Thromboelastography Profiles of Critically Ill Patients With Coronavirus Disease 2019

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Objectives: The rate of thromboembolic events among patients with coronavirus disease 2019 is high; however, there is no robust method to identify those at greatest risk. We reviewed thromboelastography studies in critically ill patients with coronavirus disease 2019 to characterize their coagulation states.

Design: Retrospective.

Setting: Tertiary ICU in New York City.

Patients: Sixty-four patients with coronavirus disease 2019 admitted to the ICU with thromboelastography performed.

Interventions: None.

Measurements and Main Results: Fifty percent of patients had a clotting index in the hypercoagulable range (clotting index > 3) (median 3.05). Reaction time and K values were below the lower limit of normal in 43.8% of the population consistent with a hypercoagulable profile. The median α angle and maximum amplitude (75.8° and 72.8 mm, respectively) were in the hypercoagulable range. The α angle was above reference range in 70.3% of patients indicative of rapid clot formation. Maximum amplitude, a factor of fibrinogen and platelet count and function, and a measure of clot strength was above reference range in 60.1% of patients. Thirty-one percent had thromboembolic events; thromboelastography parameters did not correlate with events in our cohort. Those with D-dimer values greater than 2,000 were more likely to have shorter reaction times compared with those with D-dimer levels less than or equal to 2,000 (4.8 vs 5.6 min; $p = 0.001$).

Conclusions: A large proportion of critically ill patients with coronavirus disease 2019 have hypercoagulable thromboelastography profiles with additional derangements related to fibrinogen and platelet function. As the majority of patients have an elevated thromboelastography maximum amplitude, a follow-up study evaluating platelet aggregation would be instructive. (*Crit Care Med* 2020; XX:00–00)

Key Words: coronavirus disease 2019; inflammation; thromboelastography; thromboembolism; thrombosis

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Coronavirus disease 2019 (COVID-19) is caused by severe acute respiratory syndrome coronavirus 2 first detected in Wuhan, China (1). Severe disease occurs in approximately 14% of patients with COVID-19 with approximately 6% requiring intensive care; the case fatality rate of those in the latter group approaches 50% (1, 2). Inflammation and coagulation are intimately linked; altered coagulation is a known complication of severe respiratory viral infections (3–6). Patients with COVID-19 are at increased risk for venous thromboembolism (VTE) with high rates observed despite thromboprophylaxis; case reports have noted pulmonary embolism (PE) among patients with COVID-19 pneumonia in the absence of other predisposing factors (7–11). D-dimer, a biomarker of fibrin formation and degradation, is elevated in conditions associated with thrombosis and has been associated with mortality among patients with COVID-19 (7, 8, 12, 13). Although data suggest a thrombophilia associated with COVID-19, how best to identify patients at highest risk for thrombosis remains unknown.

Thromboelastography (Haemonetics, Boston, MA) is a point of care viscoelastic test of hemostasis in whole blood which allows for measurement of global clot formation and dissolution in real time (14–16). Commonly used to guide transfusion of hemostatic products, multiple studies have demonstrated the ability of thromboelastography to identify patients at increased risk for VTE, myocardial infarction, and stroke across various clinical settings (14–20). To better characterize the coagulation states of critically ill patients with COVID-19, we carried out a retrospective analysis of thromboelastography data obtained on patients with COVID-19 admitted to the ICU.

MATERIALS AND METHODS

Patient Population and Definitions

At our institution, it became common practice for critical care providers to obtain a thromboelastography on COVID-19

patients at the time of admission to the ICU as part of routine laboratory testing. D-dimer, fibrinogen, C-reactive protein (CRP), and ferritin levels are obtained every 24–48 hours. Adult patients with a thromboelastography performed in the COVID-19 ICU at New York University Langone Health between April 1, 2020, and April 20, 2020, were included. Patients were excluded from the analysis if they met any of the following criteria: known hypercoagulable state (i.e., Factor V Leiden); active malignancy; blood product transfusion within 24 hours of thromboelastography; known history of VTE prior to admissions; thrombocytopenia with platelets less than 150; acute liver failure or history of cirrhosis; or currently receiving antiplatelet therapies. Patients admitted to the ICU at our institution are initiated on thromboprophylaxis with unfractionated heparin or enoxaparin provided no strict contraindications. Our institutional protocols further advise initiation of full-dose systemic anticoagulation for patients with COVID-19 and a D-dimer greater than 2,000, or a significant rise in D-dimer (6× to 10× admission value). If the D-dimer is to fall below 2,000 during the patient's admission, transitioning to thromboprophylaxis dosing is at the discretion of the treating physician.

Electronic medical records (Epic; Epic Systems Corporation, Milky Way, Verona, WI) were reviewed for laboratory, clinical, and outcomes data. Shock was defined by vasopressor requirement with evidence of end-organ dysfunction at the time of thromboelastography acquisition and documented by the treating team. Acute renal failure was defined as a greater than 3× increase in serum creatinine above baseline. Thromboembolic events required imaging confirmation to be included in the analysis (either venous ultrasound or chest CT). Laboratory variables obtained within 24 hours of the thromboelastography were included in our final analysis. Because of the retrospective nature of this observational review, informed consent was not required. All patient data were de-identified and collected in compliance with the hospital's institutional review board exempt protocols.

Thromboelastography

Citrated blood samples were tested in the TEG 5000 Thrombelastograph Hemostasis Analyzer (Haemonetics, Boston, MA) with citrated kaolin in heparinase as the reagent. For patients on anticoagulation, both prophylactic or therapeutic, thromboelastography were performed with and without heparinase with separate reaction times (R) reported. We evaluated five reported thromboelastography parameters in this study: R, K, α angle, maximum amplitude (MA), and lysis at 30 minutes (Ly30). The R time is measured from test initiation till initial clot formation (normal range, 5–10 min) with less than 5 minutes considered to be in the hypercoagulable range. The K is the time from initiation of clot formation to an amplitude of 20 mm (normal range, 1–3 min) with less than 1 minute considered hypercoagulable. The α angle is measured from the baseline and tangent to amplitude curve expressed in degrees (normal range 53–72°). MA of the clot is measured in millimeters (mm) (normal range of 50–70 mm) with greater than

70 mm considered hypercoagulable. The percentage of clot lysed 30 minutes post-MA is termed the Ly 30 (normal range, 0–8%). The clotting index (CI) is calculated as CI = –0.2454 R+ 0.0184 K + 0.1655 MA–0.0241 α–5.0220 with values greater than 3 considered hypercoagulable, –3 to 3 normal range, and less than 3, hypocoagulable (14–16). **Figure 1** is a diagram illustrating thromboelastography variables presented in this study. Each value correlates with a different aspect of clot formation or lysis; based on alteration in different aspects in a thromboelastography, inferences about mechanisms of clotting or bleeding can be made.

Statistical Analysis

Statistical analyses were performed using SPSS (Version 25.0; Statistical Package for Social Sciences, Chicago, IL). For descriptive analyses, variables were expressed as median values and interquartile ranges (25–75%). Fisher exact and chi-square tests were used to analyze categorical variables. Mann-Whitney U tests were used to assess nonparametric continuous variables. Spearman correlation coefficients (r_s) were used to determine correlation between thromboelastography parameters and other laboratory data. To determine the significance of D-dimer as a predictor of CI, receiver operating characteristic (ROC) analysis was used. A p value of less than 0.05 was considered statistically significant.

RESULTS

In total, 64 critically ill patients with COVID-19 had available thromboelastography meeting our inclusion criteria, and were obtained within 72 hours of ICU admission. The median age was 64 years old (57–71 yr) and 72% of patients were male. The overall mortality at a mean follow-up of 24 days was 29.6% (7.7% among those 29–49 yr old, 22.9% among those 50–69 yr old, and 32.3% among those 70–90 yr old). Sixty-one percent of the patients were in circulatory shock requiring vasopressors, 48% had acute renal failure, and 31.3% had VTE diagnosed during ICU admission. All 64 patients were receiving either prophylactic or therapeutic anticoagulation with unfractionated heparin or enoxaparin. Eighty-six percent were on full-dose systemic anticoagulation with the remaining
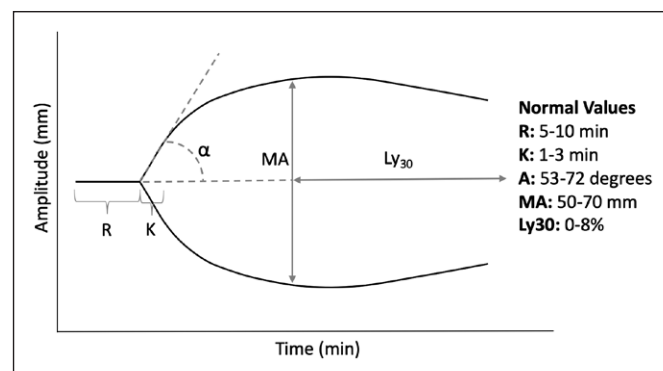

Figure 1. Diagram of thromboelastography with reference ranges. Results are displayed as *n* (%). K = kinetics, Ly30 = lysis at 30 min, MA = maximum amplitude, R = reaction time.

14% receiving thromboprophylaxis-dose anticoagulation. Most patients were treated with therapeutic anticoagulation as a result of elevated D-dimer levels and perceived thromboembolic risk as is common practice in our COVID ICU. The mean D-dimer among those on therapeutic versus prophylactic anticoagulation was 2,549 and 705 ng/mL, respectively ($p = 0.008$); no other clinical or laboratory value differed between these two groups.

Table 1 displays each thromboelastography variable by distribution in the study population with reference to normal values (15–17). Fifty percent of patients had a hypercoagulable thromboelastography profile with CI greater than 3. The R and K values were below the lower limit of normal in 43.8% of the population indicative of rapid activation of the intrinsic pathway and initial fibrin crosslinking (14, 15). Both α angle and MA were in the hypercoagulable range in the majority of our patients (70.3% and 60.1%, respectively). Figure 2 displays the distribution of each thromboelastography variable in our population as a box-whisker plot. Clot lysis (Ly30) was within reference range 95.3% of the time.

There were few associations between thromboelastography variables and labs of inflammation and coagulation using r_s. All significant associations identified were weak to moderate. The MA correlated with Fibrinogen and CRP ($r_s = 0.453$, $p = 0.001$ and $r_s = 0.290$, $p = 0.02$, respectively). The α angle correlated with platelet count ($r_s = 0.332$, $p = 0.007$) and fibrinogen ($r_s = 0.309$, $p = 0.021$). The D-dimer only correlated with R time ($r_s = -0.362$, $p = 0.003$), but not with other thromboelastography parameters.

Table 2 displays baseline patient characteristics stratified by the CI (> 3 vs ≤ 3). The median R and K times (5.15 and 1.00 min, respectively) were consistent with an intact coagulation pathway. The median α angle (75.3°, 69.9–78.4°) and MA (72.8 mm, 67.9–77.6 mm) were in the hypercoagulable range. There was no significant difference between clinical variables and CI strata in our population. Laboratory results were similar between the two groups with the exception of D-dimer levels which were higher among those with CI greater than 3 compared with those with CI less than or equal to 3 (2,779

vs 1,664 ng/mL; $p = 0.023$). Fibrinogen, ferritin, D-dimer, and CRP levels were all markedly elevated in the cohort.

We evaluated the association between radiologically confirmed VTE events with clinical and laboratory data. Of the 20 patients with confirmed VTE, 18 had only deep vein thrombosis (DVT), one had clot-in-transit in the right ventricle, and one had both PE and DVT. Forty of the 64 patients in our cohort (63%) had a venous ultrasound, and 10 patients (16%) had a CT chest with contrast performed over their admission. Patients did not undergo systematic VTE screening and all studies were ordered when clinically indicated. There were no significant differences in thromboelastography parameters between those with confirmed VTE and those without VTE with the exception of a slightly higher international normalized ratio (INR) (1.25 vs 1.1). Thirty-three patients (52%) met the combined outcome measure of either death or confirmed VTE. There was no association between thromboelastography variables and the combined outcome measure. Patients meeting the combined outcome had higher CRP (136 vs 82 mg/L; $p = 0.014$) and fibrinogen (713 vs 562 mg/dL; $p = 0.046$).

D-dimer is a biomarker associated with increased thrombosis risk and mortality among patients with COVID-19 (7, 12). Patients were stratified by those with D-dimer greater than 2,000 and less than or equal to 2,000. Our institutional guidelines suggest consideration of therapeutic anticoagulation in patients with D-dimer greater than 2,000 ng/mL ($> 8\times$ upper limit of normal) even without diagnosis of thrombosis. Table 3 displays clinical and laboratory variables stratified by D-dimer levels ($\leq 2,000$ and $> 2,000$ ng/mL). There were no significant differences in thromboelastography parameters among those with D-dimer greater than 2,000 ng/mL or less than or equal to 2,000 ng/mL with the exception of a shorter R time (4.8 vs 5.6 min; $p = 0.001$). The median CI was 2.1 (0.4–3.4) in the D-dimer less than or equal to 2,000 group as compared with 3.4 (1.7–4.0) in the D-dimer greater than 2,000 group ($p = 0.071$). ROC analysis identified a D-dimer of 2,075 ng/dL as the optimal cutoff value corresponding to a CI greater than 3 (area under the curve, 0.67; 95% CI, 0.53–0.80). A D-dimer of 2,075 ng/mL had a sensitivity of 0.75 and a specificity of 0.59 for CI greater than 3.

TABLE 1. Distribution of Thromboelastography Variables in Relation to Reference Ranges

Variable	Reference Range	Above Upper Limit of Normal, n (%)	Within Normal Range, n (%)	Below Lower Limit of Normal, n (%)
Clotting index	−3 to +3	32 (50)	30 (46.8)	2 (3.1)
R (nonheparinase)	5–10 min	13 (20.3)	32 (50)	19 (29.7)
R (heparinase)	5–10 min	1 (1.6)	35 (54.7)	28 (43.8)
Kinetics	1–3 min	2 (3.1)	34 (53.1)	28 (43.8)
α angle	53–72°	45 (70.3)	17 (26.6)	2 (3.1)
Maximum amplitude	50–70 mm	39 (60.1)	23 (36.0)	2 (3.1)
Lysis at 30 min	0–8%	3 (4.7)	61 (95.3)	0 (0.0)

R = reaction time.

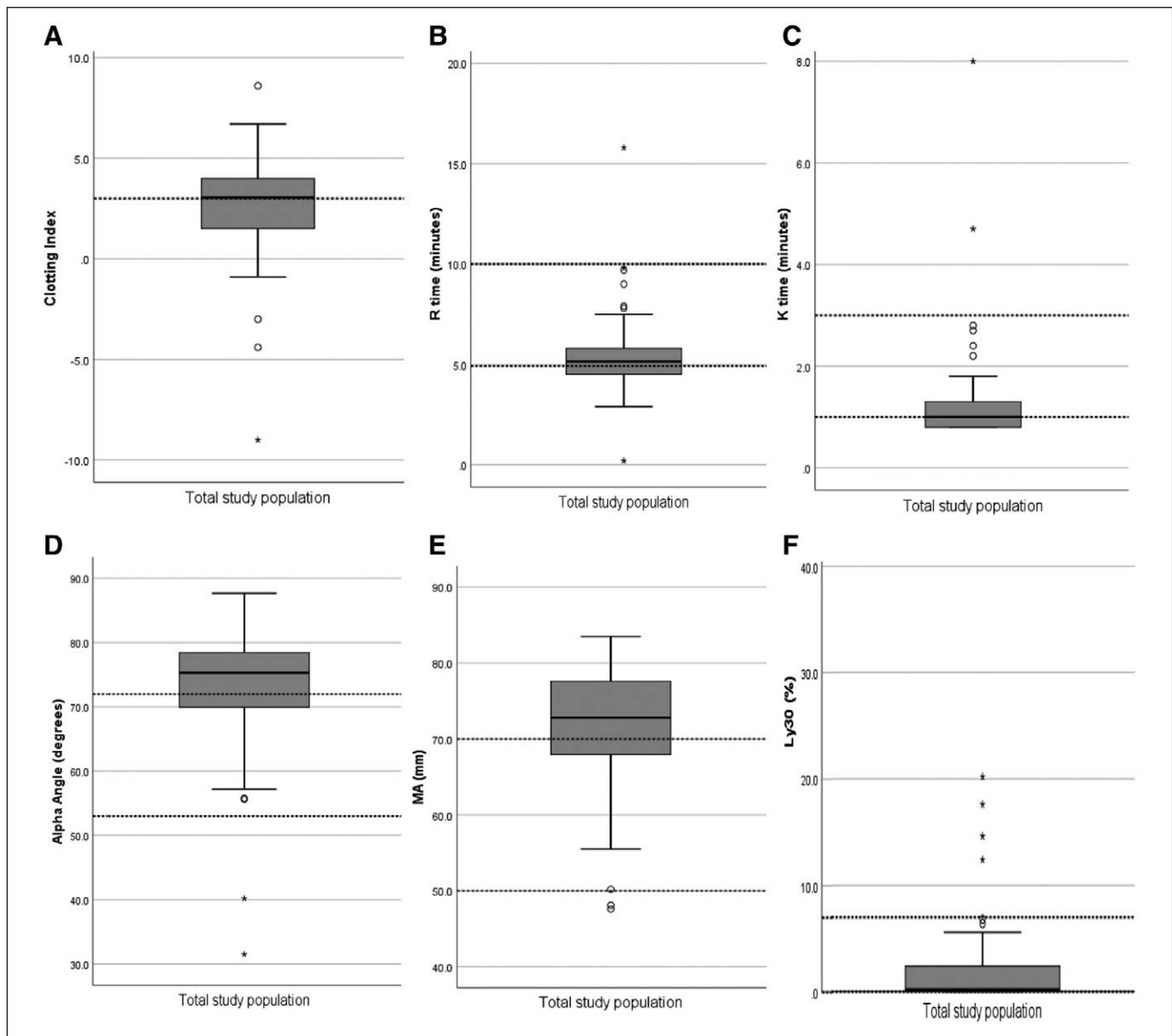Thromboelastography variables are displayed with n (%) of the population above, within, and below the reference range.

Figure 2. *Box*-and-w*hisker* plots of thromboelastography variables in the study population. *Dotted lines* indicate upper and lower reference ranges. **A**, Clotting index. **B**, Reaction time (R). **C**, Kinetics time. **D**, α angle. **E**, Maximum amplitude (MA). **F**, Lysis at 30 min (Ly30).

DISCUSSION

The occurrence rate of thrombotic complications among critically ill patients with COVID-19 is high despite thromboprophylaxis. In a study of 184 COVID-19 patients admitted to the ICU, the occurrence rate of thrombotic events, predominantly PE, was 31% (11). How best to identify those at highest risk for thrombotic complications and to define who may benefit from more aggressive treatment beyond standard thromboprophylaxis remains unknown. Thromboelastography allows for the measurement of multiple aspects of clot formation and dissolution reflecting the combined function of coagulation elements (14, 15). Although commonly used in trauma and surgery to guide transfusion of hemostatic products, multiple studies have demonstrated the utility of thromboelastography in predicting thrombotic events in hospitalized patients (17–22).

In our study of 64 critically ill patients with COVID-19 acute respiratory distress syndrome (ARDS), 50% had a hypercoagulable profile defined by CI greater than 3 with a median CI of 3.05 across the total population. A significant proportion of patients had thromboelastography variables in the hypercoagulable range (low R and K times, high α angle, and MA values). The median MA was 72.8 mm (70 mm upper limit of normal) with 60.1% having an MA greater than 70 mm. Our findings suggest a considerable proportion of critically ill patients with COVID-19 are hypercoagulable by thromboelastography. The MA represents clot strength, a factor of platelet count and function, fibrin crosslinking, and glycoprotein IIb/IIIa interactions. Although there is great attention to anticoagulation regimens for VTE prophylaxis, our findings suggest a significant fibrinogen and platelet effect to the thromboelastography

TABLE 2. Baseline Patient Characteristics Stratified by Clotting index

Variable	Total Population	CI > 3, n = 32	CI ≤ 3, n = 32	p
Age (yr)	64 (57–71)	64 (59–69)	62 (44–74)	0.262
Gender, male	46 (72)	23 (72)	23 (72)	1.000
History of cardiovascular disease	14 (22)	4 (13)	10 (31)	0.700
History of pulmonary disease	5 (8)	3 (9)	2 (6)	0.641
Chronic kidney disease	4 (6)	3 (9)	1 (3)	0.302
Shock	39 (61)	19 (59)	20 (63)	0.798
Acute renal failure	31 (48)	13 (41)	18 (56)	0.211
Venous thromboembolism	20 (31)	11 (34)	9 (28)	0.590
R (nonheparinase, min)	6.4 (4.80–9.17)	5.25 (4.50–7.62)	7.7 (5.52–9.35)	0.005
R (heparinase, min)	5.15 (4.50–5.80)	4.70 (3.52–5.37)	5.6 (4.85–6.92)	0.001
Kinetics (min)	1.00 (0.80–1.30)	0.80 (0.80–1.00)	1.25 (1.02–1.67)	0.001
α (degrees)	75.3 (69.9–78.4)	77.3 (75.4–79.0)	70.2 (63.7–75.1)	0.001
Maximum amplitude (mm)	72.8 (67.9–77.6)	76.2 (72.1–81.0)	68.8 (62.0–74.3)	0.001
Lysis at 30 min (%)	0.10 (0.00–1.20)	0 (0–1.38)	0.10 (0–1.15)	0.658
CI (−3 to +3)	3.05 (1.45–4.00)	4 (3.4–4.8)	1.5 (−0.2 to 2.25)	0.001
Platelet count (10^3/uL)	244 (176–321)	266 (197–326)	208 (161.5–295)	0.068
D-dimer (ng/mL)	2,374 (923–4,820)	2,779 (1,972–5,575)	1,664 (666–3,102)	0.023
International normalized ratio	1.20 (1.10–1.20)	1.20 (1.10–1.30)	1.20 (1.10–1.20)	0.452
Anti-Xa (international units/mL)	0.41 (0.31–0.61)	0.40 (0.27–0.56)	0.41 (0.35–0.71)	0.218
Fibrinogen (mg/dL)	669 (451–838)	711 (496–853)	631 (291–791)	0.204
C-reactive protein (mg/L)	104 (35–158)	103 (37.5–219)	111 (35.3–144)	0.519
Ferritin (ng/mL)	1,375 (780–2,650)	1,268 (671–2,341)	1,454 (905–3,129)	0.240

CI = clotting index, R = reaction time.
Demographic, clinical, and laboratory data are displayed and stratified by those with a CI > 3 vs those with CI ≤ 3. Variables are displayed as median and interquartile range and n (%).

profiles. We further demonstrated an association between MA and α angle with fibrinogen as well as an association between α angle and platelet count. The role of antiplatelet therapies in critically ill COVID-19 patients is uncertain and should be explored. Our results are consistent with those of Panigada et al (6) who evaluated thromboelastography parameters in 24 critically ill patients with COVID-19 and found hypercoagulability, supporting a severe inflammatory state. Similar to our results, the median R time in their report was within normal range, while the median α angle and MA were elevated (69.4° and 79.1 mm, respectively).

Prior studies have evaluated thromboelastography profiles in critically ill medical and surgical patients, predominantly focused on elevated MA as a marker of hypercoagulability, and have demonstrated conflicting results (23–25). In a study of 50 patients with sepsis, 30% had a hypercoagulable thromboelastography defined by elevated MA at admission to the ICU, while 22% were hypocoagulable with MA below the lower limit of normal (23). The average MA in their population was 60 mm (52–70 mm), significantly below our median value. In their study, fibrinogen levels, but not platelet count, were an independent predictor of clot strength among hypercoagulable patients. By contrast, Halset et al (24) evaluated 82 nonbleeding ICU patients and found the average MA to be 73.4 mm; 73% of patients had an MA above the upper limit of normal similar to our population. In their study, both fibrinogen and platelet count were independently associated with MA. Fibrinogen levels across our cohort were markedly elevated (669 mg/dL; normal range, 150–450 mg/dL); we demonstrated a moderate association between fibrinogen and MA. Although our median platelet count was within normal range, we did not obtain assessment of platelet aggregation and function. In severe sepsis, hypocoagulable thromboelastography profiles, possibly related to hypocoagulable disseminated intravascular coagulation (DIC), are associated with increased mortality (26–28). As most of our thromboelastography were obtained on ICU admission, overwhelmingly related to respiratory decompensation, we did not encounter hypocoagulable DIC among our patients. Similarly, none of our patients had significant elevations in INR, nor low fibrinogen or platelet counts. Further, we did not find a

TABLE 3. Clinical and Laboratory Data Stratified by D-Dimer

Variable	Total Population	D-Dimer ≤ 2,000, n = 26	D-Dimer > 2,000, n = 38	p
Age	64 (57–71)	62 (50–70)	64 (58–72)	0.603
Gender, male	46 (72)	18 (69)	28 (74)	0.697
History of cardiovascular disease	14 (22)	6 (43)	8 (57)	0.847
History of pulmonary disease	5 (8)	1 (4)	4 (11)	0.64
Chronic kidney disease	4 (6)	1 (4)	3 (8)	0.64
Shock	39 (61)	18 (69)	21 (55)	0.261
Acute renal failure	31 (48)	10 (39)	21 (55)	0.187
Venous thromboembolism	20 (31)	8 (31)	12 (32)	0.945
R (nonheparinase)	6.4 (4.80–9.17)	7.50 (5.17–12.35)	6.20 (4.70–8.12)	0.06
R (5–10 min)	5.15 (4.50–5.80)	5.60 (5.07–7.57)	4.8 (4.07–5.52)	0.001
Kinetics (1–3 min)	1.00 (0.80–1.30)	1.10 (0.80–1.30)	0.95 (0.80–1.25)	0.338
α (53–72°)	75.3 (69.9–78.4)	73.8 (70.1–78.4)	76.3 (70.0–78.6)	0.774
Maximum amplitude (50–70 mm)	72.8 (67.9–77.6)	74.2 (70.0–79.3)	71.7 (65.3–77.6)	0.277
Lysis at 30 min (0–8%)	0.10 (0.00–1.20)	0.05 (0.0–0.88)	0.10 (0.0–1.22)	0.69
Clotting index (−3 to +3)	3.05 (1.45–4.00)	2.1 (0.4–3.4)	3.4 (1.7–4.0)	0.071
Platelet count (10^3/uL)	244 (176–321)	256 (168–378)	228 (181–312)	0.738
International normalized ratio	1.20 (1.10–1.20)	1.20 (1.10–1.25)	1.20 (1.10–1.20)	0.95
Fibrinogen (mg/dL)	669 (451–838)	650 (452–800)	680 (447–887)	0.621
C-reactive protein (mg/L)	104 (35–158)	110.4 (61.7–162.7)	104.4 (28.8–153.5)	0.469
Ferritin (ng/mL)	1,375 (780–2,650)	1,375 (700–2,733)	1,325 (889–2,703)	0.913
D-dimer (ng/mL)	2,374 (923–4,820)	750 (589–1,575)	3,558 (2,569–6,832)	0.0001

R = reaction time.

Demographic, clinical, and laboratory data are displayed and stratified by those with a D-dimer ≤ 2,000 and D-dimer > 2,000. Variables are displayed as mean and interquartile range and n (%).

correlation between D-dimer and Ly30 as we suspect a higher degree of fibrinolysis may be necessary to elevate the Ly30.

We were unable to demonstrate association between thromboelastography variables and VTE events or the combined outcome of VTE and mortality. At a mean follow-up period of 24 days post thromboelastography acquisition, 20 patients had VTE (19 with DVT) with venous ultrasounds obtained on a total of 40 patients, and chest CT with contrast obtained on 10 patients. The lack of association may be the result of lack of systematic screening of our cohort and as many DVTs are asymptomatic. Alternatively, thromboelastography may not provide significant incremental value to VTE risk stratification among patients with COVID-19. By contrast to prior data demonstrating PE to be the more prevalent thromboembolic event among patients with COVID-19, DVT was the most prevalent event in our population (11). We postulate this was the result of a larger number of ultrasound studies obtained compared with CT scans. In part, clinical instability would frequently preclude transport to CT scan even in the setting of suspected PE.

The rate of VTE in our study was high at 31.3% despite 86% of the cohort being on full-dose therapeutic anticoagulation. Initiation of empiric full-dose anticoagulation was commonly triggered by a D-dimer greater than 2,000 or a significant rise above the admission value. As a result, patients may have had undiagnosed DVTs by the time of ICU admission or anticoagulation initiation. It remains unknown if increasing anticoagulation dose alone is sufficient to impact clinical outcomes in patients with COVID-19 and ARDS. Given the anti-inflammatory properties of heparin as well as high rate of acute kidney injury seen among our patients, heparin was the preferred anticoagulant. Plausibly alternative agents with less variability in pharmacokinetics may be more suitable. Anticoagulation strategies in patients with COVID-19 are the subject on ongoing randomized control trials.

Prior studies have found association between hypercoagulable thromboelastography, particularly elevated MAs, and thrombotic events (17, 19–22). Brill et al (19) reported on 983 trauma patients with admission thromboelastography with 69.6% receiving surveillance lower extremity ultrasound

studies. A hypercoagulable thromboelastography, defined as R time below, α angle above, or MA above reference range, was significantly associated with the diagnosis of DVT (15.6% vs 8%; p = 0.039). In their study, no individual marker predicted DVT but the combination of the three values was statistically significant; a hypercoagulable thromboelastography was highly sensitive for DVT (91.9%) but lacked specificity (16.1%) (20).

Based on prior literature including medical and surgical patients, the average MA of our population would be expected to be significantly associated with VTE. In a study of 240 patients undergoing surgery, an MA greater than 68 mm was associated with thrombotic complications including myocardial infarction (8.4% vs 1.4%; p = 0.0157) (21). Cotton et al (20) found an MA greater than 72 mm carried an odds ratio of 5.9 for VTE among 2,070 trauma patients. In an analysis of 215 patients admitted to the ICU, those with subsequent thromboembolism had a significantly higher MA of 71.7 versus 62.2 mm among those without thromboembolic events (p < 0.001) (22).

Our study was designed to be descriptive of the viscoelastic properties of blood in critically ill patients with COVID-19 to better understand their coagulation states. The study was not designed to evaluate clinical endpoints and patients did not undergo imaging studies to systematically evaluate for venous or arterial thromboembolic events. As most patients did not undergo CT chest, the true occurrence rate of PE in our cohort is unknown and likely underestimated. Most of the cohort remained in the ICU at the time of data analysis; additional events and all-cause mortality may have been captured with a longer follow-up period or more frequent imaging studies. thromboelastography, as well as other laboratory data, were reported at a single time point during a patient's ICU stay. A thromboelastography at a single time point may not be the optimal measure of the patient's coagulation profile over the duration of their ICU stay or hospitalization. Serial thromboelastography and their relationship to thromboembolic events may be more instructive. Due to these limitations, a trial implementing routine screening for thrombotic events may better assess the predictive value of thromboelastography variables on clinical outcomes.

CONCLUSIONS

In our study of 64 critically ill patients with COVID-19, we found a significant percent displayed hypercoagulability on thromboelastography. The predominant hypercoagulable profile was related to platelet function and fibrinogen as evidenced by elevated MA. Our study was not designed to demonstrate association between hypercoagulable thromboelastography variables and thromboembolic events. As the majority of patients have an elevated thromboelastography MA, a follow-up study evaluating platelet aggregation would be instructive.

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