Systematic Review: Impact of Health Information Technology on Quality, Efficiency, and Costs of Medical Care

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Background: Experts consider health information technology key to improving efficiency and quality of health care.

Purpose: To systematically review evidence on the effect of health information technology on quality, efficiency, and costs of health care.

Data Sources: The authors systematically searched the English-language literature indexed in MEDLINE (1995 to January 2004), the Cochrane Central Register of Controlled Trials, the Cochrane Database of Abstracts of Reviews of Effects, and the Periodical Abstracts Database. We also added studies identified by experts up to April 2005.

Study Selection: Descriptive and comparative studies and systematic reviews of health information technology.

Data Extraction: Two reviewers independently extracted information on system capabilities, design, effects on quality, system acquisition, implementation context, and costs.

Data Synthesis: 257 studies met the inclusion criteria. Most studies addressed decision support systems or electronic health records. Approximately 25% of the studies were from 4 academic institutions that implemented internally developed systems; only 9 studies evaluated multifunctional, commercially developed systems. Three major benefits on quality were demonstrated: increased adherence to guideline-based care, enhanced surveillance and monitoring, and decreased medication errors. The primary domain of improvement was preventive health. The major efficiency benefit shown was decreased utilization of care. Data on another efficiency measure, time utilization, were mixed. Empirical cost data were limited.

Limitations: Available quantitative research was limited and was done by a small number of institutions. Systems were heterogeneous and sometimes incompletely described. Available financial and contextual data were limited.

Conclusions: Four benchmark institutions have demonstrated the efficacy of health information technologies in improving quality and efficiency. Whether and how other institutions can achieve similar benefits, and at what costs, are unclear.

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Health care experts, policymakers, payers, and consumers consider health information technologies, such as electronic health records and computerized provider order entry, to be critical to transforming the health care industry (1–7). Information management is fundamental to health care delivery (8). Given the fragmented nature of health care, the large volume of transactions in the system, the need to integrate new scientific evidence into practice, and other complex information management activities, the limitations of paper-based information management are intuitively apparent. While the benefits of health information technology are clear in theory, adapting new information systems to health care has proven difficult and rates of use have been limited (9–11). Most information technology applications have centered on administrative and financial transactions rather than on delivering clinical care (12).

The Agency for Healthcare Research and Quality asked us to systematically review evidence on the costs and benefits associated with use of health information technology and to identify gaps in the literature in order to provide organizations, policymakers, clinicians, and consumers an understanding of the effect of health information technology on clinical care (see evidence report at www.ahrq.gov). From among the many possible benefits and costs of implementing health information technology, we focus here on 3 important domains: the effects of health information technology on quality, efficiency, and costs.

Methods

Analytic Frameworks

We used expert opinion and literature review to develop analytic frameworks (**Table**) that describe the components involved with implementing health information technology, types of health information technology systems, and the functional capabilities of a comprehensive health information technology system (13). We modified a framework for clinical benefits from the Institute of Medicine's 6 aims for care (2) and developed a framework for costs using expert consensus that included measures such as initial costs, ongoing operational and maintenance costs, fraction of health information technology penetration, and productivity gains. Financial benefits were divided into

See also:

Web-Only
Appendix Tables
Conversion of figure and tables into slides

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monetized benefits (that is, benefits expressed in dollar terms) and nonmonetized benefits (that is, benefits that could not be directly expressed in dollar terms but could be assigned dollar values).

Data Sources and Search Strategy

We performed 2 searches (in November 2003 and January 2004) of the English-language literature indexed in MEDLINE (1995 to January 2004) using a broad set of terms to maximize sensitivity. (See the full list of search terms and sequence of queries in the full evidence report at www.ahrq.gov.) We also searched the Cochrane Central Register of Controlled Trials, the Cochrane Database of Abstracts of Reviews of Effects, and the Periodical Abstracts Database; hand-searched personal libraries kept by content experts and project staff; and mined bibliographies of articles and systematic reviews for citations. We asked content experts to identify unpublished literature. Finally, we asked content experts and peer reviewers to identify newly published articles up to April 2005.

Study Selection and Classification

Two reviewers independently selected for detailed review the following types of articles that addressed the workings or implementation of a health technology system: systematic reviews, including meta-analyses; descriptive "qualitative" reports that focused on exploration of barriers; and quantitative reports. We classified quantitative reports as "hypothesis-testing" if the investigators compared data between groups or across time periods and used statistical tests to assess differences. We further categorized hypothesis-testing studies (for example, randomized and nonrandomized, controlled trials, controlled before-and-after studies) according to whether a concurrent comparison group was used. Hypothesis-testing studies without a concurrent comparison group included those using simple pre–post, time-series, and historical control designs. Remaining hypothesis-testing studies were classified as cross-sectional designs and other. We classified quantitative reports as a "predictive analysis" if they used methods such as statistical modeling or expert panel estimates to predict what *might* happen with implementation of health information technology rather than what *has* happened. These studies typically used hybrid methods—frequently mixing primary data collection with secondary data collection plus expert opinion and assumptions—to make quantitative estimates for data that had otherwise not been empirically measured. Cost-effectiveness and cost–benefit studies generally fell into this group.

Data Extraction and Synthesis

Two reviewers independently appraised and extracted details of selected articles using standardized abstraction forms and resolved discrepancies by consensus. We then used narrative synthesis methods to integrate findings into descriptive summaries. Each institution that accounted for more than 5% of the total sample of 257 papers was designated as a benchmark research leader. We grouped syntheses by institution and by whether the systems were commercially or internally developed.

Key Summary Points

Health information technology has been shown to improve quality by increasing adherence to guidelines, enhancing disease surveillance, and decreasing medication errors.

Much of the evidence on quality improvement relates to primary and secondary preventive care.

The major efficiency benefit has been decreased utilization of care.

Effect on time utilization is mixed.

Empirically measured cost data are limited and inconclusive.

Most of the high-quality literature regarding multifunctional health information technology systems comes from 4 benchmark research institutions.

Little evidence is available on the effect of multifunctional commercially developed systems.

Little evidence is available on interoperability and consumer health information technology.

A major limitation of the literature is its generalizability.

Role of the Funding Sources

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Data Synthesis

Literature Selection Overview

Of 867 articles, we rejected 140 during initial screening: 124 for not having health information technology as the subject, 3 for not reporting relevant outcomes, and 13 for miscellaneous reasons (categories not mutually exclusive). Of the remaining 727 articles, we excluded the 470 descriptive reports that did not examine barriers (**Figure**). We recorded details of and summarized each of the 257 articles that we did include in an interactive database (http:

Table. **Health Information Technology Frameworks***

Framework	Basis (Reference)	Elements
Components of an HIT implementation	Expert consensus	Technological (e.g., system applications) Organizational process change (e.g., workflow redesign) Human factors (e.g., user-friendliness) Project management (e.g., achieving project milestones)
Types of HIT systems	Expert consensus	Electronic health records Computerized provider order entry Decision support (stand-alone systems) Electronic results reporting (stand-alone systems) Electronic prescribing Consumer health informatics/patient decision support Mobile computing Telemedicine (data interchange–based) Electronic health communication Administration Data exchange networks Knowledge retrieval systems HIT in general Other
Functional capabilities of an HIT system†	Institute of Medicine's "key capabilities" of an electronic health record (13)	Clinical documentation (health information/data) Results management Order entry management Decision support Electronic communication and connectivity Patient support Administrative processes Reporting and population health

* HIT = health information technology.
† Assumes the electronic health record is the foundation for a comprehensive HIT system.

//healthit.ahrq.gov/tools/rand) that serves as the evidence table for our report (14). Twenty-four percent of all studies came from the following 4 benchmark institutions: 1) the Regenstrief Institute, 2) Brigham and Women's Hospital/ Partners Health Care, 3) the Department of Veterans Affairs, and 4) LDS Hospital/ Intermountain Health Care.

Types and Functions of Technology Systems

The reports addressed the following types of primary systems: decision support aimed at providers (63%), electronic health records (37%), and computerized provider order entry (13%). Specific functional capabilities of systems that were described in reports included electronic documentation (31%), order entry (22%), results management (19%), and administrative capabilities (18%). Only 8% of the described systems had specific consumer health capabilities, and only 1% had capabilities that allowed systems from different facilities to connect with each other and share data interoperably. Most studies ($n = 125$) assessed the effect of the systems in the outpatient setting. Of the 213 hypothesis-testing studies, 83 contained some data on costs.

Several studies assessed interventions with limited functionality, such as stand-alone decision support systems (15–17). Such studies provide limited information about issues that today's decision makers face when selecting and implementing health information technology. Thus, we preferentially highlight in the following paragraphs studies that were conducted in the United States, that had empirically measured data on multifunctional systems, and that included health information and data storage in the form of electronic documentation or order-entry capabilities. Predictive analyses were excluded. Seventy-four studies met these criteria: 52 from the 4 benchmark leaders and 22 from other institutions.

Data from Benchmark Institutions

The health information technology systems evaluated by the benchmark leaders shared many characteristics. All the systems were multifunctional and included decision support, all were internally developed by research experts at the respective academic institutions, and all had capabilities added incrementally over several years. Furthermore, most reported studies of these systems used research designs with high internal validity (for example, randomized, controlled trials).

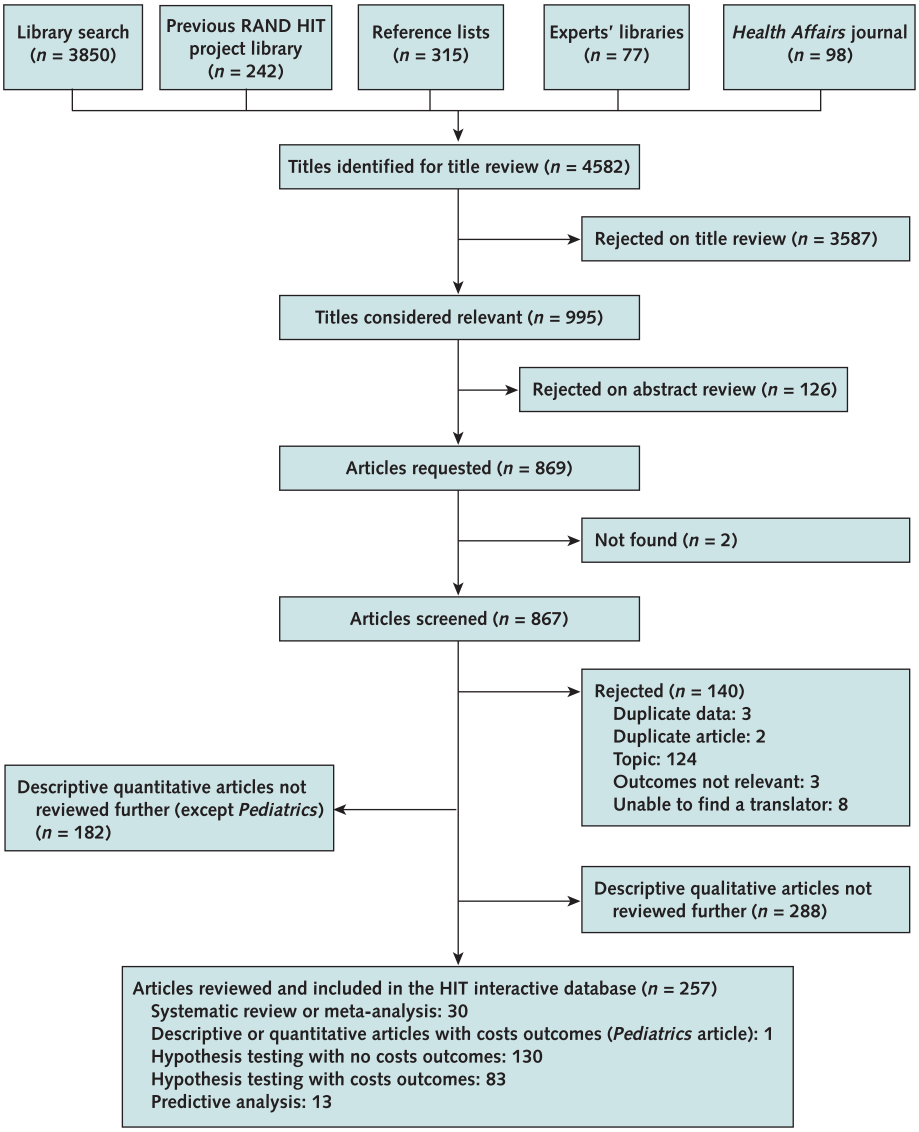
Appendix Table 1 (18–69) (available at www.annals.org) provides a structured summary of each study from the 4 benchmark institutions. This table also includes studies that met inclusion criteria not highlighted in this synthesis (26, 27, 30, 39, 40, 53, 62, 65). The data supported 5 primary themes (3 directly related to quality and 2 addressing efficiency). Implementation of a multifunctional health information technology system had the following effects: 1) increased delivery of care in adherence to guidelines and protocols, 2) enhanced capacity to perform surveillance and monitoring for disease conditions and care delivery, 3) reductions in rates of medication errors, 4) decreased utilization of care, and 5) mixed effects on time utilization.

Effects on Quality

The major effect of health information technology on quality of care was its role in increasing adherence to guideline- or protocol-based care. Decision support, usually in the form of computerized reminders, was a component of all adherence studies. The decision support functions were usually embedded in electronic health records or computerized provider order-entry systems. Electronic health records systems were more frequently examined in the outpatient setting; provider order-entry systems were more often assessed in the inpatient setting. Improvements in processes of care delivery ranged from absolute increases of 5 to 66 percentage points, with most increases clustering in the range of 12 to 20 percentage points.

Twelve of the 20 adherence studies examined the effects of health information technology on enhancing preventive health care delivery (18, 21–25, 29, 31–33, 35, 37). Eight studies included measures for primary preventive

Figure. **Search flow for health information technology (*HIT*) literature.**



care (18, 21–25, 31, 33), 4 studies included secondary preventive measures (29, 33, 35, 37), and 1 study assessed screening (not mutually exclusive) (32). The most common primary preventive measures examined were rates of influenza vaccination (improvement, 12 to 18 percentage points), pneumococcal vaccinations (improvement, 20 to 33 percentage points), and fecal occult blood testing (improvement, 12 to 33 percentage points) (18, 22, 24).

Three studies examined the effect of health information technology on secondary preventive care for complications related to hospitalization. One clinical controlled trial that used computerized surveillance and identification of high-risk patients plus alerts to physicians demonstrated a 3.3–percentage point absolute decrease (from 8.2% to 4.9%) in a combined primary end point of deep venous thrombosis and pulmonary embolism in high-risk hospitalized patients (29). One time-series study showed a 5–percentage point absolute decrease in prevention of pressure ulcers in hospitalized patients (35), and another showed a 0.4–percentage point absolute decrease in postoperative infections (37).

While most evidence for health information technology–related quality improvement through enhanced adherence to guidelines focused on preventive care, other studies covered a diverse range for types of care, including hypertension treatment (34), laboratory testing for hospitalized patients, and use of advance directives (see **Appendix Table 1**, available at www.annals.org, for the numeric effects) (19).

The second theme showed the capacity of health information technology to improve quality of care through clinical monitoring based on large-scale screening and aggregation of data. These studies demonstrated how health information technology can support new ways of delivering care that are not feasible with paper-based information management. In one study, investigators screened more than 90 000 hospital admissions to identify the frequency of adverse drug events (43); they found a rate of 2.4 events/100 admissions. Adverse drug events were associated with an absolute increase in crude mortality of 2.45 percentage points and an increase in costs of $2262, primarily due to a 1.9-day increase in length of stay. Two studies from Evans and colleagues (44, 45) reported using an electronic health record to identify adverse drug events, examine their cause, and develop programs to decrease their frequency. In the first study, the researchers designed interventions on the basis of electronic health record surveillance that increased absolute adverse drug event identification by 2.36 percentage points (from 0.04% to 2.4%) and decreased absolute adverse drug event rates by 5.4 percentage points (from 7.6% to 2.2%) (44). The report did not describe details of the interventions used to reduce adverse drug events. In the second study, the researchers used electronic health record surveillance of nearly 61 000 inpatient admissions to determine that adverse drug events cause a 1.9-day increase in length of hospital stay and an increase of $1939 in charges (45).

Three studies from the Veterans Affairs system examined the surveillance and data aggregation capacity of health information technology systems for facilitating quality-of-care measurement. Automated quality measurement was found to be less labor intensive, but 2 of the studies found important methodologic limitations that affected the validity of automated quality measurement. For example, 1 study found high rates of false-positive results with use of automated quality measurement and indicated that such approaches may yield biased results (41). The second study found that automated queries from computerized disease registries underestimated completion of quality-of-care processes when compared with manual chart abstraction of electronic health records and paper chart sources (42).

Finally, 2 studies examined the role of health information technology surveillance systems in identifying infectious disease outbreaks. The first study found that use of a county-based electronic system for reporting results led to a 29–percentage point absolute increase in cases of shigellosis identified during an outbreak and a 2.5-day decrease in identification and public health reporting time (38). The second study showed a 14–percentage point absolute increase in identification of hospital-acquired infections and a 65% relative decrease in identification time (from 130 to 46 hours) (46).

The third health information technology–mediated effect on quality was a reduction in medication errors. Two studies of computerized provider order entry from LDS Hospital (51, 52) showed statistically significant decreases in adverse drug events, and a third study by Bates and colleagues (49) showed a non–statistically significant trend toward decreased drug events and a large decrease in medication errors. The first LDS Hospital study used a cohort with historical control design to evaluate the effect of computerized alerts on antibiotic use (52). Compared with a 2-year preintervention period, many statistically significant improvements were noted, including a decrease in antibiotic-associated adverse drug events (from 28 to 4 events), decreased length of stay (from 13 to 10 days), and a reduction in total hospital costs (from $35 283 to $26 315). The second study from LDS Hospital demonstrated a 0.6–percentage point (from 0.9% to 0.3%) absolute decrease in antibiotic-associated adverse drug events (51).

Bates and colleagues examined adverse events and showed a 17% non–statistically significant trend toward a decrease in these events (49). Although this outcome did not reach statistical significance, adverse drug events were not the main focus of the evaluation. The primary end point for this study was a surrogate end point for adverse drug events: nonintercepted serious medication errors. This end point demonstrated a statistically significant 55% relative decrease. The results from this trial were further supported by a second, follow-up study by the same researchers examining the long-term effect of the implemented system (48). After the first published study, the research team analyzed adverse drug events not prevented by computerized provider order entry, and the level of decision support was increased. This second study used a time-series design and found an 86% relative decrease in nonintercepted serious medication errors.

Health information technology systems also decreased medication errors by improving medication dosing. Improvements in dosing ranged from 12% to 21%; the primary outcome examined was doses prescribed within the recommended range and centered on antibiotics and anticoagulation (47, 50, 51).

Effects on Efficiency

Studies examined 2 primary types of technology-related effects on efficiency: utilization of care and provider time. Ten studies examined the effect of health information technology systems on utilization of care. Eight showed decreased rates of health services utilization (54–61); computerized provider order-entry systems that provided decision support at the point of care were the primary interventions leading to decreased utilization. Types of decision support included automated calculation of pretest probability for diagnostic tests, display of previous test results, display of laboratory test costs, and computerized reminders. Absolute decreases in utilization rates ranged from 8.5 to 24 percentage points. The primary services affected were laboratory and radiology testing. Most studies did not judge the appropriateness of the decrease in service utilization but instead reported the effect of health information technology on the level of utilization. Most studies did not directly measure cost savings. Instead, researchers translated nonmonetized decreases in services into monetized estimates through the average cost of the examined service at that institution. One large study from Tierney and colleagues examined direct total costs per admission as its main end point and found a 12.7% absolute decrease (from $6964 to $6077) in costs associated with a 0.9-day decrease in length of stay (57).

The effect of health information technology on provider time was mixed. Two studies from the Regenstrief Institute examining inpatient order entry showed increases in physician time related to computer use (57, 64). Another study on outpatient use of electronic health records from Partners Health Care showed a clinically negligible increase in clinic visit time of 0.5 minute (67). Studies suggested that time requirements decreased as physicians grew used to the systems, but formal long-term evaluations were not available. Two studies showed slight decreases in documentation-related nursing time (68, 69) that were due to the streamlining of workflow. One study examined overall time to delivery of care and found an 11% decrease in time to deliver treatment through the use of computerized order entry with alerts to physician pagers (66).

Effects on Costs

Data on costs were more limited than the evidence on quality and efficiency. Fifteen of the 52 studies contained some data on costs (20, 28, 31, 36, 43, 47, 50–52, 54–58, 63). Most of the cost data available from the institutional leaders were related to changes in utilization of services due to health information technology. Only 3 studies had cost data on aspects of system implementation or maintenance. Two studies provided computer storage costs; these were more than 20 years old, however, and therefore were of limited relevance (28, 58). The third reported that system maintenance costs were $700 000 (31). Because these systems were built, implemented, and evaluated incrementally over time, and in some cases were supported by research grants, it is unlikely that total development and implementation costs could be calculated accurately and in full detail.

Data from Other Institutions about Multifunctional Systems

Appendix Table 2 (available at www.annals.org) summarizes the 22 studies (70–91) from the other institutions. Most of these studies evaluated internally developed systems in academic institutions. The types of benefits found in these studies were similar to those demonstrated in benchmark institutions, although an additional theme was related to initial implementation costs. Unlike most studies from the benchmark institutions, which used randomized or controlled clinical trial designs, the most common designs of the studies from other institutions were pre–post and time-series designs that lacked a concurrent comparison group. Thirteen of the 22 studies evaluated internally developed systems (70–82). Only 9 evaluated commercial health information technology systems. Because many decision makers are likely to consider implementing a commercially developed system rather than internally developing their own, we detail these 9 studies in the following paragraphs.

Two studies examined the effect of systems on utilization of care (83, 84). Both were set in Kaiser Permanente's Pacific Northwest region and evaluated the same electronic health record system (Epic Systems Corp., Verona, Wisconsin) at different periods through time-series designs. One study (1994–1997) supported the findings of the benchmark institutions, showing decreased utilization of 2 radiology tests after implementation of electronic health records (83), while the second study (2000–2004) showed no conclusive decreases in utilization of radiology and laboratory services (84). Unlike the reports from the benchmark institutions, this second study also showed no statistically significant improvements in 3 process measures of quality. It did find a statistically significant decrease in age-adjusted total office visits per member: a relative decrease of 9% in year 2 after implementation of the electronic health record. Telephone-based care showed a relative increase of 65% over the same time. A third study evaluated this electronic health record and focused on efficiency; it showed that physicians took 30 days to return to their baseline level of productivity after implementation and that visit time increased on average by 2 minutes per encounter (85).

Two studies that were part of the same randomized trial from Rollman and colleagues, set at the University of Pittsburgh, examined the use of an electronic health record (MedicaLogic Corp., Beaverton, Oregon) with decision support in improving care for depression (86, 87). The first study evaluated electronic health record–based monitoring to enhance depression screening. As in the monitoring studies from the benchmark institutions, electronic health record screening was found to support new ways of organizing care. Physicians agreed with 65% of the computer-screened diagnoses 3 days after receiving notification of the results. In the second phase of the trial, 2 different electronic health record–based decision support interventions were implemented to improve adherence to guideline-based care for depression. Unlike the effects on adherence seen in the benchmark institutions, neither intervention showed statistically significant differences when compared with usual care.

Two pre–post studies from Ohio State University evaluated the effect of a commercial computerized order-entry system (Siemens Medical Solutions Health Services Corp., Malvern, Pennsylvania) on time utilization and medication errors (88, 89). As in the benchmark institutions, time to care dramatically decreased compared with the period before the order-entry system was implemented. Relative decreases in other outcomes were as follows: medication turnaround time, 64% (88) and 73% (89); radiology completion time, 43% (88) and 24% (89); and results reporting time, 25% (88). Use of computerized provider order entry had large effects on medication errors in both studies. Before implementation, 11.3% (88) and 13% (89) of orders had transcription errors; afterward, these errors were entirely eliminated. One study assessed length of stay and found that it decreased 5%; total cost of hospitalization, however, showed no statistically significant differences (88). In contrast, a third study examining the effect of order entry on nurse documentation time showed no benefits (90).

In contrast to all previous studies on computer order-entry systems, a study by Koppel and colleagues used a mixed quantitative–qualitative approach to investigate the possible role of such a system (Eclipsys Corp., Boca Raton, Florida) in facilitating medication prescribing errors (91). Twenty-two types of medication error risks were found to be facilitated by computer order entry, relating to 2 basic causes: fragmentation of data and flaws in human–machine interface.

These 9 studies infrequently reported or measured data on costs and contextual factors. Two reported information on costs (88, 90). Neither described the total initial costs of purchasing or implementing the system being evaluated. Data on contextual factors such as reimbursement mix, degree of capitation, and barriers encountered during implementation were scant; only 2 studies included such information. The study by Koppel and colleagues (91) included detailed contextual information related to human factors. One health record study reported physician classroom training time of 16 hours before implementation (85). Another order-entry study reported that nurses received 16 hours of training, clerical staff received 8 hours, and physicians received 2 to 4 hours (89).

Discussion

To date, the health information technology literature has shown many important quality- and efficiency-related benefits as well as limitations relating to generalizability and empirical data on costs. Studies from 4 benchmark leaders demonstrate that implementing a multifunctional system can yield real benefits in terms of increased delivery of care based on guidelines (particularly in the domain of preventive health), enhanced monitoring and surveillance activities, reduction of medication errors, and decreased rates of utilization for potentially redundant or inappropriate care. However, the method used by the benchmark leaders to get to this point—the incremental development over many years of an internally designed system led by academic research champions—is unlikely to be an option for most institutions contemplating implementation of health information technology.

Studies from these 4 benchmark institutions have demonstrated the efficacy of health information technology for improving quality and efficiency. However, the effectiveness of these technologies in the practice settings where most health care is delivered remains less clear. Effectiveness and generalizability are of particular importance in this field because health information technologies are tools that support the delivery of care—they do not, in and of themselves, alter states of disease or of health. As such, how these tools are used and the context in which they are implemented are critical (92–94).

For providers considering a commercially available system installed as a package, only a limited body of literature is available to inform decision making. The available evidence comes mainly from time-series or pre–post studies, derives from a staff-model managed care organization or academic health centers, and concerns a limited number of process measures. These data, in general, support the findings of studies from the benchmark institutions on the effect of health information technology in reducing utilization and medication errors. However, they do not support the findings of increased adherence to protocol-based care. Published evidence of the information needed to make informed decisions about acquiring and implementing health information technology in community settings is nearly nonexistent. For example, potentially important evidence related to initial capital costs, effect on provider productivity, resources required for staff training (such as time and skills), and workflow redesign is difficult to locate in the peer-reviewed literature. Also lacking are key data on financial context, such as degree of capitation, which has been suggested by a model to be an important factor in defining the business case for electronic health record use (95).

Several systematic reviews related to health information technology have been done. However, they have been limited to specific systems, such as computerized provider order entry (96); capabilities, such as computerized reminders (97, 98); or clinical specialty (99). No study to date has reviewed a broad range of health information technologies. In addition, to make our findings as relevant as possible to the broad range of stakeholders interested in health information technology, we developed a Web-hosted database of our research findings. This database allows different stakeholders to find the literature most relevant to their implementation circumstances and their information needs.

This study has several important limitations. The first relates to the quantity and scope of the literature. Although we did a comprehensive search, we identified only a limited set of articles with quantitative data. In many important domains, we found few studies. This was particularly true of health information technology applications relevant to consumers and to interoperability, areas critical to the capacity for health information technology to fundamentally change health care. A second limitation relates to synthesizing the effect of a broad range of technologies. We attempted to address this limitation by basing our work on well-defined analytic frameworks and by identifying not only the systems used but also their functional capabilities. A third relates to the heterogeneity in reporting. Descriptions of health information technology systems were often very limited, making it difficult to assess whether some system capabilities were absent or simply not reported. Similarly, limited information was reported on the overall implementation process and organizational context.

This review raises many questions central to a broad range of stakeholders in health care, including providers, consumers, policymakers, technology experts, and private sector vendors. Adoption of health information technology has become one of the few widely supported, bipartisan initiatives in the fragmented, often contentious health care sector (100). Currently, numerous pieces of state and federal legislation under consideration seek to expand adoption of health information technology (101–103). Health care improvement organizations such as the Leapfrog Group are strongly advocating adoption of health information technology as a key aspect of health care reform. Policy discussions are addressing whether physician reimbursement should be altered, with higher reimbursements for those who use health information technology (104). Two critical questions that remain are 1) what will be the benefits of these initiatives and 2) who will pay and who will benefit?

Regarding the former, a disproportionate amount of literature on the benefits that have been realized comes from a small set of early-adopter institutions that implemented internally developed health information technology systems. These institutions had considerable expertise in health information technology and implemented systems over long periods in a gradual, iterative fashion. Missing from this literature are data on how to implement multifunctional health information technology systems in other health care settings. Internally developed systems are unlikely to be feasible as models for broad-scale use of health information technology. Most practices and organizations will adopt a commercially developed health information technology system, and, given logistic constraints and budgetary issues, their implementation cycles will be much shorter. The limited quantitative and qualitative description of the implementation context significantly hampers how the literature on health information technology can inform decision making by a broad array of stakeholders interested in this field.

With respect to the business case for health information technology, we found little information that could empower stakeholders to judge for themselves the financial effects of adoption. For instance, basic cost data needed to determine the total cost of ownership of a system or of the return on investment are not available. Without these data, the costs of health information technology systems can be estimated only through complex predictive analysis and statistical modeling methods, techniques generally not available outside of research. One of the chief barriers to adoption of health information technology is the misalignment of incentives for its use (105, 106). Specifying policies to address this barrier is hindered by the lack of cost data.

This review suggests several important future directions in the field. First, additional studies need to evaluate commercially developed systems in community settings, and additional funding for such work may be needed. Second, more information is needed regarding the organizational change, workflow redesign, human factors, and project management issues involved with realizing benefits from health information technology. Third, a high priority must be the development of uniform standards for the reporting of research on implementation of health information technology, similar to the Consolidated Standards of Reporting Trials (CONSORT) statements for randomized, controlled trials and the Quality of Reporting of Meta-analyses (QUORUM) statement for meta-analyses (107, 108). Finally, additional work is needed on interoperability and consumer health technologies, such as the personal health record.

The advantages of health information technology over paper records are readily discernible. However, without better information, stakeholders interested in promoting or considering adoption may not be able to determine what benefits to expect from health information technology use, how best to implement the system in order to maximize the value derived from their investment, or how to direct policy aimed at improving the quality and efficiency delivered by the health care sector as a whole.

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References

1. **Institute of Medicine.** To Err Is Human: Building a Safer Health System. Washington, DC: National Academy Pr; 2000.
2. **Institute of Medicine.** Crossing the Quality Chasm: A New Health System for the 21st Century. Washington, DC: National Academy Pr; 2001.
3. The Decade of Health Information Technology: Delivering Consumer-centric and Information-rich Health Care. A Strategic Framework. Bethesda, Maryland: Office of the National Coordinator for Health Information Technology, U.S. Department of Health and Human Services; 2004.
4. **Asch SM, McGlynn EA, Hogan MM, Hayward RA, Shekelle P, Rubenstein L, et al.** Comparison of quality of care for patients in the Veterans Health Administration and patients in a national sample. Ann Intern Med. 2004;141:938-45. [PMID: 15611491]
5. **Epstein AM, Lee TH, Hamel MB.** Paying physicians for high-quality care. N Engl J Med. 2004;350:406-10. [PMID: 14736934]
6. **Smith MF.** E-Health: Roadmap for 21st Century Health Care Consumers. Paris: Organisation for Economic Co-operation and Development Forum 2004: Health of Nations; 2004.
7. Innovators and Visionaries: Strategies for Creating a Person-centered Health System. FACCT: Foundation for Accountability; September 2003. Accessed at www.markle.org/resources/facct/doclibFiles/documentFile_599.pdf on 13 March 2006.
8. **Chassin MR, Galvin RW.** The urgent need to improve health care quality. Institute of Medicine National Roundtable on Health Care Quality. JAMA. 1998;280:1000-5. [PMID: 9749483]
9. **Ash JS, Gorman PN, Seshadri V, Hersh WR.** Computerized physician order entry in U.S. hospitals: results of a 2002 survey. J Am Med Inform Assoc. 2004; 11:95-9. [PMID: 14633935]
10. **Ash JS, Stavri PZ, Kuperman GJ.** A consensus statement on considerations for a successful CPOE implementation. J Am Med Inform Assoc. 2003;10:229-34. [PMID: 12626376]
11. **Valdes I, Kibbe DC, Tolleson G, Kunik ME, Petersen LA.** Barriers to proliferation of electronic medical records. Inform Prim Care. 2004;12:3-9. [PMID: 15140347]
12. **Audet AM, Doty MM, Peugh J, Shamasdin J, Zapert K, Schoenbaum S.** Information technologies: when will they make it into physicians' black bags? MedGenMed. 2004;6:2. [PMID: 15775829]
13. Key Capabilities of an Electronic Health Record System. Washington, DC: Institute of Medicine, Committee on Data Standards for Patient Safety Board on Health Care Services; 2003.
14. The Health Information Technology Interactive Database. Accessed at http://healthit.ahrq.gov/tools/rand on 17 March 2006.
15. **Goldman L, Cook EF, Brand DA, Lee TH, Rouan GW, Weisberg MC, et al.** A computer protocol to predict myocardial infarction in emergency department patients with chest pain. N Engl J Med. 1988;318:797-803. [PMID: 3280998]
16. **White RH, Hong R, Venook AP, Daschbach MM, Murray W, Mungall DR, et al.** Initiation of warfarin therapy: comparison of physician dosing with computer-assisted dosing. J Gen Intern Med. 1987;2:141-8. [PMID: 3295148]
17. **Burton ME, Ash CL, Hill DP Jr, Handy T, Shepherd MD, Vasko MR.** A controlled trial of the cost benefit of computerized bayesian aminoglycoside administration. Clin Pharmacol Ther. 1991;49:685-94. [PMID: 1905602]
18. **Dexter PR, Perkins SM, Maharry KS, Jones K, McDonald CJ.** Inpatient computer-based standing orders vs physician reminders to increase influenza and pneumococcal vaccination rates: a randomized trial. JAMA. 2004;292:2366-71. [PMID: 15547164]
19. **Dexter PR, Wolinsky FD, Gramelspacher GP, Zhou XH, Eckert GJ, Waisburd M, et al.** Effectiveness of computer-generated reminders for increasing discussions about advance directives and completion of advance directive forms. A randomized, controlled trial. Ann Intern Med. 1998;128:102-10. [PMID: 9441569]
20. **Overhage JM, Tierney WM, Zhou XH, McDonald CJ.** A randomized trial of "corollary orders" to prevent errors of omission. J Am Med Inform Assoc. 1997;4:364-75. [PMID: 9292842]
21. **Overhage JM, Tierney WM, McDonald CJ.** Computer reminders to implement preventive care guidelines for hospitalized patients. Arch Intern Med. 1996; 156:1551-6. [PMID: 8687263]
22. **Litzelman DK, Dittus RS, Miller ME, Tierney WM.** Requiring physicians to respond to computerized reminders improves their compliance with preventive care protocols. J Gen Intern Med. 1993;8:311-7. [PMID: 8320575]
23. **McDonald CJ, Hui SL, Tierney WM.** Effects of computer reminders for influenza vaccination on morbidity during influenza epidemics. MD Comput. 1992;9:304-12. [PMID: 1522792]
24. **Tierney WM, Hui SL, McDonald CJ.** Delayed feedback of physician performance versus immediate reminders to perform preventive care. Effects on physician compliance. Med Care. 1986;24:659-66. [PMID: 3736141]
25. **McDonald CJ, Hui SL, Smith DM, Tierney WM, Cohen SJ, Weinberger M, et al.** Reminders to physicians from an introspective computer medical record. A two-year randomized trial. Ann Intern Med. 1984;100:130-8. [PMID: 6691639]
26. **McDonald CJ, Wilson GA, McCabe GP Jr.** Physician response to computer reminders. JAMA. 1980;244:1579-81. [PMID: 7420656]
27. **McDonald CJ.** Protocol-based computer reminders, the quality of care and the non-perfectability of man. N Engl J Med. 1976;295:1351-5. [PMID: 988482]
28. **McDonald CJ.** Use of a computer to detect and respond to clinical events: its effect on clinician behavior. Ann Intern Med. 1976;84:162-7. [PMID: 1252043]
29. **Kucher N, Koo S, Quiroz R, Cooper JM, Paterno MD, Soukonnikov B, et al.** Electronic alerts to prevent venous thromboembolism among hospitalized patients. N Engl J Med. 2005;352:969-77. [PMID: 15758007]
30. **Abookire SA, Teich JM, Sandige H, Paterno MD, Martin MT, Kuperman GJ, et al.** Improving allergy alerting in a computerized physician order entry system. Proc AMIA Symp. 2000:2-6. [PMID: 11080034]
31. **Teich JM, Merchia PR, Schmiz JL, Kuperman GJ, Spurr CD, Bates DW.** Effects of computerized physician order entry on prescribing practices. Arch Intern Med. 2000;160:2741-7. [PMID: 11025783]
32. **Cannon DS, Allen SN.** A comparison of the effects of computer and manual reminders on compliance with a mental health clinical practice guideline. J Am Med Inform Assoc. 2000;7:196-203. [PMID: 10730603]
33. **Demakis JG, Beauchamp C, Cull WL, Denwood R, Eisen SA, Lofgren R, et al.** Improving residents' compliance with standards of ambulatory care: results from the VA Cooperative Study on Computerized Reminders. JAMA. 2000;284: 1411-6. [PMID: 10989404]
34. **Rossi RA, Every NR.** A computerized intervention to decrease the use of calcium channel blockers in hypertension. J Gen Intern Med. 1997;12:672-8. [PMID: 9383135]
35. **Willson D, Ashton C, Wingate N, Goff C, Horn S, Davies M, et al.** Computerized support of pressure ulcer prevention and treatment protocols. Proc Annu Symp Comput Appl Med Care. 1995:646-50. [PMID: 8563366]
36. **Evans RS, Classen DC, Pestotnik SL, Lundsgaarde HP, Burke JP.** Improving empiric antibiotic selection using computer decision support. Arch Intern Med. 1994;154:878-84. [PMID: 8154950]
37. **Larsen RA, Evans RS, Burke JP, Pestotnik SL, Gardner RM, Classen DC.** Improved perioperative antibiotic use and reduced surgical wound infections through use of computer decision analysis. Infect Control Hosp Epidemiol. 1989;10:316-20. [PMID: 2745959]
38. **Overhage J, Suico J, McDonald C.** Electronic laboratory reporting: barriers, solutions, and findings. J Public Health Manag Pract. 2001;7:60-6.
39. **Honigman B, Lee J, Rothschild J, Light P, Pulling RM, Yu T, et al.** Using computerized data to identify adverse drug events in outpatients. J Am Med Inform Assoc. 2001;8:254-66. [PMID: 11320070]
40. **Jha AK, Kuperman GJ, Teich JM, Leape L, Shea B, Rittenberg E, et al.** Identifying adverse drug events: development of a computer-based monitor and comparison with chart review and stimulated voluntary report. J Am Med Inform Assoc. 1998;5:305-14. [PMID: 9609500]
41. **Kramer TL, Owen RR, Cannon D, Sloan KL, Thrush CR, Williams DK, et al.** How well do automated performance measures assess guideline implementation for new-onset depression in the Veterans Health Administration? Jt Comm J Qual Saf. 2003;29:479-89. [PMID: 14513671]
42. **Kerr EA, Smith DM, Hogan MM, Krein SL, Pogach L, Hofer TP, et al.** Comparing clinical automated, medical record, and hybrid data sources for diabetes quality measures. Jt Comm J Qual Improv. 2002;28:555-65. [PMID:

12369158]
43. **Classen DC, Pestotnik SL, Evans RS, Lloyd JF, Burke JP.** Adverse drug events in hospitalized patients. Excess length of stay, extra costs, and attributable mortality. JAMA. 1997;277:301-6. [PMID: 9002492]
44. **Evans RS, Pestotnik SL, Classen DC, Bass SB, Burke JP.** Prevention of adverse drug events through computerized surveillance. Proc Annu Symp Comput Appl Med Care. 1992:437-41. [PMID: 1482913]
45. **Evans RS, Classen DC, Stevens LE, Pestotnik SL, Gardner RM, Lloyd JF, et al.** Using a hospital information system to assess the effects of adverse drug events. Proc Annu Symp Comput Appl Med Care. 1993:161-5. [PMID: 8130454]
46. **Evans RS, Larsen RA, Burke JP, Gardner RM, Meier FA, Jacobson JA, et al.** Computer surveillance of hospital-acquired infections and antibiotic use. JAMA. 1986;256:1007-11. [PMID: 3735626]
47. **Chertow GM, Lee J, Kuperman GJ, Burdick E, Horsky J, Seger DL, et al.** Guided medication dosing for inpatients with renal insufficiency. JAMA. 2001; 286:2839-44. [PMID: 11735759]
48. **Bates DW, Teich JM, Lee J, Seger D, Kuperman GJ, Ma'Luf N, et al.** The impact of computerized physician order entry on medication error prevention. J Am Med Inform Assoc. 1999;6:313-21. [PMID: 10428004]
49. **Bates DW, Leape LL, Cullen DJ, Laird N, Petersen LA, Teich JM, et al.** Effect of computerized physician order entry and a team intervention on prevention of serious medication errors. JAMA. 1998;280:1311-6. [PMID: 9794308]
50. **Mullett CJ, Evans RS, Christenson JC, Dean JM.** Development and impact of a computerized pediatric antiinfective decision support program. Pediatrics. 2001;108:E75. [PMID: 11581483]
51. **Evans RS, Pestotnik SL, Classen DC, Burke JP.** Evaluation of a computer-assisted antibiotic-dose monitor. Ann Pharmacother. 1999;33:1026-31. [PMID: 10534212]
52. **Evans RS, Pestotnik SL, Classen DC, Clemmer TP, Weaver LK, Orme JF Jr, et al.** A computer-assisted management program for antibiotics and other antiinfective agents. N Engl J Med. 1998;338:232-8. [PMID: 9435330]
53. **White KS, Lindsay A, Pryor TA, Brown WF, Walsh K.** Application of a computerized medical decision-making process to the problem of digoxin intoxication. J Am Coll Cardiol. 1984;4:571-6. [PMID: 6381570]
54. **Tierney WM, McDonald CJ, Hui SL, Martin DK.** Computer predictions of abnormal test results. Effects on outpatient testing. JAMA. 1988;259:1194-8. [PMID: 3339821]
55. **Tierney WM, McDonald CJ, Martin DK, Rogers MP.** Computerized display of past test results. Effect on outpatient testing. Ann Intern Med. 1987;107: 569-74. [PMID: 3631792]
56. **Tierney WM, Miller ME, McDonald CJ.** The effect on test ordering of informing physicians of the charges for outpatient diagnostic tests. N Engl J Med. 1990;322:1499-504. [PMID: 2186274]
57. **Tierney WM, Miller ME, Overhage JM, McDonald CJ.** Physician inpatient order writing on microcomputer workstations. Effects on resource utilization. JAMA. 1993;269:379-83. [PMID: 8418345]
58. **Wilson GA, McDonald CJ, McCabe GP Jr.** The effect of immediate access to a computerized medical record on physician test ordering: a controlled clinical trial in the emergency room. Am J Public Health. 1982;72:698-702. [PMID: 7046482]
59. **Chen P, Tanasijevic MJ, Schoenenberger RA, Fiskio J, Kuperman GJ, Bates DW.** A computer-based intervention for improving the appropriateness of antiepileptic drug level monitoring. Am J Clin Pathol. 2003;119:432-8. [PMID: 12645347]
60. **Bates DW, Kuperman GJ, Rittenberg E, Teich JM, Fiskio J, Ma'luf N, et al.** A randomized trial of a computer-based intervention to reduce utilization of redundant laboratory tests. Am J Med. 1999;106:144-50. [PMID: 10230742]
61. **Shojania KG, Yokoe D, Platt R, Fiskio J, Ma'luf N, Bates DW.** Reducing vancomycin use utilizing a computer guideline: results of a randomized controlled trial. J Am Med Inform Assoc. 1998;5:554-62. [PMID: 9824802]
62. **Fihn SD, McDonell MB, Vermes D, Henikoff JG, Martin DC, Callahan CM, et al.** A computerized intervention to improve timing of outpatient follow-up: a multicenter randomized trial in patients treated with warfarin. National Consortium of Anticoagulation Clinics. J Gen Intern Med. 1994;9:131-9. [PMID: 8195911]
63. **Steele MA, Bess DT, Franse VL, Graber SE.** Cost effectiveness of two interventions for reducing outpatient prescribing costs. DICP. 1989;23:497-500. [PMID: 2500784]
64. **Overhage JM, Perkins S, Tierney WM, McDonald CJ.** Controlled trial of direct physician order entry: effects on physicians' time utilization in ambulatory primary care internal medicine practices. J Am Med Inform Assoc. 2001;8:361-71. [PMID: 11418543]
65. **Kuperman GJ, Teich JM, Bates DW, Hiltz FL, Hurley JM, Lee RY, et al.** Detecting alerts, notifying the physician, and offering action items: a comprehensive alerting system. Proc AMIA Annu Fall Symp. 1996:704-8. [PMID: 8947756]
66. **Kuperman GJ, Teich JM, Tanasijevic MJ, Ma'Luf N, Rittenberg E, Jha A, et al.** Improving response to critical laboratory results with automation: results of a randomized controlled trial. J Am Med Inform Assoc. 1999;6:512-22. [PMID: 10579608]
67. **Pizziferri L, Kittler AF, Volk LA, Honour MM, Gupta S, Wang S, et al.** Primary care physician time utilization before and after implementation of an electronic health record: a time-motion study. J Biomed Inform. 2005;38:176-88. [PMID: 15896691]
68. **Wong DH, Gallegos Y, Weinger MB, Clack S, Slagle J, Anderson CT.** Changes in intensive care unit nurse task activity after installation of a third-generation intensive care unit information system. Crit Care Med. 2003;31:2488-94. [PMID: 14530756]
69. **Pierpont GL, Thilgen D.** Effect of computerized charting on nursing activity in intensive care. Crit Care Med. 1995;23:1067-73. [PMID: 7774218]
70. **Khoury AT.** Support of quality and business goals by an ambulatory automated medical record system in Kaiser Permanente of Ohio. Eff Clin Pract. 1998;1:73-82. [PMID: 10187226]
71. **Garr DR, Ornstein SM, Jenkins RG, Zemp LD.** The effect of routine use of computer-generated preventive reminders in a clinical practice. Am J Prev Med. 1993;9:55-61. [PMID: 8439440]
72. **Ornstein SM, Garr DR, Jenkins RG, Musham C, Hamadeh G, Lancaster C.** Implementation and evaluation of a computer-based preventive services system. Fam Med. 1995;27:260-6. [PMID: 7797005]
73. **Schriger DL, Baraff LJ, Rogers WH, Cretin S.** Implementation of clinical guidelines using a computer charting system. Effect on the initial care of health care workers exposed to body fluids. JAMA. 1997;278:1585-90. [PMID: 9370504]
74. **Schriger DL, Baraff LJ, Buller K, Shendrikar MA, Nagda S, Lin EJ, et al.** Implementation of clinical guidelines via a computer charting system: effect on the care of febrile children less than three years of age. J Am Med Inform Assoc. 2000;7:186-95. [PMID: 10730602]
75. **Safran C, Rind DM, Davis RB, Ives D, Sands DZ, Currier J, et al.** Guidelines for management of HIV infection with computer-based patient's record. Lancet. 1995;346:341-6. [PMID: 7623532]
76. **Day F, Hoang LP, Ouk S, Nagda S, Schriger DL.** The impact of a guideline-driven computer charting system on the emergency care of patients with acute low back pain. Proc Annu Symp Comput Appl Med Care. 1995:576-80. [PMID: 8563351]
77. **Simon GE, VonKorff M, Rutter C, Wagner E.** Randomised trial of monitoring, feedback, and management of care by telephone to improve treatment of depression in primary care. BMJ. 2000;320:550-4. [PMID: 10688563]
78. **Baird TK, Broekemeier RL, Anderson MW.** Effectiveness of a computer-supported refill reminder system. Am J Hosp Pharm. 1984;41:2395-7. [PMID: 6507445]
79. **Sanders DL, Miller RA.** The effects on clinician ordering patterns of a computerized decision support system for neuroradiology imaging studies. Proc AMIA Symp. 2001:583-7. [PMID: 11825254]
80. **Potts AL, Barr FE, Gregory DF, Wright L, Patel NR.** Computerized physician order entry and medication errors in a pediatric critical care unit. Pediatrics. 2004;113:59-63. [PMID: 14702449]
81. **Wells BJ, Lobel KD, Dickerson LM.** Using the electronic medical record to enhance the use of combination drugs. Am J Med Qual. 2003;18:147-9. [PMID: 12934950]
82. **Khoury A.** Finding value in EMRs (electronic medical records). Health Manag Technol. 1997;18:34, 36. [PMID: 10169803]
83. **Chin HL, Wallace P.** Embedding guidelines into direct physician order entry: simple methods, powerful results. Proc AMIA Symp. 1999:221-5. [PMID: 10566353]
84. **Garrido T, Jamieson L, Zhou Y, Wiesenthal A, Liang L.** Effect of electronic health records in ambulatory care: retrospective, serial, cross sectional study. BMJ. 2005;330:581. [PMID: 15760999]
85. **Krall MA.** Acceptance and performance by clinicians using an ambulatory electronic medical record in an HMO. Proc Annu Symp Comput Appl Med

Care. 1995:708-11. [PMID: 8563380]
86. **Rollman BL, Hanusa BH, Gilbert T, Lowe HJ, Kapoor WN, Schulberg HC.** The electronic medical record. A randomized trial of its impact on primary care physicians' initial management of major depression [corrected]. Arch Intern Med. 2001;161:189-97. [PMID: 11176732]
87. **Rollman BL, Hanusa BH, Lowe HJ, Gilbert T, Kapoor WN, Schulberg HC.** A randomized trial using computerized decision support to improve treatment of major depression in primary care. J Gen Intern Med. 2002;17:493-503. [PMID: 12133139]
88. **Mekhjian HS, Kumar RR, Kuehn L, Bentley TD, Teater P, Thomas A, et al.** Immediate benefits realized following implementation of physician order entry at an academic medical center. J Am Med Inform Assoc. 2002;9:529-39. [PMID: 12223505]
89. **Cordero L, Kuehn L, Kumar RR, Mekhjian HS.** Impact of computerized physician order entry on clinical practice in a newborn intensive care unit. J Perinatol. 2004;24:88-93. [PMID: 14872207]
90. **Kilgore ML, Flint D, Pearce R.** The varying impact of two clinical information systems in a cardiovascular intensive care unit. J Cardiovasc Manag. 1998; 9:31-5. [PMID: 10178729]
91. **Koppel R, Metlay JP, Cohen A, Abaluck B, Localio AR, Kimmel SE, et al.** Role of computerized physician order entry systems in facilitating medication errors. JAMA. 2005;293:1197-203. [PMID: 15755942]
92. **Aarts J, Doorewaard H, Berg M.** Understanding implementation: the case of a computerized physician order entry system in a large Dutch university medical center. J Am Med Inform Assoc. 2004;11:207-16. [PMID: 14764612]
93. **Berg M.** Patient care information systems and health care work: a sociotechnical approach. Int J Med Inform. 1999;55:87-101. [PMID: 10530825]
94. **Berg M, Langenberg C, vd Berg I, Kwakkernaat J.** Considerations for sociotechnical design: experiences with an electronic patient record in a clinical context. Int J Med Inform. 1998;52:243-51. [PMID: 9848421]
95. **Wang SJ, Middleton B, Prosser LA, Bardon CG, Spurr CD, Carchidi PJ, et al.** A cost-benefit analysis of electronic medical records in primary care. Am J Med. 2003;114:397-403. [PMID: 12714130]
96. **Kaushal R, Shojania KG, Bates DW.** Effects of computerized physician order entry and clinical decision support systems on medication safety: a systematic review. Arch Intern Med. 2003;163:1409-16. [PMID: 12824090]
97. **Bennett JW, Glasziou PP.** Computerised reminders and feedback in medication management: a systematic review of randomised controlled trials. Med J Aust. 2003;178:217-22. [PMID: 12603185]
98. **Garg AX, Adhikari NK, McDonald H, Rosas-Arellano MP, Devereaux PJ, Beyene J, et al.** Effects of computerized clinical decision support systems on practitioner performance and patient outcomes: a systematic review. JAMA. 2005;293:1223-38. [PMID: 15755945]
99. **Mitchell E, Sullivan F.** A descriptive feast but an evaluative famine: systematic review of published articles on primary care computing during 1980-97. BMJ. 2001;322:279-82. [PMID: 11157532]
100. **Frist B, Clinton H.** How to heal health care. Washington Post. 25 August 2004:A17.
101. S.1262: Health Technology to Enhance Quality Act. 2005.
102. S.1418: A bill to enhance the adoption of a nationwide inter operable health information technology system and to improve the quality and reduce the costs of health care in the United States. 2005.
103. S.1355: A bill to enhance the adoption of health information technology and to improve the quality and reduce the costs of healthcare in the United States. 2005.
104. **Leapfrog Group.** Purchasing Principles. Accessed at www.leapfroggroup.org/for_members/what_does_it_mean/purchasing_principals on 17 March 2006.
105. **Miller RH, Sim I.** Physicians' use of electronic medical records: barriers and solutions. Health Aff (Millwood). 2004;23:116-26. [PMID: 15046136]
106. **Poon EG, Blumenthal D, Jaggi T, Honour MM, Bates DW, Kaushal R.** Overcoming barriers to adopting and implementing computerized physician order entry systems in U.S. hospitals. Health Aff (Millwood). 2004;23:184-90. [PMID: 15318579]
107. **Begg C, Cho M, Eastwood S, Horton R, Moher D, Olkin I, et al.** Improving the quality of reporting of randomized controlled trials. The CONSORT statement. JAMA. 1996;276:637-9. [PMID: 8773637]
108. **Moher D, Cook DJ, Eastwood S, Olkin I, Rennie D, Stroup DF.** Improving the quality of reports of meta-analyses of randomised controlled trials: the QUOROM statement. Quality of Reporting of Meta-analyses. Lancet. 1999; 354:1896-900. [PMID: 10584742]

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Appendix Table 1. **Benchmark Leaders in Health Information Technology Research***

Study, Year (Reference), Type of Study (n = 52)	Institution	Data Collection	Primary HIT Intervention	Setting	Purpose (To Determine the Effect of . . .)	Dimensions of Care End Points	Effect Evaluated	Key Finding
Quality adherence (n = 20)								
Dexter et al., 2004 (18), RCT	Regenstrief Institute	1998–1999	DS/EHR	Inpatient	Computer-based standing orders vs. computerized physician reminders	Effectiveness	Adherence/ surveillance	12–percentage point absolute increase (from 30% to 42%) in influenza vaccinations and 20–percentage point absolute increase (from 31% to 51%) in pneumococcal vaccinations in the standing-orders group; computer identified 50% and 22% of hospitalized patients as eligible for influenza and pneumococcal vaccinations, respectively; 19% and 7% of patients screened by computer as eligible for influenza and pneumococcal vaccines stated that they had previously been vaccinated and did not require another vaccination (data from outside facilities not present in evaluated system)
Dexter et al., 1998 (19), RCT	Regenstrief Institute	NS	DS/EHR	Outpatient	Computer-generated, paper-based reminders on planning for end-of-life care vs. usual care (no reminder)	Effectiveness	Adherence	20–percentage point absolute increase (from 4% to 24%) in physicians who discussed advance directives; 11–percentage point absolute increase (from 4% to 15%) in physicians caring for patients who completed advanced care plans
Overhage et al., 1997 (20), RCT	Regenstrief Institute	1992–1993	DS/CPOE	Inpatient	Point-of-care computerized reminders on adherence to guideline-based care vs. usual care (CPOE without evaluated reminders)	Effectiveness/ efficiency	Adherence	24–percentage point absolute increase (from 22% to 46%) in adherence to guidelines; adherence increased for immediate, 24-h, and total hospital stays; little increase between immediate and 24-h adherence; 33% relative decrease (from 156 to 105) in number of pharmacist interventions; no statistically significant difference in costs or length of stay

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Appendix Table 1—Continued

Study, Year (Reference), Type of Study (*n* = 52)	Institution	Data Collection	Primary HIT Intervention	Setting	Purpose (To Determine the Effect of . . .)	Dimensions of Care End Points	Effect Evaluated	Key Finding
Overhage et al., 1996 (21), RCT	Regenstrief Institute	1992–1993	DS/EHR	Inpatient	Computer-generated reminders on use of preventive care services vs. usual care	Effectiveness	Adherence	No statistically significant effect demonstrated; high adherence to reminders was anticipated but not demonstrated, and no mechanism to capture reasons for nonadherence was incorporated
Litzelman et al., 1993 (22), RCT	Regenstrief Institute	1989	DS/EHR	Outpatient	Computerized reminders of preventive care; comparison was between requiring physicians to acknowledge the reminder vs. using reminder alone	Effectiveness	Adherence	In group requiring acknowledgment, 12–percentage point absolute increase (from 49% to 61%) in fecal occult blood testing and 7–percentage point absolute increase (from 47% to 54%) in mammography; no statistically significant improvement in Papanicolaou screening
McDonald et al., 1992 (23), RCT	Regenstrief Institute	1978–1981	DS	Outpatient	Computer-generated, paper-based reminders on need for influenza vaccination vs. no computer-based reminders	Effectiveness	Adherence	12%–18% absolute increase (15.6%–29.5% in year 3) in influenza vaccination rates
Tierney et al. (24), 1986, RCT	Regenstrief Institute	1983–1984	DS/data summary/ EHR	Outpatient	Three interventions on preventive health: 1) computer-generated, paper-based reminders provided each visit; 2) computer-generated, paper-based care summaries generated monthly; and 3) usual care	Effectiveness	Adherence	Approximate absolute effects of computerized reminders: 33–percentage point absolute increase (from 25% to 58%) in fecal occult blood testing, 33–percentage point absolute increase (from 5% to 38%) in pneumococcal vaccination, 16–percentage point absolute increase (8% to 24%) in screening mammography, and 12–percentage point absolute increase (from 12% to 24%) in metronidazole for trichomonas infections; 9 other preventive care processes evaluated showed no statistically or clinically significant improvement with reminders; effects of reminders were greater than those of the summary reports
McDonald et al., 1984 (25), CCT	Regenstrief Institute	1978–1980	DS/EHR	Outpatient	Computer-generated, paper-based reminders on adherence to protocol-based care vs. usual care (no reminders)	Effectiveness/ efficiency	Adherence	15%–20% increase in adherence to protocol-based care; greatest increases seen in preventive care (relative increase in utilization, 200%–400%); information other than laboratory and pharmacy data entered by research assistants; computer system did not capture all patient data

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Appendix Table 1—**Continued**

Study, Year (Reference), Type of Study (n = 52)	Institution	Data Collection	Primary HIT Intervention	Setting	Purpose (To Determine the Effect of . . .)	Dimensions of Care End Points	Effect Evaluated	Key Finding
McDonald et al., 1980 (26), CCT	Regenstrief Institute	NS	DS/EHR	Outpatient	Computer-generated, paper-based reminders with and without literature citations on adherence to protocol-based care vs. usual care	Effectiveness	Adherence/ medical errors	19–percentage point absolute increase (from 19.8% to 38.4%) in adherence to protocol-based care; minimal learning effects were seen when the computerized reminders were turned off
McDonald, 1976 (27), RCT	Regenstrief Institute	NS	DS/EHR	Outpatient	Computer-generated, paper-based reminders on adherence to protocol-based care for diabetes	Effectiveness/ safety/ efficiency	Adherence/ medication errors	15–percentage point increase (from 11% to 36% and from 13% to 28%) in adherence to protocols; computer systems could not capture all laboratory data kept in paper chart; physicians agreed with a maximum of 57% of computer recommendations; most reminders related to medication care; cost $2/visit to maintain computer record
McDonald, 1976 (28), RCT	Regenstrief Institute	1975	DS/EHR	Outpatient	Computer-generated, paper-based reminders on adherence to protocol-based care	Effectiveness/ safety	Adherence/ medication errors	29–percentage point absolute increase (from 22% to 51%) in adherence to protocols; computer system could not capture all laboratory data kept in paper chart; most reminders related to medication-based care
Kucher et al., 2005 (29), CCT	Partners Health Care	2000–2004	DS/CPOE	Inpatient	Computerized alerts for anticoagulation prophylaxis vs. usual care for prevention of venous thromboembolism in high-risk hospitalized patients	Effectiveness	Adherence/ surveillance	3.3–percentage point absolute decrease (from 8.2% to 4.9%) in the combined primary end point of deep venous thrombosis or pulmonary embolism within 90 d after hospitalization; 19–percentage point absolute increase (from 33.5% to 14.5%) in use of anticoagulation prophylaxis; as part of intervention, a computer-based risk assessment program was used to screen and identify inpatients at high risk for venous thromboembolism; 80% of patients enrolled had some type of cancer
Abookire et al., 2000 (30), time-series study	Partners Health Care	1995–1999	DS/CPOE	Inpatient	Trends in alerts and physician response to alerts	Safety/ effectiveness	Adherence	24–percentage point absolute reduction (from 51% to 27%) in adherence to "definite" medication allergy alerts and 26–percentage point absolute reduction in adherence (from 46% to 20%) to "possible" allergy alerts over 4 y; adherence decreased as number of alerts increased

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Appendix Table 1—**Continued**

Study, Year (Reference), Type of Study (n = 52)	Institution	Data Collection	Primary HIT Intervention	Setting	Purpose (To Determine the Effect of . . .)	Dimensions of Care End Points	Effect Evaluated	Key Finding
Teich et al., 2000 (31), pre–post study	Brigham and Women's Hospital/Partners Health Care	1993	CPOE/DS	Inpatient	Effect of CPOE on physician prescribing practices and adherence to medication formularies	Effectiveness/ safety	Adherence	66–percentage point absolute increase (from 15.6% to 81.3%) in formulary adherence for gastric H_2-blockers; 23–percentage point absolute increase (from 24% to 47%) in appropriate use of subcutaneous heparin prophylaxis; 1.5–percentage point absolute decrease (from 2.1% to 0.6%) in number of medication doses written that exceeded maximum recommended ("possibly because of increased use of order sets"); effects persisted at 1- and 2-y follow-up; cost savings from H_2-blocker, $250 000; costs to maintain system, $700 000/y
Cannon and Allen 2000 (32), RCT	VA	1998	DS/EHR	Outpatient	Guideline-based computerized vs. manual paper-based reminders on screening rates for mood disorders	Effectiveness	Adherence	25.5–percentage point absolute increase (from 61% to 86.5%) in physician screening for mood disorders with computerized system
Demakis et al., 2000 (33), RCT	VA	1995–1996	DS/EHR	Outpatient	Computerized reminders on physician adherence to ambulatory care recommendations vs. usual care (EHR without hypertension reminders)	Effectiveness	Adherence	5.3–percentage point absolute increase (from 53.5% to 58.8%) in adherence to recommended care; 5 of 13 examined care processes improved; effect of reminders decreased over time
Rossi and Every, 1997 (34), RCT	VA	1996	DS	Outpatient	Computer-generated, paper-based reminders on adherence to appropriate care for hypertension treatment vs. usual care (no reminders)	Effectiveness	Adherence	11.3–percentage point absolute increase (from <1% to 11.3%) in appropriate hypertension treatment
Willson et al., 1995 (35), pre–post study	LDS Hospital/ Intermountain Health Care	1994–NS	DS	Inpatient	Computerized guidelines for prevention and treatment of pressure ulcers	Effectiveness	Adherence	5–percentage point absolute decrease (from 7% to 2%) in ulcer development

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Appendix Table 1—**Continued**

Study, Year (Reference), Type of Study (n = 52)	Institution	Data Collection	Primary HIT Intervention	Setting	Purpose (To Determine the Effect of . . .)	Dimensions of Care End Points	Effect Evaluated	Key Finding
Evans et al., 1994 (36), RCT	LDS Hospital/ Intermountain Health Care	1990	DS/EHR	Inpatient	Computerized guidelines on appropriateness of antibiotic use	Effectiveness	Adherence	Computer program suggested correct antibiotic in 94% of cases; 17–percentage point absolute increase (from 77% to 94%) in coverage of identified organism; 27% relative decrease (from 22 to 16 h) in time to appropriate treatment after culture results; 21% relative decrease (from \$51.93 to \$41.08) in antibiotic cost; physicians ordered appropriate antibiotics within 12 h of culture collection significantly more often with use of program compared with usual care; 88% of physicians would recommend the program to other physicians, 85% said the program improved antibiotic selection, and 81% said use improved care
Larsen et al., 1989 (37), pre–post study	LDS Hospital/ Intermountain Health Care	1985–1986	DS	Inpatient	Computerized reminders on appropriateness of preoperative antibiotics and on rates of postoperative wound infections	Effectiveness	Adherence	0.4–percentage point absolute decrease (from 1.1% to 0.7%) in total postoperative wound infections; 0.9–percentage point absolute decrease (from 1.8% to 0.9%) in wound infections among patients with general indication for antibiotic prophylaxis; 18–percentage point increase (from 40% to 58%) in appropriateness of antibiotic timing
Surveillance (n = 9)								
Overhage et al., 2001 (38), case–control study	Regenstrief Institute	2000–2001	Electronic results reporting	Outpatient	Electronic laboratory reporting on public health surveillance	Access/ effectiveness	Surveillance	29–percentage point increase (from 71% to 100%) in identified cases during a shigellosis outbreak; 2.5-d decrease in reporting time
Honigman et al., 2001 (39), cohort study	Brigham and Women's Hospital/Partners Health Care	1995–1996	EHR	Outpatient	Computer program to retrospectively detect ADEs vs. chart review	Safety	Surveillance	Sensitivity for ADEs, 58%; specificity, 88%; ADE rate was 5.5/100 patients; 9% of outpatient ADEs required hospitalization
Jha et al., 1998 (40), case series	Brigham and Women's Hospital/Partners Health Care	1995	Data summary/ CPOE	Inpatient	Three interventions for identifying adverse drug events: 1) computer monitoring, 2) chart review, and 3) voluntary reporting	Safety	Surveillance	Computerized monitoring identified 45% of ADEs; chart review identified 65%; voluntary reporting identified 4%; computer was better for ADEs related to quantitative changes (e.g., laboratory values) and chart review was better for ADEs related only to symptoms; voluntary reporting was better for potential ADEs that had not yet occurred

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Appendix Table 1—Continued

Study, Year (Reference), Type of Study (n = 52)	Institution	Data Collection	Primary HIT Intervention	Setting	Purpose (To Determine the Effect of . . .)	Dimensions of Care End Points	Effect Evaluated	Key Finding
Kramer et al., 2003 (41), case series	VA	1999–2000	Electronic data collection/ EHR	Outpatient	Automated data collection algorithms vs. manual review of EHRs by trained abstracters on diagnosing new cases of depression	Effectiveness	Surveillance	High false-positive rate for diagnosis via automated algorithms; quality indicator scores based solely on automated data show agreement with manual review, but results may show some bias
Kerr et al., 2002 (42), case series	VA	1999–2000	Electronic data collection/ EHR	Mixed	Automated queries of computerized disease registries vs. manual chart abstraction (mixed EHR and paper chart sources) on measuring quality of care	Effectiveness	Surveillance	Automated queries from disease registries underestimated rates of completion for quality-of-care process indicators; no differences were noted for intermediate outcome measures; automated queries were less labor-intensive
Classen et al., 1997 (43), case–control study	LDS Hospital/ Intermountain Health Care	1990–1993	Data summary/ DS/EHR	Inpatient	Computer surveillance to identify ADEs and associated costs	Efficiency	Surveillance	Computer system was used to screen 91 574 admissions for ADEs; 2.43 ADEs/100 admissions; 2.45–absolute percentage point increase (from 1.05% to 3.5%) in crude mortality associated with ADEs; 1.9-d increase in attributable length of stay and associated $2262 increase in costs
Evans et al., 1992 (44), case–control study	LDS Hospital/ Intermountain Health Care	1989–1992	Data summary/ EHR	Inpatient	Computerized surveillance vs. manual reporting on identifying and preventing ADEs	Safety	Surveillance	2.36–percentage point absolute increase (from 0.04% to 2.4%) in identified ADEs; alerting system implemented in year 2 in which pharmacists received surveillance reports and contacted physicians; severe ADEs decreased 5.4 percentage points (from 7.6% to 2.2%); ADEs due to allergies decreased 13.6 percentage points (from 15% to 1.4%); analysis of ADE database allowed authors to design reduction initiatives that decreased significant ADEs from 56 events in year 1 to 8 events in year 3
Evans et al., 1993 (45), case–control	LDS Hospital/ Intermountain Health Care	1990–1992	Data summary/ DS/EHR	Inpatient	Computerized surveillance on determining attributable effect of ADEs on hospital length of stay and costs	Safety/ efficiency	Surveillance/ medication errors	Computer system was used to screen the records of 60 836 inpatients; 1348 ADEs were identified in 1209 patients; those with ADEs were matched to a total of 10 542 control patients; ADEs were associated with an attributable increase in length of stay of 1.9 d and increase in attributable costs of $1939

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Appendix Table 1—**Continued**

Study, Year (Reference), Type of Study (*n* = 52)	Institution	Data Collection	Primary HIT Intervention	Setting	Purpose (To Determine the Effect of . . .)	Dimensions of Care End Points	Effect Evaluated	Key Finding
Evans et al., 1986 (46), cohort study	LDS Hospital/Intermountain Health Care	1984	Data summary/EHR	Inpatient	Computer vs. manual surveillance for assessing rates of hospital-acquired infections and associated antibiotic use	Safety	Surveillance	14–percentage point absolute increase (from 76% to 90%) in identification of infections; 65% decrease (from 130 to 46 h) in time required for surveillance; 4–percentage point absolute increase (from 19% to 23%) in false-positive rates with the computer; computer screening identified patients receiving antibiotics to which infections were resistant, antibiotics with less expensive alternatives, and patients receiving prophylactic antibiotics for longer than necessary
Medication errors (*n* = 7)								
Chertow et al., 2001 (47), CCT	Brigham and Women's Hospital/Partners Health Care	1997–1998	DS/CPOE	Inpatient	Computerized drug dosing algorithm to determine effect on medication prescribing in renal insufficiency vs. usual care (CPOE without algorithm)	Efficiency/effectiveness	Medication errors/adherence	21–percentage point absolute increase (from 30% to 51%) in appropriate medication orders (dosing levels or dosing frequency); 4.5% reduction (from 4.5 to 4.3 d) in length of stay; no statistically significant decrease in costs
Bates et al., 1999 (48), time-series study	Brigham and Women's Hospital/Partners Health Care	1992–1997	CPOE/DS	Inpatient	CPOE with enhanced DS on rates of nonmissed dose errors and overall noninterrupted serious medication error rates	Safety	Medication errors	86% relative reduction (from 7.6 events/1000 patient-days to 1.1 events/1000 patient-days) in nonintercepted serious medication errors; 82% relative reduction (from 142 events/1000 patient-days to 26.6 events/1000 patient-days) in nonmissed dose errors; reductions seen for all error types; level of DS in system increased over time
Bates et al., 1998 (49), time-series study	Brigham and Women's Hospital/Partners Health Care	1993–1995	CPOE/DS	Inpatient	CPOE on rates of medication errors and preventable ADEs vs. CPOE with addition of team changes	Safety	Medication errors	55% relative risk reduction (from 10.7 events/1000 patient-days to 4.9 events/1000 patient-days) in nonintercepted serious medication errors; non–statistically significant 17% relative reduction (from 4.69/1000 patient-days to 3.86/1000 patient-days) in preventable ADEs; decreases seen for all levels of error severity; team changes conferred no additional benefit over CPOE

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Appendix Table 1—**Continued**

Study, Year (Reference), Type of Study (n = 52)	Institution	Data Collection	Primary HIT Intervention	Setting	Purpose (To Determine the Effect of . . .)	Dimensions of Care End Points	Effect Evaluated	Key Finding
Mullett et al., 2001 (50), pre–post study	LDS Hospital/ Intermountain Health Care	1998–1999	DS/EHR	Pediatric ICU	Computerized guidelines on antibiotic appropriateness and use	Effectiveness/ efficiency	Medication errors/ adherence	32% relative decrease (from 15.8 to 10.8) in number of days that antibiotics were prescribed outside the recommended dosing range; 59% relative decrease in a composite measure of need for pharmacist interventions for incorrect dosing; 6.3–percentage point absolute increase (from 60.2% to 66.5%) in proportion of ICU patients receiving antibiotics; no statistically significant differences in overall antibiotic costs; weighted antibiotic-cost statistic showed decrease in costs
Evans et al., 1999 (51), pre–post study	LDS Hospital/ Intermountain Health Care	1993–1996	DS/EHR	Inpatient	Computerized monitoring of antibiotic doses on appropriateness of dosing and ADE rates	Safety	Medication errors/ utilization of care	0.6–percentage point absolute decrease (from 0.9% to 0.3%) in antibiotic-associated ADEs; 6% relative decrease (from 50% to 40%) in patients receiving excess antibiotic doses for ≥1 d; 12% relative decrease (from 10.1 to 8.9 doses) in number of antibiotic doses prescribed and 13% relative decrease in cost (from \$92.96 to \$80.62); excess dosing was associated with increased ADE rates
Evans et al., 1998 (52), cohort study with historical control	LDS Hospital/ Intermountain Health Care	1992–1995	DS/EHR	Inpatient (ICU)	Computerized alerts on antibiotic use	Effectiveness/ efficiency/ safety	Medication errors/ adherence	Compared with the 2-y preintervention period, reductions were seen for the following: antibiotic-associated ADEs (28 vs. 4), mismatches between infection susceptibility and antibiotic (206 vs. 12 episodes), ordered drugs for which a patient had an allergy (146 vs. 35 episodes), days of excess dosing (from 5.9 to 2.7 d), antibiotic costs (from \$340 to \$102), length of stay (from 13 to 10 d), and total hospital costs (from \$35 283 to \$26 315)
White et al., 1984 (53), RCT	LDS Hospital/ Intermountain Health Care	NS	DS	Inpatient	Computer-generated, paper-based alert system on digoxin toxicity	Safety	Medication errors	2.8-fold increase in withholding digoxin on day alert was signaled; 2.7-fold increase in testing of serum digoxin levels in response to alerts; overall, 22% increase in physician actions in response to digoxin-related events (unweighted event rates in study groups not provided)

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Appendix Table 1—Continued

Study, Year (Reference), Type of Study (*n* = 52)	Institution	Data Collection	Primary HIT Intervention	Setting	Purpose (To Determine the Effect of . . .)	Dimensions of Care End Points	Effect Evaluated	Key Finding
Efficiency: utilization of care (*n* = 10)								
Tierney et al., 1988 (54), RCT	Regenstrief	1984–1985	DS/CPOE	Outpatient	Computer program that generates and displays pretest probabilities for diagnostic tests on utilization of care	Efficiency	Utilization of care	8.8% decrease (from \$12.27 to \$11.18) in diagnostic test costs per patient visit; greatest decrease was due to reduced utilization of complete blood counts and electrolytes (the 2 most common tests); mean receiver-operating characteristic curve for computer predictions, 0.80
Tierney et al., 1987 (55), pre–post study	Regenstrief	NS	DS/CPOE/EHR	Outpatient	Computer program showing previous test results as physicians are ordering new tests vs. usual care (no display of previous test results)	Efficiency	Utilization of care	8.5% decrease (from 0.56 to 0.51) in number of tests ordered per visit; 13% decrease (from \$13.99 to \$12.17) in test costs per visit; program took 4 s to display past results on screen per test
Tierney et al., 1990 (56), RCT	Regenstrief	1988	DS/CPOE/EHR	Outpatient	Effect of information on point-of-care test costs on utilization vs. usual care (CPOE without information on test costs)	Efficiency	Utilization of care	14.3% decrease (from 1.82 to 1.56) in number of diagnostic tests ordered per visit; 12.9% decrease (from \$51.81 to \$45.13) in diagnostic test costs per visit; effect was greatest for scheduled patient visits
Tierney et al., 1993 (57), RCT	Regenstrief	1990–1991	CPOE/EHR	Inpatient	CPOE on costs and utilization of health care	Efficiency	Utilization of care	12.7% reduction (from \$6964 to \$6077) in total costs per admission; statistically significant decreases in hospital bed, medication, and diagnostic test costs; 0.9-d decrease (from 8.5 to 7.6 d) in length of stay; 33-min increase in physician time spent ordering tests
Wilson et al., 1982 (58), RCT	Regenstrief	NS	EHR	Emergency department	Computer-generated, paper-based patient record summaries on utilization of care vs. usual care (no care summaries)	Efficiency	Utilization of care	Study interrupted by an interval programming error that prevented the previous 4–6 mo of a patient's data from being printed, thus dividing the study into 2 time periods, T1 and T2; 18% decrease (from 3.28 tests/visit to 2.23 tests/visit) in tests ordered for medical visits during T1; 14% decrease (from \$34.91 to \$29.94) in costs; non–statistically significant decrease in tests ordered for surgical visits during T1; no statistically significant difference in utilization or costs during T2
Chen et al., 2003 (59), pre–post study	Brigham and Women's Hospital/Partners Health Care	1995–1999	DS/CPOE	Inpatient	Computerized reminders on rates of inappropriate daily testing of antiepileptic drug levels	Effectiveness/ efficiency	Utilization of care	27% decrease (53 of 200 total) in redundant laboratory tests of antiepileptic medication levels; effect of reminders stable over 4 y

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Appendix Table 1—**Continued**

Study, Year (Reference), Type of Study (n = 52)	Institution	Data Collection	Primary HIT Intervention	Setting	Purpose (To Determine the Effect of . . .)	Dimensions of Care End Points	Effect Evaluated	Key Finding
Bates et al., 1999 (60), RCT	Brigham and Women's Hospital/Partners Health Care	1994	DS/CPOE	Inpatient	Computerized reminders on use of laboratory tests, redundant ordering, and associated costs vs. usual care (CPOE without laboratory-related reminders)	Efficiency	Utilization of care	24–percentage point absolute reduction (from 51% to 27%) in redundant tests; 31% of reminders were overridden by physicians; 41% of overrides were justified; 56% of redundant tests ordered in intervention group were not ordered via computer; only 51% of redundant tests ordered in control group were actually performed; estimated cost savings, $35 000/y (0.15% of total laboratory expenditures)
Shojania et al., 1998 (61), RCT	Brigham and Women's Hospital/Partners Health Care	1996–1997	DS/CPOE	Inpatient	Point-of-care computerized guidelines on antibiotic use vs. usual care (CPOE without antibiotic DS)	Effectiveness	Utilization of care	32% relative decrease (from 16.7 orders/physician to 11.3 orders/physician) in antibiotic orders; both initial and renewal order rates decreased
Fihn et al., 1994 (62), RCT	VA	NS	Administrative/ DS	Outpatient	Computerized scheduling system on follow-up time for anticoagulation monitoring vs. usual care	Safety/ access/ effectiveness	Utilization of care/ medication errors	Approximate 6-d increase (from 25 to 31 d) in follow-up appointment interval; no statistically significant differences in anticoagulation levels or complication rates
Steele et al., 1989 (63), RCT	VA	1987–1988	Data summary/DS	Outpatient	Computer-generated, paper-based feedback of medication costs vs. in-person pharmacist counseling on physician prescribing costs	Efficiency	Utilization of care	No statistically significant differences in costs were found with computer-based system vs. pharmacist counseling
Efficiency: time (n = 6)								
Overhage et al., 2001 (64), RCT, time-motion study	Regenstrief	1996–1998	CPOE/EHR	Outpatient	CPOE on physician time utilization	Efficiency	Time utilization	6.2% increase (from 34.2 to 36.3 min) in physician time per clinic visit; physicians continued to use paper despite CPOE, thereby duplicating tasks; with experience there was a non–statistically significant decrease in physician time of approximately 10% (3.7 min) per clinic visit
Kuperman et al., 1996 (65), cross-sectional analysis	Brigham and Women's Hospital/Partners Health Care	1995–1996	DS	Inpatient	Computerized alerts sent via pager on physician response to serious clinical events	Safety/ effectiveness	Time to utilization/ response	Physicians responded to 70% of alerts (1214 of 1730 alerts) and immediately placed orders in response to 39% of answered alerts; physicians responded to 82.5% of answered alerts (1002 of 1214) in < 15 min

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Appendix Table 1—**Continued**

Study, Year (Reference), Type of Study (n = 52)	Institution	Data Collection	Primary HIT Intervention	Setting	Purpose (To Determine the Effect of . . .)	Dimensions of Care End Points	Effect Evaluated	Key Finding
Kuperman et al., 1999 (66), RCT	Brigham and Women's Hospital/Partners Health Care	1994–1995	DS	Inpatient	Computerized alerts sent via pager on physician response time to critical laboratory results	Safety/ effectiveness	Time to care/safety	38% decrease (from 1.6 to 1.0 h) in median time until treatment ordered; 11% decrease in mean time (from 4.6 to 4.1 h) until treatment; no statistically significant decrease in ADEs
Pizziferri et al., 2005 (67), pre–post, time-motion study	Brigham and Women's Hospital/Partners Health Care	2001–2003	EHR	Outpatient	EHR use on physician time utilization in clinic	Efficiency	Time utilization	0.5-min decrease (from 27.55 to 27.05 min) in clinic visit time; physicians felt EHRs improved quality, access, and communication but negatively affected workload
Wong et al., 2003 (68), pre–post, time-motion study	VA	NS	EHR	Inpatient (ICU)	Computerized documentation on nursing time utilization	Efficiency	Time utilization	10.9–percentage point absolute decrease (from 35.1% to 24.2%) in documentation time; 8.8–percentage point absolute increase (from 31.3% to 40.1%) in time spent on direct patient care
Pierpont and Thilgen, 1995 (69), pre–post study	VA	NS	EHR	Inpatient (ICU)	Effect of computerized nursing documentation on ICU nurses' time utilization and workflow	Efficiency	Time utilization	7–percentage point absolute decrease (from 17% to 10%) in charting time; 3–percentage point decrease (from 7% to 4%) in data-gathering time; 10% of time was spent at computer reviewing data; no change in time spent in patients' rooms

* ADE = adverse drug event; CCT = controlled clinical trial; CPOE = computerized provider order entry; DS = decision support; EHR = electronic health record; H_2-blockers = histamine-2–blockers; HIT = health information technology; ICU = intensive care unit; NS = not specified; RCT = randomized, controlled trial; VA = Department of Veterans Affairs.

Appendix Table 2. **Other Institutions Researching Health Information Technology***

Study, Year (Reference), Type of Study (n = 22)	Data Collection	Primary HIT Intervention	Setting	Purpose (To Determine the Effect of . . .)	Dimensions of Care End Points	Effect Evaluated	Type of Institution	Key Findings
Commercially developed systems								
Adherence								
Rollman et al., 2002 (87), RCT	1997–1998	DS/EHR (Logician, MedicaLogic Corp.)	Outpatient	Three interventions on screening for mood disorders and physician agreement with computer-based diagnosis: 1) computer-generated, paper-based reminders for depression with treatment recommendations; 2) computer-generated, paper-based reminders with diagnosis information; on quality of depression care, and 3) usual care	Effectiveness	Adherence	Academic	No statistically significant difference in depression symptom scores or delivery of recommended processes of depression care for either intervention group when compared with usual care
Utilization of care								
Garrido et al., 2005 (84), retrospective time-series study	2000–2004	EHR (EpiCare, Epic Systems Corp.)	Outpatient	EHR on adherence to recommended care and efficiency measures	Effectiveness	Adherence	Kaiser Permanente	No statistically significant difference in depression symptom scores or delivery of recommended processes of depression care for either intervention group when compared with usual care
Chin and Wallace, 1999 (83), time-series study	1994–1997	EHR/DS (EpiCare, Epic Systems Corp.)	Outpatient	EHR with CPOE and DS on adherence to guideline-based care for radiology services and medication use	Quality/ effectiveness	Utilization of care	Kaiser Permanente	48% relative decrease (from 10.6 tests/1000 to 5.6 tests/1000) for upper gastrointestinal tract radiology studies by year 4 after EHR implementation, with a 33–percentage point absolute increase (from 55% to 88%) in adherence to protocols for test ordering; 20% decrease in chest radiographs ordered (years after implementation and information on relative or absolute decrease not provided); 2.3–percentage point absolute decrease (from 4.7% to 2.4%) in prescribing of a nonformulary antidepressant by year 2 after implementation

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Appendix Table 2—**Continued**

Study, Year (Reference), Type of Study (*n* = 22)	Data Collection	Primary HIT Intervention	Setting	Purpose (To Determine the Effect of . . .)	Dimensions of Care End Points	Effect Evaluated	Type of Institution	Key Findings
Surveillance								
Rollman et al., 2001 (86), RCT	1997–1999	DS/EHR (Logician, MedicaLogic Corp.)	Outpatient	Three interventions on quality of depression care: 1) computer-generated, paper-based reminders for depression with treatment recommendations; 2) computer-generated, paper-based reminders with diagnosis information alone; and 3) usual care	Effectiveness	Surveillance	Academic	Three days after computer notification of possible mood disorder, 65% of physicians agreed with computer-screened diagnosis, 13% disagreed, and 23% were uncertain; no differences in treatment provided across guideline-exposure condition
Time utilization/medication errors								
Koppel et al., 2005 (91), mixed quantitative/qualitative descriptive methods	2002– 2004	CPOE (Eclipsys Corp.)	Inpatient	CPOE in facilitating medication prescribing errors	Safety	Medication errors	Academic	CPOE facilitated 22 types of medication error risks; errors were classified as being due to 1) fragmentation of data and failure to integrate CPOE systems with other hospital systems and 2) flaws in human–machine interface
Mekhjian et al. (88), 2002, pre–post study	2000	CPOE/DS (Invision24, Siemens Corp.)	Inpatient/ICU	CPOE with electronic records for medication administration on care delivery time, workflow process, and costs	Efficiency	Time utilization/medication errors	Academic	64% relative decrease (from 328 to 111 min) in medication turnaround time; 43% relative decrease (from 457 to 261 min) in completion time for radiology procedures; 25% relative decrease (from 31.3 to 23.4 min) in reporting time for laboratory results; 11.3–percentage point absolute decrease (from 11.3% to 0%) in transcription errors; 5% relative decrease (from 3.91 to 3.71 d) in severity-adjusted length of stay; no statistically significant decreases in overall cost

Appendix Table 2—**Continued**

Study, Year (Reference), Type of Study (*n* = 22)	Data Collection	Primary HIT Intervention	Setting	Purpose (To Determine the Effect of . . .)	Dimensions of Care End Points	Effect Evaluated	Type of Institution	Key Findings
Cordero et al., 2004 (89), pre–post study with retrospective review	2002	CPOE/DS (Invision24, Siemens Corp.)	Neonatal ICU	CPOE with DS on medication errors and care delivery time in neonatal ICU	Safety/efficiency	Medication errors/ time utilization	Academic	13–percentage point absolute decrease (from 13% to 0%) in medication dosing errors; 73% relative decrease (from 10.5 to 2.8 h) in turnaround time for 1 medication (caffeine); 24% relative decrease (from 42 to 32 min) in radiology response time; physician and staff training started 4 wk before CPOE implementation; nurse leaders received 16 h of training, nurses and clerical staff received 8 h, and physicians received 2–4 h; during implementation, information systems staff provided 24-h support
Kilgore et al., 1998 (90), pre–post study	1995–1996	EHR (CareVue 9000, Hewlett-Packard Corp.; PIN System, Eclipsys Corp.)	ICU	Two different nursing ICU information systems with CPOE and results reporting on nurse work patterns and costs	Efficiency	Time utilization	Academic	Effect of computer systems on nurse charting time was inconclusive per authors because ICU patient census varied; staff satisfaction was higher with CareVue 9000 than with PIN System because of interface ease and greater support of workflow; expected net annual savings from preferred system were estimated at $320 359
Implementation costs								
Krall, 1995 (85), descriptive quantitative study	1994	EHR (EpiCare, Epic Systems Corp.)	Outpatient	EHR use on workflow and attitudes	Efficiency	Implementation cost	Kaiser Permanente	Physicians took 30 d to return to baseline productivity levels (patient visits/d); 2-min increase in physician time per visit; physician satisfaction with system increased over time
Internally developed systems								
Adherence								
Khoury, 1998 (70), time-series study	1993–1997	EHR/DS	Outpatient	EHR with DS on adherence to guideline-based care	Effectiveness/efficiency	Adherence	Kaiser Permanente	Adherence to guidelines improved for 6 conditions; levels of improvement ranged from 4– to 52–percentage point absolute increases in process of care delivery; estimated annual savings, $2 470 000 (cost of system development not included)

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Appendix Table 2—**Continued**

Study, Year (Reference), Type of Study (n = 22)	Data Collection	Primary HIT Intervention	Setting	Purpose (To Determine the Effect of . . .)	Dimensions of Care End Points	Effect Evaluated	Type of Institution	Key Findings
Ornstein et al., 1995 (72), pre–post study	NS	EHR/DS	Outpatient	EHR with computerized reminders on delivery of preventive care	Effectiveness	Adherence	Academic	7 of 7 counseling measures improved: absolute increase in adherence ranging from 13 to 16 percentage points; 10 of 15 screening processes improved: absolute increase approximately ranging from 3 to 20 percentage points
Garr et al., 1993 (71), pre–post study	1989–1990	DS/EHR	Outpatient	EHR with computerized reminders on delivery of preventive care	Effectiveness	Adherence	Academic	Absolute increases in delivery of preventive care, 1–8 percentage points; all 5 services included
Safran et al., 1995 (75), CCT	1992–1993	EHR/DS	Outpatient	Computerized reminders and alerts on delivery of HIV care	Effectiveness	Adherence	Academic	Approximate 22–percentage point absolute increase (from 46% to 68%) in adherence to recommended process of care at 1 y after occurrence of clinical event warranting reminder; 29–percentage point absolute increase (from 38% to 67%) in physician responses 1 mo after clinical event warranting alert
Schriger et al., 1997 (73), CCT	1992–1995	DS/EHR	Emergency department	Computerized guidelines embedded in computerized charting system designed to track 5 conditions on processes of care for exposure of health care workers to bodily fluids	Effectiveness/efficiency	Adherence	Academic	12–percentage point absolute increase (from 83% to 96%) in adherence to 5 treatment guidelines; 20–percentage point absolute increase (from 63% to 83%) in adherence to 4 guidelines on laboratory test use; 62–percentage point absolute increase (from 31% to 93%) in documented adherence to aftercare guidelines; 42–percentage point absolute increase (from 57% to 98%) in adherence to guidelines for documentation of patient history; all measures decreased toward baseline rates when computer system was turned off; 23% relative decrease (from \$520 to \$401) in total per-patient costs

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Appendix Table 2—**Continued**

Study, Year (Reference), Type of Study (n = 22)	Data Collection	Primary HIT Intervention	Setting	Purpose (To Determine the Effect of . . .)	Dimensions of Care End Points	Effect Evaluated	Type of Institution	Key Findings
Schriger et al., 2000 (74), CCT	1992–1995	DS/EHR	Emergency department	Computerized guidelines embedded in computerized charting system designed to track 5 conditions on processes of care for evaluation of febrile children < age 3 y presenting to emergency department	Effectiveness/efficiency	Adherence	Academic	Per authors' report, 13–percentage point absolute increase (from 80% to 92%) in documented adherence to guidelines for medical history and physical examination; 33–percentage point absolute increase (from 48% to 81%) in documented adherence to guidelines for aftercare instruction; all rates returned to baseline when computer system was turned off; no statistically significant differences in appropriateness of treatment, appropriateness or utilization rates of diagnostic tests, or test charges per patient
Day et al., 1995 (76), pre–post study	1992–1993	DS/EHR	Emergency department	Computerized guidelines embedded in computerized charting system designed to track 5 conditions on processes of care for lower back pain	Effectiveness/efficiency	Adherence	Academic	No statistically significant differences in appropriateness of diagnostic testing or treatment; no statistically significant decrease in costs; 12– to 51–percentage point absolute increase in documentation of 6 medical history items; 13– to 70–percentage point absolute increase in documentation of 6 aftercare counseling items
Simon et al., 2000 (77), RCT	NS	EHR/data summary/DS	Outpatient	Three interventions: 1) feedback to physicians of computerized data summaries with treatment recommendations for depression care, 2) computerized feedback plus telephone follow-up, and 3) usual care	Effectiveness/efficiency	Adherence	Nonacademic (Group Health Cooperative of Puget Sound)	No statistically significant difference in computerized DS group compared with usual care; 15% relative improvement (from 0.83 vs. 0.98) in depression scores in computerized DS with telephone follow-up group, with associated increase in likelihood of receiving antidepressant therapy; $80 increase in costs in telephone follow-up group
Utilization of care								
Baird et al., 1984 (78), RCT	NS	DS/electronic prescribing	Outpatient	Computer-generated, paper-based pharmacy reminders from hospital mainframe–based information system on prescription refill rates	Access	Utilization of care	Academic	No statistically significant difference in refill rates; initial development of software program, $200; cost per day to generate reminders, $14

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Appendix Table 2—**Continued**

Study, Year (Reference), Type of Study (n = 22)	Data Collection	Primary HIT Intervention	Setting	Purpose (To Determine the Effect of . . .)	Dimensions of Care End Points	Effect Evaluated	Type of Institution	Key Findings
Sanders and Miller, 2001 (79), pre–post study	2000–2001	DS/CPOE	Inpatient	Computerized guidelines integrated into a CPOE system on utilization of CT and MRI	Efficiency	Utilization of care	Academic	5% relative decrease in neuroradiology CT and MRI diagnostic testing; 40% of users receiving computerized guideline ordered a nonrecommended test
Surveillance								
Wells et al., 2003 (81), pre–post study	2001–2002	DS/EHR	Outpatient	EHR on identifying patients taking 2 drugs for which a combination pill is available and then generating computerized reminders to promote combination therapy	Effectiveness	Surveillance/adherence	Academic	27% of patients eligible were switched to combination therapy; cost savings related to combined therapy totaled $6159 per year; 241 patients were screened as eligible for combination therapy; total number of unique patients seen during study not given
Medication errors								
Potts et al., 2004 (80), pre–post study	2001–2002	CPOE/DS	ICU	CPOE with DS on medication errors in pediatric ICU	Efficiency	Medication errors	Academic	41% relative decrease (from 2.2 errors/100 orders to 1.3 errors/100 orders) in medication errors categorized as potential adverse drug events; 96% relative decrease (from 30 errors/100 orders to 0.2 error/100 orders) in medication prescribing orders; decreases occurred in all categories of medication errors
Implementation cost								
Khoury, 1997 (82), time-series study	1989–NS	EHR	Outpatient	Long-term costs and benefits of implemented EHR	Efficiency	Implementation cost	Kaiser Permanente	Cost of development estimated at $10 million; project took 8 y from beginning of development to full implementation; total ongoing annual expenses estimated to be $1.1 million per year; expected savings per year estimated as $3.7 million, with greatest savings from reduction in medical record room staff; system predicted to pay for itself in year 13

* City and state locations of manufacturers are as follows: MedicaLogic Corp., Beaverton, Oregon; Epic Systems Corp., Verona, Wisconsin; Eclipsys Corp., Boca Raton, Florida; Siemens Corp., New York, New York; Hewlett-Packard Corp., Palo Alto, California. CCT = controlled clinical trial; CPOE = computerized provider order entry; CT = computed tomography; DS = decision support; EHR = electronic health record; HIT = health information technology; ICU = intensive care unit; MRI = magnetic resonance imaging; NS = not specified; RCT = randomized, controlled trial.