Abdominal Radiology (2022) 47:1565–1602
https://doi.org/10.1007/s00261-021-03337-9

HOLLOW ORGAN GI

Mesenteric ischemia in patients with COVID-19: an updated systematic review of abdominal CT findings in 75 patients

Vineeta Ojha[1] · Avinash Mani[2] · Aprateem Mukherjee[1] · Sanjeev Kumar[1] · Priya Jagia[1]

Received: 10 July 2021 / Revised: 22 October 2021 / Accepted: 26 October 2021 / Published online: 10 November 2021

Abstract

Background Acute mesenteric ischemia (AMI) is a less common but devastating complication of COVID-19 disease. The aim of this systematic review was to assess the most common CT imaging features of AMI in COVID-19 and also provide an updated review of the literature on symptoms, treatment, histopathological and operative findings, and follow-up of these patients.

Methods A systematic literature search of four databases: Pubmed, EMBASE, WHO database, and Google Scholar, was performed to identify all the articles which described abdominal CT imaging findings of AMI in COVID-19.

Results A total of 47 studies comprising 75 patients were included in the final review. Small bowel ischemia (46.67%) was the most prevalent abdominal CT finding, followed by ischemic colitis (37.3%). Non-occlusive mesenteric ischemia (NOMI; 67.9%) indicating microvascular involvement was the most common pattern of bowel involvement. Bowel wall thickening/edema (50.9%) was more common than bowel hypoperfusion (20.7%). While ileum and colon both were equally involved bowel segments (32.07% each), SMA (24.9%), SMV (14.3%), and the spleen (12.5%) were the most commonly involved artery, vein, and solid organ, respectively. 50% of the patients receiving conservative/medical management died, highlighting high mortality without surgery. Findings on laparotomy and histopathology corroborated strikingly with CT imaging findings.

Conclusion In COVID-19 patients with AMI, small bowel ischemia is the most prevalent imaging diagnosis and NOMI is the most common pattern of bowel involvement. Contrast-enhanced CT is a powerful decision-making tool for prompt diagnosis of AMI in COVID-19, thereby potentially improving time to treat as well as clinical outcomes.

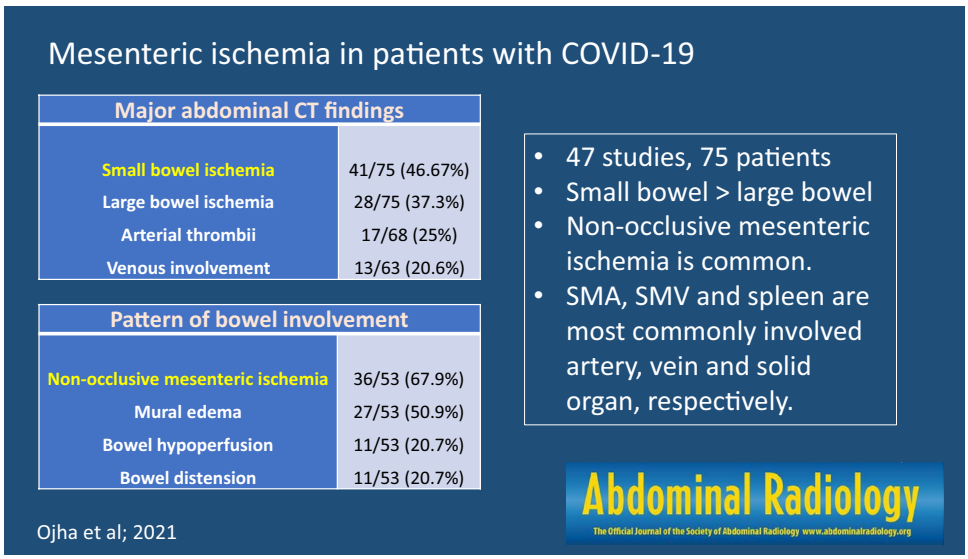
Vineeta Ojha and Avinash Mani contributed equally and share the first authorship

✉ Priya Jagia
drpjagia@yahoo.com

[1] Department of Cardiovascular Radiology & Endovascular Interventions, All India Institute of Medical Sciences, New Delhi 110029, India

[2] Department of Cardiology, Sri Chitra Tirunal Institute for Medical Sciences and Technology, Trivandrum, India

Graphical abstract



Keywords Mesenteric ischemia · COVID-19 · Small bowel ischemia

Introduction

Coronavirus disease-2019 (COVID-19) pandemic has caused an ongoing global health crisis. Initially believed to affect primarily the respiratory tract, this disease is now known to cause multiorgan involvement [1, 2]. Thromboembolic complications, in both arterial and venous systems, are being increasing recognized in patients with COVID-19 infection [3, 4]. Arterial thromboses described in patients with COVID-19 include acute coronary syndrome, stroke, acute mesenteric ischemia (AMI), and acute limb ischemia [3, 5–7]. Due to the high incidence of micro- and macrovascular involvement in COVID-19, it has also been suggested that all hospitalized COVID-19 patients should get thromboembolism prophylaxis and should undergo routine monitoring of the coagulation profile [8].

AMI is a devastating complication with a very high mortality rate (~ 60 to 80%), which increases proportionately with increasing time to diagnose and treat this condition [9]. Patients with AMI in COVID-19 may present with varied symptoms ranging from abdominal pain, diarrhea, nausea, and vomiting to abdominal distension. Due to low specificity of symptoms and laboratory tests, imaging is the mainstay for diagnosis of AMI. Prompt diagnosis and immediate treatment are imperative to prevent mortality in these patients [10]. Although abdominal radiographs and ultrasonography are readily available modalities, they have low sensitivity and specificity for the diagnosis of AMI. CT is the first-line imaging modality and has replaced catheter angiography, which is now primarily reserved for the endovascular management of this condition [11].

It is important for the clinicians and the radiologists to identify this abnormality early on CT to allow timely management and improve outcomes. However, the literature on AMI in patients with COVID-19 is heterogeneous and scattered. There is lack of a comprehensive systematic compilation of the data available in the literature pertaining to the CT imaging findings, management, laparotomy and histopathological findings, and outcomes in patients COVID-19 infection complicated by AMI. To our knowledge, this is the largest systematic review compiling data from the available literature on AMI in COVID-19 till date.

Materials and methods

Search strategy

We aimed to perform a narrative synthesis of the abdominal CT findings in patients with confirmed COVID-19 infection (on RT-PCR) who had mesenteric ischemia. The search strategy followed Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) checklist [12]. The study was registered with PROSPERO (CRD42021259511). An electronic search of four databases including Pubmed, Google scholar, Embase, and WHO library was performed on June 19, 2021, using the keywords "covid," "covid-19,"

"coronavirus," "SARS-CoV-2," "2019-nCoV," "n-CoV," "bowel ischemia," "mesenteric ischemia," "intestinal ischemia," "abdominal pain," "ischemic enteritis," and "ischemic colitis", interspersed with Boolean operators "OR" and "AND." The search was limited to articles published in 2020 and 2021. We carried out thorough additional search of the reference lists of the extracted articles to find out other potentially relevant articles. Duplicates were removed.

Study selection

Our inclusion criteria included case reports or series involving patients with confirmed COVID-19 infection (on RT-PCR) diagnosed with mesenteric ischemia on imaging/surgery/biopsy, who underwent at least one abdominal CT scan. Other inclusion criteria were articles published in English, studies conducted on humans, and with extractable full text without any restriction applied to country of research. We excluded reviews, expert opinions, editorials, patients with presumed COVID-19 infection (without RT-PCR confirmation), and preprints. The titles and the abstracts of the included studies were screened by two independent reviewers based on the above criteria and any disagreements were resolved either by mutual consensus or by the senior author, if needed.

Assessment of quality of study

All the studies were rated for their quality according to the National Institutes of Health (NIH) Quality Assessment Tool for Case Series Studies, by two independent reviewers [13]. Due to rarity of this entity, most of the included studies were either case reports or very small series of patients.

Data extraction

After thorough scrutiny of full texts of the articles included in the initial review based on the inclusion criteria, we shortlisted the final list of the articles to be included in the systematic review. Further, data extraction was done by two independent reviewers from the full text of the articles into a Microsoft Excel database using the following fields: author, country, number of patients, demographics, clinical presentation, abdominal CT findings, details of treatment, and follow-up. For extracting the relevant granular data, we used various subfields like serum levels of acute phase reactants, type of bowel wall involvement, and distribution of the abdominal CT findings across various segments of bowel and types of vessels involved. We also extracted the laparotomy and histopathological findings in the included studies to compare with imaging findings. Any discrepancies were resolved by mutual consensus. Data were analyzed using Microsoft excel and a narrative synthesis of the findings (synthesis without meta-analysis (SWiM)) was conducted.

Abdominal CT data analysis

Due to substantial heterogeneity within the data, the assessment of the major abdominal CT findings was done according to the standard definition of AMI [11]. As per the definition, AMI is thought to be caused by mesenteric arterial thrombosis (MAT), mesenteric arterial embolism (MAE), mesenteric venous thrombosis (MVT), or non-occlusive mesenteric ischemia (NOMI). The following signs on abdominal CT were considered to be suggestive of AMI: bowel wall thickening (edema, hemorrhage), high attenuation of bowel wall (hemorrhagic infarct), hyperenhancement (congestion), hypoenhancement (hypoperfusion), filling defect in the mesenteric arteries or veins, wall thinning, ileus and dilatation of the bowel wall, pneumatosis, portomesenteric venous gas, and free peritoneal gas [3].

Results

Characteristics of the studies

Five hundred and seven unique articles were identified after initial search of the four databases (Fig. 1). Out of these, 88 articles met the criteria for full-text review after initial screening. After scrutiny of these 88 articles, 47 articles which met the inclusion criteria qualified to be included in the final analysis. The demographic information about the population is given in Table 1. In 47 studies, a total of 75 patients underwent abdominal CT scans, excluding the follow-up scans which are described later. Most of the studies were case reports (Supplementary Table 1). The methodologic quality of the studies, which was assessed using the NIH Quality Assessment Tool for Case Series/Reports, was fair for most of the studies indicating limited and low-quality data available in the literature pertaining to abdominal CT findings (Supplementary Table 2).

Major imaging findings on abdominal CT

Pooled incidence of various imaging findings and their distributions as inferred from the abdominal CT scans is described in Table 2. The compilation of presenting symptoms, serology, and imaging findings as mentioned in the individual studies is given in Table 3. Abdominal pain was the most common presenting symptom. The duration between positive RT-PCR and abdominal symptom onset (range 0 to 48 days) varied widely across the studies (Table 3). Small bowel ischemia (41/75; 46.67%) was the most prevalent abdominal CT finding in patients

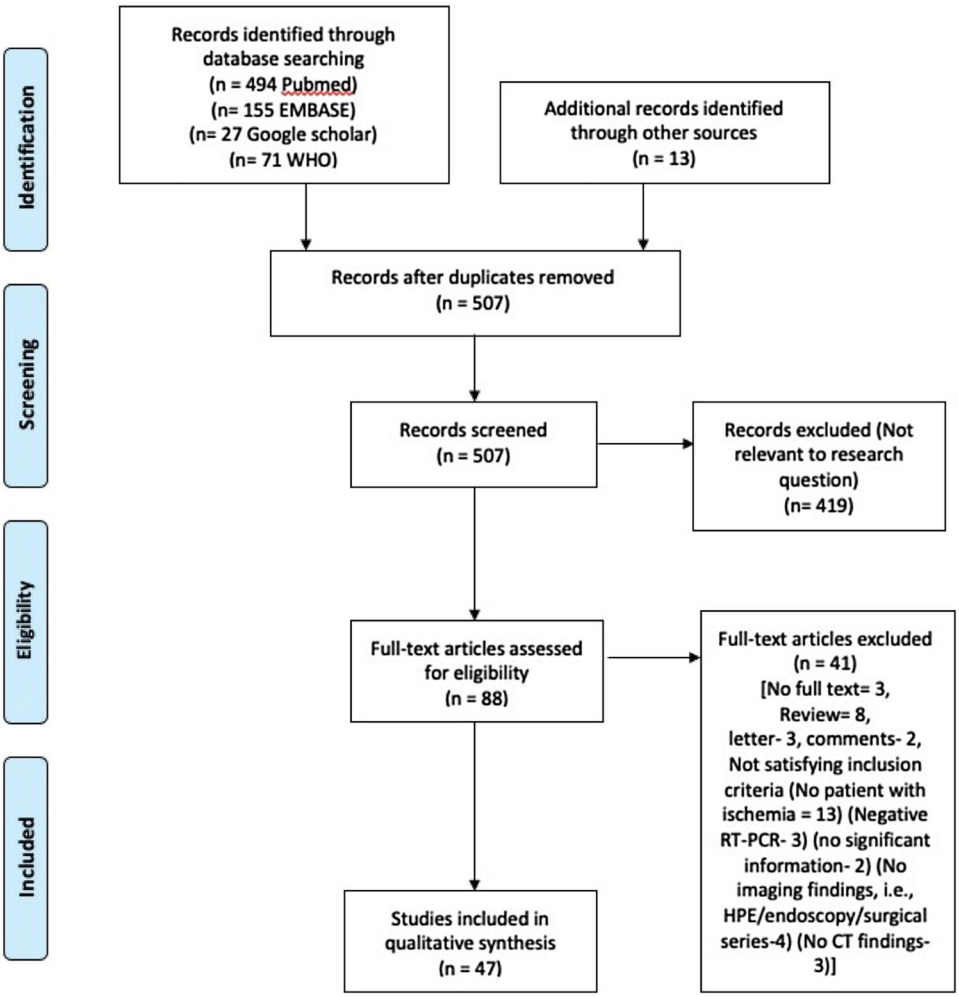


Fig. 1 PRISMA 2009 flow chart describing the study selection process for the systematic review. Adapted from Moher et al. [12]

with mesenteric ischemia. This was followed by large bowel ischemia (ischemic colitis) in 37.3% (28/75), arterial thrombi in 25% (17/68), and venous involvement in 20.6% (13/63). The less common findings were solid organ ischemia (12/63; 19%), ascites (8/45; 17.7%), pneumoperitoneum (6/53; 11.3%), and gastric ischemia (1/75; 1.3%) (Table 2, Figs. 2, 3).

Among the patients who had identifiable bowel abnormalities on CT, non-occlusive mesenteric ischemia (NOMI) (36/53; 67.9%) was the most common pattern. Mural thickening and bowel wall edema were seen in 50.9% patients (27/53). While bowel hypoperfusion and dilatation were seen in 20.7% (11/53) each, pneumatosis and signs of perforation in the bowel wall were seen in 16.9% (9/53) and 11.3% (6/53), respectively. Mucosal hyperenhancement and small intestinal obstruction were rare findings (1 patient each) (Table 2).

Distribution of bowel ischemia

Radiological signs of bowel ischemia, when present, were most commonly seen in the ileum and colon with equal frequency (17/53; 32.07% each), followed by the jejunum (7/53; 13.2%). Most studies did not specify the segment of the ileum or colon involved. Among the ones which described segmental involvement, distal ileum and ascending colon were more commonly involved than proximal ileum and descending colon, respectively. Involvement of cecum and rectum was rare (Table 2).

Distribution of arterial and venous thrombi

Among the studies which described the distribution of arterial thrombi in patients with imaging features of AMI, superior mesenteric artery (SMA) (17/68; 24.9%) was most commonly involved, followed by aorta (6/68; 8.8%). Concomitant lower limb arterial thrombus was seen in 2 patients (5.4%). Among the aortic segments, descending thoracic

Table 1 Overview of the included studies and the demographic profile of the population

First author (Ref no.)	Country of study	Number of patients with mesenteric ischemia	Male	Female	Mean age (Y)	Comorbidity
Varshney et al. [22]	India	1	0	1	50	N
Krothapalli et al. [23]	USA	1	0	1	76	DM; HTN; CAD
Abdelmohsen et al. [24]	Kuwait	2	NR	NR	60	NR
Kinjo et al. [25]	Japan	2	1 (Patient 1)	1 (Patient 2)	M 45; F 68	N
Shaikh et al. [26]	USA	1	1	0	73	DM; HTN
Bannazadeh et al. [27]	USA	1	1	0	55	HTN; Grave's disease
Amaravathi et al. [28]	India	1	1	0	45	N
Mir et al. [21]	Iran	2	1	1	M 60; F59	F: DM; M: DM, HTN
Mahruqi et al. [29]	Oman	2	2	0	Patient 1 and 2: 51	N
Goodfellow et al. [30]	UK	1	0	1	36	Post-Roux-en-Y Gastric Bypass (bariatric surgery)
Tirumani et al. [31]	USA	2	NR	NR	NR	NR
Abeysekara et al. [32]	UK	1	1	0	42	Chronic Hepatitis B
Qayed et al. [33]	USA	2	NR	NR	61	NR
Lazaro et al. [34]	Spain	1	1	0	53	Type 2 DM; Hypercholesterolemia
Costanzi et al. [35]	Italy	1	0	1	62	N
Karna et al. [36]	India	1	1	0	61	DM; HTN
Rodriguez- Nakamura et al. [37]	Mexico	2	1	1	M 45 y; F 42	Patient 1: Untreated vitiligo; Patient 2: Obesity, previous VP shunt
Osilli et al. [38]	UK	1	1	0	75	DM, Diverticular disease
Chiu et al. [39]	USA	1	0	1	49	Stage 4 CKD
Sehhat et al. [40]	Iran	1	1	0	77	HTN
Singh et al. [41]	USA	1	0	1	82	HTN, DM
Almeida Vargas et al. [42]	Spain	3	3	0	66.6	HTN; HTN, DM; HTN,DM, Dyslipidemia, Obesity, COPD
Lari et al. [43]	Kuwait	1	1	0	38	N
Fan et al. [44]	Singapore	1	1	0	30	NR
English et al. [45]	UK	1	1	0	40	Obesity
Norsa et al. [46]	Italy	7	4	3	73.1	NR
Mitchell et al. [47]	USA	1	1	0	69	NR
Norsa et al. [14]	Italy	1	1	0	62	Obesity, HTN, DM, Cirrhosis
Bianco et al. [48]	Italy	1	1	0	59	HTN
Chan et al.[49]	USA	1	1	0	73	HTN, CKD
Ignat et al. [50]	France	3	2	1	50.3	Case 1—none Case 2—HTN Obesity, DM Case 3—Chronic bronchitis, COPD, post-cardiac transplant
Azouz et al. [51]	France	1	1	0	56	NR
Bhayana et al. [7]	USA	13				NR
Cheung et al. [52]	USA	1	1	0	55	HTN
Dinoto et al. [53]	Italy	1	0	1	84	DM,HTN, renal failure, gastric ulcer disease
Macedo et al. [54]	Brazil	1	1	0	53	None
Beccara et al. [55]	Italy	1	1	0	52	N

Table 1 (continued)

First author (Ref no.)	Country of study	Number of patients with mesenteric ischemia	Male	Female	Mean age (Y)	Comorbidity
Gartland et al. [56]	USA	1	1	0	42	Type 2 DM
Vulliamy et al. [57]	London	1	1	0	75	N
Farina et al. [58]	Italy	1	1	0	70	N
Besutti et al. [59]	Italy	1	1	0	72	HTN, DM, CKD
Dane et al. [18]	USA	1	1	0	46	N
Olson et al. [60]	USA	2	1	1	M:51; F:46	F: DM
Seeliger et al. [61]	France	1	1	0	56	N
Neto et al. [62]	Brazil	1	0	1	80	HTN, CAD
Hoyo et al. [63]	Spain	1	0	1	61	Type 2 DM
Pang et al. [64]	Singapore	1	1	0	30	N

NA data not available; *NR* not reported; *Y* yes; *N* no; *DM* diabetes mellitus; *HTN* hypertension; *CAD* coronary artery disease; *CKD* chronic kidney disease

aorta (DTA) was most commonly involved (Table 2). Venous thrombi, when present, were seen most commonly in the superior mesenteric vein (SMV) (9/63; 14.3%), followed by the portal vein (PV) (6/63; 9.5%). Inferior vena cava (IVC) (3/63; 4.7%), inferior mesenteric vein (IMV), and splenic vein (2/63; 3.1% each) were less commonly involved. Concomitant lower limb DVT was seen in 1 patient (1/37; 2.7%).

Involvement of other organs and other uncommon imaging findings

Splenic infarct (8/64; 12.5%) was the most common associated imaging finding in COVID-19 patients with mesenteric ischemia, followed by renal infarct and mesenteric edema (4/64; 6.25% each). Various other rare imaging findings included associated pulmonary thromboembolism, portal venous gas, portal cavernoma, necrotizing pancreatitis, and myocardial infarct.

Serum levels of acute phase reactants in COVID-19 patients with mesenteric ischemia

There was wide heterogeneity in the studies reporting various acute phase reactants. Pooled incidences as well as final outcomes in these patients are described in Table 4. D-dimer was most commonly raised serum acute phase reactant (34/35; 97.1%), followed by C-reactive protein (CRP, 19/24; 79.2%) and serum leukocyte count (17/24; 70.8%). In those with elevated D-dimer levels, death and discharges were seen with equal frequency (16/34; 47%), when described. In patients who had elevated CRP, final outcome of death was seen in 57.9% (11/19) and discharge in 42.1% (8/19).

Treatment and outcomes in patients with mesenteric ischemia

Table 5 describes the frequency of treatment provided and the final outcomes, when described across the included studies (detailed description in Table 6). Most patients received surgical treatment (41/63; 65.07%), followed by conservative medical management (19/63; 30.15%). Only 3 patients underwent endovascular management (3/63; 4.76%). Among those who received surgical treatment, 20 (55.5%) patients got discharged, whereas 12 (33.3%) patients died. Among those who received medical management, equal number of patients died or got discharged (7/14; 50%). As far as the composite outcomes are concerned, out of a total of 56 patients in whom outcomes were reported, 24 (24/56; 42.8%) patients died, 28 (28/56; 50%) patients got discharged, and 4 (4/56; 7.1%) patients were hospitalized at the time of reporting.

Laparotomy and histopathological findings

Detailed description of the treatment provided, laparotomy and histopathological findings, outcomes, and follow-up is provided in Table 6. Laparotomy findings were described in 31 patients. All the patients with diagnosis of mesenteric ischemia on imaging showed signs of bowel ischemia on laparotomy ranging from bowel necrosis, gangrene, and distension to pallor and yellowish discoloration. SMA thrombus was seen at laparotomy in 2 patients, who also had the same finding on CT. Signs of bowel perforation were seen in 6 patients at laparotomy, 5 of whom had such signs on imaging like pneumoperitoneum and abdominal collections (Table 6, Fig. 2).

Histopathological findings were described for a total of 20 patients (Table 6). All the patients, radiologically diagnosed

Table 2 Pooled incidence of various radiological findings and their distributions (when specified) on Abdominal CT in COVID-19 patients

Abnormalities in abdominal CT	Number of studies included (where specified)	Pooled incidence (as per total number of abdominal CTs)
Major abdominal CT findings		
Small bowel ischemia	47	41/75 (46.67%)
Large bowel ischemia (Ischemic colitis)	47	28/75 (37.3%)
Gastric ischemia	47	1/75 (1.3%)
Arterial thrombi	42	17/68 (25%)
Venous involvement	39	13/63 (20.6%)
Pneumoperitoneum	38	6/53 (11.3%)
Ascites	34	8/45 (17.7%)
Solid organ ischemia	38	12/63 (19%)
Pattern of bowel involvement in patients with mesenteric ischemia (when specified)		
Bowel distension/dilatation	29	11/53 (20.7%)
Bowel hypoperfusion/ lack of enhancement	29	11/53 (20.7%)
Mural thickening and edema	29	27/53 (50.9%)
Mucosal hyperenhancement	29	1/53 (1.8%)
Pneumatosis	29	9/53 (16.9%)
Signs of perforation	29	6/53 (11.3%)
Small intestinal obstruction	29	1/53 (1.8%)
Non-occlusive mesenteric ischemia (NOMI)	29	36/53 (67.9%)
Distribution of bowel ischemia (when specified)		
Jejunum	29	7/53 (13.2%)
Ileum (Total)	29	17/53 (32.07%)
Ileum (not specified)	29	13/53 (24.5%)
Proximal ileum	29	1/53 (1.8%)
Distal ileum	29	3/53 (5.6%)
Cecum	29	2/53 (3.7%)
Colon (Total)	29	17/53 (32.07%)
Colon (not specified)	29	8/53 (15.1%)
Ascending colon	29	4/53 (7.5%)
Descending colon	29	3/53 (5.6%)
Sigmoid colon	29	2/53 (3.7%)
Rectum	29	1/53 (1.8%)
Distribution of arterial thrombi		
Aortic thrombus (total)[a]	42	6/68 (8.8%)
Descending thoracic aorta (DTA)	42	3/68 (4.4%)
Aortic arch	42	1/68 (1.4%)
Abdominal aorta	42	2/68 (2.9%)
Celiac thrombus	42	2/68 (2.9%)
SMA thrombus	42	17/68 (24.9%)
Lower limb arterial thrombosis	30	2/37 (5.4%)
Distribution of venous thrombi[b]		
Portal venous thrombosis	39	6/63 (9.5%)
Splenic venous thrombosis	39	2/63 (3.1%)
SMV thrombosis	39	9/63 (14.3%)
IMV thrombosis	39	2/63 (3.1%)
IVC thrombosis	39	3/63 (4.7%)
Lower limb DVT	30	1/37 (2.7%)

Table 2 (continued)

Abnormalities in abdominal CT	Number of studies included (where specified)	Pooled incidence (as per total number of abdominal CTs)
Solid organ involvement		
Splenic infarct	38	8/64 (12.5%)
Renal infarct	38	4/64 (6.25%)
Hepatic infarct	38	1/64 (1.5%)
Mesenteric edema	38	4/64 (6.25%)
Necrotizing pancreatitis	38	1/64 (1.5%)
Increased thickness of mesenteric fat	38	1/64 (1.5%)
Other findings		
Portal venous gas	39	2/63 (3.2%)
Mesenteric venous gas	39	1/63 (1.6%)
Portal cavernoma, gastric varices (portal hypertension)	47	1/75 (1.3%)
Diverticulosis	47	1/75 (1.3%)
Pulmonary thromboembolism	47	2/75 (2.6%)
Myocardial infarct	47	1/75 (1.3%)

SMA superior mesenteric artery; *SMV* superior mesenteric vein; *IVC* inferior vena cava; *DVT* deep vein thrombosis

[a]One patient had both DTA and abdominal aortic thrombus

[b]Most studies had multiple venous involvement

with mesenteric ischemia, showed various signs of bowel wall ischemia ranging from bowel wall necrosis, inflammation, or hemorrhages. Of note, 6 patients were seen to have microvascular thrombi, all of whom had no major vascular abnormalities on imaging. Arterial thrombus was seen in 2 patients, who were also seen to have arterial (SMA) thrombus on imaging. Mesenteric venous thrombus was seen in 5 patients, 4 of whom were seen to have mesenteric venous abnormality on imaging. No mesenteric vascular abnormality was seen in 5 patients, confirmed to have normal vessels on CT as well. Pneumatosis was seen in 1 patient on histopathology, who also had pneumatosis on imaging. 3 patients showed histopathological findings suggestive of direct SARS-CoV-2 viral involvement of the bowel mucosa, with 1 having cytological changes suggestive of viral inclusion bodies in the epithelial cells, second with viral clusters in bowel enterocyte, and the third with positive RNA ISH assay for SARS-CoV-2 (Table 6, Fig. 3).

Findings on follow-up abdominal CT

The studies which described findings on follow-up CT are detailed in Table 7. 4 studies showed signs of progression. While 1 study with ascending colon involvement at baseline showed with progressive involvement of descending colon on follow-up, 1 study with only SMV and PV thrombus at baseline showed frank bowel infarction at follow-up. 1 study with spleno-portal thrombosis at baseline developed liver, mesenteric, and splenic ischemia at follow-up. A patient treated endovascularly for SMA thrombus showed fully patent SMA at follow-up.

Discussion

Abdominal CT may depict wide range of imaging findings of mesenteric ischemia caused due to COVID-19 infection. In this systematic review, we have cohesively compiled the data from the literature regarding the common and uncommon imaging findings of mesenteric ischemia in patients with COVID-19 as deciphered on abdominal CT. Since, most studies were case reports or series with fair quality, there is a potential risk of bias. However, this bias is unavoidable due to scarcity of data on this potentially important topic in the literature. Although, most of the data are non-blinded, descriptive, and preliminary, we aimed to describe the imaging findings, treatment, and outcomes in these patients and the shortcomings were not sufficient to invalidate our findings.

On pooled analysis, small bowel ischemia (46.67%) was the most prevalent abdominal CT finding among the 75 patients diagnosed with mesenteric ischemia in COVID-19, although ischemic colitis was more prevalent diagnosis in two largest series included [7, 14]. Arterial thrombi (25%) were more commonly seen than venous thrombi (20.6%), a finding similar to the general population with AMI [11]. The most common pattern of bowel involvement in our study was NOMI (67.9%). This is in contrast to the more

Table 3 Presenting symptoms, serology, and imaging findings in the individual studies

First author (Ref no.)	No. of patients with at least 1 imaging finding of AMI	Presenting symptoms (abdominal)	Symptom onset -No of days after COVID-19 diagnosis	Chest imaging findings, if reported	D-dimer (in mg/dL if not specified) (Normal < 0.5 mg/L)	Other acute phase reactants (Fibrinogen (1.7–3.6 g/L); Ferritin (30–400 ug/L); CRP < 6 mg/L)	WBC count (Normal 4–10 K/microliter))	Duration between positive swab and abdominal CT in days; mean (range)	Major imaging manifestations in abdomen
Varshney et al. [22]	1	Abdominal pain and constipation for 5 days	14	Bilateral centrilobular GGOs on chest CT; COVID-19 pneumonia	NR	NR	NR	NR	Grossly dilated distal descending and sigmoid colon; Multiple diverticulosis; One in sigmoid colon had ruptured
Krothapalli et al. [23]	1	Diarrhea; acutely distended and tender abdomen	14	NR	2.159	Ferritin 468 ng/mL, C-reactive protein 7.97 mg/L, procalcitonin 0.40 ng/mL	9	NR	Intestinal ischemia
Abdelmohsen et al. [24]	2	Acute abdomen	During hospitalization	COVID pneumonia in a patient with bowel ischemia	24.14 (7.18–58.21)	NR	NR	11 (4–38)	Splenic infarct (1); bowel ischemia (2)
Kinjo et al. [25]	2	Patient 1: Hematochezia; Patient 2: Left dorsal pain	18; 21	NR	1.25; 2.37	NR	NR	25; 27	Patient 1: ischemic colitis; Patient 2: ischemic jejunitis; No intravascular thrombus in both (NOMI)
Shaikh et al. [26]	1	Acute abdominal pain, distention, and diarrhea	Prior to COVID-19 diagnosis	CXR- Left lobar infiltrate	27.5.7	CRP 48 mg/L; Ferritin 88 ng/L;		0	Ischemic colitis
Bannazadeh et al. [27]	1	Acute onset of severe abdominal pain	16	CXR- Right basilar infiltrate; CT- bilateral lower lobe, right middle lobe and lingula ggos	24	Lactic acid- 6.2	NR	16	SMA thrombus

Table 3 (continued)

First author (Ref no.)	No. of patients with at least 1 imaging finding of AMI	Presenting symptoms (abdominal)	Symptom onset -No of days after COVID-19 diagnosis	Chest imaging findings, if reported	D-dimer (in mg/dL if not specified) (Normal < 0.5 mg/L)	Other acute phase reactants (Fibrinogen (1.7–3.6 g/L); Ferritin (30–400 ug/L); CRP < 6 mg/L)	WBC count (Normal 4–10 K/microliter))	Duration between positive swab and abdominal CT in days; mean (range)	Major imaging manifestations in abdomen
Amaravathi et al. [28]	1	Acute epigastric and umbilical abdominal pain	Simultaneous	CT- COVID-19 pneumonia in bilateral lower lobes	5.3	Serum ferritin level of 324.3 ng/mL and a normal CRP	NR	1 day Prior	Thrombotic occlusion of the SMA and SMV
Mir et al. [21]	2	F: 1-day acute abdomen; M: Abdominal pain for 2 weeks	NR	Both CT: bilateral subpleural patchy GGO	NR	M: LDH: 601	F: 10.6; M: 15.4	NR	F: AMI and infarction; M: small and large bowel ischemia and perforation
Mahruqi et al. [29]	2	1: worsening on Day 27 of illness; 2: generalized abdominal pain for 3 days	27; 4	1: CT-ARDS; 2: NR	1: 2.5; 2: 10	1: Ferritin- 687 µg/L; 2: Ferritin- 619 µg/L	NR	27; 4	1: non-occlusive AMI (NOMI); 2: SMA thrombus and small bowel AMI
Goodfellow et al. [30]	1	24 h of epigastric pain radiating through to her back with nausea	6	NR	NR	CRP 1.2	9.65	6	SMV thrombus;
Tirumani et al. [31]	2	NR	NR	NR	NR	NR	NR	14	1: severe colitis
Abeysekara et al. [32]	1	Right upper quadrant pain	14	CT- Bilateral patchy ggos	NR	44	13.84	25	PV thrombosis
Qayed et al. [33]	2	NR	NR	NR	NR	NR	NR	NR	1: Severe colonic ischemia; 2: small and large bowel ischemia
Lazaro et al. [34]	1	Abdominal pain; vomiting	Prior to COVID-19 diagnosis	CXR- Left lung reticular opacities	NR	NR	NR	1 day Prior	Ischemic colitis
Costanzi et al. [35]	1	Fever, weight loss	31 days from low anterior resection	CT- Bilateral patchy ggos	NR	CRP-9 mg/L	12	31	Dilated colic stump and suspected CVF;
Karna et al. [36]	1	Abdominal pain, distension,	4	CXR- pneumonia basal peripheral	NR	CRP- 437 mg/dL	11.6	4	SMA thrombosis with dilated jejunoileal loops

Table 3 (continued)

First author (Ref no.)	No. of patients with at least 1 imaging finding of AMI	Presenting symptoms (abdominal)	Symptom onset -No of days after COVID-19 diagnosis	Chest imaging findings, if reported	D-dimer (in mg/dL if not specified) (Normal < 0.5 mg/L)	Other acute phase reactants (Fibrinogen (1.7–3.6 g/L); Ferritin (30–400 ug/L); CRP < 6 mg/L)	WBC count (Normal 4–10 K/microliter))	Duration between positive swab and abdominal CT in days; mean (range)	Major imaging manifestations in abdomen
Rodriguez-Nakamura et al. [37]	2	Patient 1: severe colic mesogastric pain for 48 h; nausea; diaphoresis. Patient 2: Colicky abdominal pain	14; 7	Patient 1: CXR- bilateral parahilar linear opacities, ggos, small consolidations. Patient 2: atypical pneumonia	1: NR; 2: 14,407 mcg/L	Patient 1: CRP-90.4 mg/L; Ferritin- 1480 ng/mL; Patient 2: elevated CRP-239 mg/L, normal fibrinogen 338 mg/dL	1: N; 2: 18.8 × 103/ul leukocytosis	15; NR	Patient 1: SMA thrombus, ischemia of distal ileum and cecum; Patient 2; ischemia of ileum and mesenteric venous thrombosis
Osilli et al. [38]	1	Fatigue, malaise, dry cough, abdominal pain	NR	Patchy and ground glass shadowing		CRP 200ug/L	18.1	NR	Filling defects in the descending thoracic, abdominal aorta, and SMA
Chiu et al. [39]	1	Acute abdomen, malena, hematemesis	28	NR	1.24	Fibrinogen 184 mg/dL	NR	28	Distended proximal jejunum with mural thickening
Sehhat et al. [40]	1	Intermittent abdominal pain and intolerance to the diet	13	GGO associated with progressive reticulation in lung bases	NR	CRP 80	22.9	13	Dilatation of the small intestine loops with wall thickening and increased thickness of the mesenteric fat
Singh et al. [41]	1	Severe diffuse abdominal distension and tenderness	18	NR	13	CRP 308 mg/L	22.8	18	Moderate distention of the colon with significant pneumatosis; NOMI

Table 3 (continued)

First author (Ref no.)	No. of patients with at least 1 imaging finding of AMI	Presenting symptoms (abdominal)	Symptom onset -No of days after COVID-19 diagnosis	Chest imaging findings, if reported	D-dimer (in mg/dL if not specified) (Normal < 0.5 mg/L)	Other acute phase reactants (Fibrinogen (1.7–3.6 g/L); Ferritin (30–400 ug/L); CRP < 6 mg/L)	WBC count (Normal 4–10 K/microliter))	Duration between positive swab and abdominal CT in days; mean (range)	Major imaging manifestations in abdomen
Almeida Vargas et al. [42]	3	Rectal bleeding; acute abdomen	15; 11; 19	NR	2170, 2100,7360 ng/mL (150–300)	CRP—0.38,31.6, 0.1 (0.0–0.50)	9.4,11.4,10.6	NR	Ischemic colitis, Necrotizing pancreatitis; Pneumoperitoneum Bowel perforation Distension of small bowel and right colon Pneumatosis intestinalis
Lari et al. [43]	1	Progressively worsening abdominal pain, vomiting	During hospitalization	Normal	3552 ng/mL	NR	NR	NR	Extensive thrombosis of the portal, splenic, superior and inferior mesenteric veins, mid small bowel venous ischemia
Fan et al. [44]	1	Central abdominal pain and bilious vomiting	NR	Bilateral basal pneumonia (from CT abdomen)	> 20ug/mL	Fibrinogen 4.6g/L	NR	NR	SMV thrombosis, small bowel ischemia
English et al. [45]	1	Abdominal distension	9	Severe acute respiratory syndrome	> 35 mg/L	Fibrinogen 5.48 (reference range 1.5–4 g/L)	8.6	9	Hypoperfusion of the distal small bowel with intramural gas
Norsa et al. [46]	6	Lower GI bleed, loss of appetite, vomiting, diarrhea, abdominal pain,	NR	NR	NR—case 1; 10 N, 8 N, > 70 N, > 70 N, 3 N (all elevated)	NR	NR	NR	Ischemic colitis (cases 1,2,3,5); Small bowel ischemia (4, 6, 7) SMV,IVC thrombus (case 6)

Table 3 (continued)

First author (Ref no.)	No. of patients with at least 1 imaging finding of AMI	Presenting symptoms (abdominal)	Symptom onset -No of days after COVID-19 diagnosis	Chest imaging findings, if reported	D-dimer (in mg/dL if not specified) (Normal < 0.5 mg/L)	Other acute phase reactants (Fibrinogen (1.7–3.6 g/L); Ferritin (30–400 ug/L); CRP < 6 mg/L)	WBC count (Normal 4–10 K/microliter))	Duration between positive swab and abdominal CT in days; mean (range)	Major imaging manifestations in abdomen
Mitchell et al. [47]	1	Mid epigastric pain, constipation	NR	NR	NR	NR	NR	NR	Thrombus in the proximal segment of the SMA with complete occlusion in the right ileocolic branches
Norsa et al. [14]	1	Abdominal pain and bilious vomiting	During hospitalization	Unremarkable	> 75-fold above the upper limit of normal	CRP elevated	Neutrophilia	NR	Thromboembolic filling defects in IVC, SMV; jejunal overdistension with associated signs of intramural bowel gas, small bowel hypoenhancement
Bianco et al. [48]	1	Worsening acute abdominal pain with nausea	> 5 days after hospitalization	GGOs with pulmonary consolidations	30-fold increase	NR	NR	5	Air fluid levels in the small bowel with mesenteric edema and ascites
Chan et al. [49]	1	5 to 6 episodes of bloody diarrhea for the past three days	After hospitalization	; CT—cardiomegaly, small bilateral pleural effusions, and a focus of rounded GGOs in the anterior right upper lobe	4226.0 ng/mL (0–500 ng/mL)	CRP- 7.7 mg/dL; ferritin—783 ng/mL; procalcitonin—1.65 ng/mL	3.8	After CT	Mucosal hyperenhancement with mass-like thickening of the distal sigmoid colon, and regional air within the mesenteric vessels

Table 3 (continued)

First author (Ref no.)	No. of patients with at least 1 imaging finding of AMI	Presenting symptoms (abdominal)	Symptom onset -No of days after COVID-19 diagnosis	Chest imaging findings, if reported	D-dimer (in mg/dL if not specified) (Normal < 0.5 mg/L)	Other acute phase reactants (Fibrinogen (1.7–3.6 g/L); Ferritin (30–400 ug/L); CRP < 6 mg/L)	WBC count (Normal 4–10 K/microliter))	Duration between positive swab and abdominal CT in days; mean (range)	Major imaging manifestations in abdomen
Ignat et al. [50]	3	Case 1—abdominal pain and vomiting; Case 2,3 -ARDS, multiorgan failure	1—Post-op day 1; 2,3—Confirmed on admission	Cases 2,3—bilateral viral pneumonia	NR	NR	NR	NR; 9; 6	Case 1—SMV and PV thrombosis and no sign of AMI, segmental portal hypertension with gastric varices, and portal cavernoma (previous thrombosis); Case 2—bowel ischemia and mesenteric venous gas in the proximal jejunum; Case 3—inflammatory segmental ileitis with a localized thickening of 1 small bowel loop and edema
Azouz et al. [51]	1	Abdominal pain and vomiting	1 Day after	Suggestive of COVID	NR	NR	NR	1	Free-floating thrombus of the aortic arch associated with an occlusion of the SMA; Absence of enhancement of part of the small bowel wall

Table 3 (continued)

First author (Ref no.)	No. of patients with at least 1 imaging finding of AMI	Presenting symptoms (abdominal)	Symptom onset -No of days after COVID-19 diagnosis	Chest imaging findings, if reported	D-dimer (in mg/dL if not specified) (Normal < 0.5 mg/L)	Other acute phase reactants (Fibrinogen (1.7–3.6 g/L); Ferritin (30–400 ug/L); CRP < 6 mg/L)	WBC count (Normal 4–10 K/microliter))	Duration between positive swab and abdominal CT in days; mean (range)	Major imaging manifestations in abdomen
Bhayana et al. [7]	13	Pain abdomen ($n=14$); sepsis ($n=12$); nausea, vomiting ($n=3$); diarrhea, GI bleed (n=2)	NA		NR	NR	NR	NR	Colonic or rectal thickening ($n=7$); Small bowel thickening ($n=5$); Pneumatosis or PV gas ($n=4$); Perforation ($n=1$)
Cheung et al. [52]	1	Recurrent nausea and vomiting and worsening generalized abdominal pain	13	Patchy GGOs suggestive of COVID-19 pneumonitis	3.4 nmol/L	NR	12.46	NR	Low-density clot, 1.6 cm in length, causing high-grade narrowing of the proximal SMA
Dinoto et al. [53]	1	Acute abdomen	2	COVID-19 Typical interstitial pneumonia	6937 ng/mL ($n=0$–700)	CRP 32.47 mg/dL ($n \leq 5$)	18	2	SMA origin stenosis and occlusion after 2 cm from the origin; absence of bowel mural enhancement in the proximal part of the ileum
Macedo et al. [54]	1	Epigastric pain of insidious onset, progressing to severe pain that radiated to the interscapular vertebral region, vomiting	48	NR	NR	NR	NR	48	Dilated, fluid-filled small bowel loops with thickened walls
Beccara et al. [55]	1	Diarrhea; abdominal pain	11	Interstitial pneumonia	NR	CRP- 222 mg/dL	30 K	11	SMA thrombosis with bowel distension

Table 3 (continued)

First author (Ref no.)	No. of patients with at least 1 imaging finding of AMI	Presenting symptoms (abdominal)	Symptom onset -No of days after COVID-19 diagnosis	Chest imaging findings, if reported	D-dimer (in mg/dL if not specified) (Normal < 0.5 mg/L)	Other acute phase reactants (Fibrinogen (1.7–3.6 g/L); Ferritin (30–400 ug/L); CRP < 6 mg/L)	WBC count (Normal 4–10 K/microliter))	Duration between positive swab and abdominal CT in days; mean (range)	Major imaging manifestations in abdomen
Gartland et al. [56]	1	Abdominal distension and pain	14	Posterobasal segment pulmonary embolism	NR	NR	NR	14	Small bowel ischemia with perforation
Vulliamy et al. [57]	1	Abdominal pain and vomiting	14	Diffuse bilateral consolidation and peripheral GGO	1: 3.2 mg/L elevated	NR	18.1 K	14	DTA, SMA thrombosis
Farina et al. [58]	1	Abdominal pain, nausea and fever	3	Bilateral ggos	NR	CRP- 149 mg/L elevated	15.3 K	3	Acute small bowel hypoperfusion
Besutti et al. [59]	1	Severe abdominal pain	NR	NR	6,910 ng/mL increased	CRP- 48 mg/dL increased	17.6 K	NR	Small bowel ischemia with massive splenic infarction
Dane et al. [18]	1	Epigastric pain, fever	NR	Bilateral ggos; pulmonary emboli	NR	NR	NR	NR	Thrombi of aorta extending into celiac and SMA
Olson et al. [60]	2	NR	NR	Multifocal ggos	NR	NR	NR	NR	M: Gastric ischemia; F: Small and large bowel ischemia
Seeliger et al. [61]	1	NR	NR	Bilateral involvement	NR	NR	NR	NR	Small bowel ischemia
Neto et al. [62]	1	Diffuse abdominal pain	Simultaneous	Bilateral GGOs; pneumothorax	1466.8 ng/dL	Ferritin of 1199 ng/dL	19.9 K	NR	Extensive pneumoperitoneum and ascites
Hoyo et al. [63]	1	Severe acute abdominal pain, vomiting	Simultaneous	Bibasal atelectasis	43,998 µg/mL	CRP-increased 9.43 mg/L	Leukocytosis	Simultaneous	Hepatic vein, spleno-portal axis thrombosis
Pang et al. [64]	1	Colicky abdominal pain; vomiting	NR	X ray- LLL opacities	20.0 µg/mL (raised)	Fibrinogen- 4.65 g/L (Mild raised)		Simultaneous	SMV thrombosis

Table 3 (continued)

First author (Ref no.)	Aortic thrombus (n)	SMA involvement	Celiac involvement	Bowel loops-small intestine	Ascites	Venous involvement	Colonic involvement	Other involvement (including solid organ)	Pneumoperitoneum
Varshney et al. [22]	N	N	N	N	NR	N	Grossly dilated distal descending and sigmoid colon; Multiple diverticulosis; One in sigmoid colon had ruptured	N	NR
Krothapalli et al. [23]	N	Occlusion	Occlusion	Intestinal ischemia	NR	N	N	AF with cardioembolic stroke	NR
Abdelmohsen et al. [24]	N	N	N	Small bowel ischemia (2): absence of mucosal enhancement, and luminal dilatation	NR	N	N	Splenic infarct (2)	NR
Kinjo et al. [25]	N	Patient 1: engorgement of the mesenteric vessels	N	Patient 1: N; Patient 2: marked thickening with a target sign in the upper jejunum	NR	NR	Patient 1: layered thickening of the descending colon; Patient 2: N	N	N
Shaikh et al. [26]	N	N	N	N	Y	N	Mild dilatation of the right colon with diffuse wall thickening; inflammation along the splenic flexure and descending colon	N	N
Bannazadeh et al. [27]	N	1.6 cm long thrombus in the proximal SMA causing a high-grade stenosis	N	NR	N	N	N	N	N

Table 3 (continued)

First author (Ref no.)	Aortic thrombus (n)	SMA involvement	Celiac involvement	Bowel loops-small intestine	Ascites	Venous involvement	Colonic involvement	Other involvement (including solid organ)	Pneumoperitoneum
Amaravathi et al. [28]	N	Thrombus	N	NR	N	SMV thrombus	N	N	N
Mir et al. [21]	N	NR	NR	Both: small bowel ischemia	Y (both)	NR	F: large bowel necrosis with perforation; M: Cecal and ascending colon necrosis and perforation	F: mesenteric congestion, splenic infarct; M:kidney and spleen infarction	Y (both)
Mahruqi et al. [29]	N	1: N (IMA- N); 2: SMA thrombosis	N	1: hypo-perfused small bowel; 2: non-enhancing proximal ileal loops; (small bowel AMI)	N	1: left LL DVT in LCIV and IVC	N	N	N
Goodfellow et al. [30]	N	N	N	Thickened bowel wall	N	Abrupt cut-off of the SMV in the proximal portion	N	Mesenteric edema	N
Tirumani et al. [31]	N	N	N	2: pneumatosis	N	2: PV gas	1: marked colonic wall thickening	1: pericolonic stranding	N
Abeysekara et al. [32]	N	N	N	Mural oedema of the distal duodenum, distal small bowel	N	Entire PV thrombosed with SMV thrombus	Mural oedema of the descending colon	Inflammatory stranding	N
Qayed et al. [33]	N	NR	NR	2: Severe small bowel ischemia and pneumatosis	NR	N	1: Severe diffuse colonic ischemia; 2: Severe large bowel ischemia	NR	N
Lazaro et al. [34]	N	N	N	N	NR	N	Mucosal hypoenhancement on ascending colon	NR	N

Table 3 (continued)

First author (Ref no.)	Aortic thrombus (n)	SMA involvement	Celiac involvement	Bowel loops-small intestine	Ascites	Venous involvement	Colonic involvement	Other involvement (including solid organ)	Pneumoperitoneum
Costanzi et al. [35]	NR	NR	NR	NR	N	N	Dilated colic stump and suspected CVF;: ischemic thickening of the anastomotic wall	N	N
Karna et al. [36]	N	Distal SMA (ileocolic branch) thrombosis	N	Dilated jejunoileal loops	N	N	N	N	N
Rodriguez- Nakamura et al. [37]	N	Patient 1: thrombus with partial recanalization through the middle colic artery; Patient 2: NR	N	Patient 1: ischemia of distal colon and cecum; Patient 2: edema and hypoperfusion (ischemia) of ileum	Patient 1: N; Patient 2: Collection with gas	Patient 1: N; Patient 2: thrombosis of the portal and mesenteric veins	N	N	Patient 1: N; Patient 2: Y
Osilli et al. [38]	DTA, AA	Y	N	Y	N	N	N	Mid pole infarct LK	N
Chiu et al. [39]	N	N	N	N	NR	NR	N	NR	NR
Sehhat et al. [40]	N	N	N	Y	NR	NR	Y	NR	NR
Singh et al. [41]	N	N	N	N	N	N	Y	N	N
Almeida Vargas et al. [42]	NR	NR	NR	N	Y	NR	Y	Case 3:segmental pulmonary thromboembolism	Y (Case 2,3)
Lari et al. [43]	N	N	N	Y	N	Y (SMV,IMV,PV, Spl vein)	N	Totally occluded right pulmonary artery	N
Fan et al. [44]	N	N	N	Y	N	Y (SMV)	N	N	N
English et al. [45]	NR	NR	NR	Y	NR	NR	NR	NR	NR
Norsa et al. [46]	N	N	N	Y (case 4,6,7)	N	IVC, SMV (Case 6)	Y (Cases 1,2,3,5)	Splenic infarcts (case 4,5), myocardial infarct (case 5), PTE (1)	N
Mitchell et al. [47]	N	Y	N	Y	N	N	NR	N	N

Table 3 (continued)

First author (Ref no.)	Aortic thrombus (n)	SMA involvement	Celiac involvement	Bowel loops-small intestine	Ascites	Venous involvement	Colonic involvement	Other involvement (including solid organ)	Pneumoperitoneum
Norsa et al. [14]	N	N	N	Y	N	SMV, IVC	N	NR	N
Bianco et al. [48]	NR	NR	NR	Y	Y	NR	NR	NR	NR
Chan et al. [49]	NR	NR	NR	N	NR	NR	Thickening in sigmoid	NR	NR
Ignat et al. [50]	N	N	N	Y(jejunum)	NR	1:SMV, PV; 2: Mesenteric venous gas	N	NR	N
Azouz et al. [51]	Aortic arch	Y	N	Dilatation and unenhancement of bowel wall	N	N	N	Occlusion of Rt MCA	N
Bhayana et al. [7]	N	N	N	Small bowel thickening ($N=5$)	NR	N	Thickening($n=7$)	Solid organ infarction ($n=2$)	NR
Cheung et al. [52]	N	Y	N	NR	NR	N	N	N	N
Dinoto et al. [53]	N	Y	N	Proximal ileum	N	N	N	N	N
Macedo et al. [54]	N	N	N	Dilated, fluid-filled small bowel loops with thickened walls	N	N	N	N	N
Beccara et al. [55]	N	Thrombus extending into jejunal branches	N	Dilated jejunoileal loops	N	N	N	N	N
Gartland et al. [56]	N	N	N	Small bowel ischemia	N	N	N	N	N
Vulliamy et al. [57]	Thrombus in DTA	Embolic occlusion	N	NR	N	N	N	N	N
Farina et al. [58]	N	Embolic occlusion of distal SMA	N	Dilated and ischemic small bowel loops	Y	N	N	Mesenteric edema	N
Besutti et al. [59]	Thrombus in DTA	Thrombus	N	Small bowel ischemia; decreased wall enhancement	N	N	N	Massive splenic infarcts	N

Table 3 (continued)

First author (Ref no.)	Aortic thrombus (n)	SMA involvement	Celiac involvement	Bowel loops-small intestine	Ascites	Venous involvement	Colonic involvement	Other involvement (including solid organ)	Pneumoperitoneum
Dane et al. [18]	Partial thrombus in abdominal aorta	Partial thrombus	Partial thrombus; complete thrombus of hepatic artery	NR	N	N	N	Left-sided renal and splenic infarct	N
Olson et al. [60]	N	N	N	M: Diffuse gastric wall thickening and pneumatosis; F: multifocal small bowel thickening; likely small vessel ischemia	N	M: PV thrombus and gas	F: multifocal large bowel thickening	F: altered enhancement in kidneys	N
Seeliger et al. [61]	N	N	N	Small bowel ischemia	N	N	N	N	N
Neto et al. [62]	N	N	N	N	Y	N	N	N	Extensive
Hoyo et al. [63]	N	N	N	Ileojejunal edema and hypoperfusion (ischemia)	N	Hepatic vein, spleno-portal axis thrombosis	Colonic edema and hypoperfusion (ischemia)	N (in first scan)	N
Pang et al. [64]	N	N	N	Diffuse mural thickening of jejunal loops	N	SMV thrombosis	N	N	N

NA data not available; *NR* not reported; *Y* yes; *N* no; *SMA* superior mesenteric artery; *SMV* superior mesenteric vein; *IVC* inferior vena cava; *DVT* deep vein thrombosis; *AF* atrial fibrillation; *AMI* acute mesenteric ischemia; *GGO* ground glass opacities; *LLL* left lower lobe; *DTA* descending thoracic aorta; *AA* abdominal aorta; *PV* portal vein

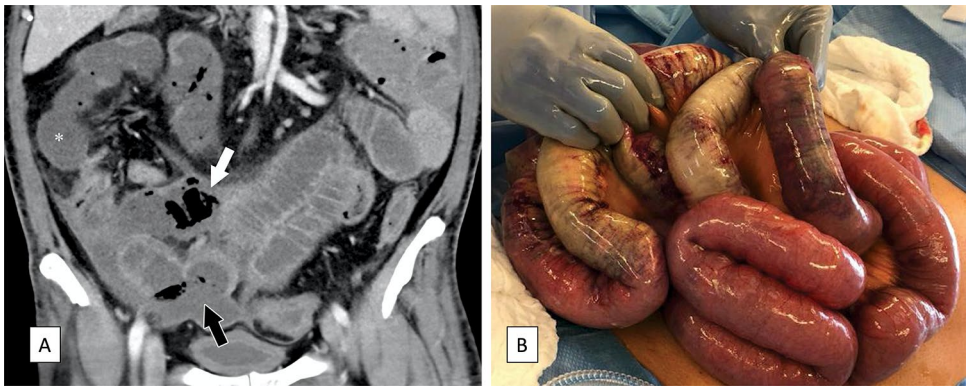


Fig. 2 **a** Coronal contrast-enhanced abdominal CT image in a 47-year-old man with abdominal tenderness shows typical findings of mesenteric ischemia and infarction, including pneumatosis intestinalis (white arrow) and non-enhancing bowel (*). Frank discontinuity of a thickened loop of small bowel in the pelvis (black arrow) is in keeping with perforation. **b** These findings are confirmed at laparotomy, with the additional observation of an atypical yellow discoloration of the bowel. Reproduced with permissions from Bhayana R, Som A, Li M D, et al. Abdominal Imaging Findings in COVID-19: Preliminary Observations. Radiology 2020;297:E207–E215 [7]

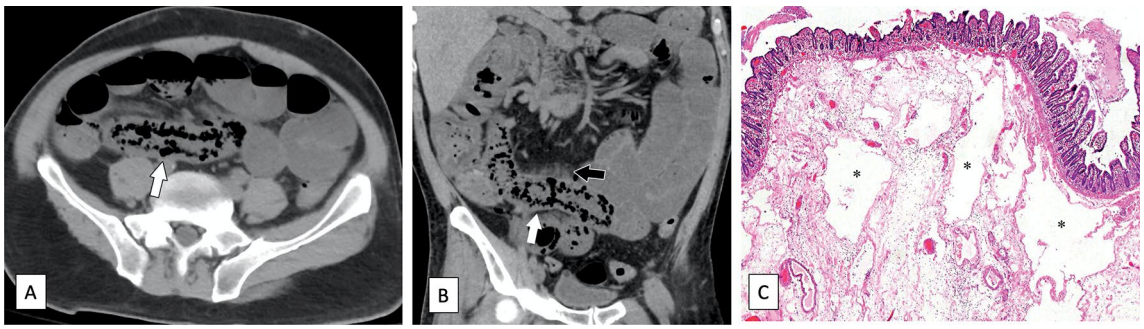


Fig. 3 Non-enhanced **a** axial and **b** coronal CT performed in a 54-year-old man show pneumatosis cystoides intestinalis (white arrows) in a long segment of ileum. Adjacent mesenteric congestion is also noted (black arrow). Laparotomy shows no frank bowel necrosis. **c** A low-power photomicrograph of the ileum shows ischemic degenerative changes of the mucosa, with villous blunting (left) and withered crypts. There is marked submucosal edema with large empty spaces, consistent with pneumatosis (*). (Hematoxylin–eosin stain; original magnification,×40). Reproduced with permissions from Bhayana R, Som A, Li M D, et al. Abdominal Imaging Findings in COVID-19: Preliminary Observations. Radiology 2020;297:E207–E215.) [7]

Table 4 Serology and outcomes of patients with mesenteric ischemia across various studies

Elevated serum levels of acute phase reactants	*n* (*n*/total number of patients in whom treatment was reported)	Outcomes (*n*/total number of patients in whom outcome was reported)
D-dimer	34 (34/35; 97.1%)	Death = 16/34 (47%) Discharged = 16/34 (47%) Hospitalized at the time of report = 4/34 (11.7%)
CRP	19 (19/24; 79.2%)	Death = 11/19 (57.9%) Discharged = 8/19 (42.1%)
Ferritin	7 (7/15; 46.7%)	Death = 4/7 (57.1%) Discharged = 2/7 (28.5%) Hospitalized at the time of report = 1/7 (14.3%)
LDH	1 (1/11; 9.1%)	Discharged = 1/1 (100%)
Serum leukocyte count	17 (17/24; 70.8%)	Death = 9/17 (52.9%) Discharged = 8/17 (47.1%)

n = number of patients

LDH lactate dehydrogenase

Table 5 Management and outcomes of patients with mesenteric ischemia across various studies

Treatment received	*n* (*n*/total number of patients in whom treatment was reported)	Outcomes (*n*/total number of patients in whom outcome was reported)
Surgical	41 (41/63; 65.07%)	Death = 12/36 (33.3%) Discharged = 20/36 (55.5%) Hospitalized at the time of report = 4/36 (11.1%)
Conservative (including medical)	19 (19/63; 30.15%)	Death = 7/14 (50%) Discharged = 7/14 (50%)
Endovascular	3 (3/63; 4.76%)	Hospitalized at the time of report = 1/1 (100%)

n = number of patients

accepted theory that MAT is the most common cause of AMI (40–50%) in general population and the incidence of NOMI in AMI is ~ 20% [9]. This finding in our study of COVID-19 patients may be related to the increasing consensus that microvascular obstruction may be a more prevalent mechanism of AMI in these patients, who may not show occlusive thrombi in big mesenteric vessels. Although the exact pathophysiological mechanism behind the causation of AMI in COVID-19 is not known, four putative mechanisms acting in varying combinations are described [4, 15]. Firstly, a hypercoagulable state due to systemic inflammatory response, immobilization, and hypoxia may lead to mesenteric vascular thrombosis, consistent with our findings of arterial, mesenteric, and portal venous thrombosis. However, conclusive demonstration of large mesenteric vessel (arterial or venous) thrombosis is limited in literature. Preliminary pathological studies have demonstrated bowel necrosis with microvascular thrombosis in the submucosal arterioles, thereby pointing toward an in situ thrombosis of mesenteric microvasculature rather than a thromboembolic event resulting from an upstream thrombus [7]. Indeed, microvascular thrombi were seen on histopathology in 6 patients who did not have vascular abnormality on CT in our study. Secondly, severe COVID-19 pneumonia is also associated with hemodynamic compromise (shock) which may lead to NOMI, often compounded by the use of vasopressors in the critical patients. These two mechanisms together may explain high prevalence of NOMI in our study. Also, most patients in our series were Intensive Care Unit (ICU) patients. Various groups, for this reason, have also suggested that when a chest CT is done in ICU patients to rule out pulmonary thromboembolism, the scan may be extended to abdomen to rule out AMI, given the benefit weighs over the risk of radiation exposure in this setting.

Other two putative mechanisms of AMI in COVID-19 include elevated levels of von Willebrand factors in severe COVID-19 and the expression of angiotensin-converting enzyme 2 (ACE-2) on the vascular endothelium [15]. The ACE-2 acts as a receptor for the SARS-CoV-2 virus and may result in endothelial cell tropism of the virus and consequent direct vascular endothelial damage and thrombosis. However, another interesting finding was noted in our study. There was evidence for direct SARS-CoV-2 viral involvement of the bowel mucosa in 3 patients, implying a possibility that direct viral invasion of the bowel may be another mechanism for bowel changes visualized in AMI. Indeed, the feco–oral route of the disease transmission has also been implicated in COVID-19 following examination of anal swabs and fecal samples in some studies [16, 17]. It also suggests that some of the symptoms of AMI in patients with COVID-19 may be due to viral enteritis rather than vascular ischemia per se.

Mural thickening and bowel wall edema were more commonly seen than bowel wall hypoenhancement in our study, consistent with the theory that bowel wall thickening has a higher sensitivity compared to bowel wall hypoperfusion which, in turn is more specific and points toward irreversible ischemia [11]. Pneumatosis was seen in ~ 17% of the patients, although this should be interpreted with caution as this may be seen secondary to mechanical ventilation in patients with severe COVID-19.

We also assessed the segment-wise involvement of the bowel wall, arteries, and veins in AMI in COVID-19, which has not been described before. We found that the ileum and colon were involved almost equally among the study population, with distal ileum and ascending colon being the most commonly involved segments. Among the arteries, SMA was most commonly involved, followed by the aorta (DTA being the most common aortic segment involved). Among the veins, SMV was most commonly involved followed by the portal vein. Spleen was the most common solid organ involved in our study. Dane et al. in their study suggested that the solid organ infarction in patients with COVID-19 may result from microthrombi and these patients often have patent vasculature, consistent with our findings [18].

Serum D-dimer and CRP were the most commonly raised serum acute phase reactant in our analysis. Although blood tests may reveal elevated levels of these reactants in AMI, they are non-specific and may be elevated in severe COVID-19 infection even without AMI [11, 19]. As regards the onset of symptoms, we noted that abdominal ischemic symptoms could present as late as 48 days after positive RT-PCR for COVID. It is imperative that the clinicians managing patients with COVID-19 should monitor these patients for

Table 6 Treatment, laparotomy and histopathological findings, outcomes, and follow-up across all the studies

First author (Ref no.)	Number of patients with at least 1 imaging finding of mesenteric ischemia	Major imaging manifestations in abdomen	Treatment	Surgical treatment	Findings during laparotomy	Histopathology	Time between COVID-PCR positivity and specimen removal	Anticoagulation	Outcome	Follow-up
Varshney et al. [22]	1	Grossly dilated distal descending and sigmoid colon; multiple diverticulosis; one in sigmoid colon had ruptured	Surgical	Drainage of the collection, left colectomy with transverse colostomy, and rectal stump closure (Hartmann procedure)	Feculent collection; gangrenous sigmoid colon; ischemic descending colon with multiple perforations	Acute intestinal ischemia at different stages of development; mucosal denudation with loss of crypts; foci of inflammation and necrosis	19 days	Anticoagulation (enoxaparin, 60 mg twice daily) post-surgery	Death due to ARDS	NA
Krothapalli et al. [23]	1	Intestinal ischemia	Conservative	Deemed not to be a candidate for surgical intervention	NA	NA	NA	Apixaban	Death	NA
Abdelmohsen et al. [24]	2	Splenic infarct (1); bowel ischemia (2)	NR	NR	NA	NA	NA	40 mg enoxaparin daily prophylaxis; therapeutic anticoagulation (1 mg/kg enoxaparin every 12 h or heparin infusion)	Death in 5 out of 8	NA
Kinjo et al. [25]	2	Patient 1: ischemic colitis Patient 2: ischemic jejunitis; No intravascular thrombus in both (NOMI)	Conservative	N	NA	NA	NA	UFH	Discharged at Day 38 and Day 15, respectively	NR
Shaikh et al. [26]	1	Ischemic colitis	Surgical	Transverse loop colostomy	NR	Marked hemorrhage in the mucosa, possibility of vascular thrombi	NR	Enoxaparin	Discharged	NR

Table 6 (continued)

First author (Ref no.)	Number of patients with at least 1 imaging finding of mesenteric ischemia	Major imaging manifestations in abdomen	Treatment	Surgical treatment	Findings during laparotomy	Histopathology	Time between COVID-PCR positivity and specimen removal	Anticoagulation	Outcome	Follow-up
Bannazadeh et al. [27]	1	SMA thrombus	Surgical	SMA thrombectomy; resection of distal ileum	SMA thrombus and necrotic distal ileum	Acute arterial thrombus	16 days	UFH–>enoxaparin on day 3 post-op	Discharged	Normal at 3 months
Amaravathi et al. [28]	1	Thrombotic occlusion of the SMA and SMV	Surgical	SMA thrombectomy; resection and anastomosis	SMA thrombus and gangrenous distal ileum	NR	1	UFH	Discharged	NR
Mir et al. [21]	2	F: mesenteric ischemia and infarction; M: small and large bowel ischemia and perforation	Surgical (both)	Resection and anastomosis	F: Peritonitis, necrotic bowel from the distal ileum to the transverse colon, with perforation of the terminal ileum; M: Cecal and asc colon necrosis	F: mucosal infarction of the intestinal wall and mesenteric vein thrombosis	NR	NR	F: Death; M: Discharged	NR
Mahruqi et al. [29]	2	1: non-occlusive AMI (NOMI) 2: SMA thrombus and acute small bowel ischemia (AMI)	1: Refused surgery 2: Surgery	1: NA 2: Resection of jejunum, distal ileum, cecum and anastomosis; SMA thrombectomy	1: NA 2: Gangrenous bowel	1: NA 2: NR	1: NA 2: NR	1: Enoxaparin 2: UFH	1:Death 2: uneventful hospital stay	NR
Goodfellow et al. [30]	1	SMV thrombus;	Medical	NA	NA	NA	NA	UFH–>Dalteparin	Discharged	Doing well at 1-month post-op; tested for procoagulant genes-negative

Table 6 (continued)

First author (Ref no.)	Number of patients with at least 1 imaging finding of mesenteric ischemia	Major imaging manifestations in abdomen	Treatment	Surgical treatment	Findings during laparotomy	Histopathology	Time between COVID-PCR positivity and specimen removal	Anticoagulation	Outcome	Follow-up
Tirumani et al. [31]	2	1: Severe colitis	NR	NA	NA	NA	NA	NR	NR	NR
Abeysekara et al. [32]	1	PV thrombosis	Medical (anticoagulation)	N	NA	NA	NA	Apixaban	Discharged	Doing well at 6 weeks
Qayed et al. [33]	2	1: Severe colonic ischemia 2: Small and large bowel ischemia	1: Surgical 2: Conservative	1: Colectomy	NR	NR	NR	NR	1: Discharged 2: Died	NR
Lazaro et al. [34]	1	Ischemic colitis	Surgical	Resection of part of small bowel and ascending colon and end-ileostomy	NR	NR	Simultaneous	Given; agent not specified	Discharged	AKI 3 weeks later
Costanzi et al. [35]	1	Dilated colic stump and suspected CVF	Surgical	Abdominoperineal resection	Colovaginal fistula and ischemic colon	Gigantocellular granulomatous inflammation area of the colon; necrotic bowel wall	31	NR	Discharged	Doing well at 2-month post-op
Karna et al. [36]	1	SMA thrombosis with dilated jejunoileal loops	Surgical	Resection, ileostomy	Gangrenous distal ileum with small perforation, thick mesentery	NR	10 days	UFH	Death after 3 days of surgery	NA

Table 6 (continued)

First author (Ref no.)	Number of patients with at least 1 imaging finding of mesenteric ischemia	Major imaging manifestations in abdomen	Treatment	Surgical treatment	Findings during laparotomy	Histopathology	Time between COVID-PCR positivity and specimen removal	Anticoagulation	Outcome	Follow-up
Rodriguez-Nakamura et al. [37]	2	Patient 1: SMA thrombus, ischemia of distal ileum and cecum; Patient 2: ischemia of ileum and mesenteric venous thrombosis	Patient 1, 2: Surgical	Patient 1, 2: Resection anastomosis	Patient 1: necrotic bowel loop 30 cm proximal to the ileocecal valve; Patient 2: fecal peritonitis, jejunal perforation	NA	NA	Patient 1: Enoxaparin –>RIVAROXABAN; Patient 2: not reported	Patient 1: Discharged; Patient 2: died	Patient 1: NR; Patient 2: NA
Osilli et al. [38]	1	Filling defects in the descending thoracic, abdominal aorta and SMA	Surgical	Small bowel resection around 30 cm	Gangrenous segment of ileum	NR	NR	IV heparin	Discharged	NR
Chiu et al. [39]	1	Distended proximal jejunum with mural thickening	Surgical	Resection of 59 cm of jejunum	Transmural ischemia at proximal jejunum	Partially organized microvascular thrombi within the submucosa, cytologic changes suggestive of viral inclusion within the cytoplasm of glandular epithelial cell	4 weeks	NR	Discharged	NR

Table 6 (continued)

First author (Ref no.)	Number of patients with at least 1 imaging finding of mesenteric ischemia	Major imaging manifestations in abdomen	Treatment	Surgical treatment	Findings during laparotomy	Histopathology	Time between COVID-PCR positivity and specimen removal	Anticoagulation	Outcome	Follow-up
Sehhat et al. [40]	1	Dilatation of the small intestine loops with wall thickening and increased thickness of the mesenteric fat	Surgical	Resection of small bowel and ascending colon up to hepatic flexure	Ischemia from the ligament of Treitz to the beginning of the hepatic flexure of the colon	Necrosis of the wall and hemorrhage with infiltration of inflammatory cells in small intestinal mucosa; extensive thrombosis in mesenteric vessels	13 days	NR	Died post-op day 1 (cardiorespiratory arrest)	NA
Singh et al. [41]	1	Moderate distention of the colon with significant pneumatosis; NOMI	Surgical	Ileostomy	Gangrenous ascending colon and markedly distended colon from the cecum to rectosigmoid junction	Extensive areas of ischemic changes, including extensive mucosal, submucosal necrosis, microvascular thrombosis, focal hemorrhages, and no perforation	NR	IV heparin	Discharged	Stable, tolerating diet on day 30
Almeida Vargas et al. [42]	3	Ischemic colitis, Necrotizing pancreatitis; Pneumoperitoneum Bowel perforation Distension of small bowel and right colon Pneumatosis intestinalis	1—Conservative, 2—Surgical, 3—Conservative	Ileostomy with peritoneal lavage	Fecaloid peritonitis, gangrenous perforation of the cecum and diffuse ischemia of the bowel and colon	NA	11 days	LMWH 7500 IU	Death in all 3 cases (1, 3—24 h after Dx, 2—shortly after surgery)	NA

Table 6 (continued)

First author (Ref no.)	Number of patients with at least 1 imaging finding of mesenteric ischemia	Major imaging manifestations in abdomen	Treatment	Surgical treatment	Findings during laparotomy	Histopathology	Time between COVID-PCR positivity and specimen removal	Anticoagulation	Outcome	Follow-up
Lari et al. [43]	1	Extensive thrombosis of the portal, splenic, superior and inferior mesenteric veins, mid small bowel venous ischemia	Surgical	Resection anastomosis	Dusky jejunal segment was identified along with turbid fluid in all quadrants	NR	NR	Heparin	Discharged	NA
Fan et al. [44]	1	SMV thrombosis, small intestine obstruction	Surgical	Resection	Small bowel obstruction	Ulceration, transmural congestion, hemorrhage, and organizing thrombosis in mesenteric veins	> 4 weeks	Enoxaparin 1 mg/kg BD	Discharged	NR
English et al. [45]	1	Hypoperfusion of the distal small bowel with intramural gas	Surgical	Resection anastomosis	Ischemic distal small bowel	NR	9 days	UFH (5000 IU TDS)	Recovering	NA
Norsa et al. [46]	6	Ischemic colitis (cases 1, 2, 3, 5); small bowel ischemia (4, 6, 7) SMV,IVC thrombus (case 6)	Surgical ($n=1$), Conservative ($n=6$)	NR	NR	NR	NR	Aspirin, Oral anticoagulants (Case 1); Aspirin (Case 2); LMWH (Cases 4,7)	Discharged (1, 2, 4); Death (3, 5, 6, 7)	NR

Table 6 (continued)

First author (Ref no.)	Number of patients with at least 1 imaging finding of mesenteric ischemia	Major imaging manifestations in abdomen	Treatment	Surgical treatment	Findings during laparotomy	Histopathology	Time between COVID-PCR positivity and specimen removal	Anticoagulation	Outcome	Follow-up
Mitchell et al. [47]	1	Thrombus in the proximal segment of the SMA with complete occlusion in the right ileocolic branches	Surgical	Resection of small bowel, SMA thromboembolectomy	NR	Thromboembolectomy-organizing thrombus; bowel—extensive mucosal necrosis, marked ischemic-type injury; Electron microscopy showed viral particles clustered within enterocyte	NR	NR	Discharged	NR
Norsa et al. [14]	1	Thromboembolic filling defects in IVC, SMV; jejunal overdistension with associated signs of intramural bowel gas, small bowel hypoenhancement	Surgical	Resection	NR	Complete ischemic necrosis of the mucosa and acute perivisceral inflammation; mesenteric vessel thrombosis; RNA ISH assay confirmed SARS cov-2 presence in the intestinal mucosa	NR	NR	Died (12 h of surgery due to refractory septic shock)	NA

Table 6 (continued)

First author (Ref no.)	Number of patients with at least 1 imaging finding of mesenteric ischemia	Major imaging manifestations in abdomen	Treatment	Surgical treatment	Findings during laparotomy	Histopathology	Time between COVID-PCR positivity and specimen removal	Anticoagulation	Outcome	Follow-up
Bianco et al. [48]	1	Air fluid levels in the small bowel with associated mesenteric edema and peritoneal free fluid	Surgical	Resection anastomosis	Segmental small bowel ischemia	NR	> 5 days	NR	Died (Post-op day 4 due to multi organ dysfunction)	NA
Chan et al. [49]	1	Mucosal hyperenhancement with mass-like thickening of the distal sigmoid colon and regional air within the mesenteric vessels	Conservative	NA	NA	NA	NA	Y (Drug not mentioned)	Died (day 5 of admission- cardiac arrest)	NA
Ignat et al. [50]	3	Case 1—SMV and PV thrombosis and no sign of ischemia, of segmental portal hypertension with gastric varices and portal cavernoma evocative of a previous episode of thrombosis; Case 2—bowel ischemia and mesenteric venous gas in the proximal jejunum Case 3—inflammatory segmental ileitis with a localized thickening of 1 small bowel loop and edema	Case 1,2—Surgical Case 3—Conservative	Case 1,2—Bowel resection and temporary ostomy	Case 1—jejunal ischemia Case 2—thickened 30-cm-long bowel loop, which was centered by 2 areas of transmural necrosis	Case 1—transmural necrosis with several thrombi in the lamina propria and submucosa Case 2—inflammatory necrosis of the mucosa. Blood clots in the lamina propria and in the submucosa	Case 1—positive in post-op Case 2—Day 9	NR	Case 1—Discharged Case 2—Recovering in ICU, Case 3—Discharged	NR

Table 6 (continued)

First author (Ref no.)	Number of patients with at least 1 imaging finding of mesenteric ischemia	Major imaging manifestations in abdomen	Treatment	Surgical treatment	Findings during laparotomy	Histopathology	Time between COVID-PCR positivity and specimen removal	Anticoagulation	Outcome	Follow-up
Azouz et al. [51]	1	Free-floating thrombus of the aortic arch associated with an occlusion of the SMA; Absence of enhancement of part of the small bowel wall	Endovascular and Surgery	Endovascular thrombectomy and a laparotomy with the resection of two meters of the small bowel	NR	NR	NR	NR	NR	NA
Bhayana et al. [7]	13	Colonic or rectal thickening ($n=7$); Small bowel thickening($n=5$); Pneumatosis or PV gas ($n=4$); Perforation ($n=1$)	Surgical ($n=4$)	Exploratory laparotomy with bowel resection ($n=3$); Laparotomy without resection ($n=1$)	Necrotic bowel at surgery ($n=2$); fibrotic ileum with pneumatosis but no obvious infarction ($n=1$); patches of yellow discoloration of the transverse colon ($n=1$)	Ischemic enteritis with patchy necrosis; submucosal arterioles containing thrombi and perivascular neutrophils ($n=2$); diffuse ischemic injury with multifocal necrosis, submucosal edema with empty spaces consistent with pneumatosis and thrombi in submucosal arterioles ($n=1$)	NR	NR	NR	NR	NA

Table 6 (continued)

First author (Ref no.)	Number of patients with at least 1 imaging finding of mesenteric ischemia	Major imaging manifestations in abdomen	Treatment	Surgical treatment	Findings during laparotomy	Histopathology	Time between COVID-PCR positivity and specimen removal	Anticoagulation	Outcome	Follow-up
Cheung et al. [52]	1	Low-density clot, 1.6 cm in length, causing high-grade narrowing of the proximal SMA	Surgical	Resection of 8 inches of necrotic bowel, SMA thromboembolectomy	Small bowel necrosis	NR	> 13 days	Heparin	Discharged	NR
Dinoto et al. [53]	1	SMA origin stenosis and occlusion after 2 cm from the origin; absence of bowel mural enhancement in the proximal part of the ileum	Endovascular	Transbrachial access simultaneous mechanical thrombectomy using a 6F catheter Export AP Aspiration Catheter (Medtronic Minneapolis, MN) and proximal SMA balloon-expandable uncovered stenting	Intraoperative angiography showed thrombus in superior mesenteric artery	NA		Aspirin, Clopidogrel, LMWH	Death on 13th post-op day (Respiratory failure)	NA

Table 6 (continued)

First author (Ref no.)	Number of patients with at least 1 imaging finding of mesenteric ischemia	Major imaging manifestations in abdomen	Treatment	Surgical treatment	Findings during laparotomy	Histopathology	Time between COVID-PCR positivity and specimen removal	Anticoagulation	Outcome	Follow-up
Macedo et al. [54]	1	Dilated, fluid-filled small bowel loops with thickened walls	Surgical	Removal of 110 cm of ileum loops with signs of wall thickening, ischemic distress, and two zones of stenosis; side-to-side enteroanastomosis	Distension of jejunal and ileal loops with two stenoses; clear transition between the proximal ischemic segment and the normal bowel. Between the two stenoses, the ileum ischemic appearance	Hemorrhagic necrosis of bowel loops, lymphangioma in enteric submucosa, reactive lymphadenopathy, and absence of pathological abnormalities in mesenteric vessel	> 48 days	Enoxaparin sodium 1 mg/kg BD, replaced with rivaroxaban 15 mg BD in follow-up	Discharged	NA
Beccara et al. [55]	1	SMA thrombosis with bowel distension	Surgical	Resection, anastomosis	NR	NR	NR	LMWH	Discharged	NR
Gartland et al. [56]	1	Small bowel ischemia with perforation	Surgical	Resection, anastomosis	Necrotic bowel till transverse colon	NR	14 days	NR	Died	NA
Vulliamy et al. [57]	1	DTA, SMA thrombosis	Endovascular, surgical	Endovascular: CDT; Surgical: resection	NR	NR	NR	NR	NR	NR
Farina et al. [58]	1	Acute small bowel hypoperfusion	Medical	NA	NA	NA	NA	NR	Died	NA
Besutti et al. [59]	1	Small bowel ischemia with massive splenic infarction	Surgical	Resection, splenectomy	NR	NR	NR	UFH	Discharged and readmitted	NR
Dane et al. [18]	1	Thrombi of aorta extending into celiac and SMA	NR	NA	NA	NA	NA	NR	NR	NR

Table 6 (continued)

First author (Ref no.)	Number of patients with at least 1 imaging finding of mesenteric ischemia	Major imaging manifestations in abdomen	Treatment	Surgical treatment	Findings during laparotomy	Histopathology	Time between COVID-PCR positivity and specimen removal	Anticoagulation	Outcome	Follow-up
Olson et al. [60]	2	M: Gastric ischemia; F: Small and large bowel ischemia	NR	NA	NA	NA	NA	NR	NR	NR
Seeliger et al. [61]	1	Small bowel ischemia	Surgical	Resection, ileostomy	NR	NR	NR	NR	Hospitalized	NR
Neto et al. [62]	1	Extensive pneumoperitoneum and ascites	Surgical	Rectosigmoidectomy with terminal colostomy	Entire GIT ischemia, perforation	Ulcerated and perforated colonic segmental necrosis	NR	NR	Died on day 2 post-op	NA
Hoyo et al. [63]	1	Hepatic vein, spleno-portal axis thrombosis	Conservative	NA	NA	NA	NA	Enoxaparin	Died on Day 3	NA
Pang et al. [64]	1	SMV thrombosis	Surgical	Resection, anastomosis	Adhesion, short segment stricture	Ischemic bowel; mesenteric venous thrombus	NR	LMWH	Discharged	NR

NA data not available; *NR* not reported; *Y* yes; *N* no; *SMA* superior mesenteric artery; *SMV* superior mesenteric vein; *IVC* inferior vena cava; *DVT* deep vein thrombosis; *AF* atrial fibrillation; *AMI* acute mesenteric ischemia; *DTA* descending thoracic aorta; *PV* portal vein

Table 7 Follow-up of abdominal CT findings in cases where abdominal CT was repeated

Study	Number of patients	Baseline CT finding	Duration of follow-up abdominal CT	Follow-up abdominal CT findings
Shaikh et al.	1	Mild dilatation of the right colon with diffuse wall thickening	NR	Dilatation of the distal transverse and descending colon, wall thickening, pericolonic infiltrative changes
Abeysekara et al.	1	Acute PV and SMV thrombus ad bowel edema	6 weeks	Chronic PV thrombosis, retracted, collateralization, and resolution of the intestinal edema
Fan et al.	1	SMV thrombosis, small intestine dilatation	17 days	Decrease in SMV thrombus, progress to small bowel obstruction
Ignat et al.	1	SMV and PV thrombosis and no sign of ischemia	Day 5	Bowel infarction in the first bowel loop
Dinoto et al.	1	SMA occlusion	24-h post-endovascular treatment	SMA patency
Hoyo et al.	1	Hepatic vein, spleno-portal axis thrombosis	NR	Liver, mesenteric, and splenic ischemia
Pang et al.	1	SMV thrombosis, mural thickening of bowel loops	NR	Dilated proximal small bowel

these potential late complications, as delay in the diagnosis can lead to increased mortality [20].

Most patients in our study received surgical treatment and among them, 30% died. On the contrary, 50% of the patients died among those who received medical management. Surgical treatment and thrombolysis have been conventionally considered the mainstay of treatment of AMI. In those without bowel necrosis or those who have contraindication to thrombolysis, endovascular treatment like catheter-directed thrombolysis may be considered and may reduce the need for more invasive surgery [11]. However, surgical treatment has remained the treatment of choice as far as AMI in COVID-19 is considered.

Findings on laparotomy and histopathology in our study was in striking agreement to the CT imaging findings in AMI. Imaging accurately identified SMA thrombus, mesenteric venous thrombosis, pneumatosis, or normal macrovascular structures. Given the high specificity of imaging in our study as well previous literature, it is worthwhile to perform contrast-enhanced abdominal CT scan containing arterial and venous phases for any COVID-19 patient with unexplained or new onset abdominal pain suspected for AMI [21].

As regards the final outcomes, 42.8% of the patients died. The mortality in patients with AMI depends upon the time to diagnosis and initiation of the management. Also, according to a previously published systematic review found that patients with NOMI or MAT were more likely to die than those with MVT [10]. Indeed, in our series, NOMI and MAT were commonly seen which could have contributed to the high mortality rate. The high mortality rate in our study may also have been compounded due to other coexisting conditions in patients with COVID-19 resulting in delay in the diagnosis and management [20].

Limitation

The major limitations of our study include the small sample size and reporting bias (probability of reporting severe cases). Also, since the data are extremely heterogeneous in terms of quality of methodology, data availability, and imaging findings, the results of this study should be interpreted with caution and only in appropriate clinical context. Presence of different types of scanners, parameters of acquisition, and the experience of the radiologists may have induced some heterogeneity in the reported abdominal CT findings. However, we believe that this would not have impacted the common imaging findings in our study.

In conclusion, contrast-enhanced CT plays a pivotal role in the early identification and follow-up of AMI in patients with COVID-19. While small bowel ischemia is the most prevalent abdominal CT finding, non-occlusive mesenteric ischemia (NOMI) (due to microvascular involvement) is the most common pattern of bowel involvement. Bowel wall thickening is more common than bowel hypoperfusion. While ileum and colon both are equally involved bowel segments, SMA, SMV, and the spleen are the most commonly involved artery, vein, and solid organ, respectively. 50% of the patients with conservative/medical management died, highlighting high mortality without surgery. Findings on laparotomy and histopathology corroborate

strikingly with CT imaging findings. It is imperative that the radiologists and clinicians are familiar with the imaging manifestations of AMI in COVID-19 on CT, so that they can make informed decision regarding management and improve outcomes in this devastating condition.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00261-021-03337-9.

Funding This research received no specific grant from any funding agency, commercial, or not-for-profit sectors.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Ojha V, Mani A, Pandey NN, Sharma S, Kumar S. CT in coronavirus disease 2019 (COVID-19): a systematic review of chest CT findings in 4410 adult patients. Eur Radiol. 2020 May 30;1–10.
2. Thakur V, Ratho RK, Kumar P, Bhatia SK, Bora I, Mohi GK, et al. Multi-Organ Involvement in COVID-19: Beyond Pulmonary Manifestations. J Clin Med. 2021 Jan 24;10(3):446.
3. Malas MB, Naazie IN, Elsayed N, Mathlouthi A, Marmor R, Clary B. Thromboembolism risk of COVID-19 is high and associated with a higher risk of mortality: A systematic review and meta-analysis. EClinicalMedicine [Internet]. 2020 Dec 1 [cited 2021 Jul 5];29. Available from: https://www.thelancet.com/journals/eclinm/article/PIIS2589-5370(20)30383-7/abstract
4. Bikdeli B, Madhavan MV, Jimenez D, Chuich T, Dreyfus I, Driggin E, et al. COVID-19 and Thrombotic or Thromboembolic Disease: Implications for Prevention, Antithrombotic Therapy, and Follow-Up: JACC State-of-the-Art Review. J Am Coll Cardiol. 2020 Jun 16;75(23):2950–73.
5. Mani A, Ojha V, Dubey MK. Coronavirus Disease-19 (COVID-19) and Heart Failure: Current Perspective. J Assoc Physicians India. 2020 Nov;68(11):66–8.
6. Putko RM, Bedrin MD, Clark DM, Piscoya AS, Dunn JC, Nesti LJ. SARS-CoV-2 and limb ischemia: A systematic review. J Clin Orthop Trauma. 2021 Jan;12(1):194–9.
7. Bhayana R, Som A, Li MD, Carey DE, Anderson MA, Blake MA, et al. Abdominal Imaging Findings in COVID-19: Preliminary Observations. Radiology. 2020 Oct 1;297(1):E207–15.
8. Iba T, Levy JH, Levi M, Connors JM, Thachil J. Coagulopathy of Coronavirus Disease 2019. Crit Care Med. 2020 Sep;48(9):1358–64.
9. Oldenburg WA, Lau LL, Rodenberg TJ, Edmonds HJ, Burger CD. Acute Mesenteric Ischemia: A Clinical Review. Arch Intern Med. 2004 May 24;164(10):1054.
10. Adaba F, Askari A, Dastur J, Patel A, Gabe SM, Vaizey CJ, et al. Mortality after acute primary mesenteric infarction: a systematic review and meta-analysis of observational studies. Colorectal Dis. 2015 Jul;17(7):566–77.
11. Kanasaki S, Furukawa A, Fumoto K, Hamanaka Y, Ota S, Hirose T, et al. Acute Mesenteric Ischemia: Multidetector CT Findings and Endovascular Management. RadioGraphics. 2018 May 1;38(3):945–61.
12. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009 Jul 21;6(7):e1000097.
13. Study Quality Assessment Tools | National Heart, Lung, and Blood Institute (NHLBI) [Internet]. [cited 2020 Apr 14]. Available from: https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools
14. Norsa L, Valle C, Morotti D, Bonaffini PA, Indriolo A, Sonzogni A. Intestinal ischemia in the COVID-19 era. Dig Liver Dis. 2020 Oct;52(10):1090–1.
15. Parry AH, Wani AH, Yaseen M. Acute Mesenteric Ischemia in Severe Coronavirus-19 (COVID-19): Possible Mechanisms and Diagnostic Pathway. Acad Radiol. 2020 Aug;27(8):1190.
16. Zhang W, Du R-H, Li B, Zheng X-S, Yang X-L, Hu B, et al. Molecular and serological investigation of 2019-nCoV infected patients: implication of multiple shedding routes. Emerg Microbes Infect. 2020;9(1):386–9.
17. Gastrointestinal symptoms of 95 cases with SARS-CoV-2 infection | Gut [Internet]. [cited 2021 Jul 6]. Available from: https://gut.bmj.com/content/69/6/997
18. Dane B, Smereka P, Wain R, Kim D, S Katz D. Hypercoagulability in Patients With Coronavirus Disease (COVID-19): Identification of Arterial and Venous Thromboembolism in the Abdomen, Pelvis, and Lower Extremities. AJR Am J Roentgenol. 2021 Jan;216(1):104–5.
19. Klok FA, Kruip MJHA, van der Meer NJM, Arbous MS, Gommers D a. MPJ, Kant KM, et al. Incidence of thrombotic complications in critically ill ICU patients with COVID-19. Thromb Res. 2020 Jul;191:145–7.
20. Wang M-K, Yue H-Y, Cai J, Zhai Y-J, Peng J-H, Hui J-F, et al. COVID-19 and the digestive system: A comprehensive review. World J Clin Cases. 2021 Jun 6;9(16):3796–813.
21. Mir MZ, Mashhadi A, Jahantigh M, Seyedi SJ. Bowel necrosis associated with COVID-19 pneumonia: A report of two cases. Radiol Case Rep. 2021 Jan 22;16(4):819–23.
22. Varshney R, Bansal N, Khanduri A, Gupta J, Gupta R. Colonic Gangrene: A Sequela of Coronavirus Disease 2019. Cureus [Internet]. [cited 2021 Jun 5];13(4). Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8153963/
23. Krothapalli N, Jacob J. A Rare Case of Acute Mesenteric Ischemia in the Setting of COVID-19 Infection. Cureus [Internet]. [cited 2021 Jun 6];13(3). Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8080990/
24. Abdelmohsen MA, Alkandari BM, Abdel Razek AAK, Tobar AM, Gupta VK, Elsebaie N. Abdominal Computed Tomography Angiography and Venography in Evaluation of Hemorrhagic and Thrombotic lesions in Hospitalized COVID-19 patients. Clin Imaging. 2021 Apr 14;79:12–9.
25. Kinjo T, Hokama A, Nakamura H, Miyagi K, Higure Y, Otsuki M, et al. Case Report: Ischemic Enterocolitis Associated with Coronavirus Disease 2019: Two Case Reports and a Review of the Literature. Am J Trop Med Hyg. 2021 Mar 18;
26. Shaikh DH, Patel H, Makker J, Badipatla K, Chilimuri S. Colonic Ileus, Distension, and Ischemia Due to COVID-19-Related Colitis: A Case Report and Literature Review. Cureus [Internet]. [cited 2021 Jun 6];13(2). Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7948695/
27. Bannazadeh M, Tassiopoulos A, Koullias G. Acute superior mesenteric artery thrombosis seven days after discharge for novel coronavirus pneumonia (NCP). J Vasc Surg Cases Innov Tech [Internet]. 2021 Feb 19 [cited 2021 Jun 6]; Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7892312/
28. Amaravathi U, Balamurugan N, Muthu Pillai V, Ayyan SM. Superior Mesenteric Arterial and Venous Thrombosis in COVID-19. J Emerg Med. 2021 May;60(5):e103–7.
29. Al Mahruqi G, Stephen E, Abdelhedy I, Al Wahaibi K. Our early experience with mesenteric ischemia in COVID-19 positive patients. Ann Vasc Surg. 2021 May;73:129–32.
30. Goodfellow M, Courtney M, Upadhyay Y, Marsh R, Mahawar K. Mesenteric Venous Thrombosis Due to Coronavirus in a Post

Roux-en-Y Gastric Bypass Patient: a Case Report. Obes Surg. 2021 May;31(5):2308–10.
31. Tirumani SH, Rahnemai-azar AA, Pierce JD, Parikh KD, Martin SS, Gilkeson R, et al. Are asymptomatic gastrointestinal findings on imaging more common in COVID-19 infection? Study to determine frequency of abdominal findings of COVID-19 infection in patients with and without abdominal symptoms and in patients with chest-only CT scans. Abdom Radiol (NY). 2021 Jan 4;1–8.
32. Abeysekera KW, Karteszi H, Clark A, Gordon FH. Spontaneous portomesenteric thrombosis in a non-cirrhotic patient with SARS-CoV-2 infection. BMJ Case Rep. 2020;13(12).
33. Qayed E, Deshpande AR, Elmunzer BJ. Low Incidence of Severe Gastrointestinal Complications in COVID-19 Patients Admitted to the Intensive Care Unit: A Large, Multicenter Study. Gastroenterology. 2021 Mar;160(4):1403–5.
34. González Lázaro P, Lomas Meneses A, Del Val Zaballos F, Morandeira Rivas A. Ischemic colitis and short bowel disease due to choronavirus disease 2019 (COVID 19). Clin Nutr ESPEN. 2020 Dec;40:406–7.
35. Costanzi A, Monteleone M, Confalonieri M, Colletti G, Frattaruolo C, Fingerhut A. Late Bowel Iischemia and Colovaginal Fistula after Low Anterior Resection in a COVID-19 Patient. Chirurgia (Bucur). 2020 Oct;115(5):677–80.
36. Karna ST, Panda R, Maurya AP, Kumari S. Superior Mesenteric Artery Thrombosis in COVID-19 Pneumonia: an Underestimated Diagnosis—First Case Report in Asia. Indian J Surg. 2020 Oct 19;1–3.
37. Rodriguez-Nakamura RM, Gonzalez-Calatayud M, Martinez Martinez AR. Acute mesenteric thrombosis in two patients with COVID-19. Two cases report and literature review. Int J Surg Case Rep. 2020 Oct 15;76:409–14.
38. Osilli D, Pavlovica J, Mane R, Ibrahim M, Bouhelal A, Jacob S. Case reports: mild COVID-19 infection and acute arterial thrombosis. Journal of Surgical Case Reports [Internet]. 2020 Sep 1 [cited 2021 Jul 6];2020(9). Available from: https://doi.org/https://doi.org/10.1093/jscr/rjaa343
39. Chiu C-Y, Sarwal A, Mon AM, Tan YE, Shah V. Gastrointestinal: COVID-19 related ischemic bowel disease. Journal of Gastroenterology and Hepatology. 2021;36(4):850–850.
40. Sehhat S, Talebzadeh H, Hakamifard A, Melali H, Shabib S, Rahmati A, et al. Acute Mesenteric Ischemia in a Patient with COVID-19: A Case Report. Arch Iran Med. 2020 Sep 1;23(9):639–43.
41. Singh B, Mechineni A, Kaur P, Ajdir N, Maroules M, Shamoon F, et al. Acute Intestinal Ischemia in a Patient with COVID-19 Infection. Korean J Gastroenterol. 2020 Sep 25;76(3):164–6.
42. Almeida Vargas A, Valentí V, Sánchez Justicia C, Martínez Regueira F, Martí Cruchaga P, Luján Colás J, et al. Severe colon ischemia in patients with severe coronavirus-19 (COVID-19). Rev Esp Enferm Dig. 2020 Oct;112(10):784–7.
43. Lari E, Lari A, AlQinai S, Abdulrasoul M, AlSafran S, Ameer A, et al. Severe ischemic complications in Covid-19—A case series. International Journal of Surgery Case Reports. 2020 Jan 1;75:131–5.
44. Fan BE, Chang CCR, Teo CHY, Yap ES. COVID-19 Coagulopathy with Superior Mesenteric Vein Thrombosis Complicated by an Ischaemic Bowel. Hamostaseologie. 2020 Dec;40(5):592–3.
45. English W, Banerjee S. Coagulopathy and mesenteric ischaemia in severe SARS-CoV-2 infection. ANZ J Surg. 2020 Sep;90(9):1826.
46. Norsa L, Bonaffini PA, Indriolo A, Valle C, Sonzogni A, Sironi S. Poor Outcome of Intestinal Ischemic Manifestations of COVID-19. Gastroenterology. 2020 Oct;159(4):1595-1597.e1.
47. Mitchell JM, Rakheja D, Gopal P. SARS-CoV-2-related Hypercoagulable State Leading to Ischemic Enteritis Secondary to Superior Mesenteric Artery Thrombosis. Clin Gastroenterol Hepatol. 2020 Jun 17;S1542-3565(20)30835-1.
48. Bianco F, Ranieri AJ, Paterniti G, Pata F, Gallo G. Acute intestinal ischemia in a patient with COVID-19. Tech Coloproctol. 2020 Jun 6;1–2.
49. Chan KH, Lim SL, Damati A, Maruboyina SP, Bondili L, Abu Hanoud A, et al. Coronavirus disease 2019 (COVID-19) and ischemic colitis: An under-recognized complication. Am J Emerg Med. 2020 Dec;38(12):2758.e1-2758.e4.
50. Ignat M, Philouze G, Aussenac-Belle L, Faucher V, Collange O, Mutter D, et al. Small bowel ischemia and SARS-CoV-2 infection: an underdiagnosed distinct clinical entity. Surgery. 2020 Jul;168(1):14–6.
51. Azouz E, Yang S, Monnier-Cholley L, Arrivé L. Systemic arterial thrombosis and acute mesenteric ischemia in a patient with COVID-19. Intensive Care Med. 2020 May 18;1–2.
52. Cheung S, Quiwa JC, Pillai A, Onwu C, Tharayil ZJ, Gupta R. Superior Mesenteric Artery Thrombosis and Acute Intestinal Ischemia as a Consequence of COVID-19 Infection. Am J Case Rep. 2020 Jul 29;21:e925753.
53. Dinoto E, Ferlito F, La Marca MA, Mirabella D, Bajardi G, Pecoraro F. Staged acute mesenteric and peripheral ischemia treatment in COVID-19 patient: Case report. Int J Surg Case Rep. 2021 Jul;84:106105.
54. Macedo VSO de, Moreira GB, Albuquerque ACF de, Oliveira SC de S, Esmeraldo MA, Barbosa FCB. Late mesenteric ischemia after Sars-Cov-2 infection: case report. J vasc bras [Internet]. 2021 Mar 15 [cited 2021 Jul 6];20. Available from: http://www.scielo.br/j/jvb/a/fVw7bcQhjHsqqqnqt5yBxkk/?lang=en
55. a Beccara L, Pacioni C, Ponton S, Francavilla S, Cuzzoli A. Arterial Mesenteric Thrombosis as a Complication of SARS-CoV-2 Infection. Eur J Case Rep Intern Med [Internet]. 2020 Apr 30 [cited 2021 Jun 27];7(5). Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7213834/
56. Gartland RM, Velmahos GC. Bowel Necrosis in the Setting of COVID-19. J Gastrointest Surg. 2020 May 3;1–2.
57. Vulliamy P, Jacob S, Davenport RA. Acute aorto-iliac and mesenteric arterial thromboses as presenting features of COVID-19. Br J Haematol. 2020 Jun;189(6):1053–4.
58. Farina D, Rondi P, Botturi E, Renzulli M, Borghesi A, Guelfi D, et al. Gastrointestinal: Bowel ischemia in a suspected coronavirus disease (COVID-19) patient. Journal of Gastroenterology and Hepatology. 2021;36(1):41–41.
59. Besutti G, Bonacini R, Iotti V, Marini G, Riva N, Dolci G, et al. Abdominal Visceral Infarction in 3 Patients with COVID-19. Emerg Infect Dis. 2020 Aug;26(8):1926–8.
60. Olson MC, Lubner MG, Menias CO, Mellnick VM, Gettle LM, Kim DH, et al. RadioGraphics Update: Venous Thrombosis and Hypercoagulability in the Abdomen and Pelvis—Findings in COVID-19. RadioGraphics. 2020 Sep 1;40(5):E24–8.
61. Seeliger B, Philouze G, Benotmane I, Mutter D, Pessaux P. Is the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) present intraperitoneally in patients with coronavirus disease 2019 (COVID-19) infection undergoing emergency operations? Surgery. 2020 Aug;168(2):220–1.
62. Corrêa Neto IJF, Viana KF, Silva MBS da, Silva LM da, Oliveira G de, Cecchini AR da S, et al. Perforated acute abdomen in a patient with COVID-19: an atypical manifestation of the disease. Journal of Coloproctology. 2020 Jul 1;40(3):269–72.
63. Del Hoyo J, López-Muñoz P, Fernández-de la Varga M, Garrido-Marín A, Valero-Pérez E, Prieto M, et al. Hepatobiliary and Pancreatic: A fatal case of extensive splanchnic vein thrombosis in a patient with Covid-19. J Gastroenterol Hepatol. 2020 Nov;35(11):1853.
64. Pang JHQ, Tang JH, Eugene-Fan B, Lee CL, Low JK. A Peculiar Case of Small Bowel Stricture in a Coronavirus Disease 2019 Patient with Congenital Adhesion Band and Superior Mesenteric Vein Thrombosis. Ann Vasc Surg. 2021 Jan;70:286–9.