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Introduction of a mobile device based tertiary survey application reduces missed injuries: A multi-center prospective study

B. Moffat[a,*], K.N. Vogt[a], K. Inaba[b], D. Demetriades[b], C. Martin[a], R. Malthaner[a], D.K. Gray[a], N.G. Parry[a]

[a] London Health Sciences Center, Canada
[b] University of Southern California, United States

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ABSTRACT

Background: 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.

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 tracked during the study period. Compliance and tertiary survey completion rates were evaluated as a marker of feasibility.

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.

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.

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 h 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].

* Corresponding author at: Division of General Surgery, Department of Surgery, Western University, London Health Sciences Center, Victoria Hospital, Rm. E2-216, 800 Commissioners Rd. E, London, ON, N6A 5W9, Canada.
E-mail address: brad.moffat@lhsc.on.ca (B. Moffat).

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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.

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 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 A).

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 single PATS device was used at LHSC where there is one trauma team; four PATS devices were used at USC: one for each of the separate trauma teams. 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 h 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 h were excluded as these patients would typically not be expected to have a tertiary survey documented.

Missed injuries were tracked contemporaneously by the study investigators during the study period. 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 h 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 (prospectively at USC and retrospectively at LHSC) 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 h); 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.

Results

London health sciences center

A total of 141 patients were admitted to LHSC over a 5-month period. Table 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% ($p < 0.001$) (Fig. 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). The single missed injury at LHSC was an extremity fracture diagnosed on x-ray that was prompted by a complaint of pain after extubation.

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 3). 37% of patients admitted for less than 24 h had no PATS file compared to 41% of patients admitted for longer than 24 h ($p = 0.68$) (Table 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 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.

Table 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).

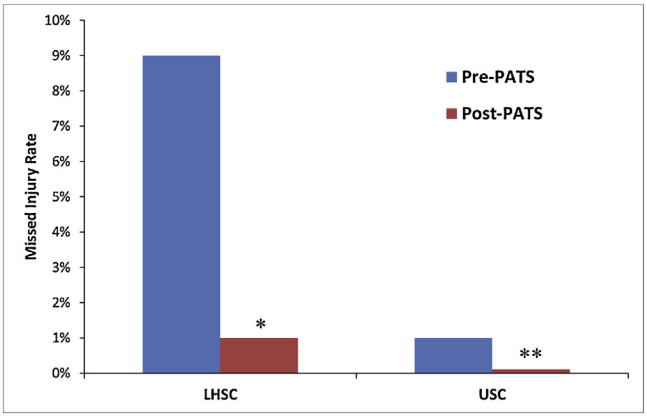


Fig. 1. Missed injury rates prior to, and following implementation of the PATS program. * $p < 0.001$, ** $p = 0.04$.

Table 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 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).

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 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% ($p = 0.04$) 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.

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 h 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 h. 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 believer, 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.

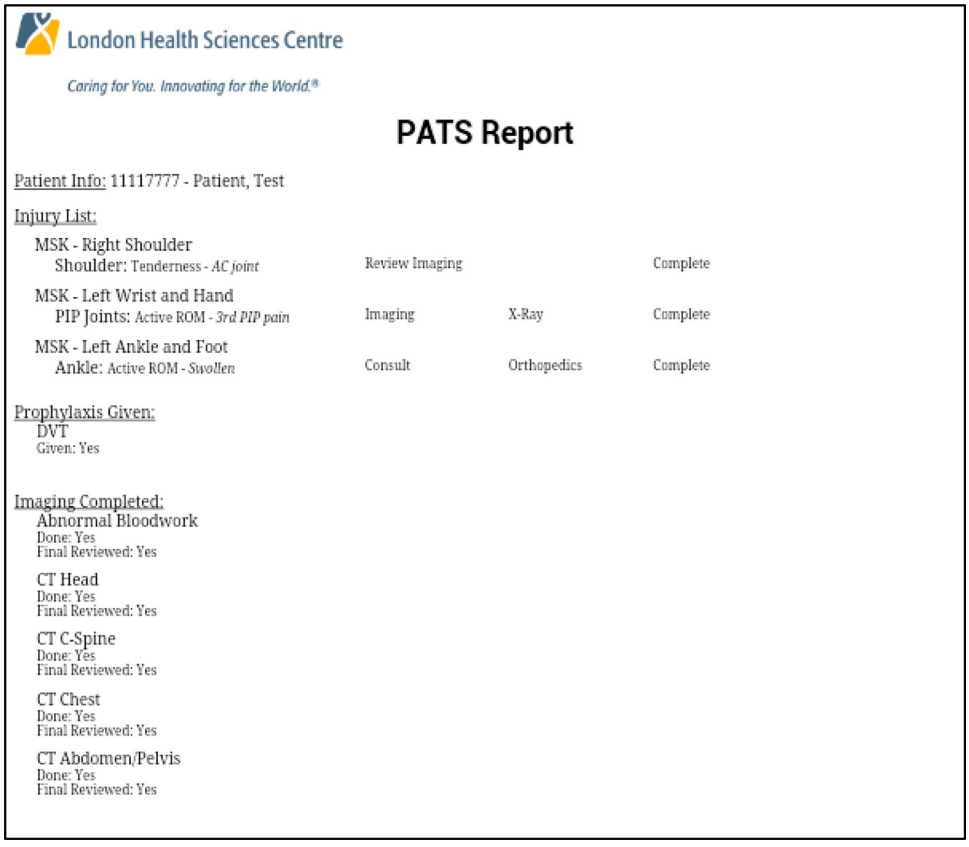
In conclusion, the introduction of the PATS program reduces missed injury rates at both a medium- and large-volume trauma center. The documentation rates also improved at both sites. User compliance was good at both sites suggesting that the implementation of this technology is a feasible means to reduce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

Declaration of Competing Interest

None of the listed authors have any financial or personal relationships with other people or organisations that could inappropriately influence this work.

Appendix A

Physician Assist Trauma Software (PATS) Example Summary Report



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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

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