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The Effectiveness of Laboratory Interventions on TAT

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ABSTRACT

Objective: To find ways that the laboratory department can assist in minimizing the TAT outliers in the specimen collection and transport and sustain proper specimen collection techniques by non-laboratory health care workers.

Methodology: This study follows up on other researchers who stated that the laboratory does not spend enough time to resolve the common causes of specimen delivery delays by non-laboratory health care workers (HCW) in the pre-analytical phase. The study utilizes a pretest-and-posttest design to gather statistical data on TAT from specimen collection to receive and from arrival to disposition of selected patients during the intervention period and one year before and after the intervention. The lab intervention involved a call directly to the specimen collector when the laboratory did not receive the specimens after 21 minutes of collection.

Results: The results suggested that the laboratory interventions during the four-month field experiment raised enough awareness on non-laboratory HCWs to submit collected samples to the lab promptly that improved the average TAT from specimen collection to receipt in the lab and from patient arrival to disposition.

Conclusions: The presence of statistically significant improvement in average TAT from specimen collection to receive in the lab and from patient arrival to disposition suggested that maximizing the potential of technological devices and inter-departmental collaboration produce a positive patient outcome.

Keywords: Turnaround Time; Laboratory Testing Workflow; Preanalytical Phase; Epic Rover; Vocera Phones

Abbreviations: HCW: Health Care Workers; ED: Emergency Department; CDC: Centers for Disease Control and Prevention; TAT: Turnaround Time; CLTs: Clinical Laboratory Technologists; LOS: Length of Stay; IOM: Institute of Medicine; MSQ: Mount Sinai Queens; PTS: Pneumatic Tube System; CPA: Central Processing Area; HIS: Hospital Information System; MANOVA: Multivariate Analysis of Variance

Introduction

The emergency department (ED) provides clinical services to anyone who needs immediate care regardless of the ability to pay. EDs around the United States are increasingly serving as the shelter for medically underserved patients and are responsible for the sharp increase of visits from 1997 to 2007 (Tang, et al. [1]). The increased visits brought ED overcrowding and long wait times that became major concerns affecting the throughput nationwide. The Centers for Disease Control and Prevention (CDC) reported that the U.S. had 139.0 million ED visits in 2017, representing 43.3 visits per 100 persons [2]. U.S. hospitals need to continually adjust to the challenges at the usual patient entry point, which is the ED and the supporting ancillary departments. Most laboratories support the ED by timely reporting of laboratory results and monitoring the turnaround time (TAT) from the time the laboratory received the specimens to the time the Clinical Laboratory Technologists (CLTs) posted the results in HIS. The clinical and anatomic departments of laboratory medicine are major contributors to the diagnosis and treatment of patients. Clinical Laboratory News reported in 2004 statements from Forsman of MAYO Clinic that the laboratory represents only 5% of healthcare costs, yet it contributes to between 60 to 70% of all critical decisions (Hallworth [3]). There are three stages of the laboratory testing, namely:

a) Pre-analytical,

b) Analytical, and

c) Post-analytical

The pre-analytical phase involves all aspects of specimen collection, specimen labeling, test order entry, and delivery to the testing station before laboratory testing can take place (Dasgupta [4]). Many research findings indicated that the pre-analytical phase of the lab testing workflow has the highest rate of errors, resulting in longer TAT of the specimen workflow (Baer, et al. [5-15]), which in turn may prolong the ED length of stay (LOS) (Blick [16-21]). The Institute of Medicine (IOM) has recommended, through three reports, the nation's widespread use of health information system (HIS) or device to improve patient safety and reduce medical errors (Aspden [22, 23]). Yet, there has been little effort to prevent simple pre-analytical errors from recurring. The ED of Mount Sinai Queens (MSQ), New York, completed the major construction of a new ED in 2016, further raising the importance of efficiency at ED and other hospital services. Clinical and anatomic laboratories of the pathology department at MSQ are some of several ancillary services that support the ED to reduce ED LOS and eventually increase throughput.

A recent study observed a positive correlation between the laboratory TAT and ED LOS and based on the calculations from the efficiency model wherein 5, 10, and 15-minute TAT reduction can potentially admit an annual total of 127, 256, and 386 additional patients, respectively (Kaushik [19]). Unfortunately, laboratory data on specimen TAT commensurate when the specimens arrive in the lab. TAT on specimens between collection to delivery to the lab is not a standard laboratory metric because the procurement process happens in a department outside the laboratory's jurisdiction. Both the ED and the laboratory conduct thorough investigations on any delays between specimen collection at the ED to specimen delivery to the laboratory. Even though most cases were identified as the common causes of delays such as distracted nurses who left specimens in a pocket, collectors forgot to send to activate the pneumatic tube system (PTS), and distracted lab clerks who incorrectly prioritized the influx of specimens, got reconciled, the damage has already been done. Delays of specimen submission in this pre-analytical phase prompted the conduction of this field experiment that allowed the laboratory personnel to intervene when the ED specimens took an unusually long time to arrive at the laboratory. This study›s focus was the collaborative efforts between the ED and the laboratory to improve TAT between specimen collection and specimen delivery to the lab in the pre-analytical phase. This study›s research question was: Is there a statistically significant difference in the average receive time of specimens from ED and the average time of disposition by ED providers between the periods of the field experiment?

Methods and Materials

Research Design

We conducted the study at the ED and laboratory departments of Mount Sinai hospital at Queens (MSQ), a community hospital in a middle-class, commercial neighborhood of western Queens, New York, and part of the eight-hospital Mount Sinai Health System. As the only hospital in Queens designated by both the New York State Department of Health and the Joint Commission as a primary stroke center, MSQ became the first choice of stroke patients, so the response time and throughput are closely monitored. A four-month (from August to November 2018) joint field experiment between the ED and the lab prompted laboratory clerks to document each call to ED nurses for any collected specimens that remain unreceived after 21 minutes was conducted at MSQ, using real-time data posted in HIS by the Epic Rover once ED HCWs collected the specimens. Through secondary data collection, we used the pretest-posttest research design to determine the effectiveness of calling ED nurses when the lab has not received specimens they collected after 21 minutes. The laboratory monitored the ED patient visit time in minutes from arrival to ED provider disposition and from specimen collection at ED to receive time in the laboratory. We chose to utilize the time it took from the moment the patient arrives in the ED to the time the ED provider makes a disposition. The decision to use the time of disposition instead of the length of stay was because of the several other factors that impact the length of stay, such as delayed services in radiology, cardiology, pharmacy, and respiratory, and the availability of specialists were not of interest in this study.

Furthermore, we selected the same range of months when we conducted the interventions in the previous year (pre-intervention) and the year after the interventions (post-intervention) to obtain the TAT data. According to the National Hospital Ambulatory Medical Care Survey of 2017 conducted by the CDC, the ED visits varied by season, with the winter having the highest number of visits in 2017 at over 43 million, followed by summer (Kang, 2017). The variation in ED visits by season was the main reason we selected to compare data from different years in the same duration of months.

The Conceptual Model

The conceptual model of the study was the brain-to-brain loop concept of laboratory testing (Figure 1), adapted from the Plebani, et al. [14] and summarized by Dasgupta [4]. There are eight steps from the brain to brain loop concept of laboratory testing. In step 1, the right question was asked from the patient by the clinician or physician. In step 2, the proper test was ordered by the physician. In step 3, the Epic Rover used ED HCW to identify the patient and corresponding lab orders positively. In step 4, the right sample was collected at the correct time, with appropriate patient preparation. In step 5, the proper technique was used to collect the sample to avoid contamination with intravenous fluids, tissue damage, prolonged venous stasis, or hemolysis. In step 6, the sample was transported adequately to the laboratory, stored at the right temperature, processed for analysis, and analyzed in a manner that avoids artifactual changes in the measured analyte levels. In step 7, the lab clerk processed the specimens in preparation for analysis. In step 8, the analytical assay measured the concentration of the analyte

corresponding to its "true" level (compared to a "gold standard" measurement) within a clinically acceptable margin of error, also known as the total acceptable analytical error (TAAE). At step 8, the raw data was verified by a lab tech, reaching the clinician contained the right result, together with interpretative information, such as a reference range and other comments, aiding clinicians in the decision-making process.

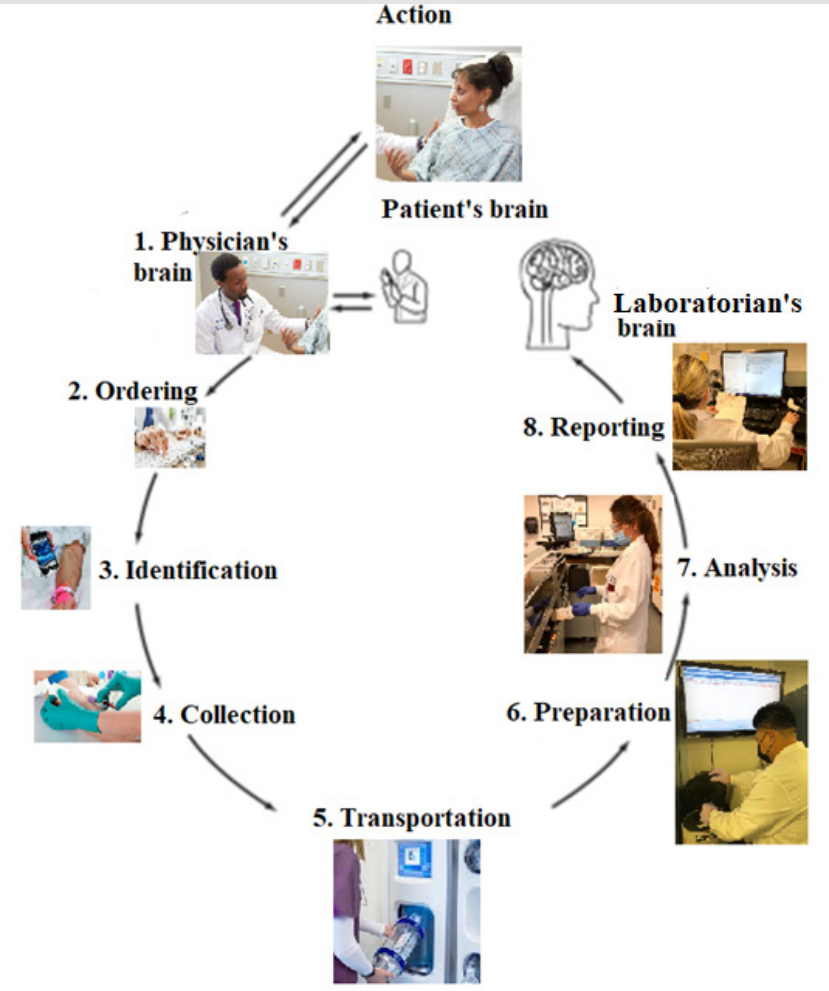

Figure 1: Brain to Brain Loop Concept for Lab Testing (Adapted from the Plebani, et al. [14]).

Instruments

The laboratory used real-time collection information transmitted by the Epic Rover to the HIS and displayed it in a laboratory monitor refreshed every three minutes. The Epic Rover is a cell phone device with a mounted barcode scanner that the treatment team uses to positively identify patients, in real-time, medication administration, update vital signs, chart review, and specimen collection documentation, among many other features. The sizeable flat-screen monitor mounted on the wall at the Central Processing Area (CPA) shows every specimen collected by ED staff, which changes color depending on the time that the collected specimens remained un-received at the laboratory. Laboratory clerks used the ED nurse user code to directly communicate with ED staff via the Vocera phones regarding any specimen collected but never received in the laboratory after 21 minutes.

Study Participants

We filtered study subjects using secondary data based on two requirements:

1) Patients seen in the ED between August to November of three different years (2017, 2018, and 2019) who required only laboratory tests based on clinical manifestations and did not have any service from ancillary departments such as cardiology, pharmacy, physical therapy, or radiology.

2) Laboratory results from patients that met requirement number one, also generated critical value that prompted notification to an ED treatment team member. After the exclusion of incomplete records on acuity level and arrival method, the final data set contained 552 patients wherein 177, 194, and 181 were seen in the ED in 2017 (pre-intervention), 2018 (intervention), and 2019 (post-intervention), respectively.

Study Variables

This study focused on the TAT from the time of collection to the time the specimen was received in the laboratory. Johnson [18] reported that the laboratory consistently met the target TAT 93% of the time while MSQ consistently met the TAT target 92 % of the time; however, the study overlooked the variables in the pre-analytical phase, specifically the times from patient arrival to provider order computer entry (door to order). Previously, Holland [17] concluded that the elimination of batch testing using an automated line that continuously processed specimens improved the laboratory TAT, decreasing the occurrence of contributing to extended ED LOS (Holland [17]). Even though both previous studies were in the pre-analytical phase, the difference with our study was the focus on the delayed specimen handoff (outliers) from the ED collectors to the laboratory. Thus, in this study, there were two dependent variables (both continuous variables):

a. TAT from test order entry to laboratory specimen receipt (TAT on COLREC), i.e., the time span (in minutes) from the time the ED provider placed the lab order to the time the Central Processing Area (CPA) department of the lab received the specimens, and

b. TAT from ED arrival to disposition (TAT on DISPO), i.e., the time span (in minutes) from the arrival of the ED patient to the time the ED provider made a disposition. The hospital information system (HIS) provided TAT in minutes from ED arrival to disposition, and the Laboratory Information System (LIS) provided TAT in minutes from test order entry to laboratory specimen receipt.

The independent variable was period, a categorical variable with 3 levels:

1) Pre-intervention,

2) Intervention, and

3) Post-intervention.

The control variables were:

a. Mode of arrival, a categorical variable with two levels (EMS vs. walk-in or self),

b. Type of test, a categorical variable with four levels (CMP, ETOH, CBC/Coag, and other tests which comprises lactic acid and troponin), and

c. Acuity level, a categorical variable with four levels (1 = immediate, 2 = emergent, 3 = urgent, and 4 = less urgent, representing acuity level from high to low).

Statistical Analysis

Data were imported into and analyzed using SPSS version 23 (IBM Corp., Armonk, NY). We examined the data for missing values. Subjects with missing values in any of the study variables were excluded from the data analysis. Frequency tables (for categorical variables) and descriptive statistics (for continuous variables) were used to summarize the data. Histogram plots were used to examine the distribution of the dependent variables.

To answer the research question, a multivariate analysis of variance (MANOVA) (Johnson [24,25]) was proposed as MANOVA can be used to determine the relationship between multiple dependent variables and independent variables. There were two dependent variables.

a. TAT on DISPO and

b. TAT on COLREC, one independent variable (period), and three control variables (mode of arrival, type of test, and acuity level).

As suggested by Olson [25,26], Pillai-Bartlett trace statistic is more robust than other multivariate statistics and hence was used as the test statistic in this study to test the hypotheses that if there was a relationship between the independent variable and the dependent variables, after controlling for the control variables. A p-value < 0.05 indicated significance at the 0.05 level. If the multivariate test results are significant, then two analysis of variances (ANOVA) (one for each dependent variable) were conducted to investigate the effects of the independent variable on each dependent variable. To ensure the validity of the analysis results, we examined the following three assumptions of the MANOVA:

1) Independence of observations,

2) Multivariate normality of the dependent variables, and

3) Equality of variance-covariance matrices of the dependent variables (Johnson [18,25]). For this study, we observed data from three different periods (pre-intervention, intervention, and post-intervention), and hence it was reasonable to assume the independence of observations.

To achieve normality, we performed the data transformation to both dependent variables. Specifically, square root transformation was applied to TAT on DISPO, and log transformation was applied to TAT on COLREC. For transformed TAT on DISPO, the skewness was 0.94, and kurtosis was 0.91, indicating the data were very close to normal. Figure 2 shows these features in the histogram plot for transformed TAT DISPO. The QQ plot for transformed TAT on DISPO (Figure 3) suggested that the data for transformed TAT DISPO were normally

distributed as the data points were very close to the 45-degree line. For transformed TAT on COLREC, the skewness was 0.04, and kurtosis was 0.72, indicating the data were also very close to normal. Figure 4 shows these features in the histogram plot for transformed TAT on COLREC. The QQ plot for transformed TAT on COLREC (Figure 5) also suggested that the data were normally distributed as the data points were very close to the 45-degree line. Therefore, we conclude that the data for transformed TAT on DISPO and transformed TAT on COLREC were normally distributed, and hence univariate normality was attained. Since the univariate normality of each dependent variable was attained (normally distributed), the multivariate normality was determined. Multivariate normality was assessed via chi squared QQ plots based on the Mahala Nobis distances squared. According to Burdenski [27], Mahala Nobis distances are the generalized squared distances of the data points from the means. When the data are multivariate and are normally distributed, the squared Mahala Nobis distances had the chi-squared distribution with p-degrees of freedom (p = 2 as there were two dependent variables). The data points in the chi squared QQ plot (Figure 6) formed an approximate a line, and hence it was concluded that multivariate normality was attained for transformed TAT on DISPO and transformed TAT on COLREC (dependent variables after data transformation). The Box's M value of 11.465 was associated with p = 0.077 (Table 1), which was interpreted as nonsignificant based on Hair [25]. Thus, the covariance matrices between the groups were assumed to be equal for the MANOVA. Thus, all three model assumptions for MANOVA

a. Independence of observations,

b. Multivariate normality of the dependent variables, and

c. Equality of variance-covariance matrices of the dependent variables, were satisfied, and it was adequate to analyze the data using MANOVA.

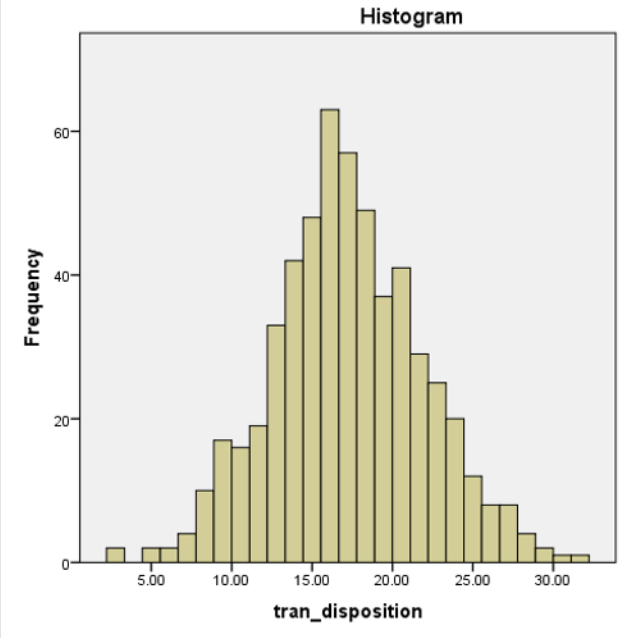

Figure 2: Histogram for TAT on DISPO After Data Transformation.

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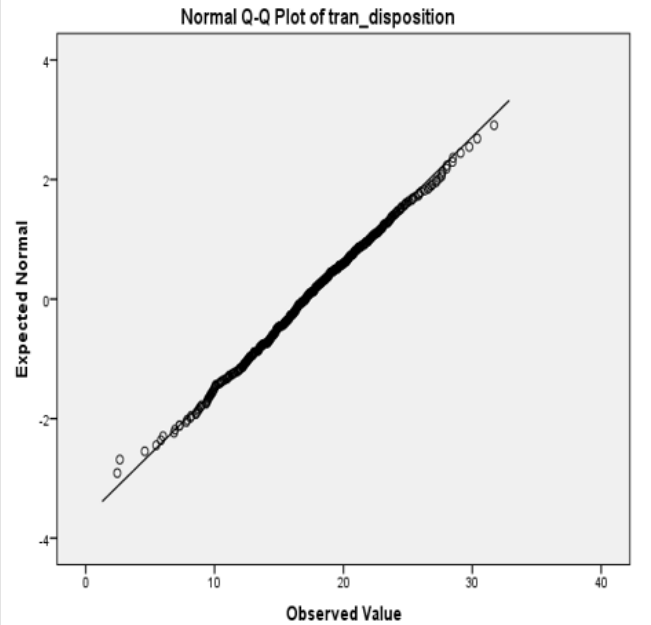

Figure 3: QQ Plot for TAT on DISPO After Data Transformation.

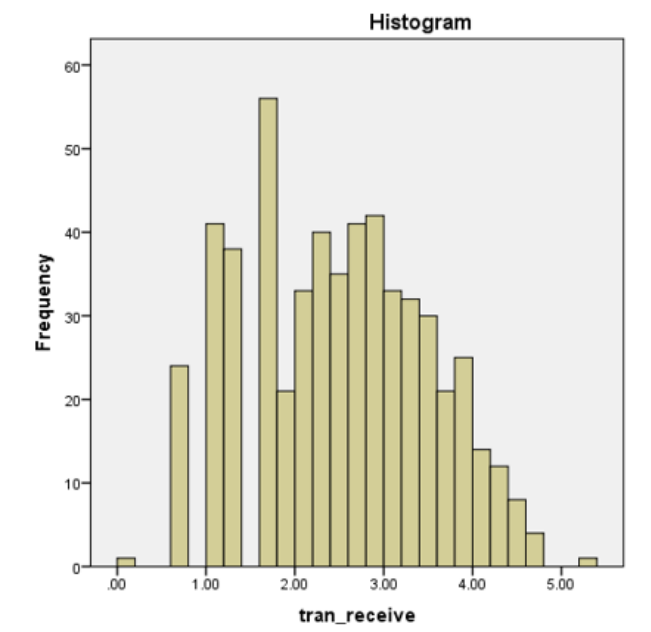

Figure 4: Histogram for TAT on COLREC After Data Transformation.

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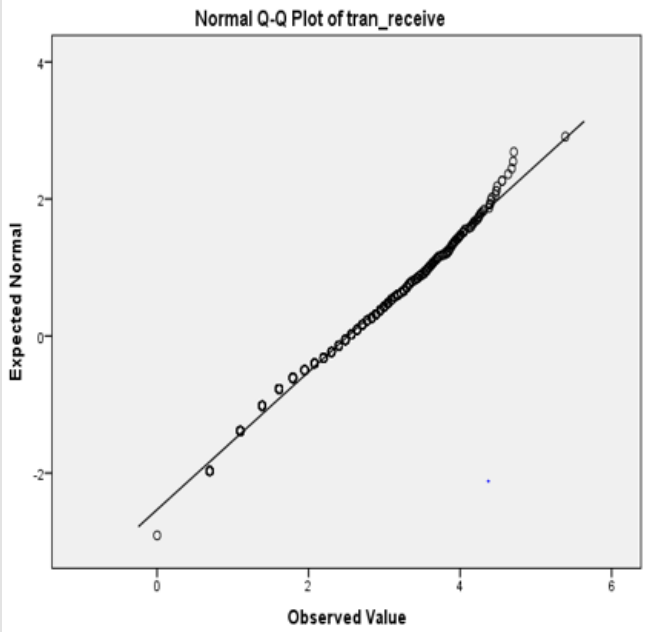

Figure 5: QQ Plot for TAT on COLREC After Data Transformation.

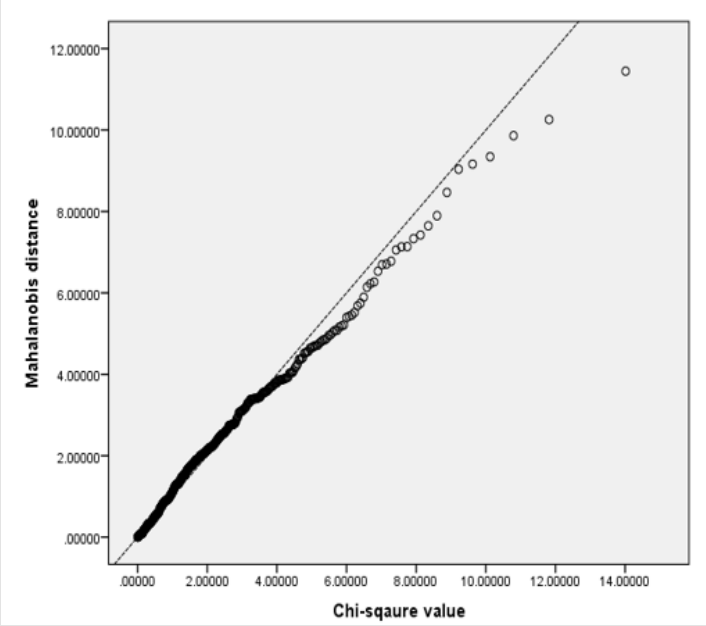

Figure 6: Chi-Square QQ Plot for the Two Dependent Variables After Data Transformation.

Table 1: Box's M Test of Equality of Covariance Matrices.

Box's M	F	df1	df2	p
11.465	1.901	6	7232262.661	0.077

Note: F = F-statistic; df1 = numerator degrees of freedom for the F-statistic; df2 = denominator degrees of freedom for the F-statistic; p = p-value.

Results

Characteristics of Patients

MSQ retained almost 80% (79/100) of the nurses during the intervention period until 2019, according to the MSQ payroll department. After the exclusion of incomplete records on acuity level and arrival method, the final data set contained 552 patients, wherein approximately one-third of the patients were in each intervention period (32.1% for pre-intervention, 35.1% for intervention, and 32.8% for post-intervention), as shown in Table 2. Table 2 also presents the characteristics of these patients in terms of the study variables of interest, including.

a. Mode of arrival,

b. Type of test, and

c. Acuity level.

Nearly 60% of the subjects arrived with EMS (59.2%). Slightly under half of the subjects underwent the ETOH test (48.0%). Approximately half of the subjects were considered urgently in terms of the acuity level (50.7%).

Table 2: Summary of Categorical Study Variables on the Effectiveness of Laboratory Interventions.

Variable	Category	N	%
Period	Pre-intervention	177	32.1
	Intervention	194	35.1
	Post-intervention	181	32.8
Arrival method	EMS	327	59.2
	Walk-in / Self	225	40.8
Type of test	ETOH	265	48.0
	CMP	213	38.6
	CBC / Coag	50	9.1
	Other (Lac/Trop)	24	4.3
Acuity level	Immediate	9	1.6
	Emergent	244	44.2
	Urgent	280	50.7
	Less urgent	19	3.4

Note: n = number of patients seen in the Emergency Department who only had laboratory services and generated critical laboratory values.

Descriptive Statistics of the Dependent Variables

Summary statistics of TAT on DISPO and TAT on COLREC are presented in Table 3. Overall, before data transformation, the average TAT on DISPO was 318.51 minutes (SD = 165.46); the average TAT on COLREC was 20.00 minutes (SD = 21.73). Overall, after data transformation, the average TAT on DISPO was 318.51 minutes (SD = 165.46); the TAT on COLREC was 20.00 minutes (SD = 21.73). When examining the TAT on DISPO by period, the average TAT DISPO seemed to be highest in the pre-intervention period (M = 350.12, SD = 178.26) and lowest in the intervention period (M = 291.94, SD = 151.35). Similarly, the average TAT COLREC seemed to be highest in the pre-intervention period (M = 31.61, SD = 23.27) and lowest in the intervention period (M = 14.07, SD = 14.90).

Table 3: Summary of Statistics of Time of Disposition by ED Providers (in minutes) and Receive Time of Specimens from ED.

Variable	Period	N	M	SD
TAT on DISPO	Pre-intervention	177	350.12	178.26
	Intervention	194	291.94	151.35
	Post-intervention	181	316.08	162.56
	Overall	552	318.51	165.46
	Overall (after data transformation)	552	17.21	4.61
TAT on COL-REC	Pre-intervention	177	31.61	23.27
	Intervention	194	14.07	14.90
	Post-intervention	181	15.02	21.95
	Overall	552	20.00	21.73
	Overall (after data transformation)	552	1.95	0.43

Results of MANOVA

We conducted a MANOVA with two dependent variables (transformed TAT on DISPO and transformed TAT on COLREC), one independent variable (period), and three control variables (mode of arrival, type of test, and acuity level) to examine if there was a relationship between TAT on DISPO and TAT on COLREC and intervention period. Table 3 shows the multivariate test results for testing the effects of period, arrival method, type of test, acuity level on the two dependent variables (transformed TAT on DISPO and transformed TAT on COLREC). According to the MANOVA results (Table 3), the effect of period on the dependent variables was statistically significant (Pillai›s Trace = 0.211, F (4, 1092) = 32.124, $p < 0.001$, multivariate $\eta 2 = .105$). The effect of arrival method on the dependent variables was not statistically significant (Pillai›s Trace = 0.010, F (2, 545) = 2.732, p = 0.066, multivariate $\eta 2 = 0.010$). The effect of the test on the dependent variables was not statistically significant (Pillai›s Trace = 0.002, F (2, 545) = 0.571, p = 0.565, multivariate $\eta 2 = .002$). The effect of acuity level on the dependent variables

was not statistically significant (Pillai›s Trace = 0.007, F (2, 545) = 1.969, p = 0.141, multivariate η2 = 0.007). Note that multivariate η2 represents the effect size of each variable. For example, for the period, multivariate η2 = 0.105, indicates that approximately 10.5% of the multivariate variance of the dependent variables was associated with the variable, period.

Results of ANOVA

Because the results of MANOVA were significant, we will now examine the univariate ANOVA results for each dependent variable. Two ANOVAs were conducted, one for each dependent variable (transformed TAT on DISPO and transformed TAT on COLREC). There was one independent variable (period) in each ANOVA and three control variables (mode of arrival, type of test, and acuity level).

Results of ANOVA for Transformed TAT on DISPO

We conducted an ANOVA with a dependent variable = transformed disposition time, one independent variable (period), and three control variables (mode of arrival, type of test, and acuity level). Tables 4-6 presented the analysis results. The R^2 = 0.089 (Adjusted R^2 = 0.074; Table 6) indicated 8.9% of the total variation in the dependent variable, transformed TAT on DISPO, can be explained by the variables in the model, including period, mode of arrival, type of test, and acuity level. Partial eta squared (Table 6) represented the effect size, which measured the amount of the variability in the dependent variable (transformed TAT on DISPO) attributed to each variable in the model (period, mode of arrival, type of test, and acuity level). The partial eta squared was 0.019, 0.001, 0.032, and 0.023 for the period, mode of arrival, type of test, and acuity level, respectively. This partial eta squared results indicated that 1.9%, 0.1%, 3.2%, and 2.3% of the variability in the dependent variable (transformed TAT on DISPO) could be explained by period, mode of arrival, type of test, and acuity level, respectively.

Effects of Intervention Period. According to the analysis results of the ANOVA, there was a statistically significant difference in the dependent variable (transformed TAT DISPO) based on period (F (2, 542) = 5.254, p = 0.005; Table 6). The estimated marginal means of transformed disposition time were 15.917, 14.407, and 15.187 for pre-intervention, intervention, and post-intervention, respectively (Table 7). These values can be transformed back to the original scale by taking the square of the number (Altman [28]).

Table 4: Multivariate Correlation Between the Effects of Period, Arrival Method, Type of Test, Acuity Level on the Dependent Variables (Transformed TAT on DISPO and Transformed TAT on COLREC).

Effect	Test statistic	Value	F	df1	df2	p	η^2
Intercept	Pillai's Trace	0.758	850.814	2	542	<0.001	0.758
	Wilks' Lambda	0.242	850.814	2	542	<0.001	0.758
	Hotelling's Trace	3.140	850.814	2	542	<0.001	0.758
	Roy's Largest Root	3.140	850.814	2	542	<0.001	0.758
Period	Pillai's Trace	0.210	31.803	4	1086	<0.001	0.105
	Wilks' Lambda	0.791	33.66	4	1084	<0.001	0.110
	Hotelling's Trace	0.263	35.523	4	1082	<0.001	0.116
	Roy's Largest Root	0.258	70.045	2	543	<0.001	0.205
Arrival method	Pillai's Trace	0.002	0.618	2	542	0.540	0.002
	Wilks' Lambda	0.998	0.618	2	542	0.540	0.002
	Hotelling's Trace	0.002	0.618	2	542	0.540	0.002
	Roy's Largest Root	0.002	0.618	2	542	0.540	0.002
Type of test	Pillai's Trace	0.009	1.183	4	1086	0.316	0.004
	Wilks' Lambda	0.991	1.182	4	1084	0.317	0.004
	Hotelling's Trace	0.009	1.180	4	1082	0.318	0.004
	Roy's Largest Root	0.006	1.749	2	543	0.175	0.006
Acuity level	Pillai's Trace	0.034	3.148	6	1086	0.005	0.017
	Wilks' Lambda	0.966	3.160	6	1084	0.004	0.017
	Hotelling's Trace	0.035	3.172	6	1082	0.004	0.017
	Roy's Largest Root	0.032	5.770	3	543	0.001	0.031

Note: F = F-statistic; df1 = numerator degrees of freedom for the F-statistic; df2 = denominator degrees of freedom for the F-statistic; p = p-value; η2 = Partial Eta squared.

Table 5: Tests of Between-Subjects Effects (Transformed TAT on DISPO).

Source	Type III SS	df	MS	F	p	η^2
Corrected Model	1050.436	9	116.715	5.90	< 0.001	0.089
Intercept	18174.989	1	18174.989	920.293	< 0.001	0.629
Period	207.528	2	103.764	5.254	0.005	0.019
Arrival method	9.295	1	9.295	0.471	0.493	0.001
Type of test	357.450	3	119.150	6.033	< 0.001	0.032
Acuity level	250.826	3	83.609	4.234	0.006	0.023
Error	10704.025	542	19.749			
Total	175820.000	552				
Corrected Total	11754.461	551				

Note: $R^2 = 0.089$ (Adjusted $R^2 = 0.074$); df = degrees of freedom; MS = mean square: F = F-statistic; η2 = Partial Eta squared; transformed data.

Table 6: Estimated Marginal Means of the Dependent Variable (Transformed TAT on DISPO).

Variable	Level	M	SE
Period	Pre-intervention	15.917	0.568
	Intervention	14.407	0.560
	Post-intervention	15.187	0.579
Arrival method	EMS	15.325	0.556
	Walk-in / Self	15.016	0.541
Type of test	ETOH	16.231	0.550
	CMP	15.284	0.512
	CBC & COAG	16.671	0.775
	Other (Lac. / Trop.)	12.496	0.978
Acuity level	Immediate	12.743	1.495
	Emergent	16.879	0.361
	Urgent	16.760	0.366
	Less urgent	14.300	1.059

Table 7: Results of Pairwise Comparisons on the Dependent Variable (Transformed TAT on DISPO).

Variable	Category (i)	Category (j)	Mean diff (i-j)	SE	p	95% CI for difference	
						Lower	Upper
Period	Pre	Intervention	1.511	0.467	0.001	0.594	2.428
	Pre	Post	0.730	0.482	0.130	-0.217	1.677
	Intervention	Post	-0.781	0.465	0.093	-1.693	0.132
Arrival method	EMS	Walk-in / self	0.309	0.450	0.493	-0.575	1.192
Type of test	ETOH	CMP	.947	.466	.043	.031	1.863
	ETOH	CBC&COAG	-.440	.738	.551	-1.889	1.010
	ETOH	Other(Lac/Trop)	3.736	.999	<.001	1.774	5.698
	CMP	CBC&Coag	-1.387	.715	.053	-2.791	.017
	CMP	Other(Lac/Trop)	2.788	.974	.004	.876	4.701
	CBC&Coag	Other(Lac/Trop)	4.175	1.123	<.001	1.970	6.381
Acuity level	Immediate	Emergent	-4.136	1.536	.007	-7.153	-1.119
	Immediate	Urgent	-4.016	1.528	.009	-7.018	-10.15
	Immediate	Less urgent	-1.557	1.827	.394	-5.145	2.031

	Emergent	Urgent	.120	.402	.766	-.671	.910
	Emergent	Less urgent	2.579	1.077	.017	.464	4.694
	Urgent	Less urgent	2.459	1.061	.021	.375	4.544

Note: SE= standard error; p = p-value; CI = confidence interval; lower = lower bound of CI; upper = upper bound of the CI. P-values were adjusted using Bonferroni's method for pairwise comparisons; transformed data.

Table 8: Tests of Between-Subjects Effects (Transformed TAT on COLREC).

Source	Type III SS	df	MS	F	p	η^2
Corrected Model	21.485	9	2.387	15.902	<0.001	0.209
Intercept	89.085	1	89.085	593.418	<0.001	0.523
Period	19.582	2	9.791	65.220	<0.001	0.194
Arrival method	0.108	1	0.108	0.716	0.398	0.001
Type of test	0.084	3	0.028	0.187	0.905	0.001
Acuity level	0.600	3	0.200	1.331	0.263	0.007
Error	81.366	542	0.150			
Total	764.263	552				
Corrected Total	102.851	551				

Note: R^2 = 0.209 (Adjusted R^2 = 0.196); df = degrees of freedom; MS = mean square: F = F-statistic; η2 = Partial Eta squared; transformed data.

Nonetheless, according to the results of pairwise comparisons presented in Table 8, the transformed TAT on DISPO was statistically significantly higher in pre-intervention than in intervention (Mean difference = 1.511, SE = 0.467, p = .001). There was no statistically significant difference in transformed disposition time between pre-intervention and post-intervention (p = 0.130) and between intervention and post-intervention (p = 0.093).

Effects of Arrival Method. There was no statistically significant difference in transformed TAT on DISPO based on arrival method (F (1, 542) = .471, p = 0.493; Table 5). The estimated marginal means of transformed TAT on DISPO were 15.325 and 15.016 for patients who arrived via EMS and walk-in, respectively (Table 6).

Effects of Type of Test. There was a statistically significant difference in the dependent variable (transformed TAT on DISPO) based on the type of test (F (3, 542) = 6.033, p < 0.001; Table 5). The estimated marginal means of transformed TAT on DISPO were 15.284, 16.231, 16.671, and 12.496 for patients with different types of tests, including CMP, ETOH, CBC plus Coag, and other tests (Lac/Trop), respectively (Table 6). According to the results of pairwise comparisons presented in Table 7, the transformed TAT on DISPO was statistically significantly lower for patients with critical CMP results than patients with critical ETOH results (Mean difference = -0.947, SE = 0.466, p = 0.043); the transformed TAT on DISPO was statistically significantly lower for patients with critical lactic acid or troponin results than patients with critical CMP results (Mean difference = -2.788, SE = .974, p = .004); the transformed TAT on DISPO was statistically significantly lower for patients with critical lactic acid or troponin results than patients with critical ETOH results (Mean difference = -3.736, SE = 0.999, p < 0.001); the transformed TAT on DISPO was statistically significantly lower for patients with critical lactic acid or troponin results than patients with critical CBC or Coag results (Mean difference = -4.175, SE = 1.123, p < 0.001). There was no statistically significant difference in transformed disposition time between patients with critical CMP results and patients with critical CBC or Coag results (p = 0.053) and between patients with critical ETOH results and patients with critical CBC or Coag (p = 0.551).

Effects of Acuity Level. There was a statistically significant difference in the dependent variable (transformed TAT on DISPO) based on acuity level (F (3, 542) = 4.234, p = 0.006; Table 5). The estimated marginal means of transformed TAT on DISPO were 12.743, 16.879, 16.760, and 14.300 for patients with different level of acuity, including immediate, emergent, urgent, and less urgent, respectively presented in Table 6. According to the results of pairwise comparisons (Table 6), the transformed TAT on DISPO was statistically significantly lower for immediate patients than emergent patients (Mean difference = -4.136, SE = 1.536, p = 0.007); the transformed TAT on DISPO was statistically significantly lower for immediate patients than urgent patients (Mean difference = -4.016, SE = 1.528, p = 0.009); the transformed TAT on DISPO was statistically significantly higher for emergent patients than less urgent patients (Mean difference = 2.579, SE = 1.077 p = 0.017); the transformed TAT on DISPO was statistically significantly higher for urgent patients than less urgent patients (Mean difference = 2.459, SE = 1.061, p = 0.021); there was no statistically significant difference in transformed TAT on DISPO between emergent patients and urgent patients (p = 0.766), and between immediate patients and less urgent patients (p = 0.394).

Results of ANOVA for Transformed TAT on COLREC

We conducted an ANOVA with a dependent variable = transformed TAT on COLREC, one independent variable (period), and three control variables (mode of arrival, type of test, and acuity level). Tables 8-10 presented the analysis results. The R^2 = 0.209 (Adjusted R^2 = 0.196; (Table 8) indicated 20.9% of the total variation in the dependent variable, transformed TAT on COLREC, can be explained by the variables in the model, including period, mode of arrival, type of test, and acuity level.

Effects of Intervention Period. According to the analysis results of the ANOVA, there was a statistically significant difference in the dependent variable (transformed TAT on COLREC) based on period ($F (2, 542) = 65.220$, $p < 0.001$; Table 8). The estimated marginal means of transformed TAT on COLREC were 1.337, .937, and .913 for pre-intervention, intervention, and post-intervention, respectively (Table 9). These values can be transformed back to the original scale by taking the antilogs (Altman [28]). Nonetheless, according to the results of pairwise comparisons (Table 10), transformed TAT on COLREC was statistically significantly higher in pre-intervention than in intervention (Mean difference = .400, SE = 0.041, $p < 0.001$). Transformed TAT on COLREC was also statistically significantly higher in pre-intervention than in post-intervention (Mean difference = 0.424, SE = 0.042, $p < 0.001$). There was no statistically significant difference in transformed TAT on COLREC between intervention and post-intervention ($p = 0.562$).

Table 9: Estimated Marginal Means of the Dependent Variable (Transformed TAT on COLREC).

Variable	Level	M	SE
Period	Pre-intervention	1.337	0.050
	Intervention	0.937	0.049
	Post-intervention	0.913	0.050
Arrival method	EMS	1.079	0.048
	Walk-in / Self	1.046	0.047
Type of test	ETOH	1.075	0.048
	CMP	1.068	0.045
	CBC & COAG	1.088	0.068
	Other (Lac. / Trop.)	1.017	0.085
Acuity level	Immediate	0.915	0.130
	Emergent	1.064	0.032
	Urgent	1.109	0.032
	Less urgent	1.161	0.092

Table 10: Results of Pairwise Comparisons on the Dependent Variable (Transformed TAT on COLREC).

Variable	Category (i)	Category (j)	Mean diff (i-j)	SE	p	95% CI for difference	
						Lower	Upper
Period	Pre	Intervention	0.400	0.041	<0.001	0.320	0.480
	Pre	Post	0.424	0.042	<0.001	0.341	0.506
	Intervention	Post	0.024	0.041	0.562	-0.056	0.103
Arrival method	EMS	Walk-in / self	0.033	0.039	0.398	-0.044	0.110
Type of test	ETOH	CMP	0.007	0.041	0.856	-0.072	0.087
	ETOH	CBC&COAG	-0.013	0.064	0.839	-0.139	0.113
	ETOH	Other(Lac/Trop)	0.058	0.087	0.509	-0.113	0.229
	CMP	CBC&Coag	-0.020	0.062	0.743	-0.143	0.102
	CMP	Other(Lac/Trop)	0.050	0.085	0.555	-0.117	0.217
	CBC&Coag	Other(Lac/Trop)	0.071	0.098	0.471	-0.122	0.263
Acuity level	Immediate	Emergent	-0.150	0.134	0.265	-0.413	0.113
	Immediate	Urgent	-0.194	0.133	0.146	-0.456	0.068
	Immediate	Less urgent	-0.246	-0.159	0.123	-0.559	0.067
	Emergent	Urgent	-0.045	0.035	0.204	-0.114	0.088

	Emergent	Less urgent	-0.097	0.094	0.304	-0.281	0.088
	Urgent	Less urgent	-0.052	0.093	0.574	-0.234	0.130

Note. SE = standard error; p = p-value; CI = confidence interval; lower = lower bound of CI; upper = upper bound of the CI. P-values were adjusted using Bonferroni's method for pairwise comparisons; transformed data.

Effects of Arrival Method: There was no statistically significant difference in transformed TAT on COLREC based on arrival method (F (1, 542) = 0.716, p = 0.398; (Table 8). The estimated marginal means of transformed TAT on COLREC were 1.079 and 1.046 for patients who arrived via EMS and walk-in, respectively (Table 9).

Effects of Type of Test: There was no statistically significant difference in the dependent variable (transformed TAT on COLREC) based on the type of test (F (3, 542) = 0.187, p = 0.905; Table 8). The estimated marginal means of transformed TAT on COLREC were 1.075, 1.068, 1.088, and 1.017 for patients with different types of tests, including CMP, ETOH, CBC plus Coag, and other tests (Lac/Trop), respectively (Table 9).

Effects of Acuity Level: There was no statistically significant difference in the dependent variable (transformed TAT on COLREC) based on acuity level (F (3, 542) = 1.331, p = 0.263; Table 8). The estimated marginal means of transformed TAT on COLREC were 0.915, 1.064, 1.109, and 1.161 for patients with different level of acuity, including immediate, emergent, urgent, and less urgent (Table 9).

Discussion

Due to the laboratory›s interventions, both the mean TAT from patient arrival to disposition and from specimen collection to receive in the laboratory significantly improved from 350.1 minutes to 291.9 minutes and from 31.6 minutes to 14.1 minutes, respectively, between the pre-intervention and the intervention periods. In other words, the average TAT in minutes of both time of collection to delivery to the laboratory (TAT on COLREC) and patient arrival at ED to provider disposition (TAT on DISPO) significantly improved during the months when laboratory clerks reached out to ED nurses after time exceeded 21 minutes from specimen collection but never delivered to the laboratory. This finding confirmed the results of past research that maximizing the use of information technology in the pre-analytical phase could reduce TAT of the specimen workflow (Baer [5-21]). Inter-departmental collaboration improved processes that eventually led to better patient outcomes. An efficient process of specimen collection and transportation from the pre-analytical phase at the ED led the workflow to a faster track on generating clinical data necessary for a provider's disposition. The study also proved that laboratory intervention made a lasting impact in such a way that TAT on both variables only slightly increased after one year since the lab stopped the intervention.

As Hammerling [10] pointed out, interdepartmental communication and cooperation played a significant role in the testing process. Both improper collection and delayed specimen delivery affect the accuracy of laboratory results. The laboratory must share a steady flow of information on proper collection techniques to reduce pre-analytical errors and reduce TAT between specimen collection and specimen delivery to the lab in the pre-analytical phase (Ghaedi [29-31]).

Limitations

There are several limitations to this study. The first limitation was the failure of some nonlaboratory HCWs to use the Epic Rover properly. The field experiment relied entirely on the information transmitted by the Epic Rover in real-time, so improper use would not allow the laboratory to intervene if the collector was distracted and left the collected sample at the nursing station. The second limitation was the lack of laboratory staffing that required prioritizing scheduled tasks such as specimens from OR, ICU, and Chemotherapy, limiting the clerks' ability to intervene. The third limitation was when the pneumatic tube system that nonlaboratory HCW used to send specimens was out of order. Specimen delivery from the ED would still be delayed even after laboratory intervention because ED staff batch the specimens before walking to the laboratory for hand delivery. The fourth limitation of this study was the inability of some nurses to maintain a working Vocera phone. Several unsuccessful attempts to reach the nurse by Vocera phones caused the lab clerks to revert to the old system of calling the ED main number and ask the clerk for the nurse or the collector. The fifth limitation of this study was nurses› inability to respond to Vocera phones, which works only on speakerphone audio, when in areas that compromise the privacy of other patients. The nurse had no choice but to ignore the call, which activates the voicemail. The study›s sixth and final limitation was the amount of time for the field experiment, which was only four months from August to November of 2018. This limitation exists due to a doctoral program›s time constraints and is very difficult to overcome unless a researcher devotes personal time for future research. Data from different seasons of the year will provide a better understanding if a particular pattern exists on the different reasons for delays in specimen delivery.

Conclusion

In this study, several key reasons were identified for failing the 21-minute requirement of TAT- Epic Rover training of HCW, use of paper requisitions, lack of adequate staff, and the pneumatic tube system failure. Of these four factors, the most actionable is the lack of the committed use of Epic Rover. A suggested follow up is to construct a weekly metric where every outlier specimen is matched with a non-use of Epic Rover and the involved HCW. This scorecard should be

presented to ED leadership as a tool to drive the improvement of HCW skill training. Upgrading the specimen collection process through the implementation of technical devices enabled the collaboration of ED and the laboratory to reduce delays or TAT outliers and improved patient outcomes. Automation in the pre-analytical phase, such as Epic Rover, PTS, and Vocera phones, can significantly improve TAT in the pre-analytical phase. However, there is still the human factor, such as being distracted during the specimen collection process, that negates the advantages of modern technology. Such distractions on ED HCWs delayed the specimen transport to the lab affecting the total TAT of the specimen workflow. Even though the laboratory could not intervene on every single outlier, the few phone calls early on the shift set the tone for the nonlaboratory HCW on timely specimen submission. The study also raised enough awareness that the outliers got worse a year after intervention but still far better than the pre-intervention data.

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