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Algorithm-based Decision Rules to Safely Reduce Laboratory Test Ordering

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Abstract

PURPOSE: Our study develops decision rules to define appropriate intervals at which repeat tests might be indicated for commonly ordered laboratory tests for hospitalized patients.

METHODS: The final data set includes 5,632 adult patients admitted to the University of Virginia Hospital between July 1995 and December 1999. These patients had a hospital length of stay of five days or more and had results recorded for three routinely ordered laboratory tests for each of the first five days of their hospitalization. We use the serum potassium test to illustrate our algorithm-based decision rule methodology.

RESULTS: Our decision rule begins with testing on the first two days of hospitalization and allows for repeat testing after observation of any non-normal values. The results show that the algorithm-based decision rule would lead to a 34% reduction for serum potassium tests for the first five days of hospitalization. Only one out of the 5,632 patients in our sample had a critical value that occurred only on a non-test day and, thus, was missed by the algorithm.

CONCLUSIONS: The algorithm results are encouraging. We demonstrate that the number of tests can be reduced while missing critical values in only a small fraction of patients. Testing algorithms such as these can be used to reduce laboratory test ordering without compromising the quality of patient care.

Keywords:

Decision Support; Diagnostic Tests; Hospital Laboratories; Laboratories, Utilization; Quality of Health Care

Introduction

Background

Studies of laboratory test ordering have shown that unnecessary utilization of diagnostic tests in teaching hospitals is common [1]. The costs of excessive testing include the marginal costs of conducting the test, increased likelihood and associated costs of false positive results, and patient discomfort. Interventions to modify physician test ordering behavior have made little progress [2,3,4]. Feedback of utilization data has inconsistent results [5,6] and results are often not lasting [7,8]. Even the elimination of physicians' ability to write standing orders has been ineffective in reducing the overall number of commonly ordered diagnostic tests [9].

The unnecessary repetition of tests is the most common type of laboratory test overutilization [10]. Studies have demonstrated that the most significant changes in test ordering were for repeated tests, suggesting that repeated rather than admission test ordering is more easily changed [11]. A study of excessive lab testing in a teaching hospital emergency room revealed a statistically significant trend for decreasing percentage of necessary tests with increasing number of tests [12]. Displaying the probability of obtaining an abnormal test result has been shown to decrease the number of low probability tests ordered by physicians [13] and computerized reminders about apparently redundant tests have proven effective when it was possible to provide them [14].

Our study focuses on excessive utilization of routine laboratory tests. Using laboratory test data from hospitalized patients, we developed decision rules to define appropriate intervals at which repeat tests might be indicated. If physicians are to be more discriminating in their use of the clinical laboratory, they need to be confident that abnormal lab values will not go undetected. By presenting physicians with the decision rules developed in this study, we hope to persuade them to order fewer unnecessary tests.

Materials and Methods

Patient Population

The initial study sample included all adult patients admitted to the University of Virginia Hospital between July 1995 and December 1999 who were hospitalized for five days or more (25,818 patients). The 557-bed tertiary care hospital is a part of the University of Virginia Health System, Charlottesville Virginia. Its clinical laboratories perform nearly 10 million tests annually.

Test Selection and Definitions

We identified thirteen laboratory tests that were high volume based on data from our hospital's financial system. These tests are generally ordered as part of a bundled group or "panel" and, thus, tend to represent the scope of common laboratory test activity in our hospital. This paper describes the results for three of these tests, one from each panel: hematocrit, calcium, and potassium. An algorithm-based decision rule is described for potassium.

Non-normal test results are classified as either "abnormal" or "critical". An abnormal test result is defined as a value that falls outside of the expected normal range but does not reach a "critical" value. While abnormal values may or may not prompt a repeat test depending on other clinical indications, critical test results almost always require some clinical decision or intervention and, thus, should not be missed. We used the normal value ranges and critical values that were identified by our clinical pathology laboratory (Table 1).

Table 1 Normal Range and Critical Test Values

Test Name	*Units*		Normal Range		Critical Values	
			Low	High	Low	High
Hematocrit	%	*male*	40.0	52.0	30.0	55.0
	%	*female*	35.0	47.0	30.0	55.0
Calcium			8.4	10.2	6.0	13.0
Potassium	mmol/L		3.5	5.0	2.5	5.9

Data Extraction

We extracted laboratory test data from the University of Virginia Health System's Clinical Data Repository (CDR), a data warehouse that contains the hospital's clinical laboratory test result data, as well as other administrative, financial and clinical data, including patient demographics, diagnoses, procedures performed, and medications prescribed [15]. The final sample data set includes all adult patients admitted to the University of Virginia Hospital between July 1995 and December 1999 who had a hospital length of stay of five days or more and who had results recorded for all three of the selected laboratory tests (hematocrit, calcium, potassium) for each of the first five days of their hospital stay. When a test was performed more than once on any given day, the worst value was selected for our analysis. The final data set includes 5,632 patients.

Testing Algorithms

There are a number of possible testing sequences that might occur over the first five days of hospital stay. Our starting point is the day of admission since patients generally have a battery of routine lab tests performed on this date. We selected seven possible testing sequences for our analysis, ranging from a single test on the admission day to a test on each of the first five days of hospitalization (Table 2).

Table 2 Possible Testing Algorithms

Day 1	Day 2	Day 3	Day 4	Day 5	# tests
X					1
X	X				2
X	X	X			3
X	X		X		3
X		X		X	3
X	X	X		X	4
X	X	X	X	X	5

In order to analyze the abnormal and critical test results that would go undetected by these testing algorithms, we introduce the concept of a "missed abnormal test" and "missed critical test". A "missed" test is defined as abnormal or critical if an abnormal or critical value was recorded on one of the days that testing would not have been done and the value was not abnormal or critical on the previous day or remain so on the subsequent testing day. For example, the algorithm shown below (Table 3) misses a critical result on Day 4, a non-test day, and, therefore, would be categorized as a "missed critical test".

Table 3 7Algorithm Example

Day	Testing on Days 1, 3, and 5
1	Normal
2	Normal
3	Normal
4	**Critical**
5	Normal

Results

During the 54-month study period, July 1995 to December 1999, 25,818 adult patients were admitted to the University of Virginia Hospital and had daily laboratory testing for the first five days of their hospitalization. Of these patients, 5,632 had hematocrit, calcium, and potassium test results recorded for each of the first five days; these patients constitute our final study sample (Table 4).

We estimated the probabilities that abnormal or critical results would be observed for each of the first five days of hospital stay for three commonly ordered laboratory tests and used these results to define reasonable intervals at which to order a test after a normal result is observed. Initially, we applied a simple algorithm that involved arbitrary testing on certain days regardless of the result of a prior test (Table 5).

Table 4 Characteristics of Study Population

Characteristic	**Patients (n=5,632)**
Age (yrs)	61.0 ± 16.4
Male, no. (%)	3,089 (54.9)
Length of Stay (days)	8 (6, 13)
In-hospital death, no. (%)	408 (7.2)
Top 5 diagnostic categories (DRGs)	
Coronary atherosclerosis	418 (7.4)
Acute myocardial infarction	347 (6.2)
Acute cerebrovascular disease	263 (4.7)
Complication of device or implant	230 (4.1)
Congestive heart failure	204 (3.6)

Results are medians; ranges (in parentheses) are 25% and 75% quartiles. Plus-minus values are mean ± SD.

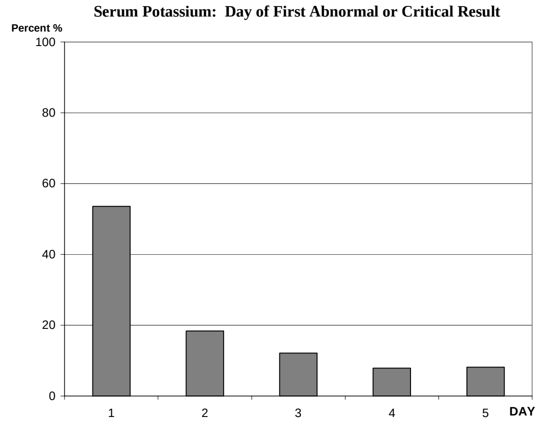

Figure 1

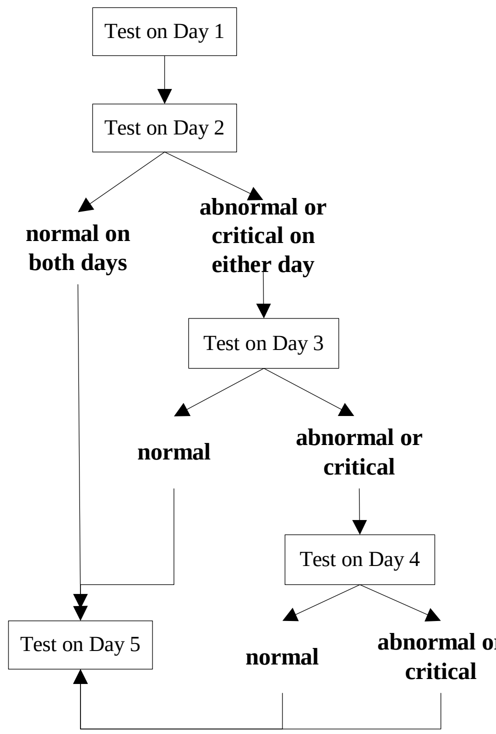

Figure 2 Modified Algorithm

Table 5 Simple Algorithm: Missed Test Results

Algorithm	**Result**	**Missed Abnormal and Critical Tests**					
		HCT		**CA**		**K**	
		no.	%	no.	%	no.	%
Day 1 only	Abnormal	870	47.18	2,011	47.50	1,881	66.12
	Critical	350	10.20	19	11.87	68	30.63
1 and 2	Abnormal	634	34.38	1,374	32.45	1,493	52.48
	Critical	139	4.05	13	8.12	40	18.02
1, 2, and 3	Abnormal	435	23.59	910	21.49	1,024	35.99
	Critical	68	1.98	7	4.37	15	6.76
1, 2, and 4	Abnormal	259	14.05	584	13.79	784	27.56
	Critical	22	0.64	5	3.12	13	5.86
1, 2, and 5	Abnormal	173	9.38	458	10.82	760	26.71
	Critical	12	0.35	2	1.25	22	9.91
1, 3, and 5	Abnormal	143	7.75	371	8.76	604	21.23
	Critical	8	0.23	2	1.25	17	7.66
1, 2, 3 and 5	Abnormal	71	3.85	178	4.20	316	11.11
	Critical	1	0.03	1	0.62	7	3.15

Increasing testing frequency decreases missed abnormal and critical test results. To avoid missing all abnormal or critical values, testing must occur daily.

Modified Algorithm Results

Our goal in developing decision rules to define appropriate testing intervals is to minimize the likelihood that abnormal values will go undetected while, at the same time, reducing the frequency of testing. Most abnormal or critical test results are detected during the first two days of hospitalization. In the case of potassium, 72% of non-normal results observed during the first five days occurred on Days 1 and 2 (Figure 1). For this reason, our modified algorithm begins with testing on the first two days.

Because it is reasonable for a physician to order a repeat test after observing a critical value or even an abnormal value, we modified our simple algorithm to allow for repeat testing after observation of any non-normal values. The flowsheet (Figure 2) illustrates the modified algorithm for a potassium test for testing on Days 1,2, and 5.

Our results show that the modified algorithm-based decision rule would lead to a 34% reduction in laboratory test orders for potassium for the first five days of hospitalization. Only one out of 5,632 patients in our sample had a critical value that occurred only on a non-test day and, thus, was undetected by the modified algorithm (Table 6).

Discussion

We estimated the probabilities that abnormal or critical results would be observed for each of the first five days of a patient's hospital stay for three commonly ordered laboratory tests and used these results to define reasonable intervals at which to order a lab test after a normal result is observed. We used the serum potassium test to illustrate our algorithm-based decision rule methodology. Our starting point is the day of admission; each patient is presumed to have a lab test on admission date. Our modified algorithm begins with testing on the first two

Table 6 Modified Algorithm Results

ABNORMAL OR CRITICAL ON A NON-TEST DAY	
Results	*Patients, no. (%)*
Abnormal	1,039 (18.5)
Critical	27 (0.5)
ABNORMAL OR CRITICAL *ONLY* ON A NON-TEST DAY*	
Results	*Patients, no. (%)*
Abnormal	399 (7.1)
Critical	9** (0.2)
ABNORMAL OR CRITICAL VALUE DETECTED BY PRIOR OR SUBSEQUENT TESTS	
Results	*Patients, no. (%)*
Abnormal	640 (11.4)
Critical	18 (0.3)

* The missed abnormal or critical value was the only time an abnormal or critical value was seen during the five days of testing.

** 8 of the 9 critical values were normal on a follow-up test and probably represent a false positive test.

hospital days and permits testing on any day following observation of either an abnormal or critical value. These preliminary results are encouraging. Unnecessary laboratory test ordering can be reduced without compromising the quality of patient care.

Limitations

This study has several limitations. Our study population is not a random sample of hospitalized patients. We chose a population that received daily testing for five days over the study period to construct our decision rule algorithms. In fact, 80% of patients do not receive daily testing. Thus, our sample is presumably a sicker population – patients that the physicians thought needed daily testing. Also, our study was conducted at one tertiary care hospital where housestaff are responsible for ordering laboratory tests. Thus, the results may not be generalizable to other institutions or settings.

Our study was intended to illustrate use of algorithm-based decision rules to reduce unnecessary test ordering. We only estimated the potential reduction based on the likelihood of observing abnormal or critical test values. Other clinical changes or factors would appropriately influence a physician's test ordering behavior. Determining how many tests might actually be eliminated will require diagnoses specific analysis, more stringent definition of appropriate testing intervals (i.e. to account for differences in tests that change more slowly over time, etc.), and a randomized trial.

Conclusion

The phenomenon of unnecessary repetition of laboratory tests in hospitalized patients is well documented. In spite of information about unnecessary ordering, physician behavior has resisted change. A major concern in efforts to reduce the number of tests is the potential for reducing the quality of patient care. Certainly, anything less than daily testing will miss some percentage of abnormal results. What is an acceptable threshold? The answer to this question is a policy issue, a societal judgment that must balance the harm caused by missing a small percentage of abnormal results against the harmful effects of daily testing, including the direct cost of additional laboratory utilization, patient discomfort, and associated costs of false positive results. This study uses actual patient laboratory data to test different algorithms for the timing of testing to define appropriate intervals at which repeat tests for commonly ordered laboratory tests might be indicated. We demonstrate that the number of tests can be reduced while missing critical values in only a very small fraction of patients. By increasing physician confidence that abnormal lab values will not go undetected, testing algorithms such as these may improve cost effectiveness and clinical effectiveness. If used with other methods to reduce unnecessary test ordering such as using clinical pathways and guidelines, providing cost information, and limiting the use of panels, algorithm-based decision rules may be even more effective.

Our future research will apply algorithm-based decision rules to other routinely ordered laboratory tests, including hematocrit and calcium tests. We will also examine other demographic (i.e. age, gender, health care insurance coverage) and clinical features as explanatory variables to understand better test ordering practices related to co-morbidities, severity of disease, and disease progression.

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References

[1] Lundberg GD. The need for an outcomes research agenda for clinical laboratory testing. *JAMA* 1998;565-66.

[2] van Walraven C, Goel V, Chan B. Effect of population-based interventions on laboratory utilization. *JAMA* 1998; 280(23):2028-33.

[3] Studnicki J, Bradham DD, Marshburn J, Foulis PE, Straumfjord JV. A feedback system for reducing excessive laboratory tests. *Arch Pathol Lab Med* 1993; 117:35-39.

[4] Axt-Adam P, van der Wouden JC, van der Dose E. Influencing behavior of physicians ordering laboratory tests: a literature study. *Med Care* 1993; 31:784-94.

[5] Solomon DH, Hashimoto H, Daltroy L, Liang MH. Techniques to improve physicians' use of diagnostic tests. *JAMA* 1998; 280(23):2020-27.

[6] Bates DW, Kupermman GJ, Jha A, Teich JM, Orav EJ, Ma'luf N, Onderdonk A, Pugatch R, Wybenga D, Winkelman J, Brennan TA, Komaroff AL, Tanasijevic MJ. Does the computerized display of charges affect inpatient ancillary test utilization? *Arch Intern Med* 1997; 157:2501-8.

[7] 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.

[8] Bates DW, Boyle DL, Rittenberg E, Kuperman GJ, Ma'Luf N, Menkin V, Winkelman JW, Tanasijevic MJ. What proportion of common diagnostic tests appear redundant? *The Amer J of Med* 1998; 104:361-67.

[9] Sussman E, Goodwin P, and Rosen H. Administrative change and diagnostic test use: the effect of eliminating standing orders. *Med Care* 1984; 22:569-72.

[10] Eisenberg JM, Williams SV, Garner L, Viale R, Smits H. Computer-based audit to detect and correct overutilization of laboratory tests. *Med Care* 1977; 15:915-21.

[11] Spiegel JS, Shapiro MF, Berman B, Greenfield S. Changing physician test ordering in a university hospital: an intervention of physician participation explicit criteria and feedback. *Arch Intern Med* 1989; 149:549-53.

[12] Bloomgarden Z, Sidel VW. Evaluation of utilization of laboratory tests in a hospital emergency room. *Am J Public Health* 1990; 70:525-28.

[13] Tierney WM, McDonald CJ, Hui SL, Martin DK. Computer predictions of abnormal test results: effects on outpatient testing. *JAMA* 1988; 259:1194-98.

[14] Bates DW, Kuperman GJ, Rittenberg E, Teich JM, Fiskio J, Ma'luf N, Onderdonk A, Wybenga D, Winkelman J, Brennan TA, Komaroff AL, Tanasijevic M. A randomized control trial of a computer-based intervention to reduce utilization of redundant laboratory tests. *Am J Med* 1999;106(2):144-50.

[15] Scully KW, Pates RD, Desper GS, Connors AF, Harrell FE, Pieper KS, Hannan RL, Reynolds RE. Development of an enterprise-wide clinical data repository merging multiple legacy databases. *AMIA Ann Symp*, 1997.

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