Customized middleware experience in a tertiary care hospital hematology laboratory

Kristine Roland⁎, Jim Yakimec, Todd Markin, Geoffrey Chan, Monika Hudoba

Vancouver General Hospital, Vancouver, BC, Canada

A R T I C L E   I N F O

Keywords:
Middleware
Autoverification
Hematology laboratory
Laboratory workflow

A B S T R A C T

Background: In the clinical laboratory, middleware is a software application that sits between the analyzer and the laboratory information system (LIS). One of the more common uses of middleware is to perform more efficient result autoverification than can be achieved by the LIS or analyzer alone. In addition to autoverification, middleware can support highly customized rules to handle samples and results from specific patient locations. The objective of this study was to review the impact of customized middleware rules that were designed and implemented in the hematology laboratory of a 1000-bed tertiary care adult academic center hospital.

Methods: Three novel initiatives using middleware rules to achieve workflow efficiencies were retrospectively reviewed over different audit periods: preliminary neutrophil result for oncopathology patients, microcytosis interpretive comments, and 1 white blood cell differential (WBCD) reported per day. In addition, autoverification rates for complete blood count and differential (CBCD) and coagulation tests were calculated.

Results: A preliminary neutrophil count was released from middleware on average 64 min before the final CBCD for Leukemia/Bone Marrow Transplant (L/BMT) outpatients, and on average 59 min earlier for oncology patients. Reflecting interpretive comments for select instances of microcytosis removed on average 500 slides per month from technologist review with an estimated cost savings of approximately $3383.33 CAD per month. The 1 WBCD per day rule resulted in a 5.1% cancelation rate, resulting in an estimated monthly cost savings of $943.46 CAD in reagents and technologist time. Finally, middleware rules achieved very high autoverification rates of 97.2% and 88.3% for CBC and CBCD results, respectively.

Conclusions: Implementation of customized middleware hematology rules in our institution resulted in multiple positive impacts on workflow, achieving high autoverification rates, reduced slide reviews, cost savings, and improved standardization.

Background

With increasing demands on productivity and decreasing resources, clinical laboratories are looking for ways to increase efficiency while maintaining accuracy and consistency of reported results. In high volume laboratories, middleware can be a useful tool for optimizing specimen handling and results reporting by virtue of highly customizable rules.

Middleware is a software application that sits between laboratory instrumentation and the laboratory information system (LIS). It can perform a variety of functions to assist technical staff such as autoverification of test results, holding and flagging results that may require additional action (e.g. failed delta check, critical value, results outside of range of the instrument), and quality control (QC) monitoring.⁴ Although an acceptable rate of autoverification can be achieved by having the autoverification algorithm fully defined in the LIS, the use of a middleware solution can further increase that rate. The sheer number of data elements (patient, specimen, test, with the ability to create end user defined elements for each type) that can be leveraged is significantly higher than what an LIS can offer. Also, there are additional locations within the middleware data stream where rules can be written than in an LIS alone.

In the clinical pathology literature, publications on middleware have largely focused on improvements to laboratory test autoverification rates.²,³ However, the potential scope of middleware is much broader in that middleware-built rules can be designed to cancel redundant tests, append interpretive comments when pre-specified criteria are met, and reflex further testing (e.g. reruns, add-on testing, specimen routing). There is little published literature on how individual laboratories have leveraged these latter capabilities.

We implemented middleware in our Hematology laboratory in February 2011, and over the last decade we sought to design highly customized rules...
to not only improve our autoverification rates but also to improve workflow, turn around time (TAT), and our ability to manage increasing test volumes. Here we report a retrospective review of our autoverification rates as well as 3 of our novel customized middleware algorithms to determine their impacts on workload and cost savings.

Materials and methods

Setting

Our Hematology laboratory is located in a 1000-bed tertiary care academic adult hospital. Major inpatient services include general medical and surgical services as well as emergency, trauma and burns, critical care, cardiothoracic surgery, solid organ transplant, and leukemia/bone marrow transplant. In addition, our laboratory processes outpatient blood samples from the neighboring Cancer Centre.

Currently, the Hematology laboratory performs around 340,000 complete blood counts (CBC) and complete blood counts with differential (CBCD), and 5100 body fluids per year using Sysmex XN9000 hematology analyzer, with addition of automated digital white blood cell (WBC) differential and morphology analyzer CellVision DI-60 (Sysmex America, Inc., Illinois, USA). Routine coagulation tests consisting of prothrombin time (PT), activated partial thromboplastin time (aPTT), fibrinogen, D-dimer, and thrombin time is 250,000 annually performed on ACL TOP 700 CTS by Instrumentation Laboratory (A Werfen Company, Bedford, MA). All instruments are interfaced to the LIS (Sunquest Laboratory version 6.4 and 10) through the middleware Data Innovations Instrument Manager (DI IM) (version 8.17, Colchester, Vermont, USA). CBCD parameters measured include 6-part WBC differential, nucleated red blood cell count (NRBC), reticulocyte count (RET), and immature reticulocyte fraction (IRF). Reticulocyte parameters are discrete and performed only if ordered.

Middleware

The implementation of the middleware occurred on February 23, 2011. The autoverification rules algorithm along with rules for automated technologist comments and pathologist interpretive reports were created to ensure consistency and accuracy (Table 1). Peripheral blood, body fluid, and sputum keyboards were created in IM in order to have as many technical and pathologist functions on the same platform as possible. Rules were written within the keyboard configurations to provide technologist guidance, calculate absolute differential counts, alert them to the presence of critical values, pathologist review criteria, and reflex a pathologist review order. In effect, the middleware rules dictate all specimen and results handling between pre-analytical specimen processing and microscopic slide review (Fig. 1).

The workspaces within the middleware are fully customizable. With the ability to use both pre-defined and free text coded entries, we were able to configure a hematology workspace application for reporting blood film, fluid morphology, and coagulation interpretations within IM. This module provides information on recent consecutive CBCs, instrument flags, technologist reason for referral, Sysmex scatterplots, and clinical diagnostic information provided in LIS (Fig. 2). No LIS enhancements were required, however, we did request analyzer driver enhancements to capture specific data elements, as is commonly required from many middleware customers. We also requested the ability to edit comments (both pre-defined and free text) which allowed for pathologist workflow to be incorporated onto the platform. Onboarding all these functions into middleware reduced reliance on paper printouts and created an essentially paperless system. The writing and maintenance of all middleware rules remains under the autonomy of the Hematology laboratory.

Customized middleware algorithms

The following algorithms were built using customized middleware rules and were selected for this retrospective analysis:

Preliminary neutrophil reporting

Our outpatient leukemia and bone marrow transplant (L/BMT) and Oncology physicians requested a preliminary neutrophil result before the full CBCD is resulted (in the event of a flagged differential that fails autoverification), in order to initiate chemotherapy treatment as quickly as possible. This was achieved by first building a new LIS trigger code to reflex order a preliminary neutrophil count. Then a rule was written within the middleware to limit the test by patient location (L/BMT clinic and Oncology clinic) and by the presence of WBC differential flags (such as the blast/abnormal lymph flag and abnormal scattergram flag). The preliminary neutrophil result is displayed as such and the final neutrophil value is resulted with the CBCD.

Microcytosis interpretive comments

As a sole abnormality, the differential diagnosis of microcytosis with or without anemia is limited. We created interpretive comments in the middleware specific to the mean cell volume (MCV), hemoglobin, red blood cell count, red cell distribution width-coefficient of variation (RDW-CV), sex and age of the patient. Based on these parameters, 1 of 6 interpretive comments is automatically appended to the CBC result by the middleware and a slide is not generated (unless there is another concurrent flag requiring slide review). The intent was to reduce slide reviews by both technologists and pathologists on a common but low-stakes finding on a CBC.

One WBC differential per day

After consultation with stakeholder physicians at our institution, it was agreed that a WBC differential did not need to be repeated on a patient within 1 calendar day, even if a repeat CBCD was ordered. The one exception was the context of autologous stem cell transplant collections, where a pre-/post-collection WBC differential was required for quality assurance purposes. We created a rule within the middleware to cancel a repeat same-day WBC differential, except for samples from autologous stem cell collections. This rule was written at the point of order download from the LIS to the middleware, so that the differential would not be run. Instead a comment would be appended to the CBC stating: “One differential reported per calendar day. See previous differential”. Full details of this project are explained elsewhere.

Autoverification rates

We created autoverification rules in the middleware (as well as LIS when appropriate) for CBC, CBCD, and coagulation tests. Our routine coagulation testing includes five parameters: aPTT, PT, thrombin time (TT), fibrinogen, and D-dimer. Autoverification is achieved when the middleware releases results into the LIS without holding them due to a programmed rule.

For this review of the above algorithms, 3 audit periods were selected based on respective test volumes. A short time period (September 2, 2021–September 15, 2021) was selected to collect autoverification rates on high volume tests (i.e. CBC and coagulation tests). An intermediate audit period (September 1, 2021–December 31, 2021) was selected to collect preliminary neutrophil reporting times, and the period of January 1, 2021–December 31, 2021 was selected to collect microcytosis interpretive comments and WBC differential cancelations. Data was extracted from the DI Instrument Manager and Sunset Laboratory databases (Oracle Corp. Austin, Texas). A Microsoft Excel spreadsheet was used for statistical analysis.

Results

Preliminary neutrophil reporting

During the 4-month audit period, there were a total of 948 CBCD tests reported with a preliminary neutrophil result (Table 2). Most of these CBCD tests were from L/BMT outpatients (806) while a smaller proportion...
Table 1
Middleware rules for complete blood count, differential and coagulation testing.

| Rule source | Rule | Hold for review | Notes |
|-------------|------|-----------------|-------|
| CBC and differential | **DI** Sample collection time >24 h | CBC, Diff | Suppress Auto diff + RBC indices |
| CBC and differential | **DI** Sample collection time >72 h | Reticulocyte | Not reported |
| CBC and differential | **DI** Patient age <3 days | | Reflex CBC, Diff, NRBC, Retic, Smear |
| CBC and differential | **DI** WBC <0.5 | Diff | Reflex smear review + referral |
| CBC and differential | **DI** WBC <0.5 + previous WBC >1.0 + not oncology | | Reflex smear review + referral |
| CBC and differential | **DI** WBC >3.0 + Outpatient | | Reflex Diff |
| CBC and differential | **DI** WBC 250.0 – 450.0 | Diff | Report RBC indices as Unavailable |
| CBC and differential | **DI** WBC exceeds linearity | WBC, HCT, Diff, Reticulocyte | Report RBC indices as Unavailable |
| CBC and differential | **DI** WBC lower limit of quantitation | | Report WBC as < xx |
| CBC and differential | **DI** Neutrophil # <1.0 + not oncology | | Reflex smear review |
| CBC and differential | **DI** Neutrophil # <0.5 | | Follow Critical Result SOP + referral |
| CBC and differential | **DI** Neutrophil # >30.0 | | Reflex smear review |
| CBC and differential | **DI** Neutrophil # >50.0 | | Referral if no previous >50.0 |
| CBC and differential | **DI** Lymphocyte # > reference interval Child | | Reflex smear review + referral |
| CBC and differential | **DI** Basophil # >0.5 | Diff | Reflex smear review + referral |
| CBC and differential | **DI** IG % >5, or >10 + previous <5, or >20 + previous <10 | | Reflex smear review + referral |
| CBC and differential | **DI** HB delta failure | All results | Follow IG # <0.2 |
| Sysmex/DI | **DI** HB outside reference interval | All results | Reflex smear review + referral |
| Sysmex/DI | **DI** HB linearity | WBC, Diff, NRBC | Reflex smear review + referral |
| Sysmex/DI | **DI** NRBC % >2.0 + not ICU/oncology | | Oncology: Reflex Preliminary ANC |
| Sysmex/DI | **DI** NRBC % >25.0 + patient age <31 d | | Reflex smear review |
| Sysmex/DI | **DI** NRBC linearity | WBC, Diff, NRBC | Reflex smear review + referral |
| Sysmex/DI | **DI** WBC abnormal scattergram + WBC >0.5 | Diff | Reflex smear review |
| Sysmex/DI | **DI** Abnormal lymphocytes/blasts flag | Diff | Reflex smear review |
| Sysmex/DI | **DI** Left shift flag - no previous results or new ED visit | | Reflex smear review + referral |
| Sysmex/DI | **DI** Atypical lymphocytes flag or new ED visit | | Reflex smear review + referral |
| CBC and differential | **DI** Differential vote-out | | Suppress Auto diff, perform manual |
| CBC and differential | **DI** RBC linearity | RBC indices | Dilute X7 |
| Sysmex/DI | **DI** RBC abnormal distribution + MCHC >375 | All results | Reflex rerun and smear review |
| Sysmex/DI | **DI** RBC agglutination | All results | Reflex rerun |
| CBC and differential | **DI** HB outside reference interval - Child | All results | Reflex smear review. Refer <80 |
| CBC and differential | **DI** HB <100 + not IDA + Outpatient / ED new admission | | Reflex smear review |
| CBC and differential | **DI** HB <75 + not IDA + Inpatient | | Reflex smear review |
| CBC and differential | **DI** HB <50 + not post-op / trauma / acute bleed / known | All results | Reflex smear review |
| CBC and differential | **DI** HB >160 female or >180 male | | Reflex smear review |
| CBC and differential | **DI** HB critical | | Reflex rerun. HB <50 or >230 |
| CBC and differential | **DI** HB linearity | HB, MCH, MCHC | Dilute X7 |
| Sysmex/DI | **DI** HB delta failure | All results | 14 days: + 40 Adult, + 20 Child |
| Sysmex/DI | **DI** Turbidity/Hb interference + MCHC >375 | CBC, Diff | For use in coagulation rules |
| CBC and differential | **DI** HCT >0.55, add Patient User Field | | Dilute X7 |
| CBC and differential | **DI** HCT linearity | CBC | Reflex smear review + referral |
| CBC and differential | **DI** MCV outside reference interval – Child | All results | Reflex smear review + referral |
| CBC and differential | **DI** MCV delta failure | PLT | 60 days: + 5 Adult, + 4 Child |
| CBC and differential | **DI** MCV <60 | Plt | Reflex PLT-F |
| CBC and differential | **DI** MCV <80 + RBC, HB, RDW, Age, Gender | | Auto comments - Microcytosis |
| CBC and differential | **DI** MCV <80 + HB <50 or HB >165 male or >150 female | | Reflex smear review and referral |
| CBC and differential | **DI** MCV 105-110 + HB <100 or PLT <50 or Neutrophil# <1.0 | | Reflex smear review and referral |
| CBC and differential | **DI** MCV >110 | | Reflex smear review |
| CBC and differential | **DI** MCHC <275 or >375 | All results | Reflex rerun |
| Sysmex/DI | **DI** PLT <100 | | Reflex smear review |
| CBC and differential | **DI** PLT <75 + previous >120 | All results | Reflex smear review + referral |
| CBC and differential | **DI** PLT <50 | All results | Reflex smear review + referral |
| CBC and differential | **DI** PLT <20 | All results | Reflex smear review |
| Sysmex/DI | **DI** PLT >800 Child | | Reflex smear review and referral |
| CBC and differential | **DI** PLT >1000 Adult | | Reflex smear review and referral |
| CBC and differential | **DI** PLT linearity | PLT | Dilute X7 and reflex smear review |
| CBC and differential | **DI** PLT delta failure | All results | 14 d: % delta is count-dependent |
| CBC and differential | **DI** PLT lower limit of quantitation | | Report PLT as < x |
| CBC and differential | **DI** Citrate PLT | Citrate PLT | Add 10% and reflex smear review |
| Sysmex/DI | **DI** PLT abnormal scattergram | | Reflex smear review |
| Sysmex/DI | **DI** PLT abnormal distribution + PLT <50 | | Reflex PLT-F |
| Sysmex/DI | **DI** PLT clumps + PLT <125 or >350 | PLT | Reflex smear review |
| Sysmex/DI | **DI** PLT clumps + PLT <75 | All results | Reflex smear review |

(continued on next page)
were from the neighboring cancer clinic (142). The TAT for laboratory results is longer for cancer patients than for L/BMT outpatients due to sample transport time; the oncology clinic is 2 blocks away from the main building housing both the Hematology laboratory and L/BMT clinic. Although there is a significant range in reporting times due to the presence of different CBCD flags, on average a preliminary neutrophil result is released 64 min before the full CBCD for L/BMT outpatients and 59 min earlier for oncology patients.

**Microcytosis interpretive comments**

During the 1-year audit period, there were 6263 microcytosis interpretive comments automatically appended to CBC results by the middleware. Table 3 shows the distribution of interpretive comments and the criteria for each. Of these, 265 (4.2%) still met slide review criteria due to other flags, initiating a slide review by the technologist, and of these 154 (2.5%) met criteria for Pathologist review. However, in the remaining 5998 cases, slides were not generated for manual review, which equates to a reduction of approximately 500 slides per month. This results in an estimated 5000 min (83.3 h) of technologist time saved monthly (based on slide preparation and manual review of approximately 10 min of technologist time per slide). At a rate of $0.47 CAD for slide materials and $37.78 CAD technologist time per hour, there is a monthly estimated cost savings of approximately $3383.33 CAD per month.

One WBC differential per day

With an average of 18 786 CBCD ordered per month, the number of canceled WBC differentials was on average 952 (range 893–1007; ±35.3SD) (Table 4). This equates to a cancelation rate of 5.1% (range 4.8–5.6%; ±0.3SD) during the 1-year audit period. At an estimated cost of $0.33 CAD per differential in reagents, this resulted in a cost savings of approximately $314.16 CAD per month (based on average 952 canceled differentials per month). In addition, some of these canceled differentials would have generated a slide review. Given our historic rate of 9.8% for flagged WBC differentials, the estimated technologist review avoidance was 93 slides per month. This equates to 930 min (or 15.5 h) of technologist time saved monthly, and a monthly savings of $629.30 CAD (using same cost analysis as for microcytosis interpretive comments).

**Autoverification rates in CBCD and coagulation**

The overall rate of CBC autoverification was 97.2% (Table 5). Of the CBC that failed autoverification, the vast majority had all results held;
only 0.1% had only Platelet result held due to a platelet clumping suspect flag on platelet results outside of the normal range. The reasons for holding all results were varied, the most frequent being mean corpuscular volume (MCV) delta check (1.0%).

Of all the CBCD, 7.1% of the WBC differentials were canceled due to existing rules (i.e. low WBC count or 1 differential per day). Of the uncanceled CBCD, the differential autoverification rate was 88.3%. The reasons for holding the differential result were varied, but the most common was the blast/abnormal lymph component, which was similar to our results of 97.2% for all CBCD and 88.3% for CBC results have ranged from 63% when rules were built in the analyzer10 to 81% when written in LIS.12 Similarly in coagulation, reported autoverification rates have ranged from 65% to 82%.5,10 High rates of LIS-based autoverification were achieved in an outpatient hematology/coagulation laboratory; however, outpatient samples may be less complex to result than predominantly inpatient population.6,7 We were able to find 1 report of a hematology laboratory that built autoverification rules in middleware and these authors used similar instrumentation and middleware as our laboratory.13 They achieved an autoverification rate of 93.5% for CBC and 89.9% for individual CBC components, which was similar to our results of 97.2% for all CBCD and 88.3% for WBC differentials.

Our review of novel middleware-built algorithms demonstrate that the capabilities of middleware extend far beyond autoverification. Two of our initiatives (1 WBC differential per day rule and standardized microcytosis comments) were successful in reducing manual slide review which saved technologist (and sometimes pathologist) time. Other authors have aimed to reduce unnecessary or redundant laboratory tests by focusing on clinician ordering practices using educational methods however results tend to be modest and temporary.14–18 Our approach using middleware has...
Fig. 2. IM middleware hematology workspace.
been sustainable with no reduction in effect over time. Finally, we showed that a preliminary neutrophil count can be released on average 1 h before a flagged CBCD is fully resulted, which can improve clinical management of hematology/oncology patients without additional workload on technologists.

Table 2
Time to release complete blood cell counts and preliminary neutrophil counts during audit period.

|                          | Time to CBCD result release | Time to preliminary neutrophil result release | Average time saved (min) |
|--------------------------|-----------------------------|---------------------------------------------|--------------------------|
|                          | Average (min) | Range (min) | Average (min) | Range (min) | Average (min) | Range (min) |
| L/BMT outpatients (n = 806) | 90           | 34 – 240   | 26           | 6 – 87      | 64           | 59          |
| Cancer patients (n = 142) | 127          | 70 – 273   | 68           | 34 – 87     | 59           |             |

CBCD = complete blood count with white blood cell differential; L/BMT = leukemia and bone marrow transplant; min = minutes.

Table 3
Interpretative comments automatically appended in middleware based on complete blood count parameters.

| Sex  | Hb  | RBC | MCV | RDW | Comment                      | Total |
|------|-----|-----|-----|-----|------------------------------|-------|
| F    | <120| <4.50| <55 | >15.8| Microcytic anemia suggestive of iron deficiency. | 4     |
| M    | <130| <4.80|     |      |                              | 313   |
| F    | <120| <4.50| 55–70| >15.8| Microcytic anemia. Common causes include iron deficiency or thalassemia. | 1699  |
| M    | <130| <4.80|     |      |                              | 268   |
| F    | <120| <5.20| 70–80| >15.8| Microcytic red blood cell morphology. Common causes include thalassemia trait, or less likely iron deficiency. | 844   |
| M    | >5.20| >4.90| >70 | <15.8| Microcytic red blood cell morphology. Common causes include thalassemia trait, or less likely iron deficiency. | 2300  |

For cases where above criteria are not met, the following comments are used:

| Any | Any | Any | <55 | <15.8| Red blood cell microcytosis, likely due to iron deficiency. | 1     |
|-----|-----|-----|-----|------|-----------------------------------------------------------|-------|
| 55–70|     | 5.20|     |      | Red blood cell microcytosis, consider iron deficiency or thalassemia. | 834   |
| 70–80|     |     | 5.20|      | Red blood cell microcytosis, consider iron deficiency, anemia of chronic disease, or thalassemia trait. | 2300  |

F = female; M = male; Hb = hemoglobin; RBC = red blood cell count; MCV = mean corpuscular volume; RDW = red cell distribution width.

Table 4
Monthly canceled white blood cell differentials due to one differential per day rule.

| Month in 2021 | Total CBCD ordered | WBC differentials canceled | % |
|---------------|--------------------|---------------------------|---|
| January       | 19 121             | 937                       | 4.9|
| February      | 18 284             | 907                       | 5.0|
| March         | 20 401             | 917                       | 4.5|
| April         | 19 501             | 963                       | 4.9|
| May           | 20 762             | 1004                      | 4.8|
| June          | 19 210             | 965                       | 5.0|
| July          | 18 255             | 979                       | 5.4|
| August        | 18 385             | 893                       | 4.9|
| September     | 17 978             | 951                       | 5.3|
| October       | 18 065             | 1007                      | 5.6|
| November      | 18 023             | 951                       | 5.3|
| December      | 17 450             | 946                       | 5.4|
| Average       | 18 786             | 952                       | 5.1|

Table 5
Autoverification rates for complete blood counts and coagulation tests during audit period.

| Parameter | Total | Autoverification rate (%) |
|-----------|-------|----------------------------|
| Total CBC and CBCD performed | 13 414 |                          |
| Number of CBC and CBCD with all results autoverified | 13 036 | 97.2                   |
| Total WBC differentials performed | 9263 |                          |
| Number of differentials canceled due to low WBC | 222 | 2.4                     |
| Number of differentials canceled due to one diff/day | 435 | 4.7                     |
| Number of remaining differentials autoverified | 7597 | 88.3                    |
| Number of reticulocytes performed | 291 |                          |
| Number of reticulocytes autoverified | 265 | 91.1                    |
| Number of INR performed | 4447 |                          |
| Number of INR autoverified | 4349 | 97.8                    |
| Number of PTT performed | 3874 |                          |
| Number of PTT autoverified | 3658 | 94.4                    |
| Number of quantitative fibrinogen performed | 513 |                          |
| Number of quantitative fibrinogen autoverified | 488 | 95.1                    |
| Number of TT performed | 91 |                          |
| Number of TT autoverified | 78 | 85.7                    |
| Number of D-dimer performed | 325 |                          |
| Number of D-dimer autoverified | 320 | 98.5                    |

CBC = complete blood count; CBCD = complete blood count with differential; WBC = white blood cells; diff = differential; INR = international normalized ratio; PTT = partial thromboplastin time; TT = thrombin time.
Conclusion

Middleware offers a flexible platform for laboratories to achieve standardized, efficient results reporting in a paperless environment. High autoverification rates using highly customized rules can be achieved for complex laboratory tests with multiple analytes such as the CBCD. In addition, laboratories can create their own context-specific rules to achieve targeted goals including, but not necessarily limited to, canceling redundant tests, appending interpretive comments, and releasing preliminary results. Using middleware to its full potential can improve workflow and result in cost savings. The use of middleware to create customized rules appears to be under-represented in the literature, and may indicate that this technology is not being used to its full potential.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of Competing Interest

The authors declare that they have no competing interests.

References

1. CAP. The Simple Definitions, Dos, and Don’ts of Installing Middleware. College of American Pathologists. Accessed Feb 15, 2021. https://www.cap.org/member-resources/clinical-informatics-resources/the-simple-definitions-dos-and-donts-of-installing-middleware.
2. Marquardt B. A Step by Step Process to 95% Autoverification. CAP. Accessed February 7, 2021. https://www.captodayonline.com/step-by-step-autoverification/.
3. Randell EW, Yenice S, Khine Wamono AA, Orth M. Autoverification of test results in the core clinical laboratory. Clin Biochem Nov 2019;73:11–25. https://doi.org/10.1016/j.clinbiochem.2019.08.002.
4. Tran A, Hudoba M, Markin T, Roland K. Sustainable laboratory-driven method to decrease repeat, same-day WBC differentials at a tertiary care center. Am J Clin Pathol Oct 7, 2021. https://doi.org/10.1093/ajcp/aqabl46.
5. Zhao Y, Yang L, Zheng G, Cai Y. Building and evaluating the autoverification of coagulation items in the laboratory information system. Clin Lab 2014;60(1):143–150. https://doi.org/10.7754/clinlab.2013.130109.
6. Froom P, Barak M. Auto-validation of complete blood counts in an outpatient’s regional laboratory. Clin Chem Lab Med Feb 2015;53(2):275–279. https://doi.org/10.1515/cclm-2014-0072.
7. Froom P, Saffuri-Elias E, Barak M. Autovalidation rates in an outpatient coagulation laboratory. Int J Lab Hematol Oct 2015;37(5):680–685. https://doi.org/10.1111/ijlh.12386.
8. Otsok L, Gustafson E, Grondlund E, et al. Autoverification of routine coagulation assays in a multi-center laboratory. Scand J Clin Lab Invest Oct 2016;76(6):500–502. https://doi.org/10.1080/00365513.2016.1200135.
9. Zhao X, Wang XP, Wang JB, et al. Multicenter study of autoverification methods of hematology analysis. J Biol Regul Homeost Agents Apr–Jun 2016;30(2):571–577.
10. Mlinaric A, Milos M, Coen Herak D, et al. Autovalidation and automation of the postanalytical phase of routine hematology and coagulation analyses in a university hospital laboratory. Clin Chem Lab Med Feb 23 2018;56(3):454–462. https://doi.org/10.1515/cclm-2017-0402.
11. Wang Z, Peng C, Kang H, et al. Design and evaluation of a LIS-based autoverification system for coagulation assays in a core clinical laboratory. BMC Med Inform Decis Mak 3, 2019;19(1):123. https://doi.org/10.1186/s12911-019-0848-2.
12. Fu Q, Ye C, Han B, et al. Designing and validating autoverification rules for hematology analysis in Sysmex XN-9000 hematology system. Clin Lab Apr 1 2020;66(4). https://doi.org/10.7754/clin.lab.2019.190726.
13. Stanko RD, Merrill AE, Davis SR, et al. Use of middleware data to dissect and optimize hematology autoverification. J Pathol Inform 2021;12:19. https://doi.org/10.4103/jpi.jpi_89_20.
14. Thakkar RN, Kim D, Knight AM, Riedel S, Vaidya D, Wright SM. Impact of an educational intervention on the frequency of daily blood test orders for hospitalized patients. Am J Clin Pathol Mar 2015;143(3):393–397. https://doi.org/10.1309/AJCPJS4EEM7UAUBV.
15. Miyakos S, Karamanof G, Lientos M, Mountokalakis TD. Factors contributing to inappropriate ordering of tests in an academic medical department and the effect of an educational feedback strategy. Postgrad Med J Dec 2006;82(974):823–824. https://doi.org/10.1136/pgmj.2006.049551.
16. Vidyarthi AR, Hamill T, Green AL, Ronenbluth G, Baron RB. Changing resident test ordering behavior: a multilevel intervention to decrease laboratory utilization at an academic medical center. Am J Med Qual Jan-Feb 2015;30(1):81–87. https://doi.org/10.1177/106286615317502.
17. Shen JZ, Hill BC, Polhill SR, et al. Optimization of laboratory ordering practices for complete blood count with differential. Am J Clin Pathol Feb 4, 2019;151(3):306–315. https://doi.org/10.1093/ajcp/aqy146.
18. Phelan MP, Nakashima MO, Good DM, Hustey FM, Procop GW. Impact of interventions to change CBC and differential ordering patterns in the emergency department. Am J Clin Pathol Jan 7, 2019;151(2):194-197. https://doi.org/10.1093/ajcp/aqy128.