The Benefits and Challenges of an Interfaced Electronic Health Record and Laboratory Information System

Effects on Laboratory Processes

Athena K. Petrides, PhD; Ida Bixho, BS; Ellen M. Goonan, MS, MT(ASCP), SH, RN; David W. Bates, MD; Shimon Shaykevich, MS; Stuart R. Lipsitz, ScD; Adam B. Landman, MD; Milenko J. Tanasijevic, MD, MBA; Stacy E. F. Melanson, MD, PhD

• *Context.*—A recent government regulation incentivizes implementation of an electronic health record (EHR) with computerized order entry and structured results display. Many institutions have also chosen to interface their EHR with their laboratory information system (LIS).

***Objective.*—To determine the impact of an interfaced EHR-LIS on laboratory processes.**

***Design.*—We analyzed several different processes before and after implementation of an interfaced EHR-LIS: the turnaround time, the number of stat specimens received, venipunctures per patient per day, preanalytic errors in phlebotomy, the number of add-on tests using a new electronic process, and the number of wrong test codes ordered. Data were gathered through the LIS and/or EHR.**

***Results.*—The turnaround time for potassium and hematocrit decreased significantly ($P = .047$ and $P = .004$, respectively). The number of stat orders also decreased significantly, from 40% to 7% for potassium and hematocrit, respectively ($P < .001$ for both). Even though the average number of inpatient venipunctures per day increased from 1.38 to 1.62 ($P < .001$), the average number of preanalytic errors per month decreased from 2.24 to 0.16 per 1000 specimens ($P < .001$). Overall there was a 16% increase in add-on tests. The number of wrong test codes ordered was high and it was challenging for providers to correctly order some common tests.**

***Conclusions.*—An interfaced EHR-LIS significantly improved within-laboratory turnaround time and decreased stat requests and preanalytic phlebotomy errors. Despite increasing the number of add-on requests, an electronic add-on process increased efficiency and improved provider satisfaction. Laboratories implementing an interfaced EHR-LIS should be cautious of its effects on test ordering and patient venipunctures per day.**

(*Arch Pathol Lab Med.* 2017;141:410–417; doi: 10.5858/arpa.2016-0146-OA)

To improve the quality of patient care and reduce errors, electronic health records (EHRs) have been increasingly adopted throughout the nation.[1–3] The Medicare and Medicaid Electronic Health Care Record Incentive Program (aka *meaningful use*) grants eligible hospitals and health care professionals incentive payments for adopting a certified EHR.[4–6] In the inpatient setting, stage 1 of meaningful use requires structured laboratory result display in the EHR for more than 40% of laboratory results.[7,8] Stage 2 of meaningful use increases the percentage of structured laboratory results to 55%.[9] Stage 2 also introduces the requirement for computerized provider order entry to be used for at least 30% of laboratory orders.[9] Although it is not required for meaningful use, many hospitals choose to interface the laboratory information system (LIS) with the EHR, to implement the LIS integrated in their EHR, or to use a middleware solution to transmit orders to the LIS and send results to the EHR.[10]

There are multiple reported benefits of EHRs, including the ability to follow patient data longitudinally, cost savings, reduction in adverse drug events, and an increase in patient-provider interactions,[11] although these do not necessarily occur and EHRs can have many unintended consequences.[12,13] A bidirectional interface between EHR and LIS is crucial for patient care, because it enables a seamless flow of information from test ordering to posting of results in the EHR.[6,8,14] Further, an EHR-LIS interface can decrease turnaround time (TAT) and improve efficiencies by reducing the need to reorder previously placed provider EHR orders into the LIS.[15–17] Successful implementation of EHRs, however, can be challenging in large hospital networks because of complex technical requirements, interface design, and the multitude of clinical and laboratory workflows.[18–20] A 2013 College of American Pathologists study[10] found that problems with displaying test comments, lack of synchro-

Accepted for publication July 29, 2016.

From the Departments of Pathology (Drs Petrides, Tanasijevic, and Melanson and Mss Bixho and Goonan), Medicine (Ms Bixho, Drs Bates and Lipsitz, and Mr Shaykevich), and Emergency Medicine (Dr Landman), Brigham and Women's Hospital, Boston, Massachusetts; and Harvard Medical School, Boston, Massachusetts (Drs Petrides, Bates, Lipsitz, Landman, Tanasijevic, and Melanson and Mr Shaykevich). Dr Petrides and Ms Bixho contributed equally.

The authors have no relevant financial interest in the products or companies described in this article.

Reprints: Stacy E. F. Melanson, MD, PhD, Department of Pathology, Brigham and Women's Hospital, 75 Francis St, Amory 2, Boston, MA 02115 (email: semelanson@partners.org).

nized test catalogs/test codes, and lack of standardized test definitions can occur when integrating LISs with EHRs. A similar review by Wilkerson et al[21] examined the issues with electronic order entries and result reporting that can occur between the LISs and EHRs, such as inability to pass on special instructions into LIS, problems with displaying of laboratory results, and the possibility of missing abnormal flags.

In this study, we evaluated the impact of implementing an interfaced EHR-LIS on key laboratory processes, TAT, the number of stat requests, the number of add-ons, and preanalytic inpatient phlebotomy errors.

METHODS

Study Site

This study was performed at Brigham and Women's Hospital, a 777-bed tertiary care center located in Boston, Massachusetts. Brigham and Women's Hospital is a founding member of Partners Healthcare, an integrated delivery system that includes, among others, Massachusetts General Hospital (cofounder), Newton Wellesley Hospital, Brigham and Women's Faulkner Hospital, and North Shore Medical Center. In November 2014, the laboratory transitioned from a custom-developed LIS to a vendor LIS, Sunquest (Sunquest Information Systems, Inc, Tuscon, Arizona). The institution was using a custom-developed EHR including computerized provider order entry for laboratory tests. However, only a results interface existed between the vendor LIS and the custom-developed EHR. On May 30, 2015, the institution implemented a new comprehensive EHR, Epic (Epic Systems, Inc, Madison, Wisconsin), including a bidirectional interface (orders and results) with Sunquest. The Brigham and Women's Hospital implementation was performed in these 2 stages to allow time for stabilization on the new LIS before introducing the new EHR. Multiple Partners sites have implemented the same instance of our EHR-LIS, and over the next 5 years all Partners hospitals will use the same LIS and EHR.

In this study we examine the effect of an interfaced EHR-LIS on our main processing area (eg, chemistry, hematology, send-out testing). Separate specimen processing areas exist at Brigham and Women's Hospital for blood bank, microbiology, and anatomic pathology and those areas are not included in our analysis. In addition, we did not include nonphlebotomy specimen collections as these collections are not performed by laboratory personnel.

Workflow Description

Test Ordering and Phlebotomy Specimen Collection.—Prior to May 2015, laboratory tests were ordered through electronic templates, through the physician order entry system, or directly onto paper requisitions. All electronic orders were transcribed onto paper requisitions and sent to the laboratory to be manually entered into the LIS (Figure 1, A). After the implementation of the interfaced EHR-LIS, the majority of laboratory orders are being placed directly in the EHR and electronically transmitted to the LIS, thus eliminating most paper requisitions (Figure 1, B).

The majority (approximately 60% or 700 venipunctures per day) of inpatient specimens are collected by phlebotomy. Preimplementation, inpatient phlebotomists performed rounds approximately every 2 hours. The nurse or unit coordinator placed the paper requisitions in the appropriate folder for phlebotomy according to the desired collection time. After consulting the provider, nursing staff would also frequently combine requisitions and/or remove duplicate orders to minimize the number of patient venipunctures. Phlebotomists used a stand-alone positive patient identification system that allowed for scanning of the patient's wristband and bedside label printing but did not provide collection instructions or eliminate the paper requisition (Figure 1, A).[22]

In May 2015, with the move to Epic, phlebotomy went live with the new collection module, the Sunquest Collection Manager, to improve the safety and efficiency of specimen collection at the bedside. A handheld device is used to view all patients who require blood draws within a specific time window.[23] The handheld is then used to confirm patient identity (using bar code scanning), print the specimen labels at the patient's bedside via a mobile printer carried by the phlebotomist, and update collection status of the specimens (Figure 1, B).

Specimen Processing and Add-On Testing.—Prior to May 2015, specimens arrived in the laboratory processing area with a paper requisition that was stamped to indicate the arrival time and waited in a queue to be processed. Specimen bags with a stat sticker were prioritized. Orders were then manually entered into the LIS using the paper requisition, LIS bar coded specimen labels were printed, and specimens were relabeled in the laboratory. After specimens were received in the LIS, they were routed to the appropriate testing area (Figure 1, A). Since May 2015, the majority of specimens arrive already bar coded in the laboratory without a requisition and are simply scanned into the LIS to record the receipt time. The specimen label has a visual indicator that the specimen has a stat priority, which allows it to be triaged accordingly (Figure 1, B). In addition, specimens from higher-priority areas (eg, emergency department, operating room) arrive with color-bordered labels.

Prior to May 2015 clinicians would call the laboratory to add on a test to a specimen that had already been received.[24,25] Clinicians would provide the patient's name, the patient's medical record number, the physician code, and the laboratory test(s) to be added.[24] If the testing could be added, the order was entered into the LIS. If it could not be added, the provider was instructed to place a new order for the test(s). The implementation of an electronic add-on process in May 2015 enabled clinicians to electronically place a laboratory add-on order. Clinicians are required to electronically fill in the name of the test(s) requested, their name, and a contact phone number. The electronic order triggers the printing of a test requisition in the laboratory, thus eliminating the phone call. Providers are only contacted if the request cannot be fulfilled.

Outcome Measures

Effect of EHR-LIS on Laboratory Processes and TATs.— Workflow in the clinical laboratory was assessed before and after interfaced EHR-LIS. The following 6 different specimen workflow categories were chosen to illustrate the benefits and challenges of an interfaced EHR-LIS: the TAT of 2 high-volume tests (ie, potassium [K] and hematocrit [Hct]), the percentage of stat specimens, the number of preanalytic errors (ie, mislabeled, unlabeled, wrong specimen received, no specimen received) in inpatient phlebotomy, the average number of patient venipunctures per day, the number of add-on tests in clinical chemistry, and the occurrence of wrong test orders/test codes.

TAT and Stat Tests.—Data were gathered from the LIS on K and Hct TATs before and after EHR-LIS. A single day per week (Wednesday) was chosen to assess TAT. All specimens, routine, stat, and timed, were included in the analysis. Data from March to May 2015 (preimplementation) and June to October 2015 (post-implementation) were included. Preimplementation TAT was measured from specimen arrival in the laboratory (ie, physical arrival of specimen in the laboratory, prior to being logged into the LIS, by time stamping the requisition form) to filing of the test result in the EHR. Postimplementation TAT was measured from specimen receipt (ie, scanning of specimen into the LIS) to filing of the test result in the EHR. To factor in the arrival to receipt time postimplementation (because these data were no longer captured thru the paper time-stamping process), we manually measured the average time between arrival and receipt into the LIS for 100 consecutive specimens. The average TAT from arrival to receipt for all specimens (stat and routine) postimplementation was 2 minutes and 54 seconds (±42 seconds) with a maximum of 3 minutes and 56 seconds. To be conservative, we added 4 minutes, the maximum time, to the postimplementation data to allow us to compare arrival with result preimplementation and postimplementation. The average TAT from arrival to result was calculated for all days

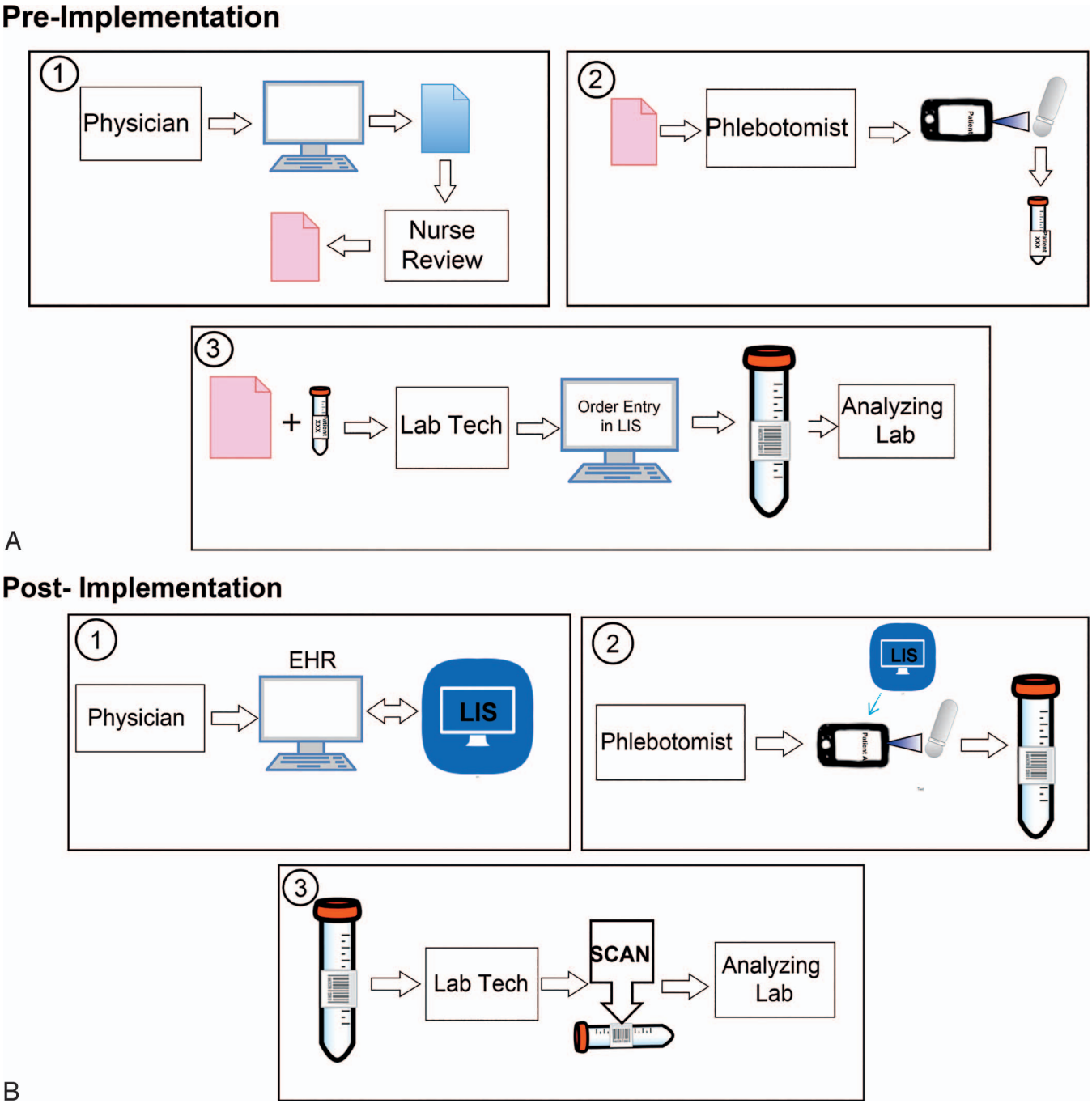

Figure 1. *Preimplementation and postimplementation electronic health record (EHR)–laboratory information system (LIS) workflow diagram. A, Preimplementation. (1) All providers are encouraged to enter orders electronically, but then the orders are transcribed onto paper requisitions (blue). Nurse, with provider's input, modifies the requisition by combining orders and/or removing duplicate orders, if necessary (pink). (2) Phlebotomists use the requisition to determine which tubes/specimens to draw and the positive patient identification device to verify patient's identification and print generic labels at bedside. (3) Specimens arrive in the processing area with paper requisition. Orders are manually entered into LIS and specimens are relabeled. B, Postimplementation. (1) Provider places laboratory order in the EHR. Orders are released to LIS and specimen collection module. (2) Phlebotomists use the handheld collection module to view orders, determine the specimens/tubes to draw, verify the patient's identification, and print LIS labels at bedside. (3) Specimens arrive in the processing area and are scanned into LIS using the LIS label to document receipt.*

included in the data analysis. The percentage of specimens resulted in less than 60 minutes for K and less than 45 minutes for Hct preimplementation and postimplementation was also determined.

The percentage of stat specimens before (March–May 2015) and after (June–October 2015) interfaced EHR-LIS implementation was calculated for Hct and K. The total number stat specimens per representative day was tallied up and divided by the total number of all specimens to calculate the percentage of stat specimens.

Number of Venipunctures and Inpatient Phlebotomy Preanalytic Errors.—The number of patient blood draws/venipunctures per day by inpatient phlebotomy was gathered from the LIS and/or EHR preimplementation for the months of June and

October 2014, and postimplementation for the months of June and October 2015. In July 2015, parameters were adjusted in our LIS collection manager to improve the combining of multiple orders from different providers and to reduce the number of tubes collected. For this reason, we define 2 periods postimplementation to reflect the number of venipunctures per day before and after the adjustments (period 1 = June 2015 and period 2 = October 2015). A comparison of preimplementation with both postimplementation windows was made. A representative day (ie, Wednesday) was chosen for each week of the periods. We calculated the average number of venipunctures and the percentage of patients with more than 2 venipunctures per day.

The number of inpatient phlebotomy preanalytic errors was gathered using an existing laboratory database. We chose to investigate the top 4 preanalytic errors (mislabeled, unlabeled, wrong specimen received, and no specimen received). If the wrong tube type was collected for the test(s) ordered, the error was categorized as a wrong specimen received error. If no tube was collected for the test(s) ordered, the error was categorized as a no specimen received error. We measured the total number of each preanalytic error per 1000 specimens and calculated the monthly average. We compared the monthly average preimplementation (August–October 2014) with that postimplementation (August–October 2015).

Add-on Testing.—The number and type of chemistry add-ons successfully performed during a preimplementation (September 28, 2014, to October 4, 2014) and postimplementation (September 24, 2015, to October 3, 2015) period was gathered. Preimplementation data were obtained from the LIS, as add-on orders were documented with the original order in the LIS after the provider's phone call to the laboratory. Postimplementation, providers followed an electronic add-on process in the EHR that triggered a laboratory add-on requisition to print in the laboratory. The number of requisitions that printed was compared with the preimplementation data; only add-on tests that the laboratory was able to perform were included.

Wrong Test Codes and Paper Requisitions.—Data were gathered from the LIS postimplementation (June through October 2015) on the type of wrong test codes ordered and their appropriate replacement. In addition, we observed the workflow in laboratory processing for 1 day and recorded the number and percentage of specimens with a paper requisition after implementation of the EHR-LIS. The receipt of paper requisitions for tests that could be ordered in the EHR was indicative that the ordering process was problematic for the provider.

Statistical Analyses

Comparisons between preimplementation and postimplementation periods for the average number of venipunctures per day and number of preanalytic phlebotomy errors were performed using a 2-sample *z* statistic test and a Fisher exact test, respectively. A *P* value $\leq$.05 was considered statistically significant.[26]

An interrupted time series analysis[27] was performed to assess changes in TAT preimplementation and postimplementation. The pre-post trends were estimated using a robust linear model that gives unbiased estimate for nonnormal outcomes.[28]

RESULTS

TAT and Stat Tests

The average TAT (arrival in the laboratory to result) for K (Figure 2, A) and Hct (Figure 2, B) decreased significantly ($P = .047$ and $P = .004$, respectively) after implementation of an interfaced EHR-LIS. The interrupted time series analysis showed that this was not due to a continuous downward trend in TAT for either analyte (data not shown). The percentage of specimens resulted in less than 60 minutes for K increased from 41% (6662 of 16 079) to 83% (20 387 of 24 584) (Figure 2, C). Similarly, the percentage of specimens resulted in less than 45 minutes for Hct increased from 55% (7875 of 14 243) to 94% (19 917 of 21 246) (Figure 2, C).

A sharp decrease in stat priority specimens was seen postimplementation for both K and Hct ($P < .001$). Preimplementation the percentage of stat specimens was 40% for both K (6432 of 16 079) and Hct (5697 of 14 243), whereas postimplementation that percentage decreased to 7% for both K (1805 of 24 584) and Hct (1562 of 21 246) (data not shown). The decrease in stats was sustained throughout the study period (data not shown).

Number of Venipunctures and Inpatient Phlebotomy Preanalytic Errors

Preimplementation, the average number of venipunctures per patient per day was 1.38 and the average percentage of patients with more than 2 venipunctures per day was 7% (n = 30 patients per day) (Table 1). In period 1 postimplementation, the average number of patient venipunctures per day increased significantly to 1.81 and an average of 20% of patients (n = 100) had more than 2 venipunctures per day ($P < .001$ compared with preimplementation). In period 2, the average number of patient venipunctures per day and the percentage of patients who had more than 2 venipunctures per day decreased moderately to 1.62 and 15% (n = 76), respectively (Table 1), still significantly higher than preimplementation ($P < .001$).

The monthly average of the top 4 inpatient phlebotomy preanalytic errors (ie, mislabeled, unlabeled, wrong specimen received, no specimen received) decreased significantly postimplementation from 2.24 to 0.16 errors per 1000 specimens ($P < .001$) (Table 2). Implementation had the most impact on no specimen received and wrong specimen received errors, with a significant reduction of 96% (from 1.97 to 0.08 errors per 1000 specimens) and 65% (from 0.23 to 0.08 errors per 1000 specimens), respectively ($P < .001$).

Add-on Testing

The top 10 most frequently ordered add-on tests preimplementation and postimplementation did not change and consisted of magnesium, hepatic function panel, phosphorus, troponin T, thyroid-stimulating hormone, triglycerides, N-terminal pro-B-type natriuretic peptide, lactate dehydrogenase, lipase, and basic metabolic panel (Table 3). Overall, there was a 16% (n = 189 additional add-ons test per week) increase in the number of add-ons postimplementation. All of the top 10 add-ons increased postimplementation, with the exception of troponin T and N-terminal pro-B-type natriuretic peptide (Table 3).

Wrong Test Codes and Paper Requisitions

To assess the effectiveness of test ordering in the EHR, we measured both the percentage of paper requisitions and the number of wrong test codes ordered. The percentage of paper requisitions decreased dramatically, from 100% preimplementation to 18% postimplementation, but paper requisitions were still being sent for tests that were orderable in the EHR. In addition, we observed that providers would often order the wrong test codes for common tests (eg, C-reactive protein, creatinine/estimated glomerular filtration rate, creatine kinase MB). In June 2015 the numbers of wrong test codes for C-reactive protein, creatinine/estimated glomerular filtration rate, and creatine kinase–MB was 53, 62, and 40, respectively. This decreased to 0, 1 and 0, respectively, in October 2015, after we updated the various ordering lists in the EHR.

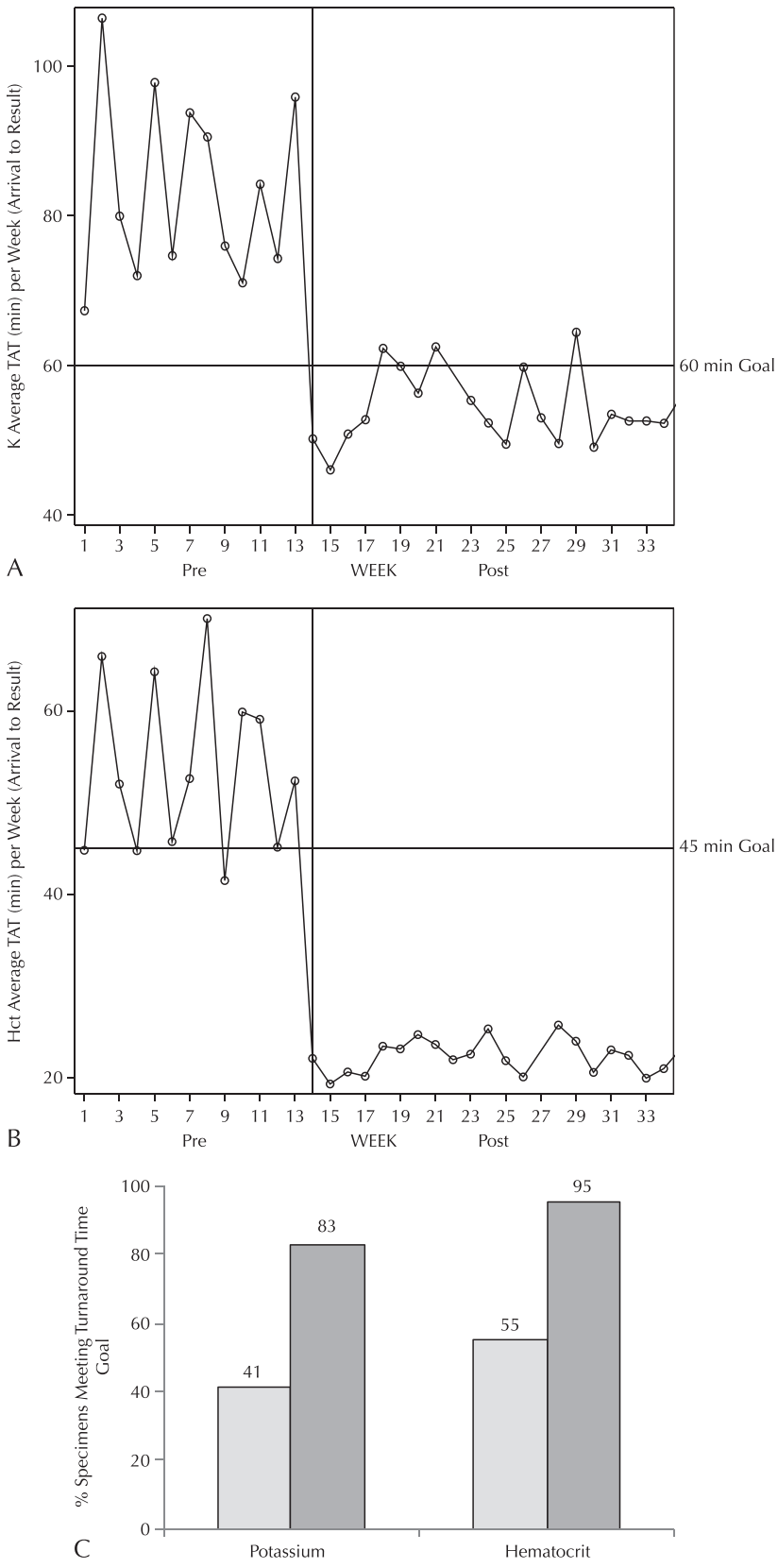

Figure 2. *Potassium and hematocrit turnaround time (TAT) preimplementation and postimplementation. A, The average TAT from arrival in the laboratory to result is plotted for potassium (K) preimplementation (Wednesdays, March–May 2015) and postimplementation (Wednesdays, June–October 2015). The solid line indicates our goal of 60 minutes. B, The average TAT from arrival in the laboratory to result is plotted for hematocrit (Hct) preimplementation (Wednesdays, March–May 2015) and postimplementation (Wednesdays, June–October 2015). The solid line indicates our goal of 45 minutes. The vertical line separates the preimplementation and postimplementation data. C, The percentage of specimens meeting TAT goal preimplementation (light gray bars) (Wednesdays, March–May 2015) and postimplementation (dark gray bars) (Wednesdays, June–October 2015) for potassium (goal is less than 60 minutes from receipt to result) and hematocrit (goal is less than 45 minutes from receipt to result) is plotted.*

DISCUSSION

We evaluated the effects of implementing an interfaced EHR-LIS, and observed a number of benefits as well as challenges. The primary benefits included a reduction in TAT and stat priority specimens. In addition, the system allowed for providers to order laboratory add-on tests more efficiently by eliminating phone calls to the laboratory. Some of the unanticipated challenges were the increase in

Table 1. Inpatient Phlebotomy Venipunctures Per Day Preimplementation and Postimplementation

Date	Venipunctures/d/ Patient, Average (±SD)	Patients With >2 Venipunctures/d, No. (%)
Preimplementation		
June 4, 2014	1.40 (±0.68)	30 (7)
June 11, 2014	1.34 (±0.60)	20 (5)
June 18, 2014	1.38 (±0.65)	24 (5)
June 25, 2014	1.39 (±0.70)	38 (8)
October 1, 2014	1.39 (±0.65)	28 (6)
October 8, 2014	1.37 (±0.64)	28 (6)
October 15, 2014	1.41 (±0.71)	37 (9)
October 22, 2014	1.36 (±0.66)	30 (7)
October 29, 2014	1.38 (±0.69)	33 (8)
Average	1.38 (±0.02)	30 (7)
Period 1 postimplementation[a]		
June 3, 2015	1.92 (±1.40)	100 (21)
June 10, 2015	1.90 (±1.32)	118 (24)
June 17, 2015	1.77 (±1.20)	96 (17)
June 24, 2015	1.67 (±1.02)	85 (16)
Average	1.81 (±0.12)	100 (20)
Period 2 postimplementation[a]		
October 7, 2015	1.60 (±0.89)	58 (13)
October 14, 2015	1.60 (±1.02)	73 (14)
October 21, 2015	1.65 (±1.24)	80 (15)
October 28, 2015	1.62 (±0.95)	92 (17)
Average	1.62 (±0.02)	76 (15)

[a] $P < .001$ when compared with preimplementation. Period 2 includes optimizations to combine multiple orders from different providers to reduce the number of tubes collected.

the number of patient venipunctures and orders placed using the wrong test code.

Not surprisingly, by reducing paper requisitions and the manual entry of orders into the LIS, the TAT from specimen arrival to result improved significantly. This can be important in many clinical situations, as labs can enable clinical decision making and influence the management of time-sensitive conditions, such as stroke. In this study, we were not able to compare TAT from specimen collection to result, as those data were not reliably available preimplementation. However, with the EHR-LIS interface now in place, we have more accurate data available on order, collection, and laboratory receipt times to include in future TAT metrics and will work with the clinicians to develop acceptable performance goals from collection to receipt to result. Preliminary analysis of TAT from collection to result postimplementation (September–October 2015) yielded a median TAT of 75 minutes for K and 49 minutes for Hct.

Stat orders decreased dramatically and consistently across analytes after the EHR-LIS implementation. The drop can be explained by the method used to determine priority status; stat sticker on the specimen bag and/or requisition (ie, clinicians had the ability to use a stat sticker even if the provider did not order the test[s] stat) preimplementation and priority transmitted to the LIS by the providers' order in EHR postimplementation. The EHR-LIS allowed us to more appropriately triage critical specimens based on the provider's electronically entered stat priority. Before implementation of the EHR-LIS, we believe clinicians labeled a high proportion of tests stat because they were unhappy with the TAT. Because of both the dramatic decrease in stat specimens and the need to continue to prioritize specimens from certain locations (eg, emergency room, operating room, neonatal intensive care), we implemented color-bordered labels in higher-priority areas as a visual indicator for the accessioning area.

Table 2. Average Inpatient Phlebotomy Preanalytic Errors per Month Preimplementation and Postimplementation

	Preimplementation Errors, per 1000 Specimens	Postimplementation Errors, per 1000 Specimens
Mislabeled	0.02	0.00
Unlabeled	0.02	0.00
No specimen received	1.97	0.08[a]
Wrong specimen received	0.23	0.08[a]
Total	**2.24**	**0.16[a]**

[a] $P < .001$ when compared with preimplementation.

Despite optimizing order and specimen-combining logic in the LIS and collection module, the number of patient venipunctures per day remained higher after the EHR-LIS implementation. This suggests that rules cannot replace the clinicians' input on what draws are clinically necessary at a specified time. For example, one could choose to have the LIS combine any routine labs written within 2 hours of each other. In this case orders placed 2 hours and 1 minute apart would be seen as separate orders on the handheld device, which may or may not be clinically appropriate depending on the order and the patient status. In addition, the new EHR does not clearly differentiate the specimen's status; both collected (but not received) and received are listed as in process. This leads to confusion and duplicate orders being placed by providers to ensure that the testing is being performed. When implementing a collection module as part of an EHR-LIS interface, hospitals should carefully review the specimen-combining rules logic, and specimen status and the potential impact on patient venipunctures.

The average number of mislabeled and unlabeled specimens per month by inpatient phlebotomy was low prior to EHR-LIS implementation because of our stand-alone positive patient identification system.[22] However, a fully integrated collection module that provided collection instructions and tube types on the labels significantly decreased the number of wrong specimens received and no specimen received errors. This decrease presumably translated into fewer patient venipunctures because the specimens did not need to be recollected. Despite fewer preanalytic errors postimplementation, the number of patient venipunctures per day still increased for the reasons outlined above.

Anecdotal evidence shows that electronic add-on ordering increases efficiency in the laboratory and improves provider satisfaction by decreasing the number of phone calls to the laboratory. Although we do not have data on the amount of time required for the completion of an add-on request preimplementation, our observations show that postimplementation add-ons take approximately 55 seconds. In addition, a dedicated person is no longer necessary to manage add-ons. Instead, add-ons can be incorporated into the client services role. The majority of add-ons increased postimplementation, by an average of 16% overall. We attribute this to the ease of the new process. However, troponin T and N-terminal pro-B-type natriuretic peptide add-ons decreased slightly, which may be because

Table 3. Top 10 and Total Add-On Tests for 1 Week Preimplementation and Postimplementation			
Add On Test	Volume/wk Preimplementation (September 28, 2014–October 4, 2014)	Volume/wk Postimplementation (September 27, 2015–October 3, 2015)	Difference, No. (%)
Magnesium	144	148	4 (3)
Hepatic function panel	80	101	21 (21)
Phosphorus	78	90	12 (13)
Troponin T	67	60	−7 (−10)
TSH	45	68	23 (34)
Triglycerides	45	58	13 (22)
NT-proBNP	37	34	−3 (−8)
LDH	32	46	14 (30)
Lipase	32	36	4 (11)
Basic metabolic panel	11	45	34 (76)
Total[a]	979	1168	189 (16)

Abbreviations: LDH, lactate dehydrogenase; NT-proBNP, N-terminal pro-B-type natriuretic peptide; TSH, thyroid-stimulating hormone.

[a] Includes all add-on ordered tests in the defined time period.

of better protocols and order sets available in the EHR for cardiac marker and heart failure testing. If laboratories decide to implement electronic add-on testing in their EHR-LIS, they should thoroughly test the printer mapping to ensure the requisition will print accurately and in a timely manner. We also strongly encourage making the provider name and contact number required in the EHR so the provider can be contacted if the laboratory is unable to perform the testing.

An interfaced EHR-LIS requires the provider to choose the appropriate tests electronically, which can be challenging when multiple hospitals are using the same EHR and offer the same tests but use hospital-specific test codes.[10,29] Providers typically have access to multiple lists from which to order tests, such as the facility list, the departmental preference list, and their personal preference list, all of which need to be kept in sync. Correcting wrong test codes, if they can be identified in the processing area, takes our staff an average of 10 minutes per specimen as it involves canceling the incorrect test, reaccessioning the correct test, and relabeling the specimen. Even though it is time consuming and requires mobilization of technical and clinical resources, to ensure provider satisfaction and improve workflow in the laboratory, hospital systems should harmonize high-volume tests prior to implementation.[10] They should also have a system for monitoring and correcting wrong test codes postimplementation.

Our study was performed in a single academic center in a specific geographic region; therefore, our results may not be generalizable to other types of centers or regions, as the systems vary considerably among hospitals. Additionally, because specimen requisitions were no longer stamped when specimens arrived at the laboratory, we estimated the arrival to receipt TAT postimplementation based on observations. We did not match the months preimplementation and postimplementation (ie, June to October) for the TAT data (similar to our other metrics) as the laboratory did not implement the vendor LIS until November 2014. The arrival time required for the TAT calculation was only available electronically in the vendor LIS. We believe our comparison of preimplementation and postimplementation data remains valid despite the months we used for comparison. We may have also overestimated the number of add-on tests postimplementation, if the technologist failed to note whether the add-on request could be completed or not on the printed add-on requisition.

CONCLUSIONS

Implementation of an interfaced EHR-LIS improved the workflow in the laboratory and had several positive clinical impacts, including decreased TAT, a reduction in stat specimens and preanalytic errors, and a more effective electronic add-on ordering process. This may be one of the earlier benefits of implementing an electronic EHR, and can thus represent an "early win." However, unanticipated challenges also emerged, especially with requiring providers to select site-specific orders in an integrated delivery system. To simplify provider ordering, institutions should harmonize test orders across different sites to the extent possible. In addition, the impact of an interfaced EHR-LIS on patient venipunctures should be considered, especially if a collection module will be implemented. Despite these challenges, laboratories should insist on interfacing their LIS to the EHR, as there are numerous clinical benefits as well as benefits to the laboratory.

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