The Impact of Peer Management on Test-Ordering Behavior

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Background: **Laboratory testing of hospitalized patients, although essential, can be expensive and sometimes excessive. Attempts to reduce unnecessary testing have often been difficult to implement or sustain.**

Objective: **Use of peer management through a resource utilization committee (RUC) to favorably modify test-ordering behavior in a large academic medical center.**

Design: **Interrupted time-series study.**

Setting: **Medical center with inpatient care provider order entry (CPOE) system and database of ordered tests.**

Participants: **Predominantly housestaff physicians but all clinical staff (attending physicians, housestaff, medical students, nurses, advance practice nurses, and other clinical staff) at Vanderbilt University Hospital who used CPOE systems.**

Intervention: **The RUC analyzed the ordering habits of providers during previous years and made 2 interventions by modifying software for the CPOE system. The committee first initiated a daily prompt in the system that asked providers whether they wanted to discontinue tests scheduled beyond 72 hours. After evaluating this first intervention, the committee further constrained testing options by unbundling serum metabolic panel tests (sodium, potassium, chloride, bicarbonate, glucose, blood urea nitrogen, and creatinine tests) into single components and by reducing the ease of repeating targeted tests (including electrolyte, blood urea nitrogen, creatinine, and glucose tests; electrocardiography; and portable chest radiography).**

Measurements: **Pre- and postintervention volumes of tests; proportion of patients with abnormal targeted chemistry levels after 48 hours; rates of repeated admission, transfer to intensive care units, and mortality; adjusted coefficient of variation for test ordering; and length of stay.**

Results: **Voluntary reduction of testing beyond 72 hours (first intervention) decreased orders for metabolic panel component tests by 24% ($P = 0.02$) and electrocardiograms by 57% ($P = 0.006$) but not orders for portable chest radiographs. Prospective constraints on recurrent test ordering with panel unbundling (second intervention) produced an additional decrease of 51% for metabolic panel component tests ($P < 0.001$) and 16% for portable chest radiographs ($P = 0.03$). Incidence of patients with abnormal targeted blood chemistry levels after 48 hours decreased after the intervention ($P = 0.02$). Postintervention-adjusted coefficients of variation decreased for metabolic panel component tests ($P = 0.03$) and electrocardiography ($P = 0.04$). Rates of (adjusted) monthly readmission, transfers to intensive care units, hospital length of stay, and mortality were unchanged.**

Limitations: **Other activities occurring during the time period of the interventions might have influenced some test-ordering behaviors, and we assessed effects on only a limited number of commonly ordered tests.**

Conclusions: **Peer management reduced provider variability by addressing the imperfect ability of clinicians to rescind testing in a timely manner. Hospitals with growing health care costs can improve their resource utilization through peer management of testing behaviors by using CPOE systems.**

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*For a list of members of the Resource Utilization Committee, see Appendix, available at www.annals.org.

Providers of clinical care order excessive tests for hospitalized patients for defensive reasons (1) or ease of access (2) or because they cannot manage the fear of uncertainty (3, 4). Excessive ordering increases the use of technology and adds unnecessary costs to the delivery of health care. Motivated by studies demonstrating substantial variation in testing behaviors among providers (2, 5–14), inappropriate or unnecessary testing (15–23), and test addiction (24–26), investigators over the past decade have tried to impose sustainable limits on diagnostic evaluations. However, many recommended approaches are too time-consuming (27), difficult to scale across an institution (28), counterproductive to training (29), detrimental to clinical decision making (26), or inappropriately intrusive (26). One study suggested that short-term reductions in the amount of testing were not sustainable (30). In a review of various approaches to limit testing, Solomon and colleagues (24) noted that multifaceted interventions are most likely to succeed.

The Institute of Medicine (31, 32) and industry leaders (33, 34) recently advocated the use of information systems to improve health care delivery, especially in the area of care provider order entry (CPOE) (35). Several studies document that computer-based reminders (25, 36–38) and "just-in-time" decision support (39) improve test-ordering practices. Care provider order entry systems also are an effective way to manage and implement change (38, 40) and can be used to reduce variability in provider behavior (41).

Citing an alarming increase in the use of expensive or duplicate testing, the Vanderbilt University Medical Center, Nashville, Tennessee, chartered a resource utilization committee (RUC) to reduce variability in laboratory testing, imaging, and formulary use without restricting access

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to necessary or reasoned inquiry. Members of the committee included many clinical leaders in the institution (Appendix, available at www.annals.org). The committee first identified specific patterns of excessive resource utilization in the hospital and subsequently devised several interventions using CPOE to reduce repetitive testing. The institutional review board approved the study, and the need for informed consent was waived.

Context

Can simple electronic aids help physicians reduce unnecessary, costly test ordering?

Contribution

In this interrupted time-series study from a large academic hospital, a committee of peer leaders selected ways to use their care provider order entry (CPOE) system to reduce unnecessary test ordering. Computer prompts questioning repetitive orders for routine tests and unbundling of tests within metabolic panel tests both reduced test orders. Patient readmission rates, length of stay, transfer to intensive care units, and mortality rates remained stable.

Implications

Peer-designed interventions using CPOE systems can improve provider test-ordering behavior.

–The Editors

Methods

Study Sample

Vanderbilt University Hospital is a 658-bed tertiary care facility that houses 2 floors of the Vanderbilt Children's Hospital. During the study period (1999 to 2001), more than 10 000 orders were placed daily through the use of CPOE systems from 35 of the 37 patient care units; these 35 units cover approximately 600 beds of the hospital. The pediatric and neonatal intensive care units (ICUs) were not using CPOE systems during this interval. The study sample consisted of attending physicians, housestaff, medical students, nurses, advance practice nurses, and other clinical staff at Vanderbilt University Hospital who used CPOE systems. Physicians directly entered 70% of orders, and other members of the patient care team entered the remainder of orders.

Care Provider Order Entry

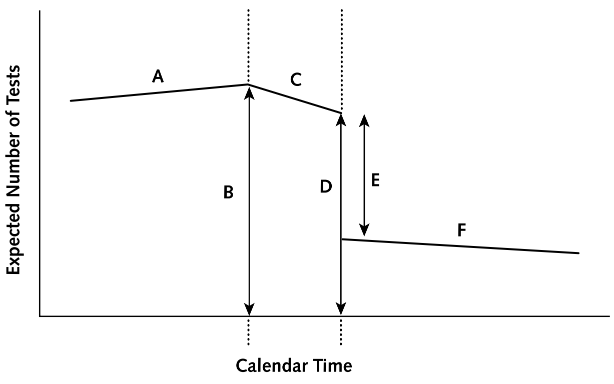
Like many systems, our CPOE system processes test orders as follows. First, a provider enters an order with a specified duration of recurrences. Second, the system generates up to 1 week of orders for individual tests. Third, each test is performed as scheduled unless a provider cancels subsequent occurrences. Finally, for recurring orders still active after each week, the software queues up a subsequent week of individual occurrences.

Resource Utilization Committee Interventions

To determine how and where to intervene, the RUC analyzed past CPOE log files for testing patterns and used bibliographic resources and its own expertise to determine optimal strategies for ordering individual tests. From December 1999 through the study period, during weekly to monthly committee meetings with all RUC members invited, the committee reviewed CPOE summary data that indicated the volume of laboratory, radiology, and cardiology tests that were ordered per month on each hospital ward. This was done prospectively to identify opportunities for intervention and was also done after the intervention to determine effectiveness. (No study intervention described in this paper was changed on the basis of this feedback, although the transition from the first intervention method to the second intervention method was catalyzed by such analysis.) Physician behaviors were not analyzed individually. Simple RUC member consensus after committee discussions determined which interventions to implement—informed by the data, the expertise of the chiefs of the clinical services serving on the RUC (who at times also consulted faculty experts within their departments and the literature), and the informatics faculty members of the RUC (who could speak to feasibility of various proposed CPOE-based interventions). In designing the educational components of the interventions, various RUC members (or their "expert" faculty designees within their departments) often provided "literature-based synopses of evidence" that were converted to hypertext markup language (HTML) documents and made available through the CPOE system at ordering time. Individuals creating such documents were responsible for regularly reviewing them to keep their content current. The first RUC intervention was implemented on 5 December 1999 as a broad attempt to reduce open-ended test ordering beyond 72 hours in the future. Each morning, the CPOE system would display a pop-up message that listed orders for scheduled laboratory tests, radiography, and electrocardiography extending beyond 72 hours. The pop-up prompted the provider to choose whether to continue the order, discontinue the order, or defer a decision until later in the day. If the provider chose to continue or discontinue the order, no other provider would receive pop-up reminders about that order until possibly the next day.

The second RUC intervention involved several specific ordering constraints. The RUC reasoned that most repetitive orders for routine blood tests, radiology, and electrocardiography could not be justified without an intervening bedside visit. They then developed several specific ordering constraints. First, individual orders were limited to 1 occurrence in a fixed period of time. Second, the metabolic panel was unbundled and could be ordered only as individual components. Third, a graphical display of results from the previous week was placed on the ordering page for frequently ordered serum chemistry tests. This display

Figure 1. **Model for test-ordering behavior.**



This graph describes the major components of the model used for analyzing test-ordering behavior after 2 Resource Utilization Committee interventions. The dotted lines indicate the times when the 2 interventions were initiated. The slope of lines A, C, and F give the change in number of tests ordered per day in the baseline period, between the interventions, and after the second intervention, respectively. The magnitude of lines B and D corresponds to the expected number of weekday daily orders at the first intervention and just before the second intervention, respectively. Line E is the overnight decrease in expected orders after the second intervention. This model has a hinge point at the first intervention and a discontinuity at the second intervention. The daily hospital census and terms to handle the decrease in orders on weekends before and after the second intervention, respectively, are also included in the model. Random variation in order rates was modeled by a time-series analysis. This model was selected by using standard data-fitting techniques.

made it difficult to claim that previous results were unknown at the time when additional tests were ordered.

On 20 January 2000, the RUC initiated the second intervention by making all portable chest radiography orders "one-time only." Starting on 1 February 2000, electrocardiograms could be ordered only "once or twice in 8 hours" per individual order. Providers still could order more electrocardiograms or portable chest radiographs by entering additional one-time orders with different start dates and times. On 21 March 2000, the RUC also implemented specific ordering constraints for unbundled components of the serum metabolic panel: Sodium, potassium, chloride, bicarbonate, and glucose tests could be ordered once or at recurring intervals up to hourly but not beyond 24 hours; blood urea nitrogen (BUN) or serum creatinine tests could be ordered only once in 24 hours. Orders for a complete blood count were not constrained during this second intervention period so that the complete blood count test could be used as a control for ordering behavior.

Statistical Analysis

The RUC examined 2 methods of counting test orders: on the basis of the day tests were first ordered or on the basis of the day tests were intended to occur. Because providers frequently enter orders to discontinue tests, the RUC defined "net orders" as the number of tests not discontinued before their time of occurrence. Some tests could be ordered as panels, so that a metabolic panel contributed 7 tests (sodium, potassium, chloride, bicarbonate, glucose, BUN, and creatinine tests) to the overall count of ordered component tests, whereas a portable chest radiograph or electrocardiogram counted as 1 test each.

The data were evaluated by using interrupted time-series analyses. Patient name, individual ordering provider, and attending physician were not identified as part of the analysis. Each order was assessed in 3 ways to account for all possible outcomes. First, we noted the date that the order was written to determine whether constraining the duration of the order resulted in increased daily ordering. Second, we analyzed the daily number of net orders to approximate the number of ordered tests performed each day. Third, we counted the number of tests "resulted" in our institutional data repository to determine the actual number of tests performed. We ultimately used orders rather than test results as our primary measure because log file review revealed that net orders for a test closely reflected the actual number of tests performed and because tests ordered during system downtime were not subject to the intervention.

The primary outcome was the daily number of new tests ordered and discontinued. Every CPOE order for each targeted test was considered. We evaluated the data by using a series of autoregressive integrated moving average models (42, 43). These time-series models allow for the fact that the numbers of tests ordered on adjacent days tend to be correlated. In building these models, we were guided by improvements in measures of goodness of fit (model deviance), as well as by residual analyses and scatter plots. Optimal fits were obtained with first-order autoregressive and moving average components. Goodness of fit improved statistically by adding the daily patient census and a variable that flagged weekend days. Exploratory analyses suggested that a change in trends of order rates occurred at the first intervention with a sharp reduction in orders at the second intervention. We therefore added parameters to the model that permitted a hinge point at the first intervention and a discontinuity at the second intervention (**Figure 1**).

We further improved the model by including separate parameters to represent the weekend effect before and after the primary intervention. Potential confounders that we considered but did not include in our final model were the mean length of hospital stay, proportion of male patients, proportion of patients who died, and mean patient age. None of these variables appreciably affected the goodness-of-fit statistics or the model parameter estimates. We derived 95% CIs and P values by using Wald statistics (44). We used the Huber–White sandwich estimator of variance to estimate the standard errors of the model parameters (45, 46).

We measured (for pre- and postintervention periods) the proportion of patients who had a "potentially clinically significant" abnormality in serum sodium, serum potassium, or serum creatinine levels more than 48 hours after the first time each test was measured. We measured this to assess whether study interventions caused altered testing patterns that placed patients at risk for "missed" early detection of trends that may lead to potentially clinically significant laboratory abnormalities during hospitalization. We chose the 48-hour interval to allow for stabilization after admission. We defined "potentially clinically significant" derangements as serum potassium levels less than 3.0 mmol/L or greater than 6.0 mmol/L (normal level in our laboratory, 3.5 to 5.0 mmol/L), serum sodium levels less than 128 mmol/L or greater than 152 mmol/L (normal level in our laboratory, 135 to 145 mmol/L), and serum creatinine levels increasing by more than 88.4 μmol/L (1.0 mg/dL) over the maximum value observed during the first 48 hours of its measurement (normal creatinine level in our laboratory for men, 61.9 to 132.6 mol/L [0.7 to 1.5 mg/dL]). We assessed differences in these incidence rates in the pre- and postintervention periods by using normal approximations to their respective binomial distributions.

Measurements for monthly discharges, case-mix index, length of stay, readmission rates, ICU transfer rates, and mortality rates were obtained from institutional demographic databases by using the last 4 months before the first intervention and the first 8 months after the second intervention. We evaluated comparisons between monthly mortality rates and readmission rates adjusted for case-mix index by using the Kruskal–Wallace nonparametric analysis of variance.

Role of the Funding Source

The Vanderbilt University Medical Center, including Vanderbilt University Hospital, School of Medicine, and Vanderbilt Medical Group, financially supports and warehouses the CPOE system databases. The Vanderbilt University Medical Center's senior administration played no role in conceiving this study and did not ask to be involved in its analysis or interpretation. The RUC invited comments on this article from the administration, and those invited readers support its findings.

Results

Figure 2 and **Table 1** report the effects of the 2 RUC interventions on test-ordering behavior. The preintervention period had a mean of 3766 component electrolyte, glucose, BUN, or creatinine tests ordered per day. Late in this baseline period, ordering decreased slightly by 1.2 tests per day ($P = 0.006$). After the first intervention, the expected average number of components of the metabolic panel test ordered per day decreased from 3701 tests to 2781 tests per day, with daily orders decreasing by 7.8 tests per day during this interval. This rate of decrease was significantly greater than that observed in the baseline period ($P = 0.02$). The second intervention caused a further decrease in the number of ordered electrolyte, glucose, BUN, and creatinine tests almost overnight, with the daily rate dropping by 51% from an expected rate of 2781 tests per day to a mean postintervention rate of 1348 tests per day ($P < 0.001$). We did not observe any further changes in test-ordering trends. A separate analysis confirmed a similar decrease in the order rates when counting the intended performance date of each occurrence or discontinuation (data not shown).

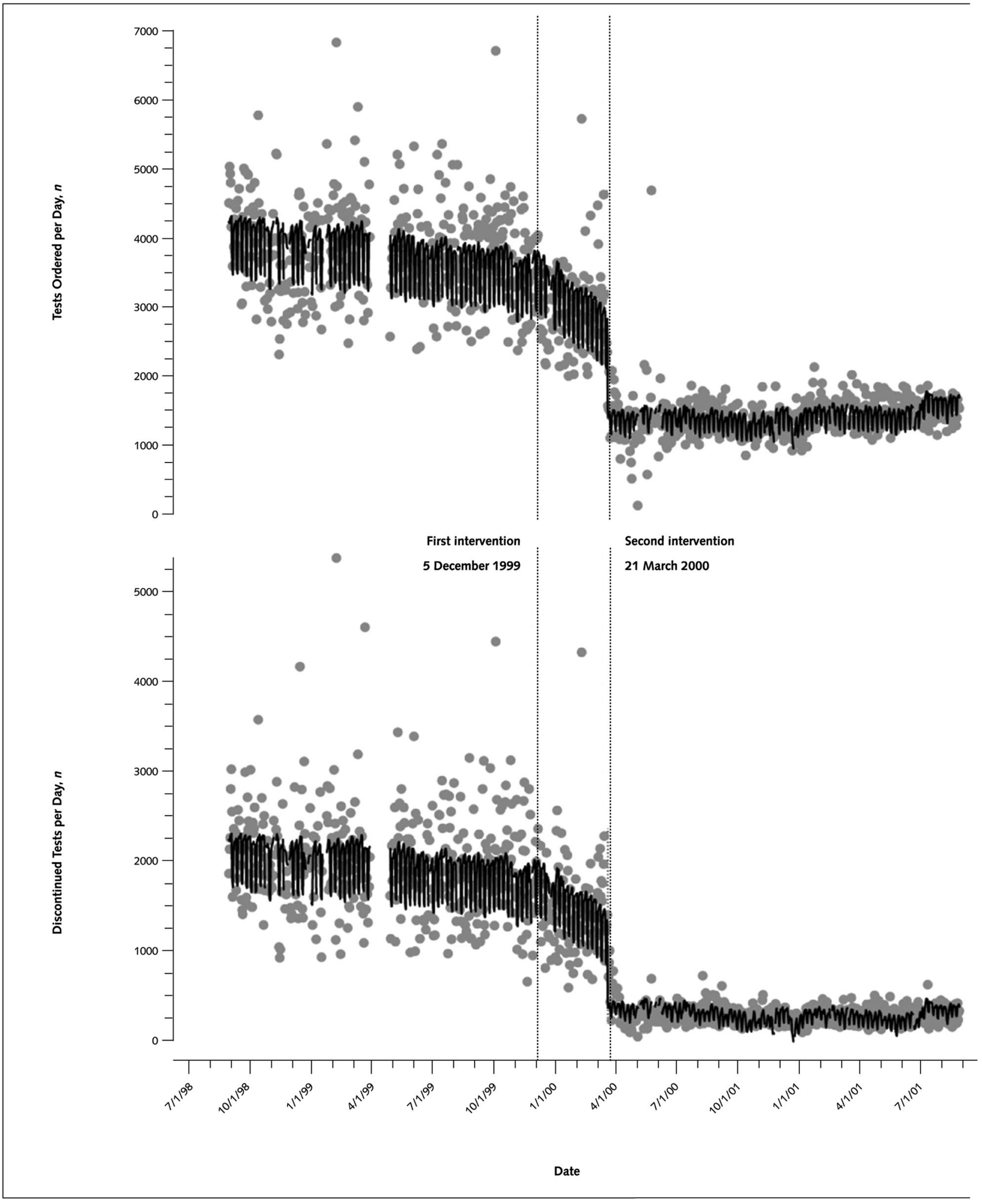
The second intervention also was accompanied by a major and immediate decrease in orders discontinued per day (**Figure 2** and **Table 2**), from an expected rate of 1298 electrolyte, glucose, BUN, and creatinine tests per day to 307 tests per day ($P < 0.001$). An additional downward trend of 0.4 discontinued test per day occurred ($P < 0.001$). When the effect of discontinuing an order was considered, the first intervention continued to influence net ordering by decreasing the expected mean net ordered components of the metabolic panel from 1803 per day to 1438 per day ($P < 0.006$). The second intervention decreased the net number of ordered electrolyte, glucose, BUN, and creatinine tests by an additional 409 tests per day ($P < 0.001$). The average net ordered electrolyte, glucose, BUN, and creatinine tests per day after the second intervention was 1124 tests. The expected proportion of tests that were discontinued decreased from 47% just before the second intervention to 23% just after it.

Instituting the first intervention for portable chest radiography resulted in no statistically significant change in ordering behavior (**Table 1**). However, the second intervention, limiting orders for portable chest radiography to one at a time, immediately decreased the rate of portable chest radiography ordered by 18.6 tests per day ($P = 0.03$). During the preintervention period, orders for electrocardiography averaged 62 orders per day with a small downward trend (−0.04 per day; $P = 0.006$) and a greater downward trend after implementing the first intervention (−0.32 per day; $P = 0.03$). No additional decrease in electrocardiogram orders occurred with the second intervention.

The adjusted coefficient of variation in net daily ordering rates for electrolyte, glucose, BUN, and creatinine tests and for electrocardiography was reduced after the first and second interventions by 32% ($P = 0.03$) and 52% ($P = 0.04$), respectively. We also observed a 26% reduction in adjusted coefficient of variation for net portable chest radiograph orders that was not statistically significant.

After the first intervention (**Table 1**), complete blood count ordering decreased by 5.1 orders per day ($P < 0.001$). Similar effects were noted for complete blood count orders analyzed by intended performance date and discontinuations (data not shown). After the second intervention on metabolic panel components, portable chest radiography, and electrocardiography, no collateral effects occurred on the average daily rates, ordering trends, or discontinuations of complete blood counts. **Table 2** compares the case-mix index–adjusted length of stay, hospital readmission, mortality, and ICU transfer rates before and

Figure 2. **Effect of the resource utilization committee (RUC) interventions on ordering components of the metabolic panel test.**



Scatter plots of numbers of serum metabolic panel tests (sodium, potassium, chloride, bicarbonate, glucose, blood urea nitrogen, and creatinine tests) ordered or discontinued daily before and after each of the 2 RUC interventions. The lines give the expected number of tests on each day. Tests dramatically decreased on weekends, particularly in the preintervention period. The vertical lines connect orders on Fridays to the following Saturdays and on Sundays to the following Mondays. The break in baseline date indicates the days during the pre-2000 conversion of the pathology laboratory system, a period during which data were not readily available.

Table 1. **Effect of Interventions on Ordering Metabolic Panel Tests, Complete Blood Count Orders, Chest Radiography, and Electrocardiography**

Test Variable*	Orders Entered		Orders Discontinued		Net Orders	
	Orders, *n*	*P* Value	Orders, *n*	*P* Value	Orders, *n*	*P* Value
Metabolic panel†						
Mean daily orders during baseline interval	3766		1929		1837	
A. Trend in the baseline daily order rate	−1.24	0.006	−0.744	0.003	−0.432	0.006
B. Expected tests at end of baseline interval	3701		1920		1803	
C. Trend in daily order rate between interventions	−7.83	0.02	−5.20	0.005	−3.04	0.006
D. Expected tests just before second intervention	2781		1298		1439	
E. Overnight decrease in orders after second intervention	−1433	<0.001	−991	<0.001	−409	<0.001
F. Trend in the postintervention daily order rate	−0.0595	>0.2	−0.436	<0.001	0.317	0.002
Mean daily orders after second intervention	1369		245		1124	
Complete blood count						
Mean daily orders during baseline interval	1774		934		840	
A. Trend in the baseline daily order rate	−0.229	>0.2	−0.126	>0.2	−0.0960	0.18
B. Expected tests at end of baseline interval	1828		991		844	
C. Trend in daily order rate between interventions	−5.12	<0.001	−3.53	<0.001	−1.93	<0.001
D. Expected tests just before second intervention	1230		581		611	
E. Overnight decrease in orders after second intervention	−65.8	>0.2	−83.2	>0.2	60.5	0.17
F. Trend in the postintervention daily order rate	−0.126	>0.2	−0.288	0.008	0.104	0.13
Mean daily orders after second intervention	1147		429		717	
Portable chest radiography						
Mean daily orders during baseline interval	128		40.6		87.0	
A. Trend in the baseline daily order rate	−0.0844	<0.001	−0.0409	0.001	−0.0440	0.001
B. Expected tests at end of baseline interval	114		34.2		80.0	
C. Trend in daily order rate between interventions	−0.392	0.18	−0.140	0.47	−0.240	>0.2
D. Expected tests just before second intervention	94.1		27.3		67.2	
E. Overnight decrease in orders after second intervention	−18.6	0.03	−15.9	0.002	−2.93	>0.2
F. Trend in the postintervention daily order rate	0.00996	>0.2	−0.00718	0.04	0.0152	0.01
Mean daily orders after second intervention	75.8		8.746		67.1	
Electrocardiography						
Mean daily orders during baseline interval	62.7		22.7		40.0	
A. Trend in the baseline daily order rate	−0.0438	0.006	−0.0268	0.008	−0.0169	0.005
B. Expected tests at end of baseline interval	55.3		17.6		38.1	
C. Trend in daily order rate between interventions	−0.324	0.03	−0.193	0.05	−0.170	0.007
D. Expected tests just before second intervention	35.9		6.261		27.2	
E. Overnight decrease in orders after second intervention	0.815	>0.2	−0.442	>0.2	3.78	0.15
F. Trend in the postintervention daily order rate	−0.00823	0.11	−0.00399	0.04	−0.00675	0.002
Mean daily orders after second intervention	33.3		4.62		28.7	

* See Figure 2 for more precise definitions of these variables. For variables A, E, and F, tests null hypothesis that the corresponding parameter value equals 0. For variable C, tests null hypothesis that the baseline trend equals the trend between the interventions.
† Metabolic panel tests were sodium, potassium, chloride, bicarbonate, glucose, blood urea nitrogen, and creatinine tests.

after intervention. No measures showed a statistically significant change. **Table 3** shows the percentages of patients who had a potentially clinically significant laboratory abnormality in serum potassium, sodium, or creatinine levels at least 48 hours after the first measurement. We compared the rates before the first intervention to those after the second intervention. For each test, the incidence of such abnormal values did not substantially differ before and after our interventions. However, the proportion of patients who had at least 1 abnormal value after the intervention significantly decreased ($P = 0.02$).

Discussion

We observed a dramatic and sustained decrease in test-ordering behavior by constructing a multistep intervention using peer management of a CPOE system. This approach produced a conforming effect on the variability in test ordering by providers while satisfying many best clinical practices (24, 27, 47–52). The programming changes to the CPOE system targeted individual clinical decisions and altered the methods for test ordering without preventing clinicians from ordering the tests they wanted. Our approach was reasonably unobtrusive to the decision makers.

The observed decrease in test-ordering behavior and the decrease in provider variability are simple to explain. Before the RUC interventions, providers were ordering large numbers of automatically recurring tests as a matter of convenience or compulsion and relied on clinical acumen, patient discharge, or their memories to discontinue

Table 2. **Effect of Resource Utilization Committee Interventions on Quality Measures***

Measured Events	Preintervention	Postintervention
Discharges per mo, *n*	2573	2624
Average monthly CMI	1.652	1.766
CMI-adjusted monthly mortality rates, %	1.7	1.8
CMI-adjusted readmission rates, %	2.3	2.0
CMI-adjusted monthly ICU transfer rates, %	4.6	4.7
CMI-adjusted monthly length of stay, *d*	3.1	2.9

* CMI = case-mix index; ICU = intensive care unit.

those orders. Allowing providers to order recurring tests facilitates excessive testing because of the fallibility of humans. This fallibility has been documented repeatedly over the past 25 years (53).

The CPOE system used at Vanderbilt University Hospital to implement peer management is not unique. Although approximately 10% of hospitals have implemented frequently used CPOE systems to replace written orders or clerical order entry (54), such systems are increasing available nationally. We have a tremendous opportunity to better track and modify provider habits by using CPOE systems (41). If the results of the present study were generalized to other hospitals where ordering repeated tests is permissible, up to 25% of high-volume laboratory testing, electrocardiograms, and radiographs may be eliminated nationally. Because payments for hospitalization based on diagnostic-related groups or per diem contracts are fixed, a reduction in unnecessary testing that maintains quality of care would benefit hospital finances or resource capacity.

We examined various quality measures for clinical outcome. Our approach was not associated with any statistically significant changes in length of stay, repeated hospitalization rates, internal ICU transfer rates, or hospital mortality rates, although we could not assess outpatient deaths. We also tested for a change in the frequency of reporting severely abnormal values for serum potassium, sodium, or creatinine levels. None was found. The average reporting for all severe abnormal values decreased slightly. Thus, we found no evidence that unlimited testing in the preintervention period resulted in better outcome measures. While other refined measures of quality outcome could be imagined, our reported variables did not detect any internal adverse events from RUC intervention.

Several potential issues or limitations of our study merit comment. First, we used historical test-ordering behavior to determine the magnitude of change from each respective intervention. For example, we interpreted the minimal decrease in repeated test ordering late in the preintervention period as evidence of early behavior modification by some providers who were aware of the locally announced RUC mandate to reduce testing. Although the magnitude of the effect caused by RUC interventions is compelling, other events in our hospital might have affected ordering behavior. However, our time-series analyses used complete blood count ordering as a comparison for the second intervention and disclosed no changes at the very time when CPOE interventions affected targeted tests. This finding suggests that RUC intervention was directly responsible for the change in ordering behavior. Second, we did not formally measure provider satisfaction with the ordering process before or after the interventions. Anecdotally, however, through weekly interactive sessions with CPOE users and reviewing on-line complaints, we received several grumblings about the intrusiveness of the first intervention but not for the second intervention or thereafter. Third, the experience level of the providers and their consultants affects test-ordering behavior, and we did not try to measure changes in this dynamic over time. We hope that everyone learned something about provider variability in the process. Finally, our report addresses only a limited number of the tests that are performed. Other successful interventions on tests that are performed less frequently or outsourced might provide additional benefit.

Our study therefore supports the use of peer management and CPOE systems to change test-ordering behavior (24, 25, 36–39, 55). We also believe the composition of the RUC was essential to our success. The presence of senior leadership from the major clinical services ensured that recommendations for modifications of CPOE were rational and within the scope of best practice. The committee used consensus to achieve maximal support for implementation decisions. Our results are consistent with a

Table 3. **Rates of Statistically Significantly Abnormal Serum Chemistry Levels before and after Interventions**

Abnormal Value*	Abnormal Value Rate per 100 Patients, %		Rate Difference (95% CI), *percentage points*
	Preintervention	Postintervention	
Potassium level > 6.0 mmol/L	2.12	1.96	−0.16 (−0.68 to 0.36)
Potassium level < 3.0 mmol/L	3.39	3.21	−0.18 (−0.84 to 0.47)
Sodium level > 152 mmol/L	0.94	0.92	−0.02 (−0.38 to 0.34)
Sodium level < 128 mmol/L	2.40	2.16	−0.24 (−0.80 to 0.32)
Creatinine level increasing > 88.4 μmol/L (>1.0 mg/dL)	2.34	2.23	−0.11 (−0.66 to 0.44)
Abnormal value for any of the above tests†	8.29	7.16	−1.13 (−2.10 to −0.16)

* Abnormal laboratory value obtained more than 48 hours after the first reported laboratory result.
† $P = 0.02$.

previous study conducted under the auspices of performance improvement (56) that documented a smaller effect in reducing outpatient testing. The duration of our data collection coupled with persistent intervention demonstrates the sustainable nature of behavioral change.

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