learning how to use the new system and how to adjust their work practices accordingly Orszag (2008).

On the costs of installation or implementation, the CBO notes that these may vary widely among physicians and among hospitals, depending on the size and complexity of those providers' operations and the extent to which a system's users wish to perform their work electronically. For instance, smaller practices will pay more per physician than larger practices to implement an HIT (Orszag, 2008).

The estimation of these costs will also be complicated by the differences in the types and available features of the systems being sold and differences in the characteristics of the practices that are adopting them. The CBO notes that existing studies of costs have tended to make the mistake of not including estimates of indirect costs, such as the opportunity costs of time which providers dedicate to learn the new system and to adopt it in their work routines (Orszag, 2008). The initial opportunity costs in terms of learning time and adapting the operations of the practice around the implemented system can turn out to be quite significant, with one survey of health IT adoption finding that reported productivity in a practice may drop between 10 to 15 per cent for several months after implementation (Gans, Kralewski, Hammons & Dowd, 2005). One study of a sample of 14 small physicians' offices implementing an HIT estimated the average drop in revenue from loss of productivity at about $7,500 per physician over a year (Miller, West, Brown, Sim & Ganchoff, 2005).

PUTTING HEALTH INFORMATION TECHNOLOGY (HIT) TO USE

Health information technology (HIT) systems are basically a repository for patient data. The physician is able to retrieve information, often in a clinically meaningful way that may not necessarily have been entered by himself/herself in the electronic health record (EHR). The information might have been acquired and created, for instance, during the patient's course in the healthcare organization. Increasingly, EHR systems are connected to regional health information networks enabling access to patient data in disparate systems, such as primary care.

Overcoming the Limitations of Paper-Based Records

The electronic patient record has been introduced to overcome perceived limitations encountered with the use of the paper-based medical record and to allow planning that goes beyond a static view of events. Some of the limitations of the paper-based patient record that can be overcome include:

- ***Accessibility***. Often the record is not accessible when it is needed. It may be stored elsewhere, or another professional may be seeking to use it concurrently. Electronic records are accessible independent of place and time, and can be rapidly retrieved using a patient identifier. It is exactly this that is most valued by clinicians. However, access is usually constrained because of data protection and privacy. Authorizations and passwords are required to allow a clinician to review patient information. Making information available both from within the hospital and from ambulatory systems is a key goal of most national efforts to implement HITs.

- ***Completeness***. Not all patient data are written in the record. This can pose problems when other professionals reading the record try to make sense of a patient problem or when a doctor tries to recall what she has done after seeing the information again. Forcing the user to enter data in all fields can improve the completeness of a patient record.
- ***Readability***. Handwriting is often hard to read. On a medication list, numbers and units of dosages can be misinterpreted and require attention of a pharmacist checking the prescription or a nurse translating and transcribing the order or trying to prepare the medication to be administered. Entering the data digitally, and even structuring the fields, can enhance readability.
- ***Analysis***. Information written in the record is generally not suited for quantitative analysis. Test results may be entered in pre-structured forms and even plotted on a graph, which may reveal a trend, but comparison with baseline data is painstakingly difficult. Auditing past records to identify and analyze patterns in a group of patients is very labor intensive and time consuming. Digitized data are exceptionally suited for computer analysis.

Some Reasons for Limited Diffusion of Health Information Technology & Electronic Health Records

If the advantages are so obvious, why then is the electronic record not widely in use and why haven't electronic records replaced paper records? It is often argued that physicians resist innovation and do not like to give up familiar tools. The wide adoption of advanced technology in health care, and certainly in emergency medicine, defies this argument. Paper-based records have proved to be durable tools for medical practice and information technology specialists have only recently become aware of this (Clarke, Hartswood, Procter, Rouncefield & Slack, 2003). As a cognitive artefact, the physician can examine the paper record easily. The layout and structure can guide the physician to find the most relevant information and ignore other items. Often the use of tabs, coloured paper, tables, and flowcharts facilitates navigation through a paper-based record. Within a short period of time a complete mental picture of the patient can be created. In contrast, using a computer, a user can be forced to page through a large number of screens in order to find the needed piece of information.

The paper-based record also allows the physician to judge the quality of the information. Handwriting or a signature can show who entered the information and inform the physician about the trustworthiness of the information. The absence of information does not necessarily imply that the record is incomplete; it often means that a particular item was considered not relevant for the case at hand (Berg, 1998). For example, if the patient has no known history of heart problems and is in good physical condition, blood pressure recordings or an electrocardiogram (ECG) may be missing from the record.

This is not to say that there are no compelling arguments to adopt electronic records; there is ample evidence that the efficiency and quality of care benefits from their use (Dick, Steen & Detmer, 1997). However, one must look carefully at the role of paper-based records in medical practice and avoid simply translating it into an electronic system.

Particular Features of Electronic Health Records That Offer Advantages over Paper Records

The two powerful and distinctive advantages that electronic records have over a paper record are summarized in the concepts of accumulating and coordinating (Berg, 1999). Accumulating refers to the fact that an EHR system allows for powerful analysis of data. For example, lab test outcome data can be accumulated to show time-dependent trends. When grouped for a large number of patients, the same data can be subjected to statistical analysis to reveal patterns. Combined with data from other sources, information can be used for planning, billing, and quality assessment. A most powerful application is the combination of patient data with decision support techniques that enable the physician to make decisions about patient care founded on accepted clinical rules stored in a database and patient data that is as complete as possible. The other concept of coordination provides the opportunity to plan and coordinate activities of healthcare professionals by allowing concurrent access to the electronic record. Access is no longer dependent on the physical location of the record, but possible from every computer that is connected to the system.

Standardization and Integration of Technologies

Many conditions have to be met in order to successfully implement HIT and the EHR, most importantly standardization of the underlying technologies and of the content and meaning of healthcare data. This may seem obvious, but it has been shown that the lack of standardization is a major impediment to the introduction of electronic records in medical practice. Technological standards are required to link systems in networks. The wide diffusion of the Internet would have been impossible without underlying standards for communicating (e.g. messages, texts, and graphics) and establishing links and pointers to other sources of information. Yet, this achievement was not possible without negotiating and consultation about what and how to standardize. Often proprietary rights and the perceived need to protect markets stand in the way.

In health care, standardization is much harder since it is not only about the underpinning rationale and scientific evidence for data standards, but also about the diverse social and cultural values within and across geographic communities that influence choice of data standards. We will not elaborate on the standards relevant for health care; they are explained elsewhere. Typical examples include TCP/IP that determines how information is communicated on the Internet, HL7 that determines how health care information can be represented and communicated between diverse applications in health care, and SNOMED CT that describes how medical concepts are defined and represented. Standardization can be effected through national and international bodies with legislative power, such as ASTM (originally American Society for Testing and Materials), ISO (International Standards Organization) and CEN (Comité Européen de Normalisation). Also standardization can be achieved through market power, e.g., Microsoft's Windows operating system accounts for about 90% of the personal computer market and can therefore be construed as a *de facto* standard for personal computer operating systems.

Implementing Health Information Technology

The traditional approach to implementing health information technology has been top-down. An important factor in this respect was the perception that health information technology is an expensive resource that usually exceeded the financial capabilities of individual physicians and physician groups. However, the advent of personal computers to some degree altered this situation, particularly in primary care. In countries such as the Netherlands, the United Kingdom and Australia, up to 90% of GPs have adopted electronic health record systems (Jha, Doolan, Grandt, Scott & Bates, 2008). However, adoption, in many cases, was helped by financial incentives given by their governments.

A key characteristic of implementing information systems is that organizational changes are an integral part of implementation. Unfortunately, however, the changes are not always for the better, and more often than not, the performance of organizations is worse after a system has been installed than before. The natural tendency is then to conclude that the system was somehow badly designed. In 1975, when the design and operation of information systems were considered primarily technical activities, Henry C. Lucas, Jr. wrote about failing systems. However, all our experience suggests that the primary cause for system failure has been organizational behavior problems (Lucas, 1975). Thirty years of research has increased our understanding of information systems in organizational contexts; yet, the record in terms of developing and implementing successful systems is still dismal (Ewusi-Mensah, 2003). HIT systems are particularly hard to implement because not only do they affect health care organizations as a whole, but also the work of health professionals who pride themselves on their professional autonomy. Implementing HIT is a social process (Aarts, Doorewaard & Berg, 2004). But the relevant organizational changes are not easily predictable.

This creates a predicament for an implementer. S/he might like to design a system according to blueprints and to plan systematically its deployment. But Ciborra (2002) advises making organizational improvisation part of the implementation process, to allow prospective users to tinker with the system and let them find ways of working that fit them best, to plan for the unexpected and value emerging practices, and to give up strict control (Ciborra, 2002).

Adverse Effects of Health Information Technology

Recent studies reveal that putting HIT to use, whatever its many advantages may be associated with unexpected outcomes. A study by Koppel et al. (2005) of one CPOE system documented 22 different error-enhancing aspects of that system. Another study reported a doubling of infant mortality after the introduction of a CPOE system, probably resulting from increased time to enter orders, reduced communication among nurses and doctors, and the loss of advance information previously radioed in from the transfer team before patients arrived at the hospital (Han et al., 2005). Nebeker, Hoffman, Weir, Bennett, and Hurdle (2005), likewise, found high rates of ADEs in the highly computerized Veterans Administration system. Shulman, Singer, Goldstone, and Bellingan (2005) found that, compared to paper-based systems, CPOE was associated with fewer inconsequential errors, but also with more serious errors. Ash, Berg, and Coiera (2004); Campbell, Sittig, Ash, Guappone, and Dykstra (2006); and Aarts, Ash, and Berg (2007) have found unintended consequences from CPOE systems to be the rule, rather than the exception. Nemeth and Cook (2005, p. 262), noting these systems' interactivity and complexity, add: "If [human error] exists, error is a consequence of interaction with IT systems. The core issue is to understand healthcare work and workers". And although "healthcare work seems to flow smoothly," the reality is "messy."

METHODS OF ASSESSING COST-EFFECTIVENESS

There have not been many rigorous studies of cost effectiveness of e-health measures in the literature. The most recent literature review of studies in this field concluded that there remained a "paucity of meaningful data on the cost-benefit calculation of actual IT implementation" (Goldzweig, Towfigh, Maglione & Shekelle, 2009, p. 292). The studies which this literature review collected, after a comprehensive selection process, can be broken into four different approaches.

One approach looks at the experience of a few large organizations that had implemented multifunctional, interoperable electronic health records (EHRs), computerized physician order entry (CPOE), decision-support systems, and other functions. However, these studies cannot be described as appropriate cost effectiveness or cost benefit analyses since they only evaluated the impacts in terms of clinical performance/ quality improvement or potential benefit in terms of patient safety measures, but did not attempt to quantify the costs of these technologies or to then derive a net benefit calculation using some common measure (for instance, some imputed welfare gain in terms of dollars).

Among the individual studies in this category:

- Three studies looked at a quality improvement project related to blood product administration that used automated alert technology associated with CPOE; electronic clinical reminders related to coronary artery disease and diabetes mellitus; and patient-specific e-mail to providers regarding cholesterol levels, and found small improvements in quality of care. (Lester, Grant, Barnett & Chueh, 2006; Rothschild et al., 2007; Sequist et al., 2005)
- Roumie et al. (2006) evaluated the impact of electronic provider alerts and found they provided a modest, non–statistically significant improvement over provider education alone as measured in terms of improvements in blood pressure control.
- Dexter, Perkins, Maharry, Jones, and McDonald (2004) compared the impact on rates of influenza and pneumococcal vaccinations of computer generated standing orders for nurses versus computerized physician reminders and found that immunization rates were significantly higher with the nurse standing order.
- Murray et al. (2004) and Tierney et al. (2005) evaluated computer-generated treatment suggestions for hypertension, and for asthma and chronic obstructive pulmonary disease (COPD), and it was found that neither of these technologies resulted in improvements in care.
- Potts, Barr, Gregory, Wright, and Patel (2004), Butler et al., (2006) and Ozdas et al., (2006) evaluated the potential benefits of CPOE. These studies arrived at mixed results but generally found improvements in patient safety with the introduction of CPOE, as well as modest improvements in quality of care when CPOE was tailored to the management of patients with acute myocardial infarction.

Insofar as there was a basis for comparison implicit in these studies, this involved comparing the refinement in existing systems, addition of new applications or enhancement of existing functionalities, against the resulting improvements. The general finding was one of modest or even no benefits from the new applications or changed functionalities (Goldzweig et al., 2009, p. 285).

A second approach found in the literature review was to look specifically at the experiences of commercial practices implementing commercially available or developed electronic health records. Among the individual studies in this category:

- Garrido, Jamieson, Zhou, Wiesenthal, and Liang (2005) compared outcomes before and after the implementation of a homegrown EHR at commercial hospitals and found that the number of ambulatory visits and radiology studies decreased after implementation, while telephone contacts nearly doubled. On the other hand, limited measures of quality (immunizations and cancer screening) did not change.
- O'Neill and Klepack, (2007) assessed the effect of implementing a commercial EHR in a rural family practice, looking specifically at financial impacts rather than quality of care measures. They found that

average monthly revenue increased 11 per cent in the first year and 20 per cent in the second year, and the charge-capture ratio increased 65 to 70 per cent, because of better billing practices.

- Asaro, Sheldahl, and Char (2006); Del Beccaro, Jeffries, Eisenberg, and Harry (2006); Feldstein et al. (2006); Galanter, Polikaitis, and DiDomenico (2004); Han et al. (2005); Palen, Raebel, Lyons, and Magid (2006); Smith et al. (2006); Steele et al. (2005); and Toth-Pal, Nilsson, and Furhoff (2004) studied the effect of adding new functionalities to existing EHRs. Some of these studies found modest benefits, some found no benefits, and a few found marked benefits.

A third group of approaches involved evaluations of stand- alone applications such as health systems that link patients with their care providers and are intended to improve the management of chronic diseases; computer/video decision aids for use by patients and providers; text messaging systems for appointment reminders; electronic devices for use by patients to improve care; and patient-directed applications for use outside traditional settings. The main findings here were also mixed, with some studies showing no or only modest effects, and many more studies providing insufficient descriptions to reach strong conclusions.

Among the individual studies in this category:

- McMahon et al. (2005) compared Web-based care management with usual care for patients with diabetes. Intervention patients had a statistically significant, modest improvement in their results for 2 out of 3 clinical measures.
- Cavanagh et al. (2006), Grime (2004), and Proudfoot et al. (2004) evaluated an interactive, multimedia, computerized cognitive behavioral therapy package. In two of the studies, statistically significant improvements of modest size were found for patients in the intervention groups compared to usual care, although the differences were no longer significant at three or six months.
- Cintron, Phillips, and Hamel (2006); Jacobi et al. (2007); and Wagner, Knaevelsrud, and Maercker (2006) looked at Internet applications that could be accessed directly by the patient with three involving randomized trials. Clinical improvements were found.

Another set of studies covered by the literature review that are not directly relevant to the issue of cost effectiveness or even general effectiveness of HIT, but nonetheless have implications for the likely costs of implementing HIT, looked at barriers to HIT adoption. One of these studies, which involved a survey of US paediatric practices found that the main barriers to HIT adoption were resistance from physicians (77 per cent of practices without an EHR reported this barrier), system downtime (72 per cent), increase in physicians' time (64 per cent), providers having inadequate computer skills (60 per cent), cost (94 per cent), and an inability to find an EHR that met the practice's requirements (81 per cent) (Kemper, Uren & Clark, 2006). A survey of the Connecticut State Medical Society Independent Practice Association found that the most commonly stated barrier was cost (72 per cent) and other barriers were time necessary to train staff (40 per cent), lack of proficiency among staff (26 per cent), and lack of an IT culture within the office (18 per cent) (Mattocks et al., 2007).

One methodological problem with demonstrating that there are particular positive associations between clinical outcomes and use of HIT is that these associations are not necessarily causal - hospitals that have more HIT tend to have greater resources and better performance. However, one study that at least attempted to control for these confounders still found a statistically significant relationship. Amarasingham, Platinga, Diener-West, Gaskin, and Powe (2009) looked at the relationship between HIT and both costs and clinical outcomes in hospitals in Texas. A particular focus in this study was whether increased automation of hospital information was associated with decreased mortality, complication rates and costs, and length of stay. They found strong relationships between the presence of several technologies and complication and mortality rates and lower costs. For instance, use of order entry was associated with decreases in mortality rate for patients with myocardial infarction and coronary artery bypass surgery. Use of decision support software was associated with a decrease in the risk of complications. Automated notes were associated with a decrease in the risk of fatal hospitalizations. The researchers controlled for the fact that hospitals that have more HIT tend to have more resources and still found that the relationships persisted, though there were also some instances in which relationships in the opposite direction were found. For example, electronic documentation was associated with a 35% increase in the risk of complications in patients with heart failure, though this may have been because it was easier to find these events due to better documentation (Bates, 2009).

In short, there is a dearth of appropriate cost effectiveness studies and of useful data for conducting such studies. Although the review by Goldzweig et al. (2009, pp. 290-291) concluded on the basis of the individual studies surveyed that "there is some empirical evidence to support the positive economic value of an EHR;" they also found that the projections of large cost savings in previous literature assumed levels of health IT adoption and interoperability that had not been achieved anywhere.

A less comprehensive survey by the US Congressional Budget Office (Orszag, 2008) focused on two prominent studies that attempted to quantify the benefits of HITs. One was a study by the RAND Institute (Girosi, Meili, & Scoville, 2005) and the other a study by the Center for Information Technology Leadership (CITL) (Pan 2004). Both these studies had estimated annual net savings to the US health care sector of about $80 billion (in 2005 dollars) relative to total spending for health care of about $2 trillion per year, though they identified different sources of those savings. The RAND research had quantified savings that the use of health IT could generate by reducing costs in physicians' practices and hospitals. In contrast, the CITL study narrowed the focus to savings from achieving full interoperability of health IT, while excluding potential improvements in efficiency within practices and hospitals.

The approach adopted by both these studies did have in common the use of various extrapolations and these were a source of criticism by the CBO that found that they were inappropriate by the standards of a rigorous cost effectiveness analysis. In particular, according to the Orszag (2008), the RAND study had the following flaws:

- It assumed "appropriate changes in health care" from HIT rather than likely changes taking into account present-day payment incentives that would constrain the effective utilization of HIT.
- It drew solely on empirical studies from the literature that found positive effects for the implementation of health IT systems, thus creating a possible bias in the results.
- It ignored ways in which some cost reductions would be mitigated by cost shifting in other areas.
- Some of its assumptions about savings from eliminating or reducing the use of paper medical records were unrealistic for small practices.

Similarly, the CITL study came in for criticism by the CBO for, in particular, not fully considering the impact of financial incentives in the analysis, estimating savings against a baseline of little or no information technology use, and using over-optimistic assumptions.

While the CBO identified the numerous ways in which two prominent studies of HIT may have overestimated the benefits of HIT, its list of benefits does suggest that there are some areas in which the long-term benefits of HIT may be underestimated insofar as the scale of use has not reached a critical mass. In particular, we would conjecture that the possible improvements in quality of care through the expansion of health care information and generation of data for research may presuppose a base of participating health care providers and institutions that have implemented HIT and are able to share data over their networks. It is possible that these benefits may not be significant until use of HIT is diffused over a greater percentage of health care providers and institutions.

In other words, some of the benefits to be derived from health IT increase in value as the network of those using the technology expands, i.e. as other providers also purchase health IT systems. This phenomenon is known to economists as network effects and is not necessarily restricted to benefits arising from exchange of information for research purposes - providers who can perform functions electronically, such as sending and receiving medical records or ordering laboratory and imaging procedures, also gain when other providers develop similar electronic capabilities. For example, the cost to a general practitioner of sending medical data to a consulting specialist is potentially lower with an HIT system, but only so long as the consulting specialist has an interoperable system that can receive the data electronically.

As a general matter, economists distinguish between direct and indirect network effects, where the former refer to "technological" externalities while the latter refer to "pecuniary" externalities. The former involve situations where use of a technology by agent A directly affects the value agent B derives from that technology (for instance, through increased inter-operability). In the latter, the effects are mediated through the price system, so adoption by agent A reduces the cost of the technology (for instance, through the achievement of greater economies of scale) and hence yields a benefit to agent B. Generally, it is assumed that the price system will take account of pecuniary externalities (although this is not always correct), but the technological externalities can drive a wedge between private and social costs at the margin. When that occurs, it is crucial that cost-benefit studies appropriately distinguish between private and social costs and benefits; this is not generally the case with the studies of HIT deployment that we have reviewed.

At the same time, when network effects are significant, there will typically be multiple equilibria; for example, private costs and benefits may be equalised at one, low level of adoption (with low net benefits), and at another, high level of adoption (with potentially higher net benefits). At the low level equilibrium, no individual non-adopter will face a private net gain from adopting. For example, in a telephone system with few customers, the marginal subscriber gains little by joining the network. A cost-benefit evaluation conducted at that low level of adoption will therefore find that the private benefits of adoption are less than the private costs. However, were adoption levels increased, joining the telephone system would allow the marginal user to communicate with a greater base of subscribers, so that the benefits of subscription (especially taking account of the gains made by those receiving the calls) exceed the private costs.

These issues of differences between private and social costs and benefits and of multiple equilibria can create biases. For example, what may seem like low benefits relative to costs may reflect an initial low level equilibrium and an associated coordination failure. In other words, if instead of looking at a decision by say, an individual practitioner or medical practice to adopt HIT, one evaluated the costs and benefits of adding a large number of practitioners or medical practices to the installed base of HIT, the balance of the costs and benefits might differ.

It is pertinent that according to a new analysis of HIT deployment in seven industrialized countries, US deployment lags well behind other countries (Davis, Doty, Shea, & Stramekis, 2009). Electronic medical records usage ranged from nearly all physicians in the Netherlands to 23 per cent in Canada and 28 per cent in the US. Incidentally, the same study also found that physicians with greater IT capacity were more likely to report feeling well-prepared to manage patients with chronic diseases. Insofar as the bulk of HIT studies have been from the US, the benefits documented from use of HIT in these studies may not be representative of benefits in countries with a higher deployment of HIT. However, this is not a hypothesis we are in a position to test.

One barrier to the achievement of the full magnitude of network effects that would maximize the benefits of using HIT may be legal restrictions. A recent US study found that privacy regulations impose costs that deter the diffusion of EMR technology (Miller & Tucker, 2009). These regulations may inhibit adoption by restricting the ability of hospitals to exchange patient information with each other, which may be particularly important for patients with chronic conditions who wish to see a new specialist, or emergency room patients whose records are stored elsewhere. The study calculated that the inhibition of network benefits from privacy regulations reduced hospital adoption of EMR by 25 per cent.

It is clear from the various literature reviews discussed so far, first, that there have been very few studies that have attempted to meet the rigorous standards of a cost effectiveness analysis, and second, that there are numerous pitfalls in conducting such analyses owing to the use of various assumptions and extrapolations in quantifying benefits or costs. Another issue which remains to be addressed with greater rigour in the literature is how to quantify the likely benefits of HIT taking into account various projections of network effects associated with different uptake rates.

CONCLUSION

The picture that emerges from our overview has several dimensions. First of all, it is evident that little is known about the overall impact of health IT on the outcomes of health care. In this chapter we have reported a number of studies that showed positive outcomes on, for example, the reduction of adverse drug events, better resource utilization, and improved adherence to clinical guidelines. These studies are well bounded in scope and size, and are mainly about the effectiveness of processes. However, the findings do not always unequivocally point to positive outcomes. Reminders and alerts are an essential feature of decision support in computerized physician order entry systems. They warn users of potentially dangerously interacting medications. A systematic review showed that they are suppressed frequently, and this may prevent detection of ADEs and thus compromise patient safety (van der Sijs, Aarts, Vulto, & Berg, 2006). Yet, the positive outcomes are often extrapolated to a larger population to make a case for the wide scale implementation of health IT.

Equally, implementing health IT often entails significant organizational change, both at the level of practicing medicine and the structure of health care organizations. However, a study of organizational change in Australian hospitals by Braithwaite, Westbrook, Hindle, Iedema, and Black (2006) provides a sobering reminder that there can be a large gap between expectations and reality. The introduction of clinical directorates, in which clinical departments, wards, and units that best fitted conceptually were joined together, was seen to increase the effectiveness of health delivery. Using diachronic data the authors found that the introduction of clinical directorates had no effect. Unfortunately, we have no way of fully knowing the effectiveness of health IT unless it has been widely adopted and diachronic data become available for analysis.

There is growing awareness that health IT is far from mature. In a report to the Office of the National Coordinator of Health Information Technology (ONCHIT), the American Medical Informatics Association writes that some current clinical decision support systems often disrupt clinical workflow in a manner that interferes with efficient delivery (Osheroff et al., 2006). In our overview we already mentioned the adverse effects of health IT, indicating how difficult implementation in practice is. In another study Koppel, Wetterneck, Telles, and Karsh (2008) also found that bar-coded medication administration systems did not reduce dispensing errors substantially because they induced workaround to mitigate unintended effects. The main causes seem to be the technology itself and the generally poor understanding of how technology affects work practices, let alone how it can improve them by introducing notions of patient-centered care and a working collaborative of different providers. A telling example is how computerized provider order entry systems are designed and implemented on the model of an individual physician prescribing medication, instead of a collaborative model involving physicians, pharmacists, and nurses who are all involved in providing medication to patients (Niazkhani, Pirnejad, Berg, & Aarts, 2009).

Often expectations are overblown. In a Dutch hospital the implementers of a CPOE system expected that physicians would use the system, because the system that was being replaced was also about electronic order entry (Aarts et al., 2004). They did not realize that physicians were not at all accustomed to electronic order entry, and that the system requires a doctor to send electronic notes, but doctors don't send notes as other people do that for them. Implementation should begin by asking the question 'what organizational problem is going to be solved,' and what can be done to engage problem owners. There is also a serious lack of organizational learning when a system is designed and implemented (Edmondson, Winslow, Bohmer, & Pisano, 2003). This may be due to the fact that implementation teams are often dissolved after the project is considered finished, leading to a change in personnel who actually use the system.

To conclude, we find ourselves in a double bind. The effectiveness of health IT is anecdotal, and increasingly unintended consequences are being reported (Ash et al., 2004). Health IT is far from mature. Hard work is needed to get safe and reliable systems to work in practice. Yet, it is a dictum that without IT, health care will grind to a halt. We have become dependent on health IT, and yet its overall contribution to health care is hard to quantify. It is comparable to the productivity paradox that some economists pointed to in the early 1990s. Society has become dependent and intertwined with information technology, and yet its contribution didn't seem to show up in the productivity figures (Brynjolfsson, 1993; Landauer, 1995). While some of the positive macroeconomic impacts did become clearer over time, the situation with respect to health IT is still at the earlier stage. This leaves a need to identify proxies for health IT effectiveness and better capture longitudinal and diachronic data to assess its impact on process and outcome.

REFERENCES

Aarts, J., Ash, J., & Berg, M. (2007). Extending the understanding of computerized physician order entry: Implications for professional collaboration, workflow and quality of care. *International Journal of Medical Informatics*, *76*(Suppl 1), 4–13. doi:10.1016/j.ijmedinf.2006.05.009

Aarts, J., Doorewaard, H., & Berg, M. (2004). Understanding implementation: the case of a computerized physician order entry system in a large Dutch university medical center. *Journal of the American Medical Informatics Association*, *11*(3), 207–216. doi:10.1197/jamia.M1372

Amarasingham, R., Plantinga, L., Diener-West, M., Gaskin, D. J., & Powe, N. R. (2009). Clinical information technologies and inpatient outcomes: a multiple hospital study. *Archives of Internal Medicine*, *169*(2), 108–114. doi:10.1001/archinternmed.2008.520

Asaro, P. V., Sheldahl, A. L., & Char, D. M. (2006). Embedded guideline information without patient specificity in a commercial emergency department computerized order-entry system. *Academic Emergency Medicine*, *13*(4), 452–458. doi:10.1111/j.1553-2712.2006.tb00325.x

Ash, J. S., Berg, M., & Coiera, E. (2004). Some unintended consequences of information technology in health care: the nature of patient care information system-related errors. *Journal of the American Medical Informatics Association*, *11*(2), 104–112. doi:10.1197/jamia.M1471

Bates, D. W. (2009). The effects of health information technology on inpatient care. *Archives of Internal Medicine*, *169*(2), 105–107. doi:10.1001/archinternmed.2008.542

Bates, D. W., Boyle, D. L., Rittenberg, E., & Kuperman, G. J., Ma'Luf, N., Menkin, V. et al. (1998). What proportion of common diagnostic tests appear redundant? *The American Journal of Medicine*, *104*(4), 361–368. doi:10.1016/S0002-9343(98)00063-1

Bates, D. W., O'Neil, A. C., Boyle, D., Teich, J., Chertow, G. M., Komaroff, A. L., & Brennan, T. A. (1994). Potential identifiability and preventability of adverse events using information systems. *Journal of the American Medical Informatics Association*, *1*(5), 404–411.

Bates, D. W., Spell, N., Cullen, D. J., Burdick, E., Laird, N., & Petersen, L. A. (1997). The costs of adverse drug events in hospitalized patients. Adverse Drug Events Prevention Study Group. *Journal of the American Medical Association*, *277*(4), 307–311. doi:10.1001/jama.277.4.307

Beresford, E. B. (1991, Jul. - Aug.). Uncertainty and the shaping of medical decisions. *The Hastings Center Report*, *21*(4), 6–11. doi:10.2307/3562993

Berg, M. (1998). Medical work and the computer-based patient record: a sociological perspective. *Methods of Information in Medicine*, *37*(3), 294–301.

Berg, M. (1999). Accumulation and coordinating: occasions for information technologies in medical work. *Computer Supported Cooperative Work*, *8*, 373–401. doi:10.1023/A:1008757115404

Braithwaite, J., Westbrook, M. T., Hindle, D., Iedema, R. A., & Black, D. A. (2006). Does restructuring hospitals result in greater efficiency?--An empirical test using diachronic data. *Health Services Management Research*, *19*(1), 1–12. doi:10.1258/095148406775322016

Brennan, P. F. (2007). CPOE: sufficient, but not perfect, evidence for taking action. *Journal of the American Medical Informatics Association*, *14*(1), 130–131. doi:10.1197/jamia.M2303

Brennan, T. A., Leape, L. L., Laird, N. M., Hebert, L., Localio, A. R., & Lawthers, A. G. (1991). Incidence of adverse events and negligence in hospitalized patients. Results of the Harvard Medical Practice Study I. *The New England Journal of Medicine*, *324*, 370–376.

Brynjolfsson, E. (1993). The productivity paradox of information technology. *Communications of the ACM*, *36*(12), 67–77. doi:10.1145/163298.163309

Butler, J., Speroff, T., Arbogast, P. G., Newton, M., Waitman, L. R., & Stiles, R. (2006). Improved compliance with quality measures at hospital discharge with a computerized physician order entry system. *American Heart Journal*, *151*(3), 643–653. doi:10.1016/j.ahj.2005.05.007

Campbell, E. M., Sittig, D. F., Ash, J. S., Guappone, K. P., & Dykstra, R. H. (2006). Types of unintended consequences related to computerized provider order entry. *Journal of the American Medical Informatics Association*, *13*(5), 547–556. doi:10.1197/jamia.M2042

Cavanagh, K., Shapiro, D. A., Van Den Berg, S., Swain, S., Barkham, M., & Proudfoot, J. (2006). The effectiveness of computerized cognitive behavioural therapy in routine care. *The British Journal of Clinical Psychology*, *45*(Pt 4), 499–514. doi:10.1348/014466505X84782

Chaudhry, B., Wang, J., Wu, S., Maglione, M., Mojica, W., & Roth, E. (2006). Systematic review: impact of health information technology on quality, efficiency, and costs of medical care. *Annals of Internal Medicine*, *144*(10), 742–752.

Ciborra, C. (2002). *The labyrinths of information, challenging the wisdom of systems*. Oxford, UK: Oxford University Press.

Cintron, A., Phillips, R., & Hamel, M. B. (2006). The effect of a web-based, patient-directed intervention on knowledge, discussion, and completion of a health care proxy. *Journal of Palliative Medicine*, *9*(6), 1320–1328. doi:10.1089/jpm.2006.9.1320

Clarke, K., Hartswood, M., Procter, R., Rouncefield, M., & Slack, R. (2003). Trusting the record. *Methods of Information in Medicine*, *42*(4), 345–352.

Coiera, E. (2003). Guide to health informatics (2nd ed.). New York: Arnold; Distributed in the USA by Oxford University Press.

Cook, R. I., Woods, D. D., & Miller, C. (1998). *A tale of two stories: contrasting views of patient safety*. Chicago: National Patient Safety Foundation.

Crosson, J. C., Ohman-Strickland, P. A., Hahn, K. A., DiCicco-Bloom, B., Shaw, E., Orzano, A. J., & Crabtree, B. F. (2007). Electronic medical records and diabetes quality of care: results from a sample of family medicine practices. *Annals of Family Medicine*, *5*(3), 209–215. doi:10.1370/afm.696

Davis, K., Doty, M. M., Shea, K., & Stremikis, K. (2009). Health information technology and physician perceptions of quality of care and satisfaction. *Health Policy (Amsterdam)*, *90*(2-3), 239–246. doi:10.1016/j.healthpol.2008.10.002

Del Beccaro, M. A., Jeffries, H. E., Eisenberg, M. A., & Harry, E. D. (2006). Computerized provider order entry implementation: no association with increased mortality rates in an intensive care unit. *Pediatrics*, *118*(1), 290–295. doi:10.1542/peds.2006-0367

Dexter, P. R., Perkins, S. M., Maharry, K. S., Jones, K., & McDonald, C. J. (2004). Inpatient computer-based standing orders vs physician reminders to increase influenza and pneumococcal vaccination rates: a randomized trial. *Journal of the American Medical Association*, *292*(19), 2366–2371. doi:10.1001/jama.292.19.2366

Dick, R. S., Steen, E. B., & Detmer, D. E. (Eds.). (1997). *The computer-based patient record* (Rev. ed.). Washington, DC: National Academy Press.

Edmondson, A. C., Winslow, A. B., Bohmer, R. M. J., & Pisano, G. P. (2003). Learning how and learning what: effects of tacit and codified knowledge on performance improvement following technology adoption. *Decision Sciences*, *34*(2), 197–223. doi:10.1111/1540-5915.02316

Evans, R. S., Pestotnik, S. L., Classen, D. C., Clemmer, T. P., Weaver, L. K., & Orme, J. F. Jr,… Burke, J. P. (1998). A computer-assisted management program for antibiotics and other antiinfective agents. *The New England Journal of Medicine*, *338*, 232–238. doi:10.1056/NEJM199801223380406

Ewusi-Mensah, K. (2003). *Software development failures*. Cambridge, MA: The MIT Press.

Farley, D., Damberg, C., Berry, S., Sorbero, M., Teleki, S., Ricc, K., & Pollock, N. (2005). *Assessment of the National patient Safety Initiative*. Context and Baseline Evaluation Report 1. Rand Corporation, United States. Agency for Healthcare Research and Quality.

Feldstein, A., Elmer, P. J., Smith, D. H., Herson, M., Orwoll, E., & Chen, C.,… Swain, M. C. (2006). Electronic medical record reminder improves osteoporosis management after a fracture: a randomized, controlled trial. *Journal of the American Geriatrics Society*, *54*(3), 450–457. doi:10.1111/j.1532-5415.2005.00618.x

Ford, E. W., Menachemi, N., Peterson, L. T., & Huerta, T. R. (2009). Resistance is futile: but it is slowing the pace of EHR adoption nonetheless. *Journal of the American Medical Informatics Association*, *16*(3), 274–281. doi:10.1197/jamia.M3042

Fries, J. F. (1994). Can prevention lower health costs by reducing demand? Yes. *Hospitals & Health Networks*, *68*(3), 10.

Galanter, W. L., Polikaitis, A., & DiDomenico, R. J. (2004). A trial of automated safety alerts for inpatient digoxin use with computerized physician order entry. *Journal of the American Medical Informatics Association*, *11*(4), 270–277. doi:10.1197/jamia.M1500

Gans, D., Kralewski, J., Hammons, T., & Dowd, B. (2005). Medical groups' adoption of electronic health records and information systems. *Health Affairs (Project Hope)*, *24*(5), 1323–1333. doi:10.1377/hlthaff.24.5.1323

Gardner, P., & Schaffner, W. (1993). Immunization of adults. *The New England Journal of Medicine*, *328*, 1252–1258. doi:10.1056/NEJM199304293281708

Garg, A. X., Adhikari, N. K., McDonald, H., Rosas-Arellano, M. P., Devereaux, P. J., & Beyene, J. (2005). Effects of computerized clinical decision support systems on practitioner performance and patient outcomes: a systematic review. *Journal of the American Medical Association*, *293*(10), 1223–1238. doi:10.1001/jama.293.10.1223

Garrido, T., Jamieson, L., Zhou, Y., Wiesenthal, A., & Liang, L. (2005). Effect of electronic health records in ambulatory care: retrospective, serial, cross sectional study. *British Medical Journal*, *330*, 581–585. doi:10.1136/bmj.330.7491.581

Girosi, F., Meili, R., & Scoville, R. (2005). *Extrapolating evidence of health information technology and costs*. Santa Monica, CA: RAND Corporation.

Goldzweig, C. L., Towfigh, A., Maglione, M., & Shekelle, P. G. (2009). Costs and benefits of health information technology: new trends from the literature. *Health Affairs (Project Hope)*, *28*(2), w282–w293. doi:10.1377/hlthaff.28.2.w282

Grime, P. R. (2004). Computerized cognitive behavioural therapy at work: a randomized controlled trial in employees with recent stress-related absenteeism. *Occupational Medicine (Oxford, England)*, *54*(5), 353–359. doi:10.1093/occmed/kqh077

Han, Y. Y., Carcillo, J. A., Venkataraman, S. T., Clark, R. S., Watson, R. S., & Nguyen, T. C. (2005). Unexpected increased mortality after implementation of a commercially sold computerized physician order entry system. *Pediatrics*, *116*(6), 1506–1512. doi:10.1542/peds.2005-1287

Harpole, L. H., Khorasani, R., Fiskio, J., Kuperman, G. J., & Bates, D. W. (1997). Automated evidence-based critiquing of orders for abdominal radiographs: impact on utilization and appropriateness. *Journal of the American Medical Informatics Association*, *4*(6), 511–521.

Jacobi, C., Morris, L., Beckers, C., Bronisch-Holtze, J., Winter, J., Winzelberg, A. J., & Taylor, C. B. (2007). Maintenance of internet-based prevention: a randomized controlled trial. *The International Journal of Eating Disorders*, *40*(2), 114–119. doi:10.1002/eat.20344

James, B.C. (1989). Improving quality can reduce costs. *QA Review: quality assurance and news, 1*(1), 4.

Jha, A. K., Doolan, D., Grandt, D., Scott, T., & Bates, D. W. (2008). The use of health information technology in seven nations. *International Journal of Medical Informatics*, *77*(12), 848–854. doi:10.1016/j.ijmedinf.2008.06.007

Johns, R. J., & Blum, B. I. (1979). The use of clinical information systems to control cost as well as to improve care. *Transactions of the American Clinical and Climatological Association*, *90*, 140–152.

Kaushal, R., Jha, A. K., Franz, C., Glaser, J., Shetty, K. D., & Jaggi, T. (2006). Return on investment for a computerized physician order entry system. *Journal of the American Medical Informatics Association*, *13*(3), 261–266. doi:10.1197/jamia.M1984

Kemper, A. R., Uren, R. L., & Clark, S. J. (2006). Adoption of electronic health records in primary care pediatric practices. *Pediatrics*, *118*(1), e20–e24. doi:10.1542/peds.2005-3000

Kohn, L. T., Corrigan, J. M., & Donaldson, M. S. (Eds.). (2000). *To err is human, building a safer health system*. Washington, DC: National Academy Press.

Koppel, R., Metlay, J. P., Cohen, A., Abaluck, B., Localio, A. R., Kimmel, S. E., & Strom, B. L. (2005). Role of computerized physician order entry systems in facilitating medication errors. *Journal of the American Medical Association*, *293*(10), 1197–1203. doi:10.1001/jama.293.10.1197

Koppel, R., Wetterneck, T., Telles, J. L., & Karsh, B. T. (2008). Workarounds to barcode medication administration systems: their occurrences, causes, and threats to patient safety. *Journal of the American Medical Informatics Association*, *15*(4), 408–423. doi:10.1197/jamia.M2616

Landauer, T. K. (1995). *The trouble with computers: usefulness, usability, and productivity*. Cambridge, MA: MIT Press.

Leape, L. L., & Berwick, D. M. (2005). Five years after *To Err Is Human*: What have we learned? *Journal of the American Medical Association*, *293*(19), 2384–2390. doi:10.1001/jama.293.19.2384

Lester, W. T., Grant, R. W., Barnett, G. O., & Chueh, H. C. (2006). Randomized controlled trial of an informatics-based intervention to increase statin prescription for secondary prevention of coronary disease. *Journal of General Internal Medicine*, *21*(1), 22–29. doi:10.1111/j.1525-1497.2005.00268.x

Linder, J. A., Ma, J., Bates, D. W., Middleton, B., & Stafford, R. S. (2007). Electronic health record use and the quality of ambulatory care in the United States. *Archives of Internal Medicine*, *167*(13), 1400–1405. doi:10.1001/archinte.167.13.1400

Lucas, H. C. Jr. (1975). *Why information systems fail*. New York: Columbia University Press.

Mattocks, K., Lalime, K., Tate, J. P., Giannotti, T. E., Carr, K., & Carrabba, A. (2007). The state of physician office-based health information technology in Connecticut: current use, barriers and future plans. *Connecticut Medicine*, *71*(1), 27–31.

McDonald, C. J. (1976). Protocol-based computer reminders, the quality of care and the non-perfectability of man. *The New England Journal of Medicine*, *295*(24), 1351–1355.

McGlynn, E. A., Ash, S. M., Adams, J., Keesey, J., Hicks, J., DeCristoforo, A., & Kerr, E. A. (2003). The quality of health care delivered to adults in the United States. *The New England Journal of Medicine*, *348*, 2635–2645. doi:10.1056/NEJMsa022615

McMahon, G. T., Gomes, H. E., Hickson Hohne, S., Hu, T. M., Levine, B. A., & Conlin, P. R. (2005). Web-based care management in patients with poorly controlled diabetes. *Diabetes Care*, *28*(7), 1624–1629. doi:10.2337/diacare.28.7.1624

Mekhjian, H. S., Kumar, R. R., Kuehn, L., Bentley, T. D., Teater, P., & Thomas, A. (2002). Immediate benefits realized following implementation of physician order entry at an academic medical center. *Journal of the American Medical Informatics Association*, *9*(5), 529–539. doi:10.1197/jamia.M1038

Miller, A. R., & Tucker, C. (2009). Privacy protection and technology diffusion: the case of electronic medical records. *Management Science*, *55*(7), 1077–1093. doi:10.1287/mnsc.1090.1014

Miller, R. H., West, C., Brown, T. M., Sim, I., & Ganchoff, C. (2005). The value of electronic health records in solo or small group practices. *Health Affairs (Project Hope)*, *24*(5), 1127–1137. doi:10.1377/hlthaff.24.5.1127

Mullett, C. J., Evans, R. S., Christenson, J. C., & Dean, J. M. (2001). Development and impact of a computerized pediatric antiinfective decision support program. *Pediatrics*, *108*(4), E75. doi:10.1542/peds.108.4.e75

Murray, M. D., Harris, L. E., Overhage, J. M., Zhou, X. H., Eckert, G. J., & Smith, F. E. (2004). Failure of computerized treatment suggestions to improve health outcomes of outpatients with uncomplicated hypertension: results of a randomized controlled trial. *Pharmacotherapy*, *24*(3), 324–337. doi:10.1592/phco.24.4.324.33173

Nebeker, J. R., Hoffman, J. M., Weir, C. R., Bennett, C. L., & Hurdle, J. F. (2005). High rates of adverse drug events in a highly computerized hospital. *Archives of Internal Medicine*, *165*(10), 1111–1116. doi:10.1001/archinte.165.10.1111

Nemeth, C., & Cook, R. (2005). Hiding in plain sight: What Koppel et al. tell us about healthcare IT. *Journal of Biomedical Informatics*,*38*(4), 262-263. doi:10.1016/j.jbi.2005.05.010

Niazkhani, Z., Pirnejad, H., Berg, M., & Aarts, J. (2009). The impact of computerized provider order entry systems on inpatient clinical workflow: a literature review. *Journal of the American Medical Informatics Association*, *16*(4), 539–549. doi:10.1197/jamia.M2419

O'Neill, L., & Klepack, W. (2007). Electronic medical records for a rural family practice: a case study in systems development. *Journal of Medical Systems*, *31*(1), 25–33. doi:10.1007/s10916-006-9040-1

Orszag, P. R. (2008). *Evidence on the costs and benefits of health information technology*. Washington, DC: The Office of the National Coordinator of Health Information Technology.

Orszag, P. R., & Ellis, P. (2007). The challenge of rising health care costs--a view from the Congressional Budget Office. *The New England Journal of Medicine*, *357*(18), 1793–1795. doi:10.1056/NEJMp078190

Osheroff, J. A., Teich, J. M., Middleton, B. F., Steen, E. B., Wright, A., & Detmer, D. E. (2006). A roadmap for national action on clinical decision support (No. HHSP233200500877P). Bethesda, MD.

Ozdas, A., Speroff, T., Waitman, L. R., Ozbolt, J., Butler, J., & Miller, R. A. (2006). Integrating "best of care" protocols into clinicians' workflow via care provider order entry: impact on quality-of-care indicators for acute myocardial infarction. *Journal of the American Medical Informatics Association*, *13*(2), 188–196. doi:10.1197/jamia.M1656

Palen, T. E., Raebel, M., Lyons, E., & Magid, D. M. (2006). Evaluation of laboratory monitoring alerts within a computerized physician order entry system for medication orders. *The American Journal of Managed Care*, *12*(7), 389–395.

Pan, W.T. (2004, November 18 - 19). *Health information technology 2004: improving chronic disease care in California. California HealthCare Foundation*. San Francisco, CA: SBC Park.

Perreault, L., & Metzger, J. (1993). A pragmatic framework for understanding clinical decision support. *Journal of Healthcare Information Management*, *13*(2), 5–21.

Pizziferri, L., Kittler, A. F., Volk, L. A., Honour, M. M., Gupta, S., & Wang, S. (2005). Primary care physician time utilization before and after implementation of an electronic health record: a time-motion study. *Journal of Biomedical Informatics*, *38*(3), 176–188. doi:10.1016/j.jbi.2004.11.009

Poissant, L., Pereira, J., Tamblyn, R., & Kawasumi, Y. (2005). The impact of electronic health records on time efficiency of physicians and nurses: a systematic review. *Journal of the American Medical Informatics Association*, *12*(5), 505–516. doi:10.1197/jamia.M1700

Potts, A. L., Barr, F. E., Gregory, D. F., Wright, L., & Patel, N. R. (2004). Computerized physician order entry and medication errors in a pediatric critical care unit. *Pediatrics*, *113*(Pt 1), 59–63. doi:10.1542/peds.113.1.59

Proudfoot, J., Ryden, C., Everitt, B., Shapiro, D. A., Goldberg, D., & Mann, A. (2004). Clinical efficacy of computerised cognitive-behavioural therapy for anxiety and depression in primary care: randomised controlled trial. *The British Journal of Psychiatry*, *185*, 46–54. doi:10.1192/bjp.185.1.46

Rothschild, J. M., Federico, F. A., Gandhi, T. K., Kaushal, R., Williams, D. H., & Bates, D. W. (2002). Analysis of medication-related malpractice claims: causes, preventability, and costs. *Archives of Internal Medicine*, *162*(21), 2414–2420. doi:10.1001/archinte.162.21.2414

Rothschild, J. M., McGurk, S., Honour, M., Lu, L., McClendon, A. A., & Srivastava, P. (2007). Assessment of education and computerized decision support interventions for improving transfusion practice. *Transfusion*, *47*(2), 228–239. doi:10.1111/j.1537-2995.2007.01093.x

Roumie, C. L., Elasy, T. A., Greevy, R., Griffin, M. R., Liu, X., & Stone, W. J. (2006). Improving blood pressure control through provider education, provider alerts, and patient education: a cluster randomized trial. *Annals of Internal Medicine*, *145*(3), 165–175.

Safran, C. (1999). Editorial. *International Journal of Medical Informatics*, *54*(3), 155–156. doi:10.1016/S1386-5056(99)00003-9

Sands, D. Z. (1999). Electronic patient-centered communication: managing risks, managing opportunities, managing care. *The American Journal of Managed Care*, *5*(12), 1569–1571.

Sequist, T. D., Gandhi, T. K., Karson, A. S., Fiskio, J. M., Bugbee, D., & Sperling, M. (2005). A randomized trial of electronic clinical reminders to improve quality of care for diabetes and coronary artery disease. *Journal of the American Medical Informatics Association*, *12*(4), 431–437. doi:10.1197/jamia.M1788

Shulman, R., Singer, M., Goldstone, J., & Bellingan, G. (2005). Medication errors: a prospective cohort study of hand-written and computerised physician order entry in the intensive care unit. *Critical Care (London, England)*, *9*(5), R516–R521. doi:10.1186/cc3793

Slack, W. V. (2001). *Cybermedicine: how computing empowers doctors and patients for better care*. San Francisco, CA: Jossey-Bass.

Smith, D. H., Perrin, N., Feldstein, A., Yang, X., Kuang, D., & Simon, S. R. (2006). The impact of prescribing safety alerts for elderly persons in an electronic medical record: an interrupted time series evaluation. *Archives of Internal Medicine*, *166*(10), 1098–1104. doi:10.1001/archinte.166.10.1098

Speicher, C. D. S.J.J. (1983). Choosing Effective Laboratory Tests, W.B. Saunders, (Ed.). Philadelphia, PA: W.B.Saunders.

Steele, A. W., Eisert, S., Witter, J., Lyons, P., Jones, M. A., Gabow, P., & Ortiz, E. (2005). The effect of automated alerts on provider ordering behavior in an outpatient setting. *PLoS Medicine, 2*(9), e255. Retrieved from Doi: 10.1371/journal.pmed.0020255

Studdert, D. M., Mello, M. M., Gawande, A. A., Gandhi, T. K., Kachalia, A, & Yoon, C.,… Brennan, T.A. (2006). Claims, errors, and compensation payments in medical malpractice litigation. *The New England Journal of Medicine*, *354*, 2024–2033. doi:10.1056/NEJMsa054479

Tang, P. C., LaRosa, M. P., Newcomb, C., & Gorden, S. M. (1999). Measuring the effects of reminders for outpatient influenza immunizations at the point of clinical opportunity. *Journal of the American Medical Informatics Association*, *6*, 115–121.

Tierney, W. M., Overhage, J. M., Murray, M. D., Harris, L. E., Zhou, X. H., & Eckert, G. J. (2005). Can computer-generated evidence-based care suggestions enhance evidence-based management of asthma and chronic obstructive pulmonary disease? A randomized, controlled trial. *Health Services Research*, *40*(2), 477–497. doi:10.1111/j.1475-6773.2005.0t369.x

Tierney, W. M., Rotich, J. K., Hannan, T. J., Siika, A. M., Biondich, P. G., & Mamlin, B. W. (2007). The AMPATH medical record system: creating, implementing, and sustaining an electronic medical record system to support HIV/AIDS care in western Kenya. *Studies in Health Technology and Informatics*, *129*(Pt 1), 372–376.

Toth-Pal, E., Nilsson, G. H., & Furhoff, A. K. (2004). Clinical effect of computer generated physician reminders in health screening in primary health care--a controlled clinical trial of preventive services among the elderly. *International Journal of Medical Informatics*, *73*(9-10), 695–703. doi:10.1016/j.ijmedinf.2004.05.007

van der Sijs, H., Aarts, J., Vulto, A., & Berg, M. (2006). Overriding of drug safety alerts in computerized physician order entry. Journal of the American Medical Informatics Association, 13(2), 138-147. Virapongse, A., Bates, D. W., Shi, P., Jenter, C. A., Volk, L. A., Kleinman, K. et al. (2008). Electronic health records and malpractice claims in office practice. *Archives of Internal Medicine*,*168*(21), 2362-7.

Wagner, B., Knaevelsrud, C., & Maercker, A. (2006). Internet-based cognitive-behavioral therapy for complicated grief: a randomized controlled trial. *Death Studies*, *30*(5), 429–453. doi:10.1080/07481180600614385

Walker, J., Pan, E., Johnston, D., Adler-Milstein, J., Bates, D. W., & Middleton, B. (2005). The value of health care information exchange and interoperability. *Health Affairs (Project Hope)*, (Suppl Web Exclusives), W5-10–W15-18.

Weick, K. E. (1990). The vulnerable system - an analysis of the Tenerife air disaster. *Journal of Management*, *16*(3), 571–596. doi:10.1177/014920639001600304

Williamson, J. W., Goldschmidt, P. G., & Jillson, I. A. (1979). Medical Practice Information Demonstration Project: Final Report. Baltimore, MD: Policy Research Inc. Office of the Assistant Secretary of Health, Department of Health, Education, and Welfare, contract 28277-0068GS.

ENDNOTES

1 Some studies suggest potential reductions in error rates from the use of health IT of between 50 per cent and over 90 per cent (Evans et al., 1998; Potts, Barr, Gregory, Wright, & Patel, 2004).

2 A review of studies on clinical decision support found that most such functions improved the performance of practitioners – see Garg et al., 2005. On the other hand, other research finds no evidence of an increase in physicians' adherence to evidence-based standards of treatment for a wide variety of conditions – see for instance Crosson et al., 2007, and Linder, Ma, Bates, Middleton, & Stafford, 2007.