The Use of Computerized Provider Order Entry to Improve the Effectiveness and Efficiency of Coagulation Testing

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• **Effective pathology services require timely communication of patient-related information between the laboratory and clinicians. The aim of this study was to measure the effect of a computerized provider order entry (CPOE) system on the frequency with which clinicians notify the Hematology Laboratory of details on heparin or warfarin treatments when ordering activated partial thromboplastin time (aPTT) or the prothrombin time (PT) and international normalized ratio (INR). Although information about the total number of patients on warfarin or heparin was unavailable, it was possible to ascertain that the percentage of abnormal results for each year ranged from 39% in 2005 to 45%, 40%, and 38% in the years 2006 to 2008. The proportion of order requests that reported whether patients were on warfarin or heparin increased from 3% of the aPTT tests (253 of 8307) and 1.9% of the PT and INR requests (161 of 8433) in August through September 2005 (before the CPOE was implemented) to 3.9% (393 of 9990; $P < .001$) and 2.6% (282 of 10814; $P = .009$), respectively, in August through September 2008 (after CPOE implementation). During that period (2005–2008), the median turnaround time for the laboratory decreased from 28 to 21 minutes for the PT and INR test results ($P < .001$) and from 34 to 23 minutes for the aPTT test results ($P < .001$). The results show that CPOE and decision-support systems can enhance laboratory efficiency and improve its contribution to effective patient care.**

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A key component of the pathology laboratory's contribution to patient care is the integration of clinical and pathologic data and their translation into meaningful answers and advice to physicians and patients.[1] This information exchange, which requires timely communication across the hospital ward and pathology laboratory interface, is increasingly underpinned by sophisticated information technology systems that are required to ensure the safe and efficient integration and transmission of data. Computerized provider order entry (CPOE) systems, with their advanced information management and decision-support structures, provide an important platform for enhancing the contribution of pathology services to the achievement of quality patient care. Existing evidence of the effect of CPOE on pathology services has demonstrated its potential to deliver major efficiency and effectiveness gains, particularly through the use of electronic decision-support features embedded within the system. These benefits include major improvements in test turnaround times (TATs)[2] and reductions in the rate of unnecessary or redundant laboratory tests.[3]

Clinical decision support involves the achievement of an objective through the delivery of one or more pieces of knowledge or datum at a specific time and place.[4] Electronic decision support can take on many forms and different levels of sophistication, ranging from alerts to guidance on the choice of test, from messages prompting the provision of relevant patient-centered information to complex algorithms that can provide clinicians with guidance in diagnosis or treatment.[5] The ability of CPOE to improve the communication of important patient-related information across the ward-laboratory interface using decision-support mechanisms has yet to be widely demonstrated.[6] Moreover, the task of implementing electronic decision-support systems to suit clinical workflow processes is widely seen as difficult and complex.[7]

For many pathologic tests, the provision of accurate and timely patient information is critical to the choice of test, to its interpretation, and to its follow-up.[8] In hematology laboratories, activated partial thromboplastin time (aPTT) or prothrombin time (PT) and international normalized ratio (INR) tests screen patients for bleeding tendency. The results of these tests are rendered abnormal (at variance with a healthy pathophysiologic state)[9] if the patient is on an anticoagulant treatment of heparin or warfarin. On paper-based laboratory requests, the ordering clinician is expected to notify the laboratories, usually through a hand-written notation, whether the patient is ''On Warfarin'' or ''On Heparin.'' Matching that information with a test result explains the appearance of an abnormal finding and prevents the series of laboratory validation procedures that are triggered by the abnormal finding.

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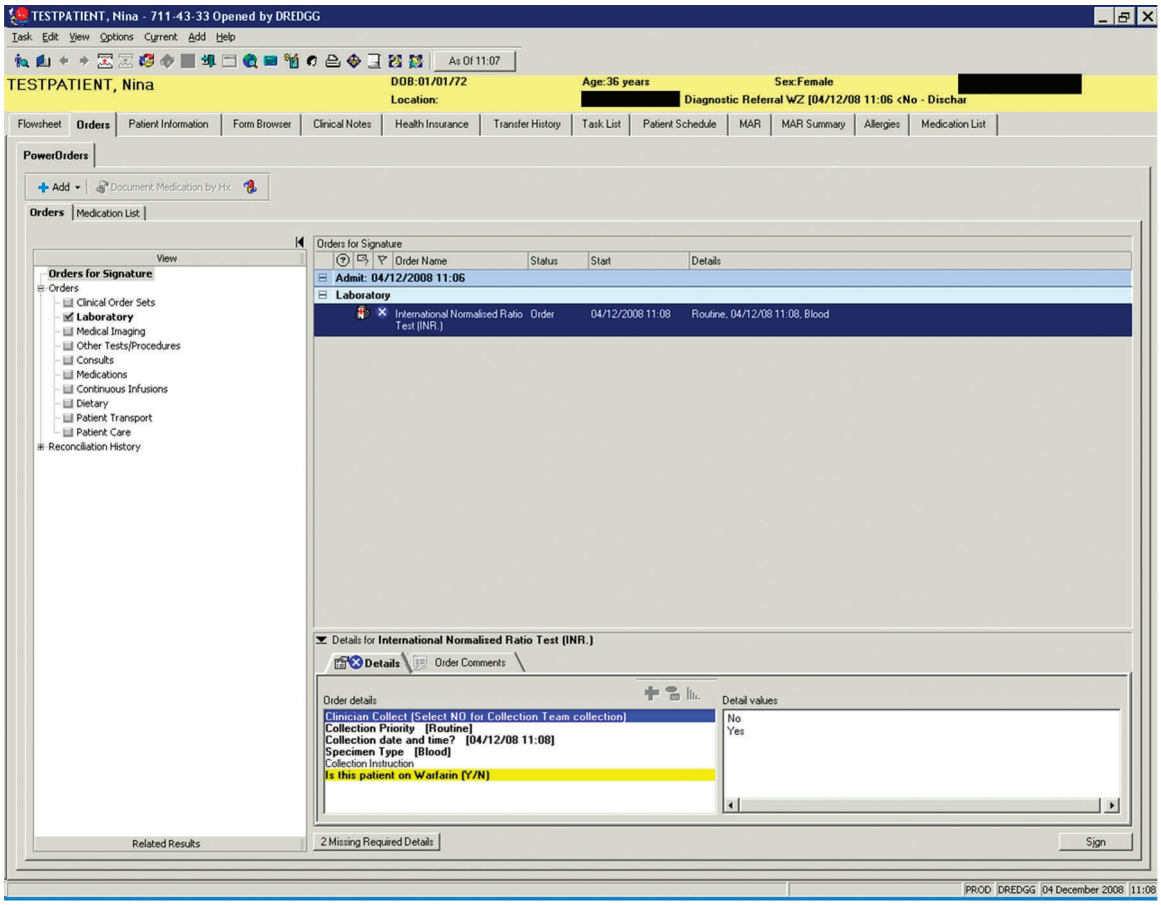

Shown is the electronic test-ordering screen that prompts for information about patient warfarin status.

These validation processes include the resubmission of the sample for further tests and review until the test result is verified and available. These processes also include a series of safe-practice guidelines to ensure the immediate and direct notification of the appropriate person responsible for taking action in response to an abnormal result.[10] Thus, the absence of information about a patient's heparin or warfarin status can lead to a sequence of potentially redundant procedures with significant time efficiency and cost consequences. The aim of this study was to measure the effect of a CPOE system on the frequency with which clinicians notify hematology laboratories about patients on heparin or warfarin treatment when ordering an aPTT or a PT or INR test and the subsequent effect on TATs.

MATERIALS AND METHODS

Research Setting

The study was conducted at a 660-bed teaching hospital in Sydney, New South Wales, Australia. The hospital houses a pathology service of more than 300 staff who service 7 hospitals across an area health service in metropolitan Sydney, Australia. The pathology service includes a Department of Hematology comprising about 35 (scientific, technical, and ancillary) staff with a workload that usually involves the processing of about 1200 to 1400 specimens per day. In November 2005, the hospital introduced the Cerner Corporation (Kansas City, Missouri) Millennium PowerChart (version 2004.01) CPOE into its workflow. This integrated system allowed physicians and other authorized clinicians to place orders electronically for a range of items, including pathology and medical imaging tests. Before the introduction of the CPOE system, clinicians were required to issue a handwritten request for a laboratory test, and the request was then transported (along with the blood specimen) to a central specimen reception area to be entered electronically by laboratory administration personnel into the (locally developed) laboratory information (and results reporting) system; then, the request and blood specimen were sent to the relevant laboratory department for processing. Any notations that indicated whether the patient was on heparin or warfarin were coded in the laboratory information system and became part of the autoverification procedures.

The information about a patient's heparin or warfarin status allows the laboratory to avoid a series of time-consuming validation and notification procedures, including the need to inform doctors of the existence of an abnormal test result, which can provide some valuable cost savings to the laboratory. After the introduction of the CPOE system, information about patients' warfarin or heparin status was requested as part of the test-ordering procedure in a free text field as illustrated in the Figure. If physicians entered yes to the question, the CPOE system triggered an automatic adjustment, which made further confirmation and validation procedures unnecessary. Because this information was placed in a free text field, the automatic response was only triggered when a yes response was recognized. In situations in which the physician may have entered the equivalent of a yes response, for example, ''on hep,'' laboratory staff were required to make a decision about whether the validation procedures were needed.

Procedures

Data relating to the provision of aPTT and PT and INR tests were extracted for the period of August 1 through September 30 for each year from 2005 (which provided baseline data of results before the introduction of the CPOE system) to 2008 (2.5 years

Table 1. Comparison of the Percentage of Activated Partial Thromboplastin Time (aPTT) and Prothrombin Time and International Normalized Ratio (PT/INR) Test Requests That Included Information About Patients' Heparin or Warfarin Status Before (2005) and After (2006–2008) Implementing a Computerized Provider Order Entry System

Test Parameter	aPTT and PPT/INR Test Requests, % (No.)				χ^2 Test (*df*)	*P* Value (2-Sided)
	2005 (n = 16 740)	2006 (n = 18 990)	2007 (n = 19 693)	2008 (n = 20 804)		
aPTT test request indicating patient was on heparin	3.0 (253 of 8307)	5.7 (518 of 9132)	4.6 (437 of 9523)	3.9 (393 of 9990)	78.1 (3)	<.001
PT/INR test request indicating patient was on warfarin	1.9 (161 of 8433)	2.5 (248 of 9858)	2.5 (254 of 10 170)	2.6 (282 of 10 814)	11.6 (3)	.009

after system introduction). Data from before the CPOE system was implemented were extracted from the previously existing, laboratory information system, and postimplementation data were gathered from the CPOE system. The study was approved by the Area Health Service and the University Human Research Ethics Committees.

Outcome Measures

The percentage of aPTT or PT and INR requests that reported heparin or warfarin treatment status were calculated for before and after the CPOE system was implemented. Laboratory TATs were defined as the time from receipt of a specimen in the Hematology Laboratory to the availability of a test result. As a means of controlling for the effect of extreme outliers, TATs were only included if they fell within the time limit of 1440 minutes (24 hours). This factor along with a small proportion of missing or incomplete data fields accounts for slight differences (of between 0.3% and 1.4%) between the total number of tests monitoring TATs and the corresponding total recording heparin or warfarin status across each year.

Analysis

The proportion of order requests that notified the laboratory about a patient's warfarin or heparin treatment status after implementation of the CPOE were compared using χ^2 analyses. Comparisons across the period from 2005 through 2008 were undertaken to examine differences in the median aPTT or INR and PT test TATs as a whole and then separately for normal and abnormal results. This analysis was performed using the Kruskall-Wallis test to compare values of 3 or more groups (ie, data by years, in this instance) across the continuous (TAT) variable. The interaction effect[11] of the provision of heparin and warfarin information on turnaround times for normal and abnormal test results was then tested using the 2-way between-groups analysis of variance. The Kolmogorov-Smirnov test of data normality was satisfied by limiting TAT data to those results greater than 0 and less than or equal to 76 minutes from the analysis. This allowed the analysis of the individual and the joint effect of 2 independent variables—the year and test status (normal or abnormal)—on the dependent TAT variable. This test provided a means of examining whether the notification of the patient's heparin or warfarin status may have also contributed to lowering the TATs.

RESULTS

Frequency of Warfarin and Heparin Notification

The proportion of aPTT or PT and INR test requests for which the Hematology Laboratory was notified that the patient was on heparin or warfarin increased significantly from the preimplementation period in 2005 and for each corresponding year up to 2008, as shown in Table 1. By 2008, the percentage of aPTT tests with information about heparin status had increased from 3% of aPTT tests (253 of 8307) in 2005 to 3.9% (393 of 9990) in 2008 ($P < .001$). During the same period, the percentage of requests with warfarin and heparin status included increased from 1.9% of all PT and INR test requests (161 of 8433) in 2005 to 2.6% (282 of 10814) in 2008 ($P = .009$). The number of abnormal aPTT or PT and INR test results, as a percentage of total tests during each year, varied from 39% in 2005 to 45%, 40%, and 38%, respectively, in each subsequent year (see Table 2).

Changes in TATs

Analysis of 2005 through 2008 records showed 16 630 aPTT and PT and INR tests requested in 2005, which increased to 20 873 by 2008. The median laboratory TAT for aPTT or PT and INR decreased significantly during that period (Table 2). The TATs for aPTT decreased 32.4%, from 34 minutes in 2005 to 23 minutes in 2008 ($P < .001$). During the same period, PT and INR TATs decreased 25.0%, from 28 to 21 minutes ($P < .001$). The TAT for normal test results decreased from 30 to 22 minutes (26.7%; $P < .001$) and for abnormal tests results from 33 to 23 minutes (30.3%; $P < .001$). The sharpest decrease in TAT occurred in 2006, the first year after the introduction of CPOE, with TAT decreasing 20.6% (−7 minutes) for aPTT, 14.3% (−4 minutes) for PT and INR, 16.7% (−5 minutes) for normal results, and 21.2% (−7 minutes) for abnormal results. Following a further drop between 2006 and 2007, the figures thereafter stabilized across each of the categories in 2007 and 2008. The 2-way between-groups analysis of variance revealed a statistically significant main effect for TATs by year ($F = 876$, $df = 3$, n = 73 522; $P < .001$) and for

Table 2. Comparison of Turnaround Times (TATs) for Activated Partial Thromboplastin Time (aPTT) and Prothrombin Time and International Normalized Ratio (PT/INR) Tests Before (2005) and After (2006–2008) Implementing a Computerized Provider Order Entry System

Test Parameter	Median TAT				Kruskall-Wallis Test, χ^2 (*df*)	*P* Value
	2005 (n = 16 630)	2006 (n = 18 830)	2007 (n = 19 416)	2008 (n = 20 873)		
aPTT test, min (No.)	34 (8249)	27 (9070)	23 (9403)	23 (10 033)	1977.5 (3)	.001
PT/INR test, min (No.)	28 (8381)	24 (9760)	21 (10 013)	21 (10 840)	936.7 (3)	.001
Normal results, min (No.)	30 (10 117)	25 (10 375)	22 (11 742)	22 (12 837)	1196.6 (3)	.001
Abnormal results, min (No.)	33 (6513)	26 (8455)	23 (7674)	23 (8036)	1580.8 (3)	.001
Abnormal results, % (No.)	39 (6513)	45 (8455)	40 (7674)	38 (8036)		

abnormal or normal result ($F = 123$, $df = 1$, n = 73 522; $P < .001$). There was also a significant interaction effect of year and abnormal or normal test result groups ($F = 948$, $df = 3$, n = 73 522; $P = .002$), which indicated that the decrease in TATs across each year was also affected by the differences in TATs with abnormal or normal test results.

COMMENT

The introduction of a structured screen prompting clinicians ordering aPTT or PT and INR tests to specify whether the patient was on heparin or warfarin treatment was associated with a significant increase in the proportion of such notifications when compared with the previous handwritten system, which relied on the physician remembering to provide that information. The CPOE was also associated with a significant decrease in TATs for aPTT and PT and INR test results. The monitoring of TATs can be influenced by many factors involving technologic (eg, laboratory equipment) and social factors (staff availability).[12] In this study, the provision of patient heparin or warfarin status to the laboratory was examined for its effect on normal and abnormal test TATs, both of which were found to have decreased significantly and contributed to an interaction effect on the overall decrease in TATs caused by the introduction of the CPOE. This is because information about a patient's heparin or warfarin status automatically triggered a faster and more efficient validation process.

Inadequate communication can be a major source of poor-quality patient care. Safe-practice procedures for dealing with critical test results have emphasized the importance of robust, standardized report processes across the laboratory and hospital ward interface,[10–13] including the identification of the responsible physician and the establishment of uniform communication policies. These procedures contribute to the goal of fostering shared accountability and teamwork across and among clinical disciplines.[8–11] These safe-practice processes can be enhanced by the timely notification of clinically relevant information to the laboratories, which can aid the laboratory's contribution to effective patient care.[14]

The introduction of electronic prompts, structured screens, and decision support in clinical settings can be challenging. There is no guarantee that the provision of such electronic support will be used effectively, if at all.[15] Successful decision support systems rely on several factors, including its usability, its perceived relevance, and even its design and presentation.[4] In this study, the information prompts in the CPOE system enhanced the provision of information, which previously relied on physicians remembering to provide the information. These results demonstrate that electronic support screens can improve communication across the ward and the laboratory and lead to efficiency gains with tangible benefits to patients reliant on the timely arrival of test results for the safe and appropriate monitoring of their treatment.

Limitations

This study compared the frequency of heparin and warfarin notifications on handwritten laboratory and electronic orders using data extracted from the laboratory and hospital information systems. No data reporting the underlying prevalence of hospital patients on heparin and warfarin were available. It is theoretically possible that the rise in heparin and warfarin notifications to the laboratory were a consequence of a dramatic rise in the number of patients on those treatments and not the effect of the CPOE system. However, senior clinical and laboratory personnel we consulted did not believe that there had been any such shift in the number of patients on warfarin and heparin. Moreover, if that had been the case, that increase should have been reflected by parallel changes in the number of abnormal test results as a proportion of total tests, which was not the case (Table 2).

CONCLUSION

Improvements in the efficiency of coagulation testing, in the form of well-designed screen formats and electronic decision-support prompts, can enhance a laboratory's contribution to effective patient care. The results in this article also indicate that the implementation and sustainability of a decision-support system is part of a hospital-wide process, and pathology laboratories are crucial in enhancing the design and monitoring the relative merits of different electronic-support features.

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