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Inadequate prophylaxis in patients with trauma: anti-Xa-guided enoxaparin dosing management in critically ill patients with trauma

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Introduction Venous thromboembolism (VTE) causes significant morbidity in patients with trauma despite advances in pharmacologic therapy. Prior literature suggests standard enoxaparin dosing may not achieve target prophylactic anti-Xa levels. We hypothesize that a new weight-based enoxaparin protocol with anti-Xa monitoring for dose titration in critically injured patients is safe and easily implemented.

Methods This prospective observational study included patients with trauma admitted to the trauma intensive care unit (ICU) from January 2021 to September 2022. Enoxaparin dosing was adjusted based on anti-Xa levels as standard of care via a performance improvement initiative. The primary outcome was the proportion of subtarget anti-Xa levels (<0.2 IU/mL) on 30 mg two times per day dosing of enoxaparin. Secondary outcomes included the dosing modifications to attain goal anti-Xa levels, VTE and bleeding events, and hospital and ICU lengths of stay.

Results A total of 282 consecutive patients were included. Baseline demographics revealed a median age of 36 (26–55) years, and 44.7% with penetrating injuries. Of these, 119 (42.7%) achieved a target anti-Xa level on a starting dose of 30 mg two times per day. Dose modifications for subtarget anti-Xa levels were required in 163 patients (57.8%). Of those, 120 underwent at least one dose modification, which resulted in 78 patients (47.8%) who achieved a target level prior to hospital discharge on a higher dose of enoxaparin. Overall, only 69.1% of patients achieved goal anti-Xa level prior to hospital discharge. VTE occurred in 25 patients (8.8%) and major bleeding in 3 (1.1%) patients.

Conclusion A majority of critically injured patients do not meet target anti-Xa levels with 30 mg two times per day enoxaparin dosing. This study highlights the need for anti-Xa-based dose modification and efficacy of a pharmacy-driven protocol. Further optimization is warranted to mitigate VTE events.

Level of evidence Therapeutic/care management, level III

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Studies examining enoxaparin dosing using anti-Xa levels in the trauma population have had mixed results, with some studies suggesting a benefit while others have shown no improvement in venous thromboembolic rates.

WHAT THIS STUDY ADDS

⇒ This study demonstrates the feasibility of a pharmacist-driven protocol for a weight-based, anti-Xa-guided enoxaparin dosing protocol in a critically ill trauma patient population. Furthermore, it demonstrates that most patients require at least one dose modification prior to achieving goal anti-Xa levels.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ This study shows the safety of a pharmacist-driven protocol for enoxaparin dose modification using anti-Xa levels in the intensive care unit.

INTRODUCTION

Venous thromboembolism (VTE), which includes the diagnoses deep vein thrombosis (DVT) and pulmonary embolism (PE), affects up to 600 000 patients and kills over 100 000 each year.[1] By itself, traumatic injury is a known risk factor for development of VTE, especially in patients with traumatic brain injuries, spinal cord injuries and severe pelvic fractures.[2–4] Yet, patients with trauma often have multiple additional risk factors for VTE, including admission to the intensive care unit (ICU), prolonged immobilization, mechanical ventilation, major and/or multiple surgeries, extended periods of sedation, central venous catheters and multiple transfusions.[2–6] Given the numerous risk factors, high rates of VTE are observed in patients with trauma, with DVT estimated to occur in 5%–63% of patients with trauma and PE in approximately 11%.[6–8] Given the high incidence of VTE in the trauma population, starting VTE prophylaxis early and with the appropriate agent and dosing is critical when taking care of these patients.

Enoxaparin has been the VTE prophylaxis of choice for patients with trauma since the mid-1990s after Geerts *et al* observed improved VTE rates with enoxaparin administration in the first randomized control trial of unfractionated heparin versus low–molecular weight heparin.[6] Since then, multiple studies, including systematic reviews and meta-analyses, have confirmed these findings in the general trauma population as well as in the geriatric and pediatric trauma populations.[9–12] Underscoring this data, enoxaparin is the recommended agent for VTE prophylaxis in patients with trauma by the American Association for the Surgery of Trauma/American College of Surgeons, Eastern Association for the Surgery of Trauma and the Western Trauma Association.[13–15] However, VTE

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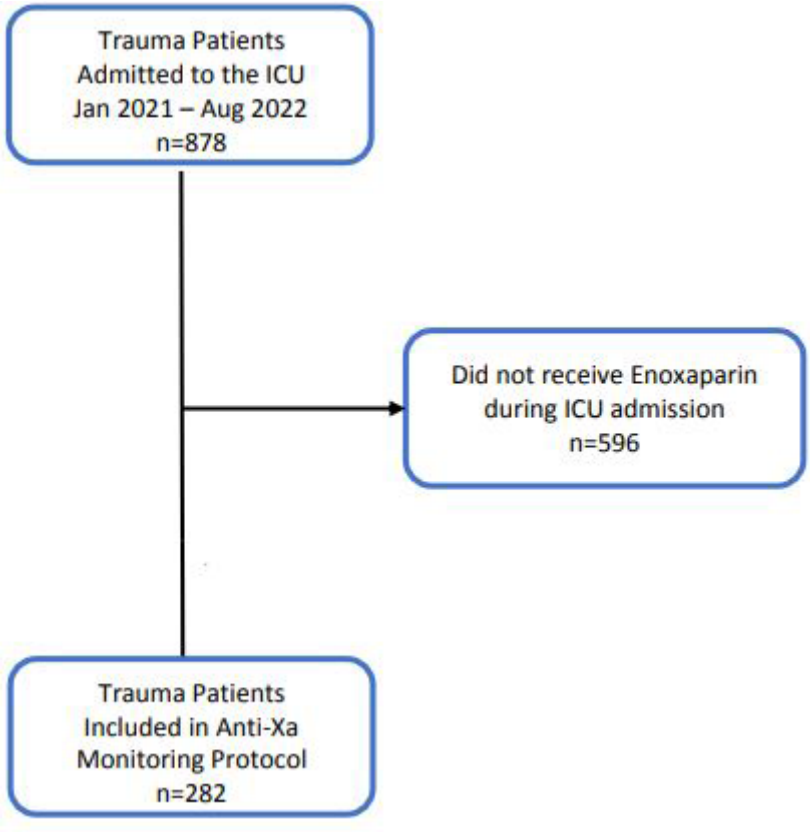

Figure 1 Consort diagram. ICU, intensive care unit.

can still occur despite early initiation and compliant enoxaparin administration.[16] In an effort to ensure patients are receiving an appropriate enoxaparin dose, anti-Xa level monitoring with subsequent enoxaparin dose titration has been introduced into the clinical practices of many trauma centers. Early results from several anti-Xa monitoring studies in trauma populations have shown improvement in achieving 'target' anti-Xa levels with one study showing an improvement in VTE rates as well.[17 18]

Despite these important advances in administration of VTE prophylaxis for patients with trauma, the 'perfect' enoxaparin dose or dose titration regimen remains unknown. In January 2021, our center instituted a new, pharmacist-driven, weight-based enoxaparin VTE prophylaxis protocol with anti-Xa monitoring for enoxaparin dose titration for critically ill patients with trauma. Here, we critically evaluate the implementation of this new protocol. We hypothesized that this pharmacist-driven, anti-Xa-based protocol for enoxaparin titration is a feasible and safe way to ensure that VTE prophylaxis is dosed to meet specific anti-Xa target levels.

METHODS AND MATERIALS

This prospective cohort study included patients admitted to the Trauma and Surgical Intensive Care Unit with a traumatic injury and need for VTE prophylaxis. An *Anti-Xa Monitoring for Enoxaparin Thromboembolic Prophylaxis in Trauma Protocol* was started in January 2021 and patients were enrolled through August 2022. Patients were excluded if they were not started on enoxaparin during their ICU admission (figure 1). Patient demographics, comorbidities, admission laboratory values, mechanism of injury, Injury Severity Score (ISS), length of stay and in-hospital mortality were obtained from the trauma registry. Rates of VTE as well as major bleeding events were also obtained from the registry and confirmed on electronic medical record review. Venous duplex ultrasonography is the primary method for diagnosis of lower extremity DVT with duplex ultrasonograpy obtained for symptomatic patients or clinician concern (eg, tachycardia, fevers, prolonged immobility). Major bleeding was considered to be any bleed significant enough to warrant holding VTE prophylaxis. Detailed electronic medical record review was undertaken to ascertain body mass index (BMI), history of VTE, baseline anticoagulation status, time of VTE prophylaxis initiation, type and dose of VTE prophylaxis, number of anti-Xa levels measured, anti-Xa levels and enoxaparin dose modifications.

The anti-Xa monitoring protocol was developed in late 2020 by our institution's Trauma and Surgical ICU Pharmacists in collaboration with members of the trauma surgery and trauma/surgical ICU teams (figure 2). The initiation of VTE prophylaxis was at the discretion of the trauma surgery and consulting teams, with enoxaparin as the VTE prophylaxis agent of choice. Unfractionated heparin could also be utilized in patients with renal insufficiency (creatinine clearance (CrCl) <30 mL/min) and at the discretion of the attending trauma surgeon for certain traumatic brain injuries and spinal cord injuries. Once the decision was made to initiate VTE prophylaxis with enoxaparin, the ICU pharmacists were responsible for adherence to the anti-Xa monitoring protocol, dose changes and anti-Xa level monitoring. The initial standard enoxaparin dose is 30 mg two times per day; however, patients with BMI >40 kg/m^2 are started at 40 mg two times per day. Anti-Xa levels are obtained 4 hours after administration of at least two consecutive and appropriately timed enoxaparin doses. Anti-Xa levels <0.2 are considered below target, those between 0.2 and 0.5 are considered on-target, and levels >0.5 are considered above target.[19–21] In patients with below target anti-Xa levels, the enoxaparin dose

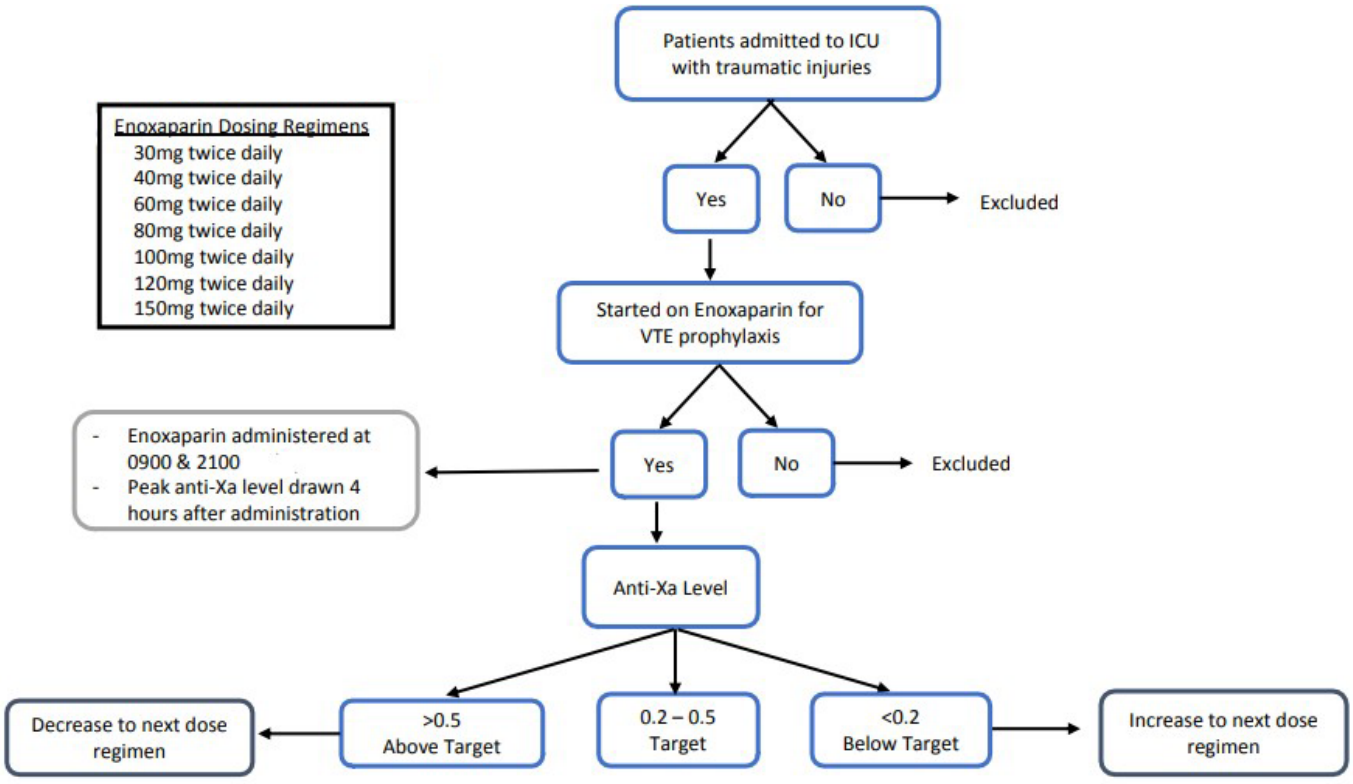

Figure 2 Anti-Xa protocol for enoxaparin titration in patients with trauma. ICU, intensive care unit; VTE, venous thromboembolism.

should be increased to the next syringe size. Those with above target anti-Xa levels should have the enoxaparin dose decreased to the next syringe size. When the anti-Xa level is in the target range, no dose titration is necessary. Syringe sizes include 30 mg, 40 mg, 60 mg, 80 mg, 100 mg, 120 mg and 150 mg. For those patients with above target anti-Xa levels on 30 mg two times per day, the frequency of the dosing is decreased to 30 mg per day. This process would be followed until the patient achieves the target prophylaxis range. Dosing titrations were continued until a maximum dose of 1 mg/kg/dose. Once the target range is reached, no further monitoring is undertaken unless significant weight loss or renal dysfunction, defined as CrCl<50 mL/min, occurs.

Retrospective analysis of this performance improvement initiative was approved by our institutional review board. Demographics, injury characteristics and outcomes were compared between patients who were found to have on-target anti-Xa levels and those who did not have a target anti-Xa level measured during their hospitalization. Similar analysis was undertaken to assess differences in those in whom the pharmacist-driven protocol was followed correctly versus those who deviated from the protocol. We considered the protocol to be followed incorrectly when the anti-Xa level was not checked while the patient was admitted to the ICU as well as when the enoxaparin dose was not increased, decreased or maintained according to the protocol. Subgroup analysis was performed to look at differences in demographics and hospitalization characteristics in those who did and did not develop VTEs.

Descriptive analysis included percentages or medians with IQRs. Two-tailed students t-tests and χ^2 analyses were used to compare cases and controls. A p value of less than 0.05 was considered significant. All data analyses were performed using jamovi (The jamovi project (2021), V.1.6, https://www.jamovi.org, Sydney, Australia).

RESULTS

A total of 282 patients with traumatic injuries were admitted to the ICU and were included in the final analysis. The majority of patients were men (79.8%) with a median age of 36 years (table 1). Just over half sustained a blunt mechanism of injury (55.3%). Most patients did not have active cancer, liver disease or history of prior venous thromboembolic event. Only six patients (2.1%) were taking therapeutic anticoagulation prior to their hospitalization. The median CrCl for all patients was 123 (96–164), though only half of patients had CrCl documented. Prophylaxis with either subcutaneous heparin or enoxaparin was started within 24 hours in 45% of patients. The median time to prophylaxis with enoxaparin initiation was 31 hours (IQR: 18–56). The median number of anti-Xa levels collected was 1 (IQR: 1–2) while the median number of enoxaparin dose modifications was 0 (IQR: 0–1). The final enoxaparin doses ranged from 30 mg two times per day (58.4%) to 100 mg two times per day (0.7%). Only 11% of patients were escalated past 40 mg two times per day of enoxaparin. Only three patients (1.1%) experienced a major bleed. One patient had tracheostomy site bleeding, another had ongoing bleeding from a traumatic retroperitoneal hematoma and the third had an upper gastrointestinal bleed. No patient died from bleeding. Of 8.8% patients experienced any kind of VTE, with 12 patients experiencing a PE and 13 patients diagnosed with a DVT. Mortality for the entire cohort was 1.1%.

Of 95.7% of patients were started on 30 mg two times per day of enoxaparin while 3.6% (10 patients) started at 40 mg two times per day and only 0.7% (2 patients) were started on 60 mg two times per day. With one exception, all patients who started

Table 1 Demographics and treatment characteristics of all study patients

	All patients
	n=282
Male (%)	79.8%
Age (median, IQR)	36 (26–55)
Mechanism (%)	
Blunt	55.3%
Penetrating injury	44.7%
Comorbidities	
Active cancer	1.4%
Liver disease	2.1%
History of VTE	1.4%
ISS (median, IQR)	17 (10–26)
BMI (median, IQR)	24.7 (22–28.7)
ICU length of stay (days; median, IQR)	4 (2 - 8)
Hospital length of stay (days; median, IQR)	10 (6–19)
Admission INR (median, IQR)	1.1 (1.0–1.2)
Creatinine clearance (median, IQR)	123 (96–164)
First enoxaparin dose	
30 mg two times per day	95.7%
40 mg two times per day	3.6%
60 mg two times per day	0.7%
First anti-Xa level (median, IQR)	0.18 (0.12–0.24)
First anti-Xa level (%)	
Subtherapeutic	56.6%
Therapeutic	42.7%
Supratherapeutic	0.7%
Total anti-Xa levels collected (median, IQR)	1 (1-2)
Dose modifications made (median, IQR)	0 (0–1)
Final enoxaparin dose (%)	
30 mg two times per day	58.4%
40 mg two times per day	30.6%
60 mg two times per day	8.9%
80 mg two times per day	1.4%
100 mg two times per day	0.7%
Reached goal anti-Xa level (%)	70.8%
Major bleeding (%)	2.1%
Venous thromboembolic events (%)	9.9%
Mortality (%)	1.1%

BMI, body mass index; ICU, intensive care unit; INR, international normalized ratio; IQR, interquartile range; ISS, Injury Severity Score; VTE, venous thromboembolism.

on 40 mg or 60 mg two times per day enoxaparin regimens had BMIs ≥40 at admission. Of those started on 30 mg two times per day, 60.5% did not have a dose adjustment while 30.5% had one dose adjustment up to 40 mg two times per day. The remaining 9.1% had between one to three dose adjustments with final enoxaparin doses between 60 mg to 100 mg two times per day.

A target anti-Xa level was measured at some point in 195 patients (69.1%) while 85 patients (30.1%) never achieved a target anti-Xa level prior to hospital discharge (table 2). Two patients were discharged from the ICU prior to the first check of anti-Xa levels. Those who achieved a target anti-Xa level had longer ICU (5 vs 3, p=0.003) and hospital lengths of stay (12 vs 8, p=0.019). Patients who achieved target anti-Xa levels had significantly lower CrCl compared with those patients who did not achieve target anti-Xa levels (117 vs 147, p=0.039). Those who did not achieve target anti-Xa levels were more likely to require higher doses of enoxaparin compared with those who

Table 2 Comparison among patients who did and did not reach target anti-Xa levels

	Target anti-Xa	Never on-target anti-Xa	
	n=195	n=85	P value
Male (%)	78.9%	82.4%	0.503
Age (median, IQR)	35 (24–56)	36 (26–50)	0.884
Mechanism (%)			
Blunt	56.2%	51.9%	0.533
Penetrating injury	43.8%	48.1%	
History of VTE (%)	1.0%	2.4%	0.396
ISS (median, IQR)	14 (9–26)	18 (10–26)	0.927
BMI (median, IQR)	24.4 (22.0–28.2)	25.2 (22.3–29.5)	0.409
ICU length of stay (days; median, IQR)	5 (2 - 9)	3 (2 - 5)	**0.003**
Hospital length of stay (days; median, IQR)	12 (7–21)	8 (5 - 15)	**0.019**
Admission INR (median, IQR)	1.1 (1.0–1.2)	1.1 (1.0–1.2)	0.922
Creatinine clearance (median, IQR)	117 (90–150)	147 (110–183)	**0.039**
First enoxaparin dose (%)			
30 mg two times per day	95.9%	95.3%	0.520
40 mg two times per day	3.1%	4.7%	
60 mg two times per day	1.0%	0.0%	
Hours to enoxaparin initiation (median, IQR)	31 (16–67)	31 (19–43)	0.079
Total anti-Xa levels collected (median, IQR)	1 (1-2)	1 (1-2)	0.050
Dose modifications made (median, IQR)	0 (0–1)	0 (0–1)	0.361
Final enoxaparin dose (%)			
30 mg two times per day	61.9%	49.4%	**0.009**
40 mg two times per day	26.3%	41.1%	
60 mg two times per day	10.8%	4.7%	
80 mg two times per day	1.0%	2.4%	
100 mg two times per day	0.0%	2.4%	
Median anti-Xa level by dose (median, IQR)			
30 mg two times per day	0.24 (0.22–0.29)	0.21 (0.07–0.16)	**<0.001**
40 mg two times per day	0.26 (0.22–0.30)	0.12 (0.07–0.14)	**<0.001**
60 mg two times per day	0.33 (0.26–0.39)	0.07 (0.05–0.09)	**0.038**
80 mg two times per day	0.40 (0.39–0.41)	0.04 (0.04–0.04)	**0.035**
100 mg two times per day	n/a	0.15 (0.14–0.17)	–
Major bleeding (%)	3.1%	0.0%	0.101
Venous thromboembolic events (%)	9.3%	9.4%	0.972
Mortality (%)	1.0%	1.1%	0.914

BMI, body mass index; ICU, intensive care unit; INR, international normalized ratio; IQR, interquartile range; ISS, Injury Severity Score; VTE, venous thromboembolism.

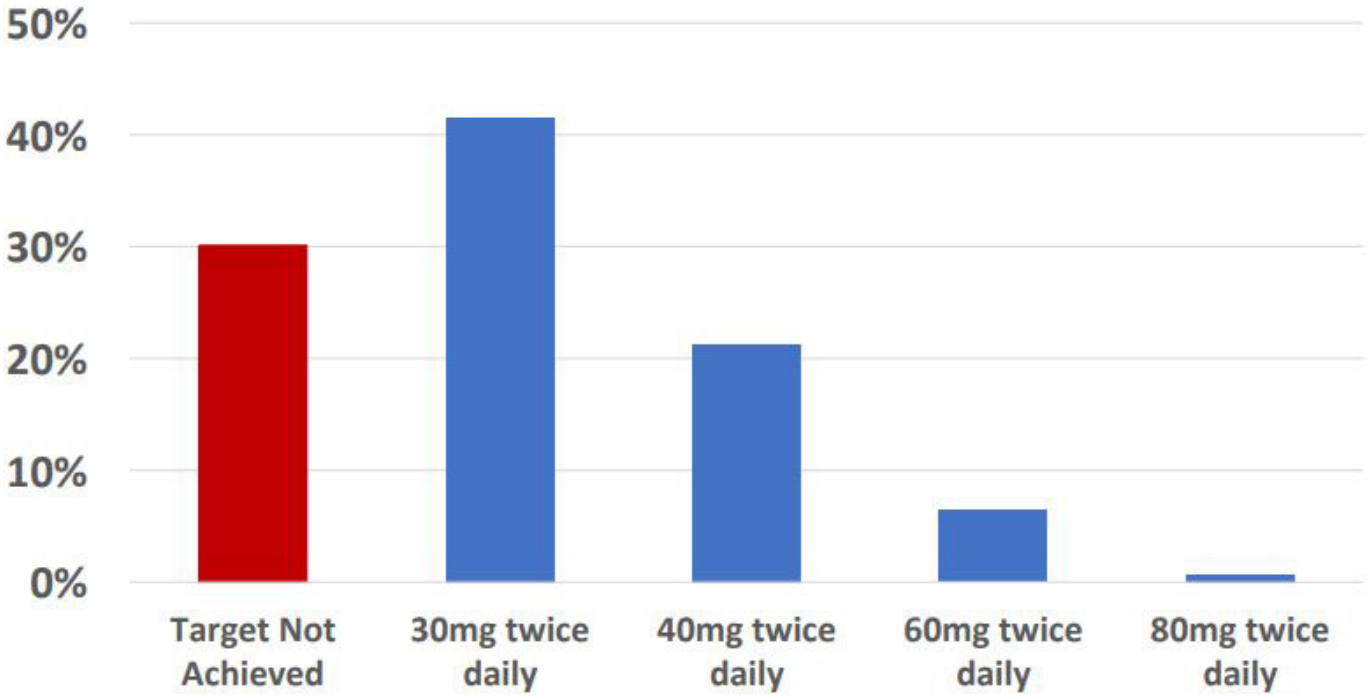

Figure 3 Enoxaparin dose at which goal anti-Xa achieved.

reached target levels (p=0.009). There were no differences in hours to enoxaparin initiation, number of anti-Xa levels collected or dose modifications. No differences were observed in rates of major bleeding, VTE or mortality between the two groups (table 2). In the 197 patients who achieved a target anti-Xa level, 59.4% were on-target at 30 mg two times per day, 30.5% were on-target at 40 mg two times per day, 9.1% were on-target at 60 mg two times per day and 1.0% were on-target at 80 mg two times per day(figure 3). The median ICU length of stay for those who did not achieve a target anti-Xa level was 3.2 (1.9–4.8) days. Only five of these patients had an ICU length of stay longer than 7 days.

A total of 25 patients experienced either DVT or PE. Twelve patients experienced either DVT or PE on 30 mg two times per day, of which nine patients had at least one on-target anti-Xa level measured prior to VTE diagnosis. Nine patients were taking 40 mg two times per day when diagnosed with their VTE, of which five patients had at least one on-target anti-Xa level measured prior to VTE diagnosis. Three patients were diagnosed with VTE on 60 mg two times per day, of which two patients had target anti-Xa levels measured prior to diagnosis. The two patients taking high doses of enoxaparin (80 mg and 100 mg two times per day) did not have anti-Xa levels measured prior to diagnosis of their PEs. No patient died as a result of VTE.

The protocol was followed correctly 91.1% of the time (table 3). Those for whom the protocol was not followed had longer ICU (15 vs 4, p<0.001) and hospital length of stays (26 vs 10, p<0.001), higher ISSs (33 vs 17, p<0.032), and more anti-Xa levels checked (3 vs 1, p<0.001). Additionally, those in whom the protocol was correctly followed were more likely to have a final enoxaparin dose of 30 mg twice daily. No differences were noted in CrCl, hours to enoxaparin initiation, dose modifications or likelihood of achieving an on-target anti-Xa level prior to discharge.

DISCUSSION

In this prospective study, we have shown that the implementation of a pharmacist-driven, weight-based protocol with anti-Xa monitoring for enoxaparin dose titration is both safe and feasible in a critically ill trauma population. Using anti-Xa levels for dose monitoring, ICU pharmacists were able to increase enoxaparin doses with confidence. Despite these dose increases, only three patients (1.1%) experienced a major bleeding event. Furthermore, the protocol was adhered to in 91% of patients, suggesting that it is practical and easy to follow. Interestingly, 69% of patients had a target anti-Xa level measured during their time in the ICU of which only 59% achieved a target level on the lowest dose of 30 mg two times per day. These results suggest that nearly half of critically ill patients with trauma will require at least one dose titration during their hospitalization to reach an enoxaparin dose that achieves adequate prophylactic anti-Xa levels.

Perhaps most importantly, these results demonstrate that this protocol is safe to use in a critically ill trauma population. Several studies have shown that this population has altered drug metabolism and pharmacokinetics, making it difficult to know what the optimal enoxaparin dose should be.[22 23] As a result, many clinicians opt to keep the enoxaparin dose at either 30 mg or 40 mg to prevent major bleeding episodes in patients who are often high risk for ongoing or subsequent hemorrhage. In one of the largest studies that examined outcomes following implementation of a similar dose titration protocol with anti-Xa levels, Gates *et al* reported that 11.9% of patients required a blood transfusion, which was not significantly different than in patients who were maintained at 30 mg two times per day.[18] In a study of their institutional anti-Xa level-based dose titration enoxaparin protocol, Taylor *et al* observed clinically significant bleeding in 5.3% of patients.[24] In this study, only 1.1% of patients experienced a major bleeding event and no patient died because of bleeding. This is likely an underestimate as we only studied

Table 3 Comparison of outcomes in patients in whom the protocol was followed

	Protocol followed	Protocol not followed	
	n=257	n=25	P value
Male (%)	78.0%	96.0%	**0.033**
Age (median, IQR)	35 (25–55)	36 (27–63)	0.527
Mechanism (%)			
Blunt	54.3%	66.7%	0.246
Penetrating injury	45.7%	33.3%	
History of VTE (%)	1.6%	0.0%	0.527
ISS (median, IQR)	17 (10–26)	33 (13–35)	**0.032**
BMI (median, IQR)	24.8 (22.1–29.3)	24.6 (21.9–26.8)	0.127
ICU length of stay (days; median, IQR)	4 (2 -7)	15 (5–25)	**<0.001**
Hospital length of stay (days; median, IQR)	10 (6–18)	26 (17–34)	**<0.001**
Creatinine clearance (median, IQR)	126 (99–166)	116 (72–137)	0.144
First enoxaparin dose (%)			
30 mg two times per day	95.7%	96.0%	0.900
40 mg two times per day	3.6%	4.0%	
60 mg two times per day	0.7%	0.0%	
Hours to enoxaparin initiation (median, IQR)	31 (16–55)	28 (19–58)	0.909
Total anti-Xa levels collected (median, IQR)	1 (1-2)	3 (2-3)	**<0.001**
Dose modifications made (median, IQR)	0 (0–1)	1 (0–1)	0.138
Therapeutic anti-Xa level (%)	69.4%	64.0%	0.577
Final enoxaparin dose (%)			
30 mg two times per day	59.6%	32.0%	**0.032**
40 mg two times per day	29.0%	60.0%	
60 mg two times per day	9.0%	8.0%	
80 mg two times per day	1.6%	0.0%	
100 mg two times per day	0.8%	0.0%	
Major bleeding (%)	2.4%	0.0%	0.438
Venous thromboembolic events (%)	8.6%	16.0%	0.225
Mortality (%)	0.8%	4.0%	0.136

The boldface signifies statistically significant p values <0.05.
BMI, body mass index; ICU, intensive care unit; INR, international normalized ratio; IQR, interquartile range; ISS, Injury Severity Score; VTE, venous thromboembolism.

patients admitted to the ICU. These results add to a body of literature supporting the safety of higher doses of enoxaparin in the trauma population and reinforce the most recent guidelines from the *American Association for the Surgery of Trauma, American College of Surgeons Committee on Trauma* and the *Western Trauma Association*, which all recommend starting enoxaparin at a dose of 40 mg two times per day.[25 26]

Pharmacist-driven protocols exist for many inpatient anticoagulant therapies and VTE prophylaxis.[27 28] Prior results in VTE prophylaxis implementation in hospitalized patients suggest that when pharmacists lead anticoagulation management services, patients experience lower bleeding and mortality rates.[28] We believe that this is the first report of such a protocol in which ICU pharmacists have been given autonomy outside of the timing of the first dose of enoxaparin in the trauma population. We demonstrate that the protocol was adhered to 91% of the time, which suggests that it has the support of the staff and is easy to follow. Furthermore, we had excellent buy-in from the trauma and critical care staff as we did not find any evidence of physician opposition to a dose increase in the setting of a sub-target anti-Xa level.

Though 70% of patients in this study had documented target anti-Xa levels prior to hospital discharge, nearly a third of patients did not achieve a target level. This was likely a result of the application of the protocol to critical care patients only, as patients who reached target levels had significantly longer lengths of hospital and ICU lengths of stay compared with those who did not reach target anti-Xa levels. There will always be a number of patients whose length of stay is too short for them to achieve on-target anti-Xa levels, however with the expansion of this protocol to those admitted to non-critical care units, we hope that the percentage of patients who achieve a target anti-Xa prior to discharge increases. Notably, we did not observe a difference in VTE rates when comparing those who did and did not achieve a target anti-Xa level. Though several studies have observed decreased VTE rates with target anti-Xa levels,[21 29 30] the data remain mixed with others reporting trends towards decreased VTE rates without statistical significance.[31–33] We suspect that if all patients admitted to the trauma service had been included, we may have seen a difference in VTE rates in those with target anti-Xa levels.

Our study is not without limitations. First, this is a prospective cohort study from a single institution that relied heavily on medical record review. As such, this may not be an accurate representation of all critically injured patients. As we only included patients who received enoxaparin, we were unable to compare rates of VTE or bleeding to patients who received a different type of VTE prophylaxis or no VTE prophylaxis. Additionally, as the current protocol has only been applied to patients admitted to the ICU, we were not able to examine the efficacy or safety of this protocol in the general trauma population. In the future, we hope to expand this protocol to all patients admitted to the hospital, including those admitted outside the ICU. Finally, the actual target anti-Xa level for enoxaparin prophylaxis was based on prior studies that showed a decrease in DVT rates with higher anti-Xa levels. Furthermore, this study only examined peak anti-Xa values and did not track anti-Xa trough levels. As more work is completed on this topic, it becomes clear that the true anti-Xa level at which patients receive a true prophylactic benefit remains somewhat unknown.[19–21]

In conclusion, VTE remains a significant cause of morbidity in the critically ill trauma population. Though enoxaparin has been shown to be the superior agent for VTE prophylaxis in the trauma population, the ideal dose and titration regimen have not yet been settled on. Here, we have demonstrated that a pharmacist-driven, dose titration regimen based on anti-Xa level monitoring in trauma patients admitted to the ICU is safe and feasible. However, there remains room for improvement as 30% of patients did not achieve a target anti-Xa level prior to discharge from the hospital. In the future, we hope to expand this quality improvement project to include all admitted patients

with trauma, not just those admitted to the ICU. Additionally, we plan to study our institutional rates of VTE in patients with trauma before and after implementation of this new protocol.

Contributors CW, RL, MZ, VP, NDM and LM developed and implemented the enoxaparin titration protocol. GMN and CW completed chart reviews and statistical analysis. GMN and NDM drafted the manuscript. All authors critically reviewed the manuscript and agreed on the final draft. NDM is the guarnator of this work and accepts full responsibility for the finished work, conduct of the study, and controlled the decision to publish.

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Competing interests None declared.

Patient consent for publication Not applicable.

Ethics approval This study was considered to be exempt from Institutional Review Board (IRB) review as it is 'secondary research' which is research involving the collection or study or study of existing data, documents, records, pathological specimens or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified.

Provenance and peer review Not commissioned; externally peer-reviewed.

Data availability statement Data are available upon reasonable request. Data is in the form of a spreadsheet and is available upon request.

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