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Introduction of a Mobile Device Based Tertiary Survey Application Reduces Missed Injuries: A Multi-Center Prospective Study

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A thesis submitted in partial fulfillment of the requirements for the degree in Master of Science

INTRODUCTION OF A MOBILE DEVICE BASED TERTIARY SURVEY APPLICATION REDUCES MISSED INJURIES: A MULTI-CENTER PROSPECTIVE STUDY

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by

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Abstract

Missed injuries in trauma patients are a significant source of preventable morbidity. The tertiary survey is a head-to-toe physical exam performed within 24 hours of admission to identify any injuries which may have been missed during initial assessment and resuscitation. The Physician Assist Trauma Software (PATS) is an electronic program designed to guide users through a thorough tertiary survey and document the results. This thesis project was designed to study the impact of implementing this novel mobile device based electronic tertiary survey program on missed injuries. The first phase of this study involved quantifying and characterizing the missed injury rate at two distinct pilot sites. The second phase compared missed injury rates before and after implementation of the PATS program. Completion rates before and after implementation were also compared as a measure of feasibility. The implementation of the PATS program significantly decreased missed injury rates and improved documentation compliance at both sites. The third phase focused on user-level feasibility by surveying the pre- and post-PATS practitioners responsible for completing the tertiary survey. Overall, users found the PATS program useful, time-saving, and effective. The PATS program appears to be an effective and feasible way to reduce missed injuries and improve documentation in trauma.

Keywords

Trauma, missed injury, electronic mobile device, tertiary survey, compliance

Co-Authorship Statement

Chapter 2: Missing the missed injury: When and how missed injuries are identified

Dr. Kelly Vogt was instrumental in the statistical analysis, and further provided insight and review into the writing of the manuscript. Dr. William Leeper and T.J. Leeper were involved in the collection of several data elements which included detailed chart reviews of patients with missed injuries. Tanya Charyk-Stewart was responsible for pulling patient data from the trauma database and also assisted in the statistical analysis. Drs. Malthaner, Parry, and Gray all provided overall project guidance, advice, and assisted in manuscript review.

Chapter 3: Missed injuries in a Level 1 Trauma Center: A contemporary analysis

Dr. Meghan Linnebur, Dr. Dimitra Skiada and Lauren Nosanov were the on-site contacts at the University of Southern California Medical Center (USC). They assisted in collecting and organizing missed injury data including detailed chart reviews. Dr. Kelly Vogt was instrumental in the statistical analysis, and further provided insight and review into the writing of the manuscript. She also assisted in data collection and interpretation. Drs. Inaba, Lam, and Demetriades all provided overall project guidance, advice, and assisted in manuscript review.

Chapter 4: Introduction of a Mobile Device Based Tertiary Survey Application Reduces Missed Injuries: A Multi-Center Prospective Study

Dr. Kelly Vogt was instrumental in the statistical analysis, and further provided insight and review into the writing of the manuscript. She was also the on-site contact at USC and coordinated implementation of the pilot instrument, daily screening for missed injuries, and monitoring of compliance rates. She was also one of the original developers of the electronic pilot instrument. Dr. Chris Martin was one of the original developers of the electronic pilot instrument. Drs. Inaba, Demetriades, Malthaner, Gray, and Parry all provided overall project guidance, advice, and assisted in manuscript review.

Chapter 5: Feasibility and User Evaluation of a Mobile Device Based Tertiary Survey Application: A Multi-Center Study

Dr. Kelly Vogt was instrumental in the statistical analysis, and further provided insight and review into the writing of the manuscript. She was also the on-site contact at USC and coordinated administration and collection of the surveys. Drs. Vogt and Martin were the original developers of the electronic pilot instrument. Drs. Inaba, Demetriades, Malthaner, Gray, and Parry all provided overall project guidance, advice, and assisted in manuscript review.

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committed her sage advice and vast research knowledge on a daily basis to ensure its success. Kelly is truly Master and Commander of all things statistics. Her incomparable number sense was invaluable to helping us all with the statistical analyses required for this work. However, I think above all else, your faith in this project and in me was inspiring. Thank you for the countless times you calmed my rage, solved some little problem, or performed some unspoken task to make things better. Finally, thank you for being such an expert SoCal tour guide. There was never a shortage of activities to leave us asking “what is my life?” I will miss that crazy California life. Eff reality.

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This project has been an incredible experience from start to finish. As my thesis journey draws to a close, my Mom is just embarking on her own difficult journey. May hers be swift and may she come home safe. In that spirit, I dedicate this thesis to her.

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List of Abbreviations

95%CI	95% Confidence Interval
ABC	Airway, Breathing, Circulation
ACS	American College of Surgeons
ACS	Acute Care Surgery
ACS-COT	American College of Surgeons Committee on Trauma
ADLs	Activities of Daily Living
AIS	Abbreviated Injury Scale
AMA	Against Medical Advice
ANOVA	Analysis of Variance
ATLS	Advanced Trauma Life Support
CT	Computed Tomography
EMR	Electronic Medical Record
GCS	Glasgow Coma Scale
ICD-9	International Classification of Disease, 9th revision
ICU	Intensive Care Unit

IQR	Inter-Quartile Range
ISS	Injury Severity Score
LAC	Los Angeles County
LHSC	London Health Sciences Center
LOS	Length of Stay
OR	Operating Room
PATS	Physician Assist Trauma Software
PGY	Post-Graduate Year
SBP	Systolic Blood Pressure
SD	Standard Deviation
TQIP	Trauma Quality Improvement Program
USC	University of Southern California Medical Center
vs	Versus
VTE	Venous Thromboembolism
WHO	World Health Organization

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Chapter 1

1 Introduction

1.1 Overview

Traumatic injury is the 3rd leading cause of death worldwide, second only to ischemic heart disease and stroke (1,2). Approximately 5 million people globally die each year from trauma, with a quarter of these deaths resulting from motor vehicle collisions (1,3). According to the World Health Organization (WHO), trauma imparts 12% of the world's total burden of disease (1,4). Trauma mortality is expected to rise over the next decade with deaths due to motor vehicle collisions set to increase by 80% from current levels by 2020 (1,3). The result would be that 10% of all deaths worldwide would involve a motor vehicle crash (1,3). The treatment-related cost alone associated with injury globally is estimated to be $500 billion (1); with that figure likely increasing many fold when the effect of insurance costs, lost wages, lost productivity, and property damage are factored in.

More than 90% of trauma-related mortality occurs in low- and middle-income nations (1,2). However, trauma represents the leading cause of death for persons aged 1-44 in developed nations (1). Each year, about 2.6 million people are admitted to hospital as a result of trauma in the United States (5). Approximately 180 000 people die as a result of trauma in the United States annually; 33 000 from motor vehicle collisions and 31 000 from firearms (6). This makes injury the leading cause of life-years lost accounting for

30% overall (1). Over 200 000 trauma patients are admitted annually in Canada (7). Approximately 12 000 people die as a result of trauma annually; with 2200 attributed to motor vehicle collisions (7).

1.2 Advanced Trauma Life Support

Prior to 1975, there was very limited understanding of the disease process and initial management of trauma – there was no standardized approach. In the late 1970's, a group of surgeons and nurses, along with the American College of Surgeons (ACS), developed a course in the basics of trauma care designed for front-line medical workers (paramedics, nurses, emergency doctors, and surgeons) (8,9). The Advanced Trauma Life Support (ATLS) course is now offered in 63 countries and serves as an international standard for trauma resuscitation and a simple, common language for trauma providers (8-10).

The ATLS course breaks down and simplifies the initial resuscitation phase with an emphasis on identifying and treating life-threatening injuries (10). It advocates a straight forward "ABCDE" approach as the first assessment or "primary survey". The ABC's of the primary survey include a rapid assessment of the patient's airway, breathing, and circulation. Any life-threatening injuries are treated immediately. This is followed by a rapid assessment of the patient's neurological status (D – disability), and a rapid whole-body survey for other life-threatening problems (E – exposure). There are several adjuncts to the primary survey including selective x-ray imaging and a focused ultrasound assessment of the abdomen and heart.

Once the primary survey is complete and all life-threatening injuries have been addressed, the next step in the ATLS approach is the "secondary survey". If the patient remains unstable (in life-threatening condition), the trauma provider should not move on to the secondary survey until the life-threatening injuries have been stabilized. The secondary survey is a head-to-toe physical exam of all body systems and body parts. The purpose of the secondary survey is to identify and catalogue all additional injuries which may not have been detected during the primary survey. Typically, these injuries do not pose an immediate threat to life. The main adjunct to the secondary survey is cross sectional – typically computed tomography (CT) – imaging. CT scans as well as additional x-rays should confirm or identify any further injuries. Therefore, a complete list of the patient's injuries should be available upon completion of the primary and secondary surveys.

The main focus of the ATLS course is on initial assessment, resuscitation, and stabilization of the trauma patient. It is targeted to the level of a community hospital provider who may have limited resources in terms of definitive management of the patient's injuries. Hence, after the primary and secondary survey, the ATLS course emphasizes transfer of the patient to definitive care. The definitive, specialized management of specific traumatic injuries falls outside the scope of the course. Likewise, the ongoing inpatient and recovery aspects of care are not addressed in the ATLS course. Tertiary trauma referral centers still follow the ATLS guidelines during the resuscitation phase; however, advanced and specialized acute, sub-acute, and long-term care is required for these complex patients.

1.3 Missed Injuries

Although a complete list of injuries should be documented upon completion of the primary and secondary surveys, some patients may have one or more injuries which were not detected during either of these exams. The possible reasons for this are many. For example, it may be that the patient was so critically injured that the resuscitation team was not able to move on to the secondary survey before transferring the patient to another hospital or to definitive care (operating room or ICU). Alternatively, the patient may be sedated or unconscious thus making a clinical exam difficult.

Regardless of the reason, any injury which is not detected during the resuscitation phase is at risk of having a significant delay in diagnosis or going undiagnosed entirely. Such injuries are termed “missed injuries”. The problem of delayed or missed diagnosis of injury in trauma has been described since the 1970’s (11). While these early studies focused on specific missed injury patterns in particular subgroups of trauma, Chan et al were the first to describe the multiply injured trauma patient as being at risk for delayed diagnosis of all types of injuries (12). They described a missed injury rate of 12% and attributed it to multiple factors including: inadequate physical exam, insufficient use of radiologic investigations, and admission to non-specialized wards; many of these issues persist as contributing factors to missed injuries today.

1.4 The Tertiary Survey

> *“Injuries will be missed. Rather than dismissing these as occurrences that happen only to the inexperienced or incompetent, one should approach the*

> *multiply injured trauma patient with both special alertness and the humility necessary to search for diagnostic oversights." – BL Enderson, 1991 (13)*

In 1990, a group headed by BL Enderson out of Knoxville Tennessee proposed that the primary and secondary survey dogma of ATLS was insufficient as a means of definitively identifying all injuries at the time of resuscitation: "In patients with multisystem trauma, serious injuries may initially be missed despite a complete primary and secondary survey." (13) They recognized that in the process of resuscitating such complex and often critically ill patients, initial diagnostic oversight may occur in favor of preserving the patient's life. "The multiply injured trauma patient presents a diagnostic and therapeutic challenge: that of discovering all injuries while simultaneously proceeding with resuscitation and maintaining life." (14) They also astutely recognized that critically ill patients are likely at higher risk of missed injury and picked up on the propensity for lapsing diagnostic acumen following the resuscitation phase: "Combative, unstable trauma patients immediately transported to the operating room are, by circumstance, incompletely diagnosed. The axiom 'treatment before diagnosis' has saved many lives, but is a pitfall for surgeons who fail to remain alert for manifestations of evolving injuries." (13)

To address these problems, the Knoxville group proposed a full head-to-toe reassessment after the patient had stabilized and once the primary and secondary surveys were complete. Following the ATLS mantra of numbered surveys, they referred to this interval reassessment as the "tertiary survey". They proposed that the tertiary survey be performed after the patient had left the resuscitation area, but within 24 hours of admission. "[The tertiary survey] is conducted during the light of day with the objective of utilizing the full diagnostic and consultative resources of the institution to identify other injuries and minimize the disability that may arise thereafter." (13) Enderson's group even had the insight to foresee the medical-legal implications of missed injuries and thus recommended that all trauma patients – not just those perceived as at risk of missed injury – be given a complete tertiary survey: "…a routine followup in-hospital assessment [tertiary survey] reduces the risk of patients leaving hospital with undiagnosed injuries, improves patient care, and may have favorable medicolegal implications … The use of such a survey is recommended in all trauma patients." (13)

Since its inception, the tertiary survey has been widely adopted at most developed trauma centers. Most trauma centers develop their own individual process for performing and documenting the tertiary survey. No particular standard exists. A thorough tertiary survey should include: a review of the patient's lab results, a detailed review of the final radiology reports from the initial trauma CT and x-ray studies (with a particular eye for any reported injuries not already documented), and a review of venous thromboembolic (VTE) and tetanus prophylaxis measures. Some centers, including London Health Sciences Center (LHSC), also include a formal or informal "quaternary survey" on patients being transferred out of the intensive care unit (ICU). This is essentially another iteration of the tertiary survey head-to-toe exam, recognizing that patients who may have been intubated and/or sedated in the ICU during their initial tertiary survey likely would not have complained of pain or reacted to pain on exam from an undiagnosed injury. Thus, the quaternary survey is performed when the patient is alert and able to cooperate with a full physical exam; which may be days or even weeks after admission.

1.5 Defining a Missed Injury

The current literature is plagued by the lack of a standard definition for a "missed injury". A literature review by Pfeifer et al reviewed 17 articles and found at least 4 distinct definitions of missed injury: injuries missed on primary and secondary survey but identified on tertiary survey, injuries identified after admission to the ICU, injuries found after complete assessment and diagnostics, and injuries missed within 6-12 hours of admission (15). Another recent review of the missed injury literature by Keijzers et al classified these injuries as type I or II (16). Type I missed injuries were those missed during the primary and secondary surveys but identified within 24 hours by the tertiary survey; type II missed injuries were those identified after 24 hours and missed on the primary, secondary, and tertiary survey. In a later publication, the same group added the type III missed injury: those that were detected after hospital discharge (17). Such diverse and vague definitions including imprecise phrases such as "found after complete assessment and diagnostics" can make it difficult to track trends in missed injury rates and interventions.

Earlier studies examining missed injuries around the time the tertiary concept was emerging often did not include the timing of the tertiary survey in their definitions. For example Janjua et al used the following definition in 1998: "injury that escaped detection during the primary and secondary survey and initial investigation in the resuscitation room and operating room." (18) Some studies are even less specific: Robertson et al 1996 "Any unrecognized injury" (19), Hirshberg et al 1994 "injuries not discovered during initial patient evaluation, diagnostic work-up, or surgical exploration." (20). Studies evaluating the effectiveness of the tertiary survey often define missed injuries as those missed during the primary and secondary survey, as a means of comparison to those that were detected by the tertiary survey (21-25). A missed injury is described in print by AB Peitzman as "injury discovered either after the completion of the initial assessment or more than 24 hours have elapsed since admission." (26)

Most recent studies define missed injuries in relation to whether they were detected prior to or after the completion of the tertiary survey (15,16). Another definition which commonly persists is that of injuries diagnosed after 24 hours (18,22,26-29). This is reasonable in cases where it is not possible to track tertiary survey documentation, as it is expected to be completed within a 24 hour period, usually on rounds the morning following admission.

1.6 Missed Injuries: Who, What, When, Why, How?

1.6.1 Who is at risk for missed injuries?

A variety of studies have addressed the question of what patient factors are associated with or predictive of having a missed injury. A large prospective study of over 3800 trauma patients showed that a lower Glasgow Coma Scale (GCS) score (<15) as well as a higher Injury Severity Score (ISS) (≥16) were associated with having a missed injury (27). Another large retrospective analysis of nearly 4000 trauma patients showed that patients with a missed injury were more likely to have a blunt mechanism of injury, and have a higher ISS (19). Other factors which have been associated with missed injuries include ICU admission (22,30) and the need for an urgent operation (31).

Patients with higher ISS scores consequently have more numerous and/or more severe injuries. Both of these factors can serve as distractions or reasons for diagnostic oversight during the resuscitation phase. Focus is drawn toward the assessment and management of more life-threatening injuries when they are present and thus less severe injuries are at risk of being missed. Likewise, when a patient has an extensive list of injuries, it is easier to overlook or inadequately document a physical exam or x-ray finding, causing it to be lost. Thus, some missed injuries may have been identified on the secondary or tertiary survey, but are never documented or followed up resulting in a delay in definitive management.

Patients with a decreased level of consciousness – whether related to their injury or to iatrogenic sedation – may not complain of, or respond to pain. Although physical findings are usually present for most injuries, for other injuries, the only presentation may be pain, which therefore requires that the patient be alert in order to diagnose them. For patients with penetrating trauma, it is easier to predict where the missile or object has traversed and therefore concentrate efforts in detecting injuries along its path. Peripheral damage is less likely in penetrating trauma. For blunt mechanisms of injury, however, the exact body areas exposed to the injury force can be difficult to discern and thus, any body area or system may be at risk of having an undiagnosed injury.

In summary, there are multiple risk factors identified in the literature which predispose patients to having an injury missed. Even a heightened awareness of these risk factors however, has not yet been sufficient to decrease the rate of missed injuries.

1.6.2 What Injuries are Missed?

Extremity injuries have consistently been shown to be the most commonly missed injury (15,16,19,27). Extremity fractures account for 26%-70% of all missed injuries with foot/ankle and hand/wrist injuries being the most common (15,16,27,28). The head, face, neck, and spine are also particularly susceptible to having missed injuries (15,16). Spine injuries are arguably the second most commonly missed injury with a miss rate ranging from 12%-29% (17,22,28,32). Facial injuries account for 5%-21% of missed injuries (16,32,33). Injuries to other body systems are missed less frequency but have been described in all major body areas and organ systems.

Extremities – especially hands and feet – are at risk of having missed injuries for a variety of reasons. The hands and feet contain multiple small bones and joints which require less force to injure than other body parts. These smaller body areas also present in a more subtle way as swelling or bruising may be confined to a small area and the patient may only complain of symptoms when they attempt fine motor actions with the effected body part. Injuries to the extremity are also much less likely to be life-threatening when compared to injuries to the head, neck, and torso; and hence the extremities garner less attention during the resuscitation phase. Liberal plain film x-ray use is advocated to limit missed fractures in the extremities (10).

Injuries to the spine are also frequently missed. These are commonly fractures of the non-articulating surfaces of the spine (transverse process, spinous process) (28,34). These small fractures are often of little clinical significance and typically heal with no intervention or limitations to the patient.

1.6.3 When are Missed Injuries Diagnosed?

Most studies focus on missed injuries which are diagnosed in a delayed fashion but picked up before hospital discharge. This is likely due in part to the significant loss to follow-up in the trauma population which makes studying trauma outpatients challenging (35,36). Most studies also do not routinely report the average delay time to diagnosis. A recent study by Giannakopoulos noted a median time of two days to identify missed injuries classified as severe (21). Leeper et al demonstrated a median time to diagnosis of 4 days (37). Houshian et al showed that 43% of missed injuries are detected from 1-3 days following admission, 23% between 4-10 days, and 15% after 10 days (38). Williams reports a mean time to diagnosis of a missed injury of 4.3 days in a pediatric population (39).

Few studies have addressed the burden of missed injury in the outpatient population. The reported range in the literature is from 2.5%-18% (17,40,41). These studies are typically based on telephone follow-up, which in itself is incomplete. Therefore most reported missed injury rates in the literature are likely moderately underestimated due to a loss to follow-up and inability to track injuries which present after hospital discharge.

1.6.4 How Many Injuries are Missed?

Published missed injury rates vary widely in the literature. Rates have been reported anywhere from 1.3% all the way to 22% (15,16,27,42). A large prospective study from the Netherlands by Vles et al reports the lowest rate at 1.3% (27). The largest prospective study from North Carolina with over 5000 patients reported a similarly low missed injury rate of 1.5% (33). A systematic review by Keijzers et al reports an average missed injury rate of 4.4% across the reviewed literature (16).

Unfortunately, the considerable variability in the definitions used for missed injury make a systematic point estimate of the missed injury rate difficult. This is likely the main factor in the broadly reported missed injury rate as many of the studies with higher missed injury rates do not include the tertiary survey in their definition. Hence, many classify injuries not documented on the primary or secondary survey as "missed", even though they could have been detected on a tertiary survey. Additionally, much of the published literature on missed injuries and tertiary surveys is more than a decade old and therefore does not take into account the widespread adoption of the tertiary survey or the improvements in imaging technology. Some institutions may be hesitant about publishing morbidity and perceived error rates, and therefore there is likely an element of publication bias as well.

1.6.5 Why are Injuries Missed?

A number of studies have attempted to address the question of why injuries are missed. There are a multitude of injury, patient, system, provider, and documentation factors which likely contribute to an injury being missed. Classifying and quantifying the magnitude of effect each of these factors imbues is challenging. However, the reality is that most missed injuries are preventable; that is to say that by changing some modifiable factor, we should be able to diagnose and address nearly all injuries within a 24 hour period. For this reason, missed injuries have become a target for quality improvement, and even a metric of quality assessment for mature trauma centers.

A study by Buduhan et al attempted to classify missed injuries as avoidable (misinterpretation of diagnostic imaging or inadequate clinical assessment), or unavoidable (due to patient factors such as hemodynamic instability or decreased level of consciousness) (43). They found that 56% of missed injuries were potentially avoidable. This classification is somewhat suspect as even hemodynamically unstable or unconscious patients should still receive a tertiary survey. Kalemoglu et al reported a similar classification with 69 distinct factors (such as human error, radiologic misinterpretation, etc.) contributing to missed injuries and 59% of missed injuries being potentially avoidable (44). Pehle et al found that the majority of missed injuries are due to misinterpretation of radiology, incomplete diagnostics, and inadequate physical exam (45).

Inadequate compliance with tertiary survey completion and documentation is another potential reason why injuries may be missed. The Keijzers group uniquely reported the tertiary survey compliance rate at a level II trauma center and found that only 20% of patients appear to have a tertiary survey completed with the majority of those having poor or missing documentation (46). A recent study by Leeper et al demonstrated that having a non-surgeon trauma team leader was associated with a higher rate of missed injuries (37). This notion is corroborated by Lin et al who showed that the missed injury rate was lower in patients treated by a dedicated trauma surgeon as compared to those treated by a non-trauma trained surgeon (47).

Gruen et al attempted to classify and attribute error patterns in a large review of 2594 deaths in a trauma population of over 44 000 (48). Missed or delayed diagnosis was implicated in 11% of the total errors committed, with 7 patients dying as a direct result. In a study by Clarke et al, missed injuries were categorized according to error theory taxonomy (24). They had a missed injury rate of 2.5% over the study period. The most common types of errors leading to missed injury were: inadequate clinical assessment, misinterpretation or failure to act on imaging, and inadequate intra-operative assessment. Trainees committed the majority of errors. Using error theory analysis, they suggested an increased awareness around the potential for error as it pertains to missing injuries and taking preventative measures, including clinical pathways and algorithms to prevent errors.

The ACS and the ACS Committee on Trauma have lead the development of an international program designed to assess and improve trauma outcomes: the Trauma Quality Improvement Program (TQIP) (49,50). This new program provides guidelines for measuring quality of care and outcomes, as well as implementing quality improvement strategies. In a recent review of trauma quality assurance, Stelfox et al proposed seven promising quality indicators; one of which was missed injuries; which among the seven indicators, had the highest evidence for measurable improved outcomes (51). It is clear that missed injuries after trauma are recognized as an important focus area requiring attention and improvement.

1.7 Medical Consequences of Missed Injuries

Missed injuries are typically classified based on whether they are clinically significant or not. A minority of investigators classify them as minor, major, or life-threatening. While not as difficult to define as a missed injury, the definition of a "clinically significant missed injury" is also not well defined in the literature. In their review, Pfeifer et al developed three main themes in the definitions of clinically significant missed injuries: associated morbidity or mortality, required additional procedures or altered therapy, and/or resulted in significant pain or disability (15).

The proportion of missed injuries classified as clinically significant ranges from 15%-22% (15,18,43). Vles et al reported that a missed injury resulted in a change in treatment in 55% of cases and surgical intervention in 24% of cases (27). Rizoli et al report that 40% of their missed injuries were clinically significant (52), while Leeper et al report 22% clinical significance with 11% requiring surgical intervention (37).

Missed injuries have a tendency to be insidious in nature and are prone to long-term complications and morbidity when treatment is significantly delayed. Once again the specter of loss to follow-up in the trauma population makes it very difficult to track the long-term complications of injuries that go untreated for prolonged periods (or altogether) as a result of being missed. One study by Keijzers et al sought to follow-up with trauma patients by telephone interview at 1 and 6 months post-discharge to characterize a variety of functional outcomes, including missed injury (17). Despite a telephone follow-up rate of less than 50%, they measured an outpatient missed injury rate of 15%-18%. At one month, 41-45% of patients were seeing an occupational or physical therapist, and 78%-81% reported some difficulty with activities of daily living (ADLs). At six months, 58%-67% were seeing an occupational or physical therapist, and 57%-65% reported some difficulty with ADLs. It is very difficult to attribute any of these generic outcomes to a specific missed injury, detected as either an inpatient or an outpatient. However, at least some of the reported morbidity in this study was attributed to delayed diagnosis and treatment of missed injuries.

1.8 Legal Consequences of Missed Injury

Missed injuries represent a source of potential litigation against trauma practitioners. Many errors or oversights in trauma may be perceived by patients as excusable or understandable in scenarios where the patient is close to death and drastic resuscitative maneuvers are being performed. The missed injury, however, poses more of an issue – how can factors related to immediate resuscitation explain why an injury may have gone undiagnosed for days or weeks?

Due to patient confidentiality provisions as well as hospital policies, it can be difficult to track the incidence and outcomes of healthcare-related legal action. The fact that many trauma events involve potential criminal ramifications also complicates the picture. A study by Stewart et al demonstrated a very low rate of trauma patient litigation at their center. Over a 12 year period in which nearly 50 000 trauma patients were admitted, only 2 lawsuits were filed resulting in a litigation rate of 0.34 per 100 000 trauma patients per year (53). However, both lawsuits were related to an apparent missed injury. A subsequent study by this group showed that errors with associated clinically significant complications were more likely to incite litigation than errors with no complications (54). Weiland et al demonstrated a total of 121 malpractice suits involving trauma patients at multiple level I and level II trauma centers (55). Missed injury was one of six factors they identified for which litigation risk was high.

Complete documentation is critical to successful defense against medical-legal scrutiny. The thorough documentation of a complete tertiary survey would today be considered crucial in legal defense against allegation of a missed injury. The defense would be enhanced if a thorough review of the relevant medical imaging was included in the documentation.

1.9 Problems with the Current Tertiary Survey Model

While the tertiary survey has been shown to be an effective tool for increasing awareness and decreasing the incidence of missed injuries (13,16,22,56), there are still some practical problems with it. The main issue is the lack of a standardized approach to performance and documentation. Each center typically develops its own tertiary survey model which may or may not be optimal for their particular patient population. This also makes it difficult to study and compare results across centers.

Another possible problem with many tertiary survey models is the issue of compliance. While a tertiary survey policy or model may be in place, compliance with performance and documentation are often problematic, especially in busy trauma centers. In their study, Huynh et al found that tertiary survey compliance ranged from 56%-76% (33). They found that 12% of patients not only did not have a tertiary survey documented but that one was never even performed. Another study by Keijzers et al from a rural trauma center found that compliance with the tertiary survey was only 20% with the majority having incomplete documentation (46).

What additional elements are included in the tertiary survey is also variable. For example, practices such as reviewing radiology reports or VTE prophylaxis as part of the tertiary survey seem rational; however, evidence as to the utility of these add-ons is lacking. The act of simply performing the tertiary survey and documenting findings is likely insufficient in and of itself. Diagnostic action needs to be taken on each abnormal finding. Furthermore, each test which is ordered needs to be followed up. For example, an x-ray may be ordered to confirm a suspected fracture but it may not be performed and have an accompanying final report until the following day. If the result is overlooked and no follow-up action is taken, treatment can still be delayed. Such an injury could be classified as a missed injury even though it may have been identified and documented on the original tertiary survey. A tertiary survey form alone – as originally described and often practiced – is insufficient as a means to ensure and document appropriate follow-up on tertiary survey abnormalities.

1.10 Mobile Technology in Trauma

The way healthcare information is documented and shared has evolved rapidly over the past decade. Nearly all healthcare systems in developed nations have moved to electronic medical records (EMR); with some having gone completely paperless. The advantages and challenges of the electronic medical record have been well described (57-59).

The care of the complex trauma patient is a challenge. An organized and prioritized approach is required to ensure optimal care and avoid oversights. Recently, the concept has been proposed of using computer support to help mitigate some of the complexity of the trauma population. The title of a commentary by Eastman asks the question: "Are Computers a New Member of the Trauma Team?" (60) The article referenced in the commentary was a randomized trial examining the effect of computer-assisted decision support during trauma resuscitation (61). In the intervention group, an evidence based software program guided the trauma team through critical steps in resuscitation. Standard trauma team resuscitation was used as the control group. The patients with computer-assisted resuscitation had fewer errors, more error-free resuscitations, and decreased morbidity.

The use of the electronic medical record in the trauma population has further been shown to improve documentation rates and even decrease mortality (62). Bilyeu et al showed that after implementation of an EMR for documenting trauma resuscitations, complete documentation rates improved by 7% (63). A more recent study demonstrated an improvement of 15% with the same intervention (64). The benefit imparted by the EMR appears to be maintained and even enhanced when applied to mobile device platforms (smart phones, tablets, etc.) (65,66) A study by Carroll et al showed that the use of such mobile device platforms on rounds in a neonatal ICU significantly decreased the rate of documentation discrepancies and errors (67).

The complexity involved in resuscitating, managing, and documenting care in trauma patients clearly lends itself to computerized support. The sheer number of injuries a severely traumatized patient may incur can leave the trauma practitioner overwhelmed, if only in documenting all the injuries. When providers are then asked to prioritize urgent treatments, coordinate a myriad of tests, be the ringleader of an army of consulting services, and continuously follow up and reassess all of them – the potential for error is extreme. Computers are designed to organize and prioritize such complex systems. Their more formal integration into all aspects of trauma care is an ongoing and natural progression of the EMR revolution.

1.11 Physician Assist Trauma Software (PATS) Development

As a means to address some of the problems with the tertiary survey, a team of residents and trauma surgeons at LHSC sought to develop a mobile clinical application which would represent a new paradigm for how the tertiary survey is performed and documented. Focus groups were held to identify key steps in how the tertiary survey is carried out. A conceptual model was developed centering on an anthropomorphic figure to guide users through the initial physical exam, document results, review key results, perform and document actions to address abnormalities, and follow-up on the results of those actions (Appendix A).

The PATS program is mounted on a mobile electronic device (tablet), and guides the user through four modes: exam mode, action mode, completion mode, and signed off mode. When a new patient encounter is created, demographics and vitals are inputted. The user is then presented with the standard anthropomorphic figure which serves as the “home screen” throughout the rest of the process. Abnormalities are indicated by selecting the affected body area and entering the exam findings. There are additional sections for a neurological exam, a review of initial and final imaging reports, and a review of VTE and tetanus prophylaxis. The user then moves on to action mode where a list of all abnormalities identified in exam mode is generated. Each item must be selected and an appropriate action indicated (eg. x-ray for a swollen wrist.) The next mode is completion mode where any body areas with outstanding actions are highlighted. The user must select each outstanding action to indicate that it has been followed up on (eg. x-ray report read) and appropriate secondary action taken (eg. orthopedics consult for a wrist fracture). Once all outstanding actions have been addressed, the user can sign off the patient file indicating that the tertiary survey is fully complete, and the expectation is that no patient be discharged home until the patient file is signed off. A printable report can be generated as any point (Appendix B).

There are several unique and novel features of the PATS program. By employing the anthropomorphic figure, the system guides the user through each step of the physical exam, thus making it less likely to miss a body area. The program is designed to require documentation of each body area prior to moving to the next mode, as a secondary check to ensure compliance. PATS also incorporates several tertiary survey "adjuncts" including documenting which radiology tests have been performed and when the final reports have been reviewed, and a review of VTE and tetanus prophylaxis – features which are often omitted from standard tertiary survey models. One of the major strengths of the PATS program is its ability to document findings and prompt users beyond the simple completion of the physical exam. Users must specify and document an action for each abnormality before PATS allows them to continue. It also has the unique functionality of generating a list of actions which need to be followed up on and further documenting that these actions were subsequently addressed. This level of functionality, documentation, and interactive, adaptive prompting is not possible using a paper tertiary survey form. Such a system, to our knowledge, has not previously been described in the literature.

1.12 Study Rationale and Objectives

The present thesis was designed to assess the effectiveness and feasibility of implementing the PATS program. The main research question was: does the implementation of the PATS program reduce missed injury rates? We also sought to determine if the implementation of PATS was feasible using quantitative and qualitative approaches. The PATS program was piloted at two distinctly different trauma centers to evaluate its overall applicability and generalizability to a variety of trauma populations.

We hypothesized that PATS would reduce the rate of missed injuries and increase documentation compliance.

1.13 Study Design

This project was divided into three phases. The first phase was to identify the baseline rates of missed injuries at each pilot site. The second phase was the pilot phase where PATS was introduced and implemented at both sites. Missed injury rates as well as tertiary survey documentation rates were compared between the pre- and post-PATS implementation groups. The third phase was a qualitative assessment of user-level feedback and feasibility. Practitioners responsible for completing the tertiary survey were surveyed about their perceptions of the pre- and post-PATS implementation models.

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Chapter 2

2 Missing the missed injury: When and how missed injuries are identified

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Gray DK, Parry NG

2.1 Abstract

2.1.1 Introduction

Missed injuries in trauma represent a source of preventable morbidity. Missed injury rates have been reported as high as 22%. The purpose of this study was to quantify the rate, predictors, and outcomes of missed injuries at our center; focusing on the timing of missed injury identification. Specifically, we sought to quantify the number of missed injuries picked up after hospital discharge.

2.1.2 Methods

A random sample of 300 patients was selected from our prospectively collected trauma database. Missed injuries were identified and characterized by cross-reference with the database and a detailed chart review. A missed injury was defined as any injury listed in the database which was not identified within 24 hours of admission. Missed injuries were classified by detection method as inpatient, outpatient, or database coder-identified.

2.1.3 Results

A total of 55 injuries were identified in 46 out of 300 patients, for an overall missed injury rate of 15%. Higher ISS (30 vs 25, $p<0.01$) and ICU admission (65% vs 42%, $p<0.01$) were associated with having a missed injury. Hospital LOS, ICU LOS, and mortality did not differ based on the presence or absence of missed injuries. Extremity fractures (38%), spine fractures (27%), and torso injuries (27%) were the most commonly missed injuries. 18% of missed injuries were clinically significant. The inpatient,

outpatient, and coder-identified missed injury rates were 9.0%, 2.0%, and 4.3% respectively.

2.1.4 Conclusions

A significant number of missed injuries are diagnosed after trauma patients are discharged from hospital. Focus on early, in-hospital diagnosis and management of these injuries may reduce resultant long-term morbidity.

2.2 Introduction

The initial resuscitation and management of the trauma patient centers around identifying and treating life-threatening injuries. Any injuries which are not identified during the initial resuscitation are at risk of being missed altogether. Historically, missed injury rates have been reported as high as 22% (1-8). These injuries have been shown to be a significant source of preventable morbidity (5,9-18).

Several factors have been shown to predict patients at risk for missed injury including: higher injury severity score (ISS), head injury, and intensive care unit (ICU) admission (1,2,19-22). The most common type of missed injury is extremity fracture which typically accounts for about half of the missed injuries in a given trauma population (1,2). Some missed injuries have no appreciable clinical consequences. However, up to 20% of missed injuries require significant clinical intervention and/or have measurable patient morbidity after they are identified (1,2,8,14,17,23,24).

Most trauma populations have a loss to follow-up ranging from 30-40% (25,26). This introduces a significant source of bias to trauma outcomes and quality improvement research. In terms of tracking missed injuries, it is not possible to identify injuries which may be picked up after discharge in the proportion of patients who are lost to follow-up. These patients may seek care from their primary care provider, local emergency department, or from a center to which they have been transferred for convalescence – none of which can be easily tracked by researchers at the primary trauma hospital. At London Health Sciences Center (LHSC), 54% of patients are given trauma clinic follow-up and of these, less than 10% are lost to follow-up. Our loss to follow-up rate is relatively low with most patients returning for trauma clinic follow-up within two weeks of discharge. This provides us with a unique opportunity to assess what happens to trauma patients after they are discharged from hospital.

The purpose of this study was to provide a contemporary analysis of the rate of missed injuries after major trauma at our center, and to identity the proportion of missed injuries which are identified after hospital discharge. Further, we wished to identify patient and injury characteristics associated with missed injuries in this population.

2.3 Methods

London Health Sciences Centre is the Level 1 trauma center for southwestern Ontario, with a catchment area of more than 1.5 million people. As part of a larger study assessing the impact of non-surgeon trauma team leaders, a random sample of 300 patients from a 10 year admission period was extracted from our prospectively collected trauma database. The selection process was driven by a random number generator (SPSS version 21) handled by administrative staff and was concealed from the study investigators. These patients formed our study cohort. Patients discharged from the emergency department or who died within 24 hours were excluded as these patients would typically not have a tertiary survey performed. All trauma inpatient records, and any subsequent outpatient or emergency room visits were reviewed to identify any potential missed injuries. The hospital system in London allows for capture of all tertiary care visits in the city through an integrated electronic medical record.

For each patient, a list of injuries was available from the trauma database. The list of injuries is generated by trained trauma database analysts using International Classification of Diseases 10th edition (ICD-10) codes. During data entry, the database analysts examine the chart and carefully extract injuries based on all available documentation. All elements in the trauma database, including the ICD-10 coded injury list, are prospectively collected.

A missed injury was defined as any injury appearing on the database ICD-10 coded list, which was not documented in the patient's chart within 24 hours from admission. A missed injury was considered clinically significant if it resulted in any additional procedure, additional length of stay, or an unplanned follow-up with a consulting service.

Details of each missed injury were collected including: time until diagnosis, method of diagnosis, and intervention (if any). Patients with missed injuries were grouped and compared according to the manner by which their missed injury was picked up: by the inpatient team, as an outpatient, or by trauma database coders. Data were presented as means with standard deviations, medians with interquartile ranges, and frequencies with associated percentages. The primary outcome of this study was the rate of missed injuries. Demographic and injury data were compared based on the method of detection of the missed injury using ANOVA for continuous variable, and chi-square for interaction. Demographic, injury data, and outcomes were compared between those with, and without, missed injuries using Student's t-test or Fischer's exact test, where appropriate. Secondary outcomes included factors associated with missed injuries, as well as outcomes including length of stay and in-hospital mortality. Secondary outcomes were analyzed in the same manner as the primary outcome.

Statistical analyses were performed using SPSS version 20 (IBM Corp, 2011. San Francisco CA). A p value of < 0.05 was considered significant.

2.4 Results

Of the 300 randomly selected patients, 46 patients (15.3%) were found to have missed injuries. Of the 46 patients with missed injuries, a total of 55 distinct missed injuries were identified. Six patients had 2 distinct missed injuries and one patient had 4 distinct missed injuries; the remainder had only 1 distinct missed injury. Basic demographic information and injury characteristics are shown in Table 2.1. Patients with a missed injury had a higher mean ISS (29.6 vs 25.4, $p<0.01$) and were more likely to be admitted to the ICU (65% vs 42%, $p<0.01$). Patients with missed injury did not have a longer length of stay (10 vs 10 days, $p=0.99$), longer ICU stay (5 vs 8 days, $p=0.08$), or higher mortality (11% vs 12%, $p=0.86$) (Table 2.2).

Details of the 55 missed injures are shown in Table 2.3. Extremity fractures were the most commonly missed injury (38%), followed by spine fractures (27%) and torso injuries (27%). 18% of the missed injuries were classified as clinically significant, with torso injuries (27%), and extremity fractures (24%), being the most likely to have clinical significance. Four missed injuries (7%) required operative intervention. 13 (24%) of the missed injuries were symptomatic, while the remainder (76%) were picked up solely on imaging. For all missed injuries, the median time from admission to diagnosis was 3 days (IQR 2.0-4.3).

Interestingly, only 35 (64%) of the total 55 missed injuries were picked up as an inpatient. Of the remaining missed injuries, 6 (11%) were picked up in the outpatient setting and 14 (25%) were only identified by trauma database coders (i.e. were identified in radiology reports but not mentioned anywhere else in the patient record). After accounting for patients with multiple missed injuries, the overall missed injury rate of

15.3% can be broken down into an inpatient missed injury rate of 9.0%, and outpatient missed injury rate of 2.0%, and a coder-identified missed injury rate of 4.3%. There were no demographic or injury characteristics which were predictive of missed injury detection method (Table 2.4). Likewise there was no single type of missed injury (extremity fracture, spine fracture, etc.) which was exclusively detected as an outpatient or by coders. 5 (14%) of the inpatient injuries, 4 (67%) of the outpatient injuries, and 1 (7%) of the coder-identified injuries were clinically significant.

Table 2.1 Demographics and injury characteristics for patients with and without missed injury.

Variable	**Overall**	**Missed Injury**	**No Missed Injury**	**p Value**
Number, (%)	300 (100)	46 (15)	254 (85)	-
Age, mean (SD)	42.4 (19)	42.4 (20)	42.4 (18)	0.87
Male gender, n (%)	217 (72)	38 (84)	179 (71)	0.053
Penetrating injury, n (%)	8 (2.7)	0 (0)	8 (2.7)	0.61
ISS, mean (SD)	27.5 (11)	29.6 (11)	25.4 (11)	**<0.01**
SBP on admission, mean (SD)	134 (33)	127 (31)	135 (34)	0.15
Admission to ICU, n (%)	136 (45)	30 (65)	106 (42)	**<0.01**
Severe head injury (AIS≥3), n (%)	126 (42)	19 (41)	107 (42)	0.92

Injury Severity Score (ISS), systolic blood pressure (SBP), intensive care unit (ICU), Abbreviated Injury Scale (AIS)

Table 2.2 Clinical outcomes for patients with and without missed injury.

	Overall	Missed Injury	No Missed Injury	P Value
LOS, mean (SD)	10 (12)	10 (10)	10 (13)	0.99
ICU days, mean (SD)	8 (14)	5 (8)	8 (15)	0.08
Mortality, n (%)	35 (12)	5 (11)	30 (12)	0.86

Length of stay (LOS), intensive care unit (ICU)

Table 2.3 Details of missed injuries.

Injury Type	Number, n (%)	Clinically Significant, n (%)	Required OR, n (%)
Total	55 (100)	10 (18)	4 (7)
Extremity fracture	21 (38)	5 (24)	1 (5)
Spine fracture	15 (27)	1 (7)	1 (7)
Transverse process	8 (53)	0 (0)	0 (0)
Other	7 (47)	1 (14)	1 (14)
Torso	15 (27)	4 (27)	2 (13)
Chest	10 (67)	2 (20)	0 (0)
Abdomen	4 (27)	1 (25)	1 (25)
Vascular	1 (7)	1 (100)	1 (100)
Head Injury	4 (7)	0 (0)	0 (0)
Fracture	3 (75)	-	-
Bleed	1 (25)	-	-

Operating room (OR)

Table 2.4 Demographics and injury characteristics by missed injury detection method.

Variable	Inpatient	Outpatient	Coder	p Value
Age in years, mean (SD)	42 (21)	43 (14)	43 (20)	0.99
Male gender, n (%)	22 (85)	4 (67)	12 (92)	0.36
ISS, mean (SD)	31 (12)	26 (8)	28 (9)	0.48
SBP on admission, mean (SD)	125 (32)	134 (39)	130 (26)	0.83
Admission to ICU, n (%)	17 (65)	4 (67)	30 (65)	0.99
Severe head injury (AIS≥3), n (%)	12 (46)	1 (17)	6 (43)	0.41

Injury Severity Score (ISS), systolic blood pressure (SBP), intensive care unit (ICU), Abbreviated Injury Scale (AIS)

2.5 Discussion

This study provides a contemporary analysis of the rate of missed injuries at a Canadian Level 1 trauma center, and a previously undocumented focus on assessment of the rate of missed injuries identified after hospital discharge. We have demonstrated a 15% overall missed injury rate and a 9% inpatient missed injury rate which corresponds with rates in the current literature.

In a recent study from Taiwan, Chen et al report a missed injury rate of 12% in a population of nearly 1000 patients over 2 years (27). This center is comparable to ours in terms of both clinical volume and missed injury rate. However, this group defined a missed injury as missed in the emergency department and picked up in the ICU, where they received a tertiary survey. In another recent retrospective study by Giannakopoulos et al from the Netherlands, they report a missed injury rate of 8.2% in a review of over 1100 patients (28). This rate decreased to 4.9% when only injuries identified after completion of the tertiary survey were included. They also showed that higher ISS was predictive of having a missed injury, which concurs with our results. As in our study, multiple studies have shown ICU admission to be a predictor for having missed injuries (4,29,30).

In a review on the topic, Pfeifer et al describe a missed injury rate ranging from 1.3%-39%, with 15%-22% being clinically significant (1). They also astutely point out the lack of a standardized definition for a missed injury noting no less than 4 prevalent definitions in the reviewed literature. Another literature review by Keijzers et al reported a missed injury rate ranging from 1.3%-65% with an average of 4% (2). This broad range of missed injury rates is likely due to multiple factors. Clinical volume and practitioner awareness of missed injuries likely affects missed injury rates. The liberal use and formalization of the tertiary survey concept since its inception in 1990 has also likely served to reduce missed injuries. Similarly, the increasingly liberal use of cross-sectional and plain film imaging may play a role in driving down missed injury rates. There is likely an element of reporting bias as centers may be reluctant to disclose patient morbidity outcomes. Finally, the lack of a standardized definition makes it difficult to discern exactly how and when various missed injuries are identified.

The definition of a missed injury varies quite widely in the literature and has matured with the wide implementation of the tertiary survey. We feel that a missed injury should be defined as any injury not detected/suspected and documented upon completion of the tertiary survey. Missing non-life threatening injuries during resuscitation is excusable so long as they are picked up and acted on appropriately in accordance with the tertiary survey; which is itself designed to pick up these injuries. Thus picking up injuries using a tertiary survey implement should not be considered a failure in the resuscitation phase, but instead a success of the tertiary survey model.

We did not detect any significant difference for in-hospital outcomes (LOS, ICU stay, mortality) between those who did or did not have missed injuries. Most studies in the literature show similar results (8,15,23,24,28). Once again, however, the rather insidious nature of these missed injuries typically results in more long-term complications and morbidity. One of the only studies to attempt to address this long-term morbidity showed some chronic pain and paraesthesia, as well as some ongoing difficulty with daily activities and ongoing follow-up with rehab services (31). However, it is difficult to attribute these outcomes solely to missed injury.

In our population, extremity fractures were the most common missed injury. This aligns with most of the published literature (1,2,8,30). Extremity injuries are among the least likely to be immediately life threatening and are thus prone to being overlooked, especially during the resuscitation phase. Furthermore, bruising or swelling may be subtle and easily missed without a thorough tertiary survey examination. Some extremity injuries may not even be apparent on exam and be detectable only by patient symptoms; thus, altered or sedated patients may not complain of pain until they are alert, which may be days or weeks after admission.

Spine fractures were also fairly commonly missed in our population. The majority were transverse process fractures which are typically of little clinical significance. However, these injuries are usually only detected on imaging which suggests that either they are being detected in a delayed fashion by radiology, or else the clinical team may be overlooking them in radiology reports. The one missed spine fracture which required operative intervention actually presented nearly a month after injury in the outpatient clinic with delayed symptoms of central cord syndrome resulting from a C5-6 subluxation which was not detected on initial imaging. Torso injuries also have a propensity to be missed. These injuries were the most likely to be clinically significant. Missing a few rib fractures or failing to appreciate a minor pulmonary contusion is often of minimal significance during the resuscitation phase. However, these types of injuries have a propensity to worsen rapidly if they are not managed aggressively up front and can quickly deteriorate to require respiratory support.

Most studies examining missed injuries in trauma focus on the injuries which are identified in hospital in a delayed fashion. There have been few studies examining the rate of missed injuries picked up after hospital discharge. Interestingly, even the group that first described the tertiary survey in the seminal 1990 paper, Enderson et al, noted the potential for outpatients to present with missed injuries: "Despite the best of efforts, some injuries may still not be evident during the hospitalization phase of trauma care. Therefore any patient who returns to the office complaining of problems not previously evaluated requires further investigation as well." (32)

By their nature, missed injuries have a tendency to have a subtle or delayed clinical presentation. Therefore it is likely that at least some patients leave hospital with undiagnosed injuries. These injuries may heal on their own such that the patient may never even know about them. Alternatively, these injuries may have clinical consequences days, weeks, or even years down the road.

We have shown that over a third of missed injuries are picked up after hospital discharge, with an outpatient missed injury rate of 2%. The majority of missed injury studies focus on inpatient pickups and thus are likely underestimating their true missed injury rate. With a loss to follow-up rate of less than 10%, we have robust trauma follow-up at our center; which is a luxury as most centers struggle to retain even half of their discharged trauma patients in follow-up. This is in part due to differences in the single-payer Canadian health care system, as compared to our American counterparts.

A large study by Keijzers et al attempted to quantify the outpatient missed injury rate, which they reported to be between 15%-18% (31). A third of these injuries were classified as clinically significant. This was based on 1-month and 6-month follow-up telephone interviews, of which less than half of patients participated. This lack of complete follow-up, as well as a reliance on patient self-reporting limits this study. Another study by Malhotra et al showed a more modest outpatient missed injury rate of 2.5% (16), but was also limited by a low follow-up rate and a reliance on patient self-reporting. Another Canadian center similar to ours reported an outpatient missed injury rate of 11% (4). This study reported the outpatient missed injury rate as a secondary outcome, and was limited by the inability to obtain all outpatient charts. The majority of these studies include outpatient missed injuries as secondary outcomes, and provided few details on the follow-up rates and details of the missed injury diagnoses. The present study, along with the Keijzer group are among the few studies specifically designed to report missed injuries detected after hospital discharge.

Ours is the first study to our knowledge to identify database coders as a source of missed injury identification. We report a coder-identified missed injury rate of 4.3%. Our trauma database coders are highly trained to extract a variety of metrics from each trauma patient's paper and electronic medical records. In all instances where a coder identified a missed injury, it was the result of them picking up an injury mentioned in a radiology report which was not documented or discussed anywhere else in the chart (resuscitation note, discharge summary, progress notes, etc.) by the clinical team. This would suggest that despite having access to the radiology reports, the clinical team somehow failed to identify these injuries. This could be a result of inadequate scrutiny by the clinical team or else a result of delayed final reporting by radiology. Either way, a thorough review of all final radiology reports should be an important task for the clinical team, and we have in fact since added a thorough radiology review to our tertiary survey. Similarly, there should be some onus on the radiology department to notify the clinical team if there are any discrepancies between the initial verbal interpretation and the final report.

This study has several limitations. Despite a random selection of patients, it is possible that there was an element of sampling bias and that our cohort over- or under-estimates the true missed injury rate. Due to the retrospective nature of this study, we were limited in our search for potential missed injuries by a lack of standardized clinical documentation. Another drawback is the lack of formal documentation of the tertiary survey at our institution during the study period. We used a 24-hour cut off assuming that the tertiary survey would be completed by this point. Since we had no formal tertiary survey documentation, our next best option was to scrutinize the clinical notes for evidence of injury identification. It is possible that some of the injuries classified as missed injuries may actually have been identified by the clinical team but never documented. Likewise, it is possible that some of the coder-identified missed injuries were known by the clinical team but never documented either due to oversight, or due to perceived clinical insignificance.

In conclusion, our inpatient missed injury rate is similar to rates published in the literature. We identified an additional number of missed injuries which are being picked up in the outpatient setting, as well as a novel source of missed injury identification in our trauma database coders. Missed injuries diagnosed after hospital discharge represent a significant proportion of all missed injuries and thus many centers may underestimate their rate of missed injuries due to a significant loss to follow-up. Missed injuries remain an important source of preventable morbidity in the trauma population. These injuries are a prime target for quality improvement, and future work should focus on methods to decrease the rate of missed injuries.

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Chapter 3

3 Missed Injuries at a Level 1 Trauma Center: A Contemporary Analysis

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3.1 Abstract

3.1.1 Introduction

Historically, the rate of missed injuries after trauma is upwards of 20%. The purpose of this study was to quantify the contemporary incidence of missed injuries at a Level 1 trauma center in the era of developed tertiary surveys and advanced imaging.

3.1.2 Methods

This prospective cohort study enrolled all injured patients ≥18 years old admitted to a Level 1 trauma center over a two month period. All patients underwent diagnostic workup at the discretion of the trauma team. A tertiary exam was performed within 24 hours, including a complete examination and review of investigations. Missed injuries were defined as those diagnosed after the tertiary exam but prior to hospital discharge. The primary outcome was the incidence of missed injuries. Secondary outcomes included length of stay, ventilator days, and mortality.

3.1.3 Results

429 patients were evaluated (mean age 41±18, 75% male, 20% penetrating, ISS 9±8) with a missed injury rate of 1% (n=4). All missed injuries were extremity fractures and all were clinically significant. On univariate analysis, higher ISS (p=0.02) was associated with missed injuries. Missed injuries were not associated with overall length of stay, ICU stay, and overall mortality.

3.1.4 Conclusions

Missed injuries remain a significant contemporary problem. Further studies are required to identify strategies to reduce the rate of missed injuries.

3.2 Introduction

The initial assessment and management of trauma patients is focused on identifying and treating injuries which represent an immediate threat to life. During this process, non-life threatening, but clinically significant injuries may be missed. This delay in diagnosis can lead to significant morbidity, and to medical-legal ramifications.

Historically, the rate of missed injuries after major trauma has been reported to be as high as 22% (1,2). However, in the time since these studies were published, the tools available for the assessment of the trauma patient have changed. Rapid and accessible advanced imaging, typically in the form of a CT scan, have enhanced our ability to evaluate the injured patient comprehensively (3). Similarly, the concept of a tertiary survey: a complete head-to-toe re-examination of the patient (4), is now a routine part of trauma assessment. It is hypothesized that these advancements have contributed to a decline in the rate of missed injuries.

Like many other large trauma centers, the University of Southern California (USC) trauma program has developed a comprehensive tertiary survey designed to minimize missed injuries. Each patient who is admitted to the trauma service undergoes a complete head-to-toe tertiary survey physical exam within 24 hours of admission. New abnormalities are addressed with appropriate diagnostics. This is typically the responsibility of the second and/or third year general surgery resident on the admitting team. Residents are also encouraged to fully review all blood work, prophylaxis measures, and final radiology reports to ensure nothing was missed. Each trauma patient has a one-page form in the medical record to document all tertiary survey findings.

This study was undertaken to identify the contemporary rate of missed injuries at a mature Level 1 trauma center in the era of the tertiary survey and advanced imaging. Further, we sought to identify factors associated with missed injuries, and the impact of missed injuries on patient outcomes.

3.3 Methods

This prospective cohort study was completed at Los Angeles County & University of Southern California Medical Center, a Level I trauma center with approximately 5000 trauma admissions annually. All consecutive adult trauma patients admitted from September 1 – October 31, 2013 were included, and followed prospectively to identify missed injuries. Patients who were observed and discharged from the emergency department, pregnant patients, and patients who died within 24 hours of admission were excluded.

Tertiary surveys are completed and documented by the house staff on all admitted trauma patients. All injuries identified during the primary, secondary, and tertiary survey were recorded. These were compared with all injuries documented at the time of discharge. Any discrepancy prompted a full review to ascertain exactly when the potential missed injury was first diagnosed and documented, as well as the clinical course and consequences identified after injury diagnosis.

A missed injury was defined as any injury diagnosed after completion of the tertiary survey, but before hospital discharge. Missed injuries were classified as clinically significant if they resulted in an unplanned procedure, resulted in additional length of stay, or generated an unplanned follow-up appointment with a consulting service. The final tertiary survey in the medical record was utilized for study purposes. Any missing fields on the tertiary survey form were treated as being incomplete.

Data were presented as means with standard deviations, medians with interquartile ranges, and frequencies with associated percentages. Demographic, injury data, and outcomes were compared between those with, and without, missed injuries using Student's t-test or Fischer's exact test, where appropriate. The primary outcome of this study was the rate of missed injuries. Secondary outcomes included factors associated with missed injuries, as well as outcomes including length of stay and in-hospital mortality.

Statistical analyses were performed using SPSS version 20 (IBM Corp, 2011. San Francisco CA). A p value of < 0.05 was considered significant.

3.4 Results

429 patients that met our inclusion criteria were admitted during the two-month study period. Four patients (1%) had a missed injury, all of which were extremity fractures. All missed injuries were classified as clinically significant.

The demographic and injury characteristics between those with and without missed injuries can be found in Table 3.1. Patients with missed injuries were more severely injured than those without missed injuries (Injury Severity Score [ISS] 19 vs. 9, p=0.02). Variables previously demonstrated to be associated with an increased rate of missed injuries (5-9), including admission systolic blood pressure (SBP) (124 vs. 137, p=0.06), ICU admission (75% vs. 31%, p=0.09), and severe head injury (50% vs 17%, p=0.13), were not associated with missed injuries (Table 3.2). Patients with missed injury did not have a statistically significant longer length of stay (11 vs 5 days, p=0.34), ICU stay (2 vs 2 days, p=0.88), or higher mortality (0% vs 3%, p=0.88).

All patients had a tertiary exam initiated, however only 68% of all patients admitted had a complete tertiary survey documented. In 82% of cases where the form was not filled out completely, the only data missing was the genitourinary exam section. Full completion of a tertiary survey was not associated with a decrease in missed injuries (67% vs. 62%, p=0.67).

Details of the 4 missed injuries are shown in Table 3.3. All injuries were detected as a result of the patient complaining of pain. In the patient with the missed metacarpal fracture, the tertiary survey was complete and the hand exam part of the form documented as normal. In the patient with the distal fibula fracture, ankle swelling was documented on the tertiary survey form but no follow-up action was taken. In the patient with the proximal fibula fracture, the tertiary survey form was blank, although there was a clinical note stating the tertiary survey exam was performed and was normal. In the patient with the tibial plateau fracture, there were multiple sections of the form which were incomplete; however, the knee portion of the exam was documented as normal. A robust quality improvement program at our center ensures that all of these discrepancies are reviewed with the physicians caring for the patient, specifically with those completing the tertiary survey, for the purposes of education and loop closure.

Table 3.1 Demographic and injury characteristics for patients with and without missed injury.

	Overall	Missed Injury	No Missed Injury	P Value
Number	429	4	425	-
Age, mean (SD)	41 (18)	29 (13)	41 (18)	0.14
Male gender, n (%)	324 (75)	4 (100)	303 (75)	0.58
Penetrating injury, n (%)	84 (20)	0 (0)	81 (20)	0.99
ISS, mean (SD)	9 (8)	19 (7)	9 (8)	**0.02**
SBP on admission, mean (SD)	135 (25)	124 (6)	137 (25)	0.06
Admission to ICU, n (%)	134 (31)	3 (75)	131 (31)	0.09
Severe head injury (AIS≥3), n (%)	72 (17)	2 (50)	70 (17)	0.13
Tertiary survey complete, n (%)	294 (68)	2 (67)	222 (62)	0.67

Injury Severity Score (ISS), systolic blood pressure (SBP), intensive care unit (ICU), Abbreviated Injury Score (AIS)

Table 3.2 Clinical outcomes for patients with and without missed injury.

	Overall	Missed Injury	No Missed Injury	P Value
LOS, mean (SD)	6 (10)	11 (11)	5 (10)	0.34
ICU days, mean (SD)	2 (5)	2 (2)	2 (5)	0.88
Mortality, n (%)	13 (3)	0 (0)	13 (3)	0.88

Length of stay (LOS), intensive care unit (ICU)

Table 3.3 Details and circumstances surrounding missed injuries (n=4).

Injury	Time to Diagnosis (days)	Circumstances of Diagnosis	Treatment	Tertiary Survey Form Status
Metacarpal fracture	6	Pain after extubation	Splint	Complete
Distal fibula fracture	2	Pain with ambulation	Air cast, physiotherapy	Complete
Proximal fibula fracture	4	Pain after extubation	Brace, left AMA	Blank
Tibial plateau fracture	5	Pain with ambulation	Brace	Incomplete

Against medical advice (AMA)

3.5 Discussion

This study was undertaken to provide a contemporary estimate of the rate of missed injuries at a mature Level 1 trauma center in the era of advanced diagnostics and tertiary surveys. We demonstrated the rate of missed injuries to be lower than previously reported in the literature. Despite this, the fact remains that missed injuries continue to occur and the majority of these missed injuries are preventable.

Our missed injury rate is one of the lowest rates published to date. The initial studies outlining the epidemiology of missed injuries document missed injury rates in the range of 8-10% (10,11) with some rates as high as 22% (12,13). A recent study on the topic by Giannakopoulos et al showed a missed injury rate of 8.2% in a retrospective review of over 1100 patients (14). In this study, a missed injury was defined as any being diagnosed after initial resuscitation. Their rate of missed injuries dropped to 4.9% when only injuries diagnosed after tertiary survey were considered as missed.

Multiple factors have likely contributed to the decline in missed injury rates over time, and also to the differing rates across centers. As previously mentioned, the increasing use of CT scanning and other imaging modalities has likely played a major role (3,15). Many of the severely injured or unexaminable but stable trauma patients will go from the resuscitation bay to the CT scanner for total body imaging, and the unstable trauma patients will often find their way to the CT scanner after they have been stabilized. Similarly, the liberal use of plain x-rays to rule out fracture underlying physical exam abnormalities has likely improved our identification of injuries. An increasing focus on trauma quality improvement and increasing awareness of the problem of missed injuries likely also contributes to decreasing missed injury rates over time, especially in the mature trauma center.

Further, some of this improvement over time is likely attributable to the implementation, standardization, and documentation of the tertiary survey. In this study, failure to document a single portion of the physical examination led to a relatively low compliance rate with tertiary survey completion; however, most patients had the majority of their tertiary survey documented. This suggests that at minimum, the physical exam portion of the survey is likely still being conducted and the appropriate diagnostics initiated. The genitourinary portion of the tertiary survey was the only item not documented in 82% of the incomplete tertiary surveys. When the genitourinary exam portion of the tertiary survey is omitted, the documentation compliance rate increases to 93%. A genitourinary exam is unlikely to identify missed injuries and is intrusive to the patient. For this reason, we are considering removing it from the next iteration of our tertiary survey form. Certainly none of the missed orthopedic injuries would have been identified by the addition of a genitourinary exam.

Keijzers et al reported a similarly poor compliance rate with tertiary survey documentation of only 20% with a corresponding missed injury rate of 3.2% (11). As with our results, a significant number of patients with missed injuries do not have a tertiary survey completely documented. The issue of tertiary survey compliance represents a prime target for quality improvement and reducing missed injuries.

Several studies have highlighted the avertible nature of missed injuries in trauma. Kalemoglu et al demonstrated in their study population that 60% of missed injuries were potentially avoidable (16). Inadequate assessment and radiologic misses were leading causes of missed injury. This highlights the need for a tertiary survey to include not just a physical exam, but also a thorough review of the relevant radiologic studies. Virtually any type of injury has the potential to be missed on initial resuscitation; however, extremity fractures are the most common missed injury type (2,12,14). This was confirmed by our study, as all missed injuries were extremity fractures. Thoracic and head injuries are also commonly missed (10,17), although none of these injuries were missed in our series. Higher ISS, lower Glasgow Comma Score (GCS), and ICU admission have been shown to be predictive of missing injuries (10,12,14,18). In our study, only higher ISS was found to be associated with missed injuries. Kalemoglu also showed that only 16% of missed injuries have a delayed presentation where symptoms are not apparent for more than 24 hours (16). We would argue that this is the only truly non-preventable form of missed injury. This most often occurs in intubated patients where the only sign of injury is pain and the patient may not be able to report that pain until they are extubated. Other rare causes of non-preventable missed injuries include such things as occult bowel injury which may not present clinically or radiographically for 24-48 hours, and vascular injuries which may be asymptomatic until they progress (eg. blunt carotid artery dissection).

This study has several limitations. First, the primary outcome of a missed injury, was a rare event. Though adequately powered for our primary outcome, identifying associations between demographic, injury characteristics, and outcomes is difficult with such a small number of missed injuries. We also used a relatively restricted definition of missed injuries. We feel that non-life threatening injuries missed during the primary and secondary survey are acceptable so long as they are assessed, documented, and managed appropriately following a timely tertiary survey. However, it is accepted that a proportion of missed injuries will not present until after hospital discharge. Given the challenge of significant loss to follow-up amongst trauma patients, we did not include injuries identified after hospital discharge so as not to bias our sample.

In this era of tertiary surveys and advanced imaging, we report a missed injury rate of 1% at a mature Level 1 trauma center. Although a miss rate of only 1% may seem a laudable accomplishment, when extrapolated to the large number of trauma patients seen annually at our institution, this still translates to upwards of 50 patients per year suffering the morbidity of missed injuries. The majority of this morbidity is preventable. Compliance with performing and documenting the tertiary survey is a sensible target for quality improvement. The goal of any well-established mature trauma center should be to eliminate all preventable missed injuries.

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Chapter 4

4 Introduction of a Mobile Device Based Tertiary Survey Application Reduces Missed Injuries: A Multi-Center Prospective Study

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4.1 Abstract

4.1.1 Introduction

Missed injuries during the initial assessment are a major cause of morbidity after trauma. The tertiary survey is a head-to-toe exam designed to identify any injuries missed after initial resuscitation. We designed a novel mobile device application (Physician Assist Trauma Software [PATS]) to standardize performance and documentation of the tertiary survey. This study was undertaken to assess the feasibility of introducing PATS into routine clinical practice, as well as its capacity to reduce missed injuries.

4.1.2 Methods

Prior to implementation of PATS, the missed injury rates at a higher-volume and a medium-volume level I trauma center were assessed. The PATS program was implemented simultaneously at both centers. Missed injuries were prospectively tracked during the study period. Compliance and tertiary survey completion rates were evaluated as a marker of feasibility.

4.1.3 Results

At the higher-volume trauma center, the missed injury rated decreased from 1% to 0% with the introduction of the PATS program ($p = 0.04$). At the medium-volume trauma center, the missed injury rate decreased from 9% to 1% ($p < 0.001$). Compliance and documentation increased from 68% to 100%, and from no formal documentation to 60% compliance at the higher- and medium-volume centers respectively.

4.1.4 Conclusions

The implementation of a mobile tertiary survey application significantly reduced missed injuries at both a higher- and medium-volume trauma center. The use of this application resulted in a significant improvement in compliance with documentation of the tertiary survey.

4.2 Introduction

Trauma resuscitation is internationally standardized according to the American College of Surgeons Committee on Trauma (ACS-COT) Advanced Trauma Life Support (ATLS) course. The principles of ATLS are to identify and treat any life threatening injuries – the primary survey; and then to perform a full head-to-toe physical exam to identify all other injuries – the secondary survey (1).

In the multiply injured patient, non-life threatening injuries may be overlooked or missed during the secondary survey. After initial resuscitation, any injuries not documented on the primary or secondary survey are at risk of going unrecognized and untreated. This propensity for missed injuries following initial resuscitation was recognized by Enderson et al. who proposed a tertiary survey be performed within 24 hours of admission with the goal of identifying any injuries which may have been missed during initial resuscitation (2). This tertiary survey typically occurs the day following admission once the patient has stabilized and when the full resources of the dedicated inpatient trauma team can be brought to bear.

The concept of the tertiary survey has been adopted by most hospitals with an inpatient trauma service; however, the way the tertiary survey is performed, documented, and what specifically is included is variable from center to center (3-5). The main focus of the tertiary survey is a detailed head-to-toe physical exam with special focus on the extremities, which have the highest rate of missed injuries per body area (6-11). Some tertiary surveys also include a review of all final imaging reports and a review of prophylaxis measures taken (venous thromboembolism [VTE], tetanus, etc.) Specific attention must also be given to patients requiring ICU admission as this has been shown to be an independent risk factor for missed injuries (12-18).

A team of investigators at London Health Sciences Center (LHSC) recognized the lack of standardization in the tertiary survey process. They sought to create a standardized, thorough, and interactive method of guiding providers through a tertiary survey and to clearly and accurately document all results. This culminated in the creation of the Physician Assist Trauma Software (PATS). PATS is a mobile device based application used to guide and document the tertiary survey in electronic format.

The primary objective of this study was to determine whether the PATS program has the capacity to reduce the rate of missed injuries at two distinct Level 1 trauma centers. Furthermore, we concurrently studied the compliance with completing the PATS program as a quantitative measure of feasibility, as well as a measure of tertiary survey documentation rates.

4.3 Methods

This prospective cohort study evaluated the PATS program as it was implemented simultaneously at two distinct trauma centers: a medium-volume and a large-volume trauma center. London Health Sciences Center (LHSC) is a Level 1 trauma center in Southwestern Ontario servicing a population of about 1.5 million with over 600 trauma admissions per year. Los Angeles County & University of Southern California Medical Center (USC) is a Level 1 trauma center in Los Angeles, California with over 5000 trauma admissions per year.

Research ethics board approval was obtained from both sites. This included strict data security measures on all PATS devices including: tablet encryption, secondary pin security to access the PATS program, and remote reset capabilities. Furthermore, tablets were always kept in a locked and secure location when not in use. All data security was cross-checked to be in compliance with hospital standards.

PATS is a mobile device based application used to guide and document the tertiary survey in electronic format. After inputting patient demographics and current vitals, the program uses a simple, color-coded anthropomorphic figure (Appendix A) to guide the user through four modes: exam mode, action mode, completion mode, and signed-off mode. In exam mode, all physical exam findings are documented. Initial imaging and prophylaxis is also entered. In action mode, PATS prompts the user to specify an action for all abnormal findings (e.g. order an x-ray for a swollen wrist.) All outstanding actions are then displayed in completion mode and the user must select each action to confirm that it has been performed and followed-up on. Once all actions have been followed-up on, the file can be signed off and is stored in a final signed-off mode. A detailed printable report can be generated at any point in the process (Appendix B).

Residents rotating through the trauma service at both sites were given a formal presentation introducing them to the PATS program including detailed instructions for how and when to use the program. All new residents rotating through the trauma service during the study period were also given the same orientation when they started. At LHSC, the trauma nurse practitioner was also thoroughly trained. A one month acclimatization period was allowed at each site before data collection began to address any logistical or technical problems that arose, and to allow for washout of the

Hawthorne effect associated with physician observation. Residents were expected to complete the exam portion of PATS within 24 hours on all patients admitted to the trauma service. Further, they were expected to follow-up on any outstanding items on each patient's PATS file and follow it through to signed-off mode. Patients discharged from the emergency room or who died within 24 hours were excluded as these patients would typically not be expected to have a tertiary survey documented.

Missed injuries were tracked prospectively by the study investigators. Trauma morbidity and mortality lists were also reviewed for any documented missed injuries. The documented initial injury list was compared to the discharge injury list. Any discrepancy prompted a full review of the patient's chart and PATS file to ascertain if any discrepant injuries were documented at the time of the tertiary survey.

A missed injury was defined as any injury identified after completion of the tertiary survey and prior to hospital discharge. A missed injury was considered clinically significant if it resulted in any additional procedure, additional length of stay, or an unplanned follow-up with a consulting service.

PATS completion rates were also tracked prospectively as a quantitative measure of feasibility. PATS files which were followed through to signed-off mode were considered complete; PATS files which had some exam information entered but were not followed through to signed-off mode were considered incomplete. Patients with a missing PATS file were considered as not started. Completion rates were broken down and analyzed by length of stay (discharged within 24 hours or not), direct admission to ICU, and also whether the patient was admitted on a weekend/holiday. These metrics were identified *a priori* as possible factors that may affect completion rates.

For the purposes of analyses, LHSC and USC were considered as two separate sites. Data were not pooled between sites due to the significant heterogeneity in the systems at the two centers. Studies were conducted in both centers to determine the baseline rate of missed injuries prior to the implementation of PATS. These studies demonstrated a 9% and 1% baseline missed injury rate at LHSC and USC respectively. It was anticipated that the introduction of PATS could be associated with a risk reduction in the rate of missed injuries of 50%. For LHSC, given a baseline missed injury rate of 9%, $\alpha = 0.05$, and for 80% power, this yields a required sample size of 380 patients. For USC, given a baseline missed injury rate of 1%, $\alpha = 0.05$, and for 80% power, this yields a required sample size of 487 patients.

The primary outcome of this study was the rate of missed injuries before and after the implementation of PATS. Missed injury rates were reported as numbers with associated percentages, and were compared between the pre- and post-PATS cohorts using Fischer's exact test. Relative risk reduction, with associated 95% confidence interval, as well as absolute risk reduction are reported. The number needed to evaluate with PATS to prevent one missed injury was calculated for each site. Demographic and injury data were compared between the pre- and post-PATS cohorts using Student's t-test for continuous, normally distributed variables; the Mann-Whitney U test for continuous, non-normally distributed variables; and chi-square for categorical variables.

Compliance with the tertiary survey was reported as numbers with associated percentages, and were compared between the pre- and post-PATS cohorts using Fischer's exact test. We identified factors *a priori* that could potentially be related to non-compliance with PATS completion. These included patient admission on weekends or holidays; patient admission for a short period of time (< 24 hours); and patient admission directly to the ICU. Sensitivity analyses were performed whereby patients were divided based on these variables, and completion rates compared using a chi-square test for interaction.

Statistical analyses were performed using SPSS version 20 (IBM Corp, 2011. San Francisco CA). A p value of < 0.05 was considered significant.

4.4 Results

4.4.1 London Health Sciences Center

A total of 141 patients were admitted to LHSC over a 5-month period. Table 4.1 shows the patient demographics and injury characteristics for the LHSC pre- and post-PATS groups. The post-PATS group was older (49 vs 42, p<0.01), more likely to have a penetrating mechanism (9% vs 2.7%, p<0.01), had a lower Injury Severity Score (ISS) (15 vs 28, p<0.01), had a higher mean systolic blood pressure (144 vs 134, p<0.01), was less likely to have an ICU admission (23% vs 45%, p<0.01), and less likely to have a severe head injury (28% vs 42%, p<0.01).

During the PATS pilot study period there was 1 (1%) missed injury at LHSC. Therefore the missed injury rate at LHSC dropped from 9% to 1% (p<0.001) (Figure 4.1). This corresponds to a relative risk of 12.7 (95%CI 1.9-251.1, $p<0.001$) and an absolute risk reduction of 8.3% (95%CI 3.6-9.3). The number needed to evaluate using PATS to prevent one missed injury was 12 (95%CI 11-28).

At LHSC, 49 (35%) patients had a complete PATS file, 37 (26%) had an incomplete PATS file, and 55 (38%) had no PATS file started. Overall, 36% of patients admitted on a weekend/holiday had no PATS file compared to 42% of patients admitted on a weekday ($p=0.48$) (Table 4.3). 37% of patients admitted for less than 24 hours had no PATS file compared to 41% of patients admitted for longer than 24 hours ($p=0.68$) (Table 4.3). 50% of patients admitted directly to the ICU had no PATS file compared to 37% of patients not admitted to ICU ($p=0.20$) (Table 4.3). Patients admitted directly to the ICU were more likely to have an incomplete or missing PATS file ($p<0.01$). The single missed injury at LHSC was clinically significant and did not have a PATS file started.

4.4.2 University of Southern California

A total of 503 were admitted to USC over a 3-month period. There were no significant differences in the patient demographics or injury characteristics between the pre- and post-PATS groups at USC (Table 4.2).

During the PATS pilot study period there were 0 (0%) missed injuries at USC. The missed injury rate at USC dropped from 1% to 0% ($p=0.04$) (Figure 4.1) with an absolute risk reduction of 1% (95%CI 0-1). The number needed to evaluate at USC was 107. Relative risk and the number needed to evaluate confidence intervals were not calculable for the USC data given the 0 missed injuries in the exposure group. All 503 patients (100%) had a complete PATS file.

Table 4.1 Demographic and injury characteristics for the pre-PATS and post-PATS groups at LHSC.

	Pre-PATS	**Post-PATS**	**P Value**
Number	300	141	--
Age, mean (SD)	42 (19)	49 (22)	**< 0.01**
Male gender, n (%)	217 (72)	97 (69)	0.41
Penetrating injury, n (%)	8 (2.7)	12 (9)	**0.01**
ISS, mean (SD)	28 (11)	15 (9)	**< 0.01**
SBP on admission, mean (SD)	134 (33)	144 (28)	**< 0.01**
Admission to ICU, n (%)	136 (45)	33 (23)	**< 0.01**
Severe head injury (AIS≥3), n (%)	126 (42)	40 (28)	**< 0.01**

Injury Severity Score (ISS), systolic blood pressure (SBP), Abbreviated Injury Scale (AIS)

Table 4.2 Demographic and injury characteristics for the pre-PATS and post-PATS groups at USC.

	Pre-PATS	**Post-PATS**	**P Value**
Number	429	503	-
Age, mean (SD)	41 (18)	39 (19)	0.30
Male gender, n (%)	324 (75)	406 (81)	0.06
Penetrating injury, n (%)	84 (20)	103 (20)	0.73
ISS, mean (SD)	9 (8)	10 (8)	0.21
SBP on admission, mean (SD)	135 (25)	132 (29)	0.09
Admission to ICU, n (%)	134 (31)	128 (26)	0.05
Severe head injury (AIS≥3), n (%)	72 (17)	91 (18)	0.60
Tertiary survey complete, n (%)	292 (68)	503 (100)	**< 0.01**

Injury Severity Score (ISS), systolic blood pressure (SBP), Abbreviated Injury Scale (AIS)

Table 4.3 PATS completion rates at LHSC by various admission characteristics.

	PATS started or complete, n (%)	No PATS, n (%)	P Value
Weekend or Holiday	31 (64)	16 (36)	-
Weekday	55 (58)	39 (42)	-
			0.48
One Day Stay	29 (63)	16 (37)	-
>1 Day Stay	57 (59)	39 (41)	-
			0.68
ICU Admission	13 (50)	13 (50)	-
Non-ICU Admission	73 (63)	42 (37)	-
			0.20

Intensive Care Unit (ICU)

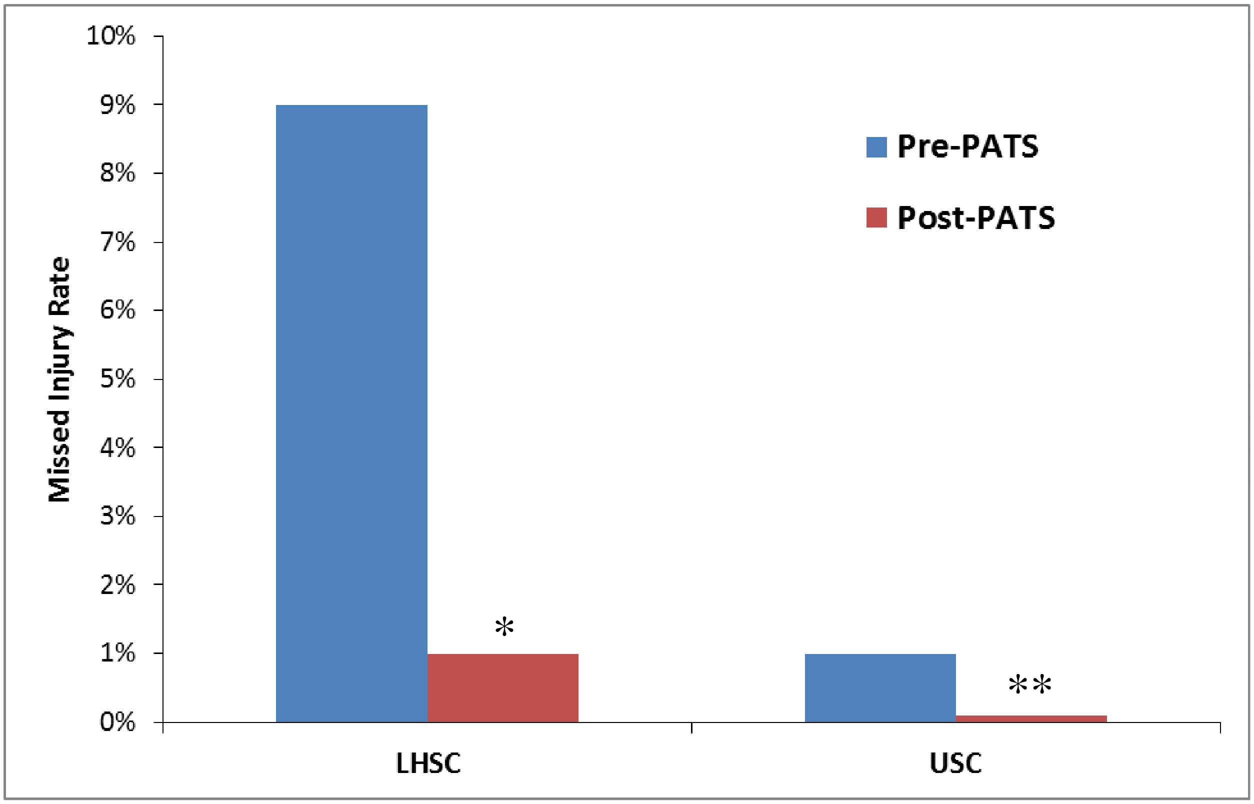

Figure 4.1 Missed injury rates prior to, and following implementation of the PATS program. * $p < 0.001$, ** $p = 0.04$.

4.5 Discussion

Missed injuries in trauma have been shown to be a significant source of morbidity and even mortality (5,19-23). The majority of these missed injuries are preventable. The present study demonstrates that the use of a mobile device based electronic tertiary survey is an effective strategy to reduce missed injuries and improve tertiary survey documentation.

The vast majority of the literature on missed injuries after trauma represents data from over a decade ago (6,24-28). A contemporary analysis was warranted, and our pilot work demonstrated that at a high-volume mature Level 1 trauma center, the pre-PATS missed injury rate was already quite low (1%). The missed injury rate at the LHSC site prior to PATS implementation was closer to average rates reported in the literature at 9%. At both centers, the apparent ability of the PATS program to significantly decrease the rate of missed injuries is impressive. At LHSC, prior to PATS, the tertiary survey was an informal process initiated by the trauma nurse practitioner and completed by the residents. The introduction of a formal program to guide and document the tertiary survey was a novel concept at this site and likely contributed to the significant drop in missed injuries over the study period. Beyond this however, the exact mechanism by which the PATS program is effecting this change is likely multifactorial. The introduction and training surrounding the implementation likely increased overall awareness and thoroughness of the tertiary survey during the study period at both sites. Despite the fact that some patients at LHSC never had a PATS file documented, we suspect that the increased awareness around the tertiary survey and missed injuries prompted at least some form of head-to-toe exam in most patients in whom it might otherwise have been overlooked. Additionally, there are several aspects of the PATS program which likely had an independent effect. The ability of the program to log and remind users not just to identify potential injuries, but also to perform appropriate tests and follow-up on those tests is a novel concept in tertiary survey design and execution. At a busy trauma center, these secondary imaging or other tests may not be ordered or may not be adequately followed. The ability to electronically document findings and results using a simple visual model is also a novel concept. Users may have found the electronic format less time consuming and tedious than filling out an entire paper tertiary survey form.

In terms of compliance with tertiary survey documentation, it is encouraging that the USC site was able to achieve a 100% compliance rate. The fact that users were knowingly having their compliance rates tracked likely provided added incentive to ensure the surveys were completed. Compliance with the PATS program at LHSC was lower than at USC. Again, the reasons for this are likely multifactorial. The level of change required by introducing PATS was more significant at LHSC – having gone from no formal process at all, to a relatively structured and detailed assessment. A level of resistance to this degree of change is to be anticipated. Further, the perceived consequences of having incomplete surveys at this Canadian site are potentially considerably less than at an American equivalent, as there are significant differences in the medical legal culture between these two countries. This however, points to one of the potential benefits of the PATS program, as medical legal pressure likely drives the focus on thorough trauma documentation. Missed injuries represent a source of litigation from the trauma population and can be difficult to defend, especially when a complete tertiary survey has not been documented. Not only does PATS effectively document a complete head-to-toe physical exam, the program also documents that the final radiology reports have been read and further documents that appropriate tests have been ordered and reviewed to address any abnormalities. Therefore a complete PATS file would likely stand up better to legal scrutiny than the previous paper format.

We sought to identify potential factors which may be causing the lower compliance rate at LHSC. Interestingly, most of the characteristics surrounding the initial 24 hours following admission (next day discharge, weekend/holiday admission, or ICU admission) did not seem to affect compliance rates significantly. This further supports the notion that other factors influenced the compliance rate in completing the PATS program. Despite having some surveys missed, the fact that nearly 2/3 of LHSC trauma patients now have a documented tertiary survey exam is a significant improvement over the previous method of informal documentation. We suspect that as this technology continues to develop and be accepted at LHSC, the compliance will improve and approach 100%. It is also worth noting that the consequences of a lower compliance rate are not yet fully known. The single missed injury at LHSC was an ischemic/perforated sigmoid colon resulting from blunt trauma. It was not detectable on initial CT scan and did not present clinically until after 24 hours. These types of injuries which have a delayed presentation are difficult to detect even using a thorough tertiary survey and likely represent the only type of injury (i.e. an injury with a significantly delayed clinical and/or radiologic presentation) in which it is understandable to have a delayed diagnosis.

It is important to note that we deliberately avoided any direct comparison between the study sites. The primary purpose of running this pilot as a multi-center study was to demonstrate generalizability to a diverse range of trauma populations. Several major differences exist between LHSC and USC including: annual admissions, amount of penetrating injuries, number of rural referrals, healthcare system, trauma inpatient team composition, etc. Therefore we focused on comparing pre-PATS versus post-PATS at each site independently. The fact that these two sites were so different speaks to the generalizability and applicability of the PATS program to a broad range of trauma populations.

It is worth noting that, while the pre- and post-PATS groups were not significantly different at the USC site, there were multiple significant differences at the LHSC site. While some differences, such as the slightly older age and higher systolic blood pressure on admission in the post-PATS group, are of doubtful clinical significance, others may have impacted study results. Patients incurring blunt trauma, admitted to the ICU, and with severe head injuries are all more likely have missed injuries (12,29-31). Compared to the post-PATS cohort, the pre-PATS cohort had more patients with each of these risk factors. Unfortunately, the small number of missed injuries in our post-PATS cohort precluded multivariable analyses to determine the independent contribution of PATS completion in reducing the rate of missed injuries. Ultimately, even with the imbalance of risk factors, more than one missed injury should have been expected in the post-PATS cohort. While the magnitude of the reduction in the rate of missed injuries may be called in to question by this imbalance, there still appears to be a reduction. With the USC site as an example, we suspect that the decrease in missed injuries at LHSC represents a true signal which will persist as we continue to accrue patients at this site.

There are several additional limitations to this study. As mentioned, the Hawthorne effect is difficult to control for in this type of study design. It would be very difficult to conceal the outcomes to PATS users. Despite this, the study investigators made efforts not to actively remind users beyond the routine training they received at the start of their rotations. The LHSC data represents interim results as we are still accruing patients to reach our power calculation. Another important consideration is the loss to follow-up in the trauma population (32). Data in press from LHSC (see Chapter 2) suggest that a significant number of missed injuries do not present until after hospital discharge and can be picked up in routine trauma follow-up. In order to avoid the potential bias introduced by this loss to follow-up, we limited our rate to the in-hospital missed injury rate. Despite this, we acknowledge that a certain number of injuries will go unrecognized in hospital and may not be accounted for once they are picked up in the outpatient environment. We have no reason to believe, however, that the proportion of injuries diagnosed in this manner would differ in the pre- and post-PATS cohorts, and therefore this should not significantly impact our results.

In conclusion, the introduction of the PATS program reduces missed injury rates at both a medium- and large-volume trauma center. The documentation rates also improved at both sites. User compliance was good at both sites suggesting that the implementation of this technology is a feasible means to reduce the burden of disease caused by missed injury in trauma.

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Chapter 5

5 Feasibility and User Evaluation of a Mobile Device Based Tertiary Survey Application: A Multi-Center Study

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5.1 Abstract

5.1.1 Introduction

Missed injuries represent a major source of morbidity among trauma patients. A mobile device based clinical application (Physician Assist Trauma Software [PATS]) was designed to guide and document the tertiary survey. This study was conducted to determine the feasibility of the model as judged by clinical users.

5.1.2 Methods

All practitioners responsible for completing the tertiary survey at a medium-volume trauma center (LHSC), and a high-volume trauma center (USC) were surveyed about their perceptions of the pre-PATS tertiary survey model. The PATS program was then piloted at both sites and all PATS users were given a similar survey about the perceptions about the PATS model.

5.1.3 Results

The pre-PATS response rates were 84% and 89% at LHSC and USC respectively. The post-PATS response rate was 100% at both sites. LHSC users found PATS more effective at identifying potential missed injuries ($p=0.04$), helpful for guiding them through the tertiary survey ($p=0.03$), and effective at documenting actions ($p=0.03$). USC users found PATS more efficient ($p<0.01$) and less time consuming ($p<0.01$), useful for handover ($p<0.01$), helpful for prompting them to order tests ($p<0.01$) and follow-up on tests ($p<0.01$), and effective at documenting test results ($p=0.01$).

5.1.4 Conclusions

The PATS program was well received and well-liked at both sites. Users found it efficient and helpful. Implementation of the PATS program is feasible at the user level.

5.2 Introduction

The tertiary survey is a complete head-to-toe physical exam performed within 24 hours on all patients admitted to hospital after trauma (1-3). The purpose of the tertiary survey is to identify any injuries which may not have been identified during the initial trauma resuscitation (1-4). Many centers also include a review of all medical imaging reports, blood work, and prophylaxis measures as part of the tertiary survey (4,5). While the concept of the tertiary survey has been widely adopted at most trauma centers, to our knowledge there is very little evidenced-based recommendations for a standardized model or approach to documentation. Most centers develop their own tertiary survey model and accompanying forms; hence, the level of detail and subsequent documentation may vary widely from site to site. Despite the concept of the tertiary survey being around for over 20 years, missed injury rates are still as high as 22% in the literature (3-10).

Several studies have demonstrated a propensity for diminishing documentation compliance with increasing form volume and complexity – a concept known as "form fatigue" (11-17). This becomes especially apparent in the trauma population where patients may have voluminous and complex injury/problem lists which require careful and detailed assessment and documentation. This proclivity for lapsing diagnostic acumen was one of the driving factors for the creation of the tertiary survey concept (1).

With the rapid advent of electronic medical records, much of the paper form documentation which used to be the mainstay of inpatient care is transitioning to an electronic format. Resuscitation, admission, progress, and discharge notes are now transitioning to be routinely entered into the electronic record instead of the traditional pen and paper approach. Multiple studies have demonstrated that implementation of electronic charting improves compliance with routine documentation (11-14,18,19). Furthermore, this benefit seems to be carried over and even enhanced when the electronic documentation is made available in portable smartphone and/or tablet format (19-24).

A team of investigators at LHSC recognized the persistent significant rate of missed injuries and the apparent inadequacy of current tertiary survey models and forms to reduce or eliminate these preventable complications. They sought to create a standardized, thorough, and interactive way to guide providers through a tertiary survey and to clearly and accurately document all results. This culminated in the creation of the Physician Assist Trauma Software (PATS). PATS is a mobile device based application used to guide and document the tertiary survey in electronic format.

The PATS program was piloted to investigate its capacity to reduce missed injuries. However, we recognized that such a technology would not be adopted if the users found it inefficient or impractical. The primary objective of this study was to determine end-user perception of the usefulness and feasibility of the PATS program.

5.3 Methods

London Health Sciences Center is a Level 1 trauma center in Southwestern Ontario servicing a population of about 1.5 million with over 600 trauma admissions per year. LA County & University of Southern California Medical Center (USC) is a Level 1 trauma center in Los Angeles, California with over 5000 trauma admissions per year.

The surveys were designed by the study investigators specifically to probe the main differences between the standard pre-PATS tertiary survey model at each site and the tertiary survey model after introduction of the PATS program. The survey questions were designed around 3 themes: the efficacy of the tertiary survey model, the efficiency of the tertiary survey model, and perceptions of the impact of an electronic resource on the tertiary survey model. Responses were represented on a standard 5-point Likert scale for positively worded questions (1=strongly disagree, 3=neutral, 5=strongly agree). Free text fields were included to identify barriers to the tertiary survey model, suggestions for improvement, and estimates of the institutional missed injury rate. Additional demographic information was collected from each respondent. (See Appendices C-E for survey implements).

Prior to survey implementation, initial survey drafts were reviewed by the study investigators for content. The surveys were then pilot tested with senior trauma trainees at both LHSC and USC, and feedback on content and question structure elicited. Minor changes were made based on feedback from these pilot sessions before the surveys were finalized and administered to the target population.

Surgical residents responsible for completing the tertiary survey were surveyed at two distinct trauma centers. Paper surveys were handed out during group teaching sessions. Any residents who were absent were contacted directly and invited to participate. Surveys were administered to residents who used the pre-PATS tertiary survey model at their respective sites. A similar survey was administered to residents who used the PATS program during the pilot period upon completion of their rotation. The theme for each question was the same between the pre- and post-PATS surveys with minor alterations made to accommodate the differences between the two different tertiary survey systems. All of the USC residents who used PATS had experience with both the pre-PATS tertiary survey model and the PATS model whereas the LHSC residents who used PATS did not have experience with the pre-PATS model. This called for minor wording differences between the LHSC and USC post-PATS survey. The theme for each question remained the same. (See Appendices C-E.)

At USC, the tertiary survey is the responsibility of the second and/or third year general surgery residents who rotate through the Acute Care Surgery (ACS) teams. All such residents were surveyed about their perceptions of the USC standard tertiary survey model prior to PATS implementation.

At LHSC, the tertiary survey is the responsibility of the first year surgical (general surgery, orthopedic surgery, neurosurgery) residents rotating through the trauma service. The trauma nurse practitioner typically leads morning rounds and prompts/teaches the residents to perform the tertiary survey. Due to the limited number of residents rotating per year, all years of general, orthopedic, and neurosurgery residents were surveyed about their first year experiences with the LHSC standard tertiary survey model. The post-PATS survey was administered only to residents rotating on the trauma service during the study period.

Data are presented as numbers with associated percentages for both demographic variables and survey content. All questions were positively-worded, and due to the small sample size, responses of “agree” and “strongly agree” were combined for the purposes of analyses. Pre- and post-PATS survey responses were compared using Fisher’s exact test. Point estimates of missed injury rates were reported as means plus standard deviation. Limited free text entry was converted to general themes by the primary author.

Statistical analyses were performed using SPSS version 20 (IBM Corp, 2011. San Francisco CA). A p value of < 0.05 was considered significant.

5.4 Results

For the pre-PATS surveys, the response rate was 84% (48/57) at LHSC and 89% (17/19) at USC. For the post-PATS surveys, all users from both sites completed the surveys resulting in a response rate of 100% at both sites (7/7 at LHSC and 8/8 at USC).

Basic demographic information is shown in Table 5.1. There was good representation from all levels of training at LHSC. There was good overall representation from each specialty (general surgery, orthopedic surgery, and neurosurgery) at LHSC. The USC sample was expectedly less diverse as only second and third year general surgery residents are responsible for the tertiary survey.

Survey results for the pre-PATS group at LHSC are shown in Table 5.2. Frequencies of responses for each question are shown. Most respondents felt that the pre-PATS tertiary survey model was efficient, thorough, and user-friendly. Surprisingly, 62% of respondents disagreed or strongly disagreed that they always completed the entire tertiary survey, suggesting that it is not done and/or not documented on some patients. The majority of respondents felt that the pre-PATS tertiary survey was effective at identifying potential missed injuries. Interestingly, most respondents either agreed or were neutral on statements involving the pre-PATS model’s ability to prompt them to follow-up on various items. Since the pre-PATS model did not involve any formal documentation, it is unclear how it would have any functionality of prompting. Likewise, the pre-PATS model at LHSC did not involve any formal documentation or form; however, the majority of respondents either agreed with or were neutral about statements concerning the pre-PATS model's efficiency at documenting findings and actions. Most respondents agreed that an electronic resource would be helpful in improving the performance and documentation of the tertiary survey and 48% felt it would save them time. Nearly two thirds of respondents felt that an electronic tertiary survey would reduce missed injuries.

Survey results for the post-PATS group at LHSC are shown in Table 5.3. Most respondents found the PATS system efficient, thorough, and user-friendly. Fewer users reported disagreement or strong disagreement with the statement about always completing the PATS program (29% vs 62%, p=0.08) (Figure 5.1). All users agreed or strongly agreed that PATS was effective at identifying missed injuries which was more than the pre-PATS respondents (100% vs 56%, p=0.04). PATS users were more likely to agree or strongly agree that the program guides them through the tertiary survey physical exam as compared to the pre-PATS model (100% vs 52%, p=0.03). Interestingly, the majority of respondents felt neutral about statements concerning PATS's helpfulness in prompting them to follow-up on test and actions. PATS users generally felt that the program was effective at documenting aspects of the tertiary survey. Specifically, they were more likely to agree or strongly agree that PATS effectively documents actions performed to address abnormal test results (71% vs 25%, p=0.03). 85% of respondents agreed or strongly agreed that PATS would decrease the missed injury rate at LHSC.

Survey results for the pre-PATS group at USC are shown in Table 5.4. The majority of respondents disagreed or strongly disagreed that the pre-PATS model was efficient, thorough, and user-friendly. All respondents felt that the pre-PATS model was time consuming. Most respondents agreed or strongly agreed that they always completed the tertiary survey form. 59% of respondents felt the pre-PATS model was effective at identifying potential missed injuries. The majority disagreed (53%) that the pre-PATS model was an effective handover tool. Most respondents disagreed with or were neutral about statements involving the pre-PATS model's ability to prompt them to follow-up on aspects of the tertiary survey. Answers were fairly evenly split as to how well the pre-PATS model documents the tertiary survey physical exam. However, most respondents disagreed that the pre-PATS model effectively documented the secondary follow-up actions generated from performing the tertiary survey. 82% of respondents felt that the tertiary survey should be done using an electronic resource. The majority also agreed or strongly agreed that an electronic resource would be helpful in improving the performance and documentation of the tertiary survey; 71% felt it would save them time. The majority (53%) felt that an electronic tertiary survey would decrease missed injury rates whereas 41% felt neutral.

Survey results for the post-PATS group at USC are shown in Table 5.5. PATS users were more likely to agree or strongly agree that the PATS program is efficient as compared to the pre-PATS model (79% vs 6%, $p<0.01$) (Figure 5.2). Fewer PATS users found the process time consuming as compared to the pre-PATS group (25% vs 100%, $p<0.01$). 75% of respondents agreed or strongly agreed that they always completed the PATS program. PATS users were more likely to agree or strongly agree that it provides an effective method for handover (76% vs 6%, $p<0.01$). More PATS users agreed or strongly agreed that PATS is helpful in prompting them to order the correct tests (88% vs 24%, $p<0.01$), and in prompting them to follow-up on test results (100% vs 29%, $p<0.01$). 75% of PATS users felt that PATS effectively documents tertiary survey findings and PATS users were more likely to agree or strongly agree that PATS effectively documents test results (75% vs 18%, p=0.01). 76% of PATS users agreed or strongly agreed that PATS will reduce the missed injury rate at USC; likewise 76% felt the PATS program was superior to the pre-PATS model.

The mean missed injury rate estimated by the pre-PATS group at LHSC was 16% (SD 12), with a range from 1-50%. The actual pre-PATS missed injury rate at LHSC was 9%. Unfortunately, most of the post-PATS survey respondents at LHSC did not provide an estimated missed injury rate and therefore a meaningful average could not be calculated. The actual missed injury rate during the PATS pilot at LHSC was 1%. The mean missed injury rate estimated by the pre-PATS group at USC was 7% (SD 4), with a range from 2-15%. The actual pre-PATS missed injury rate at USC was 1%. The mean current missed injury rate estimated by the post-PATS group at USC was 5% (SD 3), with a range from 0-10%. The actual missed injury rate during the PATS pilot at USC was 0%.

In the pre-PATS groups, respondents were asked about perceived barriers to completion of the pre-PATS tertiary survey. At LHSC, the main themes which arose were: time constraints, delay in final radiology reports, and lack of guidance/training on how/when to perform a tertiary survey. At USC, the main themes which arose were: time constraints, perceived redundant work (filling out both paper and EPR forms), and inadequate patient handover.

In the post-PATS groups, respondents were asked about barriers to completing the PATS program. They were also asked about what they liked, what they disliked, and suggestions for changes to the current PATS program. At LHSC, the main barriers to completion were time constraints and IT issues. Users liked that PATS was thorough and user-friendly. Users disliked the IT issues, and the time required for completion. The main suggestion for improvement was a larger selection of injury descriptions and possible actions. At USC, users liked that PATS was portable and liked the user interface (anthropomorphic figure). They disliked that PATS did not include the primary and secondary surveys. Their main suggestions for improvement were to add sections for the primary and secondary survey (which would allow a complete injury list to be generated), and to link PATS reports to the EPR.

Table 5.1 Pre- and post-PATS survey respondent demographics.

Demographic, n (%)	LHSC pre-PATS	LHSC post-PATS	USC pre-PATS	USC post-PATS
Total	48	7	17	8
Age				
20-24	0 (0)	0 (0)	0 (0)	0 (0)
25-29	20 (42)	6 (86)	7 (41)	4 (50)
30-34	25 (52)	1 (14)	8 (47)	4 (50)
35-40	3 (6)	0 (0)	2 (12)	0 (0)
Other	0 (0)	0 (0)	0 (0)	0 (0)
Gender				
Female	10 (20)	2 (29)	10 (0)	3 (38)
Male	38 (79)	5 (71)	7 (41)	5 (63)
Residency Program				
General Surgery	22 (46)	4 (57)	16 (94)	8 (100)
Orthopedics	22 (46)	1 (14)	0 (0)	0 (0)
Neurosurgery	4(8)	0 (0)	0 (0)	0 (0)
Other	0 (0)	2 (29)	0 (0)	0 (0)
Residency Year				
PGY 1	6 (13)	5 (71)	0 (0)	0 (0)
PGY 2	10(21)	0 (0)	2 (12)	1 (13)
PGY 3	12(25)	2 (29)	14 (82)	7 (88)
PGY 4	10 (21)	0 (0)	1 (6)	0 (0)
PGY 5	9 (19)	0 (0)	0 (0)	0 (0)
PGY 6	1 (2)	0 (0)	0 (0)	0 (0)

Post-graduate year (PGY)

Table 5.2 Survey results [n, (%)] for the pre-PATS tertiary survey model at LHSC.

Survey Question	1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree
The current tertiary survey model is efficient	1 (2)	6 (13)	21 (44)	19 (40)	1 (2)
The current tertiary survey model is thorough	1 (2)	6 (13)	18 (38)	22 (46)	1 (2)
The current tertiary survey model is user friendly	0 (0)	6 (13)	27 (56)	14 (29)	1 (2)
The current tertiary survey model is time consuming	1 (2)	7 (15)	12 (25)	25 (52)	3 (6)
I always complete the entire tertiary survey form for each patient	3 (6)	27 (56)	7 (15)	9 (19)	2 (4)
The current tertiary survey model is effective at identifying potential missed injuries	0 (0)	3 (6)	18 (38)	25 (52)	2 (4)
The current tertiary survey model provides an effective method for handover	1 (2)	9 (19)	19 (40)	17 (34)	2 (4)
The current tertiary survey model guides me through the tertiary survey physical exam	0 (0)	7 (15)	16 (33)	24 (50)	1 (2)
The current tertiary survey model is helpful in prompting me to order the correct tests (x-ray, CT, etc.)	0 (0)	9 (19)	12 (25)	25 (52)	2 (4)
The current tertiary survey model is helpful in prompting me to follow up test results	0 (0)	12 (25)	15 (31)	18 (38)	3 (6)
The current tertiary survey model is helpful in prompting me to address abnormal test results (e.g. consult ortho for a fracture)	0 (0)	8 (17)	13 (27)	25 (52)	2 (4)
The current tertiary survey model effectively documents tertiary survey physical exam findings	0 (0)	3 (6)	23 (48)	21 (44)	1 (2)
The current tertiary survey model effectively documents test results	0 (0)	9 (19)	21 (44)	16 (33)	1 (2)
The current tertiary survey model effectively documents actions performed to address abnormal test results	0 (0)	13 (27)	22 (46)	10 (21)	2 (4)
The tertiary survey should be conducted using an electronic resource	0 (0)	1 (2)	15 (31)	24 (50)	7 (15)
An electronic resource which guides me through a tertiary survey physical exam would be helpful	0 (0)	1 (2)	6 (13)	30 (63)	10 (21)
An electronic resource which reminds me to follow-up on tests would be helpful	0 (0)	1 (2)	5 (10)	29 (60)	12 (25)
An electronic resource which reminds me to address abnormal test results would be helpful	0 (0)	3 (6)	5 (10)	25 (52)	14 (29)
An electronic resource would be helpful in documenting the tertiary survey	0 (0)	0 (0)	6 (13)	26 (54)	15 (31)
An electronic tertiary survey would save me time	0 (0)	8 (17)	16 (33)	15 (31)	8 (17)
An electronic tertiary survey would decrease the rate of missed injuries	0 (0)	1 (2)	18 (38)	20 (42)	8 (17)

Table 5.3 Survey results [n, (%)] for the post-PATS tertiary survey model at LHSC.

Survey Question	1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree
The PATS program is efficient	0 (0)	2 (29)	1 (14)	4 (57)	0 (0)
The PATS program is thorough	0 (0)	0 (0)	1 (14)	3 (43)	3 (43)
The PATS program is user friendly	0 (0)	0 (0)	2 (29)	3 (43)	2 (29)
The PATS program is time consuming	0 (0)	2 (29)	1 (14)	4 (57)	0 (0)
I always complete the entire PATS program for each patient	0 (0)	2 (29)	1 (14)	3 (43)	1 (14)
The PATS program is effective at identifying potential missed injuries	0 (0)	0 (0)	0 (0)	6 (86)	1 (14)
The PATS program provides an effective method for handover	0 (0)	1 (14)	2 (29)	4 (57)	0 (0)
The PATS program is guides me through the tertiary survey physical exam	0 (0)	0 (0)	0 (0)	4 (57)	3 (43)
The PATS program is helpful in prompting me to order the correct tests (x-ray, CT, etc.)	0 (0)	1 (14)	4 (57)	1 (14)	1 (14)
The PATS program is helpful in prompting me to follow up test results	0 (0)	1 (14)	3 (43)	2 (29)	1 (14)
The PATS program is helpful in prompting me to address abnormal test results (e.g. consult ortho for a fracture)	0 (0)	0 (0)	3 (43)	4 (57)	0 (0)
The PATS program effectively documents tertiary survey physical exam findings	0 (0)	0 (0)	1 (14)	3 (43)	3 (43)
The PATS program effectively documents test results	0 (0)	1 (14)	3 (43)	3 (43)	0 (0)
The PATS program effectively documents actions performed to address abnormal test results	0 (0)	1 (14)	1 (14)	5 (71)	0 (0)
The PATS program will reduce missed injury rates	0 (0)	0 (0)	1 (14)	5 (71)	1 (14)

Table 5.4 Survey results [n, (%)] for the pre-PATS tertiary survey model at USC.

Survey Question	1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree
The current tertiary survey model is efficient	5 (29)	7 (41)	4 (24)	1 (6)	0 (0)
The current tertiary survey model is thorough	2 (12)	3 (18)	6 (35)	5 (29)	1 (6)
The current tertiary survey model is user friendly	2 (12)	6 (35)	4 (24)	5 (29)	0 (0)
The current tertiary survey model is time consuming	0 (0)	0 (0)	0 (0)	6 (35)	11 (67)
I always complete the entire tertiary survey form for each patient	0 (0)	3 (18)	3 (18)	5 (29)	6 (35)
The current tertiary survey model is effective at identifying potential missed injuries	1 (6)	3 (18)	3 (18)	10 (59)	0 (0)
The current tertiary survey model provides an effective method for handover	3 (18)	9 (53)	3 (18)	1 (6)	0 (0)
The current tertiary survey model guides me through the tertiary survey physical exam	1 (6)	5 (29)	3 (18)	8 (47)	0 (0)
The current tertiary survey model is helpful in prompting me to order the correct tests (x-ray, CT, etc.)	1 (6)	9 (53)	2 (12)	4 (24)	0 (0)
The current tertiary survey model is helpful in prompting me to follow up test results	1 (6)	7 (41)	3 (18)	5 (29)	0 (0)
The current tertiary survey model is helpful in prompting me to address abnormal test results (e.g. consult ortho for a fracture)	0 (0)	7 (41)	4 (24)	5 (29)	0 (0)
The current tertiary survey model effectively documents tertiary survey physical exam findings	0 (0)	6 (35)	4 (24)	6 (35)	0 (0)
The current tertiary survey model effectively documents test results	1 (6)	13 (77)	0 (0)	3 (18)	0 (0)
The current tertiary survey model effectively documents actions performed to address abnormal test results	1 (6)	8 (47)	4 (24)	3 (18)	1 (6)
The tertiary survey should be conducted using an electronic resource	0 (0)	0 (0)	3 (18)	5 (29)	9 (53)
An electronic resource which guides me through a tertiary survey physical exam would be helpful	0 (0)	0 (0)	1 (6)	9 (53)	7 (41)
An electronic resource which reminds me to follow-up on tests would be helpful	0 (0)	1 (6)	0 (0)	7 (41)	9 (53)
An electronic resource which reminds me to address abnormal test results would be helpful	0 (0)	2 (12)	0 (0)	6 (35)	9 (53)
An electronic resource would be helpful in documenting the tertiary survey	0 (0)	0 (0)	1 (6)	8 (47)	8 (47)
An electronic tertiary survey would save me time	0 (0)	0 (0)	5 (29)	3 (18)	9 (53)
An electronic tertiary survey would decrease the rate of missed injuries	0 (0)	1 (6)	7 (41)	2 (12)	7 (41)

Table 5.5 Survey results [n, (%)] for the post-PATS tertiary survey model at USC.

Survey Question	1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree
The PATS program is more efficient than the old tertiary survey model	0 (0)	1 (13)	1 (13)	1 (13)	5 (63)
The PATS program is more thorough than the old tertiary survey model	0 (0)	2 (25)	1 (13)	1 (13)	4 (50)
The PATS program is more user friendly than the old tertiary survey model	0 (0)	1 (13)	1 (13)	2 (25)	4 (50)
The PATS program is more time consuming than the old tertiary survey model	1 (13)	5 (63)	0 (0)	2 (25)	0 (0)
I complete the entire PATS program more often than the entire old tertiary survey form	0 (0)	2 (25)	0 (0)	4 (50)	2 (25)
The PATS program is more effective at identifying potential missed injuries	0 (0)	2 (25)	2 (25)	4 (50)	0 (0)
The PATS program provides a more effective method patient handover	0 (0)	0 (0)	2 (25)	3 (38)	3 (38)
The PATS program is more helpful in guiding me through the tertiary survey physical exam	0 (0)	1 (13)	0 (0)	4 (50)	3 (38)
The PATS program is more helpful in prompting me to order the correct tests (x-ray, CT, etc.)	0 (0)	1 (13)	0 (0)	6 (75)	1 (13)
The PATS program is more helpful in prompting me to follow up test results	0 (0)	0 (0)	0 (0)	5 (63)	3 (38)
The PATS program is more helpful in prompting me to address abnormal test results (e.g. consult ortho for a fracture.)	0 (0)	1 (13)	2 (25)	4 (50)	1 (13)
The PATS program more effectively documents tertiary survey findings	0 (0)	2 (25)	0 (0)	4 (50)	2 (25)
The PATS program more effectively documents test results	0 (0)	2 (25)	0 (0)	4 (50)	2 (25)
The PATS program more effectively documents actions performed to address abnormal test results	0 (0)	1 (13)	3 (38)	3 (38)	1 (13)
The PATS program will reduce missed injury rates	0 (0)	0 (0)	2 (25)	5 (63)	1 (13)
I prefer the PATS program to the old tertiary survey model	0 (0)	1 (13)	1 (13)	3 (38)	3 (38)

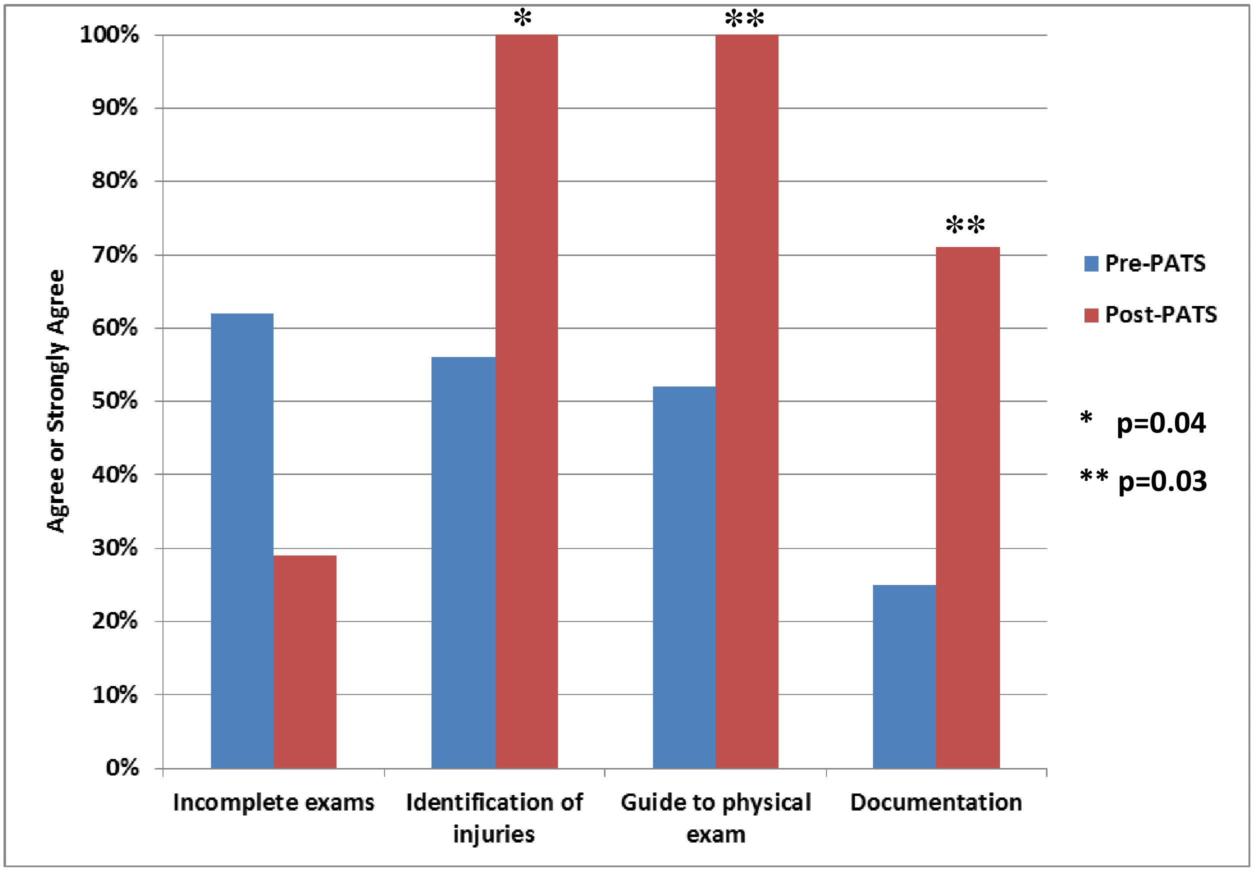

Figure 5.1 Selected questions from the LHSC group comparing pre-PATS and post-PATS responses. Response rates based on participants who answered "agree" or "strongly agree". Question #9: I always complete the entire tertiary survey form for each patient. Question #11: The current tertiary survey model is effective at identifying injuries. Question #14: The current tertiary survey guides me through the tertiary survey physical exam. Question #20: The current tertiary survey model effectively documents actions performed to address abnormal test results.

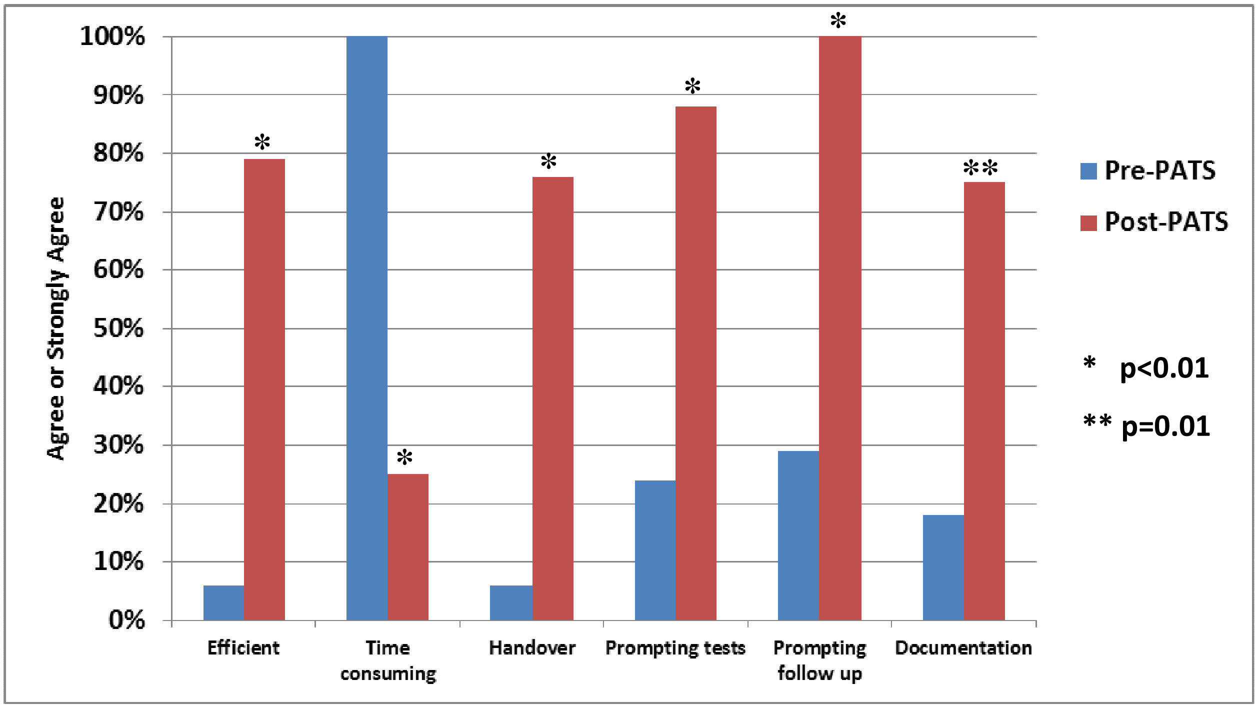

Figure 5.2 Selected questions from the USC group comparing pre-PATS and post-PATS responses. Response rates based on participants who answered "agree" or "strongly agree". Question #5: The current tertiary survey model is efficient. Question #8: The current tertiary survey model is time consuming. Question #12: The current tertiary survey model provides an effective method for handover. Question #15: The current tertiary survey model is helpful in prompting me to order the correct tests. Question #16: The current tertiary survey model is helpful in prompting me to follow up test results. Question #19: The current tertiary survey model effectively documents test results.

5.5 Discussion

The introduction of a new model for performing and documenting a standard aspect of clinical care represents a considerable challenge. In implementing the PATS program to replace the standard tertiary survey model at two distinct trauma centers, we faced multiple challenges – not just from a logistical and technological standpoint, but also from the standpoint of changing perceptions and attitudes towards the status quo. As such, it was critical to gauge attitudes towards the pre-PATS tertiary survey model and also to survey how the new PATS paradigm was received. The survey results outlined herein sought to achieve this goal, and demonstrated overall acceptance and a generally positive reception to this new program.

The issue of inadequate or incomplete documentation in trauma care has been well described (11-13,24,25). Southard et al outline the key documentation steps in trauma care (11). They point to the importance of accurate documentation not just for interdisciplinary communication, but also for medical-legal purposes. The care of multiply injured trauma patients is complex and requires careful documentation and assessment of each injury while also considering key aspects of critical care (such as DVT prophylaxis). By extension, the documentation process for such patients is similarly complex and prone to error.

At LHSC, prior to PATS implementation, there was no formal tertiary survey system or documentation process. Accordingly, more than half of residents reported that they routinely did not perform and/or document a complete tertiary survey. The majority of residents subsequently reported that they were open to the idea of an electronic resource and felt it would save them time and had the potential to reduce missed injuries. These results suggest that the pre-PATS group were able to recognize that the current tertiary survey model had some short-comings and that they would be open to an alternate process.

In contrast, the USC pre-PATS tertiary survey model was quite rigorous and included a page-long form that the residents were responsible for completing. The USC residents overall indicated that the pre-PATS model was effective at documentation and that they completed it most of the time. However, they felt strongly that filling out the form was time consuming and inefficient. Thus it is not surprising that most of them yearned for an alternate means of approaching the tertiary survey which would save them time and increase their overall efficiency. Overall, it appeared that both sites were open to change, albeit for different reasons. The LHSC group seemed to realize that their current model lacked thoroughness while the USC felt their model was quite thorough but wanted a more efficient way of approaching it.

Recent work has demonstrated the unique benefits conveyed to the trauma population by electronic charting (13,18,23-29). Electronic systems are designed to categorize vast amounts of data. This makes them ideal for application to the trauma population where injuries can be multiple and complex. Computers have the capability of organizing and prioritizing multiple problems while ensuring none are missed. Deckelbaum et al actually showed a mortality benefit when electronic medical records were implemented in a trauma setting (18). Several studies have demonstrated specific benefit when using computerized devices during trauma resuscitation (12,24,26-30). Bilyeu et al showed an improvement in documentation when an electronic medical record was used during trauma resuscitation (12). Fitzgerald et al definitively showed a decrease in errors and morbidity when computer-aided decision support was added to trauma resuscitation in a prospective randomized trial (28). These studies all suggest that the incorporation of electronic systems into trauma care can help streamline and organize the approach to these complex and difficult patients. Ours is the first technology to our knowledge designed specifically for the tertiary survey with an aim to decrease missed injuries.

Overall, the PATS program was well received at LHSC. The residents felt that PATS did a good job at identifying injuries which could potentially be missed. They also felt that PATS guided through the tertiary survey whereas the old system seemed more haphazard. PATS users also picked up on its ability to document all tertiary survey findings (normal or abnormal) which was an improvement over the old model. Most PATS users agreed that the program functionality of prompting them to take action on abnormal findings and subsequently follow-up on those actions was helpful. However, there didn't seem to be an appreciable improvement from the pre-PATS model. This is interesting since there was limited or no documentation in the pre-PATS model and hence no real form of prompting could exist beyond the astuteness of the trauma nurse practitioner. We anticipated that the PATS prompting function would be one of its primary advantages as we hypothesized that many injuries are missed due to practitioners forgetting to order confirmatory tests (eg. x-rays) or forgetting to follow-up on those test results (eg. checking the staff read on the x-ray), rather than missing clinically apparent findings altogether.

The response to the PATS program at USC was decidedly more enthusiastic. Once again we were actually surprised by this result as we were concerned that such a major change in the daily duties of the junior trauma resident would be resisted. Instead, residents were overwhelmingly in favour of the PATS program over the paper tertiary survey format. Despite some of the technical bugs, PATS users still found it more efficient and less time consuming than the old model. Subjectively, this was certainly the biggest perceived advantage. Unlike their LHSC counterparts, USC residents identified the usefulness of the prompting functions of the PATS program rating it higher in comparison to the pre-PATS model. Another interesting feature they identified was how PATS was helpful in organizing their patient handover. Instead of listing all the abnormalities and test which need to be followed up on, residents could simply ask the incoming team to refer to the PATS program which would prompt them as to what items are still outstanding and require attention. This concept of electronic handover as a compliment to electronic charting has exciting potential. Ergo, programs such as PATS may not only be helpful in eliminating errors in clinical care, but also in eliminating errors in clinical handover.

Time constraint was the overwhelming barrier to tertiary completion in the pre-PATS groups. This further supports the notion that a more efficient tertiary model is called for. The main suggestions for improvement largely centered around IT and user interface issues. We have collected all these suggestions and plan to implement them in subsequent versions of the PATS software. We were excited that many PATS users identified the potential of this technology to encompass not only the tertiary survey, but to also be expanded to include the resuscitation phase. The same user interface could easily be used to integrate the primary, secondary, and tertiary surveys which would allow for a complete list of injuries to be generated and give a more complete picture to each trauma patient. Furthermore, some users recognized the potential for this technology to be integrated into existing EPR systems, eliminating the need for paper charting and further expanding the potential of the system to integrate lab, imaging, and other results from the EPR to further enhance functionality.

The main limitation to this study is the relatively small number of residents who were able to use PATS and subsequently be surveyed about their experiences. Unfortunately we were limited by the number of residents rotating through the trauma service during the study period. While all USC residents had experience with both the pre- and post-PATS tertiary survey models, the LHSC residents were only exposed to one or the other. This is likewise a limitation of the rotation schedule of the LHSC residents. Some of the LHSC residents may also be subject to recall bias as in order to survey a reasonable number of pre-PATS users, we had to include some residents who may not have been directly involved in performing tertiary surveys for several years.

Another important consideration is the distinct differences between the two study sites. While clinical volume is the most striking difference, differences also exist in terms of medical system (Canadian vs American), resident experience, medical-legal climate, etc. Thus we did not make any direct comparisons between the two sites. Instead, the fact that these two sites were so different speaks to the generalizability and applicability of the PATS program to a broad range of trauma populations.

In conclusion, these surveys have identified several problems with current tertiary survey models. The PATS program was well received and well-liked by users performing tertiary surveys. It appears to be more efficient and less time consuming than current models. The PATS program represents a feasible and useful clinical tool for addressing the problem of missed injuries in trauma.

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Chapter 6

6 Overall Discussion

6.1 Summary of Results

6.1.1 London Health Sciences Center

At LHSC, the overall baseline missed injury rate was 15%. This was further broken down to a 9% inpatient pickup rate, a 2% outpatient pickup rate, and a 4% database coder pickup rate. Higher ISS and ICU admission were associated with increased risk of missed injury. 18% of injuries were clinically significant. After implementation of PATS, the inpatient missed injury rate dropped from 9% to 1%. Whereas there was no formal tertiary survey documentation prior to PATS, the completion rate using PATS was 60%. Users overall felt that PATS was effective at identifying potential missed injuries, helpful in guiding them through the physical exam, and was effective at documenting actions performed in response to tertiary exam findings.

6.1.2 University of Southern California

The baseline missed injury rate at USC was 1%. All missed injuries were extremity fractures and were all clinically significant. Higher ISS was associated with increased risk of missed injury. Complete tertiary survey documentation occurred 68% of the time. After implementation of PATS, the missed injury rate decreased from 1% to 0%. There were no missed injuries during the pilot period. PATS increased the complete tertiary survey documentation rate from 68% to 100%. Compared to the pre-PATS model, PATS users found it more efficient, less time consuming, helpful for handover, helpful for prompting them to order tests and follow up on tests, and effective at documenting test results.

6.2 Eradicating Missed Injuries

The vast majority of missed injuries are preventable. Between the primary, secondary, and tertiary surveys, there really is no excuse for having injuries go undiagnosed beyond 24 hours. We believe the only type of injury for which it is understandable to have such delayed diagnosis is an injury which truly has no clinical or radiologic evidence until after the 24 hour mark. Such injuries are rare as the astute practitioner using a reliable tertiary survey model (such as PATS) should pick up on most subtle exam findings and should certainly pick up on any injuries reported by radiology. Even so, injuries which may fit this description (such as blunt bowel injury, blunt carotid artery injury, etc.), are still potentially avoidable if a high index of clinical suspicion is maintained and the correct confirmatory test or procedures pursued.

Our results demonstrate that despite having multiple fail-safes in place to try to prevent missed injuries, they still occur with relative regularity. There is no doubt that the adoption and maturation of the tertiary survey has helped decreased the rate of missed injuries over time. Likewise, the improvement in trauma systems and imaging technology has helped in identifying more injuries that would otherwise be missed. Despite this, one of the busiest and most mature trauma centers in North America: USC & LAC, continues to have a modern missed injury rate of nearly 1 in every 100 patients. It would seem that our ability to prevent missed injuries given the current tools has plateaued. PATS represents the next generation modality to assess, diagnose, and manage trauma patients. This portable electronic resource brings to bear a novel tool with novel functionality to enhance existing trauma teams.

6.3 Changing the Paradigm

As the era of electronic healthcare continues to evolve, so too will the traditional ways in which trauma patients are assessed and managed. With an increasing focus on patient safety and quality improvement, missed injuries and the associated morbidity represent a prime target for ameliorating outcomes in the trauma population. The PATS program is an important technology innovation aimed at addressing the problem of missed injuries, and ultimately preventing them.

At most centers, residents typically perform the tertiary survey. The majority of the resident cohort today are of the "Generation Y" years – having grown up being bombarded with omnipresent technology and connectivity. This generation of future clinicians is not only innately comfortable with technology, but go so far as to demand it be part of their everyday practice. With this in mind, the PATS developers have come up with a system which capitalizes on both the ongoing healthcare technology boom and the eagerness of future trauma leaders to embrace new technologies.

This new reliance on technology represents a fundamental shift in the way we think about trauma, especially given the propensity (and necessity) for trauma care to be highly protocolized. Trauma systems and those who practice within them are built around these ideas and protocols and hence, instituting change within that system can be a tremendous challenge. People are used to "the way we have always done our tertiary surveys" and it is difficult to change that attitude, especially in the protocol-driven atmosphere of trauma care.

We anticipated more resistance to the PATS program; which is a prime example of changing the trauma paradigm. We were surprised that at the busier of our pilot sites (USC), residents not only were keen to learn and start using PATS, they actually preferred it to the old tertiary survey model. This level of uptake is incredible in a center which can routinely see 20-30 trauma consults daily. Conversely, the medium-volume pilot site (LHSC) had a slower and less enthusiastic uptake. The LHSC residents also had trouble with completion rates for PATS whereas the USC residents did not miss any. Although the reasons for this are likely multifactorial as discussed in Chapter 4, a resistance to the unfamiliar is likely a contributing factor.

The overall success of the *idea* of PATS cannot be understated. Not only does it appear to decrease or even eliminate missed injuries, it was successfully and feasibly integrated into mature, complex systems which typically resists change.

6.4 Limitations

The LHSC pre-PATS study (Chapter 2) was the only part of this study that was not done prospectively. The retrospective nature of this study opens it up to potential bias. There was no formal documentation of the tertiary survey prior to PATS; we therefore had to use an inferior definition of missed injury (i.e. those occurring after 24 hours). We selected a random cohort of patients for the historical control group in an attempt to limit bias. However, we suspect that despite this, our control group represents a more severely injured group than is customary at LHSC. This may be in part why the pre- and post-

PATS groups have several differences between them. Importantly, the post-PATS group at LHSC represents an interim analysis and we are continuing to collect data to reach the sample size of our original power calculation. We suspect that the differences between the groups will diminish as we collect more patients. Furthermore, with the significant decrease at the USC site as an example, we suspect the decreased in missed injuries at LHSC also represents a true difference.

Some of the success of the PATS program may in part be due to the fact that the technology was novel and that users knew it was part of a clinical study. The compliance with and effectiveness of the program does have the potential to wane with time. However, the USC site clearly preferred the PATS method to the old tertiary survey model and perhaps this would serve as incentive to continue to use it diligently. At LHSC, there is still room for improvement in terms of PATS compliance. We suspect that compliance will actually improve over time as awareness about it and emphasis from clinical leaders increases in the post-study period.

6.5 Future Directions

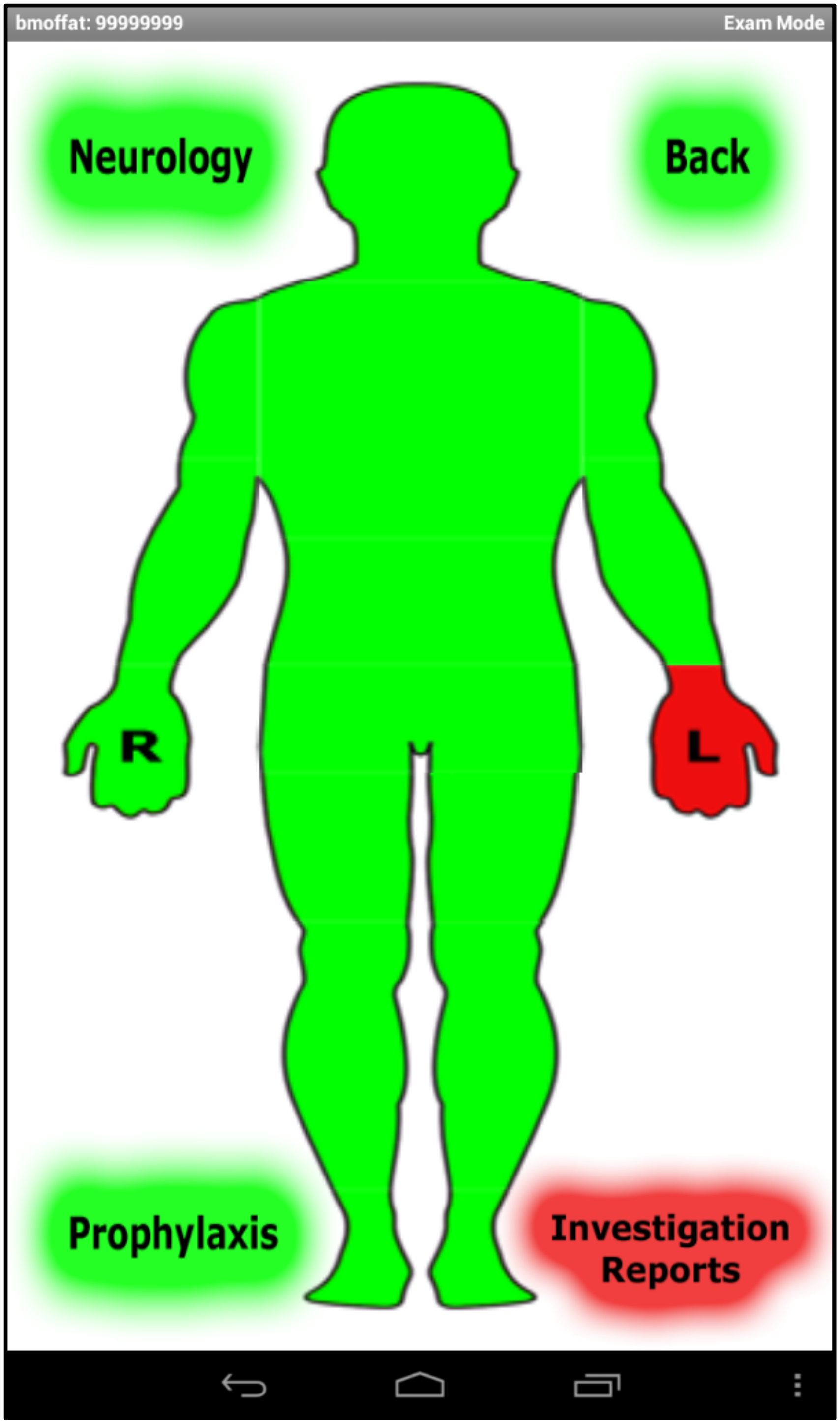
The current PATS program is a pilot version. It can be modified and improved upon over time in response to user and technology demands, and could eventually be linked to the electronic patient record. This would enhance its practicality in multiple ways. The primary benefit would be the ability to have a progressive report of the tertiary survey available for all providers using the EPR. This was one of the most popular suggestions from the USC users. The developers have also been keeping track of many user-level suggestions to improve the basic interface such as broadening the range of selections for certain menus, and including documentation functionality for additional aspects of care such as massive transfusion and incidental radiology findings.

Eventually, this mobile platform may expand beyond the tertiary survey and the immediate post-admission phase. Using an interface such as PATS, the entire care of the trauma patient, from resuscitation to rehabilitation could be documented and integrated electronically. With the primary, secondary, and tertiary survey all consolidated into one program, a complete injury list could be generated. Additional computer-aided decision processes could be integrated to ensure important steps, from the FAST scan in the trauma bay to the removal of a chest tube stitch 3 weeks later, are not overlooked. PATS is only the first step in exploiting the considerable potential of computer-assisted trauma care.

We have shown that this platform is effective and feasible across different patient populations, clinical volumes, inpatient teams, and healthcare systems. Moving forward, we would like to see it piloted and hopefully adopted across additional sites as we think the benefits are universal and any implementation challenges can be overcome.

Appendices

Appendix A. Physician Assist Trauma Software (PATS) Anthropomorphic Figure.



Appendix B. Physician Assist Trauma Software (PATS) Example Summary Report.

London Health Sciences Centre

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PATS Report

Patient Info: 11117777 - Patient, Test

Injury List:

MSK - Right Shoulder Shoulder: Tenderness - *AC joint*	Review Imaging		Complete
MSK - Left Wrist and Hand PIP Joints: Active ROM - *3rd PIP pain*	Imaging	X-Ray	Complete
MSK - Left Ankle and Foot Ankle: Active ROM - *Swollen*	Consult	Orthopedics	Complete

Prophylaxis Given:

DVT
Given: Yes

Imaging Completed:

Abnormal Bloodwork
Done: Yes
Final Reviewed: Yes

CT Head
Done: Yes
Final Reviewed: Yes

CT C-Spine
Done: Yes
Final Reviewed: Yes

CT Chest
Done: Yes
Final Reviewed: Yes

CT Abdomen/Pelvis
Done: Yes
Final Reviewed: Yes

Appendix C. Pre-PATS survey administered to LHSC and USC residents.

Physician Assist Trauma Software (PATS) – Resident Survey

Please answer the following questions about your experience with the current tertiary survey model.

1. Level of training:

   PGY1 PGY2 PGY3 Other: ___________

2. Residency program:

   General Surgery Orthopedics Neurosurgery Other: _______

3. Age:

   20-24 25-29 30-34 35-40 Other

4. Gender:

   Male Female Other Prefer not to answer

5. The current tertiary survey model is efficient.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

6. The current tertiary survey model is thorough.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

7. The current tertiary survey model is user friendly.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

8. The current tertiary survey model is time consuming.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

9. I always complete the entire tertiary survey form for each patient.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

10. Please list any barriers to completing the entire tertiary survey:
____
____

11. The current tertiary survey model is effective at identifying injuries.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

12. The current tertiary survey model provides an effective method for handover.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

13. The current rate of patients with missed injuries at my institution is _____ %

14. The current tertiary survey guides me through the tertiary survey physical exam.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

15. The current tertiary survey model is helpful in prompting me to order the correct tests (x-ray, CT, etc.)

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

16. The current tertiary survey model is helpful in prompting me to follow up test results.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

17. The current tertiary survey model is helpful in prompting me to address abnormal test results (e.g. consult orthopedics for a fracture.)

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

18. The current tertiary survey model effectively documents tertiary survey physical exam findings.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

19. The current tertiary survey model effectively documents test results.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

20. The current tertiary survey model effectively documents actions performed to address abnormal test results.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

21. The tertiary survey should be conducted using an electronic resource.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

22. An electronic resource which guides me through a tertiary survey physical exam would be helpful.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

23. An electronic resource which reminds me to follow-up on tests would be helpful.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

24. An electronic resource which reminds me to address abnormal test results would be helpful.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

25. An electronic resource would be helpful in documenting the tertiary survey.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

26. An electronic tertiary survey would save me time.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

27. An electronic tertiary survey would decrease the rate of missed injuries.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Appendix D. Post-PATS survey administered to LHSC residents.

Physician Assist Trauma Software (PATS) – Resident Survey

Please answer the following questions about your experience with the PATS program.

1. Level of training:

   PGY1 PGY2 PGY3 Other: ___________

2. Residency program:

   General Surgery Orthopedics Neurosurgery Other: _______

3. Age:

   20-24 25-29 30-34 35-40 Other

4. Gender:

   Male Female Other Prefer not to answer

5. The PATS program is efficient.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

6. The PATS program is thorough.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

7. The PATS program is user friendly.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

8. The PATS program is time consuming.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

9. I always complete the entire PATS program for each patient.

1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree

10. Please list any barriers to completing the entire PATS program:

____

____

11. The PATS program is effective at identifying injuries.

1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree

12. The PATS program provides an effective method for handover.

1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree

13. Using the PATS program, the current rate of patients with missed injuries at my institution is _____ %

14. The PATS program guides me through the tertiary survey physical exam.

1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree

15. The PATS program is helpful in prompting me to order the correct tests (x-ray, CT, etc.)

1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree

16. The PATS program is helpful in prompting me to follow up test results.

1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree

17. The PATS program is helpful in prompting me to address abnormal test results (e.g. consult orthopedics for a fracture.)

1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree

18. The PATS program effectively documents tertiary survey physical exam findings.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

19. The PATS program effectively documents test results.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

20. The PATS program effectively documents actions performed to address abnormal test results.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

21. The PATS program will reduce missed injury rates.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

22. What aspects of the PATS program did you like?

____

____

23. What aspects of the PATS program did you dislike?

____

____

24. What changes would you suggest to the PATS program?

____

____

____

____

Appendix E. Post-PATS survey administered to USC residents.

Physician Assist Trauma Software (PATS) – Resident Survey

Please answer the following questions comparing your experience with the PATS program as it compares to the old tertiary survey model.

1. Level of training:

   PGY1 PGY2 PGY3 Other: ___________

2. Residency program:

   General Surgery Orthopedics Neurosurgery Other: _______

3. Age:

   20-24 25-29 30-34 35-40 Other

4. Gender:

   Male Female Other Prefer not to answer

5. The PATS program is more efficient than the old tertiary survey model.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

6. The PATS program is more thorough than the old tertiary survey model.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

7. The PATS program is more user friendly than the old tertiary survey model.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

8. The PATS program is more time consuming than the old tertiary survey model.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

9. I completed the entire PATS program more often than the entire old tertiary survey form.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

10. The PATS program is more effective at identifying injuries.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

11. The PATS program provides a more effective method for patient handover.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

12. Using the PATS program, the current rate of patients with missed injuries at my institution is _____ %

13. The PATS program is more helpful in guiding me through the tertiary survey physical exam.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

14. The PATS program is more helpful in prompting me to order the correct tests (x-ray, CT, etc.)

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

15. The PATS program is more helpful in prompting me to follow up test results.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

16. The PATS program is more helpful in prompting me to address abnormal test results (e.g. consult orthopedics for a fracture.)

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

17. The PATS program more effectively documents tertiary survey physical exam findings.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

18. The PATS program more effectively documents test results.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

19. The PATS program more effectively documents actions performed to address abnormal test results.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

20. The PATS program will reduce missed injury rates.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

21. I prefer the PATS program to the old tertiary survey model.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

22. What aspects of the PATS program did you like?

____

____

23. What aspects of the PATS program did you dislike?

____

____

24. What changes would you suggest to the PATS program?

____

____

____

____

Curriculum Vitae

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Post-secondary Education and Degrees:
The University of Western Ontario
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2003-2007 B.MSc.

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Honors and Awards:
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Related Work Experience:
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Publications:

1. Leeper WR, Leeper TJ, Ouellette D, Moffat B, Sivakumaran T, Charyk-Stewart T, Kribs S, Parry N, Gray D. Delayed hemorrhagic complications in the non-operative management of blunt splenic trauma: early screening leads to a decrease in failure rate. J Trauma Acute Care Surg. 2014 Jun;76(6):1349-53.

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3. Hillier M, McLeod SL, Mendelsohn D, Brown A, Smallfield A, Moffat B, Arab A, Sedran S. Emergency medicine training in Canada: A survey of medical students' knowledge, attitudes and preferences. CJEM 2011;13(4):251-258.