European Journal of Public Health, Vol. 26, No. 1, 60–64

doi:10.1093/eurpub/ckv122 Advance Access published on 1 July 2015

The impact of electronic health records on healthcare quality: a systematic review and meta-analysis

Paolo Campanella, Emanuela Lovato, Claudio Marone, Lucia Fallacara, Agostino Mancuso, Walter Ricciardi, Maria Lucia Specchia

Department of Public Health, Catholic University of Sacred Heart, L.go F. Vito 1 00168, Rome, Italy

Correspondence: Paolo Campanella, Department of Public Health, Section of Hygiene, Catholic University of Sacred Heart, L.go F. Vito 1 00168, Rome, Italy, Tel: (+39) 0635019534, Fax: (+39) 0635019535, e-mail: paolo.campanella@icloud.com

Objective: To assess the impact of electronic health record (EHR) on healthcare quality, we hence carried out a systematic review and meta-analysis of published studies on this topic. **Methods:** PubMed, Web of Knowledge, Scopus and Cochrane Library databases were searched to identify studies that investigated the association between the EHR implementation and process or outcome indicators. Two reviewers screened identified citations and extracted data according to the PRISMA guidelines. Meta-analysis was performed using the random effects model for each indicator. Heterogeneity was quantified using the Cochran Q test and I2 statistics, and publication bias was assessed using the Egger's test. **Results:** Of the 23 398 citations identified, 47 articles were included in the analysis. Meta-analysis showed an association between EHR use and a reduced documentation time with a difference in mean of −22.4% [95% confidence interval (CI) = −38.8 to −6.0%; $P < 0.007$]. EHR resulted also associated with a higher guideline adherence with a risk ratio (RR) of 1.33 (95% CI = 1.01 to 1.76; $P = 0.049$) and a lower number of medication errors with an overall RR of 0.46 (95% CI = 0.38 to 0.55; $P < 0.001$), and adverse drug effects (ADEs) with an overall RR of 0.66 (95% CI = 0.44 to 0.99; $P = 0.045$). No association with mortality was evident ($P = 0.936$). High heterogeneity among the studies was evident. Publication bias was not evident. **Conclusions:** EHR system, when properly implemented, can improve the quality of healthcare, increasing time efficiency and guideline adherence and reducing medication errors and ADEs. Strategies for EHR implementation should be therefore recommended and promoted.

Introduction

Our world has been radically transformed through digital innovation. Information technologies play a growing role in healthcare delivery and help address the health problems and challenges faced by clinicians and other health professionals.

An electronic health record (EHR) is a systematic electronic collection of health information about patients such as medical history, medication orders, vital signs, laboratory results, radiology reports, and physician and nurse notes. In healthcare institutions, it automates the medication, as well as exam, ordering process ensuring standardized, readable and complete orders.

An EHR may also include a decision support system (DSS) that provides up-to-date medical knowledge, reminders or other actions that aid health professionals in decision making.[1]

Although several studies on the effects of EHR implementation have been published, evidence on EHR effects continues to be disputed. Even if most of the studies published seem to provide promising data, some reported different results, such as Han *et al.*[2] who reported an unexpected rise in mortality after the EHR implementation in a tertiary care children's hospital.

To assess the impact of EHRs on healthcare quality, we hence carried out a systematic review and meta-analysis of published studies on this topic that may provide a rational basis for recommendations.

Methods

This study was conducted and reported in accord with PRISMA guidelines for meta-analyzes and systematic reviews.[3]

Search strategy and study selection

A protocol was developed, and we searched in PubMed, Web of Knowledge, Scopus and Cochrane Library databases to identify studies that evaluated the benefits of EHR implementation using the following algorithm:#1 = 'Electronic Medical Record' OR 'Electronic Health Record' OR 'Electronic Patient Record'.
#2 = 'Computerized Physician Order Entry'.
#3 = 'Decision Support Systems'.
#4 = #1 OR #2 OR #3.
#5 = value OR impact OR benefit OR improvement.
#6 = quality OR efficiency OR risk OR safety.
#7 = #5 OR #6.
#8 = #4 AND #7.

Our search was restricted to English language studies published from 1994 to 2013.

Studies were considered eligible if they investigated the association between the EHR implementation and process or outcome indicators and if they had a control group who did not use the EHR.

One reviewer screened titles, and then, abstracts of relevant titles were identified. Full texts of potential citations were subsequently obtained; two reviewers independently screened them for inclusion, and disagreements were resolved through discussion. Additional relevant publications were identified from the references of the initially retrieved articles.

Data extraction

From each study, we extracted data on the first author's last name, year of publication and process or outcome indicators evaluated.

For indicators represented by dichotomous variables, risk ratios (RRs) with their confidence intervals (CIs) (or data necessary to obtain them) were extracted. For indicators represented by

continuous variables, sample sizes of both control and intervention groups and differences in mean (DMs) and their CIs (or data necessary to obtain them) were extracted.

All data extractions were conducted independently by two reviewers, and disagreements were resolved through discussion.

Data analysis

Meta-analysis was performed for each process or outcome indicators evaluated. Because of the significant heterogeneity expected among the studies performed in different settings, the random effects model was employed using the Der Simonian and Laird's method.[4]

Heterogeneity was quantified using the Cochran Q test and I^2 statistics.[5]

For indicators with available both studies including DSS and not subgroup analyzes were performed.

Sensitivity analyzes were conducted by excluding one study at a time from the meta-analysis to determine whether the results of the meta-analysis were influenced by individual studies and whether risk estimates and heterogeneity were substantially modified.

The presence of publication bias was assessed using a visual funnel plot inspection and Egger's test.[6]

All statistical tests were performed with Comprehensive Meta-Analysis software version 2.2.064 (Biostat, Englewood, NJ).

Results

Search results and study characteristics

Searching the online databases resulted in 23 398 articles from PubMed, Web of Knowledge, Scopus and Cochrane Library. After the initial screening of titles and abstracts, 404 articles were considered for full text review. Twelve articles were excluded because full texts were not available, and 352 articles were excluded based on the full text review. After having identified seven additional articles by reviewing bibliographies, 47 articles were included in the analysis (figure 1).

Nine studies investigated the relationship between EHR use and a reduced documentation time spent by healthcare professionals. The association between EHR and guideline adherence, medication

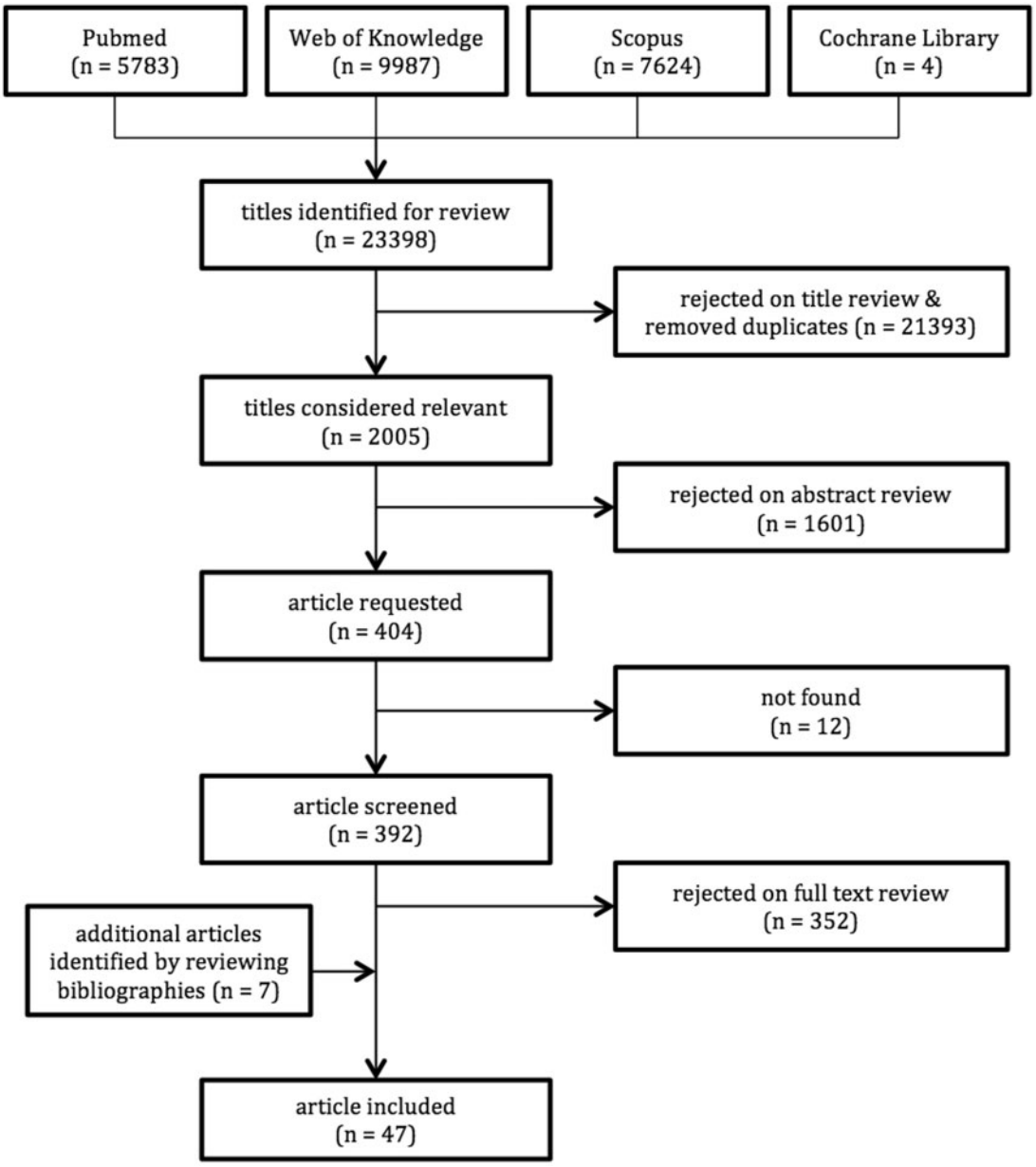

Figure 1 Search flow for EHR literature

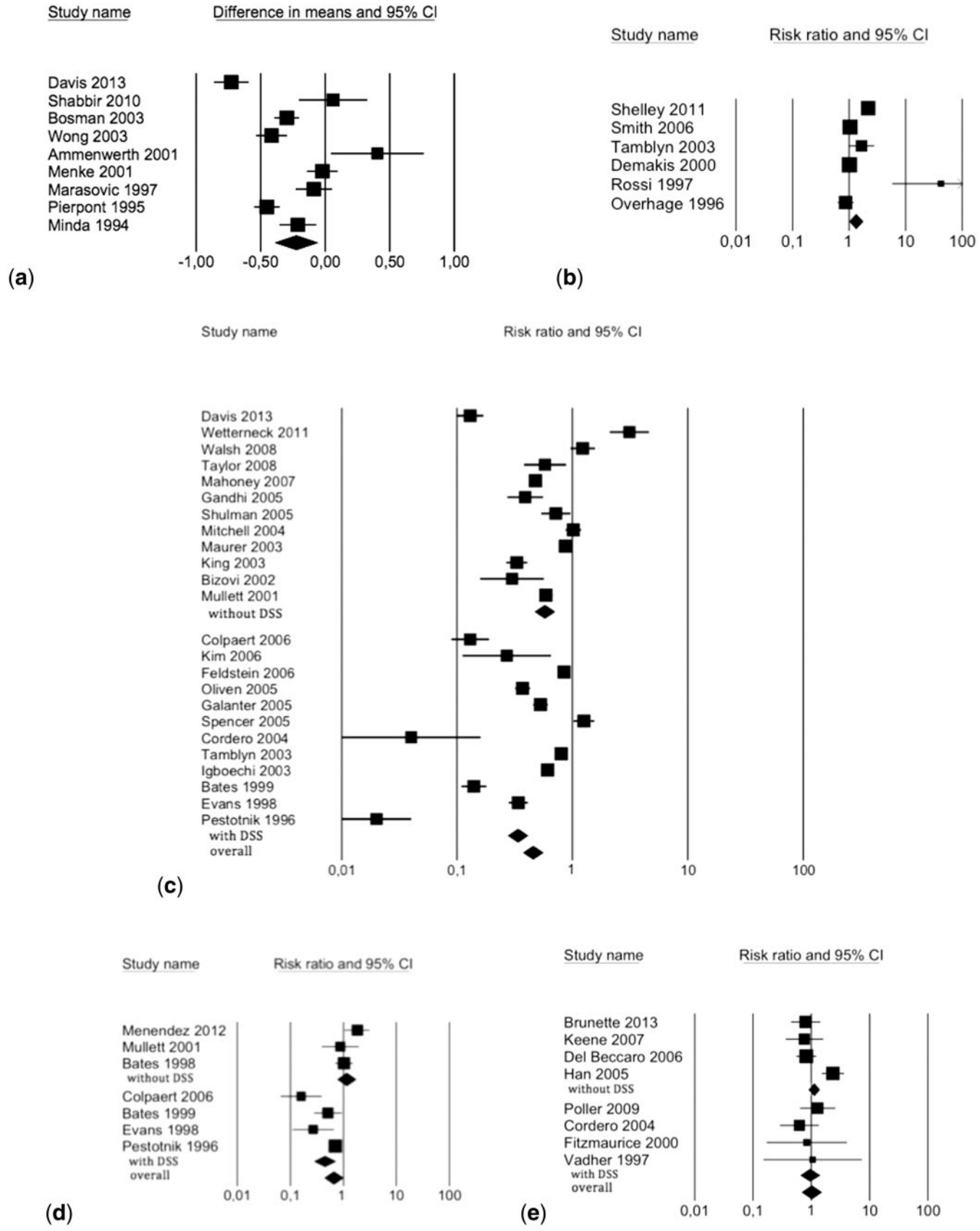

Figure 2 Forest plot for the meta-analysis of studies reporting on (**a**) EHR and documentation time, (**b**) guideline adherence, (**c**) medication errors, (**d**) ADEs and (**e**) mortality. The overall, as well as subgroup, estimates of the effect are represented by diamonds in each plot

errors, adverse drug effects (ADEs), and mortality were evaluated in 6, 24, 7 and 8 studies, respectively.

Meta-analysis

Meta-analysis showed an association between EHR use by healthcare professionals and a reduced documentation time with a difference in mean of −22.4% (95% CI = −38.8% to −6.0%; $P < 0.007$).

The EHR resulted also associated with a higher guideline adherence with an RR of 1.33 (95% CI = 1.01 to 1.76; $P = 0.049$) and a lower number of medication errors with an overall RR of 0.46 (95% CI = 0.38 to 0.55; $P < 0.001$) and ADEs with an overall RR of 0.66 (95% CI = 0.44 to 0.99; $P = 0.045$). No association with mortality was evident ($P = 0.936$) (figure 2).

High heterogeneity among the studies regarding documentation time (Q test $P < 0.001$ and $I^2 = 92.4\%$), guideline adherence (Q test $P < 0.001$ and $I^2 = 91.9\%$), medication errors (Q test $P < 0.001$ and $I^2 = 97.7\%$) and ADEs (Q test $P < 0.001$ and $I^2 = 80.8\%$) was evident. Moderate heterogeneity regarding mortality (Q test $P = 0.012$ and $I^2 = 61.0\%$) was also evident.

Sensitivity analysis and publication bias

Sensitivity analysis has shown the stability of the overall effect sizes with the withdrawal of any of the study from the analysis without a significant improvement of the heterogeneity. Publication bias was not evident from reviews of the funnel plot or Egger's test for any process or outcome indicators considered.

Subgroup analysis

For medication errors, ADEs and mortality both studies including and excluding DSS were available. Subgroup analysis confirmed the association between EHR and a reduction of medication errors and showed a better outcome for EHR including DSS, RR of 0.33 (95% CI = 0.25 to 0.45), compared with software without DSS, RR of 0.60 (95% CI = 0.45 to 0.81). Regarding the association between EHR and ADEs reduction, subgroup analysis also showed a better significant association for EHR including DSS, RR of 0.40 (95% CI = 0.21 to 0.75), but it showed a non-significant association for software not including DSS, RR of 1.20 (95% CI = 0.79 to 1.82).

Moreover, regarding the absence of significant association between EHR and mortality, subgroup analysis confirmed this absence with a slightly better outcome for EHR using DSS, RR of 0.93 (95% CI = 0.58 to 1.49), compared with EHR not using DSS, RR of 1.06 (95% CI = 0.59 to 1.92).

Discussion

This meta-analysis provides evidence that the use of EHR can improve the quality of healthcare, increasing time efficiency and guideline adherence and reducing medication errors and ADEs.

Consequently, EHR can determine also a reduction of costs associated with medical errors, ADEs and time inefficiency. In effect, several studies focused on the economics of medical errors[7–9] and ADEs[10,11] point out that considerable cost reductions are achievable through improving quality of care and reducing harm to patients.[12]

Guidelines adherence may have an impact on resource use and cost reduction, supporting specialists in their clinical choices by reducing errors and ADEs related to treatment and, consequently, unnecessary waste of resources, as some examples reported by scientific literature.[13] In fact guidelines are promoted as a means to decrease inappropriate clinical practice variability and use of ineffective therapies and to reduce medical errors,[14] thus resulting in improved patient outcomes and more cost-effective care.[15] Moreover, several studies have reported that the use of appropriate information technology in the delivery of healthcare may also improve hospital efficiency, with benefits exceeding the costs of adoption[16] and patient satisfaction rating.[17]

Subgroup analyzes for EHR with DSS compared with EHR without DSS provide also interesting results. EHR including DSS, that actively provides up-to-date medical knowledge, reminders or other actions that aid health professionals in decision making, showed in fact generally a better outcome.

So, even if in this review we are far from knowing how EHR generates these quality improvements, this may suggest that such dynamic components are ones of the most effective parts of EHRs.

Regarding the association between EHR and ADEs reduction, subgroup analysis showed a better significant association for EHR including DSS, but a non-significant association for software not including DSS. However, the absence of association with ADEs reduction for the subgroup of studies not using DSS is probably due to the limitation of having only three studies in this subgroup.

Despite the benefits that EHR can provide, a proper implementation strategy is essential. In our opinion, it is likely that there are cases where the success of EHR was not reached because of a non-effective implementation strategy.

An example of an effective strategy may be identified through the WHO guidelines for EHR in developing countries[18] and reassumed in six key actions:–review the current health record system,
–try to emulate benchmark practices,
–involve the anticipated users of the system from the onset of discussions,
–train the users to the EHR system,
–evaluate the benefits of the implemented system,
–update the system when needed.

We believe that such an implementation strategy or a similar one is crucial in effectively setting up an EHR system, reducing the resistance of medical practitioners and health professionals, ensuring that the system is used optimally, and obtaining clinical results.

Having used the tool of quantitative meta-analysis of several outcomes to synthesize the evidence on the EHR is definitely a strength of our study.

However, our study has also its limitations. In fact, we focused on different indicators and although we did a comprehensive search, we found only a limited number of articles with quantitative data among the articles identified and even less for each indicator and subgroup. High heterogeneity was also present and may have affected the robustness of the results. Possible source of such heterogeneity includes difference in the software used, their quality and usability, and different settings of implementation.

Moreover, information on technical items and procedures that shape the EHR software was not included in most studies. Further research is therefore needed to determine the differences among the various system, the different items that shape an EHR software, and the different benefits of any of them. Health information technology systems are, in fact, healthcare interventions, and systems for evaluating their efficacy and safety should be as robust as those evaluating other healthcare technologies. Such evidence may provide healthcare providers with useful indication regarding the kind of EHR software and its proper implementation to improve the quality of health care provided and to generate value.

EHR is also often considered an ideal tool to be used to assess healthcare quality and monitor health providers' performance because of the availability of stored computerized data. The last could allow automated quality assessment, avoiding manual chart review and medical record abstraction, both of which are expensive and time-consuming processes. This will require future research to focus on intervention strategies for improving both quality and comprehensiveness of clinical data stored in EHR and identifying the best process of data extraction.[19,20]

Cumulative evidence shows that EHR systems can improve the quality of healthcare by increasing time efficiency and guideline adherence and reducing medication errors and ADEs. Therefore, strategies for EHR implementation should be recommended and promoted.

Further research on technical items and procedures that shape the EHR software is needed to identify the features that have value for both clinical results and quality monitoring.

Conflicts of interest: None declared.

Key points

- Health information technology systems are healthcare interventions.
- EHR systems can improve the quality of healthcare.
- Strategies for EHR implementation should be recommended and promoted.

References

1 Murphy EV. Clinical decision support: effectiveness in improving quality processes and clinical outcomes and factors that may influence success. *Yale J Biol Med* 2014;87:187–97.

2 Han YY, Carcillo JA, Venkataraman ST, et al. Unexpected increased mortality after implementation of a commercially sold computerized physician order entry system. *Pediatrics* 2005;116:1506–12.

3 Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. *BMJ* 2009;339:b2700.

4 DerSimonian R, Laird N. Meta-analysis in clinical trials. *Control Clin Trials* 1986;7:177–88.

5 Higgins JPT, Thompson SG. Quantifying heterogeneity in a meta-analysis. *Stat Med* 2002;21:1539–58.

6 Egger M, Davey Smith G, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. *BMJ* 1997;315:629–34.

7 Andel C, Davidow SL, Hollander M, Moreno DA. The economics of health care quality and medical errors. *J Health Care Finance* 2012;39:39–50.

8 David G, Gunnarsson CL, Waters HC, et al. Economic measurement of medical errors using a hospital claims database. *Value Heal* 2013;16:305–10.

9 Goodman JC, Villarreal P, Jones B. The social cost of adverse medical events, and what we can do about it. *Health Aff* 2011;30:590–5.

10 Agency for Healthcare Research and Quality. Reducing and Preventing Adverse Drug Events To Decrease Hospital Costs: Research in Action, Issue 1. March 2001. Agency for Healthcare Research and Quality, Rockville, MD. http://archive.ahrq.gov/research/findings/factsheets/errors-safety/aderia/ade.html.

11 Pham JC, Aswani MS, Rosen M, et al. Reducing medical errors and adverse events. *Annu Rev Med* 2012;63:447–63.

12 Swensen SJ, Kaplan GS, Meyer GS, et al. Controlling healthcare costs by removing waste: what American doctors can do now. *BMJ Q Saf* 2011;20:534–7.

13 Akenroye AT, Baskin MN, Samnaliev M, Stack AM. Impact of a bronchiolitis guideline on ED resource use and cost: a segmented time-series analysis. *Pediatrics* 2014;133:e227–34.

14 Codish S, Shiffman RN. A model of ambiguity and vagueness in clinical practice guideline recommendations. *AMIA Annu Symp Proc* 2005:146–50.

15 Fritz JM, Cleland JA, Brennan GP. Does adherence to the guideline recommendation for active treatments improve the quality of care for patients with acute low back pain delivered by physical therapists? *Med Care* 2007;45:973–80.

16 Zhivan NA, Diana ML. U.S. hospital efficiency and adoption of health information technology. *Health Care Manag Sci* 2012;15:37–47.

17 Zabada C, Singh S, Munchus G. The role of information technology in enhancing patient satisfaction. *Br J Clin Gov* 2001;6:9–16.

18 World Health Organization. *Electronic Health Records: Manual for Developing Countries*. 2006. Geneva, Switzerland: World Health Organization.

19 Roth CP, Lim YW, Pevnick JM, et al. The challenge of measuring quality of care from the electronic health record. *Am J Med Q* 2009;24:385–94.

20 Chan KS, Fowles JB, Weiner JP. Review: electronic health records and the reliability and validity of quality measures: a review of the literature. *Med Care Res Rev* 2010;67:503–27.