Reducing Unnecessary Inpatient Laboratory Testing in a Teaching Hospital

Todd A. May, MD,[1,2] Mary Clancy, CLS, MS,[3] Jeff Critchfield, MD,[4,5] Fern Ebeling, RN,[6] Anita Enriquez, RN,[7] Carmel Gallagher, RN,[8] Jim Genevro,[6] Jay Kloo, RN,[7] Paul Lewis, RN,[7] Rita Smith, RN,[7] and Valerie L. Ng, PhD, MD[3,9]

Key Words: Informatics; Economic evaluation; Clinical pathology; Phlebotomy; Management; Administration; Generalist

DOI: 10.1309/WP59YM73L6CEGX2F

Abstract

After an inpatient phlebotomy–laboratory test request audit for 2 general inpatient wards identified 5 tests commonly ordered on a recurring basis, a multidisciplinary committee developed a proposal to minimize unnecessary phlebotomies and laboratory tests by reconfiguring the electronic order function to limit phlebotomy–laboratory test requests to occur singly or to recur within one 24-hour window. The proposal was implemented in June 2003. Comparison of fiscal year volume data from before (2002-2003) and after (2003-2004) implementation revealed 72,639 (12.0%) fewer inpatient tests, of which 41,765 (57.5%) were related directly to decreases in the 5 tests frequently ordered on a recurring basis. Because the electronic order function changes did not completely eliminate unnecessary testing, we concluded that the decrease in inpatient testing represented a minimum amount of unnecessary inpatient laboratory tests. We also observed 17,207 (21.4%) fewer inpatient phlebotomies, a decrease sustained in fiscal year 2004-2005. Labor savings allowed us to redirect phlebotomists to our understaffed outpatient phlebotomy service.

Unnecessary laboratory testing is widely perceived as being pervasive. This perception is supported by widely varying test ordering patterns at different sites for similar patient populations,[1,2] the observation that test ordering varies by the day of the week even though the patient population remains constant,[3] and variability in individual physician test ordering to determine the number of tests necessary for diagnosis and patient management.[4] Further complicating this issue is the apparent lack of agreement about what constitutes appropriate laboratory testing.[5,6] Numerous attempts to curtail unnecessary laboratory testing have not documented sustained results. Educational efforts directed at changing physician practice have clearly demonstrated a 25% or smaller decrease in laboratory test ordering, although such decreases are transient and time-limited.[7,8] Changes in requisition design have had a more durable effect but are labor-intensive to design and require substantial subspecialty expertise.[8-10]

This issue is compounded in teaching hospitals because the least experienced physicians—interns and residents (ie, house staff)—are responsible for ordering laboratory tests. As such, unnecessary and/or inappropriate laboratory testing is perceived as most frequent in teaching hospitals. We have tried many approaches during the past few decades in our teaching hospital to eliminate unnecessary laboratory testing. In the 1970s we tried rationing laboratory tests by assigning an annual quota of laboratory tests per resident. We issued house staff a finite number of "coupons" that could be redeemed for laboratory tests. The success of this experiment lasted only until counterfeit "coupons" appeared. We have initiated numerous educational efforts to reduce unnecessary testing during the 1980s and 1990s, only to observe—as

observed by many others[3,7,8]—that the effects quickly dissipated once the education was stopped.

The advent of computerized provider order entry systems[11] or expert systems for test ordering and interpretation ("middleware"[12]) has created a new opportunity to intervene and intercept unnecessary laboratory test orders. Numerous studies have demonstrated its effectiveness in targeted areas or for targeted diseases, many by embedding specific disease treatment clinical guidelines into ordering pathways.[13-20] To date, however, there has been no overarching system that can be applied reliably to all cases to exclude all unnecessary and/or inappropriate laboratory test orders.

We describe a different approach we took to eliminate unnecessary inpatient laboratory testing. In contrast with previous approaches, ours was a broad-based operational approach not targeted to specific laboratory tests or specific clinical diseases. Our broad-based approach relied primarily on changing the culture of inpatient test ordering, relying secondarily on electronic orders to implement this culture change. Our approach not only demonstrated a significant reduction in inpatient laboratory testing but also had the added and unanticipated benefit of sustaining a reduced demand for inpatient phlebotomy services.

Materials and Methods

Study Site

San Francisco General Hospital (SFGH; San Francisco, CA) is a licensed 539-bed acute care facility owned by the City and County of San Francisco and operated under the auspices of the San Francisco Department of Public Health. Many professional services, including most physician services, are provided through an affiliation agreement with the School of Medicine, University of California San Francisco. Most of the clinical services are staffed by University of California San Francisco physicians and faculty and house staff. The clinical laboratory performs laboratory testing for SFGH inpatients, outpatients treated at clinics on the SFGH campus, outpatients treated at any of the 5 district health centers operated by the Department of Public Health of the City and County of San Francisco or 17 affiliated clinics, and residents of the San Francisco Behavioral Health Center.

SFGH Administrative Structure

All proposals broadly affecting clinical practice must be approved by the medical executive committee (MEC), members of which include 17 chiefs of service, the chief executive officer, the chief nursing officer, the chief financial officer, the director of quality management/risk management/medical staff services, the medical director of quality management, and 6 physician members at large. A parallel nursing executive committee (NEC) also must review and approve MEC proposals that affect nursing practice.

Among the many MEC and NEC subcommittees, a new multidisciplinary nursing/information systems (IS)/clinical laboratory task force, a subcommittee of the NEC, was formed in 2000 to address issues of mutual concern to the 3 services. This task force met monthly. Membership included nurse managers representing psychiatry, intensive care units, maternal and child health, and medical-surgical units; key IS staff representing Invision (Siemens, Malvern, PA) and the Lifetime Clinical Record (Siemens); the clinical laboratory director; the clinical laboratory manager; and the point-of-care test coordinator. The laboratory IS specialist often participated.

Information Systems

Invision is used at SFGH for patient registration, admission, discharge, transfer, and electronic order placement. Financial and accounting activities are captured by the City and County of San Francisco using the Financial and Accounting Management Information System (FAMIS). The clinical laboratory IS is Misys (Misys Healthcare Systems, Raleigh, NC).

Inpatient laboratory and phlebotomy orders are placed as electronic orders through Invision and automatically transmitted to the clinical laboratory. Invision order entry access is limited to nurses and clerks who input written physician orders into the system. Completed and billable laboratory tests captured in Misys are transmitted automatically to FAMIS for accounting purposes. Billable tests are those defined by the Center for Medicare and Medicaid Services. Tests are counted individually unless part of an accepted Center for Medicare and Medicaid Services–defined panel (eg, CBC count, basic metabolic panel, hepatic panel, lipid panel), in which case, the panel is counted as a single test.

The billable annual workload of the clinical laboratory is summarized in an annual FAMIS report, reviewed annually by the clinical laboratory director to identify trends or changes in laboratory testing practices. The annual FAMIS report tabulates each test by location (inpatient, outpatient, emergency department [ED], and outside locations, ie, the 5 community-based public health centers, the San Francisco Behavioral Health Center, and other non-SFGH locations). Overall total laboratory testing is recorded by location. Individual test volumes, however, historically had been recorded as all tests performed for any SFGH location (inpatient, outpatient, plus ED combined) vs outside locations. The SFGH annual fiscal year is July through June.

Duplicate Orders

Any phlebotomy order in which the same tests were ordered as separate orders for the same phlebotomy round were identified by Misys as a "duplicate" order and canceled. The

DOI: 10.1309/WP59YM73L6CEGX2F

most common occurrence was individual orders for serum magnesium, phosphorus, and calcium for a patient for whom a comprehensive metabolic panel had already been ordered.

Phlebotomy

Inpatient phlebotomy is offered at SFGH every 2 hours daily and is provided to all inpatient units except the intensive care units (ICUs). Frequent availability of phlebotomy was instituted to relieve nursing and house staff because of nursing staff shortages and the regulatory limitation of the residents' work hours. The workload per phlebotomy round is tabulated manually by the phlebotomy staff and maintained in a spreadsheet (Excel 2000, Microsoft, Redmond, WA).

Statistical Analysis

Ordering and incidence rates were calculated. Calculated rates were compared by using a ratio measure, assuming a Poisson distribution to calculate confidence intervals and *P* values (STATA, version 9, Stata Press, College Station, TX).

The Intervention

History

Since the introduction of electronic orders at SFGH in the late 1990s, ordering inpatient phlebotomy for laboratory testing has been a multistep process. The physician must first write the order in the medical record, the nurse or ward clerk must acknowledge ("take off") the written order, and the nurse or ward clerk then must order the requested phlebotomy or test electronically via Invision. Once the order is transmitted to the clinical laboratory, a phlebotomy list is generated and the phlebotomist deployed at the specified phlebotomy round.

At least 2 options were available when phlebotomy and laboratory tests were ordered electronically—a single event or a recurring event. If ordered as a recurring event, options ranged from limiting the number of recurrences to a finite number of days, a defined end date, or until discharge. The recurring order also could be placed for multiple occurrences each day, coinciding with phlebotomy rounds that occurred every 2 hours. At the time the system was implemented, recurring orders were available in all inpatient units except the ICUs; the ICUs were restricted to single event orders only.

For many years, the clinical laboratory had received complaints about unnecessary inpatient laboratory testing from everyone—attending physicians, house staff, phlebotomists, nurses, and ward clerks. The attending physicians generally thought that any laboratory test should be ordered only if the result would affect patient management. As such, ordering laboratory tests for the future on a recurring basis was not clinically sound given that clinical conditions of inpatients changed with time. Regardless of this opinion and teaching, many house staff continued to order recurring laboratory tests ("daily labs") of varying duration. Another complication was that multiple teams of physicians often consulted on a single case, writing multiple sets of phlebotomy and laboratory orders, often duplicative. Ward clerks complained about the excessive amount of order entry. Patients, and nurses on their behalf, complained of excessive phlebotomies. The phlebotomists complained about patients being angry with them because of multiple blood draws.

An audit of 2 inpatient medical-surgical wards (4D and 5D) in August 2001 for inpatient phlebotomy and laboratory test orders confirmed many of these perceptions, including the egregious situations of patients undergoing phlebotomy every 4 to 6 hours for the entire hospitalization (range, 3-45 days). In addition, the audit revealed that the most frequently requested tests on a recurring basis were a CBC count, basic metabolic panel, and calcium, magnesium, and phosphorus levels.

There were other problems with recurring orders. House staff who wanted to cancel recurring orders were unable to do so themselves and had to seek someone with access to Invision order entry. Many nurses or clerks who were instructed to cancel recurring orders did not know how to cancel active orders. Meanwhile, clinical laboratory personnel were completely unaware of these attempts to cancel recurring orders and kept performing phlebotomy and laboratory testing as ordered originally.

Planning

This multidisciplinary issue was brought to the attention of the nursing/IS/clinical laboratory task force in 2002. After recognition of the many issues involved, the group brought in the directors of the internal medicine and family and community medicine inpatient services to assist with decision making and include consideration of house staff issues.

In general, the group agreed that daily laboratory tests (recurring orders) were unnecessary. The group also agreed that a limited set of tests (eg, troponin I to rule out acute myocardial infarction) was needed on a recurring basis for no more than a 24-hour period. In addition, the group agreed that this proposal would apply to all inpatient units except the ICUs.

After consideration of the many issues, the group agreed to a proposal in which any phlebotomy or laboratory order would expire at 24 hours. The parameters of this proposal included the following:

1. A single order (eg, CBC count at 6:00 AM) would be valid for a single occurrence only.
2. Orders for multiple serial testing within a 24-hour period would remain valid within the 24-hour window. The start of the 24-hour window would be a "rolling clock," ie, begin with the first completed order and expire 24 hours later.
3. Serial phlebotomies performed by the inpatient phlebotomy service would be limited to intervals of every 4, 6, or 12 hours.

DOI: 10.1309/WP59YM73L6CEGX2F

4. Serial phlebotomies performed by ward personnel had to be ordered as single one-time-only events.
5. Physician orders spanning more than 24 hours would not be honored. Physicians were instructed to write orders for only one 24-hour period.
6. Orders could be entered for future days, with the caveat that the orders would be valid only for that occurrence or ensuing 24-hour period.

The proposal was submitted to the MEC and NEC for approval. Both heartily endorsed the proposal. The chiefs of service on the MEC agreed to disseminate the information to all attending physicians and house staff on their services. The proposal went into effect on June 10, 2003, a date chosen to coincide with the arrival of new house staff and near the beginning of the next fiscal year.

The nursing/IS/clinical laboratory task force excluded 2 groups of patients from the proposal. One group included patients receiving total parenteral nutrition, for whom recurring laboratory tests every few days were necessary to assess efficacy of total parenteral nutrition. The other group included existing patients whose phlebotomy and laboratory tests had been ordered as "recurring until discharge." This latter group was excluded because it was expected that the patients would soon be discharged, given an average length of stay of approximately 6 days. At the time of implementation, IS had identified 27 inpatients having orders placed as recurring until discharge.

Impact on Laboratory Testing and Phlebotomy

The nursing/IS/clinical laboratory task force continued to track issues related to implementation of this new program. One month after implementation, only 3 of the original 27 patients identified as having preexisting recurring orders until discharge were still inpatients. The nurse managers of the units on which these patients were housed were instructed to contact the physicians to stop the recurring orders, if appropriate. Recurring orders for these 3 patients soon ceased.

There were surprisingly few complaints registered with the clinical laboratory about implementation of this policy. Early after implementation, nurses and ward clerks reported having to educate house staff to write laboratory and phlebotomy orders for each 24-hour period. Early in the implementation phase, internal medicine and family and community medicine attending physicians also invested substantial effort in educating their house staff about when to order laboratory tests.

Results

The overall impact of this program became apparent after tabulation and analysis of the annual FAMIS reports for inpatient laboratory testing and phlebotomy for fiscal years 2002-2003 and 2003-2004 ▮**Table 1**▮. There was little change in the total number of inpatient admissions, inpatient admission days, or number of inpatient days per inpatient. In contrast, the total inpatient laboratory test volume decreased by 72,639 tests (12.0% decrease from the previous fiscal year). Statistically significant decreases were observed in the average number of laboratory tests per inpatient day and average number of phlebotomies performed per inpatient day (Table 1). In comparison, the overall total laboratory testing increased slightly, with significant increases noted for outpatient testing and for testing provided to patients treated in the ED. Of note, no other system-wide programmatic change or major change in clinical practice was introduced during this period.

▮**Table 1**▮
Comparison of Inpatient Statistics for Fiscal Year 2002-2003 vs 2003-2004*

	2002-2003	2003-2004	Absolute (%) Difference†	Ordering Rate Ratio (95% CI)‡	*P*
Inpatient admissions	17,850	17,553	–297 (–1.7)	—	—
Inpatient admission days	115,715	114,936	–779 (–0.7)	—	—
Inpatient days/inpatient	6.48	6.55	0.07 (0.1)	—	—
Total inpatient laboratory tests§	604,847	532,208	–72,639 (–12.0)	—	—
Average laboratory tests/inpatient	33.9	30.3	–3.6 (–10.6)	—	—
Average laboratory tests/inpatient day	5.2	4.6	–0.6 (–11.5)	0.89 (0.88-0.89)	<.0001
Total inpatient phlebotomies performed	80,294	63,087	–17,207 (– 21.4)	—	—
Average phlebotomies performed/inpatient day	0.69	0.55	–0.14 (–20.3)	0.79 (0.78-0.80)	<.0001
Total laboratory tests performed (inpatient and outpatient, including for ED)	1,112,689	1,142,958	30,269 (2.7)	—	—
Total outpatient laboratory tests performed	429,990	484,836	54,846 (12.8)	—	—
Total laboratory tests performed for ED	77,852	93,142	15,290 (19.6)	—	—

CI, confidence interval; ED, emergency department.
* Data are given as number unless otherwise indicated.
† 2003-2004 volume relative to 2002-2003 volume.
‡ Ordering rates (ie, average number of inpatient tests/inpatient day, average number of phlebotomies performed/inpatient day) were calculated for each fiscal year and compared using a ratio measure as described in the "Materials and Methods" section.
§ Derived from the Financial and Accounting Management Information System reports for fiscal years 2002-2003 and 2003-2004.

DOI: 10.1309/WP59YM73L6CEGX2F

A review of individual test volumes was undertaken. The historic manner in which the test volume had been captured, unfortunately, did not allow retrieval of test volumes specific to inpatients. Overall review of the test volumes for the 5 tests frequently ordered as recurring, identified in the August 2001 phlebotomy audit, revealed 12,086 fewer CBC counts, 9,660 fewer basic metabolic panels, 1,086 fewer calcium levels, 10,045 fewer magnesium levels, and 8,888 fewer phosphorus levels in fiscal year 2002-2003 compared with fiscal year 2001-2002 **Table 2**. The reduced volume for these 5 tests totaled 41,765 and ranged individually from 7.5% to 29.1% of the previous year's test volume. The volume reductions for these 5 tests alone constituted 57.5% (41,765/72,639) of the total number of decreased inpatient tests observed. All reductions were highly statistically significant.

The overall decrease in total inpatient phlebotomies most dramatically affected the daily 6:00 AM phlebotomy rounds, with the average workload decreasing from 124 patients in fiscal year 2002-2003 to 87 inpatients in fiscal year 2003-2004. This decrease in inpatient phlebotomy was sustained for fiscal year 2004-2005.

Discussion

Previous attempts to reduce unnecessary laboratory testing have focused on 2 major approaches—education and requisition design. In academic settings such as ours, it has been well demonstrated that the educational approach is short-lived, with promising effects disappearing shortly after cessation of the educational effort.[7,8] Requisition design or redesign to guide the ordering practice of clinicians for specific diseases has a longer-lived effect.[8-10] This approach, however, is relatively labor-intensive because it involves the time of clinical subspecialists and pathologists, may result in a multitude of subspecialty-specific requisitions, and requires periodic revision to keep pace with medical advances. Efforts incorporating education, requisition design, and funding incentives or policies have demonstrated the most durable effect.[6]

Interpositioning ISs to guide clinical decisions in various aspects of clinical care holds great potential for streamlining, standardizing, and optimizing overall patient care. This potential has been realized in numerous studies demonstrating a reduction in unnecessary laboratory testing coincident with the implementation of expert system interfaces[11-14,17,18,21] but has not been an option for SFGH owing to budgetary constraints.

Although information technology can provide the tools to improve patient care, unanticipated consequences at the human-technical interface can occur.[22] Certainly we have to assert that such an example of an unanticipated consequence occurred at SFGH when electronic order entry was introduced. At the time of its introduction, the system was configured such that laboratory tests could be ordered easily on a recurring basis and phlebotomies similarly ordered for multiple occurrences daily. Although this may have been a well-intentioned process designed to ease the burden of ordering multiple recurring tests, its ease resulted in the unfortunate consequence of excess, unnecessary, recurring laboratory tests and phlebotomies. After recognizing this process needed adjusting, we implemented a "fix" that broadly affected all inpatients without regard to underlying disease. The success of our program complements and could readily be used in conjunction with all other previously reported approaches to achieve a collectively larger reduction in unnecessary phlebotomy and/or laboratory testing.

We observed a 12.0% overall decrease in inpatient laboratory testing at a time when all outpatient testing was increasing in volume. One weakness of this study was our inability to link the approximate 12% overall decrease in inpatient testing to specific tests performed for inpatients. This inability was caused by our historic practice of recording specific test volumes for all patients (ie, inpatients, outpatients, and patients treated in the ED) instead of by individual category of

Table 2
Impact of Limiting Phlebotomy and Test Orders to 24 Hours on Previously Identified, Frequently Recurring Inpatient Laboratory Tests

	No. of Tests				
Test	**FY 2002-2003**	**FY 2003-2004**	**Absolute (%) Difference***	**Incidence Rate Ratio (95% C)†**	***P***
CBC count	162,039	149,953	–12,086 (–7.5%)	0.93 (0.92-0.94)	<.0001
Basic metabolic panel	98,350	88,690	–9,660 (–9.8%)	0.91 (0.90-0.92)	<.0001
Calcium	3,736	2,650	–1,086 (–29.1%)	0.71 (0.68-0.75)	<.0001
Magnesium	50,243	40,198	–10,045 (–20.0%)	0.81 (0.79-0.82)	<.0001
Phosphorus	49,324	40,436	–8,888 (–18.0%)	0.83 (0.81-0.84)	<.0001
Total	363,692	321,927	–41,765 (–11.5%)	0.89 (0.89-0.90)	<.0001

CI, confidence interval; FY, fiscal year.
* FY 2003-2004 test volume relative to that of FY 2002-2003.
† Incidence rates (eg, No. of CBC counts performed in FY 2003-2004/No. of CBC counts performed in FY 2002-2003) were calculated and compared using a ratio measure as described in the "Materials and Methods" section.

DOI: 10.1309/WP59YM73L6CEGX2F

patients. Of the overall 72,639 fewer inpatient tests recorded, 41,765 fewer tests (57.5%) could be linked directly to the tests previously identified as commonly ordered for inpatients on a recurring basis (ie, CBC counts, basic metabolic panels, and calcium, phosphorus, and magnesium levels). Although there was individual variation in the percentage of decreased tests for each of these 5 tests, comparison of all 5 tests combined yielded an overall decrease of 11.5%, consistent with the 12.0% overall decrease noted for all inpatient testing. The other inpatient tests for which the volume decreased by our program were not immediately obvious. It is likely that a significant absolute decrease in inpatient testing may have been offset and masked by concurrent increases in noninpatient testing.

Implementation of our program did not completely eliminate unnecessary laboratory or phlebotomy orders. Our program still permitted unnecessary testing if such testing was ordered on a recurring basis (limited to a 24-hour window) or ordered for a future 24-hour period. Thus, the 12.0% decrease in inpatient testing represents the very smallest number of unnecessary tests being ordered for general inpatient care. No new clinical programs were introduced during this period that might have independently reduced inpatient test and phlebotomy ordering, and no adverse patient outcomes related to this restricted test-phlebotomy ordering program were observed, further supporting our conclusion that the observed 12.0% reduction in inpatient testing represented truly unnecessary testing. Greater decreases in testing are achievable but would require much more effort at better defining unnecessary testing[6] and linking optimal testing strategies with patient outcome.[5]

Of note, our test-phlebotomy restriction program had a disproportionately larger effect on the inpatient phlebotomy service than on inpatient testing. In other words, an overall 21.4% decrease in inpatient phlebotomy was accompanied by only a 12.0% decrease in inpatient testing. This suggests that other inpatient units not served by the inpatient phlebotomy service ordered disproportionately more tests. The ICUs were the only inpatient units to which this restricted test-phlebotomy ordering program did not apply. The logical assumption is that the ICUs must be ordering a disproportionately larger number of tests not accompanied by phlebotomy requests. This assumption would be consistent with data in many previous reports regarding extensive phlebotomy, laboratory testing, and concomitant anemia for ICU patients.[19,23-26]

Our study revealed minimal savings for individual patients—on average 0.14 fewer phlebotomies per inpatient day and 0.6 fewer tests per inpatient day. These small incremental savings, however, resulted in cumulatively large savings for the system. If the reagent cost is estimated at $1 per test for each of the 5 tests most commonly (and unnecessarily) ordered on a recurring basis, this program would have realized $72,639 in unexpended reagent costs. More important, the marginal labor savings from this test reduction created an albeit small but new labor capacity for clinical laboratory scientists, a much needed capacity given the critical national shortage of clinical laboratory scientists.[27]

Phlebotomy savings also were significant. The reduction in the 6:00 AM phlebotomy workload with the existing phlebotomy staff allowed us to not only complete 6:00 AM rounds in a shorter time, thereby completing laboratory testing ordered for the 6:00 AM rounds sooner, but also allowed us to redirect existing 6:00 AM inpatient phlebotomy staff to the chronically understaffed outpatient phlebotomy unit. This creation of a new labor capacity for our existing phlebotomy service, now redirected to the outpatient phlebotomy service, was much needed given the shortage of certified phlebotomists[27] directly related to the newly implemented phlebotomy certification requirements for California.[28] The durable effect of this program was evidenced by sustained decreases in the 6:00 AM phlebotomy workload for 2 fiscal years after its implementation.

Finally, implementation of a project of this scope would not have been possible without institutional support. We were fortunate that SFGH has a medical and administrative structure that encourages, fosters, and fully supports multidisciplinary efforts aimed at yielding savings for the organization as a whole. In this regard, our success with this project mirrors that of other multidisciplinary initiatives undertaken within established hospital administrative frameworks and involving the clinical laboratory.[29]

From the Departments of [1]Family and Community Medicine, [4]Medicine, and [9]Laboratory Medicine, School of Medicine, University of California San Francisco; and [2]Family and Community Medicine Service, [3]UCSF Clinical Laboratory at San Francisco General Hospital, [5]Medical Service, [6]Information Systems, [7]Nursing Service, and [8]Nursing Administration, San Francisco General Hospital.

Address reprint requests to Dr Ng: c/o Clinical Laboratory, Alameda County Medical Center/Highland General Hospital, 1411 E 31st St, Oakland, CA 94611.

Acknowledgment: We gratefully acknowledge Mark Pletcher for expert assistance with statistical analysis.

References

1. Flabouris A, Bishop G, Williams L, et al. Routine blood test ordering for patients in intensive care. *Anaesth Intensive Care*. 2000;28:562-565.
2. Larsson A, Palmer M, Hulten G, et al. Large differences in laboratory utilisation between hospitals in Sweden. *Clin Chem Lab Med*. 2000;38:383-389.
3. Cheng CK, Lee T, Cembrowski GS. Temporal approach to hematological test usage in a major teaching hospital. *Lab Hematol*. 2003;9:207-213.

DOI: 10.1309/WP59YM73L6CEGX2F

4. Malcolm L, Wright L, Seers M, et al. Laboratory expenditure in Pegasus Medical Group: a comparison of high and low users of laboratory tests with academics. *N Z Med J*. 2000;113:79-81.
5. Lundberg GD. The need for an outcomes research agenda for clinical laboratory testing [editorial]. *JAMA*. 1998;280:565-566.
6. van Walraven C, Naylor CD. Do we know what inappropriate laboratory utilization is? a systematic review of laboratory clinical audits. *JAMA*. 1998;280:550-558.
7. Eisenberg JM. An educational program to modify laboratory use by house staff. *J Med Educ*. 1977;52:578-581.
8. Wong ET, McCarron MM, Shaw ST Jr. Ordering of laboratory tests in a teaching hospital: can it be improved? *JAMA*. 1983;249:3076-3080.
9. Bailey J, Jennings A, Parapia L. Change of pathology request forms can reduce unwanted requests and tests. *J Clin Pathol*. 2005;58:853-855.
10. Emerson JF, Emerson SS. The impact of requisition design on laboratory utilization. *Am J Clin Pathol*. 2001;116:879-884.
11. Miller RA, Waitman LR, Chen S, et al. The anatomy of decision support during inpatient care provider order entry (CPOE): empirical observations from a decade of CPOE experience at Vanderbilt. *J Biomed Inform*. 2005;38:469-485.
12. Smith BJ, McNeely MD. The influence of an expert system for test ordering and interpretation on laboratory investigations. *Clin Chem*. 1999;45(8 pt 1):1168-1175.
13. Bates DW, Kuperman GJ, Rittenberg E, et al. A randomized trial of a computer-based intervention to reduce utilization of redundant laboratory tests. *Am J Med*. 1999;106:144-150.
14. Chen P, Tanasijevic MJ, Schoenenberger RA, et al. A computer-based intervention for improving the appropriateness of antiepileptic drug level monitoring. *Am J Clin Pathol*. 2003;119:432-438.
15. Neilson EG, Johnson KB, Rosenbloom ST, et al. The impact of peer management on test-ordering behavior. *Ann Intern Med*. 2004;141:196-204.
16. Pysher TJ, Bach PR, Lowichik A, et al. Chemistry test ordering patterns after elimination of predefined multitest chemistry panels in a children's hospital. *Pediatr Dev Pathol*. 1999;2:446-453.
17. Schubart JR, Fowler CE, Donowitz GR, et al. Algorithm-based decision rules to safely reduce laboratory test ordering. *Medinfo*. 2001;10(pt 1):523-527.
18. van Wijk MA, van der Lei J, Mosseveld M, et al. Compliance of general practitioners with a guideline-based decision support system for ordering blood tests. *Clin Chem*. 2002;48:55-60.
19. Wang TJ, Mort EA, Nordberg P, et al. A utilization management intervention to reduce unnecessary testing in the coronary care unit. *Arch Intern Med*. 2002;162:1885-1890.
20. Weydert JA, Nobbs ND, Feld R, et al. A simple, focused, computerized query to detect overutilization of laboratory tests. *Arch Pathol Lab Med*. 2005;129:1141-1143.
21. Chin HL, Wallace P. Embedding guidelines into direct physician order entry: simple methods, powerful results. *Proc AMIA Symp*. 1999:221-225.
22. Caudill-Slosberg M, Weeks WB. Case study: identifying potential problems at the human/technical interface in complex clinical systems. *Am J Med Qual*. 2005;20:353-357.
23. Andrews T, Waterman H, Hillier V. Blood gas analysis: a study of blood loss in intensive care. *J Adv Nurs*. 1999;30:851-857.
24. Hicks JM. Excessive blood drawing for laboratory tests [letter]. *N Engl J Med*. 1999;340:1690.
25. Lin JC, Strauss RG, Kulhavy JC, et al. Phlebotomy overdraw in the neonatal intensive care nursery. *Pediatrics*. 2000;106:E19.
26. Wisser D, van Ackern K, Knoll E, et al. Blood loss from laboratory tests. *Clin Chem*. 2003;49:1651-1655.
27. Chapman SE, Lindler V, Ward-Cook K. An assessment of critical issues facing the clinical laboratory workforce. *Clin Leadersh Manag Rev*. 2005;19:E4.
28. Assembly Member La Suer. AB 371. Blood Tests. California Assembly and Senate, 2003-2004 Regular Session, chaptered February 11, 2004. Available at http://www.leginfo.ca.gov/pub/03-04/bill/asm/ab_03510400/ab_371_bill_20040211_chaptered.pdf. Accessed February 15, 2006.
29. Lewandrowski K. Managing utilization of new diagnostic tests. *Clin Leadersh Manag Rev*. 2003;17:318-324.

DOI: 10.1309/WP59YM73L6CEGX2F