The Effect of Computerized Provider Order Entry Systems on Clinical Care and Work Processes in Emergency Departments: A Systematic Review of the Quantitative Literature

Andrew Georgiou, PhD; Mirela Prgomet, BAppSc(HIM); Richard Paoloni, MBBS, MMed(ClinEpi); Nerida Creswick, PhD; Antonia Hordern, MHealthSc(CDM); Scott Walter, MBiostat; Johanna Westbrook, PhD

Study objective: We undertake a systematic review of the quantitative literature related to the effect of computerized provider order entry systems in the emergency department (ED).

Methods: We searched MEDLINE, EMBASE, Inspec, CINAHL, and CPOE.org for English-language studies published between January 1990 and May 2011.

Results: We identified 1,063 articles, of which 22 met our inclusion criteria. Sixteen used a pre/post design; 2 were randomized controlled trials. Twelve studies reported outcomes related to patient flow/clinical work, 7 examined decision support systems, and 6 reported effects on patient safety. There were no studies that measured decision support systems and its effect on patient flow/clinical work. Computerized provider order entry was associated with an increase in time spent on computers (up to 16.2% for nurses and 11.3% for physicians), with no significant change in time spent on patient care. Computerized provider order entry with decision support systems was related to significant decreases in prescribing errors (ranging from 17 to 201 errors per 100 orders), potential adverse drug events (0.9 per 100 orders), and prescribing of excessive dosages (31% decrease for a targeted set of renal disease medications).

Conclusion: There are tangible benefits associated with computerized provider order entry/decision support systems in the ED environment. Nevertheless, when considered as part of a framework of technical, clinical, and organizational components of the ED, the evidence base is neither consistent nor comprehensive. Multimethod research approaches (including qualitative research) can contribute to understanding of the multiple dimensions of ED care delivery, not as separate entities but as essential components of a highly integrated system of care. [Ann Emerg Med. 2013;61:644-653.]

Please see page 645 for the Editor's Capsule Summary of this article.

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INTRODUCTION

Background

Health information technology systems, such as computerized provider order entry, can provide clinicians with timely electronic access to patient information and electronic decision support (including alerts, reminders, orders sets, or feedback)[1] to enhance clinical decisionmaking and the provision of quality clinical care.[2,3] The emergency department (ED) is a complex, high-risk, and information-intense setting confronted by severe time pressures and interruptions.[4] As such, it is an environment that is expected to benefit from the implementation of health information technology.[2] Conversely, EDs are highly susceptible to potential imperfections in the design and implementation of information technology.[5] In 2004, the US Emergency Medicine Information Technology Consensus Conference noted that if a computerized provider order entry system is to fail, it will probably happen first in the ED. The conference concluded with recommendations for a greater research focus on the ED as a whole entity and not just the more easily identifiable direct effects of health information technology.[6]

Importance

Although a growing body of evidence has emerged that identifies numerous benefits associated with the introduction of health information technology,[1,7,8] major concerns still remain about the failure of the existing evidence to demonstrate the major benefits expected.[9] The Black et al[9] overview of electronic health research highlights an accumulation of reviews in areas such as medications,[10,11] workflow,[12] pathology,[13,14] and medical imaging.[15] A notable omission is the existence of a systematic review of the effect of computerized provider order entry and decision support systems in the ED, an area that is

Editor's Capsule Summary

What is already known on this topic

Computerized provider order entry has been widely promoted to improve safety, quality, and cost, but its utility in the emergency department (ED) has been sparsely studied.

What question this study addressed

This is a systematic review of the English-language literature presenting quantitative data on the effect of computerized provider order entry in the ED.

What this study adds to our knowledge

From 1990 to 2011, there were 22 studies, all published since 2006 and roughly half arising from 3 institutions. Outcomes were heterogeneous; computerized provider order entry was associated with increased physician computer time, no decrease in patient time, and decreased medication errors.

How this is relevant to clinical practice

The published evidence for computerized provider order entry in the ED is neither comprehensive nor consistent and likely suffers from publication bias of unknown magnitude and direction.

highly reliant on the seamless integration and interaction of different wards, departments, information repositories, and people. Clinical staff and hospital management, seeking to monitor and improve ED performance, are often challenged by inadequate performance metrics, weak evidence, and administrative data that lack clinical validity.[16]

In 2011, as a consequence of an Agency for Healthcare Research and Quality supported consensus conference, Handel et al[3] proposed a research agenda to guide the consideration of health information technology and its effect on care in the ED that included patient flow and work integration (performance of clinical work), decision support systems (quality of care delivery), safety-critical computing and handoffs (safety of care delivery), and interoperability (improved exchange of patient information). This agenda is apt, particularly in light of the recommendations of the US Committee on Patient Safety and Health Information Technology, Institute of Medicine, emphasizing the importance of developing industry-wide measures, standards, and criteria for measuring the safety and quality of health information technology.[17]

Goals of This Investigation

The aim of this systematic review was to examine evidence of the effect of computerized provider order entry on clinical care and work processes in the ED, with particular reference to areas identified by Handel et al,[3] including patient flow and clinical work, decision support systems, patient safety, and interoperability.

MATERIALS AND METHODS

Study Design

Our first step in undertaking this systematic review was to develop a protocol (available at: http://www.aihi.unsw.edu.au/sites/aihi.cms.med.unsw.edu.au/files/Protocol_Systematic_review.pdf). The protocol guided the conduct of this review in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses statement.[18]

We sought to identify articles examining the effect of computerized provider order entry systems in the ED. We used OvidSP to search MEDLINE, EMBASE, and Inspec, and EBSCOhost to search CINAHL. A search strategy was developed by one of the authors (M.P.) and an initial search was conducted on August 11, 2010. A complete updated search was conducted on May 31, 2011. We also searched the Oregon Health and Science University CPOE Bibliography (CPOE.org), which contains an extensive listing of computerized provider order entry–related research. The search was supplemented by hand-searching and reference list checking.

To identify pertinent research articles, we combined subject terms and keywords relating to the intervention, with keywords describing the intervention functions, and subject terms and keywords related to the setting (Table 1). This search strategy was applied to the 4 electronic databases. To identify relevant articles within CPOE.org, the key word "emergency" was used.

Studies were required to meet 3 key eligibility criteria: (1) the study was conducted in an ED setting or involved distinct ED-related outcomes; (2) a computerized provider order entry system was a component of the intervention (but the intervention could include more than just computerized provider order entry); and (3) quantitative outcome measure(s) of the effect of the intervention were reported. We included all quantitative measures that assessed the effect of computerized provider order entry on clinical care and work processes in the ED, including turnaround times, number of orders, number of adverse events, number of prescribing errors, rate of guideline compliance, length of stay, and patient outcomes. Study design restrictions were not imposed, provided that the 3 key criteria were met. Eligibility of research articles was constrained to English-language articles published between January 1, 1990, and May 31, 2011. Studies published as abstracts or as full text were included to avoid selective reporting.

Data Collection and Processing

The combined searches yielded 1,405 citations (1,063 excluding duplicates). Figure 1 illustrates the selection process. All citations were independently screened by 3 reviewers (A.G., M.P., and N.C.) to determine eligibility. This included an initial screening of titles and abstracts and was followed by full-text reviews. Examples of exclusions based on titles are provided in Appendix E1 (available online at http://www.annemergmed.com). Articles that met the

Table 1. Electronic databases search strategy.

Search Strategy Task		OvidSP Search Strategy: MEDLINE, EMBASE, and Inspec		EBSCOhost Search Strategy: CINAHL
Intervention subject terms and key words	1	Medical Order Entry Systems/	S1	(MH "Electronic Order Entry")
	2	Electronic Prescribing/	S2	"electronic prescribing"
	3	Information Systems/	S3	(MH "Clinical Information Systems")
	4	Ambulatory Care Information Systems/	S4	(MH "Ambulatory Care Information Systems")
	5	Decision Support Systems, Clinical/	S5	(MH "Decision Support Systems, Clinical")
	6	CPOE.af.	S6	CPOE
	7	"information system*."af.	S7	"information system*"
	8	1 or 2 or 3 or 4 or 5 or 6 or 7	S8	S1 or S2 or S3 or S4 or S5 or S6 or S7
Functions of the intervention key words	9	order*.af.	S9	order*
	10	prescri*.af.	S10	prescri*
	11	view*.af.	S11	view*
	12	document*.af.	S12	document*
	13	9 or 10 or 11 or 12	S13	S9 or S10 or S11 or S12
Setting subject terms and key words	14	Emergency Service, Hospital/	S14	(MH "Emergency Service")
	15	Emergency Medical Services/	S15	(MH "Emergency Medical Services")
	16	"emergency department."af.	S16	"emergency department"
	17	emergency.af.	S17	Emergency
	18	14 or 15 or 16 or 17	S18	S14 or S15 or S16 or S17
Search limiters	19	8 and 13 and 18	S19	S8 and S13 and S18
	20	limit 19 to ("English language and yr='1990-Current")	S20	Limiters - Published Date from: 19900101–20110531; English Language

CPOE, Computerized provider order entry; *yr*, year.

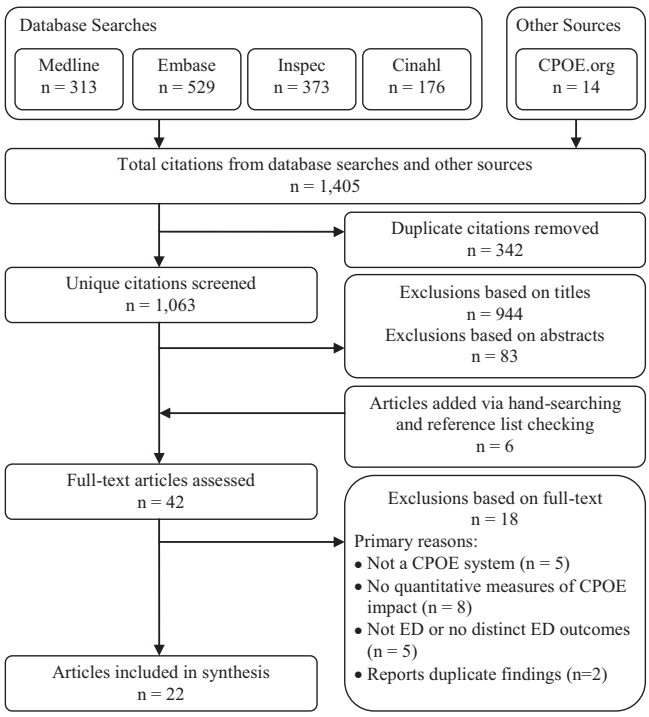

Figure 1. Citation search and article selection.

eligibility criteria were assessed by all 7 reviewers. Discrepancies arising between reviewers were resolved by discussion. Where study data were missing or unclear, we attempted to contact the study authors for clarification. One author confirmed that an abstract[19] and full-text article[20] reported results from the same study. As such, we included only the full-text article. Additionally, in cases in which the same study[21,22] or a component of a study[23,24] appeared in 2 separate articles, we ensured that studies and findings were not replicated.

To facilitate data collection, we developed 2 tables into which we documented data extracted from each study. The first (Appendix E2, available online at http://www.annemergmed.com) included the author, year of publication, country, study aim, design and sample, setting, key outcome measures, key findings, post hoc calculations, and the technical features of the computerized provider order entry system. For the second table (Table 2), we used the Handel et al[3] framework to characterize whether the key study outcome measure(s) related to the effect on patient flow/clinical work (eg, length of stay, turnaround times), effect of decision support systems (eg, guideline compliance), or effect on safety of care delivery (eg, errors, adverse events). We also categorized whether the outcome measure(s) assessed diagnostic orders (laboratory and medical imaging) or medication orders. Data were extracted by 2 reviewers (M.P. and A.H.) and verified for accuracy by 2 other reviewers (A.G. and N.C.).

Where possible, we undertook post hoc calculations to estimate measures of difference with confidence intervals (CIs). Where proportions of time were reported with CIs,[23,24] the individual CIs were used to back-calculate pre- and post-SEM. A pooled SEM was generated from these and used to calculate a CI around the difference between pre- and postproportions.

Table 2. Characteristics of the included studies.

Ref	Year	Country	Design	Year of CPOE Implementation	CPOE Type	Patient Flow/Clinical Work	DSS	Safety	Laboratory	Medical Imaging	Medications	Other
20	2011	USA	Pre/post	2006	Commercial	✓						
22	2006	USA	Time series	Unknown	Commercial		✓				✓	
23	2004	USA	Pre/post	Unknown	Unknown	✓						
24	2006	USA	Pre/post	2003	Commercial	✓			✓	✓	✓	
25	2010	USA	Pre/post	2003–2004	Commercial	✓			✓	✓		
26	2009	USA	Pre/post	2005	Commercial	✓						
27	2002	France	Time series	Unknown	Unknown		✓			✓		
28	2009	USA	RCT	Unknown	Unknown		✓				✓	
29	2010	USA	Prospective	2007	Commercial		✓				✓	
30	2010	USA	Pre/post	2008	Unknown			✓	✓			
31	2006	USA	Prospective	Unknown	Unknown		✓				✓	
32	2006	USA	Pre/post	Unknown	Unknown	✓			✓			
33	2005	USA	Pre/post	2004	Unknown	✓			✓	✓		
34	2007	USA	Pre/post	2004	Unknown			✓			✓	
35	2008	USA	Pre/post	2003	Commercial	✓						
36	2009	USA	Pre/post	Unknown	Unknown		✓	✓				✓
37	2007	Korea	Pre/post	Unknown	Unknown	✓		✓	✓	✓		
38	2008	USA	Pre/post	2004	Homegrown	✓			✓			
39	2008	USA	Pre/post	2005	Commercial		✓	✓			✓	
40	2009	USA	Pre/post	2005	Commercial	✓						
41	2010	USA	RCT	Unknown	Unknown			✓			✓	
42	2007	USA	Pre/post	Unknown	Commercial	✓			✓	✓		

DSS, Decision support systems; *RCT*, randomized controlled trial.

Where mean task times, sample sizes, and *P* values were reported,[25,26] it was possible to back-calculate the SEM, assuming *P* values came from a 2-sample *t* test based on nonequal sample sizes and nonequal variances. The derived SEM was then used to generate a CI around the difference between means. In studies reporting frequency and sample size,[22,27-32] the relative risk (RR) with 95% CI was used to assess the percentage of change between periods. Pre- and postresults reported as rates[33,34] were compared by univariate Poisson regression. Four studies reported changes but did not provide sufficient information to calculate CIs for estimates of change.[35-38] The results of the post hoc calculations are reported in the "Results" section and in Appendix E2 (available online at http://www.annemergmed.com).

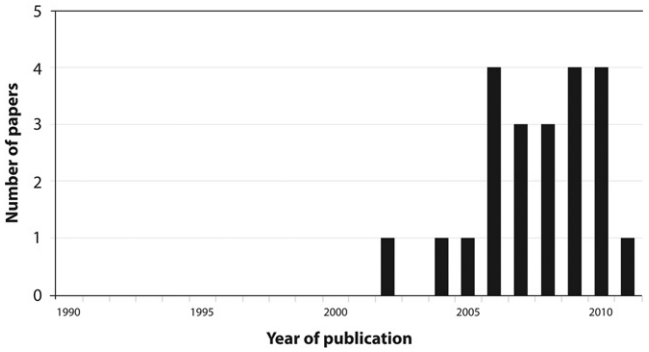

Figure 2. Distribution of included articles published per year.

RESULTS

Twenty-two studies, 16 full-text articles,[20,22,24-30,35-41] and 6 abstracts,[23,31-34,42] met our inclusion criteria. Table 2 outlines the characteristics of these studies. The majority were conducted in the United States (n=20), with the remaining studies conducted in France (n=1) and Korea (n=1). The study designs included pre/postintervention comparisons (n=16), prospective studies (n=2), randomized controlled trials (n=2), and time series studies (n=2). Study publication dates ranged from 2002 to 2011, with the majority of studies in print from 2006 onward (n=19). Figure 2 shows the distribution of published studies over time.

Studies were categorized by their key outcome measures (patient flow/clinical work, decision support systems, and safety) and subcategorized by the type of orders examined. Table 3 provides a summary of the key outcome measures used. The effect on patient flow/clinical work was examined in 12 of the 22 studies,[20,23-26,32,33,35,37,38,40,42] effect of decision support systems was examined in 7 studies,[22,27-29,31,36,39] and effect on safety was examined in 6 studies.[30,34,36,37,39,41] Two studies incorporated the effect on safety and decision support systems,[36,39] and 1 incorporated effect on patient flow/clinical work and safety.[37] Medication orders were examined in 8 studies,[22,24,28,29,31,34,39,41] laboratory orders in 8 studies,[24,25,30,32,33,37,38,42] and medical imaging orders in 6 studies.[24,25,27,33,37,42] Four studies examined both laboratory and medical imaging orders,[25,33,37,42] and 1 examined medication, laboratory, and medical imaging orders.[24] One article examined patient restraint orders.[36]

Table 3. Summary of key outcome measures within each category.

Category	Outcome Measures	Reference
Patient flow/ clinical work	Time spent on computers, using paper, or patient care	23,24,35,40
	TAT	25,33,38,42
	LOS	20,25,26
	Time between 2 points (eg, interval between a patient arriving in the ED and a test being ordered)	25,37
	Number of test orders	33,32
DSS	Use of DSS (eg, order sets)	22,39
	Compliance or noncompliance with recommendations/ guidelines (eg, on-screen alerts/prompts)	22,27
	Prescription rate (eg, of medication considered inappropriate)	28
	Time until order renewal	36
	Vaccination rates	29,31
Patient safety	Medication error rates (eg, overdose, underdose, excessive dosing, wrong route, wrong dose, wrong drug)	34,39,41
	Potential adverse events	34
	Specimen processing errors	30
	Case fatality rate	37
	Time in restraints	36

TAT, Turnaround times; *LOS*, length of stay; *DSS*, decision support system.

The outcome measures assessed by the 12 studies examining effect on patient flow/clinical work included time spent on computers, using paper, or patient care[23,24,35,40]; turnaround times[25,33,38,42]; length of stay[20,25,26]; time between 2 points (eg, time from placing a medication order to administration of medication)[25,37]; and number of orders.[32,33]

Three studies[23,24,35] examined physicians' or nurses' time within an ED where computerized provider order entry was implemented at the same time as full electronic nursing documentation. Asaro and Boxerman[35] examined both physicians' and nurses' time and found that the percentage of time spent on computers significantly increased for both physicians (15.7% to 27%; $P<.01$) and nurses (9.5% to 25.7%; $P<.01$). In the case of nurses, this was offset by a significant decrease in time spent using paper (16.5% to 1.8%; $P<.01$). Time spent in direct patient care did not change significantly for either physicians (30.5% to 24.2%; $P<.13$) or nurses (44.1% to 42.3%; $P<.65$). Asaro and Banet[23] reported that postimplementation the percentage of time physicians spent on computers increased by 10.6 percentage points (95% CI 5.1 to 16.1 percentage points), from 15.4% to 26.0%, whereas time using paper (17.9% to 17.9%) and time in direct patient care (28.8% to 26.9%) remained unchanged. Banet et al[24] found that the time nurses spent using computers significantly increased by 15.9 percentage points (95% CI 12.2 to 19.6 percentage points), from 10.1% to 26.0%, whereas time using paper significantly decreased by 15.4 percentage points (95% CI 12.5 to 18.3 percentage points), from 17.1% to 1.7%. The time nurses spent in direct patient care remained unchanged (41% to 39.2%). Conversely, Yen et al[40] examined physicians' and nurses' time after computerized provider order entry implementation and reported a significant increase in the percentage of time that attending physicians and residents spent using computers post–computerized provider order entry (2.9% to 6.4%, $P=.01$, increase of 4 minutes [95% CI 0.5 to 8.0 minutes]; and 4.2% to 9.7%, $P=.001$, increase of 9 minutes [95% CI 4.5 to 15.0 minutes], respectively). Nurses, on the other hand, experienced no significant change in time spent using computers (6.9% to 4.7%; $P=.15$; decrease of 2.5 minutes; 95% CI −0.5 to 6.0 minutes). Time spent on direct patient care did not significantly change for attending physicians (23.6% to 25.6%), residents (35.9% to 35.5%), or nurses (27.9% to 26.4%).

Baumlin et al[25] assessed turnaround times for laboratory and medical imaging orders and reported a significant decrease of 0.59 hours (95% CI 0.17 to 1.01 hours; from 2.03 to 1.44 hours; $P<.001$) in turnaround times for laboratory orders after the implementation of a fully integrated ED information system, which included computerized provider order entry. Turnaround times also decreased for medical imaging orders, significantly for computed tomography (CT) scans (1.56 hours [95% CI 0.67 to 2.45 hours] from 3.89 to 2.33 hours; $P<.001$) but nonsignificantly for radiographs (0.18 hours [95% CI −0.08 to 0.44 hours] from 0.92 to 0.74 hours; $P=.18$). Henstrom et al[42] examined laboratory and medical imaging orders and found a borderline significant decrease in turnaround times for radiograph orders (15% [adjusted RR 0.85; 95% CI 0.73% to 1.00%] from 63.1 to 55.4 minutes; $P=.047$). Turnaround times for laboratory orders (CBC count, chemistries, and troponin I level) was found to decrease by a similar proportion (RR 0.87; 95% CI 0.76 to 1.00; from 76.8 to 66.3 minutes), a decrease that was similarly of borderline significance ($P=.052$). Turnaround times also decreased in a study by Guss et al,[38] who assessed turnaround times at 3 stages: preintervention, after the introduction of pneumatic tubes for the transportation of specimens (phase 1), and after computerized provider order entry implementation (phase 2). Results showed a decrease in the median turnaround times for all 3 laboratory tests examined: from 55.9 minutes preintervention to 46.7 minutes (phase 1) and 37.2 minutes (phase 2) for serum sodium level, from 55.6 minutes to 42.2 minutes (phase 1) and 36.3 minutes (phase 2) for CBC count, and from 52.8 minutes to 41.8 minutes (phase 1) and 30.6 minutes (phase 2) for troponin I level. Adam et al[33] found no significant differences in turnaround times for CBC count (62 to 69 minutes; $P=.12$), basic metabolic panel (62 to 66 minutes; $P=.22$), cardiac enzyme levels (63 to 67 minutes; $P=.30$), ECG (37 to 38 minutes; $P=.41$), and chest radiograph

orders (80 to 80 minutes; $P=.49$) after computerized provider order entry implementation.

Baumlin et al[25] assessed length of stay (patient arrival to ED discharge) in an ED that underwent extensive process redesign followed by the implementation of a fully integrated ED information system, including computerized provider order entry. ED length of stay decreased significantly by 1.94 hours (95% CI 0.79 to 3.09 hours), from 6.69 to 4.75 hours postintervention ($P<.001$). Spalding et al[20] found that length of stay (triage to discharge) decreased by 30 minutes (95% CI 28 to 33 minutes), from 198 to 168 minutes for patients discharged from ED, whereas the length of stay for admitted patients increased by 36 minutes (95% CI 26 to 46 minutes), from 405 to 441 minutes. Vartak et al[26] found a significant increase in length of stay of 17.4 minutes (95% CI 8.7 to 26.2 minutes), from 116.8 to 134.2 minutes ($P<.001$), after the implementation of various clinical information systems, including computerized provider order entry.

Baumlin et al[25] examined patient flow through the ED after an extensive process redesign followed by the implementation of an ED information system and computerized provider order entry. The study examined means for door-to-physician time, physician to disposition decision (to admit or discharge patient) time, and disposition decision to discharge time. All 3 points decreased significantly: door-to-physician time decreased by 0.54 hours (95% CI 0.22 to 0.86 hours; from 1.22 to 0.68 hours; $P<.001$), physician to disposition decision by 1.90 hours (95% CI 0.77 to 3.03 hours; from 3.64 to 1.74 hours; $P<.001$), and disposition decision to discharge from 6.77 to 4.90 hours ($P<.001$). Nam et al[37] examined intervals after the implementation of a computerized provider order entry–based communication/notification/ordering system. Median intervals for door to CT, blood sample delivery, CBC count reports, and prothrombin time/partial thromboplastin time decreased significantly postintervention (respectively, 34 to 19 minutes, $P=.01$; 24 to 19 minutes, $P=.04$; 52 to 33 minutes, $P<.01$; and 67 to 55 minutes, $P=.02$). Additionally, there was a significant reduction in door to thrombolysis time from 79 to 56 minutes ($P<.01$).

Adam et al[33] assessed whether implementation of a computerized provider order entry system modified test ordering patterns for CBC count, basic metabolic panel, cardiac enzymes, ECG, and chest radiograph. The overall number of test orders per patient increased by 74% (RR 1.74; 95% CI 1.60 to 1.89; 9.2 to 16 orders; $P<.01$). There was a significant increase in the number of ECG orders (105 to 209 orders; $P<.01$) and chest radiograph orders (18 to 135 orders; $P<.01$). CBC count, basic metabolic panel, and cardiac enzyme order volumes remained unchanged (respectively, 112 to 116 orders, $P=.31$; 120 to 113 orders, $P=.19$; and 144 to 147 orders, $P=.42$). Satz et al[32] examined the effect of computerized provider order entry on prothrombin time orders after modifications to the computerized provider order entry order screen to make ordering of prothrombin time tests less convenient, thus leading to an expected decrease in the number of orders. Total prothrombin time tests decreased significantly by 44.6% (RR 0.55; 95% CI 0.51 to 0.60), from 1,627 to 891 orders ($P=.001$).

Seven studies examined decision support systems. Five of these examined the use of decision support systems for medication orders,[22,28,29,31,39] 1 examined medical imaging orders,[27] and 1 examined orders for the physical restraint of patients.[36]

Asaro et al[22] found increased use of order sets for acute coronary syndrome, with cases in which no order sets were used decreasing from 73% (33/45 orders) with the use of preprinted paper order forms (phase 1) to 16% (8/49 orders) (RR 0.22; 95% CI 0.12 to 0.43) 3 months after computerized provider order entry introduction with education of system use (phase 4). On the other hand, compliance with guideline recommendations for β-blockers (81% to 77%), heparin (84% to 63%), and aspirin/clopidogrel (93% to 92%) decreased across the same period (phase 1 to phase 4). Sard et al[39] examined the voluntary use of a decision support system that provided clinicians with a quick list of commonly prescribed medications and found that physicians elected to use the decision support system for 30% of orders (107 of 361 orders). Terrell et al[28] found increased compliance with the use of a decision support system intervention that advised physicians against the use of 9 potentially inappropriate medications and provided recommendations for safer substitutes. Potentially inappropriate prescriptions significantly decreased by a factor of 0.63 (95% CI 0.47 to 0.85), from 5.4% (n=103) to 3.4% (n=69) ($P=.006$), whereas the acceptance rate for the recommended alternatives in the decision support system was 43%. Reasons for rejecting recommendations included that the patient had not reported any previous problems with the medication and that the prescription was a refill. Venkat et al[29] examined whether a decision support system screening tool increased the rate of seasonal influenza vaccination. The tool was completed for 78.9% of eligible patients, whereas the vaccination rate significantly increased more than 8-fold (RR 8.59; 95% CI 6.92 to 10.67), from 2.3% to 19.8% of ED visits ($P<.001$). Dexheimer et al[31] examined the effect of a decision support system tool on pneumococcal vaccination rates, which increased by 10.6% (RR 1.11; 95% CI 0.99 to 0.124), from a baseline of 49.8% to 54.9% ($P<.01$). The authors indicated that a number of eligible patients refused vaccination because they perceived it was not necessary. Physicians who opted not to order a vaccination as per the decision support system prompt reported doing so because they were unable to verify patient eligibility or because they did not have enough time.

Carton et al[27] reported that on-screen computerized provider order entry guidelines, which recommended appropriate imaging orders for a specified clinical context, reduced medical imaging orders not conforming to guidelines within 2 EDs (33.2% to 26.9%; $P<.001$). The authors also observed a significant difference of 17.3 percentage points (95% CI 15.1 to 19.4 percentage points) in orders not conforming to guidelines

between the 2 EDs post–computerized provider order entry implementation (17.6% in site A versus 34.8% in site B; $P<.001$). The authors indicated that processes specific to ED site B, where chest radiographs were ordered for all hospitalized patients, accounted for a substantial part of this difference.

Griffey et al[36] examined whether a decision support system prompting physicians to renew or discontinue physical patient restraint orders before their expiration enhanced the timely renewal of such orders. In phase 1, a passive decision support system (no forcing function) was introduced, followed by phase 2, which denied access to the system until the reminder prompt was addressed. The authors reported that the median order renewal time significantly decreased, from 189 minutes (95% CI 182 to 196 minutes) preintervention to 125 minutes (95% CI 114 to 149 minutes) in phase 1 ($P<.001$) and 133 minutes (95% CI 120 to 148 minutes) in phase 2 ($P<.001$).

The effect of computerized provider order entry on the safety of care delivery was examined in 6 studies, 3 of which looked at safety of medication orders,[34,39,41] 1 at laboratory orders,[30] 1 at laboratory and medical imaging orders,[37] and 1 at the orders for the physical restraint of patients.[36]

Sard et al[39] assessed whether a medication quick list added to the computerized provider order entry system decreased prescribing errors. Significant decreases of 46% (from 24 to 13) (RR 0.54; 95% CI 0.39 to 0.76) and 55% (from 31 to 14) (RR 0.45; 95% CI 0.32 to 0.62) were found in the overall rate of errors per 100 visits and per 100 orders, respectively. Wrong frequency and wrong route errors also both decreased significantly, by 93% (RR 0.07; 95% CI 0.01 to 0.53; 3.7 to 0.3 errors per 100 orders; $P=.01$) and by 80% (RR 0.2; 95% CI 0.04 to 0.96; 2.4 to 0.5 errors per 100 orders; $P=.04$), respectively. Wrong dose and wrong drug errors decreased nonsignificantly, by 0.58% (RR 0.42; 95% CI 0.32 to 1.04; 8 to 5 per 100 orders; $P=.07$) and by 73% (RR 0.27; 95% CI 0.06 to 1.35; 2 to 0.5 per 100 orders; $P=.11$), respectively. Aronsky et al[34] found a 91% decrease (RR 0.09; 95% CI 0.09 to 0.10) in prescribing errors after computerized provider order entry implementation (222 to 21 errors per 100 orders) and a nonsignificant 23% decrease (RR 0.77; 95% CI 0.58 to 1.03) in potential adverse drug events (3.7 to 2.8 errors per 100 orders). Terrell et al[41] assessed whether dosing adjustment recommendations for 10 targeted medications had an effect on excessive dosing. The intervention enhanced the safety of patients with renal disease because intervention physicians prescribed excessive dosages for the targeted medications significantly less often (43%) than control physicians (74%) ($P=.001$).

After implementation of a computerized provider order entry system with bar-coding verification, Hill et al[30] assessed the effect on specimen processing errors (unlabeled requests, unlabeled specimens, mislabeled specimens, and wrong patient specimens). Preintervention, 3,007 (0.42%) total specimen errors were reported compared with 379 (0.11%) postintervention, representing a decrease of 73% (RR 0.27; 95% CI 0.25 to 0.30). Unlabeled request, unlabeled specimen, mislabeled specimen, and wrong patient specimen errors all decreased postintervention.

Nam et al[37] examined the timeliness of care for patients with warning signs of stroke and the effect of computerized provider order entry on patient outcomes. The authors reported a nonsignificant decrease in case fatality rates (29% to 8%; $P=.16$).

Griffey et al,[36] who assessed the timely renewal of restraint orders, also examined the length of time patients spent in restraints pre- and postintervention. Patient time in restraints did not significantly change (median time of 235 minutes per patient preintervention, 190 minutes in phase 1, and 130 minutes in phase 2).

There were wide variations in the descriptions of the technical features of the computerized provider order entry systems studied. Ten studies reported the use of commercially available computerized provider order entry systems,[20,22,24-26,29,35,39,40,42] 1 reported the use of a home-grown computerized provider order entry system,[38] and 11 did not specify the type of computerized provider order entry system that was assessed. Although the ability to place orders electronically implies that a computerized provider order entry system is linked to an ancillary system, its level and extent of interoperability with other hospital information technology systems was often not reported. Only 2 studies[25,30] explicitly outlined that the computerized provider order entry system was interoperable with hospital systems outside the ED (eg, a laboratory information system), whereas 1 study[27] highlighted that the computerized provider order entry system was not interoperable, with electronically entered orders printed and then sent to the relevant ancillary department.

LIMITATIONS

The heterogeneous nature of the studies and the metrics used to measure performance precluded formal meta-analyses. As such, we conducted a review in which we identified and synthesized characteristics of the studies. We also undertook post hoc calculations to provide estimates of change with 95% CIs. Variables involving intervals, however, are often skewed and hence not well represented by parametric methods that assume normality.[43] Of the 4 studies presenting interval data,[23-26] none provided sufficient information to allow nonparametric comparison.

There is the potential for publication bias that occurs when studies with positive outcomes are more likely to be published than negative outcomes.[44] This may arise because researchers are less likely to submit studies with negative or neutral findings because the incentive to demonstrate that systems are a success, given the substantial investments made, is high. Further, journals may be more likely to publish studies with positive findings.[45] Another source of possible publication bias relates to the systematic review's exclusion of gray literature and the potential for results from journal articles to systematically differ from those presented in reports, working articles, dissertations, and other sources. We found no formalized measures of

unintended consequences, workarounds, or other aspects of usability associated with computerized provider order entry that matched our inclusion criteria. This finding possibly reflects the qualitative and descriptive nature of research of these factors.

DISCUSSION

This systematic review drew on the research agenda suggested by Handel et al[3] to provide a clinically focused framework to assess the scope and nature of existing evidence about the effect of computerized provider order entry within a wider ED context[46] and to identify relevant, robust, and validated performance metrics that can be used to assess the quality and safety benefits of computerized provider order entry.[47] By doing so, it was able to make 3 important contributions to the ED evidence base.

First, it identified areas in which computerized provider order entry and decision support systems have contributed to changes in clinical care and work processes related to either patient safety (eg, reduction of medication errors, adverse drug events, excessive dosing) or improved service (eg, efficiency gains involving laboratory and imaging examination turnaround times).

Second, it provided a comparative assessment of the effect of computerized provider order entry on different aspects of ED ordering, including medications, laboratory, medical imaging, and other related areas, including those in which attention may be required to guard against unintended consequences (eg, an increase in the number of orders).

Third, the review investigated the extent and type of decision support systems features being used, together with the context and consequences of their use.

The review found that the majority of studies (n=19) appeared in or after 2006, indicating that research attention specific to the ED has lagged behind computerized provider order entry research more generally.[9] Most of the studies in the review (n=20) investigated US settings, 25% of which were conducted at the Barnes-Jewish Hospital in St Louis, MO. This prompts concerns about the generalizability of the evidence base and its applicability across US and international settings. Issues related to the external validity of existing health information technology research evidence have been flagged previously and continue to be a concern within the health informatics field.[48]

The systematic review revealed a diverse and heterogeneous array of metrics representing different parts of the clinical care process (eg, timeliness, ordering behavior, safety) and incorporating different health information technology components (eg, decision support systems, the accessibility and availability of information). The incorporation of decision support systems with computerized provider order entry was associated with improved guideline compliance,[27,36] enhanced appropriateness of medication orders,[28] and increased vaccination rates.[29,31] Although many of these findings, such as reductions in prescribing errors,[39] could reasonably be expected to contribute to improvements in the quality of patient care, the evidence from this systematic review nevertheless shows that the dominant focus of research remains geared toward measures of process rather than clinical outcome. This is a recurrent theme across many evidence-based reviews of health information technology.[9,49-51] It is also a finding that is likely to be associated with the predominant use of uncontrolled pre/post study designs, which invites some apprehension about the strength of the inferences made about the effect of computerized provider order entry systems in the ED.[52]

Although the findings point to the existence of tangible benefits associated with computerized provider order entry and decision support systems, it is difficult to speak confidently about the consistency and applicability of these findings across different ED settings.[3] These systems are complex interventions that are often shaped by issues related to the stated goals, their usability, and acceptance.[53] Information systems have the potential to disrupt work flows and practices across the hospital and existing departmental boundaries. None of the studies that involved a decision support system component considered the effect on clinical work processes (including aspects of usability, workarounds, or the existence of unintended consequences). In addition, the cost-effectiveness of either computerized provider order entry or decision support systems remains largely unaddressed.[1] The importance of such factors is highlighted by computerized provider order entry/decision support systems studies that have documented major shifts in tasks and responsibilities,[5] along with problems related to system usability,[54] increased data entry requirements, and clinicians' computing skills.[55] A retrospective study undertaken in a community hospital ED by Drescher et al[56] (that appeared after the inclusion dates for this systematic review) found that the use of decision support systems for evaluation of suspected pulmonary embolism was associated with a 4.4% higher yield of CT angiography. The authors, however, also reported that the decision support system was poorly accepted by physicians, partly because of the increased computer time, which led to the removal of the decision support system from the computerized provider order entry.

Most studies dealt separately with medication, laboratory, or medical imaging orders, often without any mention of the level of interoperability within the hospital and its ancillary departments, or regionally across hospitals. There were only 5 studies that involved a combination of medical imaging and laboratory orders and 1 study that incorporated medical imaging, laboratory, and medication orders. This finding suggests that there is still some way to go to overcome the problem highlighted by Barthell et al[57] as the ED challenge of dealing with "disparate data. . .arrayed in disparate systems," resulting in barriers to the optimal use of information.

The findings from this systematic review of quantitative ED studies are presented in relation to the technical (information technology interoperability), clinical (workflow, safety and quality of care, and patient outcomes), and organizational (integration and management) dimensions of the ED. Overall, the published literature suggests that implementation of computerized provider order entry systems does not decrease direct patient care time for physicians or nurses, does decrease

medication errors, substantially improves laboratory turnaround time, and can influence numbers of laboratory orders (positively or negatively, depending on design) but has inconsistent effects on total ED length of stay. The inclusion of decision support systems was also shown to consistently improve guideline compliance. The findings draw attention to important gaps in the quantitative evidence base. In some areas, particularly those related to the effects and interactions between the health information technology system and the environment in which it is implemented, the existing evidence base needs to be supplemented by qualitative studies.[58] Such studies are better suited to uncovering the technical, clinical, and organizational dimensions of the ED as interconnected and essential components of a highly integrated system of care.[17]

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Author affiliations: From the Centre for Health Systems and Safety Research, Australian Institute of Health Innovation, University of New South Wales, Sydney, Australia (Georgiou, Prgomet, Creswick, Hordern, Walter, Westbrook); the Emergency Department, Concord Hospital, and the Sydney Medical School, University of Sydney, Sydney, Australia (Paoloni); and the Clinical Redesign and Decision Support Unit, St Vincent's Hospital, Sydney, Australia (Creswick).

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Address for correspondence: Andrew Georgiou, PhD, E-mail a.georgiou@unsw.edu.au.

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Appendix E1. Examples of exclusions based on titles.

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Appendix E2. Quantitative studies reporting on the effect of computerized provider order entry on clinical care and work processes in emergency departments.

Author Year Country	Aim	Study Design Sample Setting	Key Outcome Measures	Key Findings	Post Hoc Calculations	Technical Features
Spalding et al,[20] 2011 USA	To measure the effect of CPOE implementation on the LOS of patients discharged from an ED	Pre/post comparison Pre: 17 mo (Feb 2005–June 2006) Post: 12 mo (July 2006–June 2007) Patients who were discharged from the ED Pre: 28,687 patients Post: 20,488 patients Level II trauma ED	Daily number of patients in the ED LOS for discharged patients (time from triage to discharge from ED) LOS for admitted patients	ED daily census: Pre: 83 patients Post: 78 patients Difference 5.2 (95% CI 5.0–5.3) Discharged LOS: Pre: 198 min Post: 168 min Difference 30 (95% CI 28–33) Admitted LOS: Pre: 405 min Post: 441 min Difference 36 (95% CI 26–46)	N/A (Calculations provided by Spalding et al)	CPOE implemented in July 2006 System changes: Pre → Paper-based and verbal orders Post → Computerized orders and real-time results reporting
Asaro et al,[22] 2006 USA	To compare ACS guideline compliance first on paper and then CPOE	Time series Four 1-mo periods: Phase 1: simple preprinted order forms; n=45 Phase 2: paper ACS order sets; n=66 Phase 3: Several weeks after CPOE ACS order sets; n=48 Phase 4: 3 mo after CPOE ACS order sets (plus education); n=49 Retrospective chart review of patients with an ED diagnosis of acute myocardial infarction, ACS, or unstable angina Barnes-Jewish Hospital; Level I trauma ED	Percentage of cases with ACS order set use Compliance with guideline recommendations for β-blocker, heparin or aspirin/clopidogrel	Cases without order set use: Phase 1: 73% (n=33) Phase 2: 55% (n=36) Phase 3: 25% (n=25) Phase 4: 16% (n=8) Compliance: β-Blocker: Phase 1: 81% of 21 Phase 2: 68% of 37 Phase 3: 69% of 26 Phase 4: 77% of 26 Heparin: Phase 1: 84% of 44 Phase 2: 78% of 55 Phase 3: 75% of 40 Phase 4: 63% of 40 Aspirin/clopidogrel: Phase 1: 93% of 45 Phase 2: 91% of 66 Phase 3: 83% of 48 Phase 4: 92% of 49	Cases without order set use: 78% lower in phase 4 compared with phase 1 (RR 0.22; 95% CI 0.12–0.43)	DSS: Embedded guidelines/order sets for chest pain/ACS (without patient-specific information) System changes: Pre → Paper guidelines/order sets. Existing EDIS with electronic tracking board, triage nurse documentation, and physician-generated discharge instructions Post → CPOE and full nursing documentation were added to the existing EDIS. Guidelines/order sets through CPOE.

Appendix E2. Continued.

Author Year Country	Aim	Study Design Sample Setting	Key Outcome Measures	Key Findings	Post Hoc Calculations	Technical Features
Asaro and Banet,[23] 2004 USA	To measure the change in time spent on various tasks by providers before and after changes in the EDIS	Pre/post comparison Physicians observed during 4-h observation sessions Pre: 35 observation sessions Post: 34 observation sessions Barnes-Jewish Hospital; Level I trauma ED	Physician time spent on computers, using paper, and direct patient care (means as percentage [95% CI] of the aggregate times)	Physicians time: On computers: Pre: 15.4% (11.8, 19.0) Post: 26.0% (21.8, 30.1) Using paper: Pre: 17.9% (13.7, 22.1) Post: 17.9% (14.3, 21.5) Direct patient care: Pre: 28.8% (22.7, 34.9) Post: 26.9% (23.6, 30.3)	Physicians time: On computers: Increased by 10.6 percentage points (95% CI 5.1–16.1)	System changes: Pre → Existing EDIS was used primarily as an electronic tracking board. Laboratory and radiology orders were entered by nurses in a separate computerized ordering system and results were retrieved by querying this system or a third enterprise-wide data repository. Post → Physicians enter all orders directly into the EDIS by desktop computers
Banet et al,[24] 2006 USA	To examine the effects of implementing CPOE and nursing documentation in an ED	Pre/post comparison Pre: 17 observation sessions (1 mo before CPOE implementation) Post: 17 observation sessions (6 mo after CPOE implementation) Nurses observed during 4-h observation sessions Barnes-Jewish Hospital; Level I trauma ED	Nurse time spent on computers, using paper documentation, and direct patient care (mean percentage [95% CI] of the total times)	Nurses time: On computers: Pre: 10.1% (7.8, 12.5) Post: 26.0% (23.2, 28.9) Using paper: Pre: 17.1% (14.4, 19.9) Post: 1.7% (0.8, 2.6) Direct patient care: Pre: 41.0% (34.9, 46.7) Post: 39.2% (33.9, 44.5)	Nurses time: On computers: Increased by 15.9 percentage points (95% CI 12.2–19.6) Using paper: Decreased by 15.4 percentage points (95% CI 12.5–18.3)	CPOE implemented in May 2003 System changes: Pre → Existing EDIS and triage nursing documentation. Nurses processed handwritten and verbal physician orders into a separate legacy computerized ordering system. Post → CPOE and full nursing documentation implemented. There is a provision for verbal orders entered by nurses but the majority of orders are entered directly by physicians. Results flow directly into the patient record in the EDIS.

Appendix E2. Continued.

Author Year Country	Aim	Study Design Sample Setting	Key Outcome Measures	Key Findings	Post Hoc Calculations	Technical Features
Baumlin et al,[25] 2010 USA	To describe efforts to improve ED patient throughput, using process redesign followed by EDIS implementation and the effect of these changes in ED efficiency	Pre/post comparison Pre: Feb/Mar 2001 (direct observations of patient's ED journey and recording of time points) Post: Feb/Mar 2005 (data extracted from EDIS and other electronic sources) Laboratory orders Pre: 121 orders Post: 271 orders CT scan orders Pre: 40 orders Post: 28 orders Mount Sinai Hospital ED	Overall LOS (time of patient arrival to time patient left ED) Door-to-physician time (mean time from triage to time physician signed up for patient) Physician to disposition time (mean time from first physician-patient contact to time of disposition [admit/discharge] decision) Disposition to discharge time (mean time from disposition decision to time patient left ED) Laboratory, radiograph, and CT scan TAT (time from order entry to time the result of test available to ED)	LOS: Pre: 6.69 h Post: 4.75 h Sig ($P<.001$) Door to physician: Pre: 1.22 h Post: 0.68 h Sig ($P<.001$) Physician to disposition: Pre: 3.64 h Post: 1.74 h Sig ($P<.001$) Disposition to discharge: Pre: 6.77 h Post: 4.90 h Sig ($P<.001$) TAT: Laboratory: Pre: 2.03 h Post: 1.44 h Sig ($P<.001$) Radiograph: Pre: 0.92 h Post: 0.74 h Sig ($P<.179$) CT scan: Pre: 3.89 h Post: 2.33 h Sig ($P<.001$)	LOS: Time decreased by 1.94 h (0.79, 3.09) Door to physician: Time decreased by 0.54 h (0.22, 0.86) Physician to disposition: Time decreased by 1.90 h (0.77, 3.03) TAT: Laboratory: Time decreased by 0.59 h (0.17, 1.01) Radiograph: Time decreased by 0.18 h (−0.08, 0.44) CT scan: Time decreased by 1.56 h (0.67, 2.45)	CPOE implemented between November 2003 and March 2004 System changes: Pre → ED processes supported by separate, disparate computer systems. Electronic admission/discharge/transfer system. Laboratory order forms handwritten and sent by a pneumatic tube. Radiology order forms handwritten and faxed. Post → Interventions made during the project include a process redesign in 2003 (changes in patient registration, order entry, and results retrieval processes), followed by the implementation of a fully integrated EDIS (documentation, CPOE, results retrieval, prescribing, DSS, and hospital data repository access).

Appendix E2. Continued.

Author Year Country	Aim	Study Design Sample Setting	Key Outcome Measures	Key Findings	Post Hoc Calculations	Technical Features
Vartak et al,[26] 2009 USA	To assess the effect of implementing clinical information systems on processes of care and outcomes in the ED	Pre/post comparison Six 1-wk periods: Pre: Three 1-wk periods (Oct 2004, Jan 2005, Apr 2005) Post: Three 1-wek periods (Jul 2005, Oct 2005, Jan 2006) Pre: 1,643 visits Post: 1,683 visits Mercy Medical Center ED	LOS (mean in minutes) CPOE adoption rates	LOS: Pre: 116.8 min Post: 134.2 min Sig ($P<.001$) CPOE adoption: Post (1 mo): 76% Post (11 mo): 87%	LOS: Increase of 17.4 min (8.7, 26.2)	CPOE implemented in July 2005 DSS: Clinical decision support rules System changes: Pre → Patient seen by a triage nurse; then waits to be registered. Post → Documentation, CPOE, tracking, and medical records system implemented at same time. Quick registration completed during triage. Full registration completed at bedside.
Carton et al,[27] 2002 France	To assess the proportion of radiologic requests that did not conform to recommendations and to assess whether a computer-based reminder system could reduce the proportion of inappropriate radiologic requests	Time series 6-mo period alternating monthly between 3 control periods and 3 intervention periods (June–Nov 1998) All fulfilled radiology requests (5,680 requests representing 6,869 examinations) Hospital Ambroise Paré ED Hospital de Pontchaillou ED	Percentage of requests that did not conform to guidelines Variation of nonconforming requests between the study sites	Non conforming requests: Overall (n=6,869): Control: 33.2% (29.8%, 37.8%, 26.9%) Intervention: 26.9% (27.5%, 27.0%, 26.0%) Sig ($P<.001$) Variation of nonconforming requests: Site A: (n=353/2,010) 17.6% Site B: (n=1,693/4,859) 34.8% Sig ($P<.001$)	Variation of nonconforming requests: Difference of 17.3 percentage points (95% CI 15.1–19.4)	DSS: On-screen reminders about appropriate radiologic examinations System changes: Pre → A computer-based system in which all radiologic requests were entered onto the computer, printed, and sent to radiology Post → Guidelines implemented. A list of clinical contexts is provided according to their relation to the examination. Guidelines not displayed if free text used. Clinicians alerted if requests did not conform. Examples of guideline recommendation included "recommended in emergency," "to delay," "not routinely," "specialist opinion needed," "not recommended"

Appendix E2. Continued.

Author Year Country	Aim	Study Design Sample Setting	Key Outcome Measures	Key Findings	Post Hoc Calculations	Technical Features
Terrell et al,[28] 2009 USA	To evaluate the effectiveness of computer-assisted decision support in reducing potentially inappropriate prescribing to older adults	RCT Emergency physicians Control: 31 physicians Intervention: 32 physicians Patients aged 65 y and older being discharged from ED Control: 2,515 visits Intervention: 2,647 visits Wishard Memorial Hospital; Level I trauma ED	Proportion of visits that resulted in prescriptions for inappropriate medications (OR [95% CI]) Proportion of all medications prescribed that were inappropriate (as a percentage of all medications prescribed by study physicians) Proportion of times that intervention physicians chose an offered alternative therapy	Visits with inappropriate prescriptions: Control: 3.9% (n=99) Intervention: 2.6% (n=69) Sig (P=.02) OR 0.55 (0.34–0.89) Inappropriate prescriptions: Control: 5.4% (n=103) Intervention: 3.4% (n=69) Sig (P=.006) OR 0.59 (0.41, 0.85) Intervention alternative acceptance rate: 43% (n=49/114 DSS recommendations)	Inappropriate prescriptions: Decreased by 37% (RR 0.63; 95% CI 0.47–0.85)	DSS: Advised against use of 9 potentially inappropriate medications and recommend safer substitute therapies System changes: Pre → CPOE was used to write all medication prescriptions. Post → The DSS intervention was implemented Jan 2005–July 2007. Decision support was provided when an intervention physician attempted to prescribe a targeted inappropriate medication. The prescriber had the option to order a recommended alternative or to reject the recommendation.
Venkat et al,[29] 2010 USA	To determine whether integration of clinical decision support into an existing ED CPOE system would allow large-scale patient screening and provision of seasonal influenza vaccination without added staffing resources	Prospective study Oct 1–Oct 25, 2009 (compared with rates from Oct 2008) All patients aged 6 mo and older presenting to an ED who had no record of influenza vaccination at the study site (n=2,884) Allegheny General Hospital; Level I trauma ED	Vaccination rate (95% CI)	Vaccination rate: Pre: 2.3% (n=90/3,900) Post: 19.8% (n=613/3,091) Sig (P<.001) Absolute difference=17.5% (16%, 19%)	Vaccination rate: Increased more than 8-fold (RR 8.59; 95% CI 6.92, 10.67)	CPOE implemented in June 2007 System changes: Post → The triage nurse had to complete the clinical decision support tool, which required asking the patient additional questions and entering this on the system. In this CPOE system, protocol orders appear for signature by the assigned physician when that person logs on to the system, and the physician cannot proceed to place new orders for any patient until these orders are signed.

Appendix E2. Continued.

Author Year Country	Aim	Study Design Sample Setting	Key Outcome Measures	Key Findings	Post Hoc Calculations	Technical Features
Hill et al,[30] 2010 USA	To determine the effect of CPOE combined with a bar-code system on the specimen labeling process	Pre/post comparison All laboratory specimens collected in the ED Pre: 724,465 specimens; Sept 2004–April 2008 (44 mo) Post: 334,039 specimens; May 2008–Sept 2009 (17 mo) Johns Hopkins Hospital ED	Processing error rate (errors included unlabeled/mislabeled/ wrong patient specimen or requisition) (95% CI)	Errors: Total errors: Pre: 3,007 (0.42%) Post: 379 (0.11%) Difference=0.31 (0.28, 0.32) Unlabeled requests: Pre: 303 (10.1%) Post: 23 (6.1%) Risk difference=4.0 (1.4, 6.6) Unlabeled specimen: Pre: 1,011 (33.6%) Post: 159 (42.0%) Risk difference=8.3 (13.6, 3.1) Mislabeled specimen: Pre: 1,455 (48.4%) Post: 135 (35.6%) Risk difference=12.8 (7.6, 17.9) Wrong patient specimen: Pre: 238 (7.9%) Post: 62 (16.4%) Risk difference=8.4 (−2.3, 4.6)	Errors: Total errors: Decrease of 73% (RR 0.27; 95% CI 0.25–0.30)	System changes: Pre → Manual ordering and labeling. Providers indicate test request on paper and nurse transcribes the order. Specimen collected, labeled, placed in bag, and sent to laboratory. Post → CPOE integrated with laboratory information system. Icon in system alerts nurse to collect specimen. Nurse scans own badge, printed labels, and patient wristband. System verifies person and tests. Specimen then collected, labeled, and sent to laboratory.
Dexheimer et al,[31] 2006 USA	To evaluate a "closed-loop" informatics-based reminder system on pneumococcal vaccination rates	Prospective study 6 wks (30 Jan–8 Mar 2006) Patients aged 65 y and older presenting to ED (n=572)	Vaccination rate	Vaccination rate: Pre: 49.8% Post: 54.9% Sig ($P<.01$)	Vaccination rate: Increased by 10.6% (RR 1.11; 95% CI 0.99–0.124)	System changes: Post → For eligible patients, the CPOE system prompted physicians for a vaccine order.
Satz et al,[32] 2006 USA	To test whether removing an option from the laboratory order screen would decrease the number of PT test orders	Pre/post comparison Pre: 2 mo; 8,645 ED test orders Post: 2 mo; 8,579 ED test orders 550-bed adult ED	Total number of PT test orders	Total PT test orders: Pre: 1,627 (18.8% order rate) Post: 891 (10.4% order rate) Increased by 74% (RR 1.74; 95% CI 1.60–1.89)Increased by 74% (RR 1.74; 95% CI 1.60–1.89) Sig ($P=.001$)	Total PT test orders: Decreased by 44.6% (RR 0.55; 95% CI 0.51–0.60)	System changes: Post → The PT test selection option was removed from the ED laboratory order screen. The test could be ordered by using the Master Laboratory order screen.

Appendix E2. Continued.

Author Year Country	Aim	Study Design Sample Setting	Key Outcome Measures	Key Findings	Post Hoc Calculations	Technical Features
Adam et al,[33] 2005 USA	To determine whether CPOE implementation changes clinicians' ordering patterns	Pre/post comparison of patients with *ICD-9* coded chief complaint of chest pain. Random selection of cases. Pre: 150 patients' charts and paper-based orders reviewed; 3 mo (Sept–Dec 2003) Post: 150 patients' charts and computerized orders reviewed; 3 mo (Sept–Dec 2004) Vanderbilt University Hospital; Level I trauma ED	Number of test orders (per patient) Order completion times (TAT) (order writing to results availability)	Test orders: Overall: Pre: 9.2 orders Post: 16 orders Sig ($P<.01$) ECGs: Pre: 105 orders Post: 209 orders; Sig ($P<.01$) CXR: Pre: 18 orders Post: 135 orders; Sig ($P<.01$) CBC counts: Pre: 112 orders Post: 116 orders; Sig ($P=.31$) BMP: Pre: 120 orders Post: 113 orders; Sig ($P=.19$) Cardiac enzymes: Pre: 144 orders Post: 147 orders; Sig ($P=.42$) TAT: ECG: Pre: 37 min Post: 38 min; Sig ($P=.41$) CXR: Pre: 80 min Post: 80 min; Sig ($P=.49$) CBC: Pre: 62 min Post: 69 min; Sig ($P=.12$) BMP: Pre: 62 min Pos t: 66 min; Sig ($P=.22$) Cardiac enzymes: Pre: 63 min Post: 67 min; Sig ($P=.30$)	Test orders: Overall: Increased by 74% (RR 1.74; 95% CI 1.60–1.89)	CPOE implemented in March 2004

Appendix E2. Continued.

Author Year Country	Aim	Study Design Sample Setting	Key Outcome Measures	Key Findings	Post Hoc Calculations	Technical Features
Aronsky et al,[34] 2007 USA	To examine medication prescribing errors before and after implementation of a CPOE in an adult ED	Pre/post comparison Medication orders from consecutive adult ED patients Pre: Two 10-day periods (Jun 2003; Jan/Feb 2004); 3,383 paper orders reviewed Post: 9 days; 2,567 CPOE orders reviewed	Number of pADE (total number of orders [number per 100 orders]) Number of medication prescribing errors	pADE: Pre: 125 (3.7) Post: 73 (2.8) Allergy to medication: Pre: 102 (3.0) Post: 64 (2.5) Prescribing errors: Pre: 7,534 (222.0) Post: 539 (21.0) Missing information: Pre: 6,592 (194.3) Post: 131 (5.1)	pADE: 23% decrease (RR 0.77; 95% CI 0.58–1.03) Prescribing errors: 91% decrease (RR 0.09; 95% CI 0.09–0.10)	CPOE implemented in March 2004
Asaro and Boxerman,[35] 2008 USA	To measure the effects of the implementation of CPOE and electronic nursing documentation on provider work flow	Pre/post comparison Pre: 11 physicians; 13 nurses observed (3–6 wks before implementation) Post: 10 physicians; 13 nurses observed (5.5–6.5 mo after implementation) Nurses and physicians observed during 4-h observation sessions Barnes-Jewish Hospital; Level I trauma ED	Physician time spent on computers, using paper, and direct patient care (mean % of time) Nurse time spent on computers, using paper, and direct patient care (mean % of time)	Physicians time: On computers: Pre: 15.7% Post: 27.0%; Sig ($P<.01$) Using paper: Pre: 15.9% Post: 16.2%; Sig ($P<.87$) Direct patient care: Pre: 30.5% Post 24.2%; Sig ($P=.13$) Nurses time: On computers: Pre: 9.5% Post: 25.7%; Sig ($P<.01$) Using paper: Pre: 16.5% Post: 1.8%; Sig ($P<.01$) Direct patient care: Pre: 44.1% Post: 42.3%; Sig ($P=.65$)	N/A (insufficient information to perform post hoc calculations)	CPOE implemented in May 2003 System changes: Pre → Existing EDIS with functionalities including electronic tracking board, triage nurse documentation, and physician discharge processing. Laboratory results were obtained by physicians from a separate legacy computer system. Post → Nursing documentation and CPOE added to the existing EDIS. There is a provision for verbal orders entered by nurses, but the majority of orders are entered directly by physicians. Results flow directly into the patient record in the EDIS.

Appendix E2. Continued.

Author Year Country	Aim	Study Design Sample Setting	Key Outcome Measures	Key Findings	Post Hoc Calculations	Technical Features
Griffey et al,[36] 2009 USA	To evaluate the effect of a CPOE system forcing function on improving timely renewal of restraint orders	Pre/post comparison Three 6-mo periods (July 2003–Dec 2004): Patient visits with orders for restraint (physical restraint/seclusion/ sitters or observers) (n=302) Pre: 120 visits Phase 1: 89 visits Phase 2: 93 visits Patient visits with renewal orders for restraint (n=139) Pre: 38 visits Phase 1: 41 visits Phase 2: 60 visits Patients physically restrained (n=170) Pre: 68 patients Phase 1: 49 patients Phase 2: 53 patients Barnes-Jewish Hospital; Level I trauma ED	Number of restraint orders per patient (mean number [95% CI]) (n=302) Time to restraint order renewal (median time in minutes [95% CI]) (n=139) Number of renewal orders per hour a patient was restrained (mean number per hour [95% CI]) (n=170) Time patient spent in restraints (median time in minutes [95% CI]) (n=170)	Restraint orders: Pre: 1.46 (1.32, 1.60) Phase 1: 1.89 (1.61, 2.16) Phase 2: 2.34 (2.03, 2.66) Sig (P=.02) [Pre v P1]; Sig (P<.001) [Pre v P2]; Sig (P=.09) [P1 v P2] Time to renewal: Pre: 189 (182, 196) Phase 1: 125 (119, 131) Phase 2: 133 (128, 138) Sig (P<.001) [Pre v P1]; Sig (P<.001) [Pre v P2]; Sig (P=.30) [P1 v P2] Renewal orders: Pre: 0.08 (0.05, 0.11) Phase 1: 0.23 (0.11, 0.35) Phase 2: 0.89 (0.44, 1.34) Sig (P=.06) [Pre v P1]; Sig (P=.003) [Pre v P2]; Sig (P=.03) [P1 v P2] Time in restraints: Pre: 235 (176, 304) Phase 1: 190 (113, 267) Phase 2: 130 (56, 204) Sig (P=.96) [Pre v P1]; Sig (P=.06) [Pre v P2]; Sig (P=.33) [P1 v P2]	N/A (insufficient information to perform post hoc calculations)	DSS: Forcing function within the CPOE to prompt physicians to renew physical restraint orders System changes: Post → Physicians received computerized reminders to renew or discontinue restraint orders before their expiration (active for 2 h). Phase 1—Initial intervention allowed acknowledgement of the reminder without further consequence (passive prompt). Phase 2—Second intervention denied access to the ED information system until the reminder was addressed.

Appendix E2. Continued.

Author Year Country	Aim	Study Design Sample Setting	Key Outcome Measures	Key Findings	Post Hoc Calculations	Technical Features
Nam et al,[37] 2007 Korea	To investigate the efficacy of the BEST program, a CPOE-based program	Pre/post comparison Patients who had intravenous tPA treatment Pre: 14 patients (June 2003–May 2004) Post: 25 patients (June 2004–May 2005)	Onset to door (symptom onset to arrival at ED) (median time in minutes [range]) Door to CT (initiation of CT scan) Blood sample delivery (technician scans bar code of blood samples) Test report for CBC and PT/PTT (results entered into CPOE) Door to thrombolysis Case fatality rates	Onset to door: Pre: 41 min (10, 135) Post: 60 min (15, 150) Sig (P=.14) Door to CT: Pre: 34 min (16, 75) Post: 19 min (9, 58) Sig (P=.01) Blood sample delivery: Pre: 24 min (9, 50) Post: 19 min (9, 42) Sig (P=.04) CBC report: Pre: 52 min (34, 65) Post: 33 min (16, 67) Sig (P<.01) PT/PTT report: Pre: 67 min (48, 90) Post: 55 min (35, 90) Sig (P=.02) Door to thrombolysis: Pre: 79 min (35, 129) Post: 56 min (23, 109) Sig (P<.01) Case fatality rates: Pre: 29% Post: 8% Sig (P=.16)	N/A (insufficient information to perform post hoc calculations)	DSS: Standard order sets and active notification of BEST team members. Rapid candidate identification and program activation in the triage area was accomplished by using simplified American Heart Association guidelines. System changes: Post → CPOE-based communication/ notification/ ordering system. BEST program activated in triage area for patients with at least 1 stroke warning sign, arriving within 12 h of symptom onset. Activation resulted in the patient's name being highlighted in orange in every team member's patient list for easy and immediate recognition of BEST patients. Preset standing order sets entered in BEST orders icon. Orders activated an alarm (beeping and pop-up window) on CT and blood technician monitors. BEST program deactivated after tPA administered or marked as not indicated.

Appendix E2. Continued.

Author Year Country	Aim	Study Design Sample Setting	Key Outcome Measures	Key Findings	Post Hoc Calculations	Technical Features
Guss et al,[38] 2008 USA	To assess the effect of sequential modifications in laboratory specimen handling and test ordering on laboratory TAT	Pre/post comparison Three 1-mo periods: Pre (pre–pneumatic tube): 1,795 tests Phase 1 (pneumatic tube): 2,137 tests Phase 2 (CPOE): 2,219 tests (Sept 2003–Feb 2004) University of California San Diego Medical Center	Laboratory TAT (time from test order to the download of results into the EMR) (median time in minutes [IQR])	TAT: Sodium: Pre: 55.9 (37.5, 80.7) Phase 1: 46.7 (31.5, 74.4) Phase 2: 37.2 (24.1, 56.6) CBC: Pre: 55.6 (38.7, 80.4) Pha se 1: 42.2 (28.5, 63.8) Phas e 2: 36.3 (23.4, 54.9) Troponin I: Pre: 52.8 (35.2, 76.8) Phase 1: 41.8 (27.7, 72.2) Phase 2: 30.6 (19.2, 50.1)	N/A (insufficient information to perform post hoc calculations)	CPOE implemented in January 2004 System changes: Pre → ED had a comprehensive EMR. Tests ordered in EMR but transferred to a printed request slip. Post → Phase 1: Specimen transport modified to use a pneumatic tube (ordering/request unchanged). Phase 2: Full computerized order management; ordering electronically transmitted directly to the laboratory.

Appendix E2. Continued.

Author Year Country	Aim	Study Design Sample Setting	Key Outcome Measures	Key Findings	Post Hoc Calculations	Technical Features
Sard et al,[39] 2008 USA	To determine whether the addition of a medication quick list to a CPOE system reduced the rate of prescribing errors	Pre/post comparison Pre: 420 patient visits; 326 medication orders Post: 420 patient visits; 398 medication orders Newton Wellesley Hospital; Level I trauma pediatric ED	Quick list use (percentage of orders) Medication error rates: Errors per 100 visits and errors per 100 orders (IRR 95% CI) Error types: Wrong dose Wrong frequency Wrong route Wrong drug (as total number of errors [number per 100 orders])	Quick list use: Post: 30% (n=107 of 361) Error rates: Pre: 24 per 100 visits Post: 13; Sig ($P<.001$) IRR 0.54 (0.39, 0.76) Pre: 31 per 100 orders Post: 14; Sig ($P<.001$) IRR 0.45 (0.32, 0.62) Error types: Wrong dose: Pre: 27 (8) Post: 19 (5); Sig ($P=.07$) Wrong frequency: Pre: 12 (3.7) Post: 1 (0.3); Sig ($P=.01$) Wrong route: Pre: 8 (2.4) Post: 2 (0.5); Sig ($P=.04$) Wrong drug: Pre: 6 (2) Post: 2 (0.5); Sig ($P=.11$)	N/A (calculations provided by Sard et al)	CPOE implemented in October 2005 DSS: A drug-dosing support tool that targets the most common medications in the study setting. Homegrown DSS. System changes: Pre → Browser-based EDIS. Integrates tracking, documentation, prescription writing, order entry, drug allergies, and drug interactions and has order sets. Drugs are selected from a search list, which opens a window with blank fields for dose, unit, route and frequency. Order sets have default doses, units, and routes, but they are standard adult doses. Post → Medication quick list added. Contains the 75 most commonly prescribed medications in the study setting. It prompts a suggested weight-based dose, unit, route, and frequency.

Appendix E2. Continued.

Author Year Country	Aim	Study Design Sample Setting	Key Outcome Measures	Key Findings	Post Hoc Calculations	Technical Features
Yen et al,[40] 2009 USA	To determine the effect of CPOE on pediatric ED care providers' allocation of time	Pre/post comparison Nurses and physicians observed Pre: 83 observation sessions (252 h) (summer 2004 and 2005) Post: 43 observation sessions (120 h) (summer 2006) Pediatric ED	Attending physicians' time spent on computer, direct patient care (% of time; median time in minutes [IQR]) Resident physicians' time spent on computer, direct patient care (% of time; median time in minutes [IQR]) Emergency nurses' time spent on computer, direct patient care (% of time; median time in minutes [IQR])	Attending physicians' time: Using computer: Pre: 2.9%; 5.0 (3.5, 6.5) Post: 6.4%; 9.5 (4.0,16.0) 4-min increase (0.5, 8.0) Sig (P=.01) Direct patient care: Pre: 23.6%; 38.8 (33.0, 51.0) Post: 25.6%; 46.0 (33.5, 59.0) Resident physicians time: Using computer: Pre: 4.2%; 5.5 (3.5, 10.0) Post: 9.7%; 14.3 (11.0, 21.0) 9-min increase (4.5, 15.0) Sig (P=.001) Direct patient care: Pre: 35.9%; 67.0 (51.0, 73.0) Post: 35.5%; 64.0 (48.5, 66.5) Sig (P=.55) Emergency nurses' time: Using computer: Pre: 6.9%; 10.0 (6.5, 17.5) Post: 4.7%; 5.8 (5.8, 12.0) 2.5-min decrease (−0.5, 6.0) Sig (P=.15) Direct patient care: Pre: 27.9%; 46.0 (33.5, 72.5) Post: 26.4%; 44.0 (34.8, 65.5)	N/A (calculations provided by Yen et al)	CPOE implemented in 2005 System changes: Pre → There was a commercial computerized tracking system. Charting and orders were written on a paper chart. Charting was free format for both the physician and nursing in a semitemplated chart. Staff informed the nurses verbally that there were orders on the chart. Post → Orders for medications, procedures, and laboratory tests were entered onto the CPOE system. Charting continued to be in a free format on a semitemplated chart. Order notification was through the computer tracking system.

Appendix E2. Continued.

Author Year Country	Aim	Study Design Sample Setting	Key Outcome Measures	Key Findings	Post Hoc Calculations	Technical Features
Terrell et al,[41] 2010 USA	To examine the extent to which DSS in an ED enhances the safety of prescribing to patients with renal disease	RCT Emergency physicians Control: 21 physicians Intervention: 21 physicians Patients aged 18 y and older who had the necessary variables in their EMR to trigger DSS Control: 1,290 visits Intervention: 1,493 visits Wishard Memorial Hospital; Level I trauma ED	Proportion of targeted medications that were excessively dosed	Excessive prescriptions: Control: 74% (n=34/46) Intervention: 43% (n=31/73) Sig (*P*=.001)	N/A	DSS: Dosing recommendations for 10 targeted medications for patients aged 18 y and older when the patient's estimated creatinine clearance level was below the threshold for dosage adjustment. System changes: Pre → CPOE was used to write all prescriptions for ED patients. Post → Serum creatinine level, age, sex, and weight required to estimate creatinine clearance level. DSS was provided when a physician prescribed one of 10 targeted medications. The physician could accept or reject the DSS recommendation.

Appendix E2. Continued.

Author Year Country	Aim	Study Design Sample Setting	Key Outcome Measures	Key Findings	Post Hoc Calculations	Technical Features
Henstrom et al,[42] 2007 USA	To assess the effect of CPOE on laboratory and radiograph TAT	Pre/post comparison Pre: 6 mo Post: 6 mo Lab (CBC count, chemistries, and troponin I) (n=482) and radiographs (n=219) Adult ED	TAT (mean minutes from initial ordering to reporting of results) (95% CI)	TAT: Laboratory: PrePre: 76.8 min Post: 66.3 min Sig (*P*=.052) Adjusted RR 0.87 (0.76, 1.00) Interval difference=0.872 (0.760–1.00) Radiograph: Pre: 63.1 min Post: 55.4 min Sig (*P*=.047) Adjusted RR 0.85, (0.73, 1.00) Interval difference=0.852 (0.727–0.998)	N/A (calculations provided by Henstrom et al)	System changes: Post → CPOE used for nursing documentation, laboratory and imaging orders, and reporting

N/A=Not applicable; *ACS*, acute coronary syndrome; *EDIS*, ED information system; *Sig*, significance; *PT*, prothrombin time; *CXR*, chest radiograph; *BMP*, basic metabolic panel; *pADE*, potentially adverse drug events; *BEST*, Brain Salvage through Emergency Stroke Therapy; *tPA*, tissue-type plasminogen activator; *PTT*, partial thromboplastin time; OR=odds ratio; *EMR*, electronic medical record; *IQR*, interquartile range; *IRR*, incidence rate ratio.