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The impact of computerised physician order entry systems on pathology services: A systematic review

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ABSTRACT

Purpose: Computerised physician order entry (CPOE) systems hold the promise of significant improvements to health care delivery and patient care. The implementation of such systems is costly and complex. The purpose of this paper is to review current evidence of the impact of CPOE on hospital pathology services.

Methods: This paper presents a review of the literature (1990–August 2004) about CPOE systems and identifies indicators for measuring the impact of CPOE on pathology services.

Results: Nineteen studies which contained some form of 'control' group, were identified. They featured a variety of designs including randomised controlled trials, quasi-experimental and before and after studies. We categorised these into three groups: studies comparing pathology CPOE systems (with no decision support) to paper systems; pathology CPOE systems (with decision support) to paper systems; and pathology CPOE systems with specific pathology features compared to systems without those features. We identified 10 areas of impact assessment and 39 indicators used to measure the impact of CPOE on different stages of the pathology test ordering and reporting process.

Conclusion: We conclude that while some data suggest that CPOE systems are beneficial for clinical and laboratory work processes, these data are limited, and further research is needed. Few data are available regarding the impact of CPOE on patient outcomes.

1. Introduction

Many potential benefits of computerised physician order entry (CPOE) in hospitals have been identified. These include improvements to physician ordering patterns, increased compliance with guidelines, optimisation of clinical time, and facilitation of communication processes in health care [1–14]. If realised, these benefits would logically lead to improvements in patient outcomes, as well as major cost efficiencies. CPOE systems are an integral part of hospital information systems and constitute an important building block for the establishment of the electronic medical record [2,7,15]. For these reasons, CPOE systems have been strongly promoted in the United States, Europe and Australia as a means of improving the quality of care, reducing errors and increasing efficiency in health care delivery [16–22].

Pathology order entry allows physicians (or other authorised staff) to enter laboratory orders directly into a computer [4,11,14,23]. Such systems may include decision support mechanisms such as defined order sets for particular conditions in order to support the selection and appropriate use of tests and treatment; parameter checks to ensure that orders are within agreed test time frames, frequency or dose limits; and more complex rule based alerts that prompt clinicians with information about previous test results, patient characteristics and available test choices [16,17,24–29].

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CPOE systems remain costly and complex to design and implement [9,13]. Despite the potential benefits, there are very few evaluations of the effect of CPOE on clinical outcomes [1], and evidence of the effectiveness of CPOE has focused predominantly on medication order systems in hospital settings [9]. One of the reasons for this may be the limited funding available for such studies. Outside of medication orders a large proportion of orders processed through a CPOE system relate to pathology and imaging services that can have a potentially significant impact on clinicians' test ordering decisions and pose a new set of challenges and opportunities for pathology managers.

Relatively little research has focused specifically on the impact of CPOE on hospital pathology services, order patterns or patient outcomes. The purpose of this paper is to review current evidence of the impact of CPOE on hospital pathology services and to identify the indicators, which have been used to measure impact.

2. Methods

A literature review was undertaken to identify all evaluation studies of computerised pathology order entry systems published between 1990 and August 2004. The following databases were searched: MEDLINE, CINAHL, EMBASE, SocScience Index and Cochrane Database of Systematic Reviews. Web-based searches using Google and hand searches of international health informatics journals were completed. The reference lists from relevant articles and additional articles by key authors were also reviewed [30]. The search terms and subject headings used are listed in Table 1. Papers were selected and reviewed by two reviewers (AG, MW). We applied only one quality criteria to select articles, namely that the study design used was experimental or quasi-experimental including before and after studies and times series studies.

Table 1 – Concepts and terms used in search strategies

Literature search for empirical studies on the impact of CPOE on pathology services

Concept 1: order entry
Order entry (T), order management (T), electronic health records (T), medical records systems, computerized ([a]SH), clinical laboratory information systems (SH), laboratory information systems

Concept 2: decision support
Database management systems (T, SH), computer-assisted decision support (T), decision making, computer assisted ([a]SH), clinical decision support systems (T), decision support systems, clinical (SH), decision support techniques (T, SH), expert systems (T, SH)

Concept 3: electronic or computerised
Computer (T), electronic (T), microcomputer (T, SH)

Concept 4: pathology/laboratory
Laboratory (T[a], SH), Pathology (T[a], SH)

T denotes text, SH denotes a subject heading.
[a] SH denotes subject heading exploded.

The results of the review are discussed under three headings, which relate to stages in pathology test ordering and reporting (see Fig. 1). These stages are: (1) *test ordering process* including the physician decision to order a pathology test; (2) *test processing* within the pathology department; and (3) *application of pathology test results* which includes the delivery of results and the subsequent actions which may impact upon patient outcomes. A further dimension, which warrants measurement is the flow of information through the three stages.

3. Results

The review identified 19 studies of the impact of CPOE systems on pathology. Eleven studies compared CPOE for pathology orders (with and without decision support) to no CPOE (Tables 2 and 3). Of these, four studies compared CPOE without defined decision support mechanisms to settings where there was no CPOE. Eight studies compared CPOE with specific decision support features to CPOE without these features (Table 4). The studies comparing CPOE with no CPOE were conducted in the USA (5), United Kingdom (UK) (2), Canada (2), Norway (1) and South Korea (1). The eight studies examining the impact of decision support systems on CPOE were carried out in three US hospitals. Across all studies there were a variety of designs used including seven randomised controlled trials (RCT), two non-randomised controlled trials, eight before and after studies, one laboratory-based quasi-experimental study and one interrupted time series study. Tables 2–4 summarise the interventions and comparisons, indicators, designs and results of these studies.

3.1. *Stage one-test ordering*

The pathology process is initiated by a physician's decision to order a test. It includes documenting the decision on a test order form, either paper or electronic. The decision to order is an area that CPOE systems are likely to have a major impact upon. This can occur through decision support mechanisms such as clinical alerts, reminder systems and standard test order sets designed to improve the appropriateness of tests ordered and minimise the number of redundant tests. These features could impact upon test volumes and total pathology costs [12,31–37].

Potential indicators of impact at this stage of the process are rate of unnecessary or redundant tests ordered, the number or volume of orders and associated test costs. Tests should comply with agreed clinical guidelines or accepted medical practice (given the patient's condition and treatment) to ensure safe and efficient care. Redundant tests occur when a test is reordered within an inappropriate time frame and provides no additional information [34,38]. Some physicians reorder tests to verify the results of a previous test. It may also be a mechanism to ensure that necessary tests are not missed [39,40]. But in many cases repeat testing is a convenience rather than a reflection of a belief that it improves patient care [39]. There is evidence that repeat and redundant tests are areas where major improvements are needed [41]. A retrospective study of test orders by Bates et al. [34] showed that 8.6% of 10 target repeat tests were judged

Table 2 – Studies comparing CPOE without decision support mechanisms to no CPOE for pathology

Reference	Setting/Country	Intervention (I)/comparison (C)	Study description	Areas of impact(measure/ indicators)	Results	Design
Studies comparing CPOE for pathology tests vs. no CPOE						
Hwang et al. [2]	Inpatients tertiary teaching hospital, South Korea	I: CPOE (all orders), C: before CPOE	A study of patients with four ICD diagnosis (medical and two surgical) in the month prior to CPOE implementation (73 patients), 3 months after (60) and 6 months after (38)	Test volume (number of diagnostic tests per patient per day) Length of stay (mean) Appropriateness of length of stay	Significant decrease (blood count, chemistry, serum, stat) Significant decrease from 11.4 days to 8.2 days ($p = 0.049$) No difference	Before and after study
Mekhjian et al. [5]	Inpatients two ICUs, Ohio State University Health System, USA	I: CPOE (all orders), C: no CPOE	A 2-month study of a surgical intensive care unit (1142 laboratory orders) with a CPOE system and a medical intensive care unit (683 laboratory orders) without a CPOE system	Laboratory turn around times (average time between receipt of specimen and order in laboratory to time of electronic results posting)	25% faster with CPOE (23 min vs. 31 min ($p = 0.001$)	Non-randomised controlled trial
Ostbye et al. [47]	Inpatients two surgical wards at Central Hospital of Akershus, Norway	I: CPOE (clinical chemistry test ordering and reporting), C: no CPOE	Clinical chemistry test volumes and turn around times were monitored on two surgical wards, one randomly assigned as the intervention and the other as the control for 17 weeks pre CPOE and 11 weeks after CPOE	Total turn around time Test volume (total number of laboratory tests per week for all tests and 10 most frequent tests)	Decrease in total TAT from 270–350 to 90–180 min No change in total volume of tests ordered before and after CPOE. Slight increase in some frequent tests	Randomised controlled trial
Shu et al. [50]	A study of medical interns, Massachusetts General Hospital, USA	I: CPOE (all orders), C: before CPOE	Comparison of physician time spent ordering and doing other activities, in the 3 months before implementation of CPOE and a 2 month period 6 months after CPOE implementation	Physician time (proportion of physician time spent writing orders) Proportion of physician time associated with ordering	Proportion of time spent writing orders increased from 2.1 to 9.0% Total time associated with ordering increased from 6.8% to 13.5% as time spent in some activities reduced	Before and after study

Table 3 – Studies comparing CPOE with decision support mechanisms to no CPOE

Reference	Setting/Country	Intervention (I)/ comparison (C)	Description	Areas of impact (measures/ indicators)	Results	Design
Bansal et al. [46]	Inpatients Intensive care units, Vanderbilt, University Medical Centre, USA	I: CPOE plus ordering advice and restrictions, C: before CPOE	Eight ICU studied (six with CPOE, two without) over 12 weeks (5 pre-and 7 post-). Computer based intervention providing patient ABG values and limits to test orders placed more than 24 h in advance	Test volume (total number of ABG tests for a period)	No significant change pre and post	Before and after study with control group
Kamal et a1. [48]	Ohio State University Medical Center, USA	I: CPOE (laboratory orders) + EDSS: order sets, C: before CPOE	A study comparing laboratory order rates in the 3 months before CPOE was implemented and the same 3 months 18 months after CPOE implementation	Test volume (number of lab orders per patient per diagnosis related groups—DRG)	Fifty percentage increase for most DRGs. Up to 200% increases for some cardiology related DRGs	Before and after study
Mutimer et al. [42]	Inpatients Liver Unit, Queen Elizabeth Hospital, UK	I: CPOE + computerised decision support: computerised protocol for laboratory tests for 'Liver Unit' patients, C: before CPOE	Three-month evaluation of transplant and non-transplant patients in a 'liver unit' before (113 patients) and after (109 patients) implementation of the system	Test volume (number of laboratory tests requested per patient per day) Physician time (average daily time spent by doctors requesting tests Average daily time spent by doctors following up laboratory tests	9.5% decrease ($p < 0.01$) in transplant recipients; 28.8% ($p < 0.01$) decrease for non-transplant recipients Fell from 6.8 to 2.3 min ($p < 0.001$) Decreased from 10 min per day to 4.1 min per day ($p < 0.001$)	Before and after study
Nightingale et al. [43]	Inpatients Liver Unit, Queen Elizabeth Hospital, UK	I: CPOE + computerised decision support: computerised protocols for laboratory tests, C: before CPOE + written protocols	Further evaluation of system assessed by Mutimer et al. [42]. Examined data for 1 year before and after system implementation. Patients were transplant and non-transplant patients in a 'Liver Unit'.	Test volume (number of laboratory tests requested per patient per day) No of lab tests ordered out of hours per patient per day Order appropriateness (% of patients requiring a particular test who actually receive it), Laboratory costs (direct laboratory costs)	Declined by 17% ($p < 0.001$) Reduced by 48% ($p < 0.001$) Increase in usage of 10 previously less often used tests for patients with specified conditions, reduction in direct laboratory costs of 28% ($p < 0.001$)	Before and after study

Table 3 (*Continued*)

Reference	Setting/Country	Intervention (I)/ comparison (C)	Description	Areas of impact (measures/ indicators)	Results	Design
Smith et al. [44]	General practitioners laboratory based Canada	I: CPOE with vomputerised decision support: Laboratory Advisory System. C: paper based requisitions and reports	Six general practitioners with 10–20 years experience were invited to present their diagnostic approach to 14 vignettes of standard clinical problems (seven using just paper based requisitions and results and seven using the Laboratory Advisory System)	Test volume (average number of laboratory tests per physician) Time to diagnosis (average time from ordering to diagnosis) Average number of venipunctures per physician Appropriateness of diagnosis (% of patients with correct diagnosis)	Decreased from 32.7 to 17.8 with LAS ($p < 0.01$). Reduced 3.2 days to 1 day using LAS Reduced from mean of 7.5 to 5.8 with LAS ($p < 0.02$) Improvement from 66% to 100% with LAS	Laboratory-based experimental study
Thompson [65]	Inpatients Intensive Care Unit, St. Paul's Hospital, Canada	I: CPOE (laboratory orders) + computerised decision support: order sets, C: before CPOE	Comparison of turn around times for STAT laboratory tests for two 1 month periods, 10 months before CPOE and 2 months after CPOE was implemented	Total turn around times Turn around time from ordering to specimen collection (Median)	Decreased from 148 to 74 min ($p < 0.001$) Reduced from 77 to 21.5 min ($p < 0.001$)	Before and after study
Wang et al [45]	Inpatients Intensive care unit, Massachusetts General Hospital, USA	I CPOE with admission orders plus Guidelines and educational efforts C: before CPOE	Comparison of test utilisation during a 3-month intervention period compared to the same months a year prior to intervention The hospital's ICU, which did not receive the specified intervention, provided control data	Test volumes (Number of tests per patient per day) Test Costs (total test costs for a period) Length of stay (mean) Adverse events (ICU readmission rate; Hospital mortality rate; average number of days ventilated per ventilated patient)	Statistically significant reductions for all chemistry tests Reduction in expenditure for routine blood tests and chest radiographs was 17% ($p < 0.001$) No significant change No significant change	Before and after study with control group

Table 4 – Studies comparing CPOE with and without specific decision support mechanisms

Reference	Setting/Country	Intervention (I)/comparison (C)	Study Description	Areas of impact (measures/Indicators)	Results	Design
Bates et al. [32]	Medical and surgical inpatients, Brigham and Women's Hospital, USA	I: CPOE + computerised decision support: computerised display of charges for laboratory (and radiology) tests, C: CPOE alone	This laboratory study involved two prospective controlled trials that included all medical and surgical inpatients during a 4-month study period with 3536 intervention and 3554 control inpatients in the group with laboratory tests	Test volume (mean number of tests per admission; total number of clinical laboratory tests)	No significant differences	Randomised controlled trial
				Test costs (cost of tests per admission, total costs of tests)	No significant differences	
Bates et al. [36]	All inpatients Brigham and Women's Hospital, USA	I: CPOE + computerised decision support: reminders to physicians about redundant tests, C: CPOE alone (reminders suppressed)	The study included all inpatients at a large teaching hospital during a 15-week period	Order appropriateness (redundant tests rates)	Nine hundred and thirty-nine apparently redundant tests in the 77,609 study tests ordered in the intervention (5700 patients) and control (5886 patients). Fifty-one percentage of redundant tests were performed in the control group and 27% of ordered redundant tests in the intervention group ($p < 0.001$).	Randomised controlled trial
				Hospital costs (estimated total annual savings)	The authors used the results to estimate an annual savings of $35,000, but noted that the overall effect was limited because many tests were performed without corresponding computer orders, and many orders were not screened for redundancy	
Kuperman et al. [35]	Medical and surgical inpatients, Brigham and Women's Hospital, USA	I: alert for critical results via page + review system for 12 conditions based on critical laboratory test results, C: critical results telephoned to ward by laboratory	A 2-month study of medical and surgical inpatients at a large academic medical centre. One hundred and ninety two alerting situations were studied	Time to treatment (median and mean time from availability of critical result to ordering of appropriate treatment)	Intervention group had a 38% shorter median time interval until an appropriate treatment was ordered (1 h vs. 1.6 h, $p = 0.003$) and shorter mean time interval (4.1 vs. 4.6 h, $p = 0.003$) than the control group	Randomised controlled trial

Table 4 (*Continued*)

Reference	Setting/Country	Intervention (I)/comparison (C)	Study Description	Areas of impact (measures/Indicators)	Results	Design
				Time to resolution of critical condition (average time interval from availability of critical result until time critical condition resolved) Adverse events (number of adverse events and rate per patient)	The median and mean times were no different between groups (median 8.4 h vs. 8.9 h, $p = 0.11$; mean 14.4 h vs. 20.2 h, $p = 0.11$) No significant differences	
Neilson et al. [37]	All medical staff using CPOE, Vanderbilt University Medical Center, USA	I: CPOE + computerised decision support: test order confirmations and constraints, C: CPOE alone	A 3-year study of metabolic panel component tests by all staff using the CPOE system, starting and continuing through the intervention period until 1 year post interventions	Test volumes (number of tests ordered per day) Daily discontinued test volumes Adverse events (proportion of patients with abnormal test results 48 h following original abnormal test; re-admission rate; rates of intensive care transfer; mortality; length of stay)	Test order confirmation decreased orders by 24%; ordering constraints led to a further 51% reduction in panel orders Decrease in orders discontinued per day The proportion of patients who had at least one abnormal value decreased ($p = 0.02$) after the intervention. No difference in the proportion of patients with abnormal test results 48 h following original abnormal test No change in other indicators	Interrupted time series study
Overhage et al., [12]	Inpatient general medicine ward, Wishard Memorial Hospital, USA	I: computerised decision support: automated guideline based reminders to physicians about recommended corollary orders, C: paper-based corollary order guidelines	Computerised reminders about corollary orders were presented to three intervention teams (48 physicians) and with held from three control teams (41 physicians) in a 6-month trial	Order appropriateness (Immediate, 24 h and hospital stay compliance to corollary orders guidelines i.e. number of times a physician ordered the corollary orders divided by the total number of corollary orders) Length of stay Total costs (average charge per admission) Adverse events (number of pharmacy interventions for life threatening, severe, or significant errors) Average maximum serum creatinine levels)	Improved compliance with computerised decisions support: immediate compliance: 46.3% vs. 21.9%; 24 h compliance: 50.4% vs. 29.0%; hospital-stay compliance: 55.9% vs. 37.1% all, $p < 0.0001$) No difference No difference Pharmacists' interventions: less with intervention (105 vs. 156) ($p = 0.003$) maximum serum creatinine levels: no difference between the groups	Randomised controlled trial

Solomon et al. [49]	Inpatient units, Brigham and Women's Hospital, USA	I: CPOE with post-test probability estimates designated serologic test. C: CPOE alone	Comparison of test cancellations of rheumatoid factor and antinuclear antibody and complement level tests ordered by house officers using CPOE	Number of cancelled tests	Higher rate of cancelled tests with CPOE: 11/99 vs. 1/236 ($p = 0.001$)	Non-randomised controlled trial
Tierney et al. [33]	Outpatients physicians, Wishard Memorial Hospital, USA	I: CPOE + computerised decision support: test charges displayed (out patients) C: CPOE alone	Physicians (121) were randomly allocated into a control group and intervention group. The study was conducted over a 26-week period with 8392 patients	Test volume (mean number of tests ordered per patient)	Intervention group ordered 14% fewer tests ($p < 0.005$)	Randomised controlled trial
				Test costs (mean test charges)	13% lower charges with CPOE ($p < 0.05$)	
Tierney et al. [31]	House officers, medical students and faculty internists, Wishard Memorial Hospital, USA	I:CPOE (all orders) + computerised decision support: costs for tests; advice about cost-effective tests for common problems C: CPOE alone	Assessment of the healthcare resource utilisation of microcomputer workstations using computerised decision support. The study included 5219 internal medicine patients and 68 teams of house officers, medical students and faculty internists who care for them	Total costs (total charges per admission)	Intervention teams generated 12.7% lower charges per admission ($p = 0.02$)	Randomised controlled trial
				Test costs (diagnostic test charges)	Significant ($p < 0.05$) reductions in diagnostic test charges with the intervention	
				Length of stay (mean)	The mean length of stay was 0.89 of a day shorter for intervention resident teams ($p = 0.11$)	
				Physician time (total time writing orders)	Interns in the intervention group spent an average of 33 min longer each day writing orders than the control group ($p > 0.0001$).	

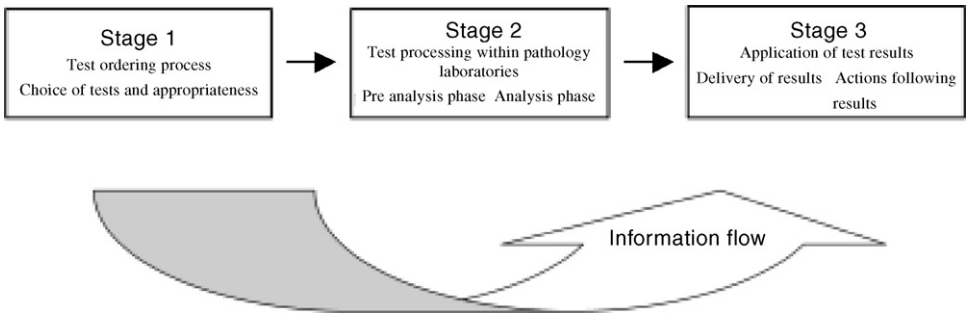

Fig. 1 – The pathology test process.

to be redundant because they were performed too early to provide useful clinical information.

Our review of papers that assessed the impact of CPOE for pathology services identified 16 papers that had used one or more indicators applicable to the physician decision to order stage. Of these papers, 11 looked at the effect of CPOE on test volumes and/or total or average test costs. There were two papers that used redundant orders as an indicator, three that studied compliance with guidelines and three that assessed clinician work practices.

3.1.1. *Impact on test volume*

Of the eleven studies of the impact of CPOE on test volumes, seven reported a significant decrease in test volume [2,33,37,42–45], three showed no change [32,46,47], and one reported an increase in tests ordered [48]. The reduction in test volume varied between studies and according to measures used. Most studies measured test volume using total tests per patient or admission per day. Two of the studies examined test volumes on the same system, one comparing volumes 3 months before and after system implementation [42] and the other comparing them 12 months before and after [43].

Two RCTs which involved the display of test charges as part of CPOE decision support were carried out in the US. One found no difference in the mean number of tests per admission and no significant reduction in the total number of tests in the intervention group [32]. The other compared the mean number of tests per outpatient and reported that the intervention group ordered 14% fewer tests ($p < 0.005$) [33]. A quasi-RCT in Norway [47] compared two surgical wards, one with CPOE, the other without. It found no change in the total number of laboratory tests per week ordered before and after.

A Canadian laboratory-based study by Smith et al. [44] compared six general practitioners using 14 vignettes of standard clinical problems (seven using paper-based requisitions and seven using a Laboratory Advisory System). They found that the mean number of tests per practitioner was 32.7 tests versus 17.8 with the Laboratory Advisory System ($p < 0.01$). An interrupted time series study carried out at Vanderbilt University Hospital in the US between 1999 and 2001 used decision support constraints and restrictions to investigate test ordering behaviour. They found that orders for metabolic order sets decreased by 24% ($p = 0.02$), while the unbundling of order sets to reduce unnecessary repeat tests produced an additional decrease of 51% ($p < 0.001$) of component tests [37].

Six studies used a before and after design, four without control groups and two with control groups. Bansal et al. [46] investigated the impact of a web-based educational text and restrictions on advanced ordering of arterial blood gases (ABG) in intensive care unit settings. The authors reported no significant change in the number of ABGs ordered citing limited power as the reason [46]. A study centred on test utilisation management to reduce unnecessary tests in the Coronary Care Unit in Massachusetts General Hospital reported significant reductions in the utilisation of all chemistry tests [45]. Mutimer et al. [42] and Nightingale et al. [43] evaluated a home grown system in England which used protocols defining all laboratory investigations for patients in a liver transplant unit. Physicians had the flexibility to add or delete tests or change other protocols. The 3-month study found that clinical chemistry tests requested per patient per day fell by 9.5% ($p < 0.01$) for transplant recipients and by 28.8% ($p < 0.01$) for non-transplant recipients [42]. Comparisons 12 months before and after implementation of the system, showed a 17% decline in the total number of tests per patient ($p < 0.001$) and 48% decrease for out of hours tests per patient ($p < 0.001$) [43].

A before and after study, between 1999 and 2000 at a tertiary teaching hospital in South Korea, selected patients from two diagnostic and two surgical procedure groups. The study reported a significant decrease in the average number of tests per patient per day for full blood count, chemistry, serum and stat tests [2]. Kamal et al. compared laboratory order patterns for 3 months before CPOE implementation and in the same 3 months, 18 months after implementation at the Ohio State University Medical Centre in the US. They found that regardless of the disease, the average number of orders per patient per Diagnostic Related Group increased by approximately 50% [48].

3.1.2. *Impact on test costs*

Five studies measured laboratory related test costs, of which four showed significant reductions [31,33,43,45], and one showed no change [32]. In most cases changes in test costs reflected underlying changes in test volume. Three RCTs examined the impact of including charges for diagnostic tests on the electronic order form. Tierney et al. [33] found that this intervention produced significant results with 13% lower charges in outpatients. A larger inpatient study undertaken later at the same hospital showed similar reductions in diagnostic test charges among the intervention group [31]. Bates et

al. [32] showed no significant decrease in costs, while Nightingale et al. reported a 28% ($p < 0.001$) reduction in direct laboratory expenditure per patient-day [43]. Wang et al. (2002) [45] used their findings of a decrease in test orders in arterial blood gases and chest radiographs to estimate a significant decrease of 17% in expenditure.

3.1.3. *Impact on redundant test rates*

The rate of redundant tests was the focus of a study at Brigham and Women's Hospital that investigated the impact of providing computerised reminders to physicians about apparent redundant tests. It reported a significantly reduced rate of redundant tests in the intervention groups (27%) compared with the control group (51%). The authors noted that the overall effect was limited because only 44% of redundant tests performed had an associated computer order; only 50% of tests ordered using the computer were screened for redundancy; and almost one-third of the reminders were overridden [36]. Neilson et al. reported a decrease in the number of discontinued tests per day following the introduction of CPOE reminders [37].

3.1.4. *Impact on compliance with guidelines*

Four studies found that CPOE systems with computerised decision support improved compliance with guideline advice. A study of the impact of clinical guidance provided by a Laboratory Advisory System (LAS) on the diagnostic approach of six clinicians in a laboratory setting found that physicians using the system arrived at the correct diagnosis in 100% of cases, as opposed to 66% using the conventional approach [44]. Another study of order appropriateness using computerised protocols for laboratory tests found an increase in usage of 10 previously less often used tests for patients with specified conditions [43]. An RCT carried out at Wishard Memorial Hospital in the US investigated the ability of guideline-based reminders of corollary orders to prevent errors of omission. It found that physicians in an intervention group ordered the suggested corollary orders in 46.3% of instances where they received a reminder, compared with 21.9% compliance for the control group, which did not receive a reminder [12]. Solomon et al. [49] compared the rate of test cancellations for a group of specified serologic test orders where the intervention group physicians were provided with displays of post-test probability estimates. The study reported a significant difference in the number of cancellations for the intervention group (11.1%) versus the control (0.4%).

3.1.5. *Impact on work practices*

Three studies examined the impact of CPOE on physician ordering time on pathology tests. A 1998 before and after study at Massachusetts General Hospital in the US compared the time physicians spent ordering in the 3 months before the implementation of CPOE with a 2 month period 6 months after implementation. The study reported that the total time spent writing orders increased from 2.1% to 9.0% ($p < 0.001$) and the amount of time spent using the computer rose from 6.8% to 13.5%. But 1.9% of time was recovered performing activities expected to take less time e.g., scheduling tests, completing forms, walking, travelling in the elevator, and looking for patients [50]. The RCT at Wishard Memorial Hospital (US) also found that interns in their intervention group (provided with CPOE plus computerised decision support) spent an average of 33 min longer during a 10 h observation period writing orders than the control group [31].

Employing a contrasting approach, Mutimer et al. (as described earlier) used computerised protocols defining laboratory investigations for patients in a liver transplant unit. The authors reported that the time spent by junior medical staff requesting laboratory investigations fell from 6.8 to 2.3 min ($p < 0.001$) and time spent on specimen enquiries and results decreased from 10 min per day to 4.1 min per day ($p < 0.001$). The authors suggested that this approach can be of substantial benefit in reducing the amount of time spent by medical officers on administrative tasks [42].

3.2. *Stage two test processing within the pathology department*

The test order process within pathology departments can be broken down into the pre-analytical and analytical phases. In the pre-analytical phase paper test orders and specimens are delivered to the pathology department and logged onto a laboratory information system [51]. Errors in this phase can include order or request errors (e.g. wrong test ordered, missing physician signature, missing patient identifiers, illegible information, and wrong location identifiers), laboratory transcription errors (i.e. where details about the patient record number, name or location; pathology test, or doctor, differ with the doctor's original order and the laboratory information system) and specimen errors (e.g. incorrect sample collection procedures).

The analytical phase is when the test is performed; data are interpreted and results written in the form of a laboratory test report. Errors that may occur in this phase include analytical errors and laboratory report errors (i.e. keyboard entry errors, wrong test reference range and incorrect address details). Analytical errors include those related to the inaccuracy or imprecision of test results, analysis of the wrong specimen, performing the wrong assay; data misinterpretations and misjudgements; or broken specimen tubes during centrifuge.

Laboratory quality control processes focus on the test processing stage. They aim to ensure the accuracy and reproducibility of laboratory results [52]. Studies of the type and frequency of errors in laboratories have found that request, specimen and transcription errors, typically associated with the pre-analytical phase contribute most to the total laboratory error rate [53,54] and cause most of the clinically significant laboratory errors [52]. Other research conducted in accordance with the Q-Probes quality assurance program of the College of American Pathologists estimated an average transcription error rate of 5% for 660 participating institutions [55]. An Australian study conducted in 1994 surveyed 18 large National Association of Testing Authorities-registered laboratories and found a mean transcription error rate of 13% (range 0–17%) [56]. This study also found analytical errors as high as 26% in one laboratory with an average of 11.4%.

Where a pathology CPOE system exists, it requires the completion of all relevant fields in the electronic test requisition form. It interfaces with the laboratory information system and

directly transfers this information. CPOE systems should have an important impact on errors in the pre-analytical phase, reducing errors arising from incomplete information, or illegible handwriting on test requisition forms. They also remove the need to transcribe information from requisition forms into laboratory computers thus reducing laboratory transcription errors and saving laboratory time.

3.2.1. *Impact on number of physician–laboratory communication*

One study from the Central Hospital of Akershus in Norway looked at telephone activity. They reported that the number of telephone calls from the intervention ward to the laboratory did not show any clear change after the installation of the new system, and the number of calls from the laboratory to the installation ward decreased after the system had stabilised (after 11 weeks) [47].

3.3. *Stage three application of pathology test results*

Once the pathology results are delivered to the clinician, they are interpreted and incorporated into the patient management plan. Often measures used in this stage of the test process focus on patient outcomes or can act as proxy measures of outcomes. It is at this stage that adverse events during the pathology ordering and reporting process will impact on patient care either through increased morbidity or inconvenience to the patient [57].

Research into adverse events relating to pathology services has been undertaken. A laboratory incident classification scheme developed by Astion et al. [58] identified preventable problems that were most likely to lead to patient injury. An adverse event is defined as an injury to a patient caused by medical management rather than by a disease process, which resulted in disability or prolonged hospital stay [12,58,59]. This classification was retrospectively applied to 129 incident reports in a US academic medical centre during a 16-month period. It found that 95% of incidents were potential adverse events, with the most common 110 (85%) being delay in receiving test results. The seven cases (5%), classified as adverse events, were phlebotomy-related injuries. The authors noted that a significant limitation to their study was the inadequacy of incident reports and the absence of information about patient care settings and patient outcomes.

An assessment of errors in STAT laboratories (where all tests are considered urgent) showed that 6.4% of errors were associated with adverse patient outcomes such as inappropriate patient care or inappropriate modification of therapy. A further 19% led to inappropriate investigations including repeat laboratory tests [53]. Other studies have shown that a small proportion of clinical laboratory and transfusion-related errors may result in delayed diagnosis, increased patient morbidity, increased length of hospital stay and even death [54,60].

Our review of CPOE pathology literature identified a range of measures that have been used to study this stage of the laboratory process. This included nine papers that considered one or more relevant measures. These papers are discussed below.

3.3.1. *Impact on patient management and time following up results*

Three papers using six different measures addressed the impact of CPOE on patient management and time following up results. Smith et al. [44] reported that the time taken to reach a diagnosis was 1 day for physicians that used a Laboratory Advisory System (LAS), and 3.2 days for those that did not. They also found that LAS users were more likely to arrive at a correct diagnosis in 100% of cases and made on average less venipunctures (bleeds) than those who did not use the system (mean 5.8 versus mean 7.5, $p < 0.02$).

Kuperman et al. [35] undertook a trial that used a computer system to detect critical conditions and automatically notify the responsible physician via the hospital's paging system. The study recorded a 38% shorter median time interval (1 h versus 1.6 h, $p = 0.003$) until an appropriate treatment was ordered when an automatic alerting system was used for critical laboratory results. There was a shorter (but not significant) median and mean time to the critical condition being resolved (8.4 h versus 8.9 h; and 14.4 h versus 20.2 h).

One paper looked at the impact of CPOE on clinician time spent following up results. It found that the time spent by junior medical staff on specimen enquiries and results fell from 10 min per day to 4.1 min ($p < 0.001$) [42].

3.3.2. *Impact on length of stay and costs*

Five studies examined the impact of CPOE on length of hospital stay [2,12,31,37,45] and three looked at costs across the hospital using measures such as total charges per admission, estimated total annual savings and estimated savings per visit [12,31,36]. Most reported no significant impact on length of stay. A South Korean before and after study measured the appropriateness of length of stay using an appropriateness evaluation protocol. It found no change in appropriateness of patients' hospital stay but did report a significant decrease ($p = 0.049$) in the length of stay [2]. Two further US papers, an interrupted times series study from Vanderbilt University Medical Centre, and a before and after study at Massachusetts General Hospital reported unchanged lengths of stay following system implementation [37,45].

Two separate studies were carried out at the Wishard Memorial Hospital in the US. Both found no significant change in length of stay. However one of these studies carried out by Tierney et al. [31] reported 12.7% lower hospital charges per admission ($p = 0.02$) from patients enrolled in an RCT at Wishard Memorial Hospital, where information on test charges and advice about cost effective tests was provided to clinicians via the ordering system. While the other study by Overhage et al. [12] calculated average charges per admission for their study of computerised decision support carried out at the same hospital and found no difference in length of stay. An RCT at Brigham and Women's hospital in the US found significant reductions in redundant tests within their intervention group and used these results to estimate annual savings of $35,000 [36].

3.3.3. *Impact on adverse events and safety*

Our review identified nine different measures of safety and adverse events that appeared in four separate studies. Kuperman et al. [35] used an alert system for critical results

comparing CPOE alerts with telephone calls to the ward. The most frequent adverse events identified were death, dialysis, transfer to intensive care unit (ICU), and delirium. They found no change in the number of adverse events when compared separately. The total adverse event rate per patient was also similar in the two groups (31 events in 94 intervention patients [0.33 events per patient] versus 27 events in 98 control patients [0.28 events per patient], $p = 0.41$). Other studies, which look at specified adverse events such as mortality [37,45], rates of transfer or readmission to ICU [37,45] also found no significant changes. However, the failure to detect significant differences in these studies may have been due to insufficient sample size.

Overhage et al. [12] measured pharmacist intervention in their evaluation of corollary test order reminders. They reported that pharmacists made 105 interventions with intervention physicians and 156 with control physicians ($p = 0.003$) for errors considered to be life threatening, severe or significant.

The Vanderbilt University Medical Centre [37] study measured the proportion of patients with abnormal test results 48 h following the original abnormal test and reported no substantial differences before and after the intervention. However, they did report that the proportion of patients who had at least one abnormal value decreased ($p = 0.02$) after the intervention. Other adverse events used were the maximum serum creatinine levels (no difference between the groups) [12] and the average number of days ventilated per ventilated patient in a CCU setting (no significant change between before and after) [45].

3.4. *Efficiency of the information flow between the three stages of pathology ordering and processing*

The previous stages of the ordering process specified areas in the initiation, processing and application of tests. The speed with which information flows between and within the three stages can also provide valuable information about the efficiency of the test process. Turnaround time (TAT) is a frequently used measure by pathology services [61]. TATs may be reported for different aspects of the laboratory and laboratory-related process. Total TAT can be defined as the time of physician request to when the physician reviews the result. Laboratory TAT measures the time a specimen arrives at the laboratory to the time of results dispatch. Physician satisfaction with pathology services is frequently related to timeliness of test results because of its influence on time to diagnosis and/or treatment, especially for patients in intensive care units or emergency departments [62,63]. Two studies carried out in 1997 and 2001, respectively determined the length of time for each component of laboratory testing processes for an emergency department and concluded that the time for specimen collection and its transport to the clinical laboratory had the most significant effect on TAT [63,64].

An important component of patient care and patient safety relates to the efficiency in communicating Critical Laboratory Results (CLR) directly (usually by phone) to the requesting physician. Evidence shows that time to treatment can be adversely affected by delays in communicating critical results to physicians [36]. One study of physician satisfaction with Emergency Department laboratories concluded that effective communication channels needed to be established between laboratories and physicians to improve operational efficiency and patient care [63].

3.4.1. *Impact on TAT*

A 2-month comparison of a surgical intensive care unit using a CPOE system, with a medical intensive care unit without a CPOE system, reported a 25% shorter average reporting time between the receipt of the specimen in the laboratory and the electronic posting of the result (laboratory TAT) ($p < 0.001$) [5]. A before and after study compared TAT for urgent laboratory tests, 10 months before the introduction of the new system and 2 months after. It found a reduced median TAT from ordering to specimen collection of 77–21.5 min ($p < 0.001$) and a reduction in total TAT from 148 to 74 min ($p < 0.001$) [65]. A Norwegian study reported a decrease in total TAT from 270–350 to 90–180 min [47].

4. Discussion

There is a growing body of research which has examined either the impact on pathology services of CPOE alone, or with decision support mechanisms. We identified 19 empirical studies published between 1990 and August 2004. The geographical scope of the research spread from the USA and Canada, to South Korea, Norway and England, reflecting international interest in this area. Six hospitals (five from the USA and one from England) featured in more than one study. The hospital where most studies (four) were carried out was Brigham and Women's Hospital in the USA [32,35,36,49].

Fifteen studies compared CPOE with and without specific decision support mechanisms. The rest compared settings with a CPOE system to settings without a system. Most studies (8/11) comparing hospitals with and without CPOE systems used a before and after design, while a greater proportion of the studies comparing CPOE with and without specific decision support mechanisms, were randomised controlled trials (6/8). The randomised controlled trials were more narrowly focused and concentrated on particular CPOE decision support features such as displays of charges, reminders and patient history. They were also the more rigorous in design and execution. This difference reflects the ongoing difficulty with implementing experimental study designs to assess large information systems in complex clinical settings.

The majority of non-RCT studies used simple analysis techniques to compare intervention and control groups or settings. It was unclear in many cases where other factors may have influenced the results, as little information was presented about consideration or adjustment for patient casemix, physician knowledge and experience of other potential confounders.

Many of the studies presented in this review are over 5 years old; four of them are now over a decade old. Some of the earlier CPOE studies assessed home-grown systems in large academic centres [12,31,33,42,43]. They played an important

Table 5 – Summary of pathology indicators used in CPOE evaluations

Stage of the pathology process	Area of impact	Measures used
Stage 1		
Physician decision to order	Test volume	Number of tests per patient per day [2,42,43,45] Number of tests per patient/admission [32,33] Number of tests per patient per DRG [48] Number of tests per physician [44] Number of tests per week (total and for frequent tests) [46,47] Number of tests per day [37] Total number of tests for a period [32,37,46]
	Test costs	Total direct laboratory costs [43] Pathology test costs per admission [31–33] Total costs of tests for period [32,45]
	Redundant test rates	Redundant tests rate/total number of tests [36] Number of discontinued tests per day [37]
	Compliance with guidelines	% of patients who require a test that actually have the test [44] Rate of physician compliance with suggested corollary orders (immediate, 24 h, hospital stay) [12] Rate of cancelled tests for antinuclear antibodies, rheumatoid factor and complement level tests where decision support is provided [49] Order appropriateness [43]
	Work practices	Time spent ordering/requesting tests [31,42]. Proportion of physician time spent writing orders/ordering [50]
Stage 2		
Test processing with in the pathology	Physician–laboratory communication	Number of telephone calls from physician to laboratory [47] Number of telephone calls from laboratory to physcian [47]
Stage 3		
Application of test results	Patient management and time following up results	Average time from test order to diagnosis [44] Average time from test order to treatment change [35] Average time from availability of critical result until time critical condition resolved [35] % of patients with correct diagnosis [44] Number of venipunctures per physician [44] Time spent following up laboratory tests [42]
	Length of stay and total costs	Mean length of stay [2,12,31,37,45] Total charges per admission [12,31] Estimated total annual savings [36]
	Adverse events/safety	Number of adverse events and rate per patient (cardiopulmonary event, MI, delirium, stroke, renal insufficiency, acute renal failure, dialysis) [35] Proportion of patients with abnormal tests results 48 h following original abnormal test [37] Re-admission rate [37,45] Rates or number of intensive care transfer [35,37] No of returns to operating room [35] Mortality rate no of deaths [35,37,45] Average maximum serum creatinine [12] Average days ventilated per ventilated patient [45] Number of pharmacy interventions [12]
Efficiency of information flow	Turn around time	Total turn around time [47,65] Laboratory turn around time [5]

role in foreshadowing the early development of specialised CPOE systems. These studies were very sharply focused on specific wards or units, and displayed a technical novelty side to their investigation. The results from such studies may not be easily generalisable to other hospitals and indeed other countries where processes and preferences are different. In today's environment, it is the "off the shelf" system that has the potential for wide application [66]. This is particularly as CPOE is more than just a niche computer system replacing handwritten orders, but has direct impact on the entire hospital-wide process of order management [3,16] and is a critical component of the electronic medical record [15].

This review found a number of areas of impact studied across the different stages of the pathology process. Most of

these areas of impact related to the physician decision to order (test volumes, test costs, redundant test rates, compliance with guidelines and work practices) and the application of test results stage (patient management, clinician time, length of stay, adverse events or total costs). Many studies concentrated on some aspect of clinical time or efficiency such as time spent ordering tests or time spent following up laboratory results. Only three studies [5,47,65] looked specifically at turnaround times-a traditional laboratory indicator [61]. We found only one study that used measures associated with the test processing stage. This may reflect the broad assumption that CPOE will virtually eliminate errors that are traditionally associated with the transcription of information on to paper orders (e.g., missing patient identifiers, illegible information, missing signatures). However, CPOE will not eliminate the physician making an inappropriate test choice (although decision support features may ameliorate this to some degree) and may generate its own class of errors by selecting the wrong test from unclear or ambiguous computer generated pick lists.

None of the studies focused on the impact of CPOE on pathology work processes, even though CPOE systems often involve a significant change in work patterns of pathology staff, which may indeed impact on the quality and efficacy of pathology processes. This remains an important area for future research, which would benefit greatly from collaboration between clinicians, pathology laboratory scientists and researchers.

A number of studies looked at areas associated with direct (e.g., adverse events, re-admission rates and mortality) and indirect measures (e.g., time to diagnosis, time to definitive treatment, number of venipunctures, transfer to ICU) of patient outcomes. The results from these studies were inconsistent possibly affected by features of the different systems being compared and the differences in decision support mechanisms incorporated into these systems. Of five studies assessing impact on length of stay, only one reported a significant reduction following the introduction of CPOE for pathology [2]. Of the studies examining effects on patient safety, only one showed an improvement in adverse events/safety following the introduction of reminders for corollary orders [12]. A quasi-experimental study of experienced physicians using a pathology advisory system showed improved time to diagnosis and lower rates of venipunctures [44]. Kuperman et al. [35] showed improved time to treatment and resolution of condition following the introduction of a paging systems to inform physicians about critical results. Outcome measures are often difficult to measure and require large sample sizes in order to detect significant differences. Sometimes, the impact of CPOE is not always immediately apparent. Nevertheless, they remain important to monitor to ensure that new systems do not adversely impact upon patient outcomes and deliver expected benefits.

Most of the studies that looked at the cost benefits of CPOE concentrated on measures from the physician decision to order stage [31–33,43,45]. Nevertheless, all the impact measures summarised in Table 5 have potential cost implications. In some cases, such as changes in turnaround times, and reduction in test errors, the cost implications can be quantified in terms of staff productivity. In other cases e.g., time to treatment, the cost benefit will not be immediately obvious, even though its value for patient care is crucial. It is notable that there is not a comprehensive economic evaluation of the impact of CPOE that brought together a number of the immediate and long-term effects of the system.

Taken together the evidence in this area provides a useful start in evaluating the impact of CPOE on pathology services. Many of the current data come from a few institutions with homegrown systems. There are still many questions that remain to be answered. CPOE has great potential to improve the functioning of pathology laboratories, and for that potential to be realised more research is needed.

Summary Points

What was known before this study?

- Computerised physician order entry (CPOE) systems hold out the promise of significant improvements in health care processes including increased compliance with guidelines and optimisation of clinical time
- These systems remain costly and complex to design and implement
- Few studies have evaluated the effect of CPOE systems on clinical outcomes
- Evidence of the effectiveness of computerised physician order entry (CPOE) systems have concentrated predominantly on medication order systems. Little research attention has been placed on pathology-based systems

What this study has added to the body of knowledge?

- A systematic review examining the impact of pathology order entry systems identified 19 studies which included some form of "control group" featuring a variety of research designs
- From these studies we found 10 areas of impact assessment and 39 indicators used to measure the impact of CPOE on different stages of the pathology ordering and reporting process
- There are data suggesting that CPOE systems are beneficial for clinical and laboratory work process. Few data however are available regarding the impact of CPOE on patient outcomes
- There remains a strong need for further research to provide robust evidence of the impact of CPOE systems on clinical and laboratory work processes

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