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Impact of total automation consolidating first-line laboratory tests on diagnostic blood loss

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Abstract

Background: Blood loss for laboratory testing may contribute to hospital-acquired anemia. When implementing the core laboratory (core-lab) section, we consolidated first-line tests decreasing the number of tubes previously dispatched to different sites. Here, hypothesized benefits of the amount of blood volume drawn were explored.
Methods: We retrieved, using a laboratory information system (LIS), the number of tubes received by laboratories interested in the change from all clinical wards in a year-based period, i.e. 2013 for pre-core-lab and 2015 for core-lab system, respectively. Data were expressed as the overall number of tubes sent to laboratories, the corresponding blood volume, and the number of laboratory tests performed, normalized for the number of inpatients.
Results: After consolidation, the average number of blood tubes per inpatient significantly decreased (12.6 vs. 10.7, $p < 0.001$). However, intensive care units (ICUs) did not reduce the number of tubes per patient, according to the needs of daily monitoring of their clinical status. The average blood volume sent to laboratories did not vary significantly because serum tubes for core-lab required higher volumes for testing up to 55 analytes in the same transaction. Finally, the number of requested tests per patient during the new osystem slightly decreased (–2.6%).
Conclusions: Total laboratory automation does not automatically mean reducing iatrogenic blood loss. The new system affected the procedure of blood drawing in clinical wards by significantly reducing the number of handled tubes, producing a benefit in terms of costs, labor and time consumption. Except in ICUs, this also slightly promoted some blood saving. ICUs which engage in phlebotomizing patients daily, did not take advantage from the test consolidation.

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Introduction

Hospital-acquired anemia (HAA) is defined by a reduction of blood hemoglobin (Hb) concentrations in hospitalized patients, in the absence of bleeding episodes occurring during the hospital stay [1, 2]. HAA worsens patient outcome, increasing morbidity and the likelihood of mortality, due to the exposure to nosocomial infections, immunological complications, thromboembolic events and the need for transfusions. Furthermore, HAA increases the length of hospitalization which reflects on the overall healthcare costs [3–5].

Although HAA etiology is usually multifactorial, one of the most important iatrogenic causes contributing to the decrease of Hb during hospitalization is the amount of blood collected for diagnostic testing [6–8]. Chronic phlebotomies during hospitalization may independently cause anemia [9]. In intensive care units (ICUs), the daily blood loss due to phlebotomy may range from 40 to 70 mL, accounting for 30% of the overall required transfusions [9–11]. However, Thomas et al., found no association between anemia and phlebotomy practices when the daily volume of blood drawing per patient was kept around 25 mL [12]. The presence of specific diseases on hospital admission also increases the risk of developing HAA. For instance, patients hospitalized for acute myocardial infarction may experience HAA, an indicator of poor outcome, both in-hospital and after discharge [13, 14]. The volume of blood phlebotomy may represent a strong predictor of anemia even in patients admitted to internal medicine departments in the absence of bleeding or other factors influencing Hb concentrations, with a 7 g/L estimated drop in Hb for each 0.1 L of drawn blood [15].

The patient blood management multidisciplinary approach includes medical and surgical working strategies based on clinical evidence, designed to maintain blood Hb concentrations at the physiological level, optimizing hemostasis and minimizing blood loss [16]. Accordingly, clinical laboratories should actively promote programs aimed at eliminating unnecessary blood loss

for diagnostic purpose [17]. Growing evidence underpins the pivotal role of clinical pathologists in driving clinicians towards appropriate laboratory test utilization [18]. Laboratory testing may aid in diagnosis, prognosis and establishment of treatment, but inappropriate requests of available tests can lead to overutilization [19, 20]. In the light of preventing HAA, guidance in test utilization to avoid inappropriate use may lead to lowering unnecessary phlebotomies. On the other hand, laboratories may request more blood than necessary, even when test requests are appropriate [21]. Blood collected for laboratory purposes often exceeds the volume required by modern analyzers and therefore considerable amounts of blood are wasted [22–24]. The College of American Pathologists estimated a median blood draw of 2.76 mL for complete blood cell count (BCC) and 1.75 mL for electrolyte panel, which corresponds to more than 8.5 and 12 times the volume necessary for analysis, respectively [25]. On the other hand, the use of small volume samples may be challenging for the laboratory testing process [23]. For micro-collection, pediatric-sized tubes have technical and operational implications, because several analytical platforms do not support them. In addition, they can be time and labor intensive, as reducing the blood volume may increase the risk of insufficient samples, requiring repetition of phlebotomy. Table 1 summarizes the main blood preservation strategies that are applicable at the laboratory and clinical ward levels.

In 2014, in our 600-bed metropolitan academic hospital, we moved from a compartmentalized system toward a decision-making based laboratory department, set up as a core laboratory (core-lab), executing first-line tests from different disciplines, and satellite laboratory sections, performing specialized tests [26]. Supported by total laboratory automation (TLA) and information technology tools, our core-lab system has promoted optimal workload efficiency, with very short laboratory turnaround times for all results useful in first-line care [18, 26]. One of the most important changes in implementing the core-lab facility was the consolidation of first-line tests from different laboratory subspecialties into a single section. Tests, which previously required different tubes for the analysis, were consolidated in a single tube moving among different core-lab platforms through a belt conveyor system (track). Despite the consolidation of tests imposed, the use of tubes warranting enough blood sample volume (5 mL) for the potential execution of all tests present in the menu on the same order, we pursued the advantage to pass from ten to three tubes, consolidating in one tube the testing for 55 analytes in the serum and in another one two whole blood tests. Through the introduction of the TLA, we eliminated the concept of "urgent" tests, moving to a system where *stat* testing is not considered anymore, therefore reducing the risk for clinicians to duplicate test orders without affecting clinicians' expectations in terms of timeliness of the laboratory service [27]. To the best of our knowledge, no studies have evaluated the impact of TLA implementation on diagnostic blood loss. Thus, in this study we did this evaluation, hypothesizing a reduction in the overall blood volume sent to the laboratory after the reorganization for each patient during his/her hospitalization.

Materials and methods

Based on the panel of tests performed by the core-lab and, previously, by the compartmentalized laboratories of different specialties (i.e. chemistry, immunochemistry, hematology, microbiology, virology, etc.), we retrieved using the laboratory information system (LIS) the number of tubes received by the laboratories interested in the change from the all hospital clinical wards on a year-based period, i.e. 2013 for the pre-core-lab and 2015 for the core-lab system, respectively. Samples sent by the Emergency Department were not included in the analysis because no substantial changes occurred for their dedicated order entry as well as in testing tube configuration (i.e. a heparinized tube was used for a restricted test menu, defined according to a recent consensus [28]). Similarly, the dedicated tubes concerning

Table 1: Strategies to minimize iatrogenic blood loss at laboratory and clinical ward levels.

Laboratory	Clinical wards
Use of small collecting tubes	Blood drawing only in the case of true clinical needs
Use of analytical platforms that require lower sample volume	Appropriateness of test requests
Minimizing the amount of wasted samples	Appropriate use of vascular catheters
Point-of-care testing	Use of non-invasive monitoring systems
Elimination of obsolete tests	Standardization of phlebotomy procedures
Implementation of local recommendations shared with the clinical staff	Use of surgical technologies that can reduce blood loss
Application of "minimum retesting interval" rules	
Alerting rules within a computerized provider order entry	
Educational programs	

Adapted from Ref. [8].

cardiac markers (i.e. cardiac troponin and amino-terminal fragment of type-B natriuretic peptide) were not included in the analysis because no changes occurred in the testing tube configuration and a dedicated pathway for these tests, not included in the TLA system, was in place [29]. The microtubes sent to the laboratory by the neonatology unit were also not included in the analysis.

The laboratory configuration in terms of tubes, sample types, blood volumes and tests performed during the two periods is reported in Table 2. The tests previously using heparinized plasma for *stat* determinations were consolidated in the serum tube for the core-lab, as serum represents the specimen of choice for immunochemistry and microbiology assays.

Table 2: Laboratory system interested by the consolidation, with reference to testing tube types and filling volumes, performed tests and laboratories performing them in the pre-core laboratory period.

Sample (tube code)	Volume	Pre-core laboratory	Core laboratory
Serum (368966-BD)	3.5 mL	Clinical Pathology Unit, routine section: ALT, albumin, AST, total CO_2, total bilirubin, conjugated bilirubin, calcium, chloride, HDL cholesterol, total cholesterol, cholinesterase, CK, creatinine, ALP, inorganic phosphate, GGT, glucose, iron, LDH, lipase, magnesium, potassium, CRP, sodium, transferrin, triglyceride, urate, urea	–
Plasma (368884-BD)	4.0 mL	Clinical Pathology Unit, STAT section: ALT, AST, total bilirubin, conjugated bilirubin, calcium, chloride, CK, creatinine, phosphorous, glucose, LDH, lipase, magnesium, potassium, CRP, sodium, urea	–
Serum (367957-BD)	3.5 mL	Clinical Pathology Unit, immunochemistry section: ferritin, total β-hCG	–
Serum (368813-BD)	4.0 mL	Pharmacology Unit: digoxin	–
Serum (367957-BD)	3.5 mL	Endocrinology Unit: TSH, fT3, fT4	–
Serum (368968-BD)	5.0 mL	Microbiology and Virology Unit: HAV Ab IgG, HAV Ab IgM, anti-HBs Ab, anti-HBc Ab, anti-HBc Ab IgM, anti-HBe Ab, HBe Ag, HBs Ag, HBs Ag qualitative, HCV Ab, HIV1/HIV2 Ag-Ab, treponema pallidum Ab	–
Serum (367955-BD)	5.0 mL	Microbiology and Virology Unit: toxoplasma Ab IgG, toxoplasma Ab IgM, rubella Ab IgG, rubella Ab IgM, CMV IgG, CMV IgM, HSV 1-2 IgG, HSV 1-2 IgM, HSV-2 IgG	–
Serum (368969-BD)	5.0 mL	–	ALT, albumin, AST, total CO_2, total bilirubin, conjugated bilirubin, calcium, chloride, HDL cholesterol, total cholesterol, cholinesterase, CK, creatinine, ALP, inorganic phosphate, GGT, glucose, iron, LDH, lipase, magnesium, potassium, CRP, sodium, transferrin, triglyceride, urate, urea, ferritin, total β-hCG, digoxin, TSH, fT3, fT4, HAV Ab IgG, HAV Ab IgM, anti-HBs Ab, anti-HBc Ab, anti-HBc Ab IgM, anti-HBe Ab, HBe Ag, HBs Ag, HBs Ag qualitative, HCV Ab, HIV1/HIV2 Ag-Ab, treponema pallidum Ab, toxoplasma Ab IgG, toxoplasma Ab IgM, rubella Ab IgG, rubella Ab IgM, CMV IgG, CMV IgM, HSV 1–2 IgG, HSV 1–2 IgM, HSV-2 IgG
Whole blood (368857-BD)	3.0 mL	Hematology Unit: blood cell count, reticulocytes	–
Whole blood (10200-Diesse)	1.0 mL	Clinical Pathology Unit: Erythrocyte sedimentation rate	–
Whole blood (368857-BD)	3.0 mL	–	Blood cell count, reticulocytes, erythrocyte sedimentation rate
Plasma (363048-BD)	2.7 mL	Hematology Unit: PT, aPTT, D-dimer, fibrinogen	PT, aPTT, D-dimer, fibrinogen

BD, Becton Dickinson; ALT, alanine aminotransferase; AST, aspartate aminotransferase; CK, creatine kinase; ALP, alkaline phosphatase; GGT, γ-glutamyltransferase; LDH, lactate dehydrogenase; CRP, C-reactive protein; hCG, human chorionic gonadotropin; TSH, thyroid-stimulating hormone, fT3, free triiodothyronine; fT4, free thyroxine; HAV, hepatitis A virus; Ab, antibody; Ag, antigen; HCV, hepatitis C virus; HIV, human immunodeficiency virus; CMV, cytomegalovirus; HSV, herpes simplex virus; PT, prothrombin time; aPTT, activated partial thromboplastin time.

We included in the analysis all samples sent to laboratories for the two study periods that were assayed for at least one of the listed tests. We estimated the total blood volume sent to laboratories by multiplying the sample numbers by the filling volume of the respective tubes. Further, the number of tests performed by laboratories for the two study periods were retrieved from the LIS and grouped according to the sample type. The analysis was done by considering the different wards of our institution, grouped according to the type of clinical subspecialty when appropriate, e.g. medical wards were grouped as "medicine" and surgical wards grouped as "surgery". Our institution is specialized in the setting of infectious diseases and this clinical area was treated independently from the others.

Data were expressed as the overall number of inpatient tubes sent to laboratories, the corresponding blood volume, and the number of performed laboratory tests, normalized for the number of inpatients. The same normalization was done in the analysis dedicated to the different clinical wards of the hospital. Further, we performed a specific analysis for samples related to biochemistry/immunochemistry/microbiology tests: data were expressed as number of patient tubes sent to laboratories, the corresponding blood volume, and number of performed laboratory tests, normalized for the number of inpatients for different clinical wards. Statistical significance in the differences between the two periods was assessed using the χ^2 (chi)-square test.

Results

Table 3 shows the number of collected blood sample tubes and performed tests in the two study periods, together with the corresponding blood volume drawn per patient during hospitalization. The test consolidation due to the implementation of the core-lab facility allowed to decrease the total number of blood tubes per patient sent to the laboratory during their hospitalization (–1.9 tubes in average). As expected according to the test integration pursued with the core-lab system, the largest decrease was charged to tubes for biochemistry/immunochemistry/microbiology tests (–21.9%) and, to a lesser extent, to those for BCC/erythrocyte sedimentation rate (ESR) analysis (–5.2%). No changes were seen for coagulation tubes for which no modification between the two periods was in fact planned. The difference in the overall number of blood samples sent to the laboratory after the normalization for the number of inpatients hospitalized in the two study periods was statistically significant ($p < 0.001$).

The total blood volume sent to laboratories did not vary significantly between the two periods ($p = 0.85$). The use of a single blood sample for core-lab potentially permitted to test up to 55 analytes in the same transaction requested enough sample volume, i.e. 5 mL, to perform all tests and, if needed, retest individual results in case of critical values, inconsistency with clinical condition, etc. This evidently nullified, in terms of the amount of blood drawn, the advantage of test consolidation, described in Table 2, when the core-lab was begun. The blood saved with the incorporation of ESR in the BCC EDTA testing tube was low (–1.2%). The main reasons are two, ESR is not often requested and the testing tube in the pre-corelab had 1 mL of filling volume. Accordingly

Table 3: Number of collected blood samples and performed tests in the two study periods, and the corresponding blood volume drawn per patient during his/her hospitalization.

	Pre-core laboratory	Core laboratory	Post vs. pre, %	p-Value
No. of patients	14,696	15,301	605 (+4.1%)	
Number of blood tubes				
Biochemistry/immunochemistry/serology	80,876	63,189	−17,687 (−21.9%)	
BCC/ESR	67,223	63,734	−3489 (−5.2%)	
Coagulation tests	37,251	36,932	−319 (−0.9%)	
Total	185,350	163,855	−21,495 (−11.6%)	
Samples per patient	12.6	10.7	−1.9 (−15%)	<0.001
Blood volume, mL				
Biochemistry/immunochemistry/serology	319,383	315,945	−3438 (−1.1%)	
BCC/ESR	193,469	191,202	−2267 (−1.2%)	
Coagulation tests	100,578	99,716	−861 (−0.9%)	
Total	613,429	606,863	−6566 (−1.1%)	
Volume per patient	41.7	39.7	−2 (−4.8%)	0.85
Number of tests				
Biochemistry/immunochemistry/serology	578,334	591,105	12,771 (+2.2%)	
BCC/ESR	66,672	67,535	863 (+1.3%)	
Coagulation tests	93,079	89,117	−3962 (−4.3%)	
Total	738,085	747,757	9672 (+1.3%)	
Test per patient	50.2	48.9	−1.3 (−2.6%)	0.019

BCC, blood cell count; ESR, erythrocyte sedimentation rate.

the overall blood saved after the consolidation of the test in the tube for BCC was not relevant and poorly contributed in the slight decrease of the overall diagnostic blood loss observed and reported in Table 2. The normalization of data to the number of patients showed a small decrease in the mean volume of blood drawn per patient during hospitalization (–2 mL). Even the number of tests per patient performed during the new system slightly decreased (–1.3 in average) ($p = 0.019$).

Table 4 shows the findings from the most important clinical wards. The ICUs were the only wards that did not reduce the number of tubes per patient after the core-lab activation, according to the need of daily monitoring of the clinical status of patients with severe illness and/or multiple organ dysfunction. On the contrary, the infectious disease department reduced the average number of tubes per patient (from 20 to 16.5), although keeping unchanged (91.2 vs. 91.0) the average number of tests performed in their patients during hospitalization, often lasting many days while caring for acute infections and their comorbidities. Overall, data reported in Table 4 indicate that the new laboratory system seems to promote a slight optimization of blood drawing, with a reduction in the number of collected tubes per patient. However, ICUs, which phlebotomized patients daily, did not receive any advantage from the test consolidation. Given that intensivists did not change their standards of care, the daily ordering of the same tests with a higher volume of blood (up to 1.5 mL more) according to the core-lab system resulted in a slight increase of blood volume sent to the laboratory.

We also investigated the impact derived from the change of an order entry system from the pre-core-lab era, characterized by duplicated entries (*stat* and ordinary) for a list of first-line tests, used differently depending on the expectation of timeliness of result delivery, toward a TLA system, where only one order entry is available and no more *stat* testing is considered. Table 5 shows results related to tubes for biochemistry/immunochemistry/serology tests, which are those mostly affected by the organizational changes. These changes allowed to consistently save samples for all clinical wards, except for ICUs. In general, this resulted in a decrease of blood volume per hospitalized patient (from 2.2 mL in Medicine and Infectious Disease Departments to 6 mL in Cardiology). The collected blood volume remained unchanged in Surgery, even if the number of tests per patients decreased from 43.4 to 36.3. As no changes were introduced in the local guidelines for preoperative tests, we can infer that, at least for these types of wards, the change in laboratory system reduced the duplication of ordered tests.

Table 4: Number of collected blood samples and performed tests in the two study periods, and the corresponding blood volume drawn per patient during hospitalization, according to different clinical wards.

Clinical ward	Pre-core laboratory						Core laboratory						Difference in volume/patient, mL[a]
	No. tubes	Blood volume, mL	No. tests	No. patients	Tubes/patient	Volume/patient, mL	Test/patient	No. tubes	Blood volume, mL	No. tests	No. patients	Tubes/patient	Volume/patient, mL	Test/patient	
Medicine	71,439	230,753	283,757	5650	12.6	40.8	50.2	59,528	222,697	284,929	5893	10.1	37.8	48.4	–3.0
Infectious disease	32,732	107,183	149,054	1635	20.0	65.6	91.2	28,459	105,419	156,969	1724	16.5	61.2	91.0	–4.4
Surgery	18,573	61,498	82,869	1478	12.6	41.6	56.1	15,962	58,459	68,930	1497	10.7	39.1	46.0	–2.5
Cardiology (including cardiac surgery)	16,391	57,119	57,235	1087	15.1	52.5	52.7	15,327	56,547	65,845	1198	12.8	47.2	55.0	–5.3
Intensive cardiac care unit	10,508	33,961	38,759	543	19.4	62.5	71.4	10,913	38,663	44,008	560	19.5	69.0	78.6	+6.5
Intensive care unit	7837	25,581	35,128	387	20.3	66.1	90.8	8189	29,084	38,459	401	20.4	72.5	95.9	+6.4

[a]All differences are statistically not significant ($p > 0.05$).

Table 5: Impact of the change in the laboratory system on the number of collected tubes, blood volume drawn and performed tests in the two study periods, related to samples for biochemistry/immunochemistry/microbiology tests.

	Pre-core laboratory						Core laboratory					
	No. tubes	Blood volume, mL	No. tests	Tubes/ patient	Volume/ patient, mL	Tests/ patient	No. tubes	Blood volume, mL	No. tests	Tubes/ patient	Volume/ patient, mL	Tests/ patient
All clinical wards												
Total	80,876	319,383	578,334	5.5	21.7	39.4	63,189	315,945	591,105	4.1	20.6	38.6
Ordinary tests	29,439	113,635	168,826	2.0	7.7	11.5						
Stat tests	51,437	205,748	409,508	3.5	14.0	27.9						
Medicine												
Total	32,476	126,741	228,116	5.8	22.5	40.4	23,912	119,560	231,461	4.1	20.3	39.3
Ordinary tests	14,015	52,897	92,118	2.5	9.4	16.3						
Stat tests	18,461	73,844	135,998	3.3	13.1	24.1						
Infectious Diseases												
Total	14,206	55,931	121,432	8.7	34.2	74.3	11,016	55,080	129,305	6.4	32.0	75.0
Ordinary tests	4787	18,255	27,805	2.9	11.2	17						
Stat tests	9419	37,676	93,627	5.8	23.0	57.3						
Surgery												
Total	7272	28,980	63,875	4.9	19.6	43.4	5860	29,300	54,384	3.9	19.6	36.3
Ordinary tests	1226	4796	4509	0.8	3.2	3.1						
Stat tests	6046	24,184	59,366	4.1	16.4	40.2						
Cardiology												
Total	8010	33,096	43,435	7.4	30.5	40.0	5882	29,410	50,596	4.9	24.5	42.2
Ordinary tests	2912	12,704	9118	2.7	11.7	8.4						
Stat tests	5098	20,392	34,317	4.7	18.8	31.6						
Intensive care units												
Total	6486	25,779	50,856	6.9	27.7	54.7	6199	30,995	57,976	6.5	32.3	60.3
Ordinary tests	1328	5147	7460	1.4	5.5	8.0						
Stat tests	5158	20,632	43,396	5.5	22.2	46.7						

Discussion

In the recent years, the consolidation of laboratory tests in a core-lab has been promoted in light of financial benefits it gives and to maximize efficiency [30]. Laboratory specialists have, however, the opportunity to be proactive in clinically optimizing these operational efficiencies [18]. We previously described how this change from a compartmentalized laboratory department to a consolidated laboratory activity may provide the occasion to create a decision-making-based laboratory department, where the core-lab should include first-line tests, with all the results reported in a clinically effective turnaround time, and satellite laboratories executing specialized tests [26].

Within a core-lab project, the consolidation of many tests in a single tube represents a potential tool to promote patient safety and to improve clinical outcome, throughout the management of diagnostic blood loss. During hospitalization, patients are exposed to repeated blood collections for laboratory testing, therefore increasing their susceptibility to develop anemia. Vincent et al. established a significant relationship between the severity of organ dysfunction and the volume of blood drawn in critically ill patients [31]. In our core-lab setting, driven by clinical governance, we consolidated first-line tests previously performed in different laboratories in single tubes for the same sample (i.e. serum, plasma and whole blood), carried through a belt conveyor from one analyzer to another one. The main aim of this study was to evaluate the impact of this reorganization on the blood volume sent to the laboratory.

In general, the configuration of tubes implemented in our core-lab (described in Table 2) did not allow reaching a marked decrease in the blood volume drawn during patient hospitalization. Despite the incorporation of 55 tests in a single serum tube, the use of 5-mL tubes, needed for the determination of all serum analytes in the same order if requested, affected the total volume of blood sent to the laboratory, limiting the blood saving that was expected by us after the laboratory reorganization. Except for ICUs, the saved volume corresponded to the amount of blood usually needed to collect one/two samples (2.5–5.3 mL), which may correspond to one phlebotomy less per patient. This indicates that the new system promoted a slight optimization of blood drawing in most clinical wards. Other possible alternatives were possible: for instance, the option using two tubes of 3.5 mL, for chemistry-immunochemistry and for virology, would add one tube per patient, but possibly reduce blood loss for the repeated chemistry tests during a long length of stay in hospital. However, our initial choice was to consolidate in only one tube as many tests as possible and then to evaluate the impact of this choice even on the amount of blood drawn. Some data did not sufficiently meet our expectations; we reported data, for example, for patients admitted to Infectious Disease wards, who experienced longer time of hospitalization due to clinical complications or difficulties in diagnosis but who were not daily phlebotomized, showing a tendency in blood saving according to our selected approach.

Our data show that ICUs had no advantage in blood saving after the changes introduced with core-lab implementation. This subset of hospitalized patients is tightly monitored for life-threatening conditions, by assaying basic tests, such as metabolic markers (e.g. electrolytes) or tests indicating organ and system dysfunctions (e.g. creatinine), which are ordered in a standard way, often daily, regardless of order entry system. They are seldom interested in ordering the full menu of tests consolidated in our core-lab tubes. Thus, the reorganization moving, for example, for serum/plasma biochemistry from 3.5/4-mL to 5-mL tubes may paradoxically worsen the situation of the requested blood volume per patient. For ICUs patients, we also showed a moderate increase (in average, +5.6) in the number of tests requested during hospitalization after laboratory consolidation.

With the change of order entries, where *stat* requests were eliminated, we observed a reduction in the overall number of tubes per patient sent to laboratory, especially for biochemistry tests (from 5.5 to 4.1). Ialongo et al. [27], previously showed that the elimination of a dedicated *stat* path by TLA implementation may produce a decrease of duplicated test requests. Although our study was not primarily designed to prove the effect of TLA introduction on test duplication, we have seen similar effects only in surgery wards, where in the previous system the *stat* path was probably adopted to anticipate some laboratory results related to vital parameters.

Our study has some limitations. Firstly, we considered all inpatients for whom at least one blood sample was sent to the laboratories interested in changes in the system, regardless to their length of stay, which represents one of the factors influencing the onset of HAA. Furthermore, patients may move to others wards during their hospitalization according to their changes in clinical conditions or occurrence of medical complications, and this may also influence the evaluated parameters. Secondly, we only accounted for the blood volumes related to the tests involved in the core-lab implementation, but clinical wards also sent blood to laboratories for other investigations. For instance, the amount of blood collected for microbial blood culture amounts to a 10 mL bottle [32]. Accordingly, the impact on the diagnostic blood loss related to the change in our system cannot be directly translated to the risk of HAA.

Conclusions

In a previous publication, we described our laboratory department model, in which the short turnaround time for all first-line tests performed by TLA in the core-lab represents the key paradigm, where no more *stat* testing is required because all samples are handled in real-time and (auto) validated results are dispatched in a time that fulfils clinical needs [26]. Here we evaluated the impact of this model on the diagnostic blood loss and the number of ordered tests. As expected, our system affected the procedure of blood drawing in the clinical wards by significantly reducing the number of handled tubes, reasonably producing a benefit in terms of costs, labor and time consumption. Except in ICUs, this also slightly promoted blood saving. Although the statistical analysis showed no significant difference in volume of collected blood per ICU patient in the two studied periods, our experience suggests that great attention should be paid in the selection of tube size when test consolidation is planned, in order to fit the optimal balance between the number of orderable tests, the availability of enough sample volume to perform them, and the corresponding blood loss. In particular, the samples tubes should be selected according to the intended users in order not to affect subjects for whom repeated phlebotomies for a reduced panel of tests are required. Our study helped to identify this subset with patients hospitalized in ICUs, the group more prone to become anemic during hospitalization. For these subjects, dedicated strategies should be further implemented to promote blood saving and avoid HAA, even in the TLA era.

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