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

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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.

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Graphical abstract

**Mesenteric ischemia in patients with COVID-19**

| Major abdominal CT findings       | 47 studies, 75 patients |
|-----------------------------------|-------------------------|
| Small bowel ischemia              | 41/75 (46.67%)          |
| Large bowel ischemia              | 28/75 (37.3%)           |
| Arterial thrombi                  | 17/68 (25%)             |
| Venous involvement                | 13/63 (20.6%)           |

| Pattern of bowel involvement      |                          |
|-----------------------------------|--------------------------|
| Non-occlusive mesenteric ischemia | 36/53 (67.9%)            |
| Mural edema                       | 27/53 (50.9%)            |
| Bowel hypoperfusion               | 11/53 (20.7%)            |
| Bowel distension                  | 11/53 (20.7%)            |

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 increasingly 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,"
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...
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
| 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                                                                         |
| Kino et al. [25]               | Japan           | 2                                          | 1    | 1      | 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           | Chronic Hepatitis B                                                        |
| Abeysekara et al. [32]         | UK              | 1                                          | 1    | 0      | 42           | N                                                                           |
| Qayed et al. [33]              | USA             | 2                                          | NR   | NR     | 61           | N                                                                           |
| Lazaro et al. [34]             | Spain           | 1                                          | 1    | 0      | 53           | Type 2 DM; Hypercholesterolemia                                             |
| Costanzi et al. [35]           | Italy           | 1                                          | 0    | 1      | 62           | DM; HTN                                                                     |
| 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; 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           | N                                                                           |
| 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                                                                 |
| Azouz et al. [51]              | France          | 1                                          | 1    | 0      | 56           | Case 2—HTN                                                                 |
| Bhayana et al. [7]             | USA             | 13                                         |      |        |               | Obesity, DM                                                                 |
| Cheung et al. [52]             | USA             | 1                                          | 1    | 0      | 55           | Case 3—Chronic bronchitis, COPD, post-cardiac transplant                    |
| 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                                                                           |
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

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**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       |
| Seelig 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                                          | 0    | 1      | 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
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)** |                                             |                                                         |
| Bowl 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)                                 | 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**                     |                                             |                                                         |
| 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%)                                           |
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 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

aOne patient had both DTA and abdominal aortic thrombus

bMost studies had multiple venous involvement
| 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/micro-liter) | 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                                                                             | 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                                                     |
| 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/micro-liter) | 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 |
| Mahrugi et al. [29]    | 2                                                   | I: 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 |


| 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 μg/L); CRP < 6 mg/L) | WBC count (Normal (4–10 K/micro-liter)) | 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 200 μg/L | 18.1 | NR | Filling defects in the descending thoracic, abdominal aorta, and SMA |
| Chiu et al. [39] | 1 | Acute abdomen, melena, 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 pneumatoasis; NOMI |
| 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/µL) | 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) | >20 ug/mL | Fibrinogen 4.6 g/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—case 1: 10 N, 8 N, > 70 N, > 70 N, 3 N (all elevated) | NR | NR | NR | NR | Ischemic colitis (cases 1, 2, 3, 5); Small bowel ischemia (4, 6, 7) SMV, IVC thrombus (case 6) |
| 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/micro-liter) | 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 hyper-enhancement 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/micro-liter) | 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 |
| 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/μlitrer) | 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                              | 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 ≤ 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 |
| 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/micro-liter) | 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                                           | NR                              | NR                                              | NR                                                              | NR                              | 14                              | Small bowel ischemia with perforation |
| Vulliamy et al. [57]   | 1                                                   | Abdominal pain and vomiting     | 14                                           | 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                  | CRP-149 mg/L elevated                           | 15.3 K                                                          | 3                               | Acute small bowel hypoperfusion   |
| Besutti et al. [59]    | 1                                                   | Severe abdominal pain           | NR                                           | 6,910 ng/mL increased           | CRP-48 mg/dL elevated                           | 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                                              | RR                               | NR                              | Thrombi of aorta extending into celiac and SMA                    |
| Olson et al. [60]      | 2                                                   | NR                              | NR                                           | Multifocal ggos                 | NR                                              | RR                               | NR                              | M: Gastric ischemia; F: Small and large bowel ischemia            |
| Seeliger et al. [61]   | 1                                                   | NR                              | NR                                           | Bilateral involvement           | NR                                              | RR                               | NR                              | Small bowel ischemia           |
| Neto et al. [62]       | 1                                                   | Diffuse abdominal pain          | Simultaneous                                 | Bilateral GGOs; pneumothorax    | Ferritin of 1199 ng/dL                          | 19.9 K                                                          | NR                              | Extensive pneumoperitoneum and ascites                             |
| Hoyo et al. [63]       | 1                                                   | Severe acute abdominal pain, vomiting | Simultaneous                               | Bihusal atelectasis             | 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           | Fibrinogen-4.65 g/L (Mild raised)               | Simultaneous                                                      | SMV thrombosis                  |                                   |
| 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                 | N                   | Grossly dilated distal descending and sigmoid colon; Multiple diverticulosis; One in sigmoid colon had ruptured | N                |
| 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)                          | N                |
| Kinjo et al. [25]     | N                   | Patient 1: engorgement of the mesenteric vessels | 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                                        | N                |
| Shaikh et al. [26]    | N                   | N              | N                 | N                           | Y      | N                 | N                   | Mild dilatation of the right colon with diffuse wall thickening; inflammation along the splenic flexure and descending colon | 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                |
| 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         | I: 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                 | N                 | Dilated colic stump and suspected CVF; ischemic thickening of the anastomotic wall | N               |
| Karna et al. [36]      | N                   | Distal SMA (ileocolic branch) thrombosis | N | Dilated jejunileal 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 | N | Patient 1: N; Patient 2: Collection with gas | 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                          | N      | N                 | N                 | NR | NR | NR | NR |
| Sehhat et al. [40]     | N                   | N              | N                 | Y                          | N      | N                 | N                 | N | N | N | N |
| Singh et al. [41]      | N                   | N              | N                 | N                          | N      | N                 | N                 | N | Y | N | N |
| Almeida Vargas et al. [42] | NR                  | NR             | NR                | N                          | Y      | N | NR | Y | Case 3: segmental pulmonary thromboembolism | Y (Case 2,3) |
| Lari et al. [43]       | N                   | N              | N                 | N                          | Y (SMV, IMV, PV, Spl vein) | N | N | Totally occluded right pulmonary artery | N |
| Fan et al. [44]        | N                   | N              | N                 | Y                          | N | Y (SMV) | N | N | N | N |
| English et al. [45]    | NR                  | NR             | NR                | Y                          | NR | NR | N | NR | N | N |
| 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 | N |
| 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               | NR                | 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                | Proximal ileum              | N       | N                | N                 | N                             | N              |
| Dinoto et al. [53]     | N                   | Y              | N                | Dilated, fluid-filled small bowel loops with thickened walls | N       | N                | N                 | N                             | N              |
| Macedo et al. [54]     | N                   | N              | N                |                             | N       | N                | N                 | N                             | N              |
| Beccara et al. [55]    | N                   | Thrombus       | N                | Dilated jejunileal 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 | N | 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
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 AMI (40–50%) in general population and the incidence of accepted theory that MAT is the most common cause 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.

Secondly, 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

| Treatment received | $n$ (total number of patients in whom treatment was reported) | Outcomes (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%) |

$n = \text{number of patients}$
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            | 40 mg enoxapar in 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              | Conservative | N                   | NA                         | NA            | UFH                                               | Discharged at Day 38 and Day 15, respectively | NR       |
| Shaikh et al. [26]    | 1                                               | Ischemic colitis                         | Surgical | Transverse loop colostomy | Marked hemorrhage in the mucosa, possibility of vascular thrombi | NR            | Enoxaparin                                        | Discharged       | NR       |           |
| 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: Death 2: UFH | 1: Death 2: uneventful hospital stay | Discharged | 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 |
| 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 (anti-coagulation)               | 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 jejunileal loops | Surgical | Resection, ileostomy | Gangrenous distal ileum with small perforation, thick mesentery | NR            | 10 days Given; agent not specified                       | UFH            | Death after 3 days of surgery | NA       |
| 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 | 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 |
| 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) |
| 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      |
| 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 | 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 |
| 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 thromboembolec tomy | NR                          | Thromboembolec tomy-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 |
| 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 | NA | 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 resection and Case 1—jejunal 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 1,2—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 | Case 1—positive in post-op Case 2—Day 9 | NR | Case 1—Discharged Case 2—Recovering in ICU, Case 3—Discharged | NR |
| 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 | 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 | NA |
| 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      |
| First author            | 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                                                  | NA             | 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                                                  | NA             | NR       | NR        |
| 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 |
| Hoyo et al. [63]      | 1                                                                      | Hepatic vein, spleno-portal axis thrombosis | Conservative | 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.
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](https://doi.org/10.1007/s00261-021-03337-9).

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**Declarations**

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

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