

Improving Critical Value Notification through Secure Text Messaging

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Abstract

Background: To improve communication between clinical providers and the laboratory, we recently implemented secure text messaging for our critical value notifications. This was done to communicate laboratory critical values (CV) to providers faster so changes to patient care could be done faster. Our previous method of communicating CV to providers was paging and relied on a call back to receive the critical value. **Methods:** We implemented delivery of CV through a secure texting application in which the CV was directly communicated to the provider on their smart phone device. **Results:** The mean pre-implementation turnaround time (TAT) was 11.3 minutes (median: 7 minutes, range: 0 - 210 minutes). The mean post- secure text messaging implementation TAT was 3.03 minutes (median: 0.89 minutes, range: < 1 - 95 minutes). When comparing pre- and post-implementation, there was a significant reduction in the TAT from using secure text messaging ($p < 0.001$). Of the 234 surveys sent out, 81 providers responded (35%). Of these responses, 85% reported that critical value notification by secure text messaging has increased their efficiency and 95% reported that critical value notification is more effective than a pager-phone-call based system. 83% of providers reported that they were able to provide better, faster care to their patients. **Conclusions:** Using secure text messaging (STM) to deliver critical values significantly reduces the CV TAT. Furthermore, providers noted they preferred to receive CV notifications through STM and reported that they were able to provide more effective care to their patients.

Keywords: Critical value turnaround time, critical values, laboratory, secure text messaging, smartphone technology

INTRODUCTION

Clinical communication and collaboration are an essential factor in the appropriate and timely management of patients across the care continuum. Unclear communication or lack of timely communication can cause delays in treatment and threaten the safety of patients as well as cause undo frustration for providers.^[1] Laboratory critical values (CVs) notification processes offer an opportunity for improvement in efficiency. The Joint Commission (TJC) defines a critical test/value as one “that requires immediate communication of results.”^[1] More specifically, TJC has defined a CV as a “test result that is significantly outside the normal range and may represent life-threatening values.”^[1] TJC requires that CV be reported in a timely manner and documentation as to whom received those results. The College of American Pathologists (CAP) checklist requires the percentage of CV results with documentation that the results have been reported to caregivers. The CAP COM.3000 checklist notes that the following must be

recorded: date of communication, time of communication, the responsible laboratory individual, the person notified (first name alone is insufficient), and the test results.^[2] Moreover, the CAP COM.30100 states that electronic transmission of CVs is acceptable. It also requires that laboratories confirm receipt of the result by the intended recipient; however, no read back is necessary.^[2] It is also noted in the CAP checklist that the evidence of compliance is via records of critical result notification. A summary of the CAP and TJC guidelines on CV notification is seen in Table 1.

Previous research has demonstrated that critical laboratory values contribute to necessary and immediate care management

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Table 1: Regulatory considerations for implementation of a CV system

Questions to Compare	Regulatory Considerations of a CV System	
	CAP	TJC
What to communicate?	1.) Patient Name 2.) Patient MRN 3.) Test Name 4.) Test Result 5.) Date of Result 6.) Time of Result	1.) Patient Name 2.) Patient MRN 3.) Test Name 4.) Test Result
How to Communicate?	Phone call or electronic	Telephone or verbal
Confirmation of result sent to Intended Recipient?	Yes, required confirmation of intended recipient (first and last name)	Yes, required confirmation of “whom” results were reported to
Readback required?	No, not required	Yes
Electronic transmission of result is acceptable?	Acceptable	Acceptable
Evidence of Compliance?	Records demonstrating the above and documentation of responsible laboratory personnel reporting result	Records demonstrating above
Guideline	1.) CAP COM.30000 2.) CAP COM.30100	1.) Standard International patient safety goal 2 (IPSG.2)

changes in approximately 98% of patients in surgical units and 91% in general medical units.^[3] This same study^[3] reported that as many as 40% of these laboratory CVs were unexpected patient findings. With so many laboratory test values necessitating immediate intervention, the historical method of identifying the responsible provider to convey the CV was fraught with delays. Once the correct provider was identified, the laboratory staff relied on a manual call back process to convey CVs, often delaying the time to intervention by hours.^[3] Often, the CV had to be relayed to a general floor staff member who could only act if protocols were in place, placing patients at risk for further delays in appropriate treatment. In large complex health systems, the increasing laboratory test volumes coupled with a manual call back process for CVs can cause significant delays and potential harm to patients. Since one of our strategic imperatives is to innovate ways to improve patient care, it was logical for our team to seek opportunity to improve this process.

In a landmark study looking at a median time interval to appropriate treatment, Kuperman *et al.* (1996) noted that computer technologies can be used to detect CVs and provide notification to the appropriate clinician, thus should be explored.^[4] We designed a prospective randomized controlled trial that examined CV response using automation. They used a proprietary system that detected a set of CVs and automatically notified the appropriate provider (s) through the hospital paging system. Their intervention group (intervention $n = 94$, control $n = 98$) had a 38% shorter median time interval ($P = 0.003$; 1.0 h vs. 1.6 h) until appropriate treatment was ordered. They concluded that an automatic alerting system reduced the time until appropriate management could be ordered and therefore delivered to patients with CVs. Their study was the first to demonstrate that automated technology can be utilized to deliver CVs in a timely and reliable fashion.

Another automated system for delivering CVs was developed at Brigham and Women’s Hospital utilizing their existing

paging system. When a set of CVs was detected, the appropriate provider was paged to “8888” which indicated that they needed to log into the computer system and view the CV alert on one of their patients.^[4] If the provider was not in proximity to a workstation, they could call “8888” and be connected to a telecommunications office where the operator would then relay the alert notification. If 15 min passed without acknowledgment from the appropriate provider, the workstations on the patient’s floor would display a red alert indicating the need for action.^[4] Over a 6-month period, there were 1945 CV alerts, of which >70% were acknowledged within 15 min and resulted in immediate orders by providers 40% of the time. Only 6% (122) of the alerts ended in delays due to the paging of the wrong provider or no provider. This was an impressive accomplishment for the clinical laboratory and patient care. A study by Saw *et al.* also reported automating CVs via short message service.^[5] Their system sent non-HIPAA compliant short text messages to providers to deliver the information. In return, the provider would respond with one of three numeric options. Parl *et al.* also demonstrated CV notification automation using an electronic system. Their system required a technologist to enter the test result into the LIS, and then, the automated system would evaluate the value based on pre-programmed logic.^[6] If the criteria were met, a text-pager notification was sent to the provider. Once received, the provider would dial an acknowledgment code. The provider also has the ability to reject the notification. These previous studies demonstrate that CV notification and responses can be automated. We aimed to improve the previously reported methodology of CV automation with a HIPAA-compliant methodology and track additional parameters not tracked by Saw *et al.* and Parl *et al.* To date, there are other studies demonstrating such impressive results with CV turnaround time (TAT), and it was our desire to design a system that would allow us to improve upon these results no matter the location of the ordering provider.

Previous state in our laboratory

Historically, our laboratory system utilized a centralized customer service center that would send out pager messages to notify a provider that a CV was waiting for acknowledgment and waited for a telephone call to provide the CV information. The list of CVs for Geisinger is seen in Supplemental Table 1. This standard procedure had a target goal of provider notification within 60 min. For inpatients at our largest academic campus, the procedure required notification to the covering physician from the Client Service Representative (CSR) using two unique patient identifiers prior to giving the CV minutes. The covering physician would read back the result (with two patient identifiers) to the CSR to confirm. The read back was recorded in the laboratory information system (LIS) and included the following: clinician’s first and last name, date, time, responsible laboratory person communicating the CV, and other pertinent laboratory results. If two unsuccessful attempts were made to contact the ordering physician, the CV would be communicated to an alternative physician that could act upon the result. If contacting the alternative physician was unsuccessful after two attempts, the on-call clinical pathologist would receive the result and decide how to proceed. For outpatients, CV notification is made within 60 min by a CSR via pager message to call them back and receive the CV. The result is then released to the physician or designee upon call back. If the outpatient site was closed (i.e., clinic), the CSR would call the appropriate answering service to contact the ordering or on-call physician to whom the critical result could be given. If this was unsuccessful, the

CSR contacted the on-call clinical pathologist who was responsible for determining how to best relay the CV in a timely manner. This method of CV delivery was manual and time consuming for all involved.

The manual nature of our current processes combined with our knowledge of research in this area and the information system capabilities led us to explore automated ways to decrease TAT and improve reliability. The purpose of this article is to describe the automation process developed to improve our performance and report results. The secondary objectives for this work were to identify:

1. Provider satisfaction with secure text messaging (STM) for laboratory CV results in delivery
2. Provider perspective of efficiency created from using STM for two-way communication in this process.

METHODS

New automation and process development

In an effort to reduce CV TAT, we implemented a HIPAA-compliant STM system to deliver CV notifications following a newly established notification escalation protocol [Figure 1]. This project was initiated and envisioned by our doctoral director and requests from providers to have direct provider notification of CVs, improved provider efficiency, and improved laboratory efficiency. Once the vision was set, system requirements were developed by involving key stakeholders, the laboratory client services department, and doctoral directors who advocated for clinical workflows. This system was developed using an agile, team-based approach.

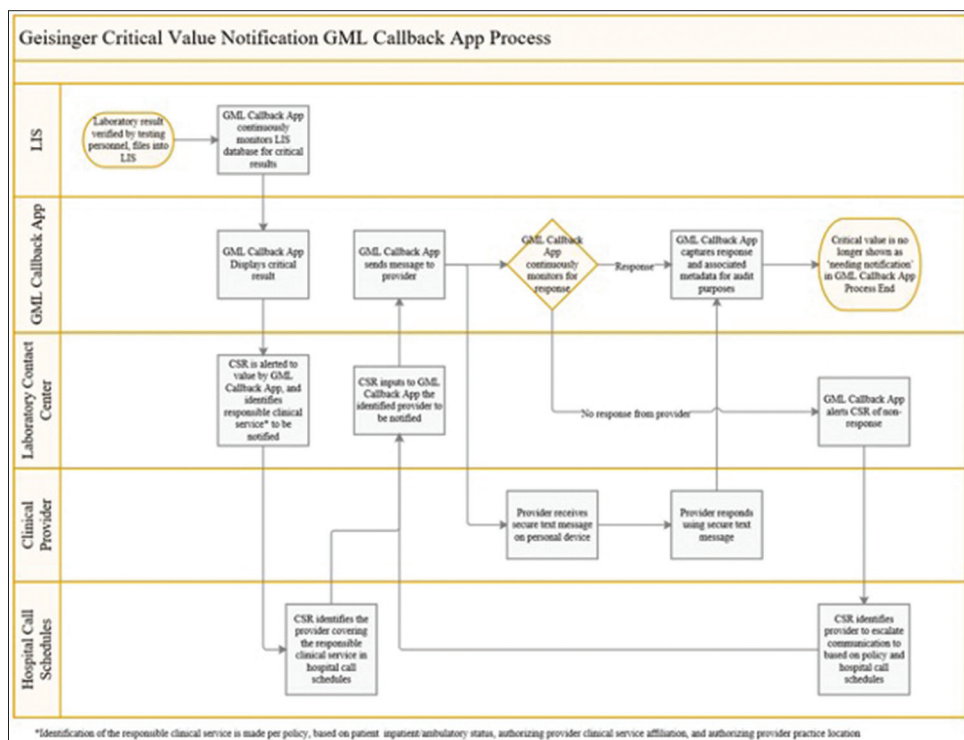


Figure 1: Geisinger new critical value process using secure text messaging

Short development “sprints” occurred, focusing on a small number of features. Initial development centered on obtaining the CVs to be called from the LIS. Once this had been tested, development concentrated on passing information to and from the application programming interface for our STM system. An audit trail/lookup feature was developed at the end to allow for reporting and CAP compliance. Testing happened throughout the development and again at the conclusion of development by the end users. This provided both hands-on experience with the system as well as an in-depth knowledge of the system for troubleshooting purposes. A summary of key considerations to replicate a critical values system is presented in Table 2. Every provider and employee in our system uses the same secure texting application, TigerConnect to quickly connect and communicate with colleagues. Furthermore, our health-care system has eliminated physical pagers and turned STM into a system where provider cell phones can be “pagers” capable of two-way communication.

To utilize our newly integrated system appropriately, we established a set of rules in our LIS for laboratory tests and corresponding CV result triggers. Once the order was written, specimen collected and test completed, our integrated system would recognize laboratory results that met threshold criteria and generate a custom CV notification. We designed a proprietary desktop application to aid in tracking CV notifications for the CSRs. The desktop application, “GML Callback”, allowed our CSRs to monitor the progress of the CV notifications. The GML callback application monitors the LIS database and when a CV is filed, then the application displays the CV. The GML callback application consists of two main windows: a working list and historical look back record. The working list is the screen where the CSR will be notified of the CV. The working list window highlights the patient’s location,

name, medical record number (MRN), accession number, test codes, result date and time, message status, provider’s name, and providers record of acknowledgment [Figure 2], allowing our CSR team to easily track the status of each CV notification. The GML callback application routes the CV to the responsible provider when the application queries pre-programmed schedules located in our electronic phonebook/on-call list. Once the appropriate provider is identified, the GML callback application triggers a STM to be sent to the provider. The CSR is alerted that the STM has been sent. If a patient has more than one CV, they will receive a single text message with all the CVs in the notification as to not cause alert fatigue and multiple text messages [Supplemental Figure 1]. Based on our criteria, if the provider reads the STM and replies with acknowledgment of the CV, the GML callback application will receive this notification. The metadata and response associated with this will then be captured and stored for audit purposes and the alert will be resolved. While on duty, the provider is unable to opt out of CV STM notifications and thus must either acknowledge or they will continue to get STM notifications.

If no response is obtained within our set timeframe, the CSR will be alerted. From there, the CSR and GML callback application will query the phonebook and schedule for the next provider on the same service and will initiate a STM to that provider [Figure 1]. If no response, then the on-call pathologist will be sent the STM through the same process. The intended goal for this level of application integration was to create a synergistic amalgam between our EMR, LIS, desktop application, and TigerConnect STM platform to deliver CVs in a timely manner to the right provider for appropriate intervention.

In addition to CAP and TJC regulations for demonstrating CV notification compliance, we wanted to also be able to rapidly

Contact	Type	Patient Name	MRN	Acc	Order Codes	Test Codes	Result Date/Time	TigerText Status	erTextRe:	Recipient
MSICU 5 IP GMC	IP				CBCD, LBG0	BUN, HGB	2/25/2019 7:37 AM	READ 2/25/2019 8:21:27 AM	Y	@getsinger.edu
BUSH PAV 8 x16579	IP				CBCD	HGB, PLT, WBC	2/25/2019 8:07 AM	SENT 2/25/2019 8:21:45 AM		@getsinger.edu
INTRAOFF GMC	IP				ANAR, ZZ00, ZZ01	CAZ, CP, CULT, FEP, GM, GS, LVX, MEM, MTYP, ORG, PIPTAZ, RPT, SDES, SREQ, TOB	2/25/2019 8:14 AM			
MSICU 5 IP GMC	IP				CBCD	HGB	2/25/2019 8:14 AM	READ 2/25/2019 8:21:02 AM	Y	@getsinger.edu
SCU3	IP				CBCD	HGB	2/25/2019 8:20 AM			

Figure 2: An example of our proprietary software (GML Callback) where secure text messaging critical value notifications are sent to providers

Search Filter	Contact	Type	Patient Name	MRN	Acc	Order Codes	Result Date/Time	TigerText Status	Recipient	Closed By
Contact	BPST IP GAC	IP	TESTING, PATIENT	999999	T494810	BLC	10/9/2018 10:46 AM			mrschuler
MRN	BPST IP GAC	IP	TESTING, PATIENT	999999	T494136	ROUT	10/9/2018 10:08 AM			mrschuler
Accession Number	BPST IP GAC	IP	TESTING, PATIENT	999999	T558802	ACET	11/6/2018 1:55 PM			VCMARTINI
Recipient	ADULT ICU X16551	IP	TESTING, PATIENT	999999	W577783	ROUT	11/7/2018 11:26 AM			mrschuler
Result Date	ADULT ICU X16551	IP	TESTING, PATIENT	999999	W640674	COMPR	12/5/2018 2:34 PM			gshaughan1
Use Date Range	ADULT ICU X16551	IP	TESTING, PATIENT	999999	F361656	BUN, CA, CAL, CL, CO2, CREATR, GLU, HGB, HSTNT, K, LAC, MG, NA, PLT, WBC	12/14/2018 10:38 AM			ELSCHEIB
Closed Date	ADULT ICU X16551	IP	TESTING, PATIENT	999999	F395187	APTT, HGB, PLT, PTINR, WBC	9/21/2018 12:19 PM			mrschuler
Use Date Range	ADULT ICU X16551	IP	TESTING, PATIENT	999999	T20721	BUN, CA, GLU, HGB, K, MG, PLT	1/29/2019 11:06 AM			kiglowatski
Search	ADULT ICU X16551	IP	TESTING, PATIENT	999999	T20721	BUN, CA, GLU, HEPU, HGB, K, MG, PLT	1/29/2019 11:06 AM			kiglowatski
	EMERGENCY MEDICINE GBH	IP	TEST, PATIENT	999999	W49222	BLC	1/30/2019 7:29 AM			dmurbanav
	EMERGENCY MEDICINE GBH	IP	TEST, PATIENT	999999	W49222	BLC, OBPCPK	1/30/2019 7:40 AM			dmurbanav
	EMERGENCY MEDICINE GBH	IP	TEST, PATIENT	999999	W49237	BLC, OBPCPK	1/30/2019 7:58 AM			dmurbanav
	EMERGENCY MEDICINE GBH	IP	TEST, PATIENT	999999	W49246	BLC, OBPCPK	1/30/2019 8:26 AM			dmurbanav
	BPST IP GAC	IP	TESTING, PATIENT	999999	T484809	RESP	10/9/2018 10:37 AM			jmserafin
	BPST IP GAC	IP	TESTING, PATIENT	999999	F395042	ACET, BUN, CA, CAL, CREATR, DNG, HSTNT, OSMO, PHEN, PHNY, THEO	9/21/2018 12:18 PM			jmserafin
	DUMMY LOCATION FOR TESTING	IP	TESTING, PATIENT	999999	H610048	BGPA	11/29/2018 9:43 PM			jmserafin
	BPST IP GAC	IP	TESTING, PATIENT	999999	T510271	K	10/16/2018 10:34 AM	READ 2/18/2019 10:28:29 AM	f12846c-a7ba-4066-b081-bb40795af1b	jmserafin
	ADULT ICU X16551	IP	TESTING, PATIENT	999999	T620068	CBDO	12/14/2018 1:42 PM	READ 2/15/2019 9:32:02 AM		jmserafin
	ADULT ICU X16551	IP	TESTING, PATIENT	999999	T20721	GLU, HGB, K, MG, PLT	1/29/2019 11:06 AM	READ 2/15/2019 9:33:50 AM		jmserafin

Figure 3: Demonstration of critical value historical search function by patient medical record number

Recipient	Date/Time Sent	Message	Delivered Date/Time	Read Date/Time	Replied Date/Time	Reply
ipginsinger.edu	2/15/2019 9:33 AM	There is a critical GLUCOSE, collected 1/29/2019 6:05:00 AM, with a result of 666 There is a critical HGB, collected 1/29/2019 6:05:00 AM, with a result of 4.5 There is a critical MAGNESIUM, collected 1/29/2019 6:05:00 AM, with a result of 0.5 There is a critical PLATELET COUNT, collected 1/29/2019 6:05:00 AM, with a result of 6 There is a critical POTASSIUM, collected 1/29/2019 6:05:00 AM, with a result of 2.1 for patient TESTING, PATIENT, MRN 999999. Please reply Y to acknowledge this critical result or reply with a provider to communicate this message to: Call 870-271-5075 or 856-271-5075 if you have any questions or concerns regarding this value.	2/15/2019 9:33 AM	2/15/2019 9:33 AM	2/15/2019 9:33 AM	Y

Order	Test	QA	Result	Normal	Units	Collection Date/Time	Order Comment
GLUCOSE	GLUCOSE	-	666	70-120	mg/dL	1/29/2019 6:05 AM	
HGB	HGB	-	4.5	12.0-16.3	g/dL	1/29/2019 6:05 AM	
MAGNESIUM	MAGNESIUM	-	0.5	1.5-2.6	mg/dL	1/29/2019 6:05 AM	
PLATELET COUNT	PLATELET COUNT	-	6	140-400	KuL	1/29/2019 6:05 AM	
POTASSIUM	POTASSIUM	-	2.1	3.5-5.1	mmol/L	1/29/2019 6:05 AM	

Figure 4: Historical view of an individual critical value record that shows the critical value message, response, and time parameters

query any previous CV notifications by searching a MRN, accession number, recipient name, or patient name [Figure 3]. This also allows us to search using a date and time range. In addition, we can see a historical view of the patient’s CV record that shows each time parameter and response [Figure 4]. This application is versatile and allows for easy auditing of CV notifications. All GML callback activities can be compiled into a report for review at any time. This feature allows for quality assurance inspection as well as for regulatory compliance for CAP and TJC. Our proprietary GML callback application allows us to export data for the examination of TAT and other trends, which is convenient to use, streamlines our TAT data analysis, and provides insight into further improvement opportunities. All GML callback activities can be compiled into a report for review at any time for these purposes.

Plan for data analysis

A mixed-method approach was designed to evaluate primary and secondary objectives for this study. After institutional review board approval, de-identified data were used to compare TAT’s pre–post new automation process using an independent samples *t*-test and nonparametric test (Kolmogorov–Smirnov). The statistical results of each were the same. To evaluate provider satisfaction and perception of efficiency, a survey instrument was developed using a Likert scale. Based on Rogers (2003) Diffusion of Innovation, a 3-month time period was chosen to evaluate providers’ perceptions with the survey.^[7] Since the providers utilized the STM prior to the process change and were comfortable in using this technology, it was felt that the timeframe was appropriate to evaluate the change of practice.

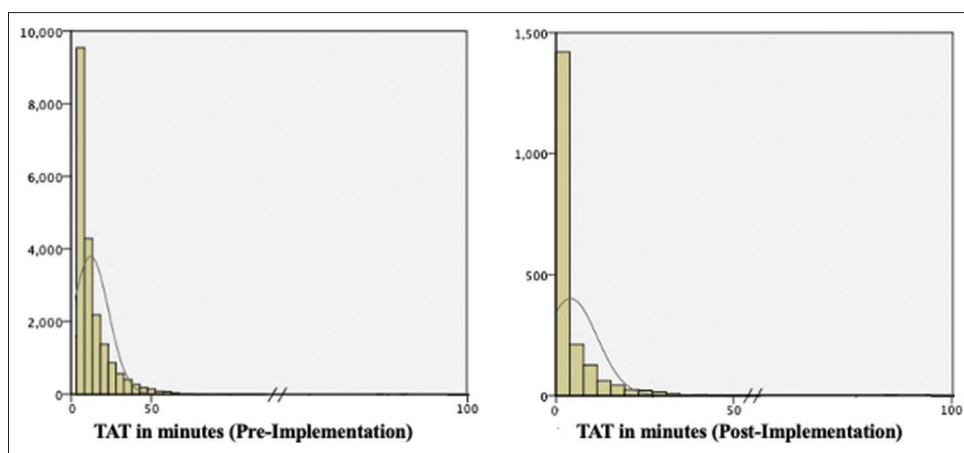


Figure 5: Histogram of critical value pre- and post-implementation

After 3 months with the new process, providers who received notifications were asked to complete an anonymous electronic survey. This survey focused on comparing perceptions of their experience receiving CVs through STM as compared to the historical method. Using a 5-point Likert scale of strongly disagree, disagree, undecided, agree, and strongly agree, providers were asked to rate the following six prompts:

1. I feel comfortable receiving CVs through STM
2. CV notification through STM has increased my efficiency
3. I feel that receiving CV notifications through STM is more effective than receiving a phone call
4. I prefer to receive a phone call alerting me to a CV than receiving it through a STM
5. I feel I am able to provide better and faster care to patients by receiving CVs through STM
6. I receive CVs through STM and frequently change patient management using our EMR application on my smart device.

RESULTS

The de-identified data for CV notification time frames were collected from the LIS and secure texting application using SQL queries. Prior to secure text notification, an 8-month total of 21,711 CV notifications were collected and after STM implementation, and 3-months data totaling 1941 CV notifications were collected for comparison [Figure 5]. Of these 1941 CVs, only 30 (30/1941, 1.5%) required escalation to the on-call pathologist. Time points collected included result available, result notification sent, result delivered, result read by the provider, and provider response. Our data demonstrated that the average CV result to delivery time was 35.30 s. The CV result to read time was approximately 1 min and 33 s. The average time of result to provider reply was 1 min and 36 s. We then compared the result to deliver and result to read TAT, which there was a significant statistical difference ($P = 0.032$). When comparing the result to read and read to reply, there was no statistical difference ($P = 0.138$). The mean TAT pre-STM implementation was 11.3 min (median: 7 min, range: 0–210 min). The mean postsecure texting implementation TAT

was 3.03 min (median: 0.89 min, range: <1–95 min). There was a statistically significant reduction by 8 min in TAT using STM ($P < 0.001$).

The results of our survey are presented in Table 3. The response rate for our survey was 35%, of which 81 providers responded out of a possible 234. Of our surveyed providers, 85% (69/81) reported that CV notification through STM has increased their efficiency. The survey also demonstrated that 92.5% (74/80) of providers felt that receiving CV notifications through STM was more effective than receiving a phone call. The majority of these providers (92.5%, 74/80) did not prefer to receive telephone notification after moving to STM for CV results

Our survey revealed that even though providers reported that CV notification is more efficient and allows them to intervene more timely on their patients' behalf, only 25% of providers reported frequently using the EMR application on a smart device (phone or tablet) to change patient management after CV notification.

DISCUSSION

This article adds to the literature on the use of STM to better manage patient care in today's complex health-care landscape. Our approach to the use of technology to manage CV notifications with the creation of the GML callback application using STM to deliver CVs has demonstrated that it is an effective and reliable method of delivery. Our results expand on previous literature by Kuperman (1996) with the documentation of project development and validation of significance.

Our implementation is different than Parl *et al.* and their implementation, as our technologists do not have to enter any test result into the LIS. Our results are automatically populated into the LIS from the middleware. We also do not require a provider to acknowledge the CV via touch-tone phone interaction. Instead, our providers just simply reply to the text message. Our system knows who is responding to the CV based on the user's account. There is no need for the

Table 2: Considerations to replicate a CV system using STM

Considerations to Replicate CV System			
Laboratory & Staff	Hospital & Hospital Users	Technology & IT Staff	Regulatory
1.) Identify key stakeholders	1.) Identify key stakeholders	1.) Identify key stakeholders	1.) Examine hospital policies
2.) Determine budget and perform cost analysis	2.) Revise departmental CV as necessary	2.) Review key computer systems and backup/downtime policies and procedures	2.) Examine CAP CV guidelines
3.) Examine current CV and revise if necessary	3.) Revise hospital policies for cellular devices	3.) Review access policies	3.) Ensure compliance of CAP guidelines
4.) Review and update CV notification practices and policies	4.) Budget planning for each service line	4.) Update phonebook and e-mail system	4.) Perform audits to ensure continued compliance
5.) Review and revise for infrastructure failures (power and internet outages, cell service disruption, etc.)	5.) Ensure all end users are compliant	5.) Review budget and financial planning	
6.) Set goals and target dates of completion	6.) Review and/or update policies for appropriate use of cellular devices	6.) Evaluation of STM systems	
7.) Work with IT and informatics teams on system build	7.) Review and/or update policies for access and termination of access	7.) Coordinate with key stakeholders with demo of STM systems	
8.) Plan and educate laboratory staff	8.) Create phonebook of users (if none exists)	8.) Select STM system	
9.) Plan and education for end users	9.) Provide feedback of program post go-live	9.) Develop/create interfaces between LIS, STM system, and create callback application	
10.) Application test prior to go-live		10.) System test prior to go-live	
11.) Post go-live analysis		11.) Fix bugs/issues, and retest	
12.) Troubleshoot as necessary		12.) Implement program with coordination of lab and end-users	
		13.) Post go-live analysis	
		14.) Troubleshoot as necessary	

Table 3: The results of the provider satisfaction survey

Survey Questions	Strongly disagree	Disagree	Undecided	Agree	Strongly agree	n
1.) I feel comfortable receiving Critical Values through STM.	2 (2.5%)	0	2 (2.5%)	19 (24%)	58 (58%)	79
2.) Critical Value notification through STM has increased my efficiency.	3 (2.5%)	1 (1.25%)	9 (11.25%)	21 (26.25%)	47 (58.75%)	80
3.) I feel that receiving critical value notifications through STM is more effective than receiving a phone call.	1 (1.25%)	4 (5%)	11 (1.25%)	23 (28.75%)	51 (63.75%)	80
4.) I prefer to receive a phone call alerting me to a critical value than receiving it through a STM.	44 (55%)	30 (37.5%)	3 (3.75%)	2 (2.5%)	1 (1.25%)	80
5.) I feel I am able to provide better and faster care to patients by receiving critical values through STM.	2 (2.47%)	1 (1.23%)	10 (12.35%)	28 (34.57%)	40 (49.38%)	81
6.) I receive critical values through STM and frequently change patient management using our EMR application on my smart device.	16 (19.75%)	29 (35.80%)	16 (19.75%)	11 (13.58%)	9 (11.11%)	81

provider to add a special identifier. Our system also does not require a telephone operator to record the acknowledgment that is done automatically when the response is received. Parl *et al.* also allow the provider to reject the CV.^[6] We do not allow our providers to reject a CV STM. They also reported that in a small number of cases, a telephone operator had to contact the nurse, who was then responsible for contacting the provider.^[6] We do not add the burden to nursing staff to track down a provider, and it is automatically escalated. In the implementation by Saw *et al.*, they relied on providers answering back a numerical response to acknowledge.^[5] Furthermore, they also were not able to capture when the message was delivered and read by providers.^[5] Our implementation added this functionality so we could examine these data. TigerConnect has allowed for us to better understand how fast providers read and acknowledge their patient's CVs. Previous implementations were successful,

and we were able to add additional functionality that has not been previously reported. Our implementation also follows the CAP checklist [Table 3] and provides the ability to confirm receipt of the CV result via TigerConnect.

Interestingly, although providers preferred the use of STM to receive CV notifications, the majority of them did not frequently use the smartphone EMR application to change management of patient care. This may be attributed to the readily accessible desktop workstations inside and outside patient rooms. Further studies are needed to explore the use of differing applications by health-care providers on the smartphone versus desktop.

One of the issues with measuring success for this project is the lack of transparency in being able to determine the impact on patient care and implications for practice. Clinically,

providers use more than laboratory CVs to manage patient care and have the opportunity to manage care at any point along the continuum, making it difficult to operationalize an endpoint for measurement. Furthermore, we hypothesized that in most cases, patient management may have already changed prior to CV notification, as providers may have anticipated laboratory result abnormalities. This problem was also identified by Kuperman *et al.* (1996), and to date, there has been no straightforward, quantifiable way to track changes in patient management, and subsequently, no straightforward ways to determine if patient outcomes are improved with faster TAT.^[4] Further advancement is needed to accomplish this goal. Our pre- and postimplementation TAT differed by approximately 8 min, which is statistically significant, but the clinical significance is not well defined. We are unable to identify if this reduction in TAT contributes to improved patient care and outcomes. It is also not clear whether the difference in the result to delivery and result to read TAT is clinically significant even though it is statistically significant. In future, we hope to have the ability to operationalize patient outcomes and quantifiably measure impact.

CONCLUSIONS

Our results demonstrate that the implementation of STM to deliver CVs is efficient and reliable and has a significant impact on TATs. Our results are consistent with prior studies that employed technology to automate the delivery of laboratory data. The reduction in TAT using STM allowed providers the option to change the management of patient care faster and was well received by providers. Our proprietary application has also allowed us to transform health care for our patients and

our providers by freeing them from calls to the laboratory to get their information verbally. We also were able to automate CVs in a CAP compliant method. This study demonstrates the powerful positive impact the clinical laboratory has on patient care when innovative solutions are employed to help improve our ability to provide safe, high-quality care.

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Nil.

Conflicts of interest

There are no conflicts of interest.

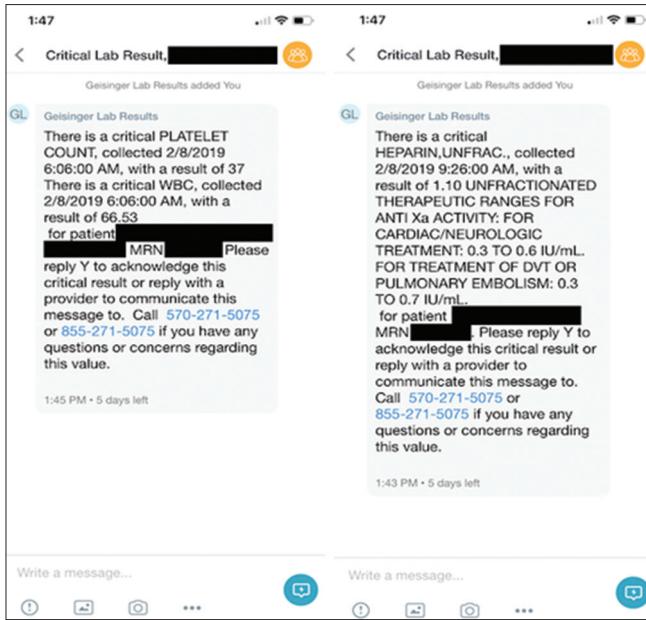
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Supplement Table 1: List of critical values for Geisinger

Chemistry critical values					
Test Name	Lower limit	Upper limit	Test Name	Lower limit	Upper limit
Acetaminophen		>150 ug/mL	pO ₂ (Arterial)	≤50 mmHg	
Ammonia		>80 umol/L	Potassium	<2.5 mmol/L	>6 mmol/L
Total bilirubin (<1 year old)		>16 mg/dL	Salicylate		>40 mg/dL
BUN		>100 mg/dL	Sodium	<120 mmol/L	>155 mmol/dL
Caffeine		>50 ug/mL	Tacrolimus (FK506)		≥15 ng/mL
Calcium ionized	<0.76 mmol/L	>1.59 mmol/L	Theophylline		>21 ug/mL
Carbamazepine		>15 ug/mL	Tobramycin (peak/random)		>12 ug/mL
CO ₂ (serum/plasma)	<12 mmol/L	>40 mmol/L	Tobramycin (trough)		>4 ug/mL
Carboxyhemoglobin		>9%	Troponin T		>100 ng/mL
Chloride	<70 mmol/L	>130 mmol/L	Valproic acid		>121 ug/mL
CK-MB		≥9 ng/mL	Vancomycin (peak/random)		>50 ug/mL
Creatinine		>10 mg/dL	Vancomycin (trough)		>25 ug/mL
Cycloproprine		>800 ng/mL	Coagulation		
Digoxin		≥2.5 ng/mL	INR		>4.99
Gentamicin in Peak		>12 ug/mL	Activated partial thromboplastin time		>120 seconds
Gentamicin in Random		>12 ug/mL	Fibrinogen	<60 mg/dL	
Gentamicin in Trough		>4 ug/mL	Heparin level (unfractionated)		>0.99 IU/mL
Glucose (includes tolerance)	<45 mg/dL	>200 mg/dL	Tobramycin (peak/random)		>12 ug/mL
Glucose (CSF)	<40 mg/dL	>200 mg/dL	Tobramycin (trough)		>4 ug/mL
Lactate		>4 mmol/dL	Troponin T		>100 ng/mL
Lead		≥70 ug/dL	Valproic acid		>121 ug/mL
Lithium		>1.5 mmol/L	Vancomycin (peak/random)		>50 ug/mL
Magnesium	<0.7 mg/dL	>6 mg/dL	Vancomycin (trough)		>25 ug/mL
pH (whole blood)	<7.2	>7.6	Coagulation		
Phenobarbital		>50 ug/mL	INR		>4.99
Phenytoin		>30 ug/mL	Activated Partial Thromboplastin Time		>120 seconds
Phenytoin (unbound)		≥3.0 ug/mL	Fibrinogen	<60 mg/dL	
pCO ₂ (arterial and capillary)		>55 mmHg	Heparin level (unfractionated)		>0.99 IU/mL
Hematology critical values					
Test Name	Lower limit	Upper limit	Test Name	Lower limit	Upper limit
Hematocrit (≥30 days old)		>66 g/dL	Hemoglobin (> 30 days old)	≤7 g/dL	≥20.0 g/dL
Hemoglobin (0-6 days old)	≤7 g/dL	>22.5 g/dL	Platelet Count	≤50 K/uL	≥1 Million K/uL
Hemoglobin (7--3 days old)	≤7 g/dL	>21.5 g/dL	White Blood Cell	≤1 K/uL	≥40 K/uL
Hemoglobin (14-30 days old)	≤7 g/dL	>20.5 g/dL			
Immunopathology/serology critical values					
Test Name	Lower limit	Upper limit			
Legionella antigen		Positive			
Urine critical values					
Test Name	Lower limit	Upper limit	Test Name	Lower limit	Upper limit
Osmolality (Serum)	<250 mOsm/kg	>325 mOsm/kg	Ketones, Urine (<5 years old)		5 mg/dL (Trace)
Ketones, Urine (>5 years old)		>80 mg/dL			

INR: Internal Normalized Ratio, BUN: Blood urea nitrogen, CK-MB: Creatine kinase myocardial band, CSF: Cerebrospinal fluid



Supplemental Figure 1: An example of the provider view of the critical value notification in their secure text messaging. Application on their smart phone