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IMPACT OF POSITIVE PATIENT IDENTIFICATION ON MEDICAL LABORATORY PRE-ANALYTICAL QUALITY INDICATORS

BY

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Approval of Thesis

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Dedication

I dedicate this paper to all those who patiently checked in with me and helped me progress through this journey.

Acknowledgments

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Abstract

Hospital identification errors can result in inappropriate treatment or diagnosis. In the laboratory, identification errors occur mainly during the pre-analytical phase and can carry through to the analytical and post-analytical phases. Positive patient identification (PPID) technology allows a phlebotomist to identify a patient using a barcode scanner, decreasing the risk of making an identification error. Lack of data on PPID's efficacy and inadequate research on its return on investment have led to hesitancy to implement this technology. A retrospective one-group pretest–posttest design was utilized to determine the impact of PPID on laboratory quality indicators such as patient identification error rates and turn-around times at ABC Hospital[1] in British Columbia. Patient identification error rates decreased to 0% after the implementation of PPID; however, sample collection turn-around times increased by 4 to 10 min.

[1] This is a pseudonym.

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Chapter 1: Introduction

Laboratory testing plays an important role in modern healthcare (Adeli, 2017), and it is widely accepted that 70% of healthcare decisions affecting treatment or diagnosis involve laboratory investigation (Badrick, 2013). Laboratory quality is defined by accuracy, reliability, and timeliness of the reported test results (World Health Organization [WHO], 2014). Laboratory testing is divided into three phases: pre-analytical, analytical, and post-analytical. The pre-analytical phase includes ordering a laboratory test, collecting the sample, and transporting the sample to the laboratory (Hawkins, 2012). The analytical phase involves testing the sample and controlling the conditions of testing to ensure accuracy. The post-analytical phase involves reporting and distributing the results.

Pre-analytical errors account for up to 75% of all errors made in the laboratory (Green, 2013); therefore, recent quality efforts have shifted to the pre-analytical phase. Examples of pre-analytical errors include collection of the wrong tube type, patient identification error, inadequate sample, hemolyzed or clotted sample, and incorrect collection time. Consequences of pre-analytical errors include negative consequences to the patient, damage to the institution's reputation, decreased confidence in the healthcare system, and an increase in laboratory operating costs (Bonini, Ceriotti, Mirandola, & Signori, 2008; Green, 2013).

Causes of Identification Errors

A major cause of patient identification errors is patients presenting with similar standard identifiers (Lippi, Mattiuzzi, Bovo, & Favaloro, 2017). The two standard identifiers are full name (first and last) and date of birth. Generally accepted laboratory

identification policies state that the phlebotomist must confirm verbally, and check the patient's wristband against labels, that both identifiers match (Clinical Laboratory Standards Institute [CLSI], 2017). However, despite this additional safety check, identification errors still occur. A possible cause of identification errors is deviation from the identification policy. Some reasons for deviation from policy are phlebotomists being unaware of the patient identification policy or not actively listening to the patient's response due to distraction (Task & Tournas, 2012).

In 2007, the WHO recommended the following solutions to reduce identification errors: standardization of procedures, re-education of phlebotomists, and introduction of positive patient identification (PPID). PPID technology reduces laboratory specimen collection errors by providing safeguards, such as barcode scanning, to ensure that the correct sample is collected on the correct patient at the correct time (Snyder et al., 2012). These safeguards, in turn, reduce the number of identification errors, incorrect results reported, and recollections required.

Statement of Problem

Patient identification errors occur during the pre-analytical identification procedure and can result in significant harm to the patient. In most cases, the harm caused to the patient is minor; however, the potential exists for major harm or death (Upreti, Upreti, Mansal, Jeelani, & Bharat, 2013). Documented identification error rates during the pre-analytical phase of medical laboratory collection are as high as 0.04 to 0.1% (Morrison et al., 2010). It is important to note that these statistics are based on documented identification errors; unreported errors are excluded in all patient

identification error rates published, as it is not possible to quantify actual identification error rates.

These numbers appear to be low; however, the impact to a patient can be significant. It is reported that 40 to 50% of transfusion-related morbidities are due to patient identification errors (Green, 2013). Each error has the potential to cause serious harm to a patient depending on what test was ordered and when the error was detected. For example, an incorrectly identified patient may receive a transfusion with an incorrect blood type, resulting in a hemolytic reaction and possible death. If a patient is identified incorrectly, there is potential for him or her to receive an incorrect diagnosis and a toxic or incorrect of dose of medication. According to internal documents I reviewed, identification error rates at the hospital study site, referred to using the pseudonym ABC Hospital, were 0.0104% prior to implementation. As per a conversation with the pre- and post-analytics supervisor, these errors impacted patient care in the form of treatment delays, possibility of misdiagnosis, and incorrect treatment.

Although one study found that a 32% reduction in patient identification errors could be realized post-PPID implementation (Ning et al., 2016), one of the barriers to justifying PPID implementation is that information regarding its impact on efficiency indicators such as turn-around times (TATs) and cost benefits is scarce. TAT data for ABC Hospital would provide information on PPID's impact on efficiency of the sample collection process. Understanding how efficiently phlebotomists implement PPID would allow for a more accurate cost–benefit analysis. Laboratory operational decisions are based on quality and budget. PPID has been shown to improve quality; however, an unknown with its implementation is its possible impact on efficiency of collections.

Background

ABC Hospital is a tertiary care hospital in British Columbia that provides general medical services such as emergency, intensive care, cardiovascular, oncology, pediatrics, neonatal intensive care, renal care, geriatrics, and pediatric emergency. ABC Hospital serves as a regional referral centre for specialized pediatrics and maternity care, hospice care, and multiple extended care units.

ABC Hospital uses a laboratory information system software called Meditech (n.d.), which allows nurses and physicians to order and access test results, and laboratory personnel to review orders and report the results of laboratory analyses. Meditech also collects data on when a test was ordered, when the sample was collected, when the sample was received in the laboratory, and when test results were reported.

Pre-implementation workflow process. Prior to PPID implementation, two phlebotomists were responsible for the workflow in ABC Hospital's pre-analytical department. Phlebotomists are trained laboratory personnel who perform venipunctures to collect blood samples. Venipuncture is the process of obtaining intravascular access for blood sampling. The other phlebotomists are responsible for collecting samples from more than 300 patients during morning rounds, which consist of routine blood collection orders for patients admitted to the hospital. Morning rounds exclude priority (time-sensitive) collections.

Workflow in the pre-analytical department involved monitoring all pending sample collections, receiving samples, and assigning pending collections to the phlebotomists. The workflow designate continuously checked Meditech for new collection requests, printed labels for phlebotomists, and contacted one of the 10

phlebotomists believed to be closest to the location of the patient requiring a venipuncture. The phlebotomist then called the workflow designate and confirmed whether he or she was close to the collection location and able to collect the sample. If so, the workflow designate sent labels using a pneumatic tube to the tube station closest to the phlebotomist. A pneumatic tube allows for rapid transport of small items such as labels and samples and is connected to the laboratory and most wards in the hospital.

The phlebotomist took the labels from the pneumatic tube and used them to determine where the patient was located. After locating the patient, the phlebotomist would (a) check the wristband (identification band that indicates the patient's first and last name, date of birth, hospital visit number, and provincial health number) against the labels to confirm the patient's identification, (b) verbally confirm the patient's full name and date of birth, and (c) proceed to collect the sample. After the sample was collected, the phlebotomist would double check the identification of the patient and label the samples. Samples were either sent to the laboratory through the pneumatic tube or delivered by hand. The workflow designate would receive and distribute the samples to the appropriate departments in the laboratory. The pre-implementation process is summarized in Figure 1.

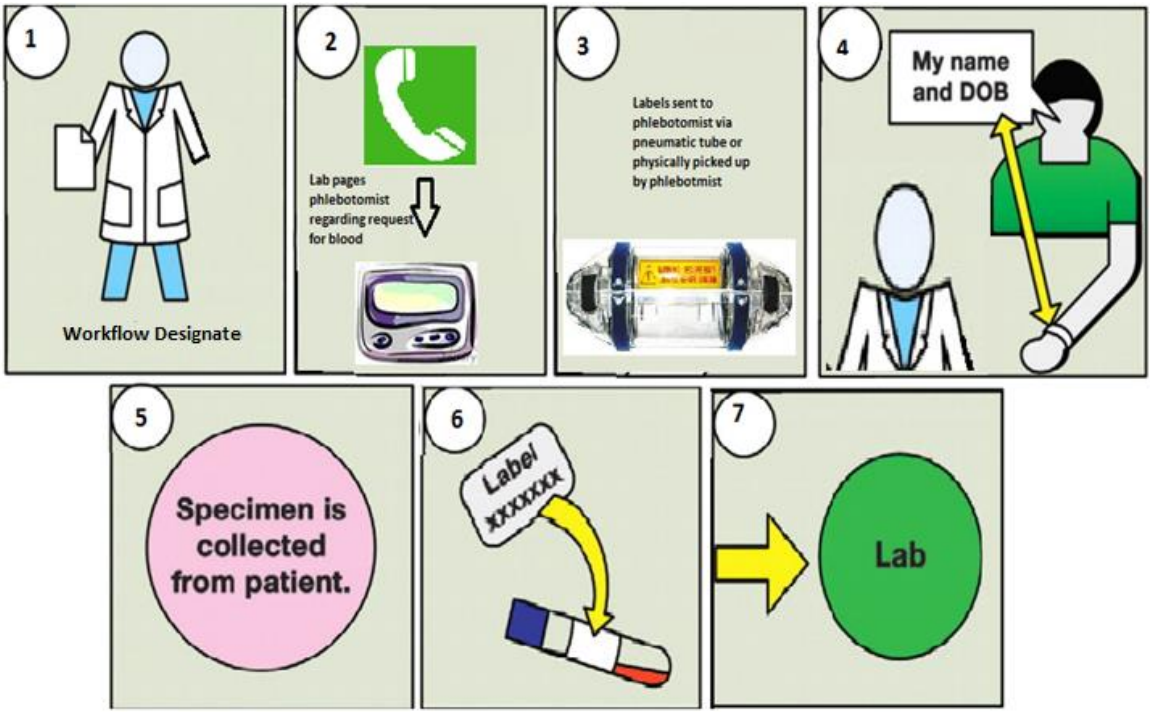

Figure 1. A summary of the pre-implementation workflow process.

1) A sample collection order is placed in Meditech and is reviewed by a workflow designate. 2) The workflow designate contacts the phlebotomist believed to be closest to the patient via pager. 3) The phlebotomist communicates with the workflow designate, who sends the patient labels through the pneumatic tube to the location closest to the phlebotomist. The phlebotomist retrieves the labels from the pneumatic tube and uses them to determine the patient's location. 4) The phlebotomist uses the labels to identify the patient and verbally confirms the patient's identification. 5) The sample is collected. 6) The phlebotomist double checks the patient's identification. The sample is labelled. 7) The sample is delivered to the laboratory.

The workflow designate position was considered stressful due to the amount of multitasking required. In addition to the workflow process described in Figure 1, the workflow designate was responsible for other tasks, including answering phone calls regarding collection and results, faxing results to physician offices, electronically entering blood work orders for extended care units, ensuring phlebotomists got breaks on time, and receiving samples from phlebotomists at ABC Hospital and referred-in samples from other hospitals. The multiple duties of the workflow designate resulted in delays in

samples being received and delivered to various departments, therefore increasing the TATs for laboratory results. Delays in laboratory test results impact physicians' ability to make accurate treatment and diagnosis decisions and may lengthen the patient's stay in the hospital (Green, 2013).

Solution to the problem. Possible solutions to reduce patient identification errors include providing procedure-specific education, standardizing or streamlining the process, and mistake-proofing the process (Novis, 2011). Studies have been conducted to determine the impact of education on patient identification procedures. These studies show short-term success (Kemp, Bird, & Barth, 2012); however, no long-term data are available. Standardizing the process involves providing written procedures, policies, and protocols that detail responsibilities to prevent improvisation. Procedures should be streamlined such that they can be performed only one way. Laboratory standards are issued by the International Organization for Standardization (ISO) and the Clinical Laboratory Standards Institute (CLSI), and all laboratories adhere to these standards to maintain accreditation. Patient identification standardization procedures have been in effect at ABC Hospital laboratory since it was opened, meeting the accreditation requirements of ISO, CLSI, and the Diagnostic Accreditation Program (College of Physicians and Surgeons of British Columbia, n.d.).

PPID is a method to mistake-proof the patient identification process. As Morrison et al. (2010) noted, it entails the correct identification of a patient and the complete linking of all specimens to the patient throughout the analytical process, including collection (pre-analytical), analysis, and reporting (post-analytical). PPID utilizes a

barcode scanner to confirm the patient's identification. This automated system helps prevent phlebotomists from collecting blood from the wrong patient (Brown, 2012).

In the PPID workflow process, the system notifies phlebotomists of any collections required on the ward they are collecting on. Scanning the patient's wristband and confirming the patient's ID results in sample labels being printed. The phlebotomist procures the specimen and applies the labels to the collection tubes. The phlebotomist then scans each collection tube label, which changes the status assigned to the samples as "collected." If the phlebotomy was unsuccessful, the phlebotomist assigns the status "unable to collect" to the sample. Collected samples are then sent to the laboratory, logged in Meditech as received (indicating the samples have arrived in the laboratory), and forwarded to the department performing the testing (see Figure 2).

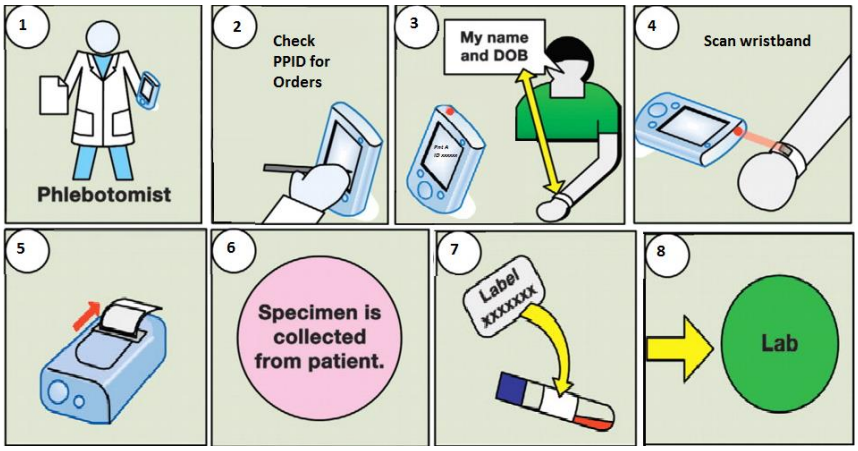

Figure 2. A summary of the PPID workflow process.

1) PPID device alerts the phlebotomist of pending collections. 2) The phlebotomist reviews orders on the PPID device. 3) The phlebotomist uses the PPID demographics to identify the patient and verbally confirms the patient's identification. 4) The PPID system allows the phlebotomist to scan the patient's wristband. 5) Scanning results in sample labels being printed. 6) The phlebotomist procures the specimen. 7) The phlebotomist double checks the patient's identification, and the sample is labelled. The phlebotomist then scans each collection tube label, resulting in the status "collected" to be assigned to the samples. If the phlebotomy was unsuccessful, the phlebotomist assigns the status "unable to collect" to the samples. 8) The sample is delivered to the laboratory.

Advantages and disadvantages of PPID. One of the advantages of the PPID system is that if the patient is wearing the correct wristband, laboratory errors due to patient identification errors should decrease (Morrison et al., 2010). This would result in patients, physicians, phlebotomists, and laboratory technologists having greater confidence in laboratory results (Green, 2013). Murphy and Kay (2004) found that phlebotomists were less likely to get distracted when performing patient identification procedures when using PPID; this finding is likely still relevant. Fewer distractions while checking patients' identification reduced the number of identification errors.

Another advantage of PPID is a reduction in the stress levels of the workflow designate. The workflow designate would not need to call phlebotomists for additional blood work because the system alerts the collector of all pending collections. The system could potentially decrease the number of phone calls the workflow designate has to make to collectors to determine location and status of a collection, allowing the workflow designate to focus on answering phone calls and receiving and distributing samples to the appropriate department for testing.

Ideally, samples would reach the appropriate department for testing more quickly after being received in the laboratory, resulting in a decrease in TAT (from time received to results). A decreased TAT means that results would be available for clinicians more quickly, and treatment, diagnosis, or discharge decisions could be expedited. Advantages realized by phlebotomists include real-time visualization of pending orders on the PPID device and ability to merge duplicate orders.

One disadvantage of using a PPID system is a false sense of security that no identification errors will occur during collection as patient identification is performed by

the PPID software. Tan et al.'s (2017) study revealed a decrease in patient identification rates, but complete elimination of patient identification error rates was not observed. Phlebotomists may become dependent on the technology and not perform a thorough visual check of the patient's identification. A patient wearing an incorrect wristband would be incorrectly identified if the phlebotomist relied solely on a barcode scanner.

There are also risks involved in over-reliance on the system. The scanner may misread labels if the barcode is corrupted (dirty or fading); therefore, the phlebotomist must ensure that the labels match the wristband and perform a verbal confirmation of the patient's identification. If the system crashes or if the patient does not have a wristband, the phlebotomy may be delayed if the phlebotomist does not know what to do without the PPID system. To ensure that phlebotomists remember patient identification procedures if the PPID device is not functioning, downtime procedures must be communicated.

PPID specifications. PPID uses handheld barcode scanners to scan wristbands. In this section I describe the specifications for the PPID device used by ABC Hospital (other variations in the process exist depending on the manufacturer and the laboratory information system being used by the site). The scanner's software, Mobilab, communicates with the laboratory information system and the printers through a wireless connection. The label printers used by PPID were compatible with the existing sample collection labels in use at ABC Hospital. Mobilab is manufactured by Iatrics Systems (Granata, 2011) and is compatible with Meditech. The software requires the phlebotomist to log in with a username and password to protect patient information. The system logs out the phlebotomist after 15 minutes of inactivity to prevent unauthorized users gaining

to access patient information. Information is bidirectionally encrypted between Meditech and the barcode scanner software.

Mobilab categorizes samples as ordered, collected, or received. Given that a requisition (a request for blood work) may include more than one sample, Mobilab tracks samples at the sample tube level (rather than just the requisition level) to ensure all the tubes have been collected, not just the partial requisition. Mobilab allows the phlebotomists to choose which ward they are located in and customize their location depending on the areas they are designated to collect from. Further, Mobilab sorts patients by location, room, and bed number.

Samples requiring collection are sorted by priority as urgent, STAT, routine, or timed, and the system flags if a sample collection is overdue. Urgent collections must have results within 60 minutes of being collected, and STAT collections must have results within 30 minutes. From the placement of the order to the test results, the allowable TAT for a routine collection is 24 hours. Order entry allows ordering personnel to decide the time of collection (commonly ordered for therapeutic drug monitoring); these collections are defined as timed collections. The sample ideally should be collected with 15 minutes of the defined time. Overdue parameters are defined specifically for each collection priority.

Mobilab software allows the phlebotomist to input comments (e.g., unable to collect, collected from IV side, IV turned off, patient refused). The system also allows phlebotomists to override the barcode scanning, after being prompted to answer a few questions prior to bypassing, to perform critical collection of samples if a wristband is not available (e.g., trauma patients in the emergency room who do not have wristbands).

Using the Mobilab software, the user responsible for workflow can review all uncollected orders on a desktop computer screen.

Research Objectives

Purpose. The purpose of the study was twofold. The first objective was to determine the impact of the implementation of PPID on pre-analytical quality indicators. Pre-analytical quality indicators included pre-analytical identification, TATs, and staff efficiency. The second objective was to determine the rate of pre-analytical identification errors that occurred during phlebotomy pre- and post-implementation.

Research questions. Two specific questions guided my research:

1. In samples collected by phlebotomists at ABC Hospital, did implementation of PPID decrease pre-analytical laboratory identification error rates compared to pre-implementation identification error rates? I hypothesized that error rates would decrease due to the extra safeguards in place in the PPID workflow process. These safeguards include an electronic check of the wristband via the handheld PPID device's barcode scanning technology and bedside label printing (to minimize the risk of mislabelling samples).
2. In samples collected by phlebotomists at ABC Hospital, did the implementation of PPID improve TAT rates compared to pre-implementation? My hypothesis was that TATs would initially increase because of the change in complexity of the phlebotomists' workflow procedures, the additional steps to follow, and a new technology to adapt to.

Assumptions. A few assumptions underpinned this research. The first assumption I made is that patient identification errors are most likely to occur in the pre-analytical

phase of medical laboratory procedures. Morrison et al. (2010) found that identification error rates during the pre-analytical phase of medical laboratory collection are high as 0.04 to 0.1%. The second assumption I made is that human error is the main cause of identification errors (Noble, 2013; Wallin et al., 2010). This assumption led to the postulation that possible solutions to patient identification errors include emphasizing the importance to phlebotomists of identifying patients using two identifiers, adopting the use of a standard wristband within a healthcare system, and providing clear protocols for identifying patients and using the PPID technology (CLSI, 2017). I also assumed that PPID technology introduces safeguards in the patient identification process to decrease identification errors. These assumptions informed my decision to understand the impact of PPID technology on the pre-analytical phase of laboratory analysis. My final assumption was that three months of pre-implementation data would be representative of the remaining nine months of the year and that the phlebotomists followed standard operation procedures.

Significance of the Study

Overall significance. Laboratory quality efficiency indicators and patient identification error rates affect patient safety and patient care. Rapid TATs and increased collections per hour (by phlebotomists) allow for timely treatment and diagnoses. Decreased patient identification error rates improve patient safety by reducing the risk of incorrect treatment or diagnosis due to incorrect results.

Implications for laboratory science. Reviewing efficiency indicators such as TATs and identifying steps to reduce error rates would allow policymakers to run a cost–benefit analysis on the effectiveness of PPID. The outcomes of this study contribute to

the knowledge base of PPID and may also inform accreditation boards' decision to implement PPID.

Chapter 2: Review of the Literature

Laboratory Quality and Testing

Laboratory quality is defined as the accuracy, reliability, and timeliness of reported test results (WHO, 2014). Laboratory test results are used in clinical and public health settings, and patient outcomes depend on the accuracy of testing and reporting. It is thought that 60 to 70% of medical decisions are made based on laboratory results (Green, 2013). Incorrect results can result in unnecessary treatment, failure to provide appropriate treatment, delay in diagnosis, and unnecessary diagnostic tests. These consequences can result in an increased cost in the form of lost time, wasted personnel effort, and poor patient outcomes (WHO, 2014).

As noted in Chapter 1, laboratory testing has three phases: pre-analytical, analytical, and post-analytical (Morrison et al., 2010). The pre-analytical phase refers to the steps involved from ordering laboratory tests to preparing the sample for testing. The analytical phase includes all steps involved in the sample analysis. The post-analytical phase covers the steps involved in reporting test results and issuing an interpretation of them. Laboratory errors are defined as any defects that occur during the testing process, from ordering tests to reporting results, that influence the quality of laboratory services (Green, 2013).

Pre-Analytical Errors

In the past, laboratory quality assurance has focused on the analytical phase (Noble, 2013). In the past 10 years, a 10-fold reduction in the analytical error rate has been noted due to improved reliability and standardization of analytical techniques, reagents, and instrumentation (Lippi et al., 2013). Advances in technology, quality

control, and quality assurance have contributed to the reduction of diagnostic errors (Lippi et al., 2013). The majority of errors now occur in the pre- and post-analytical phases (Boone, 2007; Morrison et al., 2010). Approximately 75% of total laboratory errors occur during the pre-analytical phase (Green, 2013).

The pre-analytical steps performed outside the laboratory include ordering, collecting, and transporting the sample to the laboratory. The steps internal to the laboratory during the pre-analytical phase include receiving the sample, preparing the sample for testing, and transporting the sample to the appropriate department. The most common pre-analytical errors are hemolysis (the destruction of red blood cells), incorrect patient identification, insufficient sample volume, clotted samples, incorrect tube, incorrect sample volume, and lost samples (Grecu, Vlad, & Dumitrascu, 2015). When errors occur, 26% of them result in unnecessary investigations or inappropriate treatment (Green, 2013).

Of the laboratory errors that occur during the pre-analytical phase, patient identification errors account for 27% (Patra, Mukherjee, & Das, 2013). Labelling errors account for 56% of all identification errors, and 10 to 20% of patient identification errors result in patient harm (Lippi, Mattiuzzi, et al., 2017). Identification errors are made at a higher rate by nonlaboratory staff collecting samples (Salinas et al., 2009).

Laboratory errors happen in all laboratories, and it is not possible to prevent all of them. However, it is possible to reduce their occurrence, detect and resolve them sooner, and reduce the risk of repeating the same error (Noble, 2013). The pre-analytical phase is highly dependent on manual procedures. Phlebotomists are healthcare workers trained to draw blood from a patient for clinical or medical testing. They are responsible for

identifying the patient, collecting the sample, and labelling the sample. The human role in sample collection makes the complete elimination of errors associated with laboratory testing impossible (Rana, 2012). Factors contributing to these errors include similar patient identifiers, familiarity of the patient, incorrect labelling of the specimen, heavy workloads, missing wristbands, failure to check wristbands, and individual behaviour, such as noncompliance with recommendations and use of shortcuts and work-arounds (WHO, 2007).

Solutions for Identification Errors

To decrease identification errors, the WHO (2007) recommended healthcare organizations take several precautionary measures: emphasize to healthcare workers their responsibility to identify patients using two identifiers, use standard wristbands within a healthcare system, provide clear protocols for identifying patients who lack identification or for comatose patients, encourage patients to participate in the identification process, label patient samples in the presence of the patient, and provide clear protocols for maintaining patient samples throughout the pre-analytical, analytical, and post-analytical phases. The WHO (2007) recommendations are consistent with the accreditation requirements of laboratory standard and accreditation associations such as the CLSI (2017) and the Diagnostic Accreditation Program (College of Physicians and Surgeons of British Columbia, n.d.).

Accurate patient identification is necessary to prevent medical errors. Identification errors can result in inappropriate management, treatment, or diagnosis, and possibly result in patient harm (Lichenstein et al., 2016). Damir, Dhatt, James, Matarelli, and Sankaranarayanan (2011) reported that there are 98,000 deaths in U.S. hospitals

annually due to identification errors. I could not find published Canadian statistics for identification error rates. Three basic strategies exist to minimize errors: education, standardization/streamlining, and mistake-proofing (Novis, 2011). All laboratories must adhere to these standards to maintain accreditation (CLSI, 2017; College of Physicians and Surgeons of British Columbia, n.d.).

Kemp et al. (2012) implemented a short-term intervention on wards (or departments) in two controlled trials at three hospitals in an attempt to decrease pre-analytical errors. The short-term intervention consisted of designing a poster to educate staff on the reasons for following phlebotomy protocols. The posters were explained to the senior nurse and displayed in phlebotomy supply rooms and in nurses' and doctors' rooms for two weeks in one hospital. During this two-week period, informal qualitative interviews were held to determine which staff were involved in phlebotomy and their level of awareness of phlebotomy errors (Kemp et al., 2012). The remaining two hospitals were treated as the control group. Kemp et al. then compared pre-analytical error rates before and after the intervention. Their statistical analysis revealed no significant impact from the intervention. Long-term studies of the implementation of interventions to reduce patient identification errors have not been performed; therefore, it is difficult to ascertain the sustainability of the effects of an intervention (Hayden et al., 2008).

Salinas et al. (2009) implemented a system of statistical process control that involved collecting data on rejected samples for 35 months. A report was generated each month and forwarded to the collection centre to share with the phlebotomists. The head of the laboratory held quarterly meeting to discuss the statistics with the phlebotomists.

Salinas et al. stated that a decrease of rejected samples was seen post-implementation. However, data were collected only for approximately two months post-implementation, and findings do not indicate if the changes were sustained for longer than two months or if participating staff returned to their original collection practices.

Morrison et al. (2010) identified PPID as a possible solution for identification errors by correctly identifying a patient and linking all specimens to that patient throughout the entire analytical process. Automating the system by using a barcode scanner to confirm the patient's identification and scanning that information wirelessly to generate labels for the patient's blood work prevents common pre-analytical errors.

Positive Patient Identification

The case for PPID. Patient misidentification stems mainly from similar standard identifiers (Lippi, Mattiuzzi, et al., 2017), which are full name and date of birth. The risk increases in neonatal and maternity units, where multiple births may occur (Gray et al., 2006). Laboratory identification policy requires the phlebotomist to confirm that both identifiers match the specimen label and/or requisition. Also, the phlebotomist must verbally confirm the spelling of the patient's full name and ask the patient to state his or her date of birth (Canadian Standards Association, 2012); however, identification errors are still noted. A possible cause of these errors could be deviation from the policy due to high workload.

The PPID system prompts phlebotomists to confirm the patient's identification after scanning the wristband. Unless phlebotomists both scan the wristband and confirm the patient's identity, they will not be able to obtain sample collection labels. A procedure does exist to print labels if a patient does not have a wristband; however, it is lengthy,

requiring phlebotomists to answer a series of prompts before a label is generated. The software is intentionally designed to discourage phlebotomists from deviating from laboratory policy.

Most PPID software generates a real-time outstanding list of pending blood tests on the handheld barcode scanning device. This pending list can be used to track orders and decrease the risk of two collectors collecting the same sample. The pending lists are normally colour coded to indicate if any time sensitive order is overdue (STAT, urgent, or timed), and they can be used to ensure that therapeutic drug levels are collected at the appropriate time. The software also issues an alert when a STAT order is entered. This feature ensures that the phlebotomist is aware of a STAT order immediately, instead of relying on communication from the laboratory via phone or pager.

Use of PPID. In 1988, Karen Lounge first demonstrated the use of an integrated system for applying a barcoded wristband and using it to follow the patient through the entire admission procedure at the American Hospital Association annual meeting (Aller, 2005). This was one of the first documented accounts of using PPID and was a benchmark finding. In the next few years, several laboratory information system vendors introduced PPID systems for phlebotomy (Aller, 2005).

Although PPID may significantly reduce identification errors, it was not adopted widely because laboratories were not interested (Aller, 2005). Reasons for lack of interest were that laboratories did not acknowledge that they made patient identification errors, clients were not complaining about patient identification errors, and the laboratories had other pressing priorities. Today it is recognized that identification errors do occur and

PPID may decrease their rate; thus, laboratories have begun embracing the technology (Ning et al., 2016).

Morrison et al. (2010) implemented a barcode-based PPID system for phlebotomy and used a before-and-after design to evaluate the impact of the identification system on mislabelled and unlabelled samples in the laboratory. Their study revealed that errors dropped from 5.45 errors in 10,000 patients to 3.2 errors in 10,000 (Morrison et al., 2010). In one year, an estimated 108 patient identification errors were prevented. After the implementation, a greater number of patients reported having their wristbands checked, although the authors noted that phlebotomists used the technology only 85% of the time due to the short life of the battery. Before PPID, auditing data such as time of collection and the phlebotomists' identification were not always legible, but with the implementation of PPID, auditing data were printed clearly on the labels generated. No change in collection times was observed. Morrison et al. implemented their study on a site that used paper-based requisitions. The authors noted that during the second phase, they planned to introduce electronic requisition orders (Morrison et al., 2010).

In 2016, Ning et al. published a 10-year retrospective study of patient identification errors. Their study incorporated multiple measures to reduce patient identification errors, varying from rejecting unlabelled samples to introducing PPID. They revealed that a 32% reduction in errors was noted after the implementation of PPID (Ning et al., 2016).

A peer-reviewed abstract from the Summer Institute of Nursing Informatics revealed that nursing and laboratory staff of a large academic hospital successfully implemented PPID (Stein et al., 2011). The aims of the project were to decrease patient

identification errors, reduce labelling errors, and prevent unnecessary blood collection due to duplication of orders. The outcomes were reduced labelling errors, decreased laboratory processing times, and decreased duplicate orders.

Implications for laboratory professionals. Decreased patient identification errors result medical laboratory technologists having increased confidence in the results they are reporting. Decreased rates of identification errors may also result in fewer samples needing to be recollected, therefore resulting in savings of supplies and resources. However, if TATs are increased as a result of using PPID, it is possible that results would be delayed. This would increase the burden of cost on the healthcare system with longer patient stays due to delays in treatment or diagnosis (Green, 2013).

The WHO (2007) has identified some possible risks of using PPID, including reliance on technical solutions without adapting to new workflow processes, reliance on an imperfect solution as if it were perfect, technical solutions distracting from the basic process of care, elimination of visual confirmation of patient identity, and the possibility of compromising patient confidentiality.

Data Gaps

Most errors in laboratory medicine occur in the pre-analytical phase and result from human mistakes (Wallin et al., 2010). As noted above, patient identification errors can result in reporting erroneous results and may have negative consequences to the patient (Söderberg, Brulin, Grankvist, & Wallin, 2009). Tan et al. (2017) have shown that PPID technology can reduce identification errors without significantly compromising the speed of sample collection. However, Tan et al.'s study simultaneously introduced other interventions, such as an electronic requisition system. Therefore, it is difficult to infer

from their findings that their results, such as the improved TAT, were due to implementation of PPID.

Other gaps in the literature show that accepted research and data for implementing PPID technology are insufficient, as is the economic rationale regarding cost–benefit analysis or return on investment. However, studies have noted that a reduction in patient identification errors would result in a more cost-effective healthcare system (Randell & Schneider, 2013). The present study helps to fill the gap by providing data on the impact of PPID on medical laboratory pre-analytical quality indicators.

Chapter 3: Methods

In this chapter, I describe the quantitative design I used to collect and analyze descriptive data to determine the impact of PPID on pre-analytical laboratory patient identification error rates and TATs at ABC Hospital.

Design and Data Sources

I used a retrospective one-group pretest–posttest study design. I selected a retrospective design because PPID technology had already been implemented at ABC Hospital's laboratory, and I used the pretest–posttest format to determine if changes were observed in pre-analytical patient identification error rates and TATs following its implementation. To answer the research questions, I conducted my retrospective cohort analysis using data derived from Meditech and the Patient Safety Learning System (PSLS). Meditech allows physicians and nurses to order tests and access laboratory results; enables laboratory personnel to review pending orders, edit orders, and report test results; and stores laboratory quality indicators. PSLS is "a web-based patient safety event reporting, learning and management tool used by care providers across British Columbia. Data are stored in one database and the information is shared with healthcare leaders across the province" (BCPSLS Central, n.d., para. 1).

Using quantitative methods, I sought to determine the impact of PPID on the rate of identification and labelling errors during the phlebotomy process. Specimen identification error rates were compared to published error rates detected at 0.04 to 0.1% (Morrison et al., 2010) to determine if the population sampled in this study is generalizable to other medical laboratories. I also measured pre-analytical error rates pre- and post-implementation to ensure that the PPID device was impacting identification

error rates. Finally, I reviewed TATs to determine if phlebotomy collection efficiency was impacted by the use of PPID.

The experiment group data were inpatient and emergency department sample collection data collected by phlebotomists at ABC Hospital laboratory. In March 2017, I went to ABC Hospital laboratory to collect data from the appropriate databases with the help of the laboratory information systems technologist responsible for maintaining the PPID software. Sample data were collected from September 2013 to September 2014. PPID technology was implemented on December 10, 2013. Baseline data for the Pre-Implementation Phase were collected from September 1, 2013, to November 30, 2013 (3 months of baseline data). Post-Implementation Phase 1 data were collected from January 1, 2014, to March 31, 2014 (the three-month period immediately post change). Finally, Post-Implementation Phase 2 data were collected from April 1, 2014, to September 30, 2014 (the six-month period three to nine months post-implementation). I separated the post-implementation measurements into two phases to see if any changes were noted between the earlier and later time periods (I reviewed a total of nine months of post-analysis data). I expected that the effect of PPID may change because the workflow procedures had changed, and phlebotomists' familiarity with PPID would increase as time passed.

Study Population

The study took place in ABC Hospital, an acute care hospital, and the population represented by the data varied from pediatric to geriatric patients. The population data included all patients with varying conditions, such as renal, oncological, and cardiological.

Inclusion criteria. I included all laboratory-procured phlebotomy sample collection data for STAT and urgent collections from inpatient wards and the emergency department at ABC Hospital. Anonymous laboratory quality indicator data were extracted based on the collected data of patients admitted to the hospital from September 1, 2013, to September 30, 2014.

Exclusion criteria. I excluded outpatient collection data because outpatients are not identified by a wristband; therefore, PPID technology cannot be utilized. I also excluded samples collected at extended units not located on ABC Hospital campus, due to the unavailability of wireless Internet connection to support PPID devices. Any collection data that had a negative TAT or were greater than 24 hours were excluded. A negative TAT is not a true value (it occurs when an order is placed after a sample has been collected), and TAT times greater than 24 hours indicate that the test was ordered 24 hours in advance (and therefore was not a true STAT or urgent collection).

Description of Variables

The independent variable was PPID implementation, and the dependent variables were the rate of patient identification errors and TATs. Rate of patient identification errors is the percentage of patients incorrectly identified by the medical laboratory during the pre-analytical phase of medical laboratory testing. Patient identification error rates are continuous ratio data. TAT is the time it takes to collect a priority sample, from when it is ordered to when it is received in the laboratory. I broke the TAT data down into order to collect and collect to receive. TAT data are continuous data.

Uncontrolled variables of interest were staffing levels, time of day of collections (morning, evening, and night shift), and patient demographics (average age, gender,

number of morbidities, number of isolation patients, and number of admitted patients). I obtained patient demographic information for the three phases of the study from health records. The pre- and post-analytical department supervisor provided me with average phlebotomist demographics and staffing level information.

Data Collection and Extraction Procedures

I used Meditech, the laboratory information system, to determine the total volume of collections procured by the laboratory. The PSLS was used to determine the total number of identification errors made by phlebotomists. As noted above, I used PSLS data to determine the rate of errors for the three months prior to implementation of PPID to establish a baseline (September 1, 2013, to November 30, 2013), the first three months post-implementation (Phase 1: January 1, 2014, to March 31, 2014), and the next six months post-implementation (Phase 2: April 1, 2014, to September 30, 2014). To ensure anonymity of patient information, the laboratory manager pulled the reports and provided the summaries to me, without any patient information.

PSLS events are self-reported; therefore, the number of errors reported is likely to be slightly lower than the actual number of errors. Reasons for under-reporting include a reliance on self-reporting, distraction by workload or dealing with the error, hesitance in reporting errors made by oneself or one's coworkers, and near misses that do not translate into direct patient harm because the error was caught prior to reporting results (Lippi, Chiozza, Mattiuzzi, & Plebani, 2017). Errors are typically reported by the person who discovers the error (most commonly, the laboratory technologist notices discrepant results). I expected the under-reporting rate to remain constant given that no additional

PSLS reporting education or promotional information was provided to medical laboratory collectors during the study time frame.

Meditech data were used to generate a report to determine the total volume of collections collected by phlebotomists pre- and post-implementation of PPID, as follows: three months prior to implementation (September 1, 2013, to November 30, 2013), three to six months post-implementation (Phase 1: January 1, 2014 to March 31, 2014), and six to nine months post-implementation (Phase 2: April 1, 2014 to September 30, 2014). Using Meditech, I generated a report to determine the TAT of urgent and STAT orders from three months prior to implementation to nine months post-implementation.

Analysis

Error rates. Error rates at baseline were determined by collecting three months of pre-implementation descriptive data on the number of samples collected. The data collected were discrete, interval data. The descriptive data included the mean, standard deviation, and range of error rates. I also collected descriptive data to determine the average number of samples collected per phase.

I analyzed these data using IBM SPSS Statistics Version 22 (https://www-01.ibm.com/support/docview.wss?uid=swg21646821). To determine the rate of errors at baseline, the average number of errors was divided by the average number of samples collected. I repeated the calculations at one to three months post-implementation and three to nine months post-implementation. I expected that calculations from Post-Implementation Phase 1 would not reflect the true impact of the technology because it would take approximately three months for staff to adapt to the changes in workflow and the implementation of the new technology. To determine if there were significant

differences ($p < 0.05$) in patient identification errors rate means, I performed a chi square (2x3 table).

TATs. Descriptive data including mean, median, and range were collected for TATs; these were continuous, interval data. I again analyzed the extracted data using SPSS version 22. I measured TATs from the time the requisition was ordered to the time the sample was collected. The TATs were averaged for the pre-implementation for STAT and urgent order priority. I repeated these calculations for post-implementation phase 1 and 2.

As with the rate of errors, calculations for TATs post-implementation phase 1 may not reveal the true impact of the technology because it would take staff time to adapt to the changes in workflow and the implementation of the new technology. TATs were analyzed in four parts. The first analysis was to determine if a significant difference exists between TATs of all samples collected from inpatient and emergency areas of the hospital in the three study phases: Pre-Implementation, Post-Implementation Phase 1, and Post-Implementation Phase 2. In the second part of the analysis, I separated the data by location (inpatient and emergency areas of the hospital) to determine if a significant TAT difference was observed in one or both areas. For the third part of the analysis, I performed a one-way ANOVA to see if there was any significant difference observed in the priority of testing (using urgent and STAT data). The fourth part of the analysis involved a two-way ANOVA to determine if a significant difference in TATs was observed during different working hours, using day (07:00–14:59), evening (15:00–22:59), and night (23:00–06:59) shifts.

Regression analysis was performed. The dependent variable was TAT times (order to collect, collect to receive and order to receive) and the predictors considered were phase (pre-implementation, post implementation phase 1 and 2), priority (urgent and STAT) and shift (day, evening, and night). The analysis was separated by location (ER and inpatient collections).

I also collected hospital census data pre- and post-implementation of PPID. This information included the number of hospital visits, phlebotomist staffing levels, the number of samples collected by the laboratory, the number of isolation patients (airborne and contact), and the number of mortalities. Using these data, I determined whether a fluctuation in the census contributed to any changes in patient identification error rates and/or TATs.

Ethical Considerations

I obtained ethical approval for this research from the Research Ethics Board of Fraser Health Authority and Athabasca University (see Appendix A) and an ethics exemption from Athabasca University Ethics Board (see Appendix B). No participants were enrolled in the study. Anonymous data were collected and stored electronically with password protection. The results will be stored on a secured computer belonging to the ABC Hospital laboratory for a period of 5 years after the completion of the study. All data files will be deleted after 5 years. Appendix C summarizes the dissemination plan for the findings of this study.

Chapter 4: Results

In this chapter, I present the results of the data analysis. The two research questions I posed were, "In samples collected by phlebotomists at ABC Hospital, did implementation of PPID decrease pre-analytical laboratory identification error rates compared to pre-implementation identification error rates?" and "In samples collected by phlebotomists at ABC Hospital, did the implementation of PPID improve TAT rates compared to pre-implementation?" Statistical analysis revealed that after the implementation of PPID, patient identification errors were significantly reduced and TAT rates were significantly increased.

Patient Identification Error Rates

Chi square results show a statistically significant reduction in error rates: $_{\chi}^{2}(2) = 10.59$, $p = 0.005$. Table 1 summarizes the error rates documented in the PSLS system. I was not provided patient identification error data with location or priority detail; therefore, I was unable to identify patient location.

I analyzed hospital census data to determine if there was a significant difference observed between the different phases (Pre-Implementation, Post-Implementation Phase 1, and Post-Implementation Phase 2). Table 2 summarizes the phlebotomist staffing levels in the inpatient and emergency areas of the hospital during the various phases. Inpatient staffing levels $_{\chi}^{2}$ (2) = 0.50, $p = 0.780$; emergency department staffing levels $_{\chi}^{2}$ (2) = 0.00, $p = 1.000$; and total staffing levels $_{\chi}^{2}$ (2) = 0.32, $p = 0.854$ were not significantly different. These findings indicate that staffing levels did not significantly increase post-implementation of PPID.

Table 1

Patient Identification Error Rates

	Errors		No errors		Total	
Phase	Count	%	Count	%	Count	%
Pre-Implementation	3*	0.01%	28,862	99.99%	28,862	100.00%
Post-Implementation Phase 1	0*	0.00%	33,914	100.00%	33,914	100.00%
Post-Implementation Phase 2	0*	0.00%	68,010	100.00%	68,010	100.00%
Total	3*	0.01%	13,0783	100.00%	130,786	100.00%

* $p < 0.01$.

Table 2

Inpatient and Emergency Department Phlebotomist Staffing Levels by Phase

Area	Phase	Observed *N*	Expected *N*	Residual
Inpatient staffing	Pre-Implementation	10	12.0	-2.0
	Post-Implementation Phase 1	13	12.0	1.0
	Post-Implementation Phase 2	13	12.0	1.0
	Total	36		
Emergency staffing	Pre-Implementation	7	7.0	0.0
	Post-Implementation Phase 1	7	7.0	0.0
	Post-Implementation Phase 2	7	7.0	0.0
	Total	21		
Total staffing	Pre-Implementation	17	19.0	-2.0
	Post-Implementation Phase 1	20	19.0	1.0
	Post-Implementation Phase 2	20	19.0	1.0
	Total	57		

I also analyzed collection volumes in the inpatient and emergency areas to determine if there was a significant difference in collection volumes after implementation of PPID (refer to Table 3). Collection volume chi square test results were as follows: inpatient χ^2 (2) = 20,802.12, $p < 0.001$; emergency department $\chi^2(2) = 10{,}242.05$, $p < 0.001$; and total $\chi^2(2) = 10{,}620.40$, $p < 0.001$. These values were all different. A significant increase was observed in the inpatient and emergency volumes.

Table 3

Inpatient and Emergency Department Collection Volumes by Phase

Hospital area	Phase	*N*
Total	Pre-Implementation	28,861*
	Post-Implementation Phase 1	33,914*
	Post-Implementation Phase 2	68,010*
	Total	130,785*
Inpatient collections	Pre-Implementation	14,942*
	Post-Implementation Phase 1	16,319*
	Post-Implementation Phase 2	33,852*
	Total	65,113*
Emergency collections	Pre-Implementation	13,919*
	Post-Implementation Phase 1	17,595*
	Post-Implementation Phase 2	34,158*
	Total	65,672*

* $p < 0.001$.

Hospital census data: sex breakdown and mortality rates of all patients admitted and of admitted patients on isolation precautions was analyzed these to determine if there were any significant changes to the admitted population prior to and after implementation of PPID. Data analysis revealed $\chi^2(2) = 1.04$, $p = 0.595$ admitted patients and $\chi^2(2) = 2.42$, $p = 0.299$ admitted patients on isolation. These results allow for the conclusion that a

significant difference in gender of patients admitted or admitted on isolation protocols did not exist. There was a significant improvement in mortality rates of all admitted patients: $\chi^2(2) = 6.84$, $p = 0.033$. The mortality rate change was not significantly different for admitted patients under isolation precautions: $\chi^2(2) = 3.29$, $p = 0.193$.

Turn-Around Times

Part 1. The descriptive data summary in Table 4 reveals a general increase in TATs for order to collect, collect to receive, and order to collect after implementation of PPID. I performed Levene's statistic for homogeneity of variance; $p < 0.05$ was observed for order to collect, collect to receive, and order to receive. These results indicate that the implementation phases did not have an equal variance.

I then performed a one-way ANOVA analysis to determine if there was a significant difference in the means of the groups. A value of $p < 0.05$ indicated a significant difference of means. The ANOVA revealed significant differences between the phases and TATs. Due to the limitations of the one-way ANOVA, I also computed Welch's F. The computed value of Welch's F was $(2,76530.5) = 130.545$, $p < 0.001$ for order to collect. For collect to receive, Welch's F was $(2,80396.6) = 227.648$, $p < 0.001$. For order to receive, Welch's F was $(2,77233.399) = 260.68$, $p < 0.001$. These values indicate that there was a significant phase effect (Pre-Implementation, Post-Implementation Phase 1, and Post-Implementation Phase 2) on the TAT variables as $p < 0.05$.

Table 4

Turn-Around Times Pre- and Post-Implementation of PPID

Turn-around time	Phase	*N*	*M*	*SD*	Std. Error
Order to collect (min)	Pre-Implementation	28,861	24.99*	50.55	0.30
	Post-Implementation Phase 1	33,914	27.58*	58.67	0.32
	Post-Implementation Phase 2	68,010	31.87*	80.67	0.31
	Total	130,785			
Collect to receive (min)	Pre-Implementation	28,861	11.20*	14.45	0.09
	Post-Implementation Phase 1	33,914	12.43*	21.68	0.12
	Post-Implementation Phase 2	68,010	14.78*	32.76	0.13
	Total	130,785			
Order to receive (min)	Pre-Implementation	28,861	36.19*	53.05	0.31
	Post-Implementation Phase 1	33,914	40.04*	63.25	0.34
	Post-Implementation Phase 2	68,010	46.65*	88.39	0.34
	Total	130,785			

* $p < 0.001$.

In post-hoc ANOVA testing, I used the Bonferroni test to prove significance. The Bonferroni pairwise comparison indicated that all the phases were significantly different from one another: $p < 0.001$. The Student Newman-Keuls test revealed that the means were significantly different. The means for the groups were not grouped together; therefore, they are not equal.

Part 2. Table 5 summarizes the data for the TATs separated by location (emergency and inpatient). The data in the table reveal that TAT values for order to collect, collect to receive, and order to receive all increased. Levene's test of

homogeneity of variances was performed; for both inpatient and emergency collections, a $p < 0.001$ was observed for order to collect, collect to receive, and order to receive TATs.

Table 5

Turn-Around Times Pre- and Post-Implementation of PPID by Location

Location	TAT	Phase	*N*	*M*	*SD*	Std. Error
Emergency	Order to collect (min)	Pre-Implementation	13,919	18.22*	21.39	0.18
		Post-Implementation Phase 1	17,595	21.07*	21.80	0.16
		Post-Implementation Phase 2	34,158	19.26*	20.46	0.11
		Total	65,672			
	Collect to receive (min)	Pre-Implementation	13,919	10.85*	10.92	0.09
		Post-Implementation Phase 1	17,595	12.64*	17.05	0.13
		Post-Implementation Phase 2	34,158	14.36*	22.96	0.12
		Total	65,672			
	Order to receive (min)	Pre-Implementation	13,919	29.07*	24.18	0.21
		Post-Implementation Phase 1	17,595	33.71	28.24	0.21
		Post-Implementation Phase 2	34,158	33.62	31.18	0.17
		Total	65,672			
Inpatient	Order to collect (min)	Pre-Implementation	14,942	31.28*	66.53	0.54
		Post-Implementation Phase 1	16,319	34.60*	80.91	0.63
		Post-Implementation Phase 2	33,852	44.60*	111.04	0.60
		Total	65,113			
	Collect to receive (min)	Pre-Implementation	14,942	11.53	17.09	0.14
		Post-Implementation Phase 1	16,319	12.20	25.76	0.20
		Post-Implementation Phase 2	33,852	15.20	40.29	0.22
		Total	65,113			
	Order to receive (min)	Pre-Implementation	14,942	42.82*	69.28	0.57
		Post-Implementation Phase 1	16,319	46.79*	85.82	0.67
		Post-Implementation Phase 2	33,852	59.80*	119.82	0.65
		Total	65,113			

* $p < 0.001$.

I then performed a one-way ANOVA to determine if the significance in TATs was observed in the inpatient or emergency patient samples. For inpatient and emergency samples, $p < 0.001$ was observed, indicating a significant increase in TATs. The Welch's F test revealed a significant difference in TATs. For the emergency patient population, Welch's F for order to collect was (31888.179) = 72.59, $p < 0.001$; collect to receive was (39847.149) = 262.58, $p < 0.001$; and order to receive was (35413.894) = 176.26, $p < 0.001$. For the inpatient population, Welch's F for order to collect was (38420.339) = 140.48, $p < 0.001$; collect to receive was (39784.350) = 101.14, $p < 0.001$; and order to receive was (38682.652) = 202.33, $p < 0.001$.

A Bonferroni test revealed a significant difference in the means of TAT data for all three phases for inpatient and emergency populations, with $p < 0.001$, except for order to receive data for emergency patients and collect to receive data for inpatients. The Student Newman-Keuls test revealed that the means were significantly different, apart from order to receive data for emergency patients. The Student Newman-Keuls test further revealed that the emergency patient data for order to receive for Post-Implementation Phases 1 and 2 were grouped together.

Part 3. For the third part of the analysis, I further separated data from Part 2 into urgent and STAT priorities. Table 6 summarizes the descriptive values for TATs separated by location and priority of collection. I performed Levene's test for homogeneity of variance to test for equivalence of variation; $p < 0.001$ was observed for all TATs except for STAT order to collect. Those latter TATs were not significantly different during the three implementation phases.

Table 6

Turn-Around Times Pre- and Post-Implementation of PPID by Location and Priority

Location	Priority	TAT (min)	Phase	*N*	*M*	*SD*	Std. Error
Emergency	Urgent	Order to Collect	Pre-Implementation	13,472*	18.39	21.60	0.19
			Post-Implementation Phase 1	16,527*	21.37	22.12	0.17
			Post-Implementation Phase 2	32,259*	19.45	20.57	0.11
		Collect to Receive	Pre-Implementation	13,472*	10.85	10.91	0.09
			Post-Implementation Phase 1	16,527*	12.83	17.41	0.14
			Post-Implementation Phase 2	32,259*	14.44	21.60	0.12
		Order to Receive	Pre-Implementation	13,472*	29.24	24.37	0.21
			Post-Implementation Phase 1	16,527*	34.20	28.71	0.22
			Post-Implementation Phase 2	32,259*	33.89	30.32	0.17
	STAT	Order to Collect	Pre-Implementation	447*	13.40	12.87	0.61
			Post-Implementation Phase 1	1,068*	16.44	15.38	0.47
			Post-Implementation Phase 2	1,899*	16.12	18.18	0.42
		Collect to Receive	Pre-Implementation	447*	10.81	11.21	0.53
			Post-Implementation Phase 1	1,068*	9.71	9.26	0.28
			Post-Implementation Phase 2	1,899*	13.00	39.50	0.91
		Order to Receive	Pre-Implementation	447*	24.20	16.96	0.80
			Post-Implementation Phase 1	1,068*	26.15	17.98	0.55
			Post-Implementation Phase 2	1,899*	29.11	43.11	0.99
Inpatient	Urgent	Order to Collect	Pre-Implementation	1,2077*	32.91	68.90	0.63
			Post-Implementation Phase 1	12,830*	36.70	84.25	0.74
			Post-Implementation Phase 2	26,886*	48.51	116.41	0.71
		Collect to Receive	Pre-Implementation	12,077*	11.95	18.34	0.17
			Post-Implementation Phase 1	12,830*	13.01	28.48	0.25
			Post-Implementation Phase 2	26,886*	16.18	42.85	0.26
		Order to Receive	Pre-Implementation	12,077*	44.86	71.86	0.65
			Post-Implementation Phase 1	12,830*	49.71	89.76	0.79
			Post-Implementation Phase 2	26,886*	64.69	125.74	0.77
	STAT	Order to Collect	Pre-Implementation	2,865	24.42	54.95	1.03
			Post-Implementation Phase 1	3,489	26.85	66.69	1.13
			Post-Implementation Phase 2	6,966*	29.50	85.64	1.03
		Collect to Receive	Pre-Implementation	2,865	9.80	10.11	0.19
			Post-Implementation Phase 1	3,489	9.22	10.47	0.18
			Post-Implementation Phase 2	6,966*	11.42	28.02	0.34
		Order to Receive	Pre-Implementation	2,865	34.21	56.32	1.05
			Post-Implementation Phase 1	3,489	36.07	68.37	1.16
			Post-Implementation Phase 2	6,966*	40.92	91.06	1.09

* $p < 0.05$

The one-way ANOVA test revealed a significant difference in the means of TATs for the various phases. The computed values of Welch's F for the TAT for urgent emergency samples were as follows: order to collect (2, 30460) = 74.39, $p < 0.001$; collect to receive (2, 37222) = 283.81, $p < 0.001$; and order to receive (2, 33349) = 182.88, $p < 0.001$. The Welch's F values for the TATs for STAT emergency samples were as follows: order to collect (2, 1356) = 8.90, $p < 0.001$; collect to receive (2, 1375) = 6.89, $p = 0.001$; and order to receive (2, 1521) = 7.42, $p = 0.001$. Welch's F values for the TATs for urgent inpatient samples were as follows: order to collect (2, 30644) = 141.58, $p < 0.001$; collect to receive (2, 31277) = 93.52, $p < 0.001$; and order to receive (2,30816.153) = 200.64, $p < 0.001$. Welch's F values for the TATs for STAT inpatient samples were as follows: order to collect (2, 7633) = 6.15, $p = 0.002$; collect to receive (2, 8493) = 16.90, $p < 0.001$; and order to receive (2, 7721) = 10.30, $p < 0.001$. These values indicate a significant phase effect on the TAT variables when data were separated by location and priority, as $p < 0.05$.

A Bonferroni pairwise comparison and a Student Newman-Keuls test indicated that STAT emergency collections means were significantly different for all phases: $p < 0.05$. For urgent emergency sample collections and inpatient urgent collections, the means were significantly different for all phases. For STAT inpatient collections, no significant difference for Pre-Implementation and Post Implementation Phase 1 was noted. Phase 2 was significantly different than Pre-Implementation and Phase 1.

Part 4. In the fourth part of the analysis, the data were further separated according to the shift in which the blood work was ordered. Using a 24-hour clock, I defined day shift as 07:00–14:59, evening shift as 15:00–22:59, and night shift as 23:00–06:59. A

two-way ANOVA (3x3 design) was performed to determine if TATs were affected by phase (Pre-Implementation, Post-Implementation Phases 1 or 2), shift, or a combination of phase and shift. the data were broken down by TAT indicator: order to collect, collect to receive, and order to receive.

Order to collect. Descriptive values and data analysis revealed a significant interaction between shifts and phases for urgent emergency collections and STAT and urgent inpatient collections. For urgent emergency collections, phase shift effect ($F(4, 62249) = 11.59$, $p < 0.001$) indicates that the shift effect varies with phase or phase varies with shift. The urgent emergency collections pairwise comparison revealed that phase effect significantly varied with day shift and evening shift. Pre-Implementation Phase day shift and night shift did not show a difference in the order to collect mean. For urgent emergency collections, a shift effect that varied with phase was significantly noted for day and evening shift order to collect time. No significant difference was noted for the order to collect time for night shift.

Univariate analysis reveals that phase effect varies with shift. Figure 3 reveals no significant changes were observed for order to collect TATs of emergency urgent samples collected on night shift. On day and evening shifts, an increase in TATs was observed in Post-Implementation Phase 1, followed by a decrease in TATs in Post-Implementation Phase 2.

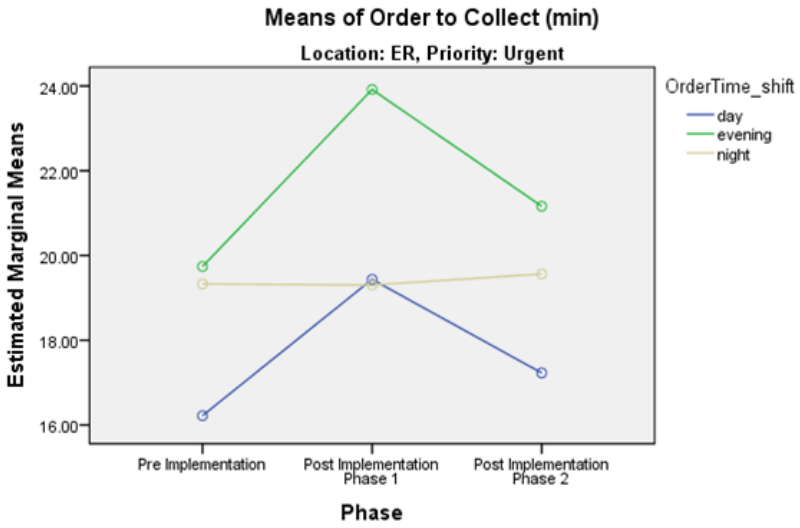

Figure 3. Order to collect and shift interaction on emergency urgent collections.

For emergency STAT collections, phase shift effect ($F(4, 3405) = 1.338$, $p = 0.253$) indicated that a significant interaction between phase and shift does not exist. A statistically significant phase effect was noted ($F(2, 3405) = 4.56$, $p = 0.011$). No shift effect was noted ($F(2, 3405) = 0.12$, $p = 0.887$). There was a significant difference between the means of all phases except for those of Post-Implementation Phases 1 and 2. Figure 4 is a graphical representation of the order to collect TATs of STAT emergency room samples.

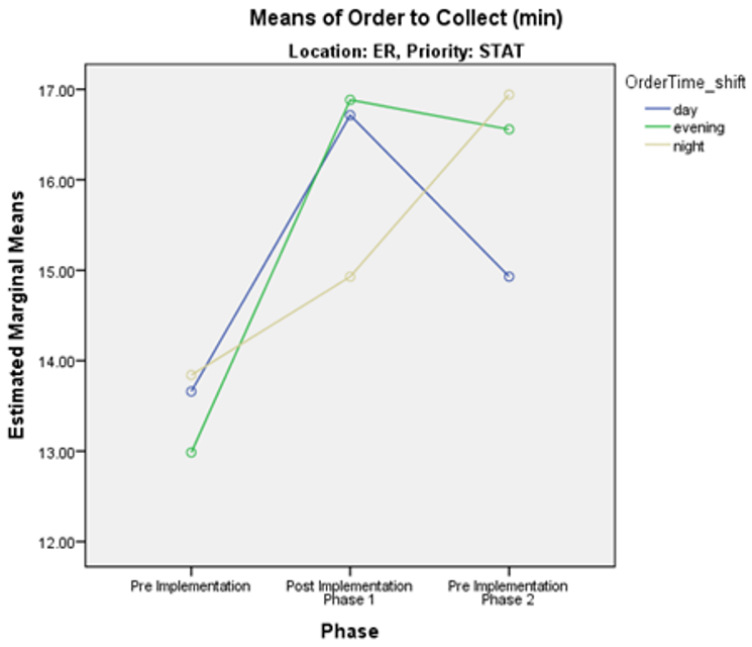

Figure 4. Order to collect TATs and shift interaction on emergency STAT collections.

For urgent inpatient collections, phase shift effect ($F(4, 51784) = 274.72$, $p < 0.001$) indicates that the shift effect varied with phase or phase varied with shift. The urgent inpatient collections pairwise comparison revealed that night shift TAT means were significantly different for all three phases and compared to the other two shifts. Evening shift and day shift means were statistically similar to each other for all phases expect for Post-Implementation Phases 1 and 2 (the means were significantly different). Figure 5 reveals a significant change was observed for order to collect TATs of urgent inpatient samples collected on night shift. On day and evening shifts, a slight increase in TATs was observed in Post-Implementation Phases 1 and 2.

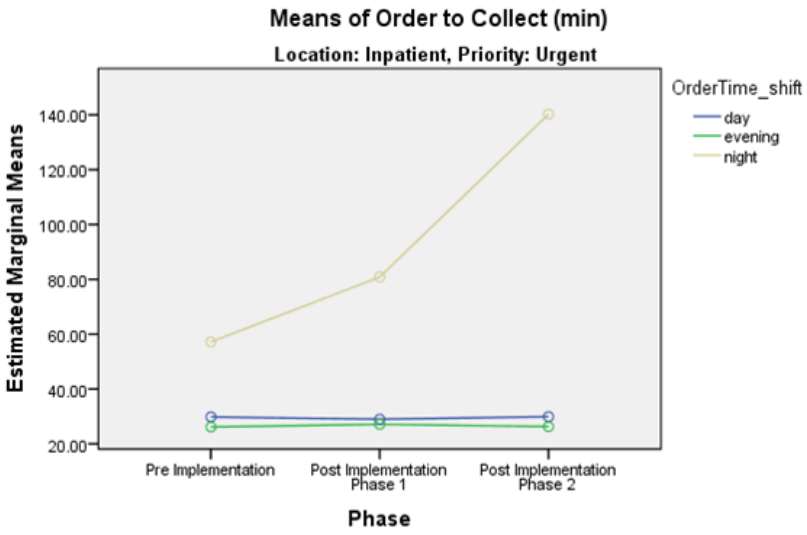

Figure 5. Order to collect TATs and shift interaction on urgent inpatient collections.

STAT inpatient collections phase shift effect ($F(4, 51784) = 274.72$, $p < 0.001$) indicates that the shift effect varied with phase or phase varied with shift. The STAT inpatient collections pairwise comparison revealed that night TAT means were significantly different for all three phases and compared to the other two shifts. Evening shift and day shift means were statistically similar to each other for all phases. Univariate analysis revealed that phase effects varied with shifts. Figure 5 shows that a significant change was observed for order to collect TATs of samples collected on night shift. On evening shift, a slight increase in TATs was observed in Post-Implementation Phases 1 and 2. On day shift, a slight decrease in TATs was observed in Post-Implementation Phases 1 and 2.

A Bonferroni test revealed a significant difference between the means of all phases except for the means of Post-Implementation Phases 1 and 2. For urgent inpatient and emergency collections, there was a significant difference in the means of all three shifts. For STAT collections, no significant difference in means was noted, except for

STAT inpatient evening and day shift collections. The Student Newman-Keuls test revealed that order to collect means for urgent inpatient collections were significantly different, and the means for inpatient urgent collections were significantly different for all three phases.

Inpatient STAT collections were significantly different on night shift than day and evening shift. Inpatient STAT collections for the Pre-Implementation Phase and Post-Implementation Phase 1 were significantly different. Post-Implementation Phases 1 and 2 were not significantly different, nor were Pre-Implementation and Post-Implementation Phase 2. Urgent emergency collections means were significantly different for all three phases and all shifts, but STAT emergency collection means were not significantly different for any of the shifts. The Pre-Implementation Phase mean of STAT emergency samples was significantly different than those of Post-Implementation Phases 1 and 2. The means of the post-implementation phases were not significantly different. Figure 6 summarizes the order to collect phase and shift interactions for inpatient STAT collections.

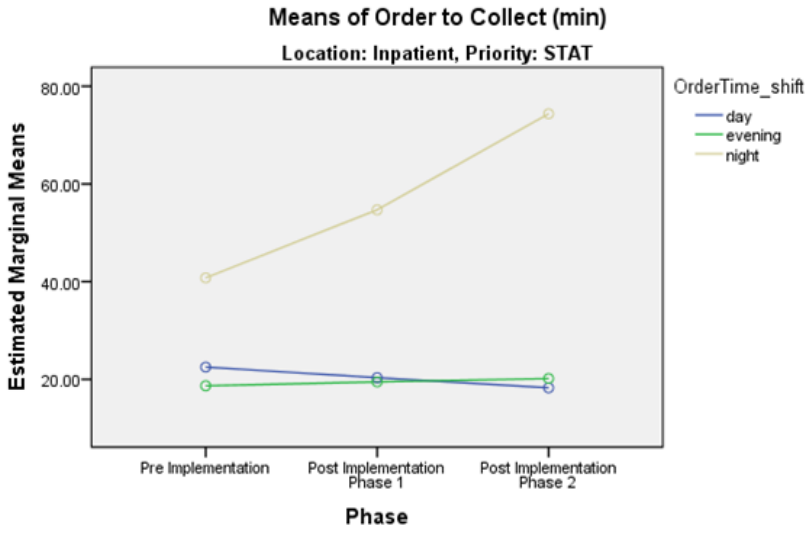

Figure 6. Order to collect TATs and shift interaction on inpatient STAT collections.

Collect to receive. An increase in collect to receive TATs was generally observed, except for inpatient and emergency STAT collections. It appears that in comparison to the Pre-Implementation Phase, TATs decreased in Post-Implementation Phase 1. Post-Implementation Phase 2 TATs for STAT collections were greater than those of Post-Implementation Phase 1 and Pre-Implementation.

There is an interaction between phase and shift. Phase shift effect for urgent emergency collections was ($F(4, 62249) = 2.72$, $p < 0.001$). Urgent emergency collection means of different shifts were similar during the Pre-Implementation Phase, except for the difference during day and evening shifts, which was significantly different. In Post-Implementation Phases 1 and 2, the means were significantly different for all shifts except day and night shift. The phases were significantly different during all shifts. Figure 7 summarizes the interaction between the phases and the different shifts for emergency urgent collections. In general, collect to receive TATs increased as implementation progressed.

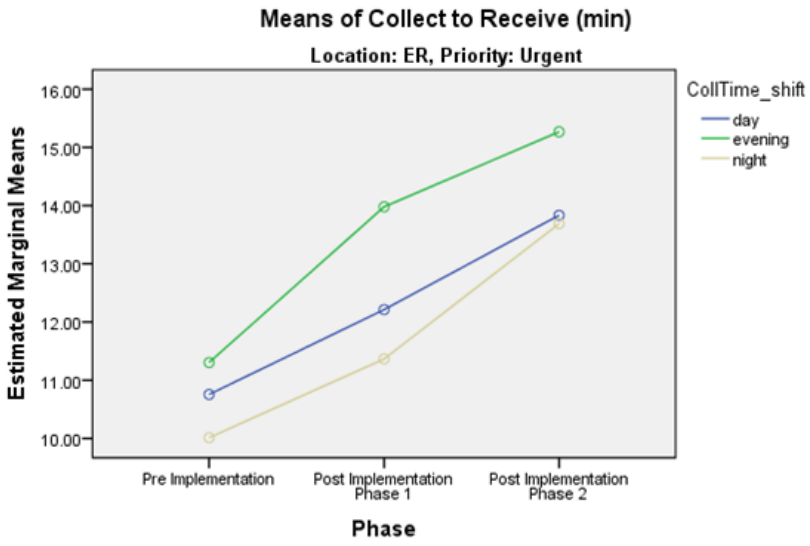

Figure 7. Collect to receive TATs and shift interaction on emergency urgent collections.

A phase and shift interaction for collect to receive STAT emergency collections did not exist ($F(4, 3405) = 0.69$, $p = 0.598$). A significant phase effect was noted ($F(2, 3405) = 3.89$, $p < 0.05$); however, a shift effect was not noted ($F(2, 3405) = 0.58$, $p = 0.560$). The only phase effect for STAT collections appears to be a significant difference in the means of Post-Implementation Phases 1 and 2. Figure 8 is graphical representation of the collect to receive TATs in relation to phase and shift for emergency STAT collections. Generally, TATs for collections on night shift increased as implementation progressed. There was a general trend of evening and day shift collect to receive TATs decreasing during Post-Implementation Phase 1; however, there was a significant increase in TATs during Phase 2.

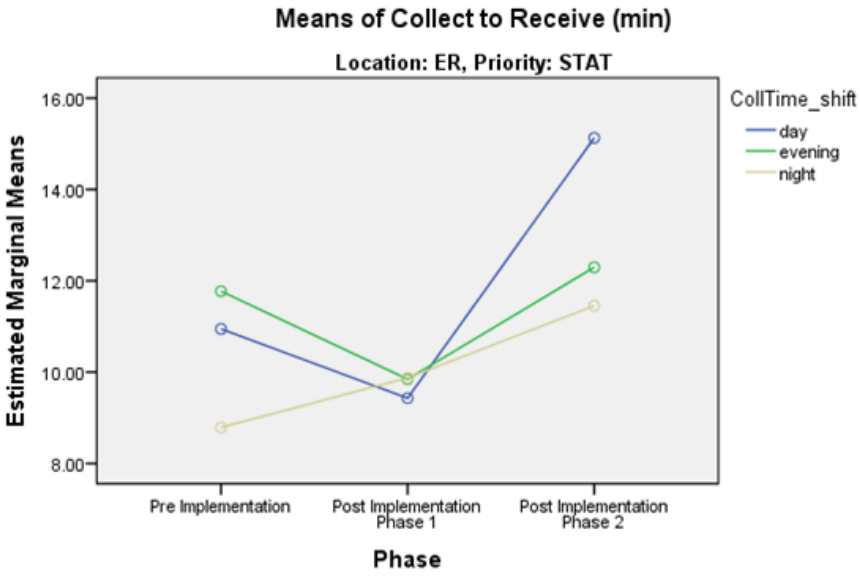

Figure 8. Collect to receive TATs and shift interaction on emergency STAT collections.

A phase and shift interaction can be ruled out for collect to receive TATs for urgent inpatient collections ($F(4, 51784) = 0.46$, $p = 0.760$). A significant shift effect

(F(2, 51784) = 9.70, $p < 0.001$) and a significant phase effect (F(2, 51784) = 59.98, $p < 0.001$) were both noted (independent of interaction). There was a significant difference between TATs of all phases except Pre-Implementation and Post-Implementation Phase 1. A significant difference between the means of the shifts was noted, except for evening and night shift. Figure 9 summarizes the relationship between phase and shift for inpatient urgent collections. The collect to receive TATs increased for all three shifts as implementation proceeded.

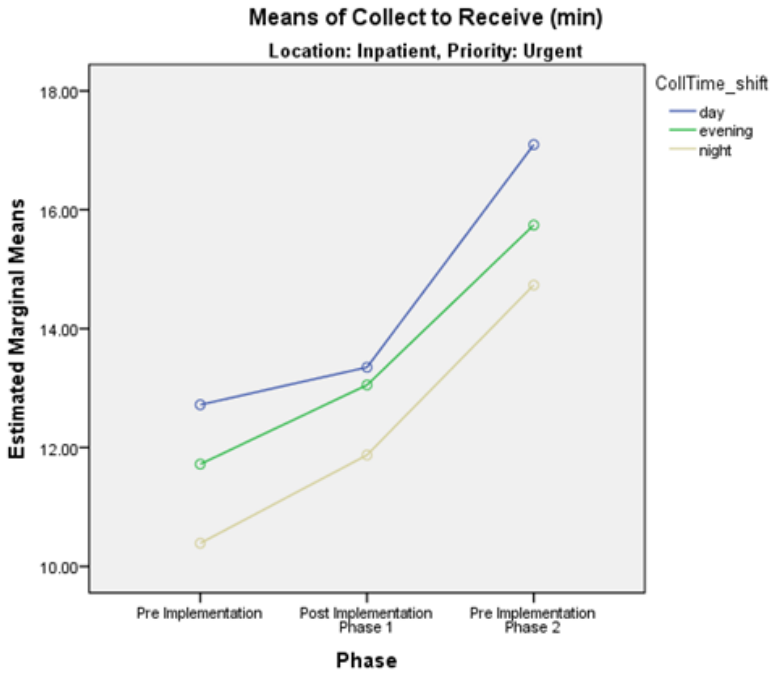

Figure 9. Collect to receive TATs and shift interaction on inpatient urgent collections.

A phase and shift interaction can be ruled out for collect to receive TATs for STAT inpatient collections (F(4, 13311) = 1.01, $p = 0.402$). A significant shift effect (F(2, 13311) = 8.780, $p < 0.001$) and a significant phase effect (F(2, 51784) = 9.00, $p < 0.001$) were both noted (independent of interaction). There was a significant difference between TATs of all phases except Pre-Implementation and Post-Implementation Phase

1. A significant difference between the means of the shifts was noted, except for a difference between the evening and day shift.

Figure 10 summarizes the collect to receive TATs observed for inpatient STAT collections as implementation progressed, which increased for all three shifts. TATs for collections on night shift increased throughout the phases. TATs for evening and day collections decreased during Post-Implementation Phase 1; however, there was a significant increase during Phase 2.

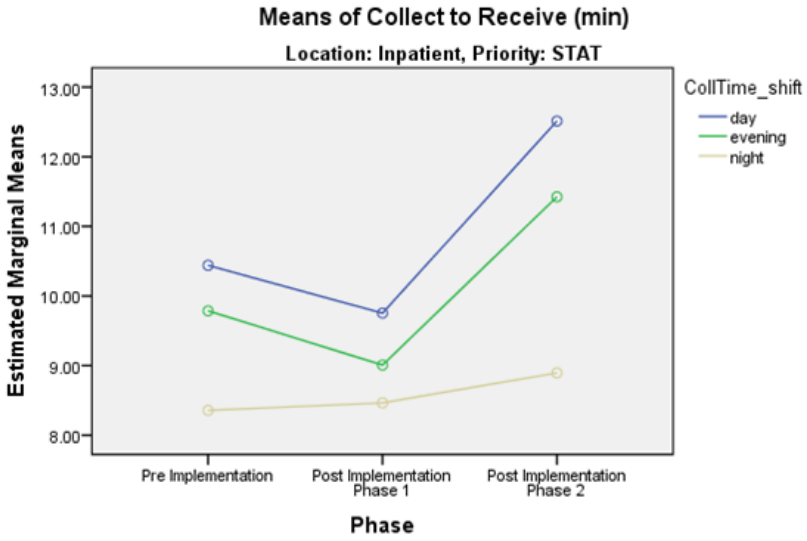

Figure 10. Collect to receive TATs and shift interaction on inpatient STAT collections.

A Bonferroni phase analysis revealed that the collect to receive means of the urgent emergency collections were significantly different. For STAT emergency collections, there was no significant difference between means except for the means of Post-Implementation Phases 1 and 2. For urgent and STAT inpatient collections, a significant mean difference was noted for all phases except between the Pre-

Implementation and Post-Implementation Phase 1. Urgent inpatient and emergency inpatient collections revealed significantly different means for all shifts, except between the means of day and night shift collections for urgent emergency collections. In that case, no difference in mean was noted. For emergency STAT collections, all means were significantly similar. Inpatient STAT collections were significantly different except for the means of day and evening shift samples. These results were confirmed by the Student Newman-Keuls test.

Order to receive. A phase shift effect interaction exists for order to receive urgent emergency patient samples ($F(4, 62249) = 15.18$, $p < 0.001$). All mean differences were significantly different for all phases and shifts for urgent emergency collections, except for the difference between evening and night shift; here no significant difference was noted. All shifts had a significant mean difference for all phases except for day shift (a significant difference did not exist between Post-Implementation Phases 1 and 2). Also, no significant difference was noted on night shift for Pre-Implementation or Post-Implementation Phase 1.

Figure 11 summarizes the interaction between phase and shift for order to receive TATs for emergency urgent collections. It is noted that from Pre-Implementation to Post-Implementation Phase 2, an increase in TATs was observed for all shifts. In Post-Implementation Phase 2, order to receive TATs decreased except for night shift. For night shift, it appears there was an increase in TATs.

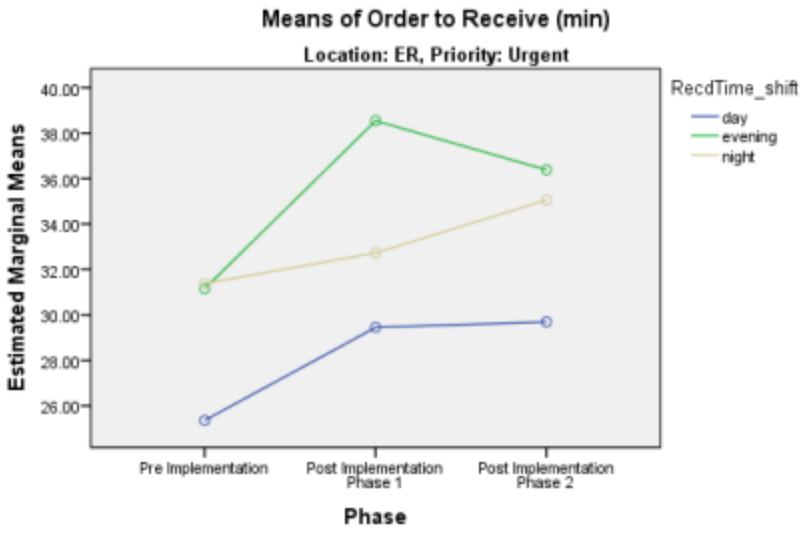

Figure 11. Order to receive TATs and shift interaction on emergency urgent collections.

An interaction was not observed between phase and shift for order to receive STAT emergency collections ($F(4, 3405) = 0.67$, $p = 0.593$), nor does a shift effect exist ($F(2, 3405) = 0.25$, $p = 0.783$). A phase effect was noted ($F(2, 3405) = 5.58$, $p = 0.003$), and a significant mean difference was noted for all phases except for Pre-Implementation and Post-Implementation Phase 1. Figure 12 summarizes the interaction between phase and shift for order to receive emergency STAT collections. Generally, an increase in order to receive TATs was observed for emergency STAT collections as implementation progressed.

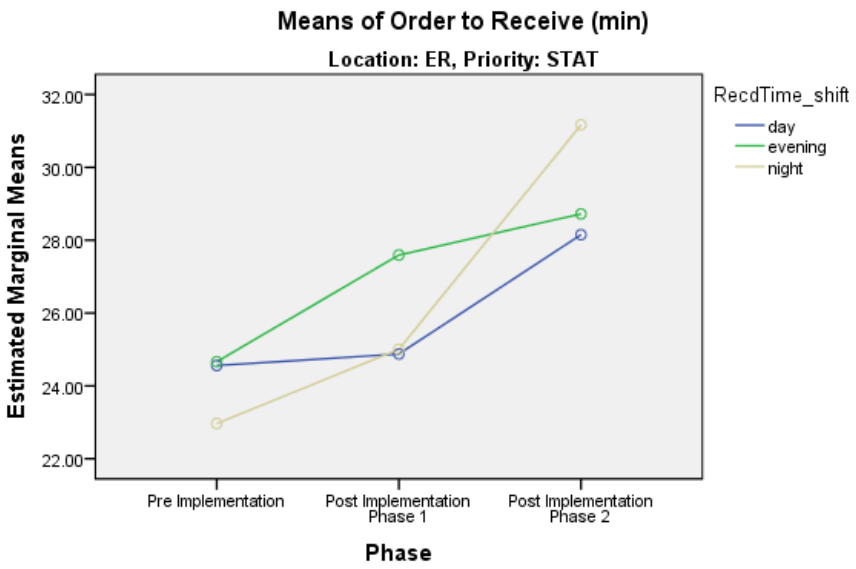

Figure 12. Order to receive TATs and shift interaction on emergency STAT collections.

An interaction between phase and shift was observed ($F(4, 51784) = 9.27$, $p < 0.001$) for order to receive urgent inpatient collections. During Pre-Implementation and Post-Implementation Phase 1, no significant difference was observed between the means of shifts except for evening and day shifts. A significant difference was noted for all shifts during Post-Implementation Phase 2. During day and night shifts, there was no significant difference between Pre-Implementation and Post-Implementation Phase 1. Figure 13 summarizes the interaction between phase and shift for order to receive inpatient urgent collections. There was an increase in order to receive TATs during all shifts as implementation progressed.

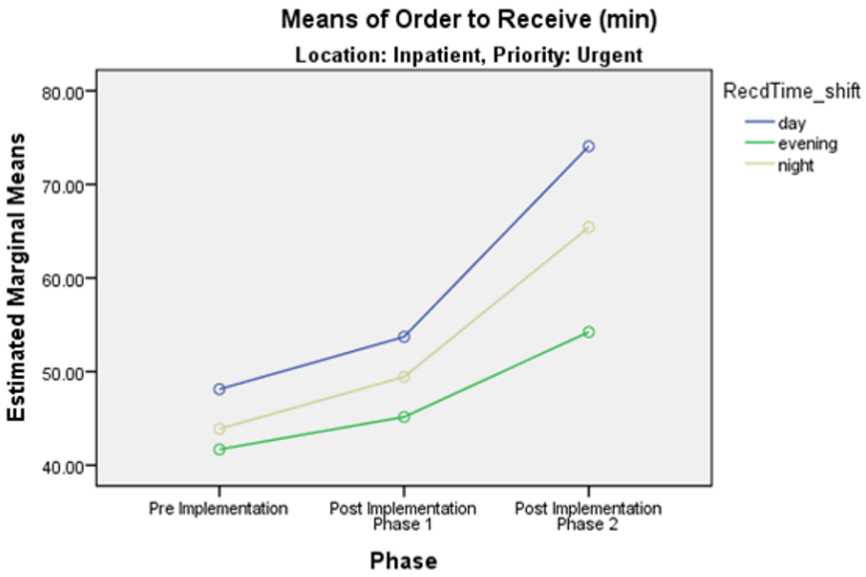

Figure 13. Order to receive TATs and shift interaction on inpatient urgent collections.

Phase and shift interaction was not observed for order to receive STAT inpatient collections ($F(4, 13311) = 1.86$, $p = 0.115$). A phase effect ($F(2, 13311) = 147.26$, $p < 0.001$) and shift effect ($F(2, 13311) = 56.60$, $p < 0.001$) were noted without an interaction between shift and phase. A significant difference of means was observed between all phases except for Pre-Implementation and Post-Implementation Phase 1. A significant difference was observed for all shifts except for night shift. Figure 14 summarizes the interaction between phase and shift for order to receive inpatient STAT collections. For day and evening shifts, an increase in order to receive TATs was observed during all phases. For night shift, a decrease in TATs was observed during Post-Implementation Phase 1, followed by an increase during Post-Implementation Phase 2.

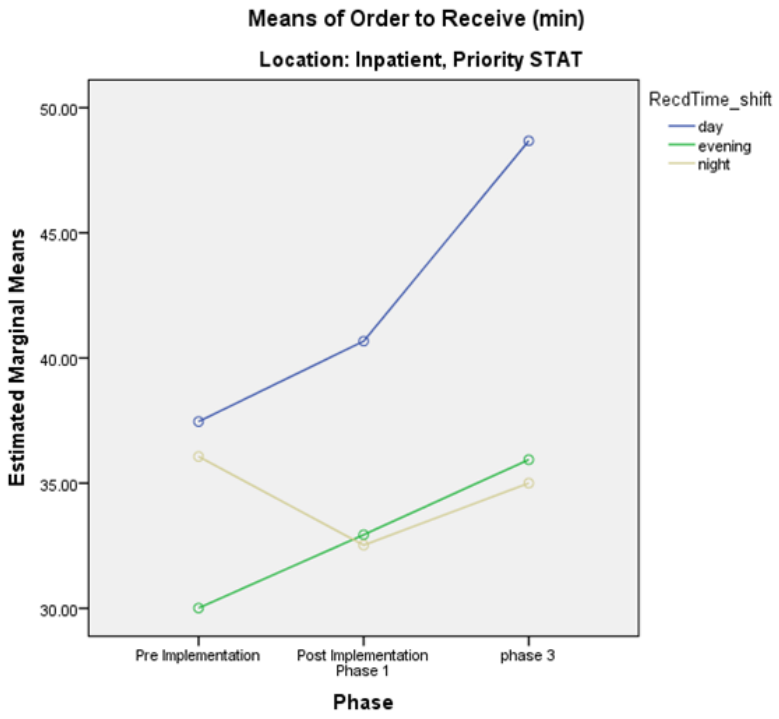

Figure 14. Order to receive TATs, phase, and shift interaction on inpatient STAT collections.

A Bonferroni analysis revealed that urgent inpatient and emergency collection order to receive means were significantly different for all shifts. Emergency STAT collection means were similar during all shifts. STAT inpatient collection means were significantly different except for the means of night and evening shifts. For urgent emergency collections, the means were significantly different for all phases except for Post-Implementation Phases 1 and 2. STAT emergency collections had similar means during all phases; however, a difference was noted among the means of Pre-Implementation and Post-Implementation Phase 2.

Order to receive means for inpatient urgent collections were significantly different during all three phases. For STAT inpatient collections, all means were significantly

different during the phases except the means of Pre-Implementation and Post-Implementation Phase 1, which were similar. Similar results were observed in the Student Newman-Keuls test. Emergency and inpatient urgent collections were grouped separately for all three shifts (indicating that they were all significantly different).

STAT emergency collections for all three shifts were grouped together, indicating that the order to receive means were not significantly different. For STAT inpatient collections, the means of evening and night shift were the same (but significantly different than day shift means). Inpatient urgent collection means were significantly different for all three phases. For inpatient STAT collections, no difference was observed for order to receive TAT between Pre-Implementation and Post-Implementation Phase 1 (Post-Implementation Phase 2 was grouped separately). Emergency urgent collections for Post-Implementation Phases 1 and 2 were grouped together (Pre-Implementation was grouped separately). For STAT emergency samples, no significant difference was observed between Pre-Implementation and Post-Implementation Phase 1. Post-Implementation Phases 1 and 2 were not significantly different; however, Pre-Implementation and Post-Implementation Phase 2 were grouped separately.

Part 5. In the fifth part of the analysis multiple regression analysis was performed to learn more about the relationship between TATs and the following predictors: phase, shift and priority. The testing was performed for inpatient and ER patients. Table 7 summarizes the results of multiple regression analysis.

Table 7

Multiple Regression Analysis Results

TAT	Location	Predictor	*F*	R^2
Order to collect	Emergency	Phase	84.926*	0.01
		Priority	126.465*	
		Shift	217.298*	
	Inpatient	Phase	118.572*	0.09
		Priority	305.120*	
		Shift	2,904.199*	
Collect to receive	Emergency	Phase	174.724*	0.01
		Priority	27.614*	
		Shift	45.634*	
	Inpatient	Phase	86.305*	0.01
		Priority	147.948*	
		Shift	19.365*	
Order to receive	Emergency	Phase	146.254*	0.02
		Priority	138.554*	
		Shift	358.003*	
	Inpatient	Phase	185.648*	0.01
		Priority	331.865*	
		Shift	115.010*	

Multiple Regression analyses was conducted to learn about the relationship between turn around times and various predictors. Order to collect results for emergency patients indicate a statistical significant phase effect ($F(2, 65666) = 84.93$, $p < 0.001$), collection priority effect ($F(1, 65666) = 126.47$, $p < 0.001$), and shift effect ($F(2, 65666) = 217.30$, $p <0 .001$). For inpatients, there was a statistical significant phase effect ($F(2, 65107) = 118.57$, $p < 0.001$), collection priority effect ($F(1, 65107) = 305.12$, $p <.0001$), and shift effect ($F(2, 65107) = 2904.20$, $p <0.0001$). For ER collections 1.10 % of variance is explained by the predictors $R^2 =0.01$, $F(5, 65666) = 142.04$, $p < 0.001$ and for

inpatients 8.90% the patients the variance is resulting from the predictors R^2 =0.09, F(5, 65107) = 1268.83, p < 0.001.

It was found that post implementation phase 1 significantly predicted order to collect turn around times (β = 0.06, *t* =12.59, *p* < 0.001), as did post implementation phase 2 (β= 0.03, *t* =5.33, *p* < 0.001) for ER patient collections. Phase 1 is a more significant predictor than phase 2. For ER patients urgent collection priority significantly predicted order to collect turn around times (β = 0.04, *t* =11.24, *p* < 0.001). ER evening collection were found to be a significant predictor of order to collect turn around times (β = 0.09, *t* =20.79, *p* < 0.001) and night shift collections were also a significant predictor (β= 0.03, *t* =7.94, *p* < 0.001) for ER patient collections. Evening collections are a more significant predictor than night shift. Inpatient post implementation phase 1 significantly predicted order to collect turn around times (β = 0.02, *t* =3.37, *p* < 0.001), as did post implementation phase 2 (β= 0.07, *t* =14.03, *p* < 0.001) for inpatient patient collections. Phase 2 is a more significant predictor than phase 1. For inpatient patients urgent collection priority significantly predicted order to collect turn around times (β = 0. 07, *t* =17.47, *p* < 0.001). Inpatient evening collections were found to be a significant negative predictor of order to collect turn around times (β = -0.01, *t* =-3.27, *p* < 0.001) and night shift collections were also a significant predictor (β= 0.28, *t* =69.84, *p* < 0.001) for inpatient patient collections.

Collect to receive results indicate that for emergency patients, there was a significant phase effect (F(2, 65666) = 174.72, *p* <0.001), collection priority effect (F(1, 65666) = 27.61, *p* <0.001), and shift effect (F(2, 65666) = 45.63, *p* <0.001). For

inpatients, there was a statistical significant phase effect ($F(2, 65107) = 86.31$, $p < .001$), priority effect ($F(1, 65107) = 147.95$, $p < 0.001$), and shift effect ($F(2, 65107) = 19.37$, $p < 0.001$). For ER collections 0.70% of variance is explained by the predictors $R^2 = 0.01$, $F(5, 65666) = 224.71$, $p < 0.001$ and for inpatients 0.60% the patients the variance is resulting from the predictors $R^2 = 0.01$, $F(5, 65107) = 186.94$, $p < 0.001$. It was found that post implementation phase 1 significantly predicted collect to receive turn around times ($\beta = 0.04$, $t = 8.37$, $p < 0.001$), as did post implementation phase 2 ($\beta = 0.09$, $t = 18.25$, $p < 0.001$) for ER patient collections. Phase 2 is a more significant predictor than phase 1 as it has a larger β *and t* value. For ER patients urgent collection priority significantly predicted collect to receive turn around times ($\beta = 0.02$, $t = 5.26$, $p < 0.001$). ER evening collection were found to be a significant predictor of collect to receive turn around times ($\beta = 0.03$, $t = 6.95$, $p < 0.001$) and night shift collections were a negative predictor ($\beta = -0.01$, $t = -2.55$, $p < 0.001$) for ER patient collections. Evening collections are a more significant predictor than night shift. For inpatient post implementation phase 1 significantly predicted collect to receive turn around times ($\beta = 0.01$, $t = 1.96$, $p < 0.001$), as did post implementation phase 2 ($\beta = 0.06$, $t = 11.55$, $p < 0.001$) for inpatient patient collections. Phase 1 is a more significant predictor than phase 2. For inpatient patients urgent collection priority significantly predicted collect to receive turn around times ($\beta = 0.02$, $t = 12.16$, $p < 0.001$). Inpatient evening collections were found to be a significant negative predictor of collect to receive turn around times ($\beta = -0.02$, $t = -3.52$, $p < 0.001$) and night shift collections were also a negative predictor ($\beta = -0.03$, $t = -6.05$, $p < 0.001$) for inpatient patient collections.

Order to receive results for emergency patients showed a significant statistical significant phase effect ($F(2, 65666) = 174.72$, $p < 0.001$), collection priority effect ($F(1, 65666) = 27.61$, $p < .001$), and shift effect ($F(2, 65666) = 45.63$, $p < .0001$). For the inpatient population there was a significant phase effect ($F(2, 65107) = 86.31$, $p < 0.001$), collection priority effect ($F(1, 65107) = 147.95$, $p < 0.001$), and shift effect ($F(2, 65107) = 19.37$, $p < 0.001$). For ER collections 1.7% of variance is explained by the predictors $R^2 = 0.02$, $F(5, 65666) = 91.56$, $p < 0.001$ and for inpatients 1.4% the patients the variance is resulting from the predictors $R^2 = 0.01$, $F(5, 65107) = 72.39$, $p < 0.001$.It was found that post implementation phase 1 significantly predicted order to receive turn around times ($\beta = 0.07$, $t = 14.79$, $p < 0.001$), as did post implementation phase 2 ($\beta = 0.08$, $t = 16.00$, $p < 0.001$) for ER patient collections. Phase 2 is a more significant predictor than phase 1. For ER patients urgent collection priority significantly predicted order to receive turn around times ($\beta = 0.05$, $t = 11.77$, $p < 0.001$). ER evening collection were found to be a significant predictor of order to receive turn around times ($\beta = 0.12$, $t = 26.55$, $p < 0.001$) and night shift collections were a significant predictor ($\beta = 0.07$, $t = 15.58$, $p < 0.001$) for ER patient collections. Evening collections are a more significant predictor than night shift. Inpatient post implementation phase 1 significantly predicted order to receive turn around times ($\beta = 0.02$, $t = 3.67$, $p < 0.001$), as did post implementation phase 2 ($\beta = 0.08$, $t = 17.32$, $p < 0.001$) for inpatient patient collections. Phase 2 is a more significant predictor than phase 1. For inpatient patients urgent collection priority significantly predicted order to receive turn around times ($\beta = 0.07$, $t = 18.22$, $p < 0.001$). Inpatient evening collections were found to be a significant negative predictor of order to receive

turn around times (β = -0.06, t =-15.14, $p < 0.001$) and night shift collections were also a negative predictor (β= -0.03, t =-6.25, $p < 0.001$) for inpatient patient collections.

Chapter 5: Discussion

In this chapter, I discuss the data analysis findings, provide insight into the possible causes of the results, and evaluate the impact of PPID on error rates and TATs at ABC Hospital.

Patient Identification Error Rates

As expected, a significant decrease in patient identification errors was noted. All patient identification errors were eliminated during the phases investigated as part of the study, indicating that the PPID worked as expected. This was a significant improvement in error rates: Initial error rates for this project were 0.0104%, well below rates cited in the literature of 0.04 to 0.1% (Morrison et al., 2010). Studies have revealed that a 32% reduction in patient identification errors can be realized (Ning et al., 2016), and in this case, a 100% reduction in errors was realized, eliminating the risk of patient harm resulting from patient identification errors. In 2004 a study performed by Iatrics revealed similar findings: the use of PPID resulted in a 100% reduction of patient identification errors (Task, 2014; Task & Tournas, 2012).

If PPID negatively impacted TATs, it would be expected that an increase in TATs would be observed during Post-Implementation Phase 1, and those increased times would remain stable during Post-Implementation Phase 2 as no other variables were introduced. If PPID positively impacted TATs, it would be expected that TATs would decrease during Post-Implementation Phase 1 and then plateau during Post-Implementation Phase 2. If PPID did not have any impact, then the TATs would not change during any of the three phases. However, none of these trends were noted for any of the three shifts. It is

likely that uncontrolled variables caused this deviation from expected results, which I discuss in greater detail below.

Turn-Around Times

Parts 1 and 2. TAT values for order to collect, collect to receive, and order to receive increased for both inpatient and emergency collections. These were unexpected results; studies have revealed a reduction in TATs ranging from 7–17 min (Task, 2014; Task & Tournas, 2012). Behling, Marrone, Hunter, and Bierl (2015) performed a study in 2013 that revealed a decrease in TATs by 30% with the introduction of PPID; however, in their study, a collection manager was simultaneously introduced. ABC Hospital already had a collection management system in place prior to the implementation of PPID, and therefore may not have seen the added benefit in TATs a computer management system could bring. It is possible that the implementation of PPID may have resulted in an increase in TATs at ABC Hospital due to the additional steps of identifying the patient (scanning the wristband and answering PPID prompts).

To gain a better understanding of what was increasing TATs, I reviewed collect to receive times. Other studies have monitored only order to collect TATs; therefore, comparable data are not available. Collect to receive times, which means the time it took for samples to be received in the laboratory, increased from 1 to 3 min. This result indicates that variables other than PPID contributed to the increase. Given that the footprint of the ABC Hospital campus increased, one possible explanation for this delay is an increase in physical distance travelled by phlebotomists or the pneumatic tube. The increased TAT could also be indicative of an increase in the number of collections; phlebotomists may have batched samples to avoid multiple trips to the pneumatic tube.

Delays in receiving samples in the laboratory could also have increased collect to receive TATs. During Post-Implementation Phase 2, ABC Hospital changed the process of receiving samples. The samples were moved from being received by the workflow designate to the automated line. The workflow designates were now required to retrieve the samples from the phlebotomist or the pneumatic tube, and then sort and deliver them to the analyzers, among other tasks they were performing. In the past, a workflow designate could receive samples while dispatching or answering phone calls, even though they may not have been delivered until the laboratory assistant had time to drop them off to the appropriate department. With this new process, the sample was not marked as received in the laboratory until it was delivered and loaded on the instrumentation.

Part 3. A significant increase in collect to receive TATs was observed for all STAT and urgent collections, except for STAT emergency samples. Order to collect times also increased significantly for all urgent and STAT samples, indicating it took longer for samples to be collected post-implementation of PPID. The increase observed ranged from 3 to 9 min. When PPID was implemented, it was expected that TATs would increase by approximately 1 min because the phlebotomist was now required to perform additional steps: locate the patient in the PPID software, barcode scan the patient's wristband, answer prompts, and generate a label. The increase in TATs observed in this study may have been the result of a significant increase in sample volumes but no corresponding increase in collection staff. I discuss this factor further below.

Part 4. When the data were separated at the shift level, there was variation in TATs of the different priority of samples on different shifts. If PPID was resulting in an increase in TATs, the expectation would be that during Post-Implementation Phase 1 the

TATs would increase and would remain constant. In theory, this pattern should have been observed for the different priority samples during various shifts. Since the pattern is not visible, it is difficult to argue that PPID alone is resulting in an increase in TATs during the various shifts.

Order to receive TATs increased for inpatient and emergency collections that were STAT or urgent during day, evening, and night shifts. During the night shift, an increase in TATs was noted for all priorities (inpatient and emergency collections). This indicates that the time it took to collect, transport, and receive samples increased. On evening shift, emergency collection TATs during Post-Implementation Phase 1 increased; a slight decrease in TATs was noted during Post-Implementation Phase 2. For inpatient collections, an increase was observed during Post-Implementation Phase 1, and an additional increase was noted during Post-Implementation Phase 2. It is possible that prioritization changes were introduced during the evening shift (e.g., that emergency collections took priority over inpatient collections).

During day shifts, for inpatient collections, an increase in order to collect was not significant. TATs increased for collect to receive, indicating that the increase was due to a delay in receiving or transporting samples. An increase in TATs was observed for emergency day shift collections for order to collect and collect to receive. As with the night shift, this increase indicates that the time it took to collect, transport, and receive samples increased.

Part 5. Multiple regression analysis results indicate that TATs were affected by phase, shift, and collection priority. Comparing the standardized beta coefficients, I noted that for overall turn around times the post implementation phase 2 was the most

significant predictor than the other predictors reviewed. Due to ethics restrictions, raw data for staffing levels and error rates were not available. Therefore, it was not possible to perform regression analysis for staffing levels or error rates, and the effect of these predictors cannot be determined.

Conclusion

Study findings indicate a reduction in patient error rates after implementation of PPID, but a significant increase in TATs was also observed. Many variables were not controlled for during this study, and they may account for the inconsistency in results compared to the study performed by Morrison et al. (2010). Additionally, Morrison et al.'s study was structured slightly differently, as their system used paper-based requisitions. At ABC Hospital, the requisition ordering system is electronic: orders are received sooner and are electronically recorded. With the paper-based system, order time was defined as the time the laboratory received the requisition. This definition would falsely decrease the TAT of collections as the orders were placed prior to the laboratory receiving the requisition.

Based on the data collected, I calculated that prior to PPID implementation at ABC Hospital, a phlebotomist collected on average 8.8 urgent or STAT collections per day. During Post-Implementation Phases 1 and 2, the numbers increased to 9.45 and 9.15, respectively (excluding timed and routine collections that would add to the workload). During a brief discussion with the site supervisor, I learned that overall, the ABC Hospital laboratory noted a significant increase in total patient collection volumes during Post Implementation Phases 1 and 2 (this included routine, urgent, STAT, and timed collections). Staffing levels were not significantly increased in comparison to the increase

in collection volumes, which means that the overall workload of the phlebotomists increased. Although an increase in TATs was observed, it would appear that the efficiency of collections did not decrease.

PPID increased TATs by 4 to 10 min and, in the first year, reduced patient identification errors to 0%. It is important to determine if a 4 to 10 min time increase clinically impacts the patient. In most situations, such a delay in receiving results would not hinder patient outcomes. Theoretically, if a 4 to 10min delay were going to impact the patient's treatment, the physician would be treating the patient based on symptoms and referring to the results as confirmation of his or her diagnosis (after the patient had been treated). Although it is unlikely that a 4 to 10 min delay in results would negatively impact a patient, a formal risk assessment needs to be performed. This assessment should take into consideration the reduction of error rates, increase in TATs, collection volumes, staffing levels, and costs.

Limitations

There were a number of limitations to the study. First, PSLS is a self-reporting system; therefore, it is expected that falsely low levels of identification errors are being identified due to healthcare professionals' heavy workloads, reliance on others to report, forgetfulness to report, and hesitance to report (Lippi, Chiozza, et al., 2017). I assumed that the rate of nonreporting would remain the same because no additional PSLS education was provided during the study period.

A limitation of the design I chose is that a one-group pretest–posttest design change can be measured, but one cannot conclude causation (Leedy & Ormrod, 2010).

Therefore, further control group studies need to be performed to tentatively conclude causation.

Many variables were not controlled for in this study, such as any downtime (software crashes) of Meditech or PPID. Another uncontrolled variable to take into consideration is that in May of 2014, after implementation of PPID, ABC Hospital expanded and the laboratory was moved to a new location. This resulted in many process changes for staff (including new equipment, a new laboratory, increased campus size, and new roles). The expansion changed the distances phlebotomists had to travel to get to the laboratory, increasing the distance for some inpatient areas and decreasing it for others. The difference in the distances should not affect the overall TATs. However, new travel pathways for phlebotomists may have resulted in an increase in TATs because it would take time for them to determine the most efficient route through the hospital from the new location of the laboratory.

Another factor that could have resulted in an increase in TATs is the introduction of new staff, resulting in a loss of experienced and skilled staff. Like in most laboratories, it is a common occurrence for staff at ABC Hospital to leave their jobs. When recruitment occurs and staff are hired from different sites, they will take longer to adapt to a new tool (such as PPID). Staff recruitment is an ongoing cycle and can vary, and was not controlled for in this study.

Recommendations for Future Research

One of the key questions of this research study was to determine if patient identification error rates decrease after implementation of PPID. During the first year of implementation at ABC Hospital, no patient identification errors were observed.

However, a conversation with the site supervisor indicated that approximately one year after implementation, the first patient identification error was noted due to a deviation from the procedure. The phlebotomist failed to verbally confirm the patient's identification, and the patient's armband had been incorrect. It is important to note that the phlebotomist cannot solely rely on the PPID device to confirm a patient's identification. I recommend that the error rates found in this study be reviewed post-implementation years 1 and 2 to see if they are continuously maintained at a significantly lower rate.

Another area in which to perform further research would be the implementation of PPID for nonlaboratory staff who collect samples. The number of errors made by nonlaboratory staff is significantly higher. Implementing PPID for these staff may dramatically reduce their patient identification errors.

In order to rule out variables other than PPID that may have resulted in an increase in TATs, I recommend repeating this study while controlling for the following variables: sample collection volumes, staffing levels, size of hospital, and number of beds. If more variables could be controlled, stakeholders would have a better understanding of the impact that can be gained from PPID and would be able to perform a risk assessment and a cost–benefit analysis.

The literature review I conducted revealed that PPID technology can reduce identification errors without significantly compromising the speed of sample collection (Morrison et al., 2010). There is an insufficient amount of accepted research and data, and a lack of economic cost–benefit analyses, for implementing the technology. Review of reliable data on error rates and TATs would allow healthcare administrators to make

informed decisions regarding PPID implementation. To determine the true rate of error reduction and impact on TATs, further studies are required.

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Appendix A: Ethics Approval

Fraser Health Authority Approval

Fraser Health Research Ethics Board
FHA, Evaluation and Research Services
#400, 13450 102nd Avenue, Surrey, BC V3T 0H1
Phone: 604.587.4436 Fax: 604.930.5425

fraserhealth

CERTIFICATE OF FHREB APPROVALS

Official Notification - FHREB Number *(to be used on all future correspondence)*: ***2016-036***				
Principal Investigator: DULAY, Harwinder		**Hospital/Facility & Department:** /Laboratory Medicine		
Institution(s) or Geographical Areas where research will be carried out:				
Co-Investigator(s): N/A				
Funding Agencies and/or Corporate Sponsor: Unfunded				
Title: Impact of Positive Patient Identification on Medical Laboratory Preanalytical Quality Indicators				
Documents Included in this Approval	**Date of Approval**	**Date of Expiry**	**Type of Approval**	**Approval of the FHREB**
• Application for Initial Ethical Review 2016 March 18 • Protocol Version 1.0 2016 March 10 *(*The FHREB has determined that the collection of the data elements as described in the protocol/data collection form are justified and required in order to conduct the research)*	2016 October 24	2017 October24	Initial Approval; Delegated Review	

CERTIFICATION:

With respect to clinical trials:

1. The membership of the Fraser Health Research Ethics Board complies with the membership requirements for research ethics boards as defined in Part C Division 5 of the Food and Drug Regulations and the Tri-Council Policy Statement.
2. The Fraser Health Research Ethics Board carries out its functions in a manner consistent with Good Clinical Practices.
3. The Fraser Health Research Ethics Board has reviewed and approved the clinical trial protocol and the informed consent form for the trial which is to be conducted by a qualified investigator named at the specified clinical trial site. This approval of the documentation listed above and the views of the Fraser Health Research Ethics Board have been documented in writing.

With respect to delegated review:

A co-chair or delegated member of the FHREB has reviewed and approved the documentation listed above for the forenamed research study in accordance with the FHREB Policy on "Ethical Conduct of Research and Other Studies Involving Human Subjects", the Tri-council Policy Statement: Ethical Conduct for Research Involving Humans", and the "International Conference on Harmonisation Guidance E6: Good Clinical Practice E6: Consolidated Guidelines".

With respect to full board review:

Full FHREB review and approval of the documentation listed above was completed for non-expedited review in accordance with the FHREB Policy on "Ethical Conduct of Research and Other Studies Involving Human Subjects", the Tri-council Policy Statement: Ethical Conduct for Research Involving Humans" and the "International Conference on Harmonisation Guidance E6: Good Clinical Practice E6: Consolidated Guidelines".

The FHREB approval for this study expires ONE year from the approval date of this certificate. Researchers must submit a Request for Annual Renewal for ongoing research studies prior to the expiry date in order to receive annual re-approval.

fraserhealth

LETTER OF AUTHORIZATION TO CONDUCT RESEARCH

Date: 2016 October 24 **PI Name:** DULAY, Harwinder

Address:

FHREB File #: 2016-036 **Study Protocol #:**

Study Title: Impact of Positive Patient Identification on Medical Laboratory Preanalytical Quality Indicators

The following required applicable approvals have been received and are in order:

☒ FH REB Certificate of Initial Approval
Dated: 2016 October 24
☒ Consent not required
Reason: This is a retrospective chart review study
☐ Consent Waived
Reason:

☐ Consent Required and approved:
The signed signature page of the consent form for a specific study must be submitted to Health Records/Health and Business Analytics for the release of any of that participant's personal information.

☒ Department Agreement for Providing Research-related Services Authorization Services (DAR Form)
☐ Not Applicable

☐ Privacy Impact Assessment (PIA)
☒ Not Applicable

☒ N2 Privacy and Confidentiality SOP template attached. Please ensure this SOP is used to maintain confidentialtiy of data.

☐ Health Canada Letter of No Objection
☒ Not Applicable

TRAINING: ☐ TCPS Certificate
Note: N2 CITI courses available at www.citiprogram.org for all FH researchers. Indicate affiliation as Fraser Health.

☐ Clinical Trial Registration No.
☒ Not Applicable

Registered at: ☐ www.ClinicalTrials.gov
☐ www.Controlled-trials.com
Type of Research: Clinical

Funding: Cost-Centre Not Required
☒ Unfunded
☐ Industry: ☐ REB fee received
☐ Grant-in-aid
☐ Grant awarded to non-Fraser Health Institution

Cost-Centre Required: Budget:
Funder:
☐ Grant/grant-in aid award to Fraser Health
☐ Grant awarded by Fraser Health
☐ Grant funds transferred to Fraser Health by academic sponsor
☐ External grant fund reimburses Fraser Health
☐ Industry
Please note that FH Research Policy prohibits over-spending on research grants by the principal investigator.

Agreements:
☐ Executed Clinical Trial Agreement for Industry Sponsored Trials
☐ Affiliated Researchers: Executed "Research Collaboration Agreement" dated:
☐ Research Grant Contribution Agreement dated: Name of Granting Agency:

This letter authorizes the principal investigator to begin research-related procedures in compliance with all FH research-related and privacy policies http://fhpulse/policies_guidelines/org_policies/pages/default.aspx.

Please note that the ethical approval for this study must be renewed before the one year expiry date of the certificate of initial approval if the study will be ongoing at that time.

Authorized by:
Susan Chunick
Director, FH Department of Evaluation and Research Services

Digitally signed by Susan Chunick
DN: cn=Susan Chunick, o=Fraser Health Authority, ou=Department of Evaluation and Research Services, email=susan.chunick@fraserhealth.ca, c=CA
Date: 2016.10.24 15:22:42 -07'00'

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Appendix B: Ethics Exemption from Athabasca University Ethics Board

October 27, 2016

Ms. Harwinder Dulay
Faculty of Health Disciplines\Centre for Nursing & Health Studies
Athabasca University

File No: 22087

Expiry Date: March 07, 2017

Dear Harwinder Dulay,

The Faculty of Health Disciplines Departmental Ethics Review Committee, acting under authority of the Athabasca University Research Ethics Board to provide an expedited process of review for minimal risk student researcher projects, has reviewed your project, 'IMPACT OF POSITIVE PATIENT IDENTIFICATION ON MEDICAL LABORATORY PRE-ANALYTICAL QUALITY INDICATORS'.
Your application has been **Approved on ethical grounds** and this memorandum constitutes a ***Certification of Ethics Approval***. Thank you for providing ethics approvals from Fraser Health. You may begin the proposed research.

AUREB approval, dated March 08, 2016, is valid for one year less a day.

As you progress with the research, all requests for changes or modifications, ethics approval renewals and serious adverse event reports must be reported to the Athabasca University Research Ethics Board via the Research Portal.

To continue your proposed research beyond March 07, 2017, you must apply for renewal by completing and submitting an Ethics Renewal Request form. Failure to apply for **annual renewal** before the expiry date of the current certification of ethis approval may result in the discontinuation of the ethics approval and formal closure of the REB ethics file. Reactivation of the project will normally require a new Application for Ethical Approval and internal and external funding administrators in the Office of Research Services will be advised that ethical approval has expired and the REB file closed.

When your research is concluded, you must submit a Project Completion (Final) Report to close out REB approval monitoring efforts. Failure to submit the required final report may mean that a future application for ethical approval will not be reviewed by the Research Ethics Board until such time as the outstanding reporting has been submitted.

At any time, you can login to the Research Portal to monitor the workflow status of your application.
If you encounter any issues when working in the Research Portal, please contact the

system administrator at research_portal@athabascau.ca.

If you have any questions about the REB review & approval process, please contact the AUREB Office at (780) 675-6718 or rebsec@athabascau.ca.
Sincerely,

Sherri Melrose
Chair, Faculty of Health Disciplines Departmental Ethics Review Committee
Athabasca University Research Ethics Board

Athabasca University Approval

CERTIFICATION OF ETHICAL APPROVAL - RENEWAL

The Athabasca University Research Ethics Board (AUREB) has reviewed and approved the research project noted below. The AUREB is constituted and operates in accordance with the current version of the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS) and Athabasca University Policy and Procedures.

Ethics File No.: **22087**

Principal Investigator:

Ms. Harwinder Dulay, Graduate Student

Faculty of Health Disciplines\Centre for Nursing & Health Studies

Supervisor:

Dr. Kimberley Lamarche (Supervisor)

Project Title:

IMPACT OF POSITIVE PATIENT IDENTIFICATION ON MEDICAL LABORATORY PREANALYTICAL QUALITY INDICATORS

Effective Date: February 15, 2017 **Expiry Date**: February 14, 2018

Restrictions:

Any modification or amendment to the approved research must be submitted to the AUREB for approval.

Ethical approval is valid *for a period of one year*. An annual request for renewal must be submitted and approved by the above expiry date if a project is ongoing beyond one year.

A Project Completion (Final) Report must be submitted when the research is complete *(i.e. all participant contact and data collection is concluded, no follow-up with participants is anticipated and findings have been made available/provided to participants (if applicable))* or the research is terminated.

Approved by: **Date:** February 15, 2017

Joy Fraser, Chair

Athabasca University Research Ethics Board

Athabasca University Research Ethics Board

University Research Services, Research Centre

1 University Drive, Athabasca AB Canada T9S 3A3

E-mail rebsec@athabascau.ca

Telephone: 780.675.6718

Appendix C: Dissemination of Study Findings

It is expected that dissemination will occur with Laboratory Management at ABC Hospital and managers at other Fraser Health Authority laboratory sites. The following are peer-reviewed journals that would be appropriate to publish the results of this research:

- *Canadian Journal of Medical Laboratory Science* (CJMLS) http://www.csmls.org/About-Us/Publications.aspx
- *ASCP Laboratory Medicine* http://labmed.ascpjournals.org/site/misc/ifora.xhtml

Peer-reviewed conference venues include the following:

- Annual CSMLS Conference – poster presentation http://labcon.csmls.org/en/program/poster-abstract-submission/
- Annual BCSLS Conference –podium presentation http://www.gifttool.com/registrar/ShowEventDetails?ID=1625&EID=18749