# A Cost-Effective Method for Reducing the Volume of Laboratory Tests in a University-Associated Teaching Hospital

MALKA ATTALI, M.D[1]., YOSEF BAREL, M.D.[1], MARINA SOMIN, M.D.[1], NICK BEILINSON, M.D.[1], MARK SHANKMAN, M.D.[2], ADA ACKERMAN, B.S.[1], AND STEPHEN D.H. MALNICK, M.A., M.SC., M.B.B.S.[1]

## Abstract

**BACKGROUND:** Laboratory tests comprise a significant portion of hospital expenditure. Attempts to reduce their use have had mixed results.

**OBJECTIVE:** To investigate the effect of an intervention based on a simple form-based system for ordering laboratory tests by physicians, on both use of laboratory resources and diagnostic accuracy.

**DESIGN:** At Kaplan Medical Center in Rehovot, Israel, there are 4 similar internal medicine departments. In one department (C), the new system was initiated, whereas in the other 3 departments (A, B and D), the traditional method of ordering blood tests was continued. The intervention used was a requirement for tests to be specifically requested by residents following unbundling of test panels, with hands-on supervision by a senior physician. In addition, the residents attended a series of lectures on the economic implications of laboratory testing. The intervention study lasted for 3 years.

**MEASUREMENTS:** Total number of tests performed in each department, number of tests per admission and total cost of each test at Medicare reimbursement prices.

**RESULTS:** The number of tests per admission prior to the intervention was 1.91± 0.89; it decreased for each of the next 3 years: 0.76±0.61, 0.80±0.62 and 0.78±0.63 respectively. There was a total decrease of 97,365 tests during the 3-year period, saving $1,914,149. There was no difference in the readmission rate or in the number of diagnoses of conditions based primarily on blood tests such as hypokalemia or hyponatremia, between department C and the other departments.

**CONCLUSIONS:** The intervention developed here produced significant and sustained reduction of financial savings in the number of laboratory tests ordered, without negatively impacting diagnostic capability or patient care.

**Key Words:** Cost reduction, laboratory, testing, hospital.

## Introduction

DURING THE LAST SEVERAL DECADES there has been an increase in the use of laboratory tests by physicians. These tests are considered essential tools for disease screening, diagnosis and monitoring. Although laboratory testing represents an enormous expenditure (1), there is wide variation in its use for similar indications (2 – 4), and some diagnostic testing is probably inappropriate (5), although the evidence to support this is weak (6).

Several explanations have been offered to explain the variation in the use of diagnostic tests, including the inability of physicians to predict test performance characteristics, inaccurate interpretation of diagnostic test results, and difficulties in mastering the most effective diagnostic strategies (7 – 14). In addition, tests may be ordered for defensive reasons (15), ease of access (16), fear of uncertainty (17), or "test addiction" (18 – 20). With increasing economic pressures worldwide on health systems, attempts are being made to achieve a more cost-effective use of laboratory resources.

Six general methods of reducing the number of unnecessary tests by changing physicians' practices have been described: education, feedback, physician participation in efforts to produce change, administrative rules, financial incentives and penalties (21). A systematic Medline review of 102 articles reporting the results of interventions aimed at changing physicians' testing practices (19) found that the majority of interventions reported claimed some success, but that those interventions based on multiple behavioral factors were most successful. However, many approaches have been criticized as being time-consuming (22), difficult to implement institutionally (23), counter-

[1]Kaplan Medical Center, Rehovot, Israel, and [2]Newton-Wellsley Medical Center, Newton, MA.

Address all correspondence to Dr. Stephen D.H. Malnick, Department of Internal Medicine C, Kaplan Medical Center, Rehovot 76100 Israel; e-mail stevash@trendline.co.il

Accepted for publication October 2005.

productive to physician training (24), detrimental to clinical decision making (25), or too intrusive (26).

More recently, the use of information systems to improve health care delivery has been suggested (27), especially in the area of care provider order entry (CPOE) (28). A recent study from Vanderbilt University has reported the sustained success of an intervention based on software for the CPOE system (29). This technique requires an initial investment of resources and may not be appropriate for poorer countries. In addition, it may not be easily applicable in every institution, or in different systems in different countries.

We have developed a multi-faceted intervention, not based on software changes, in order to reduce the expenditures for lab tests, in an internal medicine department of a university-associated medical center. The purpose of this study was to investigate if any savings in the cost of lab testing could be achieved over a several-year period without compromising the quality of medical care.

## Methods

### Background

Kaplan Medical Center is a 650-bed university-affiliated hospital in Rehovot, Israel. It serves a population of 350,000 and there are approximately 16,000 medical admissions per year. There are 4 internal medicine departments that admit patients, each on an equal basis. Each department receives every fourth patient requiring admission. Medical manpower is nearly identical in each department, with a total of 11 physicians on staff. The internal medicine departments are responsible for 25% of all laboratory investigations in the medical center, compared to 8.4% for the surgery departments. The vast majority (>98%) of admissions to the internal medicine departments are via the department of emergency medicine.

In the emergency department, initial blood tests are performed. These include a complete blood count (CBC), coagulation profile, blood urea nitrogen (BUN), serum sodium, potassium, and glucose for all admitted patients. Additional tests, as for bilirubin, amylase creatine phosphokinase (CPK), troponin and arterial blood gases, are performed at the discretion of the admitting physician in the emergency room.

In the department of internal medicine, a first-day profile of blood tests is taken. This includes: erythrocyte sedimentation rate (ESR), CBC, glucose, urea, sodium, potassium, calcium, phosphorus, BUN, creatinine, uric acid, aspartate transaminase (AST), alanine transaminase (ALT), alkaline phosphatase, and a coagulation profile. In addition a lipid profile, CPK, CPK of muscle band (CPK-MB), serum troponin and amylase may be ordered at the discretion of the admitting physician in the department (one of the department residents). The form and the test tubes for the blood tests are prepared by nursing students at night on the basis of a set of instructions written in a notebook by the residents during the evening rounds. These tests include not only the first-day profile, but also additional tests ordered by the residents as they see necessary.

We decided to initiate a multi-tiered program in order to reduce the use of lab tests on a continuous, sustainable basis without impacting negatively on patient care. In order to do so, we chose the following approach:

1. We organized a lecture to the residents and senior physicians of Department of Internal Medicine C, describing the economic implications of the excessive use of blood tests and drawing attention to the current inappropriate ordering of blood tests (e.g., testing the lipid profile 3 times during a 3-day admission for unstable angina).
2. We included the residents in the process of changing the current method of ordering blood tests.
3. We made an administrative change. The required blood test needed to be specifically ordered by the resident, instead of ordering large groups of tests (e.g., lipid profile, SMA analysis). This meant the unbundling of serum metabolic panel tests. The other three departments of internal medicine were informed of the unbundling of the serum metabolic panel tests and received a short lecture from one of the physicians from Department C (MA) regarding the expenditure incurred due to lab tests.
4. A senior physician of the department supervised the ordering of the lab tests. This step would also be included, with the chance for hands-on teaching regarding the problems of the patient and the pertinence of the relevant blood tests.

An estimate of cost was obtained by computing the hospital fees that Medicare reimburses for routine blood tests (data supplied from the billing department, Newton-Wellesley Hospital, Newton, MA). We chose to use the costing system common in the U.S. so that any total savings would be more relevant to an audience outside of Israel.

For statistical analysis, we used the SPSS program (11th edition). Student's t-test was performed and was 2-tailed. A p value of less than 0.05 was regarded as significant. The study of this program lasted for 3 years.

## Results

In order to assess the impact of the program of intervention, it was first necessary to determine the number of lab tests performed in Internal Medicine C in the period before the intervention was initiated. For the period from July 1, 2000 to June 30, 2001, there were a total of 15,073 days of hospital admission and 4,158 admissions. The numbers of routine biological tests are shown in Table 1. The range was from 20 for glycosylated hemoglobin ($HbA_{1c}$) to 9,291 for serum glucose determinations. The average number of investigations per hospital admission for each parameter was calculated and is also shown in Table 1. There was no significant difference in the mean number of tests performed per admission between the 4 internal medicine departments prior to the intervention (Fig. 1).

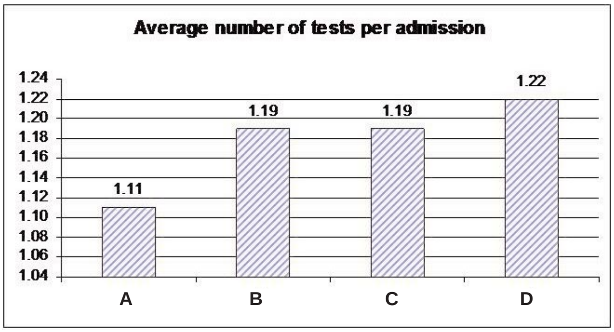


**Fig. 1.** The mean number of tests per admission prior to starting the intervention.
p > 0.5 for comparison between Department C and the other departments.

Following the initiation of the new program for ordering blood tests, there was a significant decrease in the number of tests per hospital admission for all the major laboratory tests ordered from the Internal Medicine C Department (Fig. 2). Prior to the intervention the mean number of blood tests per admission was 1.19±0.89, and the values for the subsequent 3 years (the intervention period) were 0.76±0.61, 0.80±0.62 and 0.78±0.63, respectively ($p < 0.05$ for all tests). This decrease in the number of tests ordered per admission was maintained during the course of the next 2 years, during which the new method of ordering blood tests was continued.

No change in the work methods of the other internal medicine departments was carried out. Fig. 3 shows the mean number of laboratory tests per admission for each of the other internal medicine departments for the year prior to the study and the 3 years of the study. The pattern of test usage for each department was similar during the period of the study. Interestingly, in all departments, following the initial intervention in Department C, there was a decrease in the mean number of blood tests ordered per admission, then a subsequent rise, followed by another decrease, during the 3-year pe-

**TABLE 1**
*Number of Tests Ordered and Number per Admission for the Department of Internal Medicine C from July 1, 2000 to June 30, 2001, prior to the Start of the Intervention*

| Test | Number Ordered | Number per Admission |
|---|---|---|
| Amylase | 3640 | 0.88 |
| Antinuclear Ab | 200 | 0.05 |
| Cholesterol, HDL | 762 | 0.18 |
| C-Reactive Protein | 619 | 0.15 |
| D-Dimer | 172 | 0.04 |
| Ferritin | 373 | 0.09 |
| Folic Acid | 281 | 0.07 |
| GGT | 1867 | 0.45 |
| Hemoglobin A1C % | 20 | 0 |
| HGB | 8188 | 1.97 |
| Iron | 483 | 0.12 |
| Myoglobin , Blood | 101 | 0.02 |
| PT % | 5947 | 1.43 |
| PT-INR | 5947 | 1.43 |
| Transferrin | 441 | 0.11 |
| TSH | 964 | 0.23 |
| Vitamin B12 | 566 | 0.14 |
| Cholesterol, LDL | 792 | 0.19 |
| Creatinine | 8840 | 2.13 |
| Glucose | 9291 | 2.24 |
| Potassium | 9155 | 2.20 |
| Sodium | 9155 | 2.20 |
| Urea | 9137 | 2.20 |
| Albumin | 7824 | 1.88 |
| Alk. Phosphatase | 7806 | 1.88 |
| Bilirubin, Direct | 8007 | 1.93 |
| Bilirubin, Total | 8007 | 1.93 |
| Calcium | 7950 | 1.91 |
| Cholesterol | 7392 | 1.78 |
| CPK | 7536 | 1.81 |
| GOT (AST) | 7864 | 1.89 |
| GPT (ALT) | 7859 | 1.89 |
| LDH | 7996 | 1.92 |
| Phosphorus | 7786 | 1.87 |
| Protein, Total | 8040 | 1.93 |
| Triglycerides | 7374 | 1.77 |

PT = prothrombin time, PT-INR = PT/international normalized ratio, GGT = gamma-glutamyl transferase, HGB = hemoglobin, TSH = thyroid-stimulating hormone, CPK = creatine phosphokinase, LDL = low-density lipoprotein, HDL = high=density lipoprotein, GOT(AST) = glutamic-oxaloacetic transaminase (aspartate aminotransferase), GPT(ALT) = glutamic pyruvic transaminase (alanine transaminase).

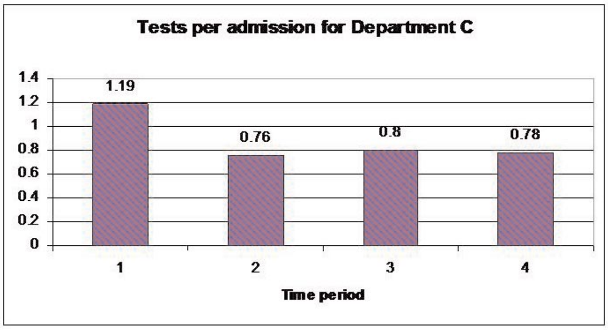


**Fig. 2.** The number of tests per admission for the Department of Internal Medicine C.
Period 1 = July 1, 2000– June 30, 2001 (prior to the intervention). Period 2 = July 1, 2001–June 30, 2002. Period 3 = July 1, 2002– June 30, 2003. Period 4 = July 1, 2003–December 31, 2004.

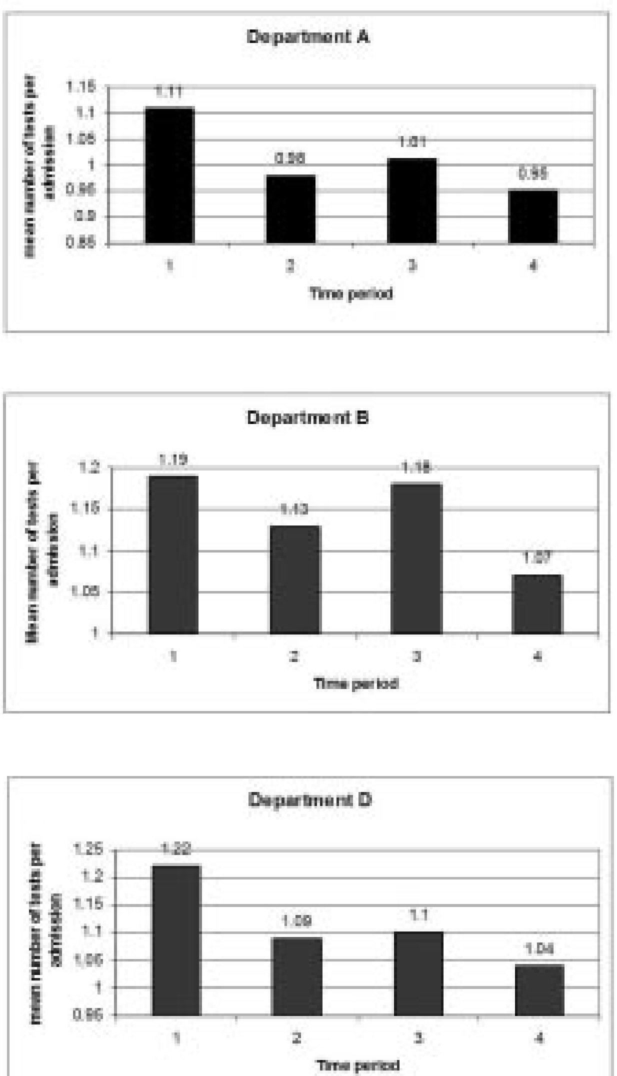


**Fig. 3.** The mean number of tests per admission for departments A, B and D for each of the time periods described in Fig. 2.

riod. We suggest that this reflects a "spillover" of the intervention to the other departments based on verbal reports from the hospital administration, followed by a lack of reinforcement, and then subsequently another decrease following reinforcing comments from the hospital administration.

In Fig. 4 the mean number of tests per admission for several of the most common tests is shown for the Department of Internal Medicine C versus a mean of the other 3 departments combined. It shows a significantly lower usage of each of these tests by the Department of Internal Medicine C compared to the other departments, for all tests except for troponin. During this period of time, the test for troponin was introduced into the diagnostic armamentarium at Kaplan Medical Center, together with a clear protocol for its use, and each department received an explanatory lecture from the cardiologists prior to starting the test. The usage of this test was similar in all 4 departments. This suggests that physician behavior is an ac-

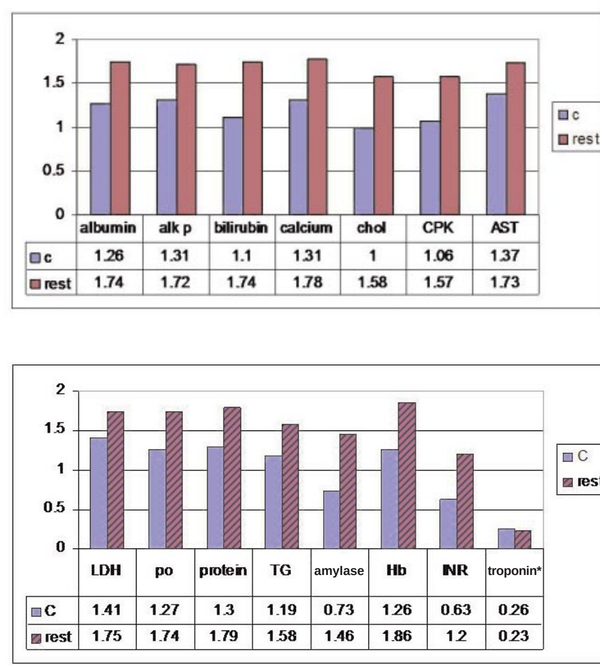


**Fig. 4.** A comparison between the Department of Internal Medicine C and the other 3 internal medicine departments grouped together for a series of laboratory tests per admission. The figures refer to the mean number of tests per admission after the intervention (±95% confidence intervals.
alk P = alkaline phosphate; chol = cholesterol; CPK = creatine phosphokinase; AST = aspartate transaminase; LDH = lactate dehydrogenase; po =phosphorus; TG = triglycerides; Hb = hemoglobin; INR = international normalized ratio.
C refers to the Department of Internal Medicine C and the other group represents the three other departments grouped together. All of the differences had a p value < 0.05, except for troponin. * p = 0.4.

**TABLE 2**

*Total Number of Admissions for Each of the Internal Medicine Departments for the Years 2000 to 2004. There Was No Significant Difference between the Departments for the Years 2002 to 2004. Prior to this, the Department of Internal Medicine D Was Only Operating on a Reduced Schedule, and thus the Numbers Are Smaller*

| Year | A | B | C | D |
|---|---|---|---|---|
| 2000 | 4,535 | 4,452 | 4,513 | 2,634 |
| 2001 | 3,854 | 3,882 | 3,910 | 3,758 |
| 2002 | 3,879 | 3,906 | 3,911 | 3,815 |
| 2003 | 3,945 | 3,942 | 3,910 | 3,618 |
| 2004 | 3,293 | 3,311 | 3,383 | 2,922 |

quired characteristic and that appropriate conditioning and education of physicians when a new test is introduced can result in a more rational use.

The admissions to the 4 internal medicine departments are completely random, and thus there is likely to be a high degree of homogeneity for the hospitalized patients between departments. It is likely that the medical treatment is similar in all 4 departments, although we do not have any data to confirm or refute this assumption. The total number of admissions was very similar in departments A, B and C throughout the 3 years following the intervention (Table 2). Department D, which was a new department, operated at a lower than full capacity for the years 2000 and 2001 and thus had a smaller number of total admissions during this period. It subsequently operated at full capacity and had a similar number of admissions.

We estimate that our intervention resulted in a saving of 97,365 laboratory tests in the three-year period. There was a total of 1,017,401 tests performed in departments A, B and D during this 3-year period, which is an average of 339,113 tests per department during the 3-year period. The actual number of test performed by Department C

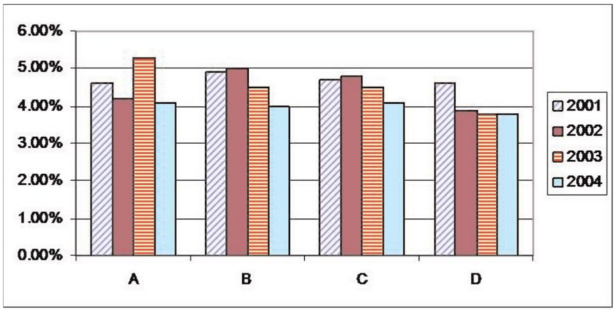


**Fig. 5.** Readmission rate for each department per time period. $p > 0.5$ between Department C and the other departments for each time period.

**TABLE 3**

*Number of Tests per Admission for the Period prior to Intervention, for the Departments of Internal Medicine*

| Test | C | A | B | D |
|---|---|---|---|---|
| Albumin | 1.88 | 1.61 | 1.86 | 1.95 |
| Alk. Phosphatase | 1.88 | 1.60 | 1.84 | 1.94 |
| Bilirubin, Direct | 1.93 | 1.67 | 1.92 | 2.04 |
| Bilirubin, Total | 1.93 | 1.67 | 1.92 | 2.04 |
| Calcium | 1.91 | 1.63 | 1.89 | 2.00 |
| Cholesterol | 1.78 | 1.46 | 1.61 | 1.85 |
| CPK | 1.81 | 1.57 | 1.80 | 1.85 |
| GOT (AST) | 1.89 | 1.62 | 1.85 | 1.96 |
| GPT (ALT) | 1.89 | 1.62 | 1.85 | 1.96 |
| LDH | 1.92 | 1.64 | 1.88 | 1.98 |
| Phosphorus | 1.87 | 1.60 | 1.85 | 1.94 |
| Protein, Total | 1.93 | 1.65 | 1.89 | 2.02 |
| Triglycerides | 1.77 | 1.46 | 1.60 | 1.85 |
| Amylase | 0.88 | 1.55 | 1.71 | 1.0 |
| Antinuclear Ab | 0.05 | 0.05 | 0.1 | 0.04 |
| Cholesterol, HDL | 0.18 | 0.6 | 0.13 | 0.13 |
| C-Reactive Protein | 0.15 | 0.07 | 0.14 | 0.08 |
| D-Dimer | 0.04 | 0.04 | 0.07 | 0.06 |
| Ferritin | 0.09 | 0.04 | 0.07 | 0.06 |
| Folic Acid | 0.07 | 0.07 | 0.07 | 0.05 |
| GGT | 0.45 | 0.86 | 0.87 | 0.53 |
| Hemoglobin A1C % | 0 | 0.02 | 0.01 | 0.01 |
| HGB | 1.97 | 1.77 | 1.9 | 2.19 |
| Iron | 0.12 | 0.08 | 0.09 | 0.07 |
| Myoglobin, Blood | 0.02 | 0.04 | 0.03 | 0.05 |
| PT % | 1.43 | 1.63 | 1.36 | 1.06 |
| PT-INR | 1.43 | 1.63 | 1.36 | 1.06 |
| Transferrin | 0.11 | 0.07 | 0.06 | 0.06 |
| TSH | 0.23 | 0.2 | 0.21 | 0.21 |
| Vitamin B12 | 0.14 | 0.15 | 0.12 | 0.08 |

$p > 0.3$ for all the other departments compared to C.
See Table 1 for definitions of abbreviations.

during this period was 241,768. Thus the difference is 97,345 tests.

In order to determine whether the decreased number of lab tests ordered as a result of this intervention impacted on diagnostic accuracy, we examined the incidence of conditions that are diagnosed mainly on the basis of lab tests, e.g., hyponatremia, hypercalcemia and anemia. We determined the total number of patients with hyperkalemia, hypokalemia, hypernatremia, hyponatremia, hypercalcemia and anemia that were diagnosed in the lab for each department for each time period. The definitions of hyper- or hypokalemia, hyper- or hyponatremia and hypecralcemia were based on a result above or below the normal limits for the Kaplan Medical Center laboratory.

There was no significant difference in the number of cases diagnosed with anemia, hyponatremia, hyperkalemia or hypercalcemia between Internal Medicine C and the other three internal medicine departments following the CPOE inter-

**TABLE 4**
*Mean Number of Diagnoses per Year of Hyponatremia, Hyperkalemia, Hypokalemia, Hypercalcemia and Anemia in Department C Compared to the Average of the Other Three Departments*

| Diagnosis | Department C | Other 3 Departments |
|---|---|---|
| Hyponatremia | 55.33 | 55 |
| Hyperkalemia | 10 | 17.23 |
| Hypokalemia* | 30 | 18 |
| Hypercalcemia | 20.33 | 15.53 |
| Anemia | 238.3 | 234.61 |

* $p<0.05$

vention. There was, however, a significant increase in the number of cases of hypokalemia diagnosed (Table 4). This suggests that the decrease in the number of tests ordered did not result in a decreased diagnostic ability for conditions that are laboratory-dependent for diagnosis.

In order to determine whether the intervention affected the quality of care, we looked at the rate of readmission within 2 weeks following the initial discharge. The internal medicine departments in Israel have a very aggressive policy on discharge, with a high rate of bed turnover and a short length of stay. This is in part necessitated by a low number of hospital beds. There was a steady decrease in the rate of 2-week readmission for all of the departments during the period of the study. There was, however, no statistically significant difference in the 2-week readmission rate between department C and the other departments (Table 5). Taken together, the similarity between the departments in terms of both diagnostic numbers for laboratory-dependent diagnoses and readmission rates, suggests that the change in policy of ordering lab tests did not negatively impact on patient care.

In order to estimate the savings achieved by this intervention, we calculated the total cost of the tests performed on the basis of the charges that would have been submitted to Medicare. During the 3-year period of the intervention, a total of 348,737 laboratory tests were performed, which would have been billed for a total of $2,318,828. The other three departments performed a total of 1,741,864 tests, at a total cost of $12,698,130. The average cost per department was thus $4,232,977 over the 3-year period. The difference in cost between this average and the cost of the tests performed by department C is $1,914,149. This represents a saving of $638,049 per department per year.

The cost of the intervention is difficult to assess but is likely to be very small. The initial lecture to the medical staff lasted one hour and replaced a formal continuing medical education (CME) session in the department. The interaction with a senior physician took place together with the usual supervision of residents on the afternoon rounds. Thus no extra salary costs were incurred. In addition, there was a 3.5% increase in total admission days from 2001 to 2004 (from 13,815 to 14,294 days) and a 4.6% increase in the number of admissions (from 3,910 to 4,906). Thus, despite the interventions described above, the same medical staff treated more patients, with a resulting increase in the income generated by the department.

**TABLE 5**
*Readmission Rates during the Two Weeks Following Discharge in the Departments of Internal Medicine from 2001 through 2004*

| Year | Dept A | Dept B | Dept C | Dept D |
|---|---|---|---|---|
| 2001 | 4.6% | 4.9% | 4.7% | 4.6% |
| 2002 | 4.2% | 5% | 4.8% | 3.9% |
| 2003 | 5.3% | 4.5% | 4.5% | 3.8% |
| 2004 | 4.1% | 4% | 4.1% | 3.8% |

## Discussion

We have developed a CPOE system that achieved a marked, sustainable decrease in the test-ordering behavior of residents in an internal medicine department of a university-affiliated teaching hospital. The intervention chosen does not require sophisticated software development.

It is widely acknowledged that there is a need for a rational, cost-effective approach to the ordering of laboratory tests. The U.S. Institute of Medicine has recommended the use of information systems to improve health care delivery (27). It has been shown that computer-based reminders (19, 30–32) and "just-in-time" decision making can improve test-ordering practices (33). CPOE systems have been employed previously (28, 29). They have been shown to be an effective method of changing ordering procedures (32, 34) that result in reduced variability in provider behavior (35).

We describe a CPOE method of ordering lab tests that is easy to establish, requires no sophisticated equipment or investment of resources, and produces clear and sustained results. After the initial lecture to the resident staff and the regular presence of a senior physician to discuss with the residents the ordering of blood tests, there was a marked and consistent decrease in the number of blood tests ordered. In the Kaplan Medical Center, the admissions to the four internal medicine departments are randomly allocated. Each department receives every fourth admission. Since they have an equivalent allocation of both material and human resources and similar numbers and types of patients, the other departments can act as a control. The differences between the other internal medicine departments and our department were significant and maintained over the course of three years.

During this period the test for serum troponin was introduced together with clear guidelines to physicians. Interestingly, the use of troponin was similar for all the departments. This suggests that conditioning of physician behavior is possible and is easily achieved if a new test is introduced together with clear guidelines. It is, however, much harder to change physician behavior with well-established tests.

There is a possibility that the decrease in the use of lab tests could negatively impact diagnosis or treatment. We examined the incidence of conditions that are diagnosed mainly on the basis of lab tests in modern medicine—e.g., disturbances in sodium, potassium, calcium or magnesium levels, as well as anemia. We found no significant differences in the incidence of these diagnoses between the different departments. Thus, we believe it is unlikely that our diagnostic ability was impaired as a result of the lower rate of utilization of lab tests in Department C.

In order to check for any adverse effect on the quality of patient care, we determined the readmission rate (within 2 weeks) for each of the internal medicine departments. There was no significant difference in the readmission rates between the 4 departments of medicine, although interestingly there was a steady decline in the readmission rate in each department over the 3-year period of the study. Thus the decrease in the number of blood tests ordered did not result in a decrease in the number of diagnoses that are based mainly on lab test results, nor on the quality of care as represented by the rate of readmissions within 2 weeks of discharge.

Excessive laboratory testing is likely to generate a number of false positive blood tests or incidental findings of no clinical significance, which would require further resources to investigate. We have not been able to estimate the magnitude of this problem, but it represents an additional source of saving from the intervention we performed.

Recently, a study from Vanderbilt University reported their experience of using a peer-management CPOE system based on a computerized multi-step intervention system (29). The first step of this system involved a query that asked providers if they wanted to discontinue tests scheduled beyond 72 hours. After this intervention, they then unbundled serum metabolic panel tests into single components, reducing the number of repeated targeted tests. This study reported a 24% decrease in the rate of ordering metabolic component panel tests.

This study is different from ours in two principal areas. First, the intervention on ordering did not come into effect until after the first 72 hours of admission. This would clearly not be of any value in the typical hospital setting in Israel, where the average stay in an internal medicine department is approximately 3.6 days. The system that we describe here came into effect immediately upon admission of the patient to the internal medicine department from the emergency room and did not require the establishment of any special software. In addition, the Vanderbilt study lasted 2 years, whereas ours lasted 3 years. Also, their comparison was made for tests ordered in different time periods—a baseline prior to the intervention and a period of follow-up extending slightly more than one year. There may have been other changes made in hospital procedure during this period that were not identified by the authors and that may have been confounding factors.

One strength of our study is that the comparison was made in real time between one internal medicine department and three others, all of which have approximately equal patient populations and an equal distribution of medical resources. This reduces the likelihood of confounding factors and makes the comparison more reliable.

The residents in the departments of internal medicine do not work on the day following a night on call. In addition, they do not work in the department for a full year of their 4-year residency, due to rotations to other specialties. Thus, there is a large mix of residents working in the department over a 3-year period. We could not obtain data on the number of tests ordered per physician, but we believe that this would be similar per time period. In addition, the number of tests ordered by a resident with his or her own signature decreases as he or she progresses through the residency—the actual signing for the tests is subsequently performed by the more junior residents. Thus, the total number of tests ordered by Department C is unlikely to be influenced by the actions of a specific physician.

A further possible benefit of this system, which we have not evaluated, is its the effect on the career-long ordering practices of the residents who are physicians-in-training. Residents in internal medicine programs gain permanent employment in many different sectors of medical practice. It is likely that test-ordering behavior that is acquired in the residency period will have a career-long impact, and that the effect of this behavior, spread over many years in many different clinical settings, could result in further significant savings.

### References


1. Health Care Financing Administration. Health care Financing Review, Medicare and Medical Statistical Supplement. 1997:150 – 151.
2. Wennberg JE. Dealing with medical practice variations: a proposal for action. Health Aff (Millwood) 1984; 3(2):6 – 32,
3. Bass EB, Steinberg EP, Luthra R, et al. Variation in ophthalmic testing prior to cataract surgery. Results of a national survey of optometrists. Cataract Patient Outcome Research Team. Arch Ophthalmol 1995; 113(1):27 – 31.
4. Daniels M, Schroeder SA. Variation among physicians in use of laboratory tests II. Relation to clinical productivity and outcomes of care. Med Care 1977; 15(6):482 – 487.
5. Leese B. Is there too much laboratory testing? York, England: University of York; 1991.
6. van Walraven C, Naylor CD. Do we know what inappropriate laboratory utilization is? A systematic review of laboratory clinical audits. JAMA 1998; 280(6):550 – 558.
7. Davidoff F, Goodspeed R, Clive J. Changing test ordering behavior. A randomized controlled trial comparing probabilistic reasoning with cost-containment education. Med Care 1989; 27(1):45 – 58.
8. Thompson RS, Kirz HL, Gold RA. Changes in physician behavior and cost savings associated with organizational recommendations on the use of "routine" chest X rays and multichannel blood tests. Prev Med 1983; 12(3):385 – 396.
9. Mozes B, Lubin D, Modan B, et al. Evaluation of an intervention aimed at reducing inappropriate use of preoperative blood coagulation tests. Arch Intern Med 1989; 149(8):1836 – 1838.
10. Wong ET, McCarron MM, Shaw ST Jr. Ordering of laboratory tests in a teaching hospital. Can it be improved? JAMA 1983; 249(22):3076 – 3080.
11. Zaat JO, van Eijik JT, Bonte HA. Laboratory test form design influences test ordering by general practitioners in The Netherlands. Med Care 1992; 30(3):189 – 198.
12. Durand-Zaleski I, Rymer JC, Roudot-Thoraval F, et al. Reducing unnecessary laboratory use with new test request form; example of tumour markers. Lancet 1993; 342(8864):150 – 153.
13. Novich M, Gillis L, Tauber AI. The laboratory test justified. An effective means to reduce routine laboratory testing. Am J Clin Pathol 1985; 84(6):756 – 759.
14. Dixon RH, Laszlo J. Utilization of clinical chemistry services by medical house staff. An analysis. Arch Intern Med 1974; 134(6):1064 – 1067.
15. Dekay ML, Asch DA. Is the defensive use of diagnostic tests good for patients, or bad? Med Decis Making 1998; 18(1):19 – 28.
16. Epstein AM, McNeil BJ. Physician characteristics and organizational factors influencing use of ambulatory tests. Med Decis Making 1985; 5:401 – 415.
17. Sonnenberg A. A medical uncertainty principle. Am J Gastroenterol 2001; 96(12):3247 – 3250.
18. Werner M, Altshuler CH. Cost effectiveness of multiphasic screening: old controversies and a new rationale. Hum Pathol 1981; 12(2):111 – 117.
19. Solomon DH, Hashimoto H, Daltroy L, Liang MH. Techniques to improve physicians' use of diagnostic tests: a new conceptual framework. JAMA 1998; 280(23):2020 – 2027.
20. 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.
21. Greco PJ, Eisenberg JM. Changing physicians' practices. N Engl J Med 1993; 329(17):1271 – 1273.
22. Hillman AL, Pauly MV, Kerstein JJ. How do financial incentives affect physicians' clinical decisions and the financial performance of health maintenance organizations? N Engl J Med 1989; 321:86 – 92.
23. Emerson JF, Emerson SS. The impact of requisition design on laboratory utilization. Am J Clin Pathol 2001; 116:879 – 884.
24. Tierney WM, Miller ME, McDonald CJ. The effect on test ordering of informing physicians of the charges for outpatient diagnostic tests. N Engl J Med 1990; 322:1499 – 1504.
25. 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.
26. Boice JL, McGregor M. Effect of residents' use of laboratory tests on hospital costs. J Med Educ 1983; 58:61 – 64.
27. Axt-Adam P, van der Wouden JC, van der Does E. Influencing behavior of physicians ordering laboratory tests: a literature study. Med Care 1993; 31(9):784 – 794.
28. Milstein A, Galvin RS, Delbanco SF, et al. Improving the safety of health care: the leapfrog initiative. Eff Clin Pract 2000; 3(6):313 – 316. Erratum in: Eff Clin Pract 2001; 4(2):94.
29. Neilson EG, Johnson KB, Rosenbloom T, et al. The impact of peer management on test-ordering behavior. Ann Intern Med 2004; 141:196 – 204.
30. Sanders DL, Miller RA. The effects on clinician ordering patterns of a computerized decision support system for neuroradiology imaging studies. Proc AMIA Symp 2001; 583 – 587.
31. Tierney WM, Miller RE, Verhage JM, McDonald CJ. Physician inpatient order writing on microcomputer workstations. Effects on resource utilization. JAMA 1993; 269:379 – 383.
32. Bates DW, Pappius E, Kuperman GJ, et al. Using information systems to measure and improve quality. Int J Med Inf 1999; 53(2 – 3):115 – 124.
33. Chueh H, Barnett GO. "Just-in-time" clinical information. Acad Med 1997; 72:512 – 517.
34. Tierney WM, McDonald CJ, Hui SL, Martin DK. Computer predictions of abnormal test results. Effects on outpatient testing. JAMA 1988; 259(8):1194 – 1198.
35. 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(2):144 – 150.