Harnessing the Electronic Health Record and Computerized Provider Order Entry Data for Resource Management During the COVID-19 Pandemic

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Abstract

Background: The coronavirus disease 2019 (COVID-19) pandemic resulted in shortages of diagnostic tests, personal protective equipment (PPE), hospital beds, and other critical resources.

Objective: We sought to improve management of scarce resources by leveraging electronic health record (EHR) functionality, computerized provider order entry, clinical decision support (CDS), and data analytics.

Methods: With complex eligibility criteria for COVID-19 tests and a challenging EHR implementation of associated testing orders, providers faced obstacles selecting the appropriate test modality. As test choice was dependent upon specific patient criteria, we built a decision tree within the EHR to automate test selection using a branching series of questions that linked clinical criteria to the appropriate SARS-CoV-2 test and triggered an EHR flag for patients who met our institutional persons under investigation (PUI) criteria.

Results: The percentage of tests that had to be canceled and reordered due to errors in selecting the correct testing modality was 3.8% (23/608) pre-CDS implementation and 1.0% (262/26,643) post-CDS implementation (P < .0001). Patients who had multiple tests ordered during a 24-hour period accounted for 0.8% (5/608) and 0.3% (76/26,643) of orders pre- and post-CDS implementation, respectively (P = .035). Nasopharyngeal molecular assay results for patients classified as asymptomatic were positive in 3.4% (826/24,170) of patients compared to 10.9% (1,421/13,074) for symptomatic patients (P < .0001). Positive tests were more frequent among asymptomatic patients with a history of exposure to COVID-19 (12.7%, 36/283) than among asymptomatic patients without such history (3.3%, 790/23,887; P < .0001).

Conclusions: Leveraging the EHR and our CDS algorithm decreased order entry errors and appropriately flagged PUI status. These interventions optimized reagent and PPE usage. Data collection in the decision tree regarding symptom and exposure status correlated with the likelihood of positive test results, suggesting that clinicians appropriately utilized questions in the decision tree algorithm.

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Keywords:
COVID-19; computerized provider order entry; electronic health record; resource utilization; personal protective equipment; SARS-CoV-2 testing; clinical decision support

Introduction

Coronavirus disease 2019 (COVID-19) is caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and has quickly emerged as a global pandemic since its initial description in December 2019 [1]. Increased testing and isolation of COVID-19 patients are important means of limiting spread of the infection. Many laboratories in the United States have expanded their testing capabilities rapidly [2]. As a result, the overall testing capacity in the US is substantially larger than what the CDC and state health agencies were able provide at the start of the pandemic. Testing shortages however persisted throughout 2020 and, to a lesser extent, into 2021, due to inadequate supplies of collection swabs, viral transport media, RNA extraction regents, and other reagents, and consumables [3, 4]. Institutions have had to prioritize testing by taking into account severity of illness, rapidness of results, bed availability, and staffing needs [4]

Electronic health records (EHR) and computerized provider order entry (CPOE) systems offer the potential to reduce medical errors and improve care quality by facilitating communication, providing access to information, monitoring patients, providing decision support, and enhancing clinician situational awareness [5-7]. However, EHRs can also inadvertently lead to clinicians introducing new errors, overlooking existing orders, and duplicating work [8-10]. Apart from the need to reduce costs, preventing duplicate testing of patients for COVID-19 is essential to conserve existing testing supplies and maximize the number of patients that can be tested.

While the availability of testing is important, so is the timely dissemination of the results to providers to optimally allocate valuable hospital resources such as limited supplies of personal protective equipment (PPE) effectively [4]. Testing capacity has increased since the early days of the pandemic, but the proliferation of different testing platforms and methodologies has led to variations in test turnaround time and assay sensitivity. Commercial vendors have produced high throughput, cartridge-based instruments that promise shorter testing turnaround times; however, demand for

these instruments currently exceeds available supplies [4].

To meet the testing needs of our patient population despite equipment shortages, institutions such as our pediatric healthcare system had to assemble a variety of COVID-19 testing modalities with varying performance characteristics. Matching the testing modalities to the appropriate clinical scenario was a challenge. Some institutions developed decision-making algorithms to stratify their patient population into risk groupings [11]. Here, we describe and evaluate the CPOE clinical decision support tools developed to optimize ordering of COVID-19 testing, the EHR functionalities leveraged to manage persons under investigation (PUIs), and the data analysis tools essential to monitor changing variables such as ordering patterns and available reagent supplies.

Materials and Methods

Setting and Institutional Approach to COVID-19

Our academically affiliated pediatric healthcare system in North Texas consists of three acute care hospitals licensed for a total of 601 beds and 24 ambulatory specialty care centers. Together these facilities care for more than 227,000 unique patients per year and provide services including more than 19,600 surgeries and 107,800 emergency department visits [12]. Our health system's efforts to prepare for patients with COVID-19 began early in 2020 and included activation of the Hospital Incident Command Structure (HICS) on March 5. A sick isolation unit (SIU) was opened on March 23 for management of patients who did not require critical care with either suspected COVID-19—designated as patients under investigation (PUIs)—or confirmed infection. The first positive test result for SARS-CoV-2 for a patient in our system was received later that month on March 31. With the HICS activation, we recognized that the pandemic would require an organized, sustainable, and adaptable approach to care for children with COVID-19 while minimizing staff exposure and optimizing the use of personal protective equipment (PPE) and testing reagents and supplies. In this report, we describe and evaluate tools developed within the electronic health record (EHR) that were

vital components of this approach.

As COVID-19 spread across the world and within the US, the epidemiology of the disease morphed from at first emphasizing exposure during travel, then contact with a limited number of confirmed local cases, and finally widespread community transmission [13-15]. In early 2020, the criteria recommended by the Centers for Disease Control and Prevention for identifying a person as a PUI changed several times [16,17]. Reflecting the changing disease epidemiology, these PUI definitions—which had initially focused on symptomatic individuals with history of travel to Wuhan, China, or contact with a laboratory-confirmed case of COVID-19—later were expanded by addition of criteria related to travel from mainland China, travel from affected geographic areas within the United States, and finally even to individuals with no known exposure risk factors [16]. Following the initial period during which SARS-CoV-2 testing was available at our institution only through public health laboratories, the options for testing increased first with offerings from commercial reference laboratories and then the launch of an internal, laboratory-developed test (LDT) with a turnaround of approximately 24 hours. Later, our laboratory implemented commercial rapid testing platforms that offered a further improvement in turnaround times for a limited number of specimens depending on availability of the required kits (Table 1).

Table 1. SARS-CoV-2 Assays Implemented

Assay	Modified CDC SARS-CoV-2 Assay (laboratory developed test)	Biofire Respiratory Panel 2.1 (bioMérieux)	Xpert Xpress SARS-CoV-2 (Cepheid)	SARS Antigen FIA (Quidel)	Reference Lab 1; Alinity m SARS-COV-2 Assay (Abbott)	Reference Lab 2; cobas SARS-CoV-2 (Roche)
Analyte	RNA	RNA	RNA	Antigen	RNA	RNA
Sample Collection	NP swab in UTM	NP swab in UTM	NP swab in UTM	Anterior nares swab	NP swab in UTM	NP swab in UTM

SARS-CoV-2 Target	N-gene	M-gene S-gene	E-gene N2-gene	Nucleocapsid protein	N-gene RdRp-gene	E-gene RdRp-gene
SARS-CoV-2 LoD[a]	260 copies/mL	160 copies/mL	250 copies/mL	113 TCID50/mL	100 copies/mL	0.003 TCID50/mL
Other Target(s)		21 additional viruses and bacteria				
Instrument(s)	EMAG (extraction; bioMérieux) ABI 7500 (PCR; Thermo Fisher)	FilmArray Torch System	GeneXpert XVI	Sofia 2	Alinity m System	cobas 6800
Maximum Throughput[b]	150 samples/ 8-hour shift (extraction) 150 samples/ 8 hours shift (PCR)	<1 hour/ test/ instrument module	<1 hour/ test/ instrument module	20 min test/ instrument module	300 tests/ 8-hour shift	864 tests/ 8-hour shift
Time to results (average ± stdev)[c]	0.79 ± 0.85 days	70 ± 17 min	77 ± 29 min	27 ± 5 min	0.53 ± 0.35 days	2.03 ± 1.56 days

[a]LoD – limit of detection shown is the lowest reported (highest sensitivity) either on the package insert or demonstrated in the laboratory
[b]Maximum throughput assumes sufficient reagents. Maximum throughput volumes were not achieved for most platforms due to limited reagent allocations.
[c]Duration from specimen (primary orders) or order (add-on orders) receipt in the lab to result reporting. Includes transport to outside lab (send out testing only), laboratory processing, sample preparation, on instrument time, and reporting.
NP, nasopharyngeal; UTM, universal transport medium

New institutional policies and procedures in response to the COVID-19 pandemic were instituted in parallel with changed understanding of disease epidemiology, the illness, and its transmission. These changes included adoption on April 28, 2020, of universal SARS-CoV-2 testing

for all patients admitted through the emergency department or directly to inpatient floors and intensive care unit. At first, rapid testing was prioritized for patients with fever, respiratory symptoms, or a close contact with COVID-19 infection, while other patients were tested using the LDT. This strategy directed limited resources for rapid testing toward those patients with the highest likelihood of infection at that point but resulted in a delay in identifying asymptomatically positive cases, which represent a considerable portion of SARS-CoV-2 infections in children. As rapid testing became increasingly available, such testing was deployed subsequently for all admitted patients.

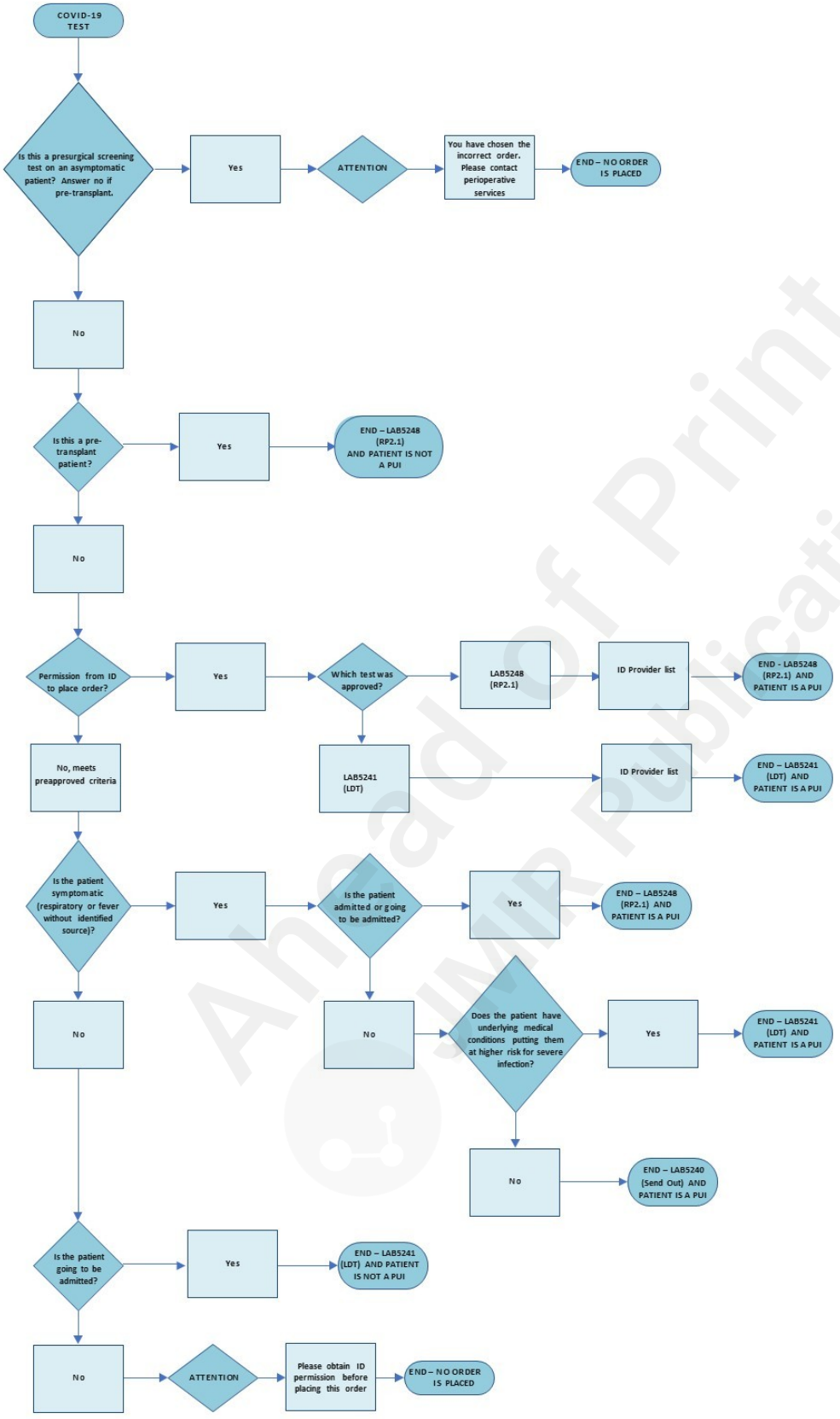
To optimize the use of resources such as negative pressure rooms and personal protective equipment (PPE), we developed a policy for aerosol-generating procedures (AGPs). The policy governed performance of AGPs—including any preceding SARS-CoV-2 testing and PPE requirements—in a systematic manner driven by the patient's symptoms, COVID-19 status if known, prevalence of infection in the community, and the classification of AGPs into two risk tiers. SARS-CoV-2 testing was initially required in advance for all patients undergoing scheduled surgery, and empiric use of PPE including N95 respirators was reserved for urgent or emergent cases when testing was not feasible. As community spread increased and access to rapid testing improved, the testing requirement was extended to any urgent surgical procedures for which sufficient time was available.

EHR Decision Tree for SARS-CoV-2 Test Order Placement

Given the scarcity of testing resources and growing demand early in the pandemic, formal criteria for SARS-CoV-2 testing were developed at our institution through consensus among physician and clinical laboratory leaders. Prior to the pandemic, our institution did not restrict the ordering of assays for non-COVID respiratory viruses nor collect data on the reasons for ordering such tests systematically. Developing an ordering system that would be intuitive for clinicians to use and that would capture data to guide prioritization of orders and subsequent revisions to indications for ordering were therefore important priorities. However, the criteria for ordering specific COVID-19 tests were complex and the metadata were frequently revised as new clinical scenarios were

incorporated and new testing options became available. Implementation of the detailed ordering criteria in the EHR posed a challenge that increased with the number of available testing options. More importantly, the growing list of test indications created a hard-to-navigate obstacle for providers who needed to place orders. To ease the burden of ordering the correct test from a long list of choices, we built a decision tree within the EHR to automate the selection process based on answers provided to a branching set of hierarchical questions. This decision tree (Figure 1) was first implemented on April 28, 2020, and subsequently updated and modified frequently during the early response to the pandemic.

Figure 1. EHR Decision Tree for Ordering SARS-CoV-2 Tests. Flow diagram showing the branching set of hierarchical questions resulting in capture of data for test prioritization and symptom status. Abbreviations: LDT, laboratory developed test; RP2.1, BioFire Respiratory Panel 2.1.



PUI Flagging in the EHR

In addition to linking clinical indications to the appropriate SARS-CoV-2 test, the ordering process required to set a flag in the EHR for any patient who met our institutional PUI criteria. The flag alerted healthcare personnel to the patient's PUI status and the need to use PPE beyond standard precautions, including N95 respirators or powered air purifying respirators (PAPRs) when caring for the patient.

Testing for an infectious disease usually suggests a clinical index of suspicion that in itself may justify flagging the patient in the EHR for the possibility of that infection. In the case of COVID-19, however, institutional policies required SARS-CoV-2 testing upon admission or before surgery for all patients even in the absence of symptoms or exposure, thereby rendering the presence of an ordered test functionally meaningless as an indicator of clinical suspicion. Although some of the patients may be asymptomatic carriers and thus could expose the workforce, the pre-test probability of infection in such patients was not expected to be above that of the general population. The universal usage of N95 respirators for all healthcare encounters during the pandemic was neither recommended nor feasible given limited supplies. Therefore, our institution decided that patients without compatible symptoms or recent exposure would not be designated as PUIs even when routine testing was required by institutional screening protocols. Consequently, in addition to guiding the selection of the correct SARS-CoV-2 test, the decision tree needed to assign the appropriate PUI status to each patient based on the indication for testing.

The introduction of additional testing modalities with decreased sensitivity compared to molecular testing of nasopharyngeal (NP) samples presented another challenge. Whereas positive results from these lower sensitivity assays were considered reliable, negative results were not and required confirmation with a more sensitive molecular test. Accordingly, the EHR rules for clearance of PUI flags were constructed to require a negative molecular test from an NP sample even if the flag had originally been triggered by an order for a less sensitive screening test.

A flagging system was also created for displaying SARS-CoV-2 test results that had recently been performed at outside facilities with interoperable EHRs. Such outside test results were either flagged as being reliable and approved by our system's laboratory as equivalent to internal testing (using the "Happy Together" EHR collaborative that includes Children's Health, Parkland Hospital, and UT Southwestern Medical Center) or otherwise flagged as not having established equivalence. Whether these patients were being seen in the Emergency Department or directly admitted to the wards, availability of this information allowed the bedside physician to avoid unnecessary SARS-CoV-2 testing and thereby minimized waste of limited testing resources.

EHR Tools and Maintenance of PPE Supply

Like many US healthcare institutions, we recognized early in the pandemic the potential for a shortfall in critical PPE supplies required for COVID-19 patient care, including N95 respirators. Providing appropriate protection to healthcare workers while minimizing PPE consumption made the accurate identification and flagging of PUIs essential. Our supply of N95 respirators reached a nadir in late March—with less than 14 days of stock on hand overall and less than 7 days supply for the scarcest respirator size—but subsequently recovered. Although multiple concurrent strategies—including UV reprocessing and enhanced scrutiny of N95 usage—contributed also to successful management of this shortfall, proper assignment of PUI status was a critical component in the struggle to reduce PPE use. Improvements in the supply of N95 respirators nationally have since reduced the acute importance of these considerations, but strategies developed during the COVID-19 pandemic to manage limited PPE supplies will be beneficial approaches to future resource challenges.

Results

SARS-CoV-2 Ordering Metrics

The frequencies with which orders for SARS-CoV-2 testing needed to be revised due to user

error or had to be repeated were used as measures for the impact of the CDS tools. The percentage of tests that were canceled and reordered due to errors in selecting the correct testing modality was 3.8% (23/608) prior to implementation and 1.0% (262/26,643) after implementation of CDS (Fisher's exact test, $P < .0001$). The percentages of patients who had multiple tests ordered during a 24-hour period were 0.8% (5/608) and 0.3% (76/26,643) prior and after implementation as of October 31, 2020, respectively (Fisher's exact test, $P = .035$).

SARS-CoV-2 Infection Frequency

If the information captured by the decision tree in assigning SARS-CoV-2 test modality and PUI status accurately reflected the risk of infection, it would be expected that the incidence of positive tests results would vary accordingly. Patients were classified as symptomatic or asymptomatic within the decision tree based on the presence or absence of fever without an identified source or respiratory symptoms. Consistent with expectations, the observed frequency of positive NP molecular assays for asymptomatic patients (3.4%, Table 2) was significantly lower ($P < .0001$, Fisher's exact test) than for symptomatic patients (10.9%). Likewise, the incidence of positive test results was higher among asymptomatic patients with history of exposure to an individual with COVID-19 (12.7%) than among asymptomatic patients without such exposure history (3.3%; Fisher's exact test, $P < .0001$).

Table 2. SARS-CoV-2 test volumes and results by ordering indication

Testing Indication Category[a]	**Testing Volume**[b]	**Number positive**[b] **(%)**
Asymptomatic patients[c]	24,170	826 (3.4)
Pre-procedural screening[d]	12,864	428 (3.3)
Admission screening	10,625	329 (3.1)
Screening before behavioral health placement	398	33 (8.3)
Admission screening with history of COVID-19 close contact	283	36 (12.7)
Symptomatic patients	13,074	1,421 (10.9)
Admission screening or hospitalized patients	5,573	433 (7.8)
Pre-procedural screening[d]	298	31 (10.4)
Outpatients with risk factors for severe illness	307	48 (15.6)
Lower respiratory tract disease without alternative explanation[e]	30	3 (10.0)

Symptomatic patient with history of COVID-19 close contact[e]	3	0 (0.0)
Symptomatic patient without other specified criteria	6863	906 (13.2)
Symptom status not specified	15,341	1,146 (7.5)
Pre-procedural screening[d]	6,796	177 (2.6)
Unrestricted send-out testing	5,330	791 (14.8)
Testing approved by Infectious Diseases	535	72 (13.5)
Patient screening after healthcare exposure	89	2 (2.2)
Unclassified testing	2591	104 (4.0)
Total testing	52,585	3,393 (6.5)

[a]The test indication categories listed above summarize a larger number of actual indications displayed in the EHR, which were dynamically modified over the course of the pandemic,

[b]Testing data cover the period from 3/13/2020 through 3/24/2021,

[c]Patients without fever and without respiratory symptoms were classified as asymptomatic,

[d]Includes testing before surgery and other qualifying AGPs,

[e]These criteria were used only briefly during early pandemic after which test eligibility was expanded to symptomatic patients without consideration of these factors.

Another group of asymptomatic patients for whom we observed a significantly increased incidence of positive SARS-CoV-2 test results included patients awaiting behavioral health placement (8.3%, compared to 3.3% for other asymptomatic patients without history of COVID-19 exposure, $P < .0001$). The reason for this increased positivity rate is unclear, but some of these patients likely had a history of prior infection and were referred to our facilities for repeated testing before placement to assess for viral clearance. Furthermore, the behavior patterns of these patients may have included decreased adherence to prevention measures such as mask wearing and social distancing, placing them at an increased infection risk.

Testing for symptomatic patients was initially targeted when resources were most limited toward those who 1) required hospitalization, 2) had comorbid conditions that increased the risk for developing serious illness, 3) had a history of COVID-19 exposure, or 4) had lower respiratory tract

infection without another explanation. As availability of test reagents improved, eligibility was expanded more broadly to symptomatic patients and several of these more specific indications were retired. However, the decision tree continued to identify hospitalized patients and those with risk factors for severe illness to prioritize such patients for rapid testing. All symptomatic patients were designated as PUIs even when the decision tree did not require more detailed information.

Symptom status was not captured for a subset of test orders (29.2%). Many of these tests were either assays sent out to off-site laboratories for non-hospitalized patients or collected as screening tests several days in advance of a scheduled procedure. In the first case, symptomatic patients were instructed to isolate at home pending the result of the test. In the second case, presurgical screening results were generally available by the time the patient returned for surgery. Empiric assignment of PUI status in the EHR at the time of testing was therefore not prioritized for these patients. Since September 2020, however, improvements in implementation resulted in consistently capturing symptom information for 80% or more of patients tested monthly.

To manage rare or unanticipated circumstances, our testing algorithm allowed for physicians in the Division of Infectious Diseases to authorize testing outside of the approved indications implemented in the EHR. Once off-site testing became unrestricted, this approval option was used primarily with requests for tests performed locally that offered a shorter turnaround time or clinical indications that favored a specific testing platform. This approval route was needed only for 1.0% of orders, indicating that the decision tree effectively managed the large majority of scenarios and prevented the approval activity from becoming an excessive burden on the physicians tasked with evaluating these nonstandard requests. The yield of positive results from such tests approved by Infectious Disease physicians was high (13.5%), as was the frequency of positive results among unrestricted send-out testing (14.8%). These high rates of positive results suggest that clinicians were applying appropriate judgement in selecting patients for testing under these ordering options.

Discussion

During the period following implementation of CDS for SARS-CoV-2 test ordering, we documented improvement in the number of cancelled and reordered tests as well as a decrease in the number of patients who had unnecessary duplicate testing. The goals of CPOE systems include submitting appropriate and efficient orders for patients [5]. It can be argued from our data that this was indeed accomplished using the Decision Tree for SARS-CoV-2 test ordering to help clinicians navigate the complex eligibility criteria.

However, implementation of CPOE and CDS has been found to provoke strong emotions in providers, with negative emotions being the most prevalent. In addition to contributing to the stressors that providers already face, poorly implemented CDS can fail if they are too cumbersome to be used as intended [18]. A successful CDS needs to provide clinicians with the 1) best available knowledge when needed with high adoption and effective use, and 2) continuous improvement of knowledge [19].

Evaluating the effective adoption of CDS can be difficult as providers always have the option of selecting criteria randomly in order to complete the ordering process. In evaluating the positivity rates for the patient groups defined by the decision tree algorithm, we found statistically significant differences as expected in rates of positivity for the categories of asymptomatic versus symptomatic and asymptomatic without a history of exposure versus asymptomatic with a history of exposure as defined by the decision support algorithm. These findings suggest that clinicians appropriately utilized the questions in the CDS to help triage the patient.

Limitations

Our study has several limitations. First, this was an observational study and not a randomized controlled trial. Therefore, other interventions and institutional changes could have explained the decrease in order error rates. Furthermore, the period prior to implementation of CDS

was relatively brief with comparatively lower volume of testing performed. In addition, the decision tree was continually modified over time with new indications such as behavioral health patients added relatively late in the pandemic. Some of the positivity rates seen in particular patient cohorts could have been influenced by fluctuation in the infection rate in the community.

Conclusions

Leveraging the electronic health record and implementation of the decision support algorithm decreased order entry errors—including the percentages of cancelled and reordered SARS-CoV-2 tests and of duplicate testing—and also appropriately flagged PUI status. Collectively, these interventions optimized reagent and PPE usage and protected healthcare workers. The data gathered through the decision tree could be used to predict differences in the likelihood of positive test results for the distinct categories of patients, suggesting that clinicians appropriately utilized the questions in the decision tree algorithm.

Conflict of Interest

Dr. Filkins is an unpaid advisory board member for Avsana Labs and has received grant funding for an investigator-initiated study from Biofire Diagnostics.

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Supplementary Files

Figures

EHR Decision Tree for Ordering SARS-CoV-2 Tests. Flow diagram showing the branching set of hierarchical questions resulting in capture of data for test prioritization and symptom status. Abbreviations: LDT, laboratory developed test; RP2.1, BioFire Respiratory Panel 2.1.