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Pandemic Response in the Clinical Laboratory: The Utility of Interactive Dashboards

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ABSTRACT

The ability to access and analyze data is critical to manage a laboratory and respond and adapt to changes, particularly during a pandemic. Data analytic tools can not only improve laboratory operations, but also increase the visibility of the laboratory in the healthcare system and demonstrate the positive impact of the laboratory on patient care. In this article, we describe the creation and utility of laboratory dashboards. Several dashboards were designed to assist with pandemic response. For each dashboard, a stored procedure was created that performed a SQL query of our laboratory information system mirror database. We utilized the business analytics platform, Tableau, for data visualization. Users could modify the data by selecting a specific date range, time window, work shift, institution(s), specific test(s), and/or testing platform(s). Access was controlled by OKTA integration to the host server over the web, behind the hospital firewall. During the April 2020 surge, we saw an increase in blood gas testing and corresponding decrease in non-critical testing such as Vitamin D. At our institution, SARS-CoV-2 molecular testing was performed using four primary platforms, four in-house and one send-out. Weekly and hourly testing volumes as well as turnaround times fluctuated based on reagent availability, new testing requests, staffing, and operational changes. Productivity dashboards indicated that coagulation testing volumes were highest on the third shift and that all three analyzers may not be necessary. Further, specimen volumes and productivity of accessioning staff varied throughout the day. Phlebotomy venipuncture volumes and patient wait times also varied throughout the pandemic. A decrease in ambulatory draws was seen during the surge but after reopening draw volumes, particularly at offsite locations, surpassed prepandemic volumes. We demonstrate that data analytics and interactive dashboards are powerful tools, are helpful in response to a pandemic and lead to improved TAT, supply utilization, staffing and workflows. Furthermore, dashboards provide objective data to review with hospital leadership and promote collaboration.

Introduction

The COVID-19 (COVID) pandemic has had a profound impact on the clinical laboratories and has highlighted some areas that could be strengthened in preparation for future pandemics.[1] One important area for improvement is data analytics. The ability to access and analyze data is critical to manage a laboratory and respond and adapt to changes particularly during a pandemic. The clinical laboratory generates a large amount of data, but many laboratories do not have the infrastructure and/or resources to maintain, retrieve, and share data.[2,3] Data analytic tools can not only improve laboratory operations, but also increase the visibility of the laboratory in the healthcare system and demonstrate the positive impact of the laboratory on patient care.[4]

Traditionally, dashboards have focused on monitoring clinical laboratory turnaround time (TAT), identifying outliers and implementing improvements.[4–6] In a two part study, Cassim et al.[5,6] reported that a visual display improved TAT and allowed the team to identify several root causes for delays. Dashboards have also been used to track blood bank inventory,[7] improve blood product utilization,[8] monitor test ordering,[9] track quality metrics,[10–13] gain efficiency in hematopathology,[14] and identify bottlenecks in anatomic pathology.[15] In one study, residents were emailed a link to a static dashboard comparing their test utilization to their colleagues.[9] The dashboard reportedly increased awareness of test utilization, but it was not dynamic and did not account for patient complexity. Similar to this study, other studies state that interactive dashboards that assist laboratory directors with resolving issues quickly by providing current data are the most effective.[4,7,15]

Outside of pathology, dashboards have been implemented to assist hospitals in their response to the COVID pandemic by tracking telemedicine volumes, test ordering patterns, and emergency communications.[16–18]

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In article by Grange et al.,[16] ED length of stay, personal protective equipment (PPE) on hand, number of admitted COVID positive patients, and calls per day related to COVID were tracked and monitored. This allowed incident command to make informed decisions, communicate important changes, and deploy resources. The United States government also created publicly viewable dashboards in response to the pandemic so states could access total deaths, total cases, new cases, laboratory tests, and hospitalizations.[19]

In this article, we describe the creation and utility of laboratory dashboards, in particular the use of actionable data to resolve a diverse set of problems during a pandemic. Supply management was assessed using test volume dashboards. Staffing was adjusted based on test volumes, venipuncture volumes, productivity, and/or patient wait times dashboard data. Furthermore, the volume of COVID testing by platform and TAT dashboards allowed us to modify test routing and respond to new testing requests.

Methods

Setting

Our hospital is a 793-bed tertiary care hospital. The Clinical Laboratories process approximately 6 million specimens/year. The laboratory information system (LIS) is Sunquest (SQ; Sunquest Information Systems, Inc., Tucson, AZ) and electronic health record (EHR) is Epic (Epic Healthcare Systems, Verona, WI). Our institution is one of the founding members of an integrated healthcare delivery system that includes five other acute care hospitals and six community hospitals.

In 2020, we had five primary options for SARS-CoV-2 molecular (COVID) testing; four in-house options and one send-out option (Table 1). In-house testing included the Cepheid GeneXpert (our most rapid testing platform), the Hologic Panther Fusion, the Biofire, and the Thermo Fisher TaqPath. Requests for ambulatory COVID testing were sent to a reference laboratory. During the pandemic, COVID testing reagents, particularly for rapid testing platforms, were on allocation (e.g., we were limited to only a certain volume of reagents per week for the hospital network) which prompted our hospital network to implement a testing ordering algorithm [called the pandemic respiratory order (PRO)] that would route patient specimens to a rapid testing platform (e.g. Cepheid) only if the patient met certain clinical criteria (e.g., symptomatic, high risk).[1] The PRO was implemented on December 8, 2020.

Creation, Display and Maintenance of Dashboards

Laboratory leadership and our COVID response testing group, which included pathology informatics representation, determined which dashboards would be valuable during the pandemic to assist with workflow adjustments and respond to hospital requests. The decisions were based on experience, review of the literature, and the data required to inform decisions. Dashboards were developed to monitor COVID volumes and TAT. In addition, we monitored volumes of the core laboratory testing ordered to manage COVID patients (e.g., blood gas, coagulation testing, blood cultures, inflammatory and cardiac markers, liver function tests, and electrolytes) to determine supply needs and staffing. To assist with staffing adjustments, it was also determined that we should monitor the volume of testing performed primarily for ambulatory patients (e.g., vitamin D) on our stand-alone (i.e., not performed on the automated chemistry line) analyzers. Some dashboards, created before the pandemic, such as total specimen volumes accessioned, productivity, phlebotomy venipuncture volumes, and patient wait times, were also deemed valuable for responding to the pandemic.

For each dashboard, the pathology informatics team created a stored procedure that performs a SQL query of our LIS mirror database. We utilized a business analytics platform, Tableau (Tableau Software, Seattle, WA), for data visualization. Specific visualization features included selection of a date range, time window (e.g., daily, weekly), shift (defined as first (7:30 AM–3:30 PM), second (3:30 PM–11:30 PM), third (11:30 PM–7:30 AM)), institution(s), specific test(s) or batteries (e.g., all components of blood gas), and/or testing platform(s). Beta testing including functional testing of filters and data validation was performed by selected users before publishing in production. A refresh occurred daily at 12:15 AM. The dashboards had secure user access. Access was controlled by OKTA integration to the host server over the web, behind the hospital firewall.

Results

Test Volumes

We created an interactive dashboard that displayed test volumes for critical tests in COVID patients and testing ordered primarily in ambulatory patients run on a stand-alone core laboratory platform (e.g., vitamin D) (Figs 1 and 2). During the April 2020 COVID surge, there was a rapid increase in both venous and arterial blood gas (from approximately 1000 to 3000 per week) with the highest volume on the third shift (Fig. 1) and corresponding decrease in non-critical ambulatory testing such as vitamin D (from approximately 450 to 100 per week) for which testing was shifted from second to first shift (Fig. 2).

As a result of the test volume dashboard, both reactionary and preventative actions were taken to improve laboratory operations. We were too late to prevent a shortage of blood gas syringes. However, we were able to remove the PRN blood gas order from our EHR to conserve our limited supply of blood gas syringes, which led to a decrease in testing volumes as shown in week 17 and 18 (Fig. 1). We also made some proactive changes including: (1) ordering additional reagents to accommodate increasing volume of inflammatory marker testing, (2) shifting staff to benches with increasing volume and simultaneously reducing the frequency of non-urgent testing (e.g., reduce testing from five days/week to two days/week), (3) shifting testing to shifts with additional capacity (e.g., switching vitamin D testing from second to first shift to free up the second shift technologist operating the stand-alone vitamin D analyzer to assist with more critical testing on automated line and help with staffing shortages), and (4) validating alternatives for supplies such as swabs and media in case a shortage arose. As a result of these changes, we have not encountered a situation as critical as the shortage of blood gas syringes to date.

Table 1
COVID testing platforms.

Platform (Performing lab)	Hours testing offered	Turnaround time (from receipt)	Estimated capacity	Testing performed (when clinically indicated)
Cepheid GeneXpert (In-house, Microbiology)	24/7	1–2 hr	350/week[a]	COVID, influenza A, influenza B, RSV
Hologic Panther Fusion (In-house, Microbiology)	24/7 (if staffing permits)	4–6 hr	2,500/week	COVID, influenza A, influenza B, RSV, EVP
Biofire (In-house, Microbiology)	24/7	2–4 hr	400/week	COVID, influenza A, influenza B, RSV, EVP
Thermo Fisher TaqPath (In-house, Molecular)	12/7	8–24 hr	5000/week	COVID
Send Out Laboratory	24/7	18–48 hr	8500/week[b]	COVID

RSV = respiratory syncytial virus.
EVP = extended viral panel (includes adenovirus, metapneumovirus, rhinovirus, enterovirus, and parainfluenza).
[a] Limited reagent supplies.
[b] This number reflects our weekly capacity to collect and process send out samples, not the testing capacity at the send out laboratory.
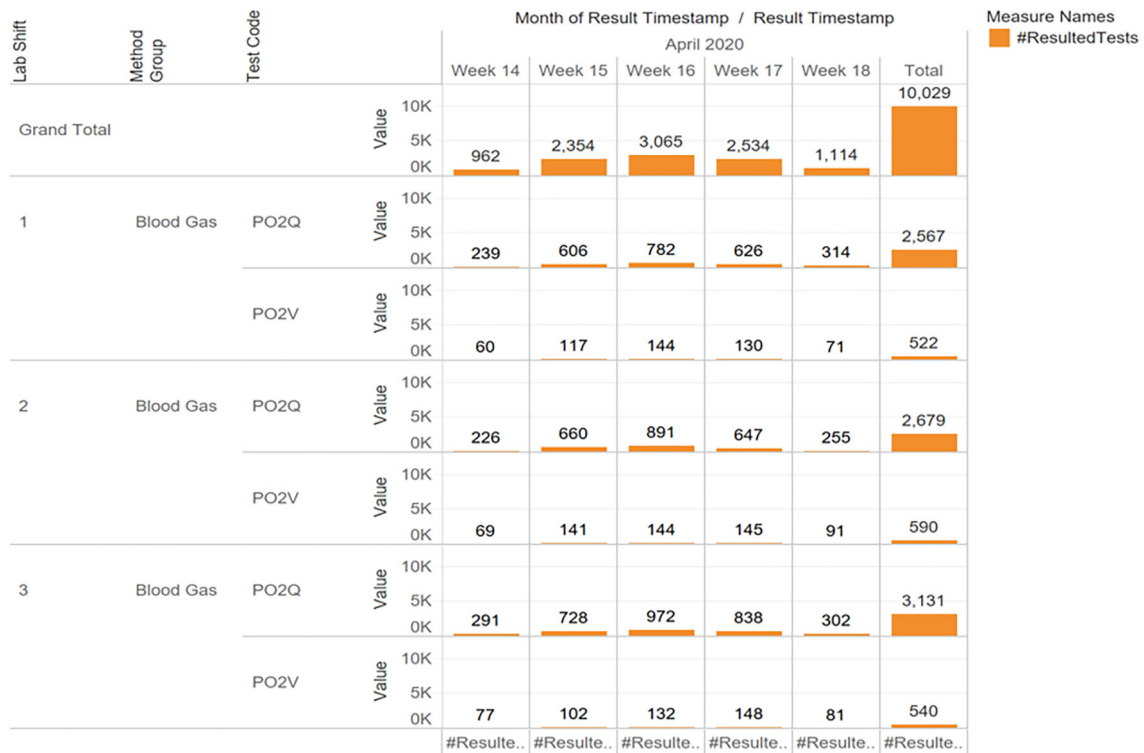
Fig. 1. Blood gas testing volumes. The weekly volumes in April 2020 for arterial (as indicated by the test code PO2Q) and venous (as indicated by the test code PO2V) blood gases are shown. Total volumes as well as volumes per lab shift (1, 2, or 3) are displayed.

COVID Volumes and TAT

During the pandemic, it was critical to monitor the COVID testing volumes by platform and hour of the day and the TAT to allow us to adjust for reagent and supply shortages and allocations, to accommodate new testing requests, and to determine workflow impacts. According to our COVID dashboard, despite the anticipated increase in the number of test requests and the need for additional respiratory testing, we were able to remain within our reagent allocation for Cepheid testing (i.e., less than 1100 per month for both cepheid and cepheid 4-plex) after the implementation of the PRO by spreading testing across our in-house platforms (Fig. 3). If we subsequently exceeded capacity, the dashboard prompted us to review what specimens and clinical indications

should be routed to a particular platform, to update the PRO and shift testing to other platforms/sites, or to borrow reagents from sites in the system underutilizing their allocation. We have made several changes to the PRO since December 2020 allowing us to remain within our rapid testing allocation.

In early October 2020, after a cluster of positive COVID cases in the hospital in late September, the laboratory was asked to perform COVID surveillance testing for all hospitalized patients every three days and provide a TAT of less than 24 hr. According to the September 2020 dashboard, average TAT from collection to receipt for Send Out Laboratory, Panther, and Thermo Fisher was 32.2 hr, 4.5 hr, and 20.0 hr, respectively (Fig. 4a), suggesting the Thermo Fisher would be acceptable for surveillance testing. As shown in Fig. 4b, none of the platforms, including
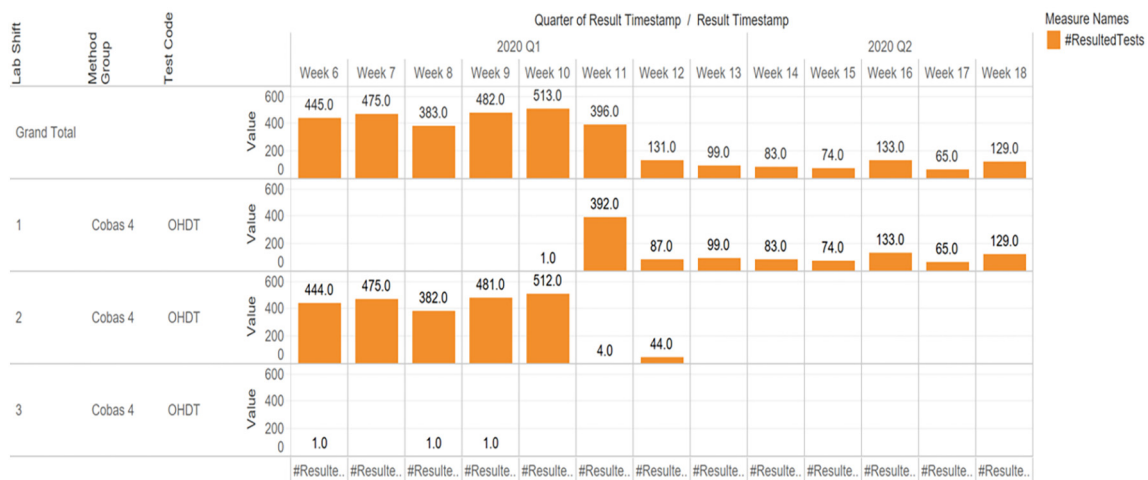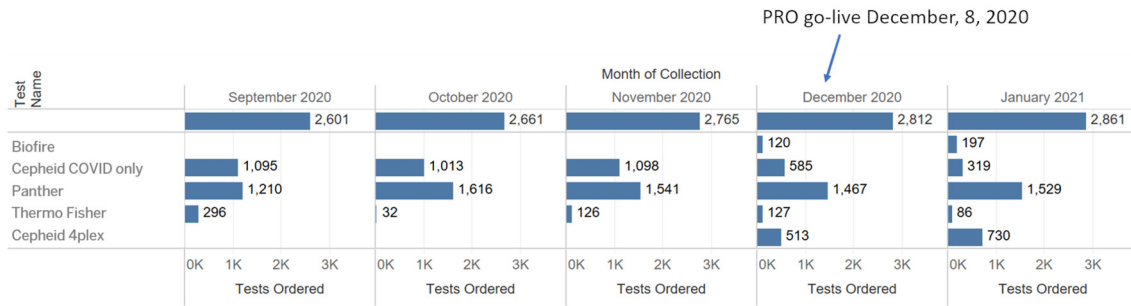

Fig. 2. Vitamin D testing volumes. The weekly volumes for Vitamin D (as indicated by the test code OHDT) in Q1 and Q2 of 2020 are shown. Total volumes as well as volumes per lab shift (1, 2, or 3) are displayed. Vitamin D testing is performed on the Roche Cobas e601 analyzer (as indicated by Cobas 4).

Fig. 3. COVID testing volumes for in-house platforms in the emergency room. The monthly volumes of COVID testing for our in-house platforms in September 2020, October 2020, November 2020, December 2020, and January 2021 in the emergency room are shown. The pandemic respiratory order (PRO) went live on December 8 as indicated by the arrow. The cepheid 4-plex included testing for influenza A, influenza B, and respiratory syncytial virus.

Thermo Fisher, were operating near capacity (Table 1). Additionally, the supply chain for reagents and consumables was most reliable for Thermo Fisher.

Hourly volumes by patient type (Fig. 5a) and platform (Fig. 5b) were also available in the dashboards. Volumes were consistently higher for in-patients on the two days in early September shown in Fig. 5a. The Cepheid was utilized throughout the day and volumes ranged from 0 to 13 tests per hour, whereas the Panther was operated on only two shifts with volumes ranging from 0 to 14 per hour (Fig. 5b). The hourly COVID testing volumes were utilized to determine the impact of a planned downtime (i.e., is it okay to hold specimens as volumes are low or should we route to another platform?) or staffing shortages (i.e., will there be impact if we stop cepheid between 2:00 AM and 5:00 AM until more staff arrive?). At a minimum, the dashboard provided the laboratory with information that they could relay to providers on the impact of downtimes or staffing shortages on hospital operations.

Productivity

Staffing adjustments are necessary during pandemics and productivity dashboards can help inform decision-making. If productivity and volumes are low at one or more benches, staff can be shifted to assist at other benches or with the pandemic response. It may also be appropriate to ask staff to work from home to keep a healthy pool of technologists. Productivity dashboards can also identify areas for improvement such as the need to switch to more efficient and/or rapid testing platforms. In reviewing the productivity of our technologists on the automated chemistry line, we noticed that number of anemia tests resulted per hour was lower than that for other automated testing with similar preanalytical and analytical times. Upon investigation, we determined that anemia testing, unlike other chemistry testing, was not being auto-verified (i.e., results meeting specified rules going directly from the analyzer to the EHR without a technologists' intervention). Therefore, we implemented auto-verification rules
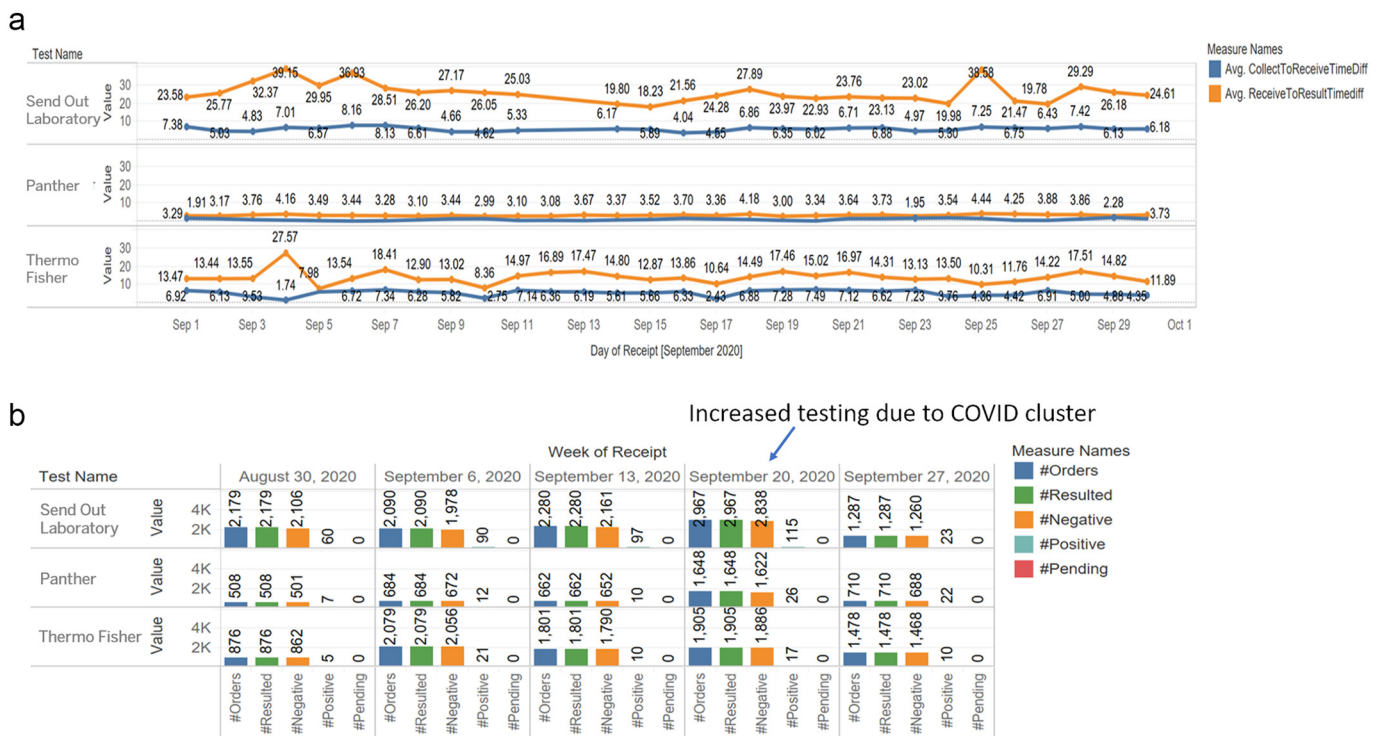
Fig. 4. COVID testing TAT and volumes. (a) The average daily TAT in hours from collection to receipt (blue) and receipt to result (orange) in September 2020 for the send out laboratory, Panther, and Thermo Fisher assays are shown. (b) The corresponding (September 2020) weekly volume of COVID tests ordered (blue), resulted (green), negative (orange), positive (light blue), and pending (red) for the send out laboratory, Panther, and Thermo Fisher assays are depicted. The COVID cluster occurred the week of September 20, 2020 as indicated by the arrow.
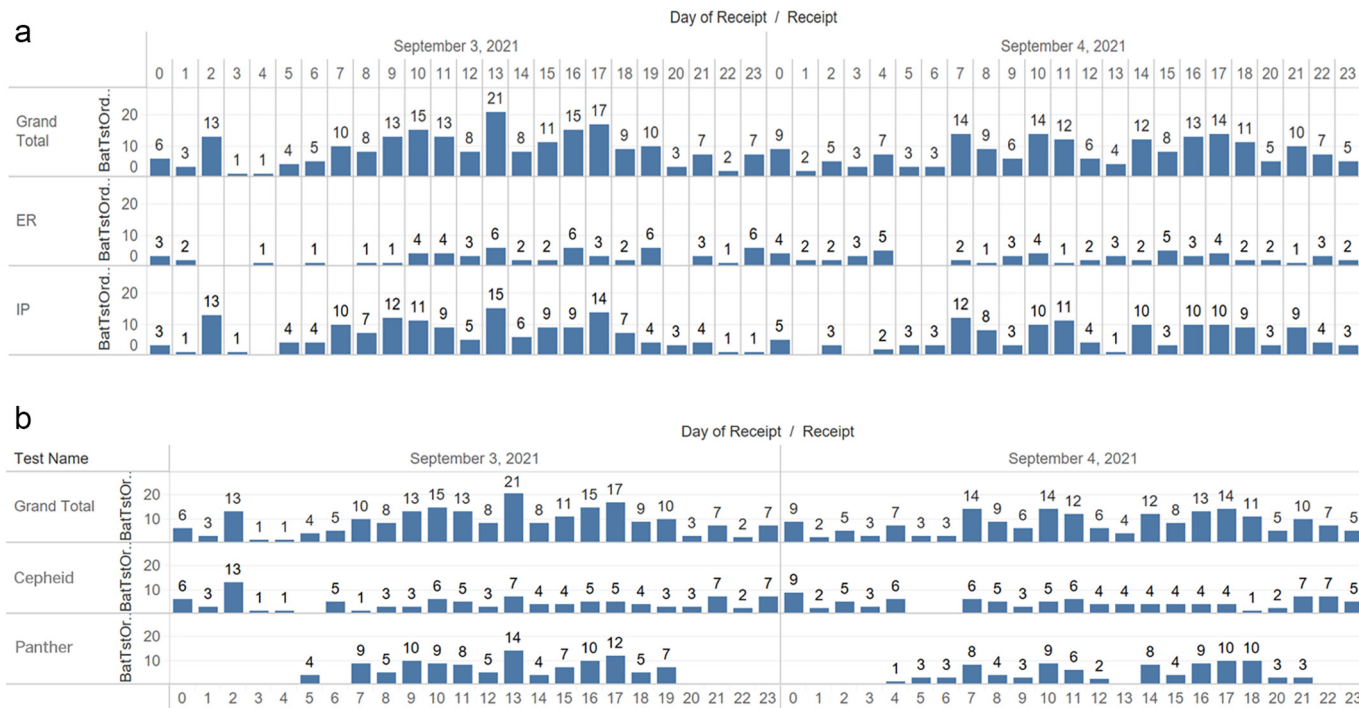
Fig. 5. Hourly COVID testing volumes. (a) Hourly COVID received volumes by patient type (emergency department (ER) and inpatient (IP)) for two days in September 2021 are shown. (b) Hourly COVID received volumes by platform (Cepheid and Panther) for two days in September 2021 are shown.

and confirmed the improved technologist productivity using the dashboard (data not shown).

In our laboratory, productivity dashboards also demonstrated that coagulation testing on the Stagos was distributed among all three Stago analyzers (Fig. 6a) but occurred primarily on the third shift (Fig. 6b). Stago 3 was utilized on the second shift, whereas Stago 1 and 2 were operated on the first shift (Fig. 6a). Most results were auto-verified (95%, 95%, 94%, 95%, 96%, 96%, and 96% on April 12, 13, 14, 15, 16, 17, and 18, respectively). Total volumes in the accessioning area and associated staffing were viewable in the dashboards (Fig. 7). The highest number of specimens (300–450 per hour) arrived between 6:00 AM and 8:00 AM when staffing ranged from 8 to 13 technologists. At 9:00 AM, staffing increased to 17 technologists despite volumes typically remaining less than 250 per hour for the remainder of the first shift (Fig. 7). Using the dashboard, we determined that only two Stagos were likely needed for coagulation testing and that the third analyzer could be removed from the automated line to provide space for other instrumentation or online storage. We will consider this after the pandemic. Although the dashboard provided data to support shifting staff earlier in the day, we have been unable to recruit personnel to work different hours; an example of how human factors can stall change despite the data to support it.

### Phlebotomy Draws and Wait Times

Phlebotomy is the face of the clinical laboratory due to their interaction with patients in both the hospitalized and ambulatory setting. Tracking venipuncture volumes in both settings can help determine staffing, PPE needs especially during a pandemic and space requirements for physical distancing. The volume of phlebotomy draws varied throughout the pandemic. During the April 2020 surge, there was a slight increase in inpatient phlebotomy draws, many involving donning and doffing of PPE for COVID positive patients, leading to an increase in the amount of time to draw patients (data not shown). A corresponding decrease in outpatient phlebotomy draws was seen (Fig. 8). The average daily draw volumes at a representative ambulatory site was 186 in February 2020 (Fig. 8). The average volumes

decreased to 113, 71, and 111 in March, April, and May 2020; respectively. As we reopened the hospital, we tracked the increase in ambulatory draws, particularly at ambulatory locations outside the city, and saw that volumes surpassed pre-COVID volumes likely due to the increase in telemedicine visits and comfort level of patients (Fig. 8). The average daily draw volumes increased to 195, 256, 236, and 271 in June, July, August, and September 2020, respectively. Therefore, we redistributed staff to accommodate the increasing volumes and prioritized the redesign of the higher volume sites to enable us to safely draw patients. At collection sites with limited space, we worked with the practice to draw patients safely in an exam room.

Despite the increase in volume our wait times ranged from 6 to 15 min with an average wait time of 7.8 min on September 15, 2020 (Fig. 9). At 1 PM and 4 PM, average wait times exceeded our goal 10 min, which may be due to lower staffing compared to other hours of the day with similar volumes. At most phlebotomy locations, we are able to maintain average wait times less than 10 min by frequent monitoring of the dashboards and either shifting staff or hiring temporary staff. To increase the quantity and quality of data feeding our dashboards, we also implemented electronic applications to capture wait times and throughput that could be utilized to adjust workflows.

Discussion

We demonstrate that data analytics and interactive dashboards are powerful tools, are helpful in response to a pandemic and lead to improved TAT, supply utilization, staffing, and workflows. Furthermore, dashboards can ensure collaboration across the institution by providing objective data to collectively review and promote the visibility of the laboratory to leadership and administration which may assist with obtaining the proper resources. Importantly, the COVID dashboards provided a visual display of the complexity of laboratory processes (e.g., number of testing platforms and routing logic required, multiple components of TAT including collection, transport, receipt, testing, and resulting) and the impact of any interventions, particularly those that lead to a reduction in TAT (e.g., instrument interfacing, new IS build).

a

b
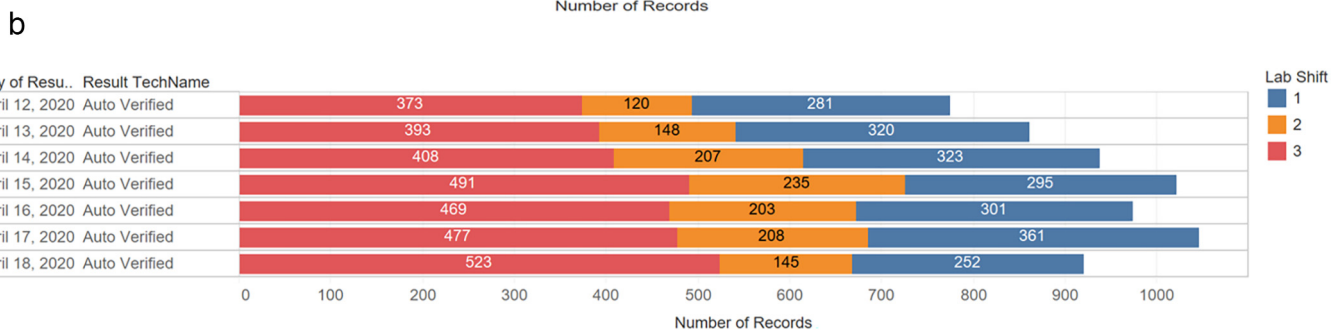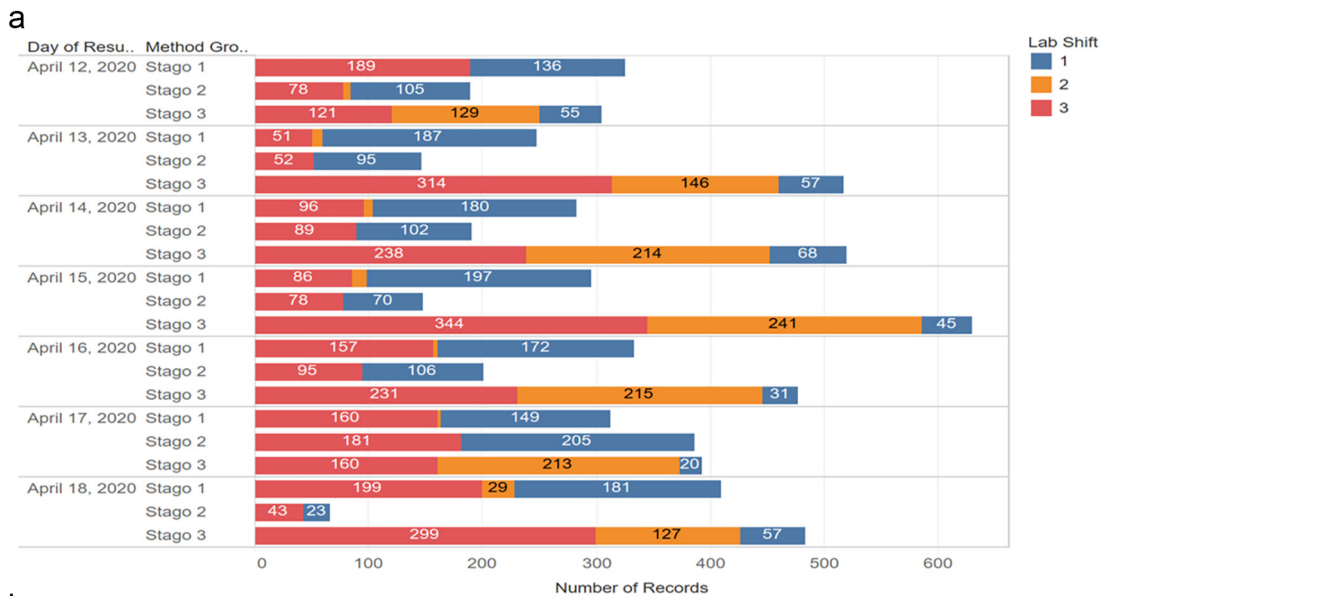
Fig. 6. Coagulation testing distribution and resulting. (a) For one week in April 2020, the volumes of coagulation testing on first (blue), second (orange), and third (red) shift and the platforms on which testing occurred (Stagos 1, 2, and 3) are shown. (b) The number of results auto-verified per day per shift (first (blue), second (orange), and third (red)) are displayed.

There were additional benefits of interactive dashboards. Data requested by hospital leadership, our healthcare system, or the United States Department of Health and Human Services could be rapidly reviewed and displayed. This was a significant time savings for laboratory directors who no longer had to manually pull data. It also solidified collaborations with our clinicians and laboratory colleagues and helped ensure our participation in hospital and system decision-making. As examples, the dashboards allowed us to determine, communicate, and mitigate the impact of instrument downtime and staffing shortages on COVID TAT, to effectively justify the need for additional rapid testing platforms, to prompt new policies on test ordering to control volumes or respond to supply shortages (e.g., blood gas syringes), to demonstrate the need to adjust the PRO order to match platform capacity, to indicate how a requested change may impact operations, and to address concerns and safety reports related to laboratory performance (e.g., TAT, patient wait times).

There are several lessons learned from our experience with building and utilizing dashboards. First, it was critical that our IS team had an in-depth
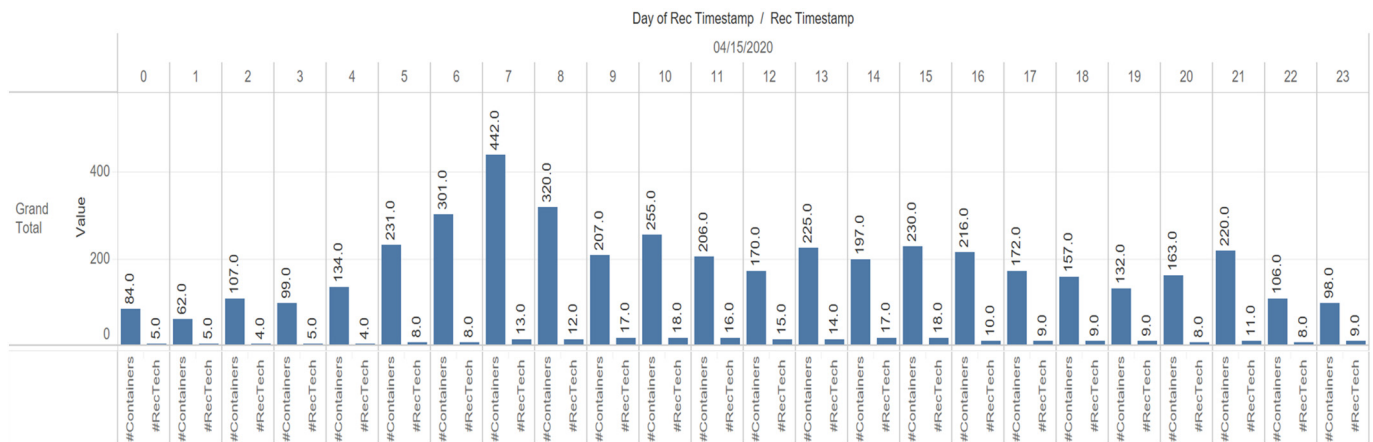
Fig. 7. Specimens received per hour and associated staffing. The volume of containers (# Containers) received in the laboratory per hour of the day and associated number of technologists (# RecTech) receiving specimens are shown for one day in mid-April 2020.
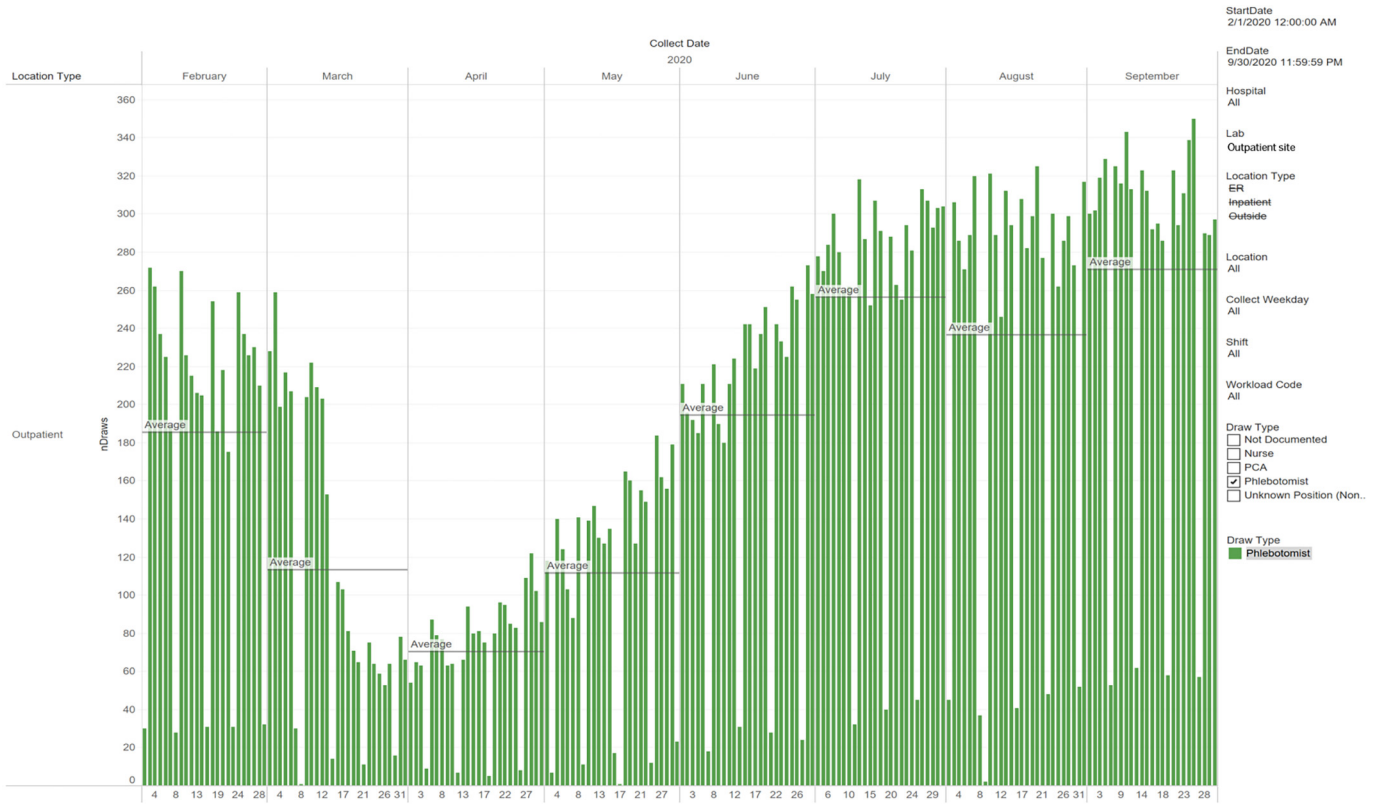
Fig. 8. Phlebotomy volumes. The daily volume of draws from February 2020 to September 2020 at one ambulatory facility is shown.
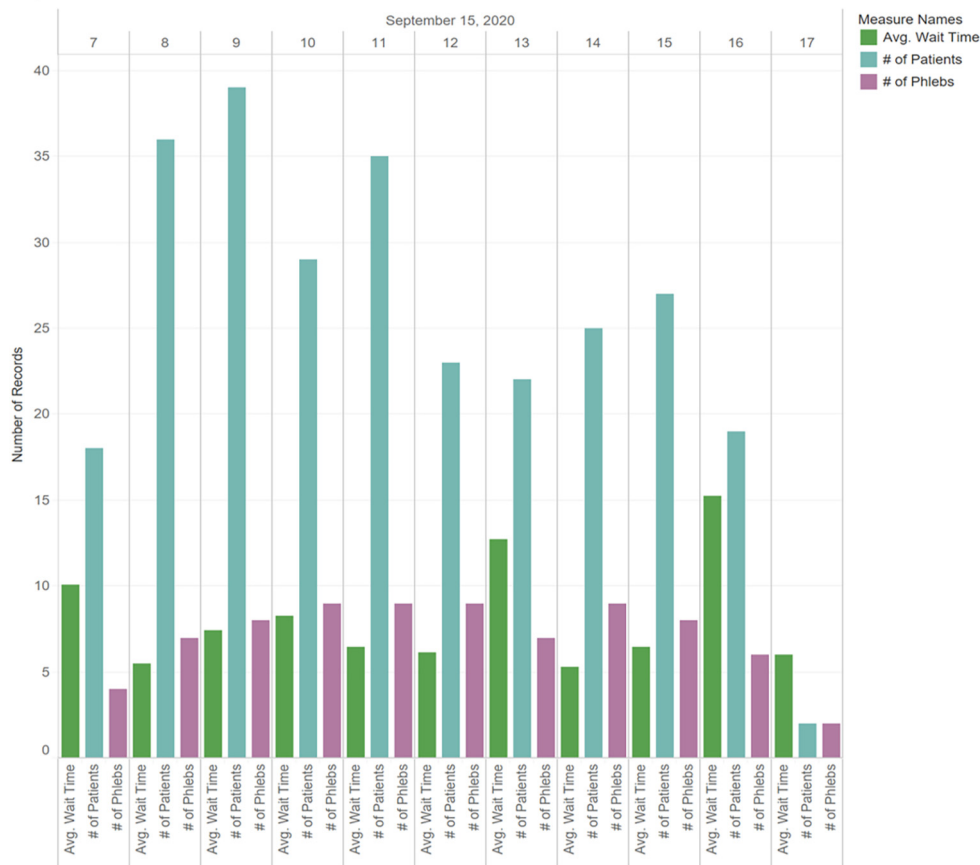

Fig. 9. Phlebotomy wait times. The average wait time per hour from patient arrival to collection (green), number of patients per hour (blue), and number of phlebotomists drawing each hour (purple) are displayed for September 15, 2020 at one ambulatory facility.

understanding of the data structure in our LIS and how to pull reports from our mirror database. We also had access and experience with Tableau before the pandemic which expedited dashboard development. We learned, early in the pandemic, to create dynamic, data-rich dashboards with the ability to filter data fields. This minimized the need to modify dashboards. In addition, the dashboards were designed with a knowledge of clinical workflows and their utility. Importantly, we built dashboards based on the frequency of data refreshes (e.g., nightly), understood the limitations and took alternative approaches if nightly data refreshes were not sufficient (e.g., application to display COVID cycle threshold values). Finally, we standardized our process with testing and displaying reports that populated the dashboards to facilitate creation of new dashboards. We currently have more than 20 active dashboards in production.

There were limitations to utility of our dashboards beyond the frequency of data refreshes. It was a cultural change for both the laboratory and hospital to access and filter data on the dashboards. We continue to train and remind staff to utilize the dashboards and make requests for modifications or additional dashboards. As seen with our total accessioning volume, supportive data does not necessarily translate into an improvement or workflow changes. Barriers include lack of staffing, resistance to change, limited space, and/or inadequate financial resources.

Data analytics is a powerful tool and the laboratory with its wealth of data is uniquely positioned to capitalize on this tool. In the future, we anticipate expanding our dashboards to include inventory management at both a local and enterprise level and developing benchmarking standards for productivity and TAT to guide dashboard review. However, dedicated IS staff to create and maintain dashboard and dedicated laboratory staff to review and implement changes will be required for success.

Competing Interests

The authors declare that they have no competing interests.

Authors' contributions

AKP: conception and design, acquisition of data, analysis and interpretation of data, critical manuscript revision

MJC: acquisition of data, analysis and interpretation of data, critical manuscript revision

TT: acquisition of data, analysis and interpretation of data, critical manuscript revision

SEFM: conception and design, analysis and interpretation of data, drafting of manuscript, critical manuscript revision

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