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Resolution of acute pulmonary embolism using anticoagulation therapy alone in coronavirus disease 2019

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ABSTRACT

Objective: To investigate the radiographic resolution of acute pulmonary embolism (PE) using contrast-enhanced computed tomography (CECT) examinations in patients diagnosed with acute PE while hospitalized with coronavirus disease 2019 (COVID-19) and to understand the mid-term and long-term implications of anticoagulation therapy.

Methods: We identified patients with acute PE per CECT and at least one follow-up CECT from March 11, 2020, to May 27, 2021, using a prospective registry of all hospitalized patients with COVID-19 infection receiving care within a multicenter Health System. Initial and follow-up CECT examinations were reviewed independently by two radiologists to evaluate for PE resolution. The Modified Miller Score was used to assess for thrombus burden at diagnosis and on follow-up.

Results: Of the 6070 hospitalized patients with COVID-19 infection, 5.7% (348/6070) were diagnosed with acute PE and 13.5% (47/348) had a follow-up CECT examination. The mean \pm standard deviation time to follow-up imaging was 44 \pm 48 days (range, 3-161 days). Of 47 patients, 47 (72.3%) had radiographic resolution of PE, with a mean time to follow-up of 48 \pm 43 days (range, 6-239 days). All patients received anticoagulation monotherapy for a mean of 149 \pm 95 days and this included apixaban (63.8%), warfarin (12.8%), and rivaroxaban (8.5%), among others. The mean Modified Miller Score at PE diagnosis and follow-up was 4.8 \pm 4.2 (range, 1-14) and 1.4 \pm 3.3 (range, 0-16; $P < .0001$), respectively. Nine patients (19%) died at a mean of 13 \pm 8 days after follow-up CECT (range, 1-27 days) and at a mean of 28 \pm 16 days after admission (range, 11-68 days). Seven of the nine deaths (78%) were associated with progression of COVID-19 pneumonia.

Conclusions: Hospitalized patients with COVID-19 have a clinically apparent 5.7% rate of developing PE. In patients with follow-up imaging, 72.3% had radiographic thrombus resolution at a mean of 44 days while on anticoagulation. Prospective studies of the natural history of PEs with COVID-19 that include systematic follow-up imaging are warranted to help guide anticoagulation recommendations. (*J Vasc Surg Venous Lymphat Disord* 2022;10:578-84.)

Keywords: Pulmonary embolism; COVID-19; Resolution of pulmonary embolism

COVID-19 infection is associated with a procoagulant state leading to increased incidence of venous thromboembolism (VTE).^{1,2} Previous reported deep venous thrombosis and pulmonary embolism (PE) incidence in patients with COVID-19 ranges from 9%³ to 26%.⁴ The exact pathophysiology of this condition remains unknown, but a theory has been put forth by McGonagle et al.⁵ They proposed that a macrophage activation-like state triggers an extensive immunothrombosis in the

lung's vessels, leading to pulmonary intravascular coagulopathy. American and European consensus statements on COVID-19 management incorporate guidelines for anticoagulation therapy in patients with COVID-19-associated VTE and are largely based on data for treatment of non-COVID-19 VTE.^{6,7} However, the natural history of PE resolution with anticoagulation in the COVID-19 population remains poorly understood. The purpose of this study was to assess the radiographic

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resolution of PE in hospitalized patients with documented COVID-19 infection and acute PE on contrast enhance chest computed tomography (CECT) and contrast this with known responses in non-COVID-19 PE patients.

METHODS

Patient selection. The MC NEWS Study (IRB No. 20-003457) is a registry of all patients affected by the COVID-19 pandemic identified within the three campuses the reporting institutions health system located in Arizona, Florida, Minnesota, and Wisconsin. Using a shared electronic medical record (Epic; Verona, WI), we identified all patients from March 11, 2020, to May 27, 2021, who tested positive for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) by polymerase chain reaction testing or serology. These dates were selected because the start of standardized polymerase chain reaction testing within our institutions, March 11, 2020, and the date of final follow-up for patients included within the study, May 27, 2021. From this cohort, any individual hospitalized because of the SARS-CoV-2 infection requiring treatment and concurrently diagnosed with an acute PE per CECT was included in this study, a total of 50 patients met these criteria. Manual chart review of 50 identified patients was performed to ensure that hospitalization was for treatment of SARS-CoV-2 infection as well as how the patient was treated for their PE. Three patients were excluded from the study (one patient underwent thrombectomy and two patients received inferior vena caval filters). Written informed consent was waived owing to the retrospective and anonymized nature of the data collection and reporting.

Imaging protocols and evaluation. There was no standardized imaging protocol for patients with SARS-CoV-2 and for whom there was a suspicion for PE; therefore, a CECT obtained for any reason as a part of clinical care was included in the study. CECT examinations were included in this study if they meet diagnostic quality by having a Hounsfield units value of greater than 250 in the lobar pulmonary arteries; this included CT pulmonary angiogram (CTPA) and CECT examinations of the chest.⁸ Cross-sectional imaging was performed using 64, 128, 256, or 384 multidetector computed tomography. CTPA were performed using a 0.6 mm collimation, 1.5 to 10.0 mm reconstruction, 12 rotation time being 0.25 to 0.50 seconds, and a 3 mm/rotation table speed using a bolus tracking threshold of 100 Hounsfield units on the pulmonary artery, using up to 100 mL of intravenous Omnipaque 300. CECT of the chest was performed using a 0.6-mm collimation, 1.5 to 10.0 mm reconstruction, rotation time of 0.5 seconds, and 3 mm/rotation table speed using a 40 second delay and 75 mL of intravenous Omnipaque 300. Both initial and follow-up CECTs were

ARTICLE HIGHLIGHTS

- **Type of Research:** Multicenter retrospective cohort study
- **Key Findings:** Computed tomography angiography demonstrated complete resolution of coronavirus disease 2019 (COVID-19)-associated pulmonary embolism at a mean of 44 days in 34 of 47 patients with COVID-19 and PE treated with anticoagulation alone. Nine of 47 patients died, 7 owing to COVID-19 infection.”
- **Take Home Message:** Anticoagulation alone is associated with a high rate of resolution of PE in patients with PE and COVID -19 infection.

reviewed independently by two board-certified radiologists (C.A.R. and J.T.S.) blinded to the original radiologist's interpretation. When indeterminate or discrepant findings arose, final interpretations were rendered as an agreement between the interpreters. All images were reviewed on a Visage PACs (Pro Medicus Limited, Australia).

The degree of thrombus burden was quantified using the Modified Miller Score (MMS) system adapted from the original Miller Scoring system for thrombus burden on diagnostic angiography.^{9,10} This score pertains to the number of pulmonary artery branches occluded by a thrombus on CECT and does not evaluate flow. Using segmental pulmonary artery anatomy (nine segments on the right, seven on the left) the presence of thrombus within a segmental artery distribution is assigned a point (Fig 1). A thrombus proximal to the segmental level was scored based on the number of downstream segmental vessels affected (an MMS of 16 could represent thrombus in all segmental arteries or saddle embolism). Subsegmental thrombus was given a score of 1 for its associated segmental vascular territory.¹ An MMS of 12 or greater is considered a very large thrombus burden and has been shown to correlate with right ventricular strain and failure.¹¹ A binomial outcome was assigned to CECT with either complete resolution (CR) or residual thrombus (RT). CR was defined as a follow-up CECT examination without evidence of thrombus; an MMS of 0. RT was defined as follow-up CECT examination with a RT burden within the original vascular territory or new thrombus burden from the prior; an MMS of greater than 0. No attempt was made to quantify the volume of RT when present or to assess for the presence of webs and strictures.

Assessment of COVID-19 severity. The quick COVID-19 severity index (qCSI) was used as to assess disease severity from the infectious stand point to justify intensive care unit (ICU) care.¹² Scores range from 0 to 12 and there are three categories measured, which include

- RMPA= Right Main Pulmonary Artery
- LMPA= Left Main Pulmonary Artery
- RUL= Right Upper Lobe
- RIL= Right Interlobar
- RML= Right Middle Lobe
- RLL= Right Lower Lobe
- LUL= Left Upper Lobe
- LIL= Left Interlobar
- LLL= Left Lower Lobe

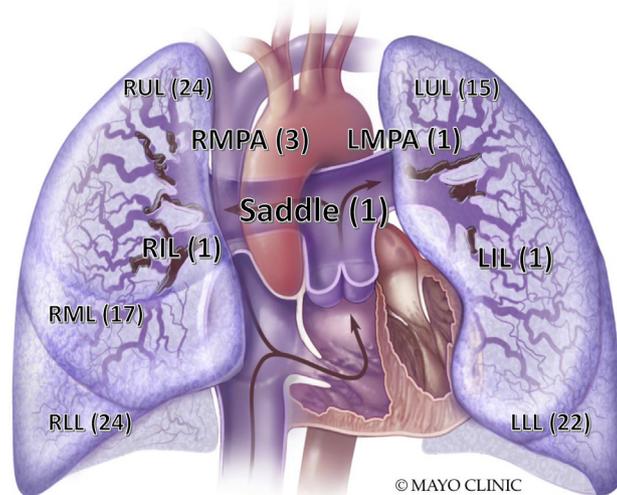


Fig 1. Graphic representation of the location of pulmonary emboli according to lobes of the lung on initial cross-sectional imaging.

respiratory rate (breaths/minute), oxygen saturation (% oxygen saturation measured by pulse oximeter) and amount of oxygen needed to maintain the oxygen saturation measured (L/minute) at the time of evaluation. A score of less than 3 is considered low risk (with an estimated 4% risk); a score between 4 and 6 is considered low to intermediate risk (with an estimated 30% risk), a score between 7 and 9 is considered high to intermediate risk (with an estimated 44% risk), and a score between 10 and 12 is considered high risk (with an estimated 57% risk) of needing invasive modes of critical illness management, such as mechanical ventilation and ICU care.

Statistical methods. Descriptive data were reported using means and standard deviations for continuous variables or as frequencies for categorical variables. Wilcoxon-Mann-Whitney test and Fisher's exact tests were performed for continuous and categorical parameters.

RESULTS

Patient characteristics. In the cohort of 6070 hospitalized patients during the study period with active COVID-19 infection, 5.7% (348/6070) were identified with an acute PE on CECT. Concurrent deep venous thrombus was identified on Doppler ultrasound examination in 34% of patients (16/47). Of these, 14.6% of patients (51/348) underwent follow-up CECT examinations and 13.5% (47/348) were of diagnostic quality for PE. The mean \pm standard deviation age of this cohort was 63 ± 16 years and 63.8% (30/47) were men. Fifty-nine percent of patients (28/47) were from Minnesota or Wisconsin, 21.3% (10/47) from Florida, and 19.1% (9/47) from Arizona. Relevant comorbidities included hypertension (57.4%), hyperlipidemia (44.7%), and coronary artery disease

(19.1%), among others (Table I). The reasons for obtaining a follow-up CECT imaging study were also recorded and included most frequently shortness of breath (29.8%) and follow-up after initial PE diagnosis (25.5%). Comorbidities and reasons for follow-up CECT are shown in Table I. Of the 47 patients, 7 (14.9%) had a history of cancer, and only one patient (2.1%) had a known history of thrombophilia (heterozygous for factor V Leiden). Forty-two percent of patients (20/47) required ICU care; their ICU length of stay and length of hospitalization was 7 ± 14 and 14 ± 19 days, respectively. The D-dimer on the day of PE diagnosis was $14,971.2 \pm 14,697.9$ mg/mL fibrinogen equivalent units. All patients were anticoagulated on the day of PE diagnosis and were discharged most often on apixaban (63.8%) with a plan for at least 3 months of anticoagulation (149 ± 95 days) (Table II). The time to follow-up imaging was 44 ± 48 days (range, 3-161 days). Nine (19%) deaths occurred within the cohort at a mean of 16.3 ± 13 days after follow-up CT (range, 6-41 days) and at a mean of 28 ± 16 days after admission (range, 11-68 days). Seven deaths (77.8%) were associated with progression of COVID-19 pneumonia. At the time of writing, none of the 47 patients within this cohort received a COVID-19 vaccination before the initial diagnosis or were vaccinated at the time of follow-up imaging.

Imaging findings. At the time of PE diagnosis, 12.8% patients (6/47) had an MMS of 12 or greater (Supplementary Table, online only). CR of PE was observed in 72.3% patients (34/47) with a mean time to follow-up CECT of 48 ± 43 days (range, 6-239 days). RT was seen in 21.3% (10/47) with a mean time to follow-up of 15 ± 13 days (range, 2-49 days; $P = .44$). Twenty-two patients received follow-up imaging in less than 28 days, of which 11 patients had CR of PE (50%). Eight deaths occurred within the cohort

Table I. Demographics and typical comorbidities of our cohort with pulmonary embolism (PE) and follow-up imaging

Characteristic	No. or mean \pm standard deviation
Male sex	30 (63.8)
Age (years)	63 \pm 16
Medical comorbidities	
Hypertension	27 (57.4)
Hyperlipidemia	21 (44.7)
Coronary artery disease	9 (19.1)
Smoker	9 (19.1)
History of cancer	7 (14.9)
Congestive heart failure	6 (12.8)
Diabetes mellitus	6 (12.8)
Chronic obstructive pulmonary disease	5 (10.6)
Ischemic stroke	4 (8.5)
Atrial fibrillation	3 (6.4)
Chronic kidney disease	3 (6.4)
Peripheral vascular disease	2 (4.3)
Thrombophilia	1 (2.1)
Reason to obtain repeat cross-sectional imaging	
Shortness of breath	14 (29.8)
Follow-up after initial PE diagnosis	12 (25.5)
New oxygen requirement	5 (10.6)
Rising D-dimer	5 (10.6)
Chest pain	3 (6.4)
Reevaluation owing to enlarged lymph nodes, unwitnessed fall, elevated white blood cell count, cancer assessment, refractory hypoxemia, evaluation of pulmonary infiltrate, spontaneous pneumothorax	8 (17.0)

during this time interval, of which six patients had CR of their PE (75%). Twenty-five patients received follow-up imaging after 28 days, of which 23 patients had CR of PE (92%). One death occurred within the cohort during this time interval: CR was seen at day 41 of follow-up. Four patients (8.5%) had a new or increased thrombus burden, identified on follow-up days 9, 20, 41, and 121 with a mean time to follow-up of 47.8 ± 30.5 days (range, 9-121 days) (Supplementary Fig, online only). These four individuals included one patient with apixaban breakthrough who was switched to warfarin therapy; two patients with subtherapeutic coumadin therapy, who were switched to apixaban; and the fourth patient, who had most likely continued PE formation from the initial PE diagnosis owing to worsening respiratory symptoms as a

Table II. Hospitalization data on our cohort with pulmonary embolism (PE) and follow-up imaging

Data point	No. (%) or mean \pm standard deviation
Need of ICU care	20 (42.6)
Length of ICU care, days	7 \pm 14
Length of hospitalization, days	14 \pm 19
Days from SARS-CoV-2 diagnosis to initial cross-sectional imaging, days	4.9 \pm 7.5
D-Dimer on day of PE diagnosis, ng/mL fibrinogen equivalent units	14971.2 \pm 14697.9
Length of in-hospital anticoagulation treatment before discharge, days	12.8 \pm 18.0
Treatment modality at discharge/death	
Apixaban	30 (63.8)
Warfarin	6 (12.8)
Heparin ^a	5 (10.6)
Rivaroxaban	4 (8.5)
Enoxaparin	2 (4.3)
Mean oral anticoagulation therapy, days	149 \pm 95
Initial MMS at the time of PE diagnosis	4.8 \pm 4.2
MMS on follow-up cross sectional imaging	1.4 \pm 3.3
Mean follow-up time to second cross-sectional imaging study, days	44 \pm 48
Mean follow-up time to second cross-sectional imaging study in patients, who experienced CR of PE, days	48 \pm 43
Mean follow-up time to second cross-sectional imaging study in patients, who experienced PR of PE, days	24 \pm 30
Deaths owing to COVID-19 infection	7 (77.8)

COVID-19, Coronavirus disease 2019; CR, complete resolution; ICU, intensive care unit; MMS, Modified Miller Score; PR, partial resolution; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.
^aFour expired patients and one patient, who continues to be hospitalized by the time of article submission.

result of COVID-19 infection while on apixaban. The mean initial MMS was 4.8 ± 4.2 (range, 1-14) and the mean MMS on follow-up imaging was 1.4 ± 3.3 (range, 0-16; $P < .0001$). The most frequent areas of involvement were the right lower lobe segmental pulmonary arteries at the time of initial PE diagnosis (Fig 1). A typical example of resolution of PE is demonstrated in Fig 2.

Patients requiring ICU versus no ICU care. Of these 47 patients, 7 required ICU care (42.6%). There was no

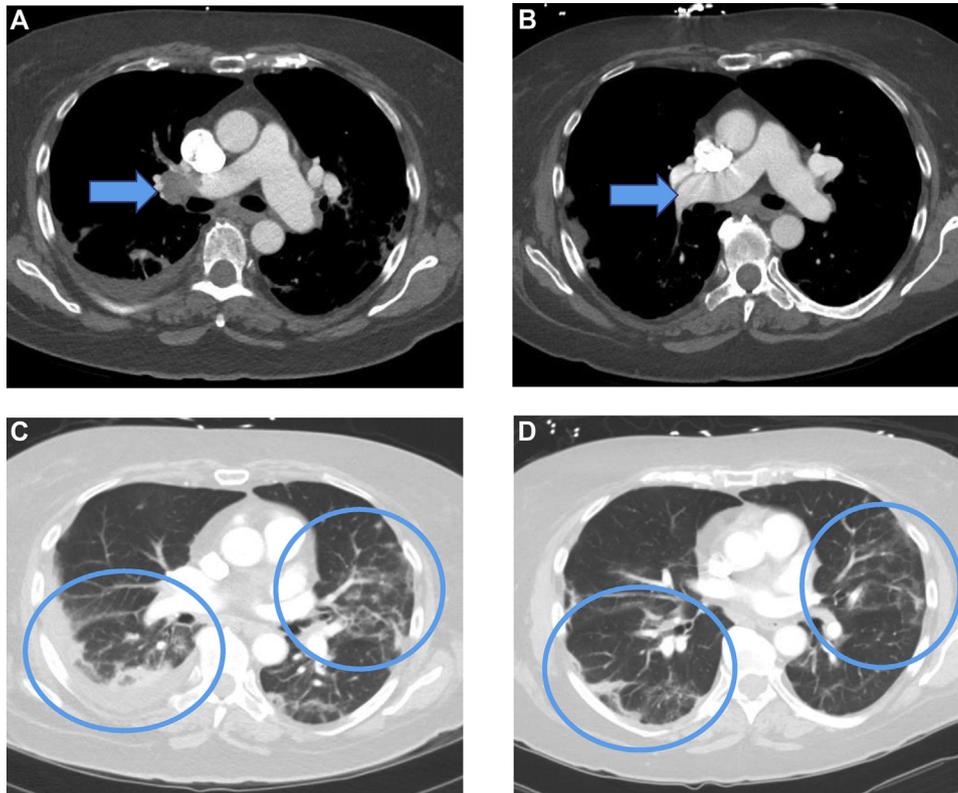


Fig 2. Axial cuts of a computed tomography angiography on a hospitalized patient with coronavirus disease 2019 (COVID-19) infection demonstrating: **(A)** the presence of pulmonary embolism (PE) (blue arrow) and **(B)** resolution of PE (blue arrow) on follow-up imaging 21 days later after the initiation of anticoagulation therapy; **(C)** lung window demonstrating degree of parenchymal disease owing to COVID-19 infection (blue circle) and **(D)** improvement of parenchymal disease on follow-up imaging (blue circle).

difference in the MMS at the time of diagnosis for PE (mean MMS, 4.0 ± 3.9 vs 5.5 ± 4.4 ; $P = .23$) and on follow-up imaging (mean MMS, 1.1 ± 2.8 vs 1.6 ± 3.6 ; $P = .61$) between those individuals who required ICU versus no ICU care ($n = 27$). There was also no difference in the proportion of deaths in each group (10.6% vs 4.3%; $P = .12$). However, the qCSI was different among groups who required ICU care versus those who did not (mean qCSI, 5.9 ± 3.7 vs 2.5 ± 3.4 ; $P = .0021$); which correlates with the

infectious disease burden in those individuals with already a PE diagnosis (Table III).

Comparison between the cohort with follow-up CECT and the entire PE group. Within the initial cohort diagnosed with PE, 33.9% required ICU care as opposed to 42.6% of the follow-up CECT cohort ($P = .41$). In addition, the number of deaths within each cohort was also similar (13.3% vs 12.8%, $P = 1.00$). Lastly, the number of

Table III. Comparison among patients hospitalized with coronavirus disease 2019 (COVID-19) in need of intensive care unit (ICU) care versus not

	No ICU care (n = 27)	ICU care (n = 20)	P value ^a
Initial MMS	5.5 ± 4.4	4.0 ± 3.9	.23
Final MMS	1.6 ± 3.6	1.1 ± 2.8	.61
Final CR	20 (42.6)	15 (31.9)	.99
Quick COVID-19 severity score	2.5 ± 3.4	5.9 ± 3.7	.0021
D-Dimer at diagnosis, ng/mL fibrinogen equivalent unit	$12,367.6 \pm 13,999.2$	$18,397.1 \pm 14,891.4$.16
Deaths	2 (4.3)	5 (10.6)	.12

CR, Complete resolution; MMS, Modified Miller Score.

Values are mean \pm standard deviation or number (%).

^aTests for comparison between the dead and alive groups were Mann-Whitney U and Fisher's exact tests for continuous and categorical parameters, respectively.

Table IV. Comparison among patients with follow-up contrast-enhanced computed tomography (CECT) imaging and those patients within the initial pulmonary embolism (PE) cohort

	Patients with follow-up CECT (n = 47)	Patients with PE-patients with follow-up CECT (n = 301)	P value ^a
Need for ICU care	20 (42.6)	102 (33.9)	0.41
Patients with diagnosed deep venous thrombosis	10 (21.3)	54 (17.9)	0.55
Deaths	6 (12.8)	40 (13.3)	.99

Values are number (%).
^aTests for comparison between the dead and alive groups were Mann-Whitney U and Fisher's exact tests for continuous and categorical parameters, respectively.

patients affected with deep venous thrombosis in each cohort was again similar (17.9% vs 21.3%; $P = .55$) (Table IV).

DISCUSSION

This study identified 47 patients with PE in a cohort of hospitalized COVID-19 patients who also underwent follow-up CTCE. Seventy-two percent had resolution of PE with anticoagulation alone at a mean of 44 days. The thrombus burden using the MMS did not correlate with the need for ICU care ($P = .23$) or increased mortality ($P = .072$). In 2010, Stein et al¹³ described complete thrombus resolution in 81% of their cohort of 69 patients with non-COVID-related PE. Within this cohort, those who received follow-up after 28 days had a 75% resolution with an overall mean time to follow-up of 83 days (range, 29-290 days).¹³ Our study, analogous to the study design by Stein et al, demonstrated a higher rate of rate of thrombus resolution after 28 days (92%) at a mean time to follow-up of 74 days (range, 29-161 days), but a similar overall complete resolution for the cohort (72.3% vs 81.0%). A prospective multicenter study using CTPA to evaluate response to anticoagulation therapy by den Exter et al¹⁴ reported a recurrent PE rate of 10.4%, similar to the observation of increased thrombus burden on follow-up scan of 8.5% observed in the present study.

COVID-19 is associated with a hypercoagulable state¹⁵ with active inflammatory cytokines that seem to contribute to mortality in critically ill patients.¹⁶ Both a fibrinolytic shutdown and the formation of antiphospholipid antibodies have been described in COVID-19-associated PE.¹⁷⁻²⁰ The incidence of VTE in patients hospitalized with COVID-19 infection has been reported to be 9%³ and as high as 27% in those requiring ICU care.² Although non-COVID-19 PEs most likely originate as deep venous thrombosis, the pathophysiology of COVID-19-associated PE is incompletely understood.²¹ Even though COVID-19-associated PE may be the sequelae of VTE, thrombosis in situ or immunothrombosis are also considered a possible source.¹ Immunothrombosis is attributed to endothelial cell dysfunction cytokine storm and/or macrophage activation syndrome potentiating the coagulation cascade.²² Both entities

have been reported in COVID-19 patient autopsies, findings not yet described in non-COVID-associated PE.^{22,23} Currently, there is no routine clinical method to differentiate between VTE and immunothrombosis as the source for PE in COVID-19 patients. The ability to differentiate the mechanism of PE may be useful for guiding therapy. Furthermore, the optimal type and duration of anticoagulation therapy for patients with COVID-19-associated PE has yet to be investigated in randomized controlled trials.

Current treatment algorithms for COVID-19 anticoagulation duration are not formalized and currently modeled on the management of provoked non-COVID-19-associated VTE, leading to treatment recommendations of 3 months, minimum.²⁴⁻²⁷ Extrapolating the time course of thrombus resolution with anticoagulation in COVID-19-associated PE from other populations may be flawed; however, our data demonstrate that this assumption may be sound and warrants further evaluation.

Limitations. The limitations of this study include the small sample size and retrospective observational analysis. The retrospective design required limiting our review to cases where the follow-up imaging was triggered by clinical indication and thus follow-up imaging was not done in 86% of the cases and not at regular intervals, which leads to selection bias. Furthermore, it is important to emphasize that the rate of infection during our study period is also lower than the current number of patients infected by this virus. Additionally, there were no standardize anticoagulation treatment protocols or recommendations across the multiple sites. A prospective study with serial follow-up imaging at defined time-points would best define resolution times and optimization of treatment. A larger sample size would potentially facilitate predictive modeling for thrombus resolution to personalize treatment duration as well as assessing if initial thrombus burden is predictive of outcomes.

CONCLUSIONS

Hospitalized patients with COVID-19 have a clinically apparent 5.7% rate of PE. In patients with follow-up

imaging, 72.3% had radiographic thrombus resolution at a mean of 44 days while on anticoagulation, similar to non-COVID-19-associated PE resolution. Given the limitations of this study, prospective investigation with systematic CECT follow-up and standardized anticoagulation protocols are needed to more definitively characterize resolution of COVID-19-associated PE and to define treatment protocols that promote resolution of COVID-19-associated PE.

AUTHOR CONTRIBUTIONS

Conception and design: CRit, MJ, JS, HI, BT, RPF, SM, PG, HB, CRiv, MS, PMF, DS, CM, RM, MP, JO, JM, YE

Analysis and interpretation: CRit, YE

Data collection: SF, CFM

Writing the article: CRit, YE

Critical revision of the article: CRit, MJ, JS, HI, BT, RPF, SM, SF, CFM, PG, HB, CRiv, MS, PMF, DS, CM, RM, MP, JO, JM, YE

Final approval of the article: CRit, MJ, JS, HI, BT, RPF, SM, SF, CFM, PG, HB, CRiv, MS, PMF, DS, CM, RM, MP, JO, JM, TE

Statistical analysis: Not applicable

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Overall responsibility: CRit, YE

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Supplementary Table (online only). Modified Miller Score (MMS) at the time of diagnosis and follow-up of pulmonary embolism (PE)

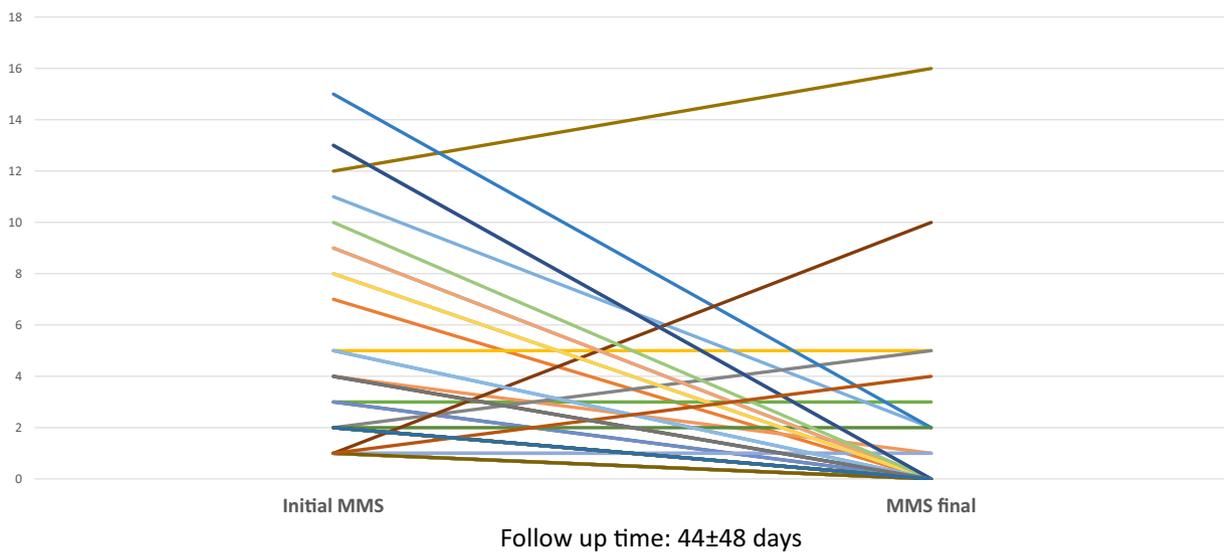
Patient	Initial MMS	Thrombus distribution	MMS final	Thrombus distribution	Outcome
1	14	RUL (3), RML (2), RLL (4), LUL (2), LLL (3)	12	RUL (3), RML (1), RLL (4), LUL (2) LLL (2)	RT
2	7	RLL (1), LLL (3), LUL (3)	0	No thrombus	CR
3	1	RUL (1)	1	RUL (1)	RT
4	5	RUL (1), RML (1), RLL (3)	5	RUL (1), RML (1), RLL (3)	RT
5	5	RUL (2), RLL (3)	0	No thrombus	CR
6	3	RML (1), RLL (2)	3	RML (1), RLL (2)	RT
7	1	RUL (1)	0	No thrombus	CR
8	3	RUL (3)	0	No thrombus	CR
9	1	RLL (1)	0	No thrombus	CR
10	12	Right main PA (9), LLL (3)	16	Saddle (16)	RT
11	2	RUL (2)	0	No thrombus	CR
12	13	Right main PA (9), LUL (2), lingula (2)	0	No thrombus	CR
13	3	RUL (1), LLL (2)	0	No thrombus	CR
14	4	RUL (3), LUL (1)	1	RLL (1)	RT
15	1	LLL (1)	0	No thrombus	CR
16	2	RLL (2)	0	No thrombus	CR
17	11	RUL (3), RML (1), RLL (4), LUL (1), LLL (2)	2	LLL (2)	RT
18	2	RLL (2)	0	No thrombus	CR
19	1	LUL (1)	0	No thrombus	CR
20	4	LUL (4)	0	No thrombus	CR
21	2	RLL (2)	5	RLL (2), LLL (2), RUL (1)	RT
22	2	RLL (2)	0	No thrombus	CR
23	15	RUL (3), RML (2), RLL (4), LUL (4), LLL (2)	2	RLL (2)	RT
24	2	LLL (2)	2	LLL (2)	RT
25	1	RLL (1)	1	RLL (1)	RT
26	1	RUL (1)	0	No thrombus	CR
27	4	RLL (4)	0	No thrombus	CR
28	8	RUL (2), RML (2), RLL (4)	0	No thrombus	CR
29	8	RUL (2), RML (2), LUL (4)	0	No thrombus	CR
30	1	LLL (1)	0	No thrombus	CR
31	2	RUL (2)	0	No thrombus	CR
32	1	RLL (1)	10	Right Main (9), LLL (1)	RT
33	4	RML (1), RLL (2), LLL (1)	0	No thrombus	CR
34	1	RLL (1)	0	No thrombus	CR
35	2	RUL (1), RLL (1)	0	No thrombus	CR
36	2	RLL (2)	0	No thrombus	CR
37	9	RLL (4), LUL (4), LLL (1)	0	No thrombus	CR
38	9	RLL (4), left interlobar (5)	0	No thrombus	CR
39	13	RUL (3), RLL (4), LUL (3), LLL (3)	0	No thrombus	CR
40	8	RML (2), LUL (4), LLL (2)	0	No thrombus	CR
41	5	RML (2), RLL (2), LLL (1)	0	No thrombus	CR
42	10	RUL (2), RLL (2), LUL (4), LLL (2)	0	No thrombus	CR

(Continued on next page)

Supplementary Table (online only). Continued.

Patient	Initial MMS	Thrombus distribution	MMS final	Thrombus distribution	Outcome
43	13	Right interlobar (6), left main PA (7)	0	No thrombus	CR
44	1	RLL (1)	4	RUL (1), RML (2), RLL (1)	RT
45	4	RML (1), RLL (2), LLL (1)	0	No thrombus	CR
46	2	RML (1), RLL (1)	0	No thrombus	CR
47	2	RLL (2)	0	No thrombus	CR

CR, Complete resolution of PE; LUL, left upper lobe; PA, pulmonary artery; RLL, right lower lobe; RML, right middle lobe; LLL, left lower lobe; RT, residual thrombus (partial resolution of original thrombus or new thrombus); RUL, right upper lobe.



Supplementary Fig (online only). Relationship between the initial Modified Miller Score (MMS) and the MMS on subsequent follow-up cross-sectional imaging.