Optimization of Laboratory Ordering Practices for Complete Blood Count With Differential

Jeffrey Z. Shen,¹ Benjamin C. Hill, MD,³ Sherry R. Polhill, MBA, MT(ASCP),⁵ Paula Evans, MT(ASCP),⁵ David P. Galloway, MD,⁴ Robert B. Johnson, RRT, MS,⁶ Vishnu V.B. Reddy, MD,¹ Patrick L. Bosarge, MD,² Lisa A. Rice-Jennings, MT(ASCP),⁵ and Robin G. Lorenz, MD, PhD¹

From the Departments of ¹Pathology and ²Medicine, University of Alabama at Birmingham; ³Department of Pathology and ⁴Division of Gastroenterology, Hepatology, and Nutrition, Children's Hospital of Alabama, Birmingham; and ⁵Clinical Laboratories and ⁶Department of Respiratory Care, University of Alabama at Birmingham Hospital.

Key Words: Complete blood count; Laboratory test utilization; University hospital; Educational intervention; Quality improvement

Am J Clin Pathol March 2019;151:306-315

DOI: 10.1093/AJCP/AQY146

ABSTRACT

Objectives: To investigate the utilization of CBC and CBC with differential (CBC wldiff) tests at University of Alabama at Birmingham Hospital, and to determine if a reduction in CBC wldiff tests could be achieved without negatively impacting patient care.

Methods: The quantity of testing and distribution of repeated tests before, during, and after an educational intervention were compared.

Results: CBC wldiff tests were ordered 10-fold more frequently than CBC tests. The trauma burn intensive care unit ordered the most CBC wldiff tests, with repeat tests done every 4 or 12 hours. The educational intervention reduced the number of CBC wldiff tests ordered and tests repeated every 12 hours.

Conclusions: The educational intervention changed the ordering practices of CBC wldiff and CBC tests. This was sustained after the intervention and no negative effects on patient care were noted. Similar interventions may lead to optimization of ordering practices of other laboratory tests.

Health care expenditures are estimated to rise to \$3.6 trillion in 2018,¹ with accelerated growth in hospital spending and spending on physician and clinical services. Excess health care costs are estimated to be \$750 billion, and are caused by unnecessary services, inefficient delivery of services, high prices, excess administrative costs, missed prevention opportunities, and medical fraud. Out of these six reasons, unnecessary services are the largest contributor to excess health care costs.

More than 5 billion laboratory tests are performed each year, over 20% of which have been reported to be unnecessary.² In 2012, the American Board of Internal Medicine Foundation initiated the Choosing Wisely campaign to increase awareness of wasteful or unnecessary medical tests, procedures, and treatments.^{3,4} More than 70 individual medical and physician societies are now participating in the Choosing Wisely³ campaign and have released recommendations designed to reduce these wasteful and unnecessary tests.

Often tests are ordered routinely without a clear rationale. Not only do these routine tests increase health care spending but are also a source of iatrogenic blood loss and anemia in hospitalized and critical care patients.⁵ Hospital-acquired anemia has been associated with increased blood transfusions (and the subsequent increased exposure to infection), as well as increased length of stay and mortality.⁶ It has been estimated that it would only take 9 to 14 days of routine blood draws to

take a critical care hospitalized patient below the RBC transfusion threshold.^{5,7}

Because of its wide-reaching potential for disease diagnosis, the complete blood count (CBC) and complete blood count with differential (CBC w/diff) tests are, respectively, the first and second most performed tests in the clinical hematology laboratory.⁸ Choosing Wisely³ recommends eliminating repetitive CBC and chemistry testing for clinically stable patients. However, in investigating repeat testing, it has been suggested that the CBC w/diff test should only be ordered if there are symptoms or risk of anemia, if the patient is bleeding or at risk of bleeding due to a pending surgical intervention or procedure, if there are signs of infection, if the patient has a disease that affects blood cells, or if the patient is receiving a treatment that would affect blood cells.^{8,9} Along with evaluating the rationale for ordering the CBC w/diff test, the frequency at which the test is repeated should be determined. This frequency can be estimated by the time it takes for the last neutrophil progenitor to be released in the blood as a neutrophil, because neutrophils have the shortest half-life of the cell types analyzed by the CBC w/diff test. Multiple studies in both animals and humans have estimated that this time is 6 to 7 days when an individual is healthy, and 2 days in diseased individuals.¹⁰

Based on these data, several studies have defined the criteria for appropriate ordering of the CBC w/diff test for both initial test ordering and repeated testing. In 1989, the criteria for appropriate CBC w/diff initial testing included: emergency admission, a temperature of greater than 38.0°C, suspected infection, primary hematologic disorder (ie, anemia, myeloproliferative disorder, aplasia, platelet disorder), anticipation of a therapy toxic to the bone marrow, or suspicion of disorders associated with eosinophilia, monocytosis, lymphocytosis, or basophilia.¹¹ A second study, completed in 1984, evaluated the utility and cost effectiveness of the CBC w/diff test among inpatients.¹² The criteria in this study for a justified order for a CBC w/diff test included those listed above for initial ordering, as well as any new symptom arising in the hospital that was potentially a manifestation of an infection or a hematologic process that was recorded in the chart by the physician and a follow-up of an increased WBC count ($>11,000/\mu\text{L}$) or a decreased WBC count ($<4,000/\mu\text{L}$). To determine the criteria used to determine if there is a clinically significant change in the results from a repeated CBC w/diff test, a retrospective cohort study was performed in 1998.¹³ This study defined a redundant CBC w/diff test as one done within 36 hours of a previous CBC w/diff test (except for patients in which treatment was based on the differential, ie, a cancer patient with

neutropenia). The United Kingdom has issued national minimal retesting interval guidelines, which state that repeat CBC (without diff) testing should have a minimum interval of once daily for unstable patients without active bleeding or receiving cytotoxic drugs and once in 4 days for stable patients.¹⁴ Indications for repeat CBC include clinically significant changes such as a massive hemorrhage, in which it is appropriate to order a CBC every hour to check on the patient's status.

Furthermore, one study from the University Hospitals of Cleveland indicates that 90% of physicians report that they only routinely used four of 11 parameters of the CBC with/diff.¹⁵ These were hemoglobin, hematocrit, platelet count, and WBC count. These are all parameters reported in the basic CBC test, and this indicates that most physicians do not use the majority of additional data reported in the CBC w/diff test analysis. Therefore, it is possible that many CBC w/diff tests are ordered when the rationale for a CBC test, but not CBC w/diff test, is met.

Several types of interventions have been evaluated to determine their impact on optimizing laboratory ordering practices; however, the results of these studies are often inconsistent. Educational methods, such as flyers and periodic email reminders, have attempted to encourage ordering of blood tests by internal medicine providers only if the results would change management. This approach successfully reduced average daily ordering of CBC and basic metabolic panel (BMP).⁶ Another study used lectures on appropriate utilization of laboratory tests for residents in an outpatient clinic, and their results demonstrated a reduction in the total number of ordered tests.¹⁶ There also have been successful approaches that incorporate multiple different methods, including education, intensive care unit (ICU) rounds checklists, and electronic medical record interventions to only allow ordering of tests for accepted indications.¹⁷

Several studies have shown that residents order more redundant testing than the faculty attendings, which has been attributed to lack of education on appropriate laboratory testing and knowledge of costs for ordering laboratory tests.^{18,19} Interventions specifically focusing on improving resident education have been successful in reducing redundant laboratory testing.²⁰⁻²² However, there is little research on interventions focused on changing physician ordering from one test to another more appropriate test.

Therefore, our team designed a study to determine if a reduction in CBC w/diff test frequency could be achieved, without negatively impacting patient care by delaying diagnosis of sepsis. By analyzing data on laboratory ordering patterns of CBC and CBC w/diff tests in

the electronic medical records, our team created a process map of how laboratory tests were currently ordered in our ICUs and then utilized this information to determine the top reasons that contributed to overutilization of CBC w/diff testing. We then investigated the effects of an educational intervention at one unit of University of Alabama at Birmingham (UAB) Hospital on the quantity of tests, practices of repeat testing, as well as appropriate test ordering (CBC tests instead of CBC w/diff tests in cases when the differential is not needed or used).

Materials and Methods

UAB Hospital is a 1,022-bed tertiary care academic medical center with eight intensive care units, including trauma burn (TBICU), medical (MICU), neurosciences (NICU), and surgical (SICU) intensive care units. The number of beds in TBICU is 25, NICU 26, SICU 20, and MICU 19 and the occupancy rate is approximately 100%. TBICU was chosen because it was found to have the highest number of CBC w/diff tests ordered out of all inpatient units. SICU and NICU were chosen as controls because both are units that, like the TBICU, have a high frequency of ordering CBC and CBC w/diff tests. These both are also surgical ICUs like the TBICU. MICU was chosen as a nonsurgical ICU unit control, ordering the highest number of CBC and CBC w/diff tests out of

the nonsurgical ICU units, and higher than most other inpatient units. The clinical laboratory at UAB Hospital performs laboratory testing for all inpatients at UAB Hospital.

Approaches

The study design included four steps. First, we collected data from Power Insight and Cerner on UAB Hospital-wide laboratory ordering patterns to determine the most ordered tests from January 2015 to April 2015. It was found that the CBC w/diff test was the most ordered test at 97,515 and the CBC the eighth most ordered test at 9,871. It was unexpected that the CBC w/diff test was ordered about 10 times more frequently than the CBC, so we decided to focus our investigation on the ordering practices for these two laboratory tests.

Second, we collected data about total CBC and CBC w/diff orders from comparator hospitals by asking several questions (listed in **Table 1**) of hospitals that are part of the University Health System Consortium, a national organization comprising most of the nation's leading academic medical centers. Third, we determined the hospital unit that ordered the most CBC w/diff tests, which was the TBICU. We met with TBICU staff to present the initial data on CBC test and CBC w/diff test ordering practices and to gather information on specific ordering patterns. Utilizing this information, a process map was created for how clinical laboratory tests were

Table 1
CBC and CBC W/Diff Utilization Across the University Health System Consortium of Academic Medical Centers

Institution	What Is Your Academic Bed Size?	How Many Intensive Care Units Do You Have?	What Is Your Volume of CBC for IP and OP?	What Is Your Volume of CBC W/Diff for IP and OP?	Ratio CBC Orders to CBC W/Diff Orders
A	660	9	IP: 97,000 OP: 38,000 Total: 135,000	IP: 122,000 OP: 173,000 Total: 295,000	IP: 0.97:1 OP: 0.21:1 Total: 0.46:1
B	726	6	Total 180,000	Total 120,000	Total 1.5:1
C	1,243	8	IP: 298,267 OP: 130,467 Total: 428,734	IP: 205,044 OP: 111,601 Total: 316,645	IP: 1.45:1 OP: 1.17:1 Total: 1.35:1
D	750	10 (3 hospitals)	Total: 156,000	Total: 192,000	Total: 0.81:1
E	501	9	IP: 67,246 OP: 36,503 Total: 103,749	IP 89,790 OP: 97,486 Total: 187,276	IP: 0.75:1 OP: 0.37:1 Total: 0.55:1
F	576	4	IP: 92,279 OP: 32,776 Total: 125,055	IP: 44,356 OP: 65,493 Total: 109,849	IP: 2.08:1 OP: 0.50:1 Total: 1.14:1
G	722	6	Total: 87,000	Total: 131,400	Total: 0.66:1
Average of UHC comparator hospital ratios (based on total CBC and CBC w/diff order volume)			IP: 554,792 OP: 237,746 Total: 1,215,538	IP: 461,190 OP: 447,580 Total: 1,252,170	IP: 1.20:1 OP: 0.53:1 Total: 0.97:1
UAB Hospital	1,022	9	IP: 43,392 OP: 36,324 Total: 79,716	IP: 250,416 OP: 147,216 Total: 397,632	IP: 0.17:1 OP: 0.24:1 Total: 0.20:1

IP, inpatients; OP, outpatients; UAB, University of Alabama at Birmingham; UHC, University HealthSystem Consortium; w/diff, with differential.

ordered for patients on the TBICU and this process map was utilized to generate a Pareto chart to identify “reasons for ordering” data that impacted overutilization of CBC w/diff tests **Figure 1**. Finally, because of previous success of educational interventions at other academic medical centers, we decided to implement an educational intervention and then analyze the effects of that intervention on laboratory ordering practices during the time of the intervention and 2 months after (to see whether any improvements were retained).

Data Collection

This study was approved by the institutional review board (IRB) of University of Alabama Birmingham (IRB-160826009). We first collected data on laboratory ordering patterns of CBC tests and CBC w/diff tests at UAB hospital through the Cerner database during January of 2016. This included information of all inpatient units, quantity of each test ordered, the time they were collected, the time they were ordered, who ordered the test, and the patient for whom they were ordered. These data were used for the rest of our analyses, as the majority of the CBC w/diff test orders in an inpatient setting are due to repeat testing over the duration of the patient’s stay

Figure 1 Pareto chart listing “Reason for ordering” for CBC with differential (w/diff) test overutilization. The top failure was “CBC w/diff test is default.” At University of Alabama at Birmingham (UAB) Hospital in early 2016, there were 2104 different ordering PowerPlans that had the CBC w/diff test as a component of their orders and approximately 20% had the CBC w/diff test as a routine order more frequently than once/day. The UAB Hospital units with the most PowerPlans with these frequent CBC w/diff test orders were the trauma burn intensive care unit and the surgical intensive care unit.

in the hospital. We next determined the intervals between CBC w/diff test orders over the entire UAB Hospital and the most frequent intervals for repeat testing.

Intervention

We implemented a three-step approach to reducing repetitive or unnecessary CBC w/diff testing in the TBICU. First, team members met with the entire TBICU staff to introduce the project and show the initial analysis. This initial encounter demonstrated several unanticipated barriers and ordering practices that were then considered in the second phase of the project (March 14, 2016, to March 28, 2016), where the TBICU providers and staff agreed to follow the flowchart guiding CBC ordering practices shown in **Figure 2A**. The most significant changes in ordering recommendations was a switch from ordering the CBC w/diff test every 4 to 6 hours for all new trauma patients to ordering a CBC test (no diff) every 4 to 6 hours. If the patient was considered stable at 48 hours after admission, then the repeat orders were changed to a CBC w/diff test every 12 hours for the rest of the hospitalization. Additionally, a pocket educational tool was developed and given to all TBICU providers and staff, in order to have an additional method to remind them of the new ordering protocol **Figure 2B**.

After the 2-week trial of these new ordering practices, data were analyzed through the use of both control and run charts for effectiveness of the intervention and the key stakeholders were surveyed for their input on the process and its implications for patient care and outcomes. Repeat tests were defined as a test of the same type collected for the same patient within 22 hours; this time was chosen to avoid categorizing routine daily tests as repeat tests. This data analysis was repeated 2 months after the educational intervention (on data collected May 14, 2016, to May 28, 2016) to determine if the changes seen in CBC w/diff test ordering patterns were retained.

In discussions with TBICU providers, one reason stated for ordering frequent CBC w/diff tests for patients was to use the differential as an early biomarker for sepsis. Therefore, we designed a component of our study to determine if the educational intervention (and the switch to CBC tests instead of CBC w/diff tests during the first 48 hours of hospitalization) had the negative effect of delaying identification of sepsis. We took 20 patients in the TBICU during January 2016 (before the intervention) who had the most repeat testing done and reviewed their charts to see whether they fit the criteria of having: (1) no clinical signs of infection, as well as (2) CBC w/diff test result shows greater than 10% bands. Then we did the same for 20 patients in the TBICU who had the most

Figure 2 Educational guides designed to reduce overutilization of CBC with differential (w/diff) testing in the trauma burn intensive care unit (TBICU) setting. **A**, Flow sheet ordering tool placed on clip boards and given to frontline staff. **B**, Pocket ordering tool given to frontline staff.

repeat tests done for them during the March intervention period.

Statistical Analyses

Excel XSTAT was used to perform statistical analyses of the data. For comparing ordering patterns across different units and across different months, we used a two-sample *t* test for unequal variances. CBC ratios were calculated by taking the fraction of CBC w/diff ordered over the CBC without differentials. We then calculated the percentage reduction by taking the difference in ratio between 2 months and dividing over the original number (CBC ratio in January).

Results

A survey of utilization patterns across comparable institutions in the University Health System Consortium during 2016 demonstrated an average ratio of CBC test orders to CBC w/diff test orders of 0.97:1 (range 0.46:1 to 1.5:1). For the year 2016, the ratio at UAB Hospital was 0.20:1 [Table 1](#), which clearly demonstrates that the CBC w/diff test is utilized much more frequently than the CBC test for patients at UAB Hospital when compared to University HealthSystem Consortium comparator academic medical center hospitals. This knowledge prompted a more in-depth analysis of which units at UAB Hospital ordered the most CBC w/diff tests. In January 2016, the utilization of CBC w/diff tests at UAB Hospital

was investigated by determining how many patients had CBC w/diff testing with less than 22 hours between repeat orders. This initial analysis of ordering patterns demonstrated that the unit with the highest volume of repeat CBC w/diff testing was the TBICU (data not shown). Thus, we took the opportunity to implement a three-step approach to reducing repetitive or unnecessary CBC w/diff tests in the TBICU (described under Intervention section above).

We first considered whether the total number of CBC w/diff test orders changed upon the intervention. **Figure 3** shows the trend of decreasing quantities of orders per day. The mean number of CBC w/diff test orders per day was 59 in January, 47 in March, and 48 in May. The reduction from January to March, during the intervention is significant ($P < .0001$) and this change was retained in May ($P = .0024$ for difference between January and May).

Out of 886 total CBC w/diff tests ordered from January 14 to 28, 740 (83%) were tests repeated on the same patient in 22 hours or less. Our analysis showed that repeat tests were often taken every 4 hours and 12 hours **Figure 4**. The number of CBC w/diff tests repeated on the same patient every approximately 12 hours (time between repeats, 11-13 hours) was considerably reduced from 306 in January to 217 in March and 209 in May.

Although we saw a reduction in the total number of CBC w/diff tests in the TBICU, after comparing with other similar units (SICU and NICU), we found that they experienced a reduction as well **Table 2**. The TBICU ordered 886 CBC w/diff tests from January 14 to 28, 711

from March 14 to 28, and 718 from May 14 to 28. The NICU decreased their CBC w/diff tests from 737 to 707 ($P = .2$) and 612 ($P < .01$) in the respective time periods while the SICU decreased theirs significantly from 547 to 489 ($P = .03$) and 423 ($P < .01$) in the respective time periods. However, the MICU did not show significant changes as their numbers were 379, 380, and 380 in the respective time periods.

From our analysis (Table 2), 761 out of 886 total CBC w/diff tests ordered at the TBICU were within 22 hours for the same patient (86% repeat tests); 623 (82%) of those tests were ordered by the same provider who had ordered the earlier test. Out of 64 total providers ordering CBC tests and CBC w/diff tests, 22 providers ordered

repeat CBC w/diff tests. None of the ordering providers were attendings. Furthermore, the top three ordering personnel alone ordered 524 (84%) of these 623 repeat tests. These three were physician assistants who are primarily based in the TBICU and do not rotate between services. During our intervention period, 388 of 521 (75%) were ordered by the same provider who had ordered the earlier test, with 281 (72%) ordered by these top three orderers.

The next dataset that we evaluated to determine the effectiveness of our intervention was the impact on turn-around time (TAT) for CBC w/diff testing ordered by the TBICU. A control chart for TBICU TAT during our intervention period demonstrated that the average TAT for a CBC w/diff test prior to our intervention was 42.6

Figure 3 Data on CBC with differential tests ordered per day at trauma burn intensive care unit were collected for three 2-week time periods in January 2016 before the intervention (circles), March during the intervention (squares), and May after the intervention (triangles).

Figure 4 Data on CBC with differential repeat tests ordered in the trauma burn intensive care unit with an interval of less than 22 hours. Any number “n” on the x axis refers to a test repeated on the same patient between the hours “n” and “n – 1.” Circles represent tests done on January 14 to 28, 2016, before the intervention, squares March 14 to 28, 2016, during the intervention, and triangles May 14 to 28, 2016, after the intervention.

Table 2
CBC and CBC W/Diff Tests Ordered Before, During, and After the Educational Intervention

Unit	Test	No. of Tests		
		Jan 14-28	Mar 14-28	May 14-28
TBICU	Total	14,422	14,219	13,986
	Total CBC (no diff)	2,200	2,320	2,383
	Total CBC w/diff	12,222	11,899	11,603
	Total ratio ^a	0.18:1	0.19:1	0.21:1
	CBC (no diff)	9	118	81
	CBC w/diff	886	701	713
	Repeat CBC w/diff ≤22 h	761	521	552
	Ratio ^a	0.01:1	0.17:1	0.11:1
NICU	CBC (no diff)	38	86	159
	CBC w/diff	738	707	611
	Repeat CBC w/diff ≤22 h	410	338	272
	Ratio ^a	0.05:1	0.12:1	0.26:1
SICU	CBC (no diff)	60	113	122
	CBC w/diff	547	488	423
	Repeat CBC w/diff ≤22 h	412	314	290
	Ratio ^a	0.11:1	0.23:1	0.29:1
MICU	CBC (no diff)	115	106	72
	CBC w/diff	379	380	380
	Repeat CBC w/diff ≤22 h	122	90	110
	Ratio ^a	0.30:1	0.28:1	0.19:1

diff, differential; MICU, medical intensive care unit; NICU, neurosciences intensive care unit; SICU, surgical intensive care unit; TBICU, trauma burn intensive care unit.

^aRatio is number of CBC tests ordered: CBC w/diff tests ordered.

minutes. During our intervention period of March 14 to 28, 2016, the average TAT for the TBICU was decreased to 37.4 minutes. This decreased TAT clearly directly impacts patient care by getting critical results back to the patient care providers faster so that they can use the results in making patient treatment decisions.

Finally, we also investigated whether altering the ordering intervals for CBC w/diff tests would have the potential negative effect of delaying diagnosis of sepsis. The 20 patients who had the most repeat testing done in January 14 to 28, 2016, accounted for 74% of the total repeat CBC w/diff testing. A chart review of these patients showed that 18/20 had leukocytosis during this time period, and two of 20 had bands greater than 10% (bandemia, an indicator of sepsis from the CBC w/diff test that would not have been obtained by a CBC test without diff). Of these two patients, both had leukocytosis. One was actively being treated for pneumonia before developing bandemia. The presence of bands did not change the medical treatment plan, and the bands decreased without a change in antibiotic regimen. The other had bandemia on admission; there was no mention of the differential in the note when discussing the medical treatment plan. The leukocytosis and bands both resolved after an operation with routine perioperative antibiotics. The 20 patients who had the most repeat testing done in March 14 to 28, 2016, accounted for 71% of the total repeat CBC w/diff testing; 15/20 had leukocytosis during this period of time.

Again, only two of 20 patients had bandemia. One was not considered to be septic at the time of his bandemia, as he had no leukocytosis or other clinical signs of infection at the time, and antibiotics were not started. The other had bandemia on admission, which resolved after an operation with routine perioperative antibiotics.

Discussion

Over 20% of laboratory testing has been reported to be unnecessary.² As part of the national Choosing Wisely campaign, several societies, including the Society of Hospital Medicine, the American Association of Anesthesiologists, and the American Society for Clinical Pathology, have identified the CBC test and/or the CBC w/diff test as a key focus of their campaign to reduce repetitive or unnecessary medical tests, as these “routine” tests should not be automatically ordered but instead should only be ordered if there is clinical evidence of need.²³⁻²⁵ Therefore, following these recommendations, the laboratory test that we identified to study and potentially alter ordering practices was the CBC w/diff test. We specifically addressed a gap in the literature regarding whether an educational intervention could shift the quantity and ordering practices of CBC w/diff testing to CBC (without a differential). This shift should result in both decreased follow-up testing (secondary to decreased

potential of false-positive results in the differential) and decreased turnaround time (as the automated differential often necessitates a manual “double-check” by a technologist of flags generated by the automated analysis).

The utilization of CBC w/diff tests at UAB Hospital was investigated by determining how many patients had CBC w/diff testing with less than 22 hours between repeat orders. This initial analysis indicated that the majority of frequently repeated CBC w/diff testing was being utilized in our ICUs. Therefore, in this study, we investigated how an educational intervention at the ICU with the highest number of repeat CBC w/diff test orders, the TBICU, might change the quantity and ordering practices of CBC tests and CBC w/diff tests. We found that our educational intervention, which recommended replacement of the CBC w/diff test with a CBC test during the first 48 hours of inpatient care in the TBICU, decreased the total quantity of CBC w/diff tests ordered and increased the total quantity of CBC tests (without diff) ordered (Table 2). The number of CBC w/diff tests taken within 22 hours of each other also decreased significantly, especially those repeated every 12 hours. These changes were retained for at least 2 months after the intervention. However, these changes are also seen with the SICU and NICU, other surgical ICUs. We hypothesize that this may be due to the sharing of information between staff among these three units. There was no significant change in total quantity of CBC w/diff tests or repeats at the MICU, another ICU that orders a relatively high number of CBC w/diff tests that does not share staff with surgical ICUs.

Although educational interventions are known to be effective temporarily, they often do not provide long-term results, as reformed practices quickly revert to old methods after cessation of the educational efforts.^{6,26} In our study, changes in the ordering practices of CBC tests and CBC w/diff tests were retained for at least 2 months after educational sessions were over and also seemed to impact ICUs that were not directly involved in the intervention. This may have been because we provided a physical reminder (Figure 2) of appropriate test ordering practices that may have been retained by the providers for much longer than the 2-week educational intervention.

Others have reported that educational interventions with cost reminders can alter testing practices; however, they noted that although the quantity of CBC w/diff tests decreased, the CBC test was increased enough to where the total number of tests did not decrease.²⁷ In our study, the total quantity of CBC and CBC w/diff tests combined was decreased from 895 in January to 819 in March and 794 in May. The reasons for this difference in the impact on total order numbers may be explained by the fact that

at the institution where the total number of tests did not decrease, the ratio of CBC tests to CBC w/diff tests was 1:1. In our study the ratio in the TBICU was 0.01:1, and we were able to successfully increase this ratio to 0.17:1 during our intervention, and 0.11:1 at 2 months after the intervention.

Our educational materials were handed out to providers during face-to-face interactions, which provided us the opportunity to explain the rationale for the new CBC and CBC w/diff test ordering best practices. This type of information may have helped with the retention of improved testing patterns, as others have published that providing information, such as the laboratory cost of commonly ordered tests, can significantly improve test ordering practices and reduce the average cost of laboratory orders per visit.¹⁶ However, our study is the first to investigate the effects of this type of intervention on reducing repeat testing.

Feldhammer et al²⁸ found that around 55% of CBC testing done at internal medicine services were repeat testing done within 23 hours. Less than 1% of this repeat testing was ordered by the same provider, indicating that suboptimal continuity of care may be responsible for a majority of repeat testing in their study. In order to determine if this was also true for the repeat testing seen in our TBICU, we did a provider ordering analysis of our data from the TBICU during the initial observation phase (January 14 to 28). This analysis demonstrated that the majority of repeat CBC w/diff tests were ordered by the same personnel who ordered the previous test, and that only a small minority of providers order the majority of repeat tests. Therefore, suboptimal continuity of care or lack of communication about laboratory orders does not seem to be an underlying cause of the repeat CBC w/diff tests orders in the TBICU.

The opportunities for efficiencies in ordering and resulting less frequent CBC benefits the patients because less blood is taken and there is a decreased potential for false-positive results. It also benefits the hospital, as if less blood is taken for routine laboratory testing, then fewer patients will need RBC transfusions to replace this blood. In order to investigate the amount of blood loss in TBICU patients from “routine” laboratory testing (CBC tests, CBC w/diff tests, BMP tests, and prothrombin time tests), we calculated the amount of blood drawn for these tests from 24 TBICU patients during the timeframe of December 20, 2015, to January 31, 2016. The patients averaged a total of 411.8 mL of blood draw over an average patient stay of 23.8 days. This is a blood draw volume of 17.3 mL/patient/day (range, 11.05-30.25 mL/patient/day). As there is approximately 500 mL of blood in a unit of whole blood,

this means that almost one unit of blood is removed from the patient for routine tests during an average patient stay in the TBICU.

Our intervention did not result in any negative impact on or delay in the diagnosis of sepsis. Bandemia was present in two patients' preintervention and two patients during the intervention period. There was no documented change in plan regarding management of infection due to the presence of bandemia. Our intervention also taught providers better practices for care and added value by reducing unnecessary utilization of laboratory tests. It remains of interest whether a similar intervention in other units of the hospital would have the same effect on ordering practices, and for how long the changes are retained. As our current study focuses only on CBC tests and CBC w/diff tests, we wish to expand our study to include other frequently ordered laboratory tests.

Corresponding author: Robin G. Lorenz, MD, PhD; rlorenz@uabmc.edu.

Acknowledgments: We thank Dr Jorge Alsip, Chief Medical Information Officer for University of Alabama at Birmingham (UAB) Health System, and Deanne Guthrie, Systems Analysis at UAB Health System, for assistance in collection of CBC and CBC with differential testing numbers; Dr Leslie Hayes for advice and guidance as the faculty advisory for our UAB Healthcare Quality and Safety Academy; and the providers and nursing staffs from the Trauma Burn Intensive Care Unit for their willingness to implement the utilization strategies described in this report.

Funding: This work was supported by internal funds from the Department of Pathology, University of Alabama at Birmingham (UAB) and the UAB Hospital Clinical Laboratories; and the National Institutes of Health (grant number TL1 TR001418 to J.Z.S.). This study was initiated as a project for the UAB Healthcare Quality and Safety Academy.

References

- Centers for Medicare and Medicaid Services. National Health Expenditure Accounts. <https://www.cms.gov/Research-Statistics-Data-and-Systems/Statistics-Trends-and-Reports/NationalHealthExpendData/NationalHealthAccountsHistorical.html>. Accessed April 24, 2018.
- Zhi M, Ding EL, Theisen-Toupal J, et al. The landscape of inappropriate laboratory testing: a 15-year meta-analysis. *Plos One*. 2013;8:e78962.
- American Board of Internal Medicine Foundation. Choosing wisely. <http://www.choosingwisely.org/>. Accessed August 22, 2018.
- Waibel E, Garcia E, Kelly M, et al. Systematic review of non-ASCP choosing wisely recommendations relevant to pathology and laboratory medicine. *Am J Clin Pathol*. 2018;149:267-274.
- Lyon AW, Chin AC, Slotsve GA, et al. Simulation of repetitive diagnostic blood loss and onset of iatrogenic anemia in critical care patients with a mathematical model. *Comput Biol Med*. 2013;43:84-90.
- Thakkar RN, Kim D, Knight AM, et al. Impact of an educational intervention on the frequency of daily blood test orders for hospitalized patients. *Am J Clin Pathol*. 2015;143:393-397.
- Smoller BR, Kruskal MS. Phlebotomy for diagnostic laboratory tests in adults. Pattern of use and effect on transfusion requirements. *N Engl J Med*. 1986;314:1233-1235.
- Gulati G, Song J, Florea AD, et al. Purpose and criteria for blood smear scan, blood smear examination, and blood smear review. *Ann Lab Med*. 2013;33:1-7.
- Thachil J. Do we need "routine" blood counts? *Br J Hosp Med (Lond)*. 2014;75:644-646.
- Tak T, Tesselaar K, Pillay J, et al. What's your age again? Determination of human neutrophil half-lives revisited. *J Leukoc Biol*. 2013;94:595-601.
- Spiegel JS, Shapiro MF, Berman B, et al. Changing physician test ordering in a university hospital: an intervention of physician participation, explicit criteria, and feedback. *Arch Intern Med*. 1989;149:549-553.
- Shapiro MF, Hatch RL, Greenfield S. Cost containment and labor-intensive tests: the case of the leukocyte differential count. *JAMA*. 1984;252:231-234.
- Bates DW, Boyle DL, Rittenberg E, et al. What proportion of common diagnostic tests appear redundant? *Am J Med*. 1998;104:361-368.
- Lang T, Lee JPW, Elgass K, et al. Macrophage migration inhibitory factor is required for NLRP3 inflammasome activation. *Nat Commun*. 2018;9:2223.
- Sandhaus LM, Meyer P. How useful are CBC and reticulocyte reports to clinicians? *Am J Clin Pathol*. 2002;118:787-793.
- Leung E, Song S, Al-Abboud O, et al. An educational intervention to increase awareness reduces unnecessary laboratory testing in an internal medicine resident-run clinic. *J Community Hosp Intern Med Perspect*. 2017;7:168-172.
- Merkeley HL, Hemmett J, Cessford TA, et al. Multipronged strategy to reduce routine-priority blood testing in intensive care unit patients. *J Crit Care*. 2016;31:212-216.
- Miyakis S, Karamanof G, Liontos M, et al. Factors contributing to inappropriate ordering of tests in an academic medical department and the effect of an educational feedback strategy. *Postgrad Med J*. 2006;82:823-829.
- Sedrak MS, Patel MS, Ziemba JB, et al. Residents' self-report on why they order perceived unnecessary inpatient laboratory tests. *J Hosp Med*. 2016;11:869-872.
- Gupta SS, Voleti R, Nyemba V, et al. Results of a quality improvement project aimed at eliminating healthcare waste by changing medical resident test ordering behavior. *J Clin Med Res*. 2017;9:965-969.
- Ellenbogen MI, Ma M, Christensen NP, et al. Differences in routine laboratory ordering between a teaching service and a hospitalist service at a single academic medical center. *South Med J*. 2017;110:25-30.
- Sandhu GS. Commentary on "differences in routine laboratory ordering between a teaching service and a hospitalist service at a single academic medical center." *South Med J*. 2017;110:31-32.
- Hilborne LH. When less is more for patients in laboratory testing. *Am J Clin Pathol*. 2013;139:271-272.

24. Bulger J, Nickel W, Messler J, et al. Choosing wisely in adult hospital medicine: five opportunities for improved healthcare value. *J Hosp Med.* 2013;8:486-492.
25. Onuoha OC, Arkoosh VA, Fleisher LA. Choosing wisely in anesthesiology: the gap between evidence and practice. *JAMA Intern Med.* 2014;174:1391-1395.
26. Eisenberg JM. An educational program to modify laboratory use by house staff. *J Med Educ.* 1977;52:578-581.
27. Melendez-Rosado J, Thompson KM, Cowdell JC, et al. Reducing unnecessary testing: an intervention to improve resident ordering practices. *Postgrad Med J.* 2017;93:476-479.
28. Feldhammer M, M'enasco D, Zhang W, et al. A targeted, evidence-based clinical decision support intervention to reduce unnecessary complete blood count orders. *Am J Clin Pathol.* 2017;147(suppl 2):S154-S155.