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HEPATOBILIARY

CT angiography of abdomen and pelvis in critically ill COVID-19 patients: imaging findings and correlation with the CT chest score

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Abstract

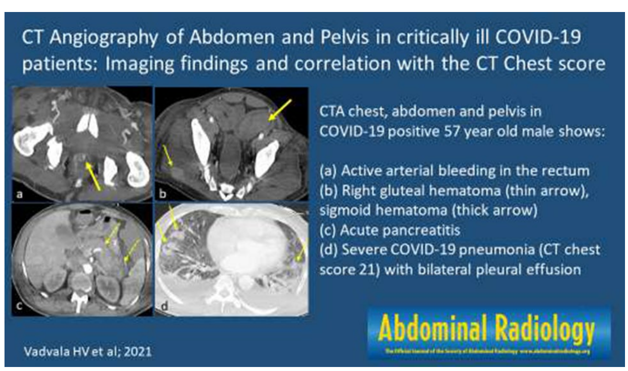
Purpose To assess the spectrum of computed tomography angiogram (CTA) abdominal and pelvic findings in critically ill COVID-19 patients and investigate correlation with CT chest scores.

Methods An IRB approved retrospective study of CTA of the chest, abdomen and pelvis between dates March 1st to September 15th, 2020 was performed in the hospitalized COVID-19 positive patients. CTA studies of solely the chest were excluded. Medical record review was performed to note patient demographics, CTA scan details and coagulation profile. CTA findings were reviewed to record vascular and non-vascular findings. CT chest was reviewed to calculate CT chest score. Logistic regression analyses were performed to correlate CT chest scores with odds of vascular and other abdomen–pelvis findings. A $p < 0.05$ was considered statistically significant.

Results A total of 45 consecutive hospitalized COVID-19 positive patients with 61 years mean age and M:F (2:1) gender ratio were evaluated, out of which majority 68.9% ($n = 31$) had CTA chest, abdomen and pelvis. The most common vascular findings were hematoma 46.7% ($n = 21$), active extravasation 24.4% ($n = 11$) and vascular occlusion 17.8% ($n = 8$). Higher CT chest scores were significantly associated with hematoma/extravasation (OR 1.19, 95% CI 1.07–1.34, $p < 0.01$). The most common non-vascular abdomen–pelvis findings were seen in organs gallbladder 20% ($n = 9$), liver 20% ($n = 9$) followed by kidney 15.6% ($n = 7$). Higher CT chest scores were significantly associated with bowel findings (OR 1.28, 95% CI 1.01–1.63, $p < 0.05$) and cholestasis (OR 13.3, 95% CI 1.28–138.9, $p < 0.05$).

Conclusion Patients with moderate to severe COVID-19 pneumonia have significantly higher rate of vascular complications in the abdomen and pelvis.

Graphic Abstract



Keywords CT angiography of abdomen and pelvis · COVID-19 · CT chest score · Critically ill patients

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Introduction

The coronavirus disease 2019 (COVID-19) pandemic is an unprecedented global healthcare crisis. SARS-CoV-2 is a highly infectious virus not only responsible for severe lower respiratory tract infection but also has high propensity for distinct coagulation disorders [1]. Severe COVID-19 is often complicated by coagulopathies such as venous thromboembolism (VTE) and disseminated intravascular coagulation, especially in patients admitted to intensive care unit (ICU) [2]. The reported incidence of VTE in these patients ranges from 21 to 69% with high mortality (40%) in absence of prophylactic anticoagulation [2–5]. Hence COVID-19 patients with abnormal coagulation profile including markedly elevated D-dimer are routinely on prophylactic anticoagulation (e.g., low molecular weight heparin {LMWH}) due to better prognosis [6]. However, the bleeding risks associated with anticoagulation are well-established and warrant close clinical monitoring in these patients [7–9]. Therefore, it becomes important to perform imaging assessment to evaluate for possible vascular complications secondary to COVID-19 infection itself as well as anticoagulation. It is known that symptomatic patients with high viral load of COVID-19 have higher rates of systemic and vascular complications [4]. Several case reports in the literature have depicted imaging findings of intra-abdominal bleeding complications in COVID-19 patients [10–12]. Prior studies evaluating abdomen–pelvis findings in COVID-19 have shown associations with lower hemoglobin and small vessel thrombosis with possible correlation with hospitalized patients [13, 14]. However, a gap in the literature exists to depict association between severity of COVID-19 pneumonia and findings of abdomen–pelvis and blood vessels.

The aim of our study is to assess the spectrum of computed tomography angiography (CTA) abdomen and pelvis findings in critically ill COVID-19 patients and to correlate the vascular findings with the severity of pneumonia. To our knowledge, this is the first original study depicting vascular complications on body CTA of critically ill COVID-19 patients correlating with CT chest score.

Materials and methods

Patient eligibility

This retrospective HIPPA-compliant study was approved by the Institutional Review Board (IRB) and an informed consent was waived. An electronic medical record (EMR) search of COVID-19 patients who underwent CTA chest, abdomen and pelvis (CAP) or CTA abdomen and pelvis (AP) studies was performed within the institutional database.

Inclusion criteria were: Adult patients (≥ 18 years) with diagnosis of COVID-19 who had undergone a CTA CAP or AP study. In patients with multiple studies, only the first relevant study was included in the analysis. Exclusion criteria were: Studies performed prior to the diagnosis of COVID-19 and more than 3 months later to first COVID-19 positive laboratory report, or performed on asymptomatic patients in the ambulatory setting for pre-existing non-emergent conditions.

EMR review was performed to note patient demographics, date of COVID-19 positive test, date of study, indication of study, location of admitted patients, ventilator use and coagulation profile including anticoagulation agent(s), if used.

Image acquisition

CTA CAP and AP studies were scanned with SOMATOM Sensation 64 slice helical CT scanner or SOMATOM Definition Flash 128 slice helical CT scanner, Siemens Healthineers, Forchheim, Germany. Same CTA protocols were used for 64 and 128 slice CT scanners. A dual phase scan following intravenous power injection of 100–120 mL Omnipaque 350 or Visipaque 320 IV contrast dye (based on patient weight) at the rate of 4–5 mL/s was done for all the CTA scans acquiring arterial phase at 25–30 s and portal venous phase at 50–70 s. Whenever possible, water (as a negative contrast) was given per orally to obtain luminal distention of the stomach and small bowel. A reconstruction of 3 mm thick axial slices and 0.75 mm thin axial slices was performed for both the arterial and venous phases. The reconstruction kernel used for soft tissue was B20f and for lungs was B80f.

Post processing was performed to obtain coronal and sagittal reformats as well as vascular mapping using 3D MIP and volume rendering (VR).

Image analysis

The review of all CTA studies and calculations of CT chest score was done independently by 2 experienced body imaging subspecialized radiologists, HV and RG, both with 8 years of experience reading body CTA studies. All the studies were reviewed on Carestream PACS software (Carestream Health, Inc., NY) and graphics tool of caliper and ROI was used for any measurements if needed. The study indications were divided into three categories: general (evaluate for source of bleed, sepsis or ischemia), chest related (shortness of breath, chest pain, pulmonary embolism and hypoxia) and abdomen–pelvis related (abdominal pain, gastrointestinal bleed, bowel ischemia and nausea/vomiting/

diarrhea). The following findings were recorded on the CTA images: presence of hematoma, active contrast extravasation, vascular thrombosis or occlusion, GI tract involvement (ileus, ischemia, pneumatosis, perforation or bowel wall thickening), hepatobiliary involvement (hepatitis, hepatic infract, cholestasis, biliary ductal dilation, acute cholecystitis), splenic involvement (infarct, hematoma), genitourinary tract involvement (renal infract, hydronephrosis, pyelonephritis, cystitis, hemorrhage), pancreatitis, musculoskeletal involvement (hematoma, myositis) and other miscellaneous findings (fluid collections, free air).

CT chest findings were reviewed to deduce a score based on extent of lung involvement by COVID-19 pneumonia defined as "CT chest score" in patients who had CTA CAP according to previously published data [15, 16]. All five lung lobes were individually scored on a scale of 0 to 5: score of 0 for no lung involvement, 1 for less than 5%, 2 for 5–25%, 3 for 26–50%, 4 for 51–75% and 5 for more than 75% involvement. The sum of scores of all 5 lobes with a range between 0 (no lung involvement) and 25 (maximum lung involvement) was calculated as the final "CT chest score" for that patient. In patients with only CTA AP, the CT chest findings were recorded on the available CT chest study performed within 1 week range of the CTA AP study.

Statistical analysis

STATA statistical software (version 1.51, STATA corp) was used to perform all the analysis. A combination of non-parametric and parametric testing was performed. Summary statistics were completed, followed by Chi squared analysis to investigate associations between patient demographics, vascular and non-vascular findings, type of CTA study, and CT chest scores. Two-sided *T*-testing was conducted to assess differences in CT chest score by presence of vascular findings. Logistic regression was then performed examining abdomen–pelvis vascular and non-vascular findings, CT chest scores and outcomes such as patient death. A $p < 0.05$ was considered statistically significant.

Results

Patient demographics

The initial search of institutional database yielded 41 studies with CTA CAP and 43 studies with CTA AP. Other search data including sole CTA chest studies ($n = 442$), CT CAP studies ($n = 139$) and CT AP studies ($n = 288$) were not included in this analysis. Due to repeat imaging in the same patients 18 studies were excluded. An additional 21 studies were excluded as they were performed before the diagnosis of COVID-19 ($n = 9$), 3 months after diagnosis of COVID-19 ($n = 6$), or were performed for unrelated or pre-existing non-emergent condition (n = 6).

The details of patient demographics and CTA study type are shown in Table 1. A total of 45 consecutive CTA studies of patients with median age of 61 years (range 26–88 years) and gender ratio of 2:1 for male and female (30 male, 15 female) were included in the analysis. Thirty-one patients underwent CTA CAP, 9 patients underwent CTA AP, 3 patients underwent CTA AP with extremity runoff, and 2 patients underwent CTA CAP with extremity runoff. A total of 55.5% patients were admitted to ICU at time of the CT scan, 40% were intubated and 20% had subsequently deceased. Patients presented with multiple indications as detailed in Supplementary Table S1. The most common indication was to evaluate for any source of bleeding, followed by abdominal pain and shortness of breath.

CT angiography and vascular findings

A total of 21 patients (46.7%) had hematomas at common locations including retroperitoneum, abdominal wall, gluteal regions and upper thigh. Involvement of the

Table 1 Patient demographics and CTA study type

Patient	CTA study				
	Chest abdomen–pelvis	Abdomen–pelvis	Abdomen–pelvis with runoff	Chest abdomen–pelvis with runoff	Total
Patient number (%)	31 (68.9)	9 (20.0)	3 (6.7)	2 (4.4)	45 (100.0)
Mean age (years)	60	63	57	63	61
Male (%)	20 (64.5)	6 (66.7)	3 (100)	1 (50)	30 (66.7)
Unit location (%)					
ICU	19 (61.3)	4 (44.4)	1 (33.3)	1 (50.0)	25 (55.5)
Floor	6 (19.3)	4 (44.4)	2 (66.7)	0 (0.0)	12 (26.7)
ED	6 (19.3)	1(11.1)	0 (0.0)	1 (50.0)	8 (17.8)
Ventilator use (%)	12 (38.7)	3 (33.3)	2 (66.7)	1 (50.0)	18 (40.0)
Patient death (%)	7 (22.5)	1 (11.1)	0 (0.0)	1 (50.0)	9 (20.0)

Table 2 Summary of CTA study type and imaging findings

Findings	CTA Study				
	Chest abdomen–pelvis	Abdomen–pelvis	Abdomen–pelvis with runoff	Chest abdomen–pelvis with runoff	Total (%)
Mean CT chest score	11	14	19	14	12
Vascular findings (%)					
Hematoma	13 (41.9)	5 (55.6)	1 (33.3)	2 (100.0)	21 (46.7)
Vascular extravasation	5 (16.1)	4 (44.4)	1 (33.3)	1 (50.0)	11 (24.4)
Occlusion	7 (22.6)	1 (11.1)	0	0	8 (17.8)
Abdomen–pelvis findings (%)					
GI tract	2 (6.5)	3 (33.3)	0	0	5 (11.1)
Liver	6 (19.4)	3 (33.3)	0	0	9 (20)
Cholestasis	7 (22.6)	2 (22.2)	0	0	9 (20)
Pancreas	1 (3.2)	1 (11.1)	0	0	2 (4.4)
Kidney	5 (16.1)	2 (22.2)	0	0	7 (15.6)
Spleen	1 (3.2)	1 (11.1)	0	0	2 (4.4)
Total (%)	31 (68.9)	9 (20.0)	3 (6.7)	2 (4.4)	45 (100.0)

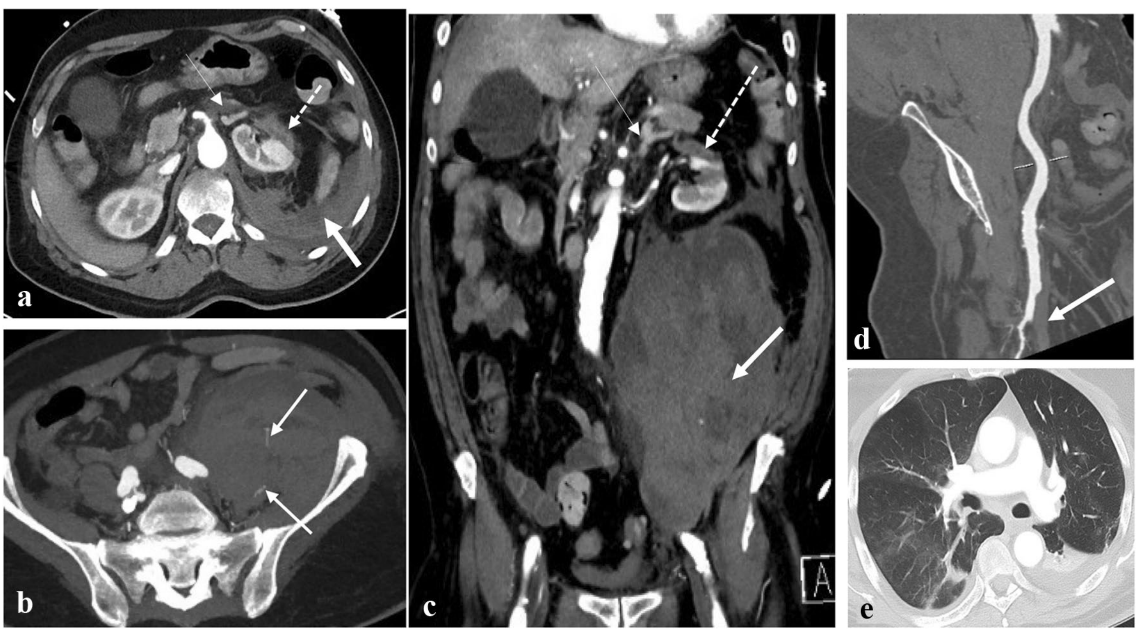

Fig. 1 Sixty-four year old male with large retroperitoneal hematoma. Axial and coronal CTA arterial phase image **a**, **c** show large left retroperitoneal hematoma (thick arrow) involving the left iliopsoas muscle and extending to pelvis. Note left renal infract (**c**, dashed arrow) and hyperenhancing left adrenal gland (**c**, thin arrow) suggestive of shock. Axial MIP image **b** shows active arterial extravasation within the left retroperitoneal hematoma (arrows). CTA arterial phase curved planar reconstruction (CPR) image **d** shows thrombotic occlusion of left superficial femoral artery (thick arrow). CT chest lung window **e** shows moderate COVID-19 pneumonia (CT chest score 14) with mild left pleural effusion and compressive atelectasis

musculoskeletal system seen in 17 patients (37.8%) (Table 2, Figs. 1, 2, 3, 4 and 5). Active vascular extravasation was seen in 11 patients (24.4%) (Figs. 1 and 5). Out of 8 patients with vascular occlusion, arterial thrombosis was seen in 3 patients: one with internal iliac and superficial femoral artery thrombus, one with common iliac artery thrombus, and one with superficial femoral artery thrombus (Fig. 1). Arterial pseudoaneurysms were seen in 3 patients including one within the abdominal wall, one involving right common femoral artery and one patient with mycotic aneurysms of both descending thoracic aorta and left pulmonary artery (Fig. 6).

Through logistic regression, higher CT chest scores were significantly associated with increased odds of

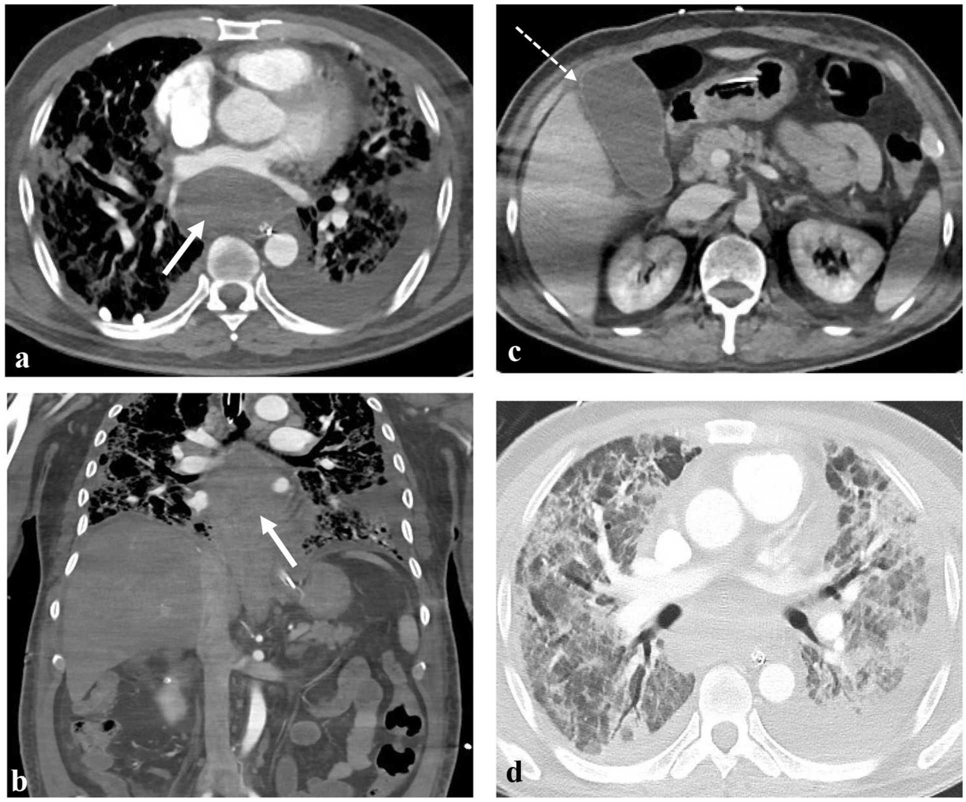

Fig. 2 Sixty year old male with large posterior mediastinal hematoma. Axial and coronal CTA arterial phase images **a**, **b** shows a large posterior mediastinal hematoma (arrow) extending to upper abdomen. Axial venous phase image **c** of abdomen shows distended gall bladder indicative of cholestasis (dashed arrow). CT chest lung window **d** shows severe COVID-19 pneumonia (CT chest score 25) and bilateral pleural effusion

Fig. 3 Sixty year old male with large left gluteus hematoma. Axial arterial phase **a** and coronal venous phase **c** images show a large left gluteus hematoma (thick arrow). Axial and coronal venous phase **b**, **c** show left renal cortical infracts (dashed arrow). CTA of chest **d** shows a right lower lobar pulmonary embolism and lung window **e** shows moderate COVID-19 pneumonia (CT chest score 15)

hematoma or extravasation (OR 1.19, 95% CI 1.07–1.34, $p < 0.01$) (Table 4). This association was also found when comparing CT chest score categories, where patients with moderate (11–17) or severe (18–25) scores were 6.22 or 21.0 times more likely to have hematoma or extravasation versus patients with mild (0–10) scores (Table 4). There was a non-significant association between CT chest scores and odds of vascular occlusion (moderate: $p = 0.47$; severe: $p = 0.31$) (Table 4).

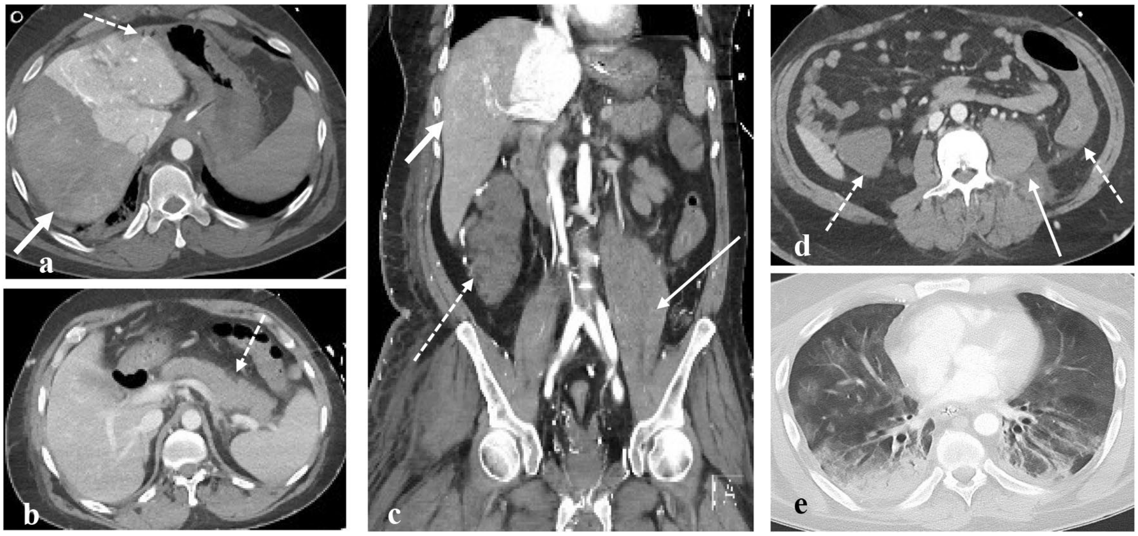

Fig. 4 Forty-nine year old male with multi-organ involvement. Arterial phase axial and coronal CTA **a**, **c** shows hypoperfusion of right lobe of liver concerning for infraction (thick arrow). Note portal venous gas (**a**, dashed arrow), left psoas hematoma (**c** and **d**, thin arrow) and colonic wall thickening concerning for ischemia (**c** and **d**, dashed arrow). Venous phase axial images (**c**) shows peripancreatic fat stranding suggestive of acute pancreatitis (**b**, dashed arrow). CT chest lung window (**e**) shows severe bilateral COVID-19 pneumonia (CT chest score 21)

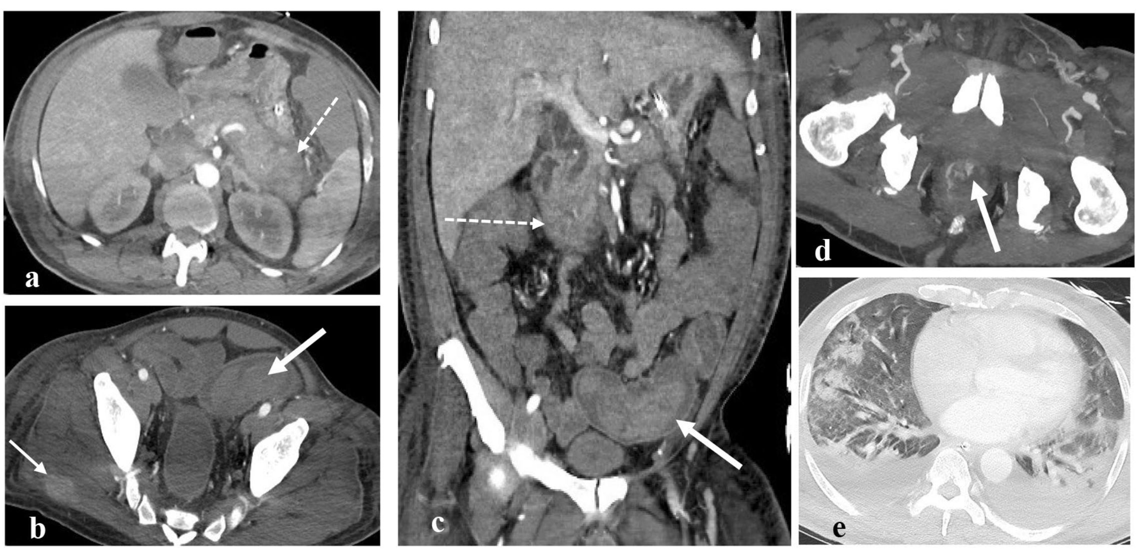

Fig. 5 Fifty-seven year old male with active arterial extravasation in the rectum. Arterial phase axial image of abdomen (**a**), axial image of pelvis (**b**) and coronal image (**c**). Diffuse pancreatic swelling with fat stranding (**a**, **c**) consistent with acute pancreatitis (dashed arrow), large intraluminal hematoma within the sigmoid colon (**b**, **c** thick arrow) and small right gluteus hematoma (**b**, thin arrow). Axial MIP image of pelvis **d** shows active arterial extravasation within the rectum (thick arrow). CT chest lung window **e** shows severe COVID-19 pneumonia (CT chest score 21) and bilateral pleural effusion

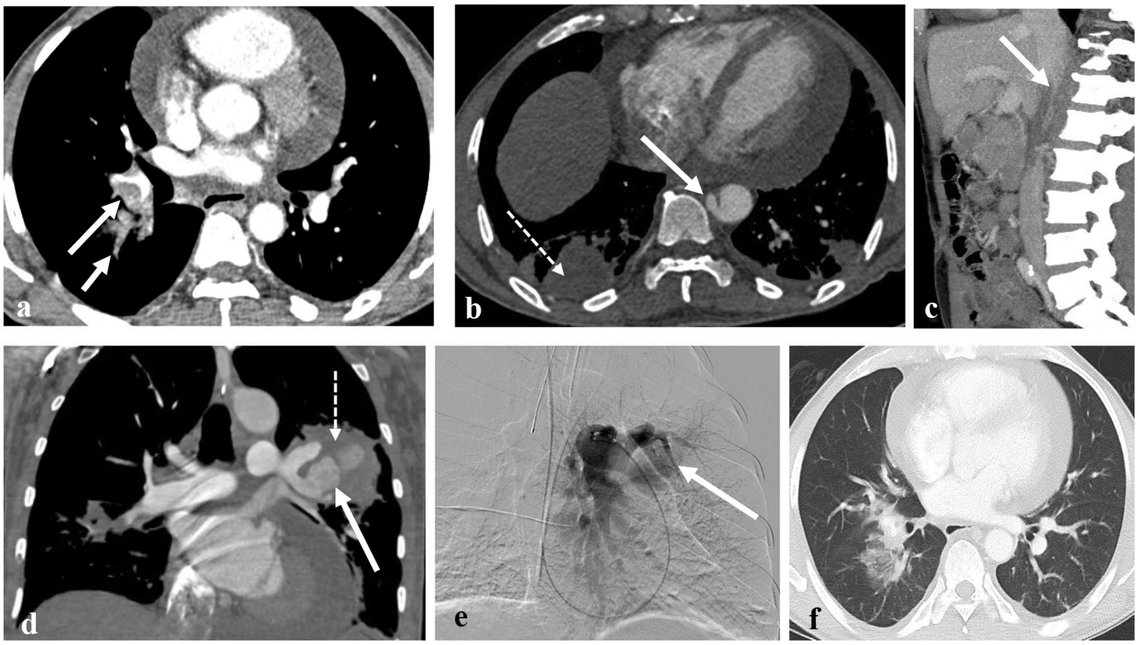

Fig. 6 Fifty-two year old male with mycotic pseudoaneurysms. Axial CTA image **a** shows right lower lobar and segmental pulmonary emboli (arrows). Note pseudoaneurysm arising from descending thoracic aorta (**b**, arrow) and right lower lobe pulmonary infarct (**b**, dashed arrow). Sagittal MIP image **c** shows partially occlusive infrahepatic IVC thrombus (arrow). Follow up coronal CTA **d** performed after 17 days shows a large pseudoaneurysm arising from left upper lobe segmental pulmonary artery (arrow) with associated pulmonary hemorrhage (dashed arrow) confirmed on Pulmonary Angiography **e**. CT chest lung window **f** shows mild COVID-19 pneumonia (CT chest score 4)

CT abdomen and pelvis non-vascular findings

Nine patients (20%) had evidence of cholestasis including dilatation of the biliary system and gall bladder (Table 2). Acute pancreatitis was seen in 2 patients and acute cholecystitis was seen in one. Hepatic involvement included presence of hepatomegaly ($n=4$), hepatitis ($n=2$), hepatic infract ($n=1$) and periportal edema ($n=2$). Renal involvement included segmental renal infarcts ($n=2$), swollen hypoenhancing kidneys ($n=3$) and pyelonephritis ($n=2$). Two patients had splenomegaly and one had splenic infarct. One patient with shock had bilateral adrenal gland hyperenhancement. Gastrointestinal tract involvement ($n=5$, 11.1%) included 1 patient with rectosigmoid hematoma, one patient with bowel ischemia, one with acute diverticulitis and two with ileus.

To analyze abdomen–pelvis findings by chest score categories, only regression for liver, cholestasis, and kidney was performed due to small sample size (Table 4). Examining CT chest score as a continuous variable, patients with higher scores were significantly more likely to have GI tract involvement on abdomen–pelvis CT (OR 1.28, 95% CI 1.01–1.63, $p<0.05$). Associations with liver, cholestasis, pancreas, or kidney findings were non-significant. Patients with severe (18-25) chest scores were more likely to have cholestasis on imaging versus those with mild (0–10) scores (OR 13.33, 95% CI 1.28–138.85, $p<0.05$).

CT chest score

CT chest scores were available in 42 patients (93.3%). The mean and median CT chest score of all patients was 12, suggestive of moderate lung involvement. Mean CT chest score in patients with hematoma/extravasation ($n=21$) was 16.7, patients with vascular occlusion ($n=8$) was 15.3 and patients without vascular findings ($n=19$) was 8.7 (Table 3). Patients with vascular findings had significantly higher CT chest scores than those without any vascular findings (Two-sided *T* test: 15.7 vs 8.1, $p<0.01$) (Table 4).

Findings in deceased patients

The details of deceased patient such as demographics, CTA findings and CT chest score distribution are shown in Table 5. Out of the 9 deceased patients, 55.6% had mild to moderate pneumonia (CT chest score 0–17) and 44.4% had severe pneumonia (CT chest score 18–25) with mean CT chest score of 16. Of note, vascular involvement was present in all the deceased patients. For patient death, an odds ratio of 4.29 for patients with severe scores vs mild CT chest score ($p=0.14$) was observed.

Table 3 Summary of CT chest scores and CTA study findings

CT chest score	Vascular findings			Abdomen–pelvis findings				
	Hematoma/extravasation	Vascular occlusion	No vascular findings	GI Tract	Liver	Cholestasis	Pancreas	Kidney
Mean (SD) = 12.3 (7.9)	16.7 (7.2)	15.3 (7.0)	8.1 (6.6)	21.5 (2.5)	15.6 (7.1)	17.1 (7.8)	21.0 (0.0)	14.9 (7.0)
Categories (*n*)								
Mild (0–10)	3	2	12	0	1	1	0	2
Moderate (11–17)	8	3	5	0	3	2	0	3
Severe (18–25)	9	3	2	4	4	5	2	2
Total *n* = 42	21	8	19	4	8	8	2	7

Table 4 Logistic regression of CT chest score and CTA study findings

CT Chest Score	Vascular findings		Abdomen–pelvis findings				
	Hematoma/extravasation	Vascular occlusion	GI tract	Liver	Cholestasis	Pancreas	Kidney
	Odds ratio (95% CI)		Odds ratio (95% CI)				
CT chest score as continuous variable	1.19 (1.07–1.34)**	1.06 (0.96–1.18)	1.28 (1.01–1.63)*	1.07 (0.97–1.19)	1.12 (0.99–1.25)	1.22 (0.92–1.64)	1.05 (0.95–1.17)
Category							
Mild (0–10)	Reference		Reference				
Moderate (11–17)	6.22 (1.21–31.94)*	2.05 (0.29–14.39)	–	4.36 (0.40–47.61)	2.67 (0.22–32.96)	–	2.05 (0.29–14.39)
Severe (18–25)	21.0 (2.9–151.41)**	2.81 (0.39–20.46)	–	9.14 (0.86–97.26)	13.33 (1.28–138.85)*	–	1.67 (0.20–13.98)

*$p < 0.05$; **$p < 0.01$

Table 5 Details of deceased patients and CT chest score

Deceased patients	Mild and Moderate (0 to 17)	Severe (18 to 25)	All pneumonia (0 to 25)
CT chest score mean (SD)	11 (4)	23 (2)	16 (7)
Number of deceased patients	5 (55.6%)	4 (44.4%)	9 (100%)
Age mean (SD)	69 (14)	63 (14)	67 (14)
Male (%)	4 (80)	3 (75)	7 (77.8)
Days of survival mean (SD)	25 (31)	39 (30)	31 (31)
ICU	4 (80%)	4 (100%)	8 (88.9%)
Ventilator	2 (40%)	4 (100%)	6 (66.7%)
All CTA scan findings	5	19	24
Vascular findings	1	8	9
Abdomen–pelvis findings (MSK hematoma)	4 (1)	11 (4)	15 (5)
Anticoagulant			
Heparin infusion	3	2	5
Heparin sc	0	1	1
Aspirin	1	0	1
Bivalirudin	0	1	1
None	1	0	1

Coagulation profile and anticoagulation

The patient details of coagulation profile and anticoagulants use as well as CTA vascular findings is shown in Supplementary Table S2. All patients with vascular findings had abnormally elevated levels of PT, aPTT, D-dimer and had INR values within therapeutic range. The mean platelet count was within normal range for all the patients. Majority of the patients (82.2%) were on anticoagulation with the most common agent being Heparin infusion, followed by Enoxaparin and Warfarin. Anticoagulants were clinically contraindicated in the remaining patients (17.8%). All patients with hematoma or vascular extravasation were receiving anticoagulation.

Discussion

In this study, we depict the scope of vascular complications seen on body CTA in critically ill COVID-19 patients. There is a well-established role of CTA chest in COVID-19 patients to diagnose pulmonary embolism and detection of other lung complications which could alter management. However, there is a paucity of published articles on abdomen–pelvis findings particularly with reference to vascular complications, with only a few case reports showing retroperitoneal hematomas in critically ill patients [10, 12]. Symptomatic hospitalized patients frequently get imaging studies including CT abdomen and pelvis to investigate a variety of suspected complications, but the presence of vascular findings could potentially alter management. In our study we found that the most common study indication for request of CTA CAP or AP study was to evaluate for any source of bleeding or related complications. More than half of our COVID-19 cohort was admitted to the ICU (55.5%) with 40% being intubated and 20% subsequently deceased, indicating critical illness in these patients.

Several published reports have emphasized the benefits of empirical anticoagulation therapy in COVID-19. Nadkarni et al. examined 4389 patients, showing lower rates of inpatient mortality and intubation in COVID-19 patients who received prophylactic and therapeutic anticoagulation in comparison with those who did not receive anticoagulation [17]. A total of 2% of patients had major bleeding with 3% on therapeutic, 1.7% on prophylactic, and 1.9% patients without any anticoagulation. Higher bleeding rates were found in patients on therapeutic anticoagulation with relatively higher bleeding rates with LMWH in comparison with oral anticoagulants. Similarly, Paranjpe et al. demonstrated major bleeding events in 3% patients who received therapeutic anticoagulation versus 1.9% in patients who did not get anticoagulation [8]. Bleeding events occurred more frequently in intubated patients (7.5%) than non-intubated patients (1.35%). In another study on 187 COVID-19 patients, 43.3% patients had thrombotic complications, 13.3% had arterial complications with 95.1% patients on prophylactic or therapeutic anticoagulation [4].

In our study, we found that 46.7% of patients who underwent CTA had developed a hematoma within the abdomen or pelvis or extremity, with the retroperitoneum being the most common location. In addition, 37.8% of patients had involvement of the musculoskeletal system due to intramuscular hematoma, most commonly of the iliopsoas, gluteus and muscles of the upper thigh. Of note, 24.4% of patients had evidence of active vascular extravasation suggesting need for urgent surgical or vascular intervention. All patients with evidence of bleeding on CTA were receiving anticoagulation and had abnormal coagulation profiles. From the literature, Al-Samkari et al. demonstrated an overall thrombotic complication rate of 9.5%, overall bleeding rate of 4.8%, and a major bleeding rate of 2.3% out of 400 patients with initial presentation of elevated D-Dimer > 2500 ng/mL (OR 3.56; 95% CI 1.01–12.66) and thrombocytopenia (platelet count $< 150 \times 10^9$/L, OR, 2.90; 95% CI 1.05–7.99) at as strong predictors of bleeding complications in the admitted patients [1]. Thus the literature suggest caution in empiric escalation of anticoagulation beyond that of recommended guidelines in very sick COVID-19 patients. A study performed by Musoke et al. on 355 COVID-19 patients demonstrated significantly higher rate of bleeding in patients receiving therapeutic anticoagulation (11%) in comparison with prophylactic dose (4%), subtherapeutic dose (5%) and no anticoagulation (2%) [7]. Similar to our observations, inpatient death rate was 23%, though older age (OR 1.04 95% CI (1.01 to 1.07) $p = 0.008$) and therapeutic anticoagulation (OR 6.16 95% CI (2.96 to 12.83) $p \le 0.0001$) were independent associations for mortality. We observed 20% mortality in our COVID-19 cohort after mean of 31 days of survival with at least one vascular complication on CTA. Thus, our observations suggest higher mortality with presence of vascular complications on CTA studies in patients admitted to ICU.

Other less common vascular findings seen in our study included extremity arterial occlusion and pseudoaneurysms (both $n = 3$). Critically ill patients have a risk of vascular access-related complications, including arterial dissections, pseudoaneurysms or catheter-related thrombosis. One patient had a mycotic pseudoaneurysm of the descending thoracic aorta and subsequently developed a large segmental pulmonary artery pseudoaneurysm associated with presumed septic pulmonary embolism. The underlying etiology for development of arterial thrombosis and pseudoaneurysms may be related to vascular endothelial damage and inflammation associated with SARS-COV-2 virus [1, 5]. Our results show significant association of higher CT chest scores with odds of hematoma or extravasation, but not vascular occlusion. However, there was a non-significant trend with vascular occlusion, and this lack of significant findings may be due to low statistical power due to smaller sample size.

A prior study by Francone et al. showed a positive correlation of CT chest score with advanced age, inflammatory biomarkers and severity of sickness in admitted COVID-19 patients. The authors also demonstrated that a CT chest score of more than 18 was predictive of patient mortality [16]. In our study we found an average CT chest score of 12 (mean and median) suggestive of moderate pulmonary involvement in patients undergoing body CTA. Patients with vascular findings had a higher CT chest score than patients without vascular findings. Hence, we suggest a lower threshold for performing CTA studies of symptomatic patients with moderate to severe lung involvement.

Other abdomen–pelvis findings were less common in comparison to vascular complications, with cholestasis or biliary dilation being most common (20%). Organ infraction was seen in 20% of patients, most often involving the kidney. Two patients had development of pancreatitis, one had acute cholecystitis, one had perforated sigmoid diverticulitis, and one had bowel ischemia. Similar to our results for vascular findings, analysis was limited by sample size. However, overall patients with more severe CT chest scores were more likely to also have abdomen–pelvis findings.

In the literature, Bhayana et al. found gastrointestinal abnormalities in 13 out 42 (31%) COVID-19 patients on CT study and gallbladder distension and sludge in 20 out of 37 (54%) of right upper quadrant ultrasound [14]. A study of 81 COVID-19 patients who received an abdominal CT performed by Horvat et al. showed intestinal imaging findings in 24% with small bowel thickening in 12%, intestinal distension in 18% and perforation in 1% [18]. Gastrointestinal findings were associated with poor outcomes such as death or ventilator requirement. Goldberg-Stein et al. also found positive findings on 80 out of 141 (57%) COVID-19 patients who received an abdomen–pelvis CT with findings related to gastrointestinal tract (mural thickening) seen in 31.2% and organ infract seen in 18% and gallbladder and biliary abnormalities seen in 25%. Similarly we found that higher CT chest scores were significantly associated with bowel findings.

There are some limitations in our study. A retrospective design and inclusion of patients who only underwent CTA study can introduce a selection bias. In addition, our sample size of 45 CTA studies is relatively low in comparison to COVID-19 patients who often get non-angiogram CT studies of the abdomen and pelvis. However, the purpose of our study was to exclusively evaluate CTA studies of symptomatic hospitalized COVID-19 positive patients for assessment of vascular and abdomen–pelvis findings and to investigate possible correlation with the CT chest scores. Although sample size was small, to our knowledge this is the largest cohort of CTA abdomen and pelvis studies in COVID-19 patients published to date.

In conclusion, a variety of findings are found in body CTA studies of the COVID-19 patients, comprising of vascular complications (hematoma, extravasation, and occlusion) and other abdomen–pelvis findings. Patients with vascular findings had significantly higher CT chest scores than those without, and odds of hematoma/extravasation were significantly higher with those with moderate or severe scores. Based on our observations, we suggest a lower imaging threshold and careful scrutiny of vascular structures on CTA studies performed on symptomatic COVID-19 patients, especially those with moderate to severe pneumonia.

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Data availability The JH-CROWN registry.

Declarations

Conflict of interest None of the authors have anything to disclose and have no conflict of interest.

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