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Abdominal Imaging Findings in COVID-19: Preliminary Observations

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Abbreviations: ICU = intensive care unit; ACE2 = angiotensin converting enzyme 2; COVID-19 = Coronavirus disease 2019; RUQ = right upper quadrant; SARS-CoV-2 = Severe acute respiratory syndrome coronavirus 2.

Key Results:

- 33% of inpatients with COVID-19 had abdominal imaging and 17% had cross-sectional imaging. Imaging was associated with age (OR 1.03 per year increase) and intensive care unit (ICU) admission (OR 17.3).
- 54% of right upper quadrant ultrasounds demonstrated findings of cholestasis.
- 31% of CTs showed bowel wall abnormalities. Signs of late ischemia were seen on 20% of CTs in ICU patients (2.7% of ICU patients), with pathologic correlation suggesting small vessel thrombosis.

Summary Statement: Bowel abnormalities, including ischemia, and cholestasis were common findings on abdominal imaging of inpatients with COVID-19.

Abstract:

Background: Angiotensin converting enzyme 2 (ACE2), a target of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), demonstrates its highest surface expression in the lung, small bowel, and vasculature, suggesting abdominal viscera may be susceptible to injury.

Purpose: To report abdominal imaging findings in patients with coronavirus disease 2019 (COVID-19).

Materials and Methods: In this retrospective cross-sectional study, patients consecutively admitted to a single quaternary care center from 3/27/2020 to 4/10/2020 who tested positive for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) were included. Abdominal imaging studies performed in these patients were reviewed and salient findings recorded. Medical records were reviewed for clinical data. Univariable analysis and logistic regression were performed.

Results: 412 patients (average age 57 years; range 18->90 years; 241 men, 171 women) were evaluated. 224 abdominal imaging studies were performed (radiographs, n=137; ultrasound, n=44; CT, n=42; MRI, n=1) in 134 patients (33%). Abdominal imaging was associated with age (odds ratio [OR] 1.03 per year increase, p=0.001) and ICU admission (OR 17.3, p<0.001). Bowel wall abnormalities were seen on 31% of CT scans (13 of 42) and were associated with ICU admission (OR 15.5, p=0.01). Bowel findings included pneumatosis or portal venous gas, seen on 20% of CT scans in ICU patients (4 of 20). Surgical correlation (n=4) revealed unusual yellow discoloration of bowel (n=3) and bowel infarction (n=2). Pathology demonstrated ischemic enteritis with patchy necrosis and fibrin thrombi in arterioles (n=2). Of right upper quadrant ultrasounds, 87% (32 of 37) were performed for liver laboratory findings, and 54% (20 of 37) demonstrated a dilated sludge-filled gallbladder suggestive of cholestasis. Patients with a cholecystostomy tube placed (n=4) had negative bacterial cultures.

Conclusion: Bowel abnormalities and cholestasis were common findings on abdominal imaging of inpatients with COVID-19. Patients who went to laparotomy often had ischemia, possibly due to small vessel thrombosis.

Introduction

The coronavirus disease 2019 (COVID-19) pandemic, caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), presents an ongoing global threat. Common clinical features reported in early confirmed infections included fever, cough, and myalgias or fatigue (1,2). But as testing capacity and case numbers have increased worldwide, gastrointestinal (GI) symptoms such as diarrhea, nausea/vomiting, abdominal pain, and loss of appetite have been increasingly recognized (3–5). Although lung injury is most common, liver injury of uncertain etiology has been observed in patients with COVID-19, with increased frequency in severe cases (6).

SARS-CoV-2 is thought to gain access to cells via surface expression of angiotensin converting enzyme 2 (ACE2) (7). Thus, tissues with high levels of ACE2 expression are assumed to be susceptible to direct infection (8). ACE2 surface expression is most abundant in lung alveolar epithelial cells, enterocytes of the small intestine, and vascular endothelium (9). The large amount of ACE2 surface expression in the gastrointestinal tract and, less so, biliary epithelium have been offered as possible explanations of GI symptoms and liver injury (10,11). In addition, SARS-CoV-2 has been identified in stool samples of a substantial proportion of infected patients (12–14).

Several reports have evaluated chest imaging findings in COVID-19, leading to a greater understanding of pathogenesis in the lung (15,16). Despite the widening recognition of abdominal manifestations, to our knowledge, corresponding abdominal imaging findings have not yet been reported. Imaging findings may help understand abdominal phenomena in SARS-CoV-2 infection. Further, radiologists should be aware of abdominal imaging findings in patients with COVID-19. The purpose of this study is to explore abdominal imaging findings in patients with COVID-19.

Materials and Methods

Patients and Study Design

This was a retrospective cross-sectional study performed at a large quaternary care academic institution, with Institutional Review Board (IRB) approval and requirement of informed consent waived by the IRB. All data were collected in compliance with the Health Information Portability and Accountability Act (HIPAA). All aspects of the study were performed in accordance with the Declaration of Helsinki.

We included all adult patients (>18 years) consecutively admitted at our institution over a two-week period (03/27/2020 to 4/10/2020) who tested positive for SARS-CoV-2. No patients were excluded. We queried our electronic radiology database on our Picture Archiving and Communications System (PACS) to identify all abdominal imaging examinations performed in these patients from seven days prior to admission to 04/21/2020. The patients underwent abdominal imaging studies including radiography, US, CT of the abdomen and pelvis, and MRI.

Imaging Acquisition:

All CT scans were performed on 64-slice or 128-slice multidetector CT scanners. The CT scans were performed with (n=35) or without (n=7) intravenous contrast media. In patients undergoing contrast-enhanced CT, axial acquisition of the abdomen and pelvis in the portal venous phase was performed after injection of 80-120 cc of iodinated contrast media (Omnipaque 350 mgI/ml, GE Healthcare) at a flow rate of 3-5 ml/sec followed by a 40 ml saline chaser at the same rate. Axial images were reconstructed at 5mm thickness with an interval of 5 mm. Coronal and sagittal reformatted images were created at 3mm thickness. All ultrasound examinations were performed by a registered sonographer (1-30 years of experience).

Our limited right upper quadrant ultrasound (RUQ US) protocol includes evaluation of the liver, gallbladder, central biliary tree, and portal vein. Cine and static gray scale and color doppler images were acquired and sent to our picture archiving and communications system (PACS) for interpretation by a fellowship-trained abdominal radiologist (1-47 years of experience). Radiographs were performed in the supine position with scan coverage extending from above the dome of the diaphragm to below the pubic symphysis. The abdominal MRI examination (n=1) was a liver MRI with gadolinium performed on a 3T MRI.

Data Collection and Image Analysis

All cross-sectional imaging studies (US, CT, MRI) were interpreted in a clinical setting by a fellowship-trained abdominal radiologist (1-47 years of experience). Images were independently reviewed, an average of 13 days after the initial report, by a board-certified radiologist (RB, abdominal imaging fellow, 5 years of experience including training), who was blinded to clinical data. Discrepancies with initial interpretation reached consensus in consultation with a fellowship-trained abdominal radiologist (AK, 8 years of experience). Since assessment of certain features can be subjective, the following criteria were adhered to when reviewing

images: (i) bowel wall thickening on CT was defined as single wall thickness >3 mm in distended loops and >5mm in collapsed loops; (ii) fluid filled colon was defined as homogeneous dependent low attenuation colonic content; (iii) gallbladder distension was defined as a transverse dimension >4 cm; (iv) gallbladder sludge was defined as echogenic non-shadowing debris in the gallbladder; (v) gallbladder wall thickening was defined as single wall thickness > 3 mm in an adequately distended gallbladder on sonographic images specifically interrogating the gallbladder; (vi) fatty liver on ultrasound was defined as increased echogenicity of the hepatic parenchyma obscuring periportal echogenicity +/- diaphragmatic echogenicity. These thresholds were intentionally set to be more specific than sensitive to reduce false positive observations.

Following review of imaging studies, surgery and pathology notes were collected from electronic medical records and reviewed by two radiologists (RB, AK). Surgical findings were verified in consultation with a critical care surgeon (GV, 24 years of experience). Pathology findings were verified by a gastrointestinal pathologist, who reviewed pathologic images (JM, 20 years of experience). Demographic and clinical data (presence of GI symptoms, ICU admission) were collected from electronic medical records by independent investigators (AS, first year radiology resident; MDL, second year radiology resident; or DEC, third year medical student), who were blinded to imaging findings. Presence of GI symptoms at presentation was defined as documentation of nausea, vomiting, diarrhea, or abdominal pain on the clinical note at initial hospital evaluation. All data were compiled and analyzed by two radiologists (RB, AK).”

Statistical Analysis

Demographic, clinical, and imaging data from patients admitted to the ICU were compared to other inpatients using univariable statistical tests including independent t-test, chi-square test, and fisher’s exact test. Logistic regression analyses were performed to assess for an association between imaging parameters (number of abdominal imaging studies, cholestasis, bowel wall abnormality) and demographic/clinical data (age, gender, GI symptoms at presentation, ICU admission). P values of less than 0.05 were considered to indicate a significant difference. All statistical analyses were performed using the stats package in R (version 3.6.3; R Foundation for Statistical Computing, Vienna, Austria) (17).

Results

Patient Characteristics and Imaging Utilization:

A total of 412 adult patients who tested positive for SARS-CoV-2 were admitted at our institution during the study period, of which 136 (33%) were admitted to the ICU. Patients included 241 males (58%) and 171 females (42%), with an average age of 57 years (range 18 - >90 years; SD 18 years). Patients admitted to the ICU were, on average, older than other inpatients (59 vs 56 years, p=0.04). The proportion of patients who initially presented with at least one GI symptom was 34% (n=142/412), with no difference in proportion between those admitted to the ICU and other inpatients (29 vs 37%, p=0.08). Patients were followed for an average of 16.8 days (range 11-25 days) after admission.

For all patients, 224 abdominal imaging studies were performed (radiography, n=137; US, n=44; CT, n=42; MRI, n=1) on 134 of 412 patients (33%). In total, 72 patients (17%) had at least one cross sectional abdominal imaging study. Of patients with cross-sectional imaging, 92% (n=66/72) were admitted for a diagnosis of COVID-19, rather than for other reasons and then testing positive for SARS-CoV-2. Abdominal imaging studies were associated with age (odds ratio [OR] 1.03 per year increase, p=0.001) and ICU admission (OR 17.3, p<0.001). Abdominal imaging tended to be more likely in patients with GI symptoms at presentation, though this was not statistically significant (OR 1.61, p=0.09).

The most common indications for CT were abdominal pain (n=14/42, 33%) and sepsis (n=12/42, 29%). Of the ultrasounds performed (n=44), right upper quadrant ultrasound (RUQ US) was most common (n=37/44, 84%). The majority of RUQ US were performed on ICU patients (n=32/37, 86%). The most common indication for RUQ US was abnormal liver laboratory findings (n=31/37, 84%). Table 1 demonstrates descriptive data of inpatients, including abdominal imaging studies performed and study indications.

CT Findings:

Most CT scans were performed with IV contrast (n=35/42, 83%). Bowel wall abnormalities were found on 31% (n=13/42) of abdominal CT scans, and were associated with ICU admission (OR 15.5, p=0.01). The presence of bowel wall abnormalities was not associated with age (OR 1.06 per year of increase, p=0.10), gender (female OR 0.59, p=0.54), or GI symptoms at

presentation (OR 2.02, p=0.40). Bowel wall thickening was identified on 29% (n=12/42) of CT scans, and included colon/rectal thickening (n=7) and small bowel thickening (n=5) (Figure 1). Small bowel thickening was exclusively seen in ICU patients in our study sample (ICU, n=5; non-ICU, n=0). Pneumatosis or portal venous gas (Figures 2-5) was identified on 20% of CT scans performed on ICU patients (n=4/20), constituting 2.9% of all ICU patients (n=4/136). A vascular cause was not identified on any of these CT scans. One of these patients (Figure 5) had pneumatosis cystoides intestinalis (PCI). In 3 of 4 patients with pneumatosis or portal venous gas, the finding was first identified on radiograph (n=2) or ultrasound (n=1) prior to CT being performed. One of the four patients had perforated small bowel, as evidenced by frank bowel wall discontinuity (Figure 2A).

In one patient who underwent abdominal CT for gastrointestinal symptoms, who was not being considered for SARS-CoV-2 infection at the time, lung base findings led to a diagnosis of COVID-19. Other CT findings included fluid-filled colon on 43% of scans (n=18/42), suggestive of diarrhea. ICU patients were more likely to have this finding than other inpatients (65 vs 23%, p=0.04). Two patients (4.8% of CT scans), both in the ICU, demonstrated evidence of at least one acute infarct in a solid organ (renal, splenic, or hepatic). CT findings are compiled in Table 2.

Ultrasound Findings:

Gallbladder sludge and distention were seen in 54% (n=20/37) of RUQ ultrasounds, suggestive of cholestasis (Figure 6). Findings of cholestasis were not associated with age (OR 1.03 per year increase, p=0.32), gender (female OR 0.44, p=0.36), ICU admission (OR 5.83, p=0.17), or GI symptoms at presentation (OR 1.97, p=0.43). Four patients with findings of cholestasis, all ICU patients, went on to have cholecystostomy tubes placed by interventional radiology that revealed negative bacterial culture. Sonographic evidence of fatty liver was noted in 27% of studies (n=10/37). One ICU patient was incidentally found to have portal venous gas on ultrasound (Figure 4A), which was subsequently confirmed on CT. Ultrasound findings are outlined in Table 2.

Surgical and Pathologic Correlation:

All patients with pneumatosis or portal venous gas at CT (n=4), suggestive of ischemia, underwent exploratory laparotomy. Two were found to have frankly necrotic bowel at surgery (those in Figures 2-3). In both patients, a yellow discoloration of small bowel loops was

specifically noted by the surgeon at laparotomy (Figure 2B), in contrast to the usual purple or black color of necrotic bowel. One had bowel resection, with pathology (Figure 3C) demonstrating ischemic enteritis with patchy necrosis ranging from mucosal to full thickness. Subjacent to necrotic mucosa, submucosal arterioles contained fibrin thrombi and others showed damage with perivascular neutrophils.

The other two patients did not have frank bowel necrosis at laparotomy. In one, with ileal pneumatosis cystoides intestinalis at CT (Figure 5A, 5B), laparotomy demonstrated fibrotic ileum with pneumatosis but no obvious infarction. Pathology (Figure 5C, 5D) revealed diffuse ischemic injury with multifocal necrosis, marked submucosal edema with empty spaces consistent with pneumatosis (Figure 5C), and occasional fibrin thrombi in submucosal arterioles beneath necrotic mucosa (Figure 5D). In the last patient, who had mesenteric gas adjacent to the transverse colon (Figure 4B), patches of yellow discoloration on the antimesenteric aspect of the transverse colon were seen at surgery. Second look laparotomy in this patient demonstrated no infarcted bowel but noted yellow discoloration of the stomach. No bowel was resected in this patient.

Discussion

Abdominal manifestations, including gastrointestinal symptoms and liver enzyme elevation, have been reported frequently in COVID-19 (1,3). But, to our knowledge, corresponding abdominal imaging findings have not been published. In our study, 34% of inpatients had gastrointestinal symptoms at presentation, similar to recent reports (4,5). Abdominal imaging was performed in 33% of inpatients with COVID-19, and 17% of patients had cross-sectional imaging. CT was most commonly performed for abdominal pain or sepsis, and ultrasound was most frequently performed for elevated liver enzymes.

Bowel wall findings were common on CT, and associated with ICU admission (OR 15.5, p=0.01). Findings included bowel wall thickening, pneumatosis, and portal venous gas. Pneumatosis and portal venous gas are often seen in patients with mesenteric ischemia, which is common in critically ill patients (18). But numerous other etiologies including viral enteritis and positive pressure ventilation exist (19,20). Of the four patients in our series with pneumatosis or portal venous gas, three had either frank bowel infarction at laparotomy (n=2) or ischemic mucosal necrosis on pathology (n=2). At laparotomy, a yellow appearance of bowel was noted in three patients. Bowel infarction with gangrenous change can appear tan-yellow, which likely

explains this appearance in the two patients with infarcted bowel at surgery (21). However, one patient in our study with gas in the transverse mesocolon at CT (Figure 4B) had corresponding patchy yellow discoloration of the antimesenteric transverse colon of unknown etiology.

Possible explanations for the spectrum of bowel findings in patients with COVID-19 include direct viral infection, small vessel thrombosis, or nonocclusive mesenteric ischemia. ACE2 surface expression is most abundant in lung alveolar epithelium, enterocytes of small intestine, and vascular endothelium, suggesting that small bowel and vasculature may be susceptible to SARS-CoV-2 infection (8,9). Findings suggestive of SARS-CoV-2 having a direct inflammatory effect on vascular endothelium have been reported (22). Further, systemic coagulopathy is common in critically ill patients with COVID-19 (23). This observation has been supported by descriptions of complement-mediated microvascular injury and vascular imaging abnormalities (24,25). Pathology in patients with bowel resection in our series demonstrated ischemic mucosal necrosis and fibrin thrombi in submucosal arterioles of necrotic segments. Although it can be difficult to determine whether fibrin thrombi are the cause of ischemia in necrotic bowel, given the coagulopathy these patients experience, they are likely pathogenic (26). The biologic basis that explains the spectrum of bowel imaging findings in COVID-19 patients warrants further investigation.

In three of the four patients with pneumatosis or portal venous gas, the finding was initially identified on radiograph or ultrasound. This emphasizes the importance of radiologists being alert to these findings on all imaging modalities. Although ultrasound is sensitive for portal venous gas, radiography is insensitive for both pneumatosis and portal venous gas (27). Two cases with pneumatosis or portal venous gas in our series were initially detected on radiograph, the most commonly performed modality in our study, raising the possibility that these manifestations are present more frequently than we have recognized. On CT, fluid-filled colon was seen frequently, often considered to indicate diarrhea. Diarrhea is common in ICU patients (28), and fluid-filled colon was more common in ICU patients in our study. However, GI symptoms such as diarrhea are common at presentation in COVID-19 and can be overlooked (3). Although liquid stool often escapes comment on CT, this finding might provide the first indication of gastrointestinal symptoms in COVID-19 patients.

Although elevated liver enzymes have been reported frequently in patients with COVID-19 (1,6), the etiology is uncertain. Findings of cholestasis were seen on 54% of RUQ US in our series. Of

the 20 patients with findings of cholestasis, 4 had cholecystostomy tubes placed that had negative bacterial culture. Imaging and laboratory findings of cholestasis are common in critically ill patients admitted to the ICU (29,30). Although ICU patients with COVID-19 are often hypercoagulable (31), we did not identify any patients with portal vein thrombosis.

The main limitation of this study was that of a single center retrospective study, which limits its generalizability and introduces selection bias. Pathologic correlation and clinical follow-up was not available for many patients with imaging abnormalities.

In conclusion, abdominal imaging was often performed for inpatients with COVID-19. RUQ US most frequently demonstrated cholestasis, which is common in critically ill patients. Bowel wall abnormalities identified by CT, mostly in ICU patients, included pneumatosis and portal venous gas suggestive of ischemia. Laparotomy and pathology findings confirmed small bowel ischemia in some patients, which may have been due to small vessel thrombosis. The cause of bowel abnormalities in patients who did not go to surgery remains uncertain. Further studies are required to clarify the cause of bowel findings in patients with COVID-19, in particular the role of small vessel thrombi and coagulopathy in bowel ischemia, and to determine whether SARS-CoV-2 plays a direct role in bowel or vascular injury.

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Table 1. Descriptive data of inpatients who tested positive for SARS-CoV-2, including number of abdominal imaging studies performed and study indications.

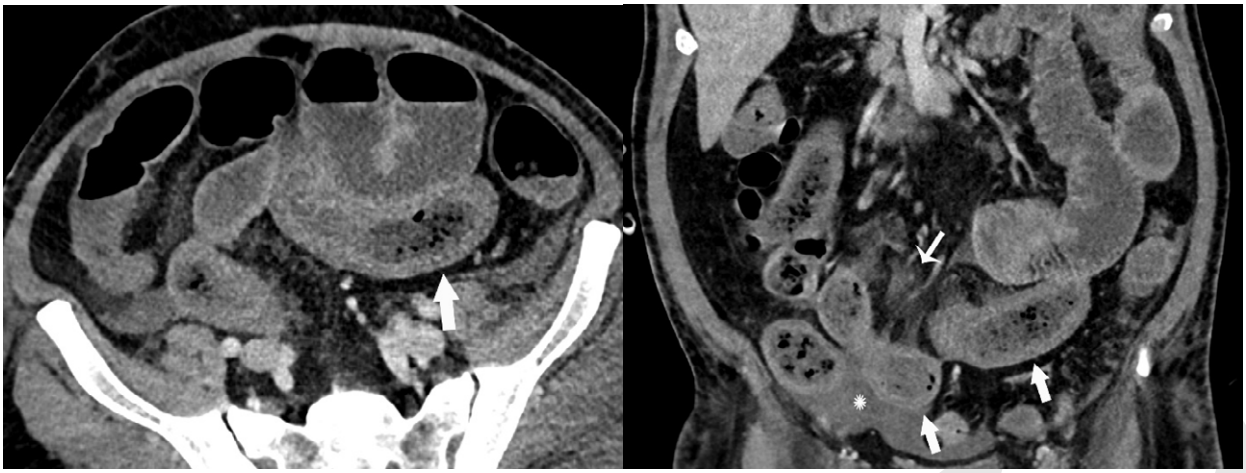
		All Inpatients	ICU	Non-ICU	p value
Number of patients		412	136	276	
Age years (range)		57 (18 - >90)	59 (24 - >90)	56 (18 - >90)	**0.04**
Sex	M (%)	241 (58)	85 (63)	155 (56)	0.26
	F (%)	171 (42)	51 (38)	121 (44)	
GI symptoms at presentation		142 (34)	40 (29)	102 (37)	0.08
Number of patients w/ abdominal imaging (%), total number of studies		134 (33), 224	97 (71)	37 (13)	**<0.001**
	Radiographs	79 (19), 137	69 (51), 125	10 (3.6), 12	**<0.001**
	All cross-sectional	72 (17), 87	43 (32), 53	29 (11), 34	**<0.001**
	All CT	40 (10), 42	20 (15), 20	20 (7.2), 22	**0.03**
	CT with contrast	34 (8.3), 35	16 (12), 16	18 (6.5), 19	0.14
	All US	40 (10), 44	30 (22), 33	10 (3.6), 11	**<0.001**
	RUQ US	34 (8.3), 37	29 (21), 32	5 (1.8), 5	**<0.001**
	Renal US	5 (1.2), 6	0 (0), 0	5 (1.8), 6	0.27
	Testicular US	1 (0.2), 1	1 (0.7), 1	0 (0), 0	0.72
	MRI	1 (0.2), 1	0 (0), 0	1 (0.4), 1	>0.99
Study Indications					
Abdominal CT	Pain (%)	14 (33)	5 (25)	9 (41)	0.34
	Infectious Source (%)	12 (29)	8 (40)	4 (18)	0.17
	Nausea/Vomiting (%)	3 (7.1)	0 (0)	3 (14)	0.23
	Diarrhea (%)	2 (4.8)	0 (0)	2 (9.1)	0.49
	GI Bleed (%)	2 (4.8)	2 (10)	0 (0)	0.22
	Ischemia (%)	2 (4.8)	2 (10)	0 (0)	0.22
	Abnormal prior (%)	2 (4.8)	2 (10)	0 (0)	0.22
	Other (%)	5 (12)	1 (5)	4 (18)	-
RUQ US	Elevated LFTs (%)	32 (86)	27 (84)	5 (100)	>0.99
	Infectious Source (%)	3 (8.2)	3 (9.4)	0 (0)	>0.99
	Pain (%)	2 (5.4)	2 (6.3)	0 (0)	>0.99
Renal US	AKI (%)	3 (50)	0 (0)	3 (50)	-
	Infectious Source (%)	3 (50)	0 (0)	3 (50)	-

ICU = Intensive care unit; RUQ = Right upper quadrant; AKI = Acute kidney injury; LFTs = “Liver function tests”

Table 2. CT and right upper quadrant ultrasound imaging findings in inpatients who tested positive for SARS-CoV-2.

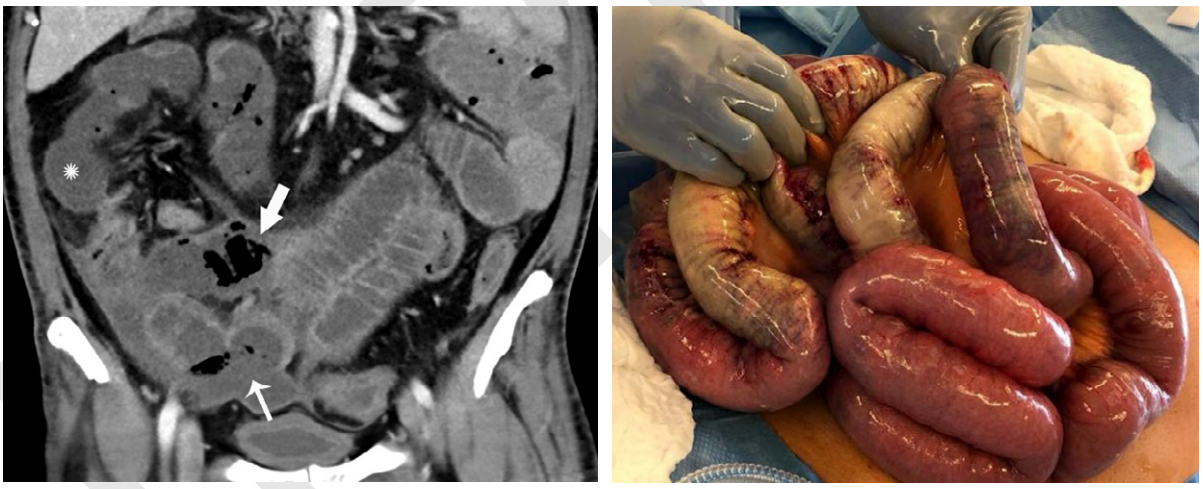
Imaging Findings	All (%)	ICU (%)	Non-ICU (%)	p value
CT Abdomen and Pelvis	***42***	***20***	***22***	
Abnormal bowel wall	13 (31)	10 (50)	3 (14)	**0.02**
Colonic or rectal thickening	7 (17)	4 (20)	3 (14)	0.69
Small Bowel Thickening	5 (12)	5 (25)	0 (0)	**0.02**
Pneumatosis or PV Gas	4 (9.5)	4 (20)	0 (0)	**0.04**
Perforation	1 (2.4)	1 (5)	0 (0)	0.48
Fluid-filled colon	18 (43)	13 (65)	5 (23)	**0.01**
Solid organ infarct	2 (4.8)	2 (10)	0 (0)	0.22
Pancreatitis	1 (2.4)	0 (0)	1 (4.5)	>0.99
Findings suggestive of hepatitis (GB thickening, heterogeneous liver)	1 (2.4)	1 (5)	0 (0)	0.48
Right upper quadrant US	***37***	***32***	***5***	
GB sludge and distension	20 (54)	19 (59)	1 (20)	0.16
GB sludge, nondistended	2 (5.4)	2 (6.3)	0 (0)	>0.99
GB wall thickening	1 (2.7)	1 (3.1)	0 (0)	>0.99
Pericholecystic fluid	1 (2.7)	1 (3.1)	0 (0)	>0.99
Fatty liver	10 (27)	8 (25)	2 (40)	0.6
Portal Venous Gas	1 (2.7)	1 (3.1)	0 (0)	>0.99
Portal Vein Thrombosis	0 (0)	0 (0)	0 (0)	-

PV = Portal venous; GB = Gallbladder



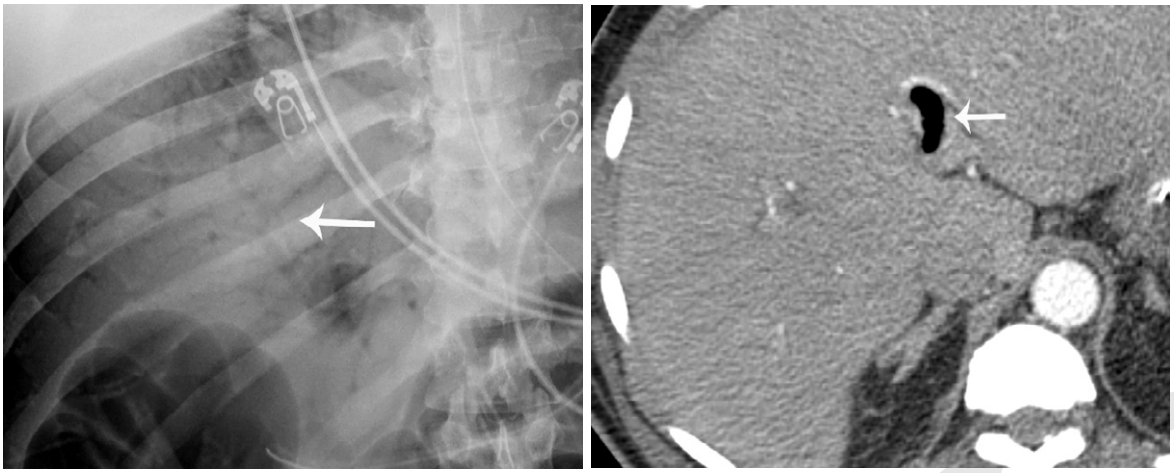
A B

Figure 1. Axial (A) and coronal (B) CT of the abdomen and pelvis with IV contrast in a 57-year-old man with a high clinical suspicion for bowel ischemia. There was generalized small bowel distension and segmental thickening (arrows), with adjacent mesenteric congestion (thin arrow in B), and a small volume of ascites (* in B). Findings are nonspecific but suggestive of early ischemia or infection.

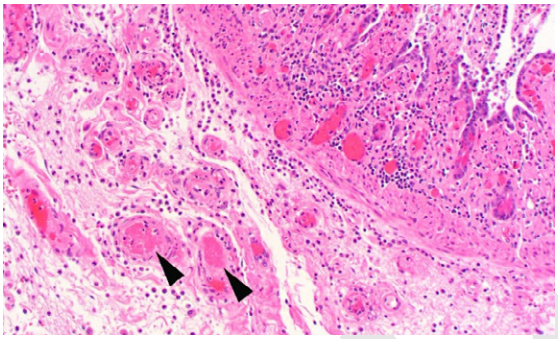


A B

Figure 2. Coronal (A) CT of the abdomen and pelvis with IV contrast in a 47-year-old man with abdominal tenderness demonstrates typical findings of mesenteric ischemia and infarction, including pneumatosis intestinalis (arrow) and non-enhancing bowel (*). Frank discontinuity of a thickened loop of small bowel in the pelvis (thin arrow) is in keeping with perforation. These findings were confirmed at laparotomy (B), with the additional observation of atypical yellow discoloration of bowel.

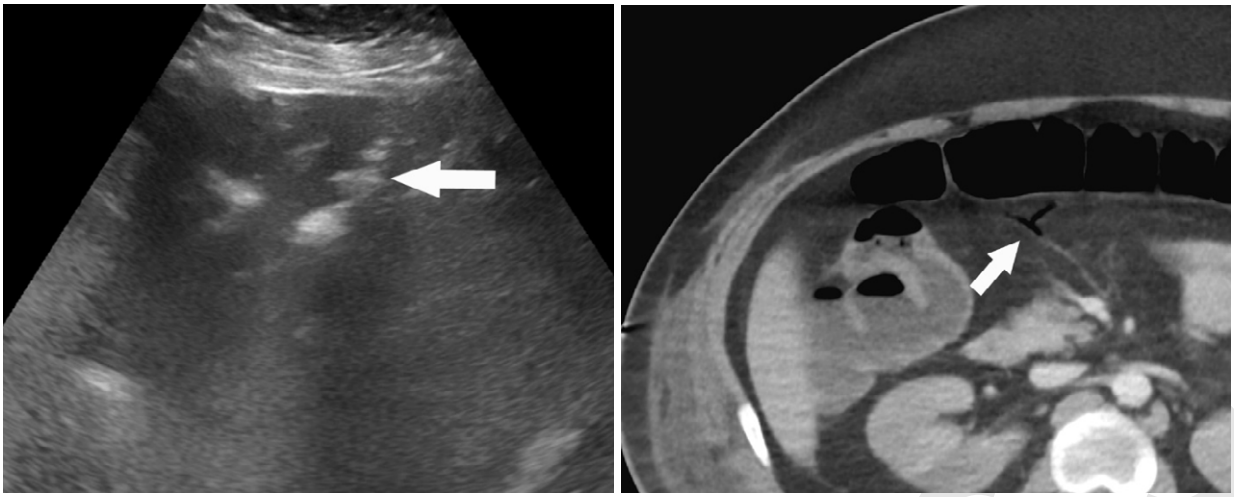


A B



C

Figure 3. Abdominal radiograph (A) in a 52-year-old man demonstrates portal venous gas (thin arrow in A), suggestive of bowel infarction. Post-operative CT (B) also demonstrates portal venous gas (thin arrow in B). At laparotomy, ischemic and necrotic bowel was identified along with an atypical yellow discoloration of small bowel. Photomicrograph (H and E, 400x) (C) demonstrated submucosal arterioles with fibrin thrombi (arrowheads). The overlying mucosa (upper right) is partially necrotic with crypt dropout and partial loss of the surface epithelium.



A B

Figure 4. Abdominal ultrasound (A) performed for elevated liver enzymes in a 34-year-old man incidentally noted peripheral echogenic branching foci (arrow) with dirty shadowing (*), in keeping with portal venous gas. Subsequent CT abdomen and pelvis with IV contrast (B) confirmed portal venous gas and demonstrated gas in the transverse mesocolon vasculature (arrow). At laparotomy, patchy areas of yellow discoloration were identified on the antimesenteric aspect of the transverse colon of uncertain etiology. Second look laparotomy demonstrated yellow discoloration of the stomach and no ischemia.

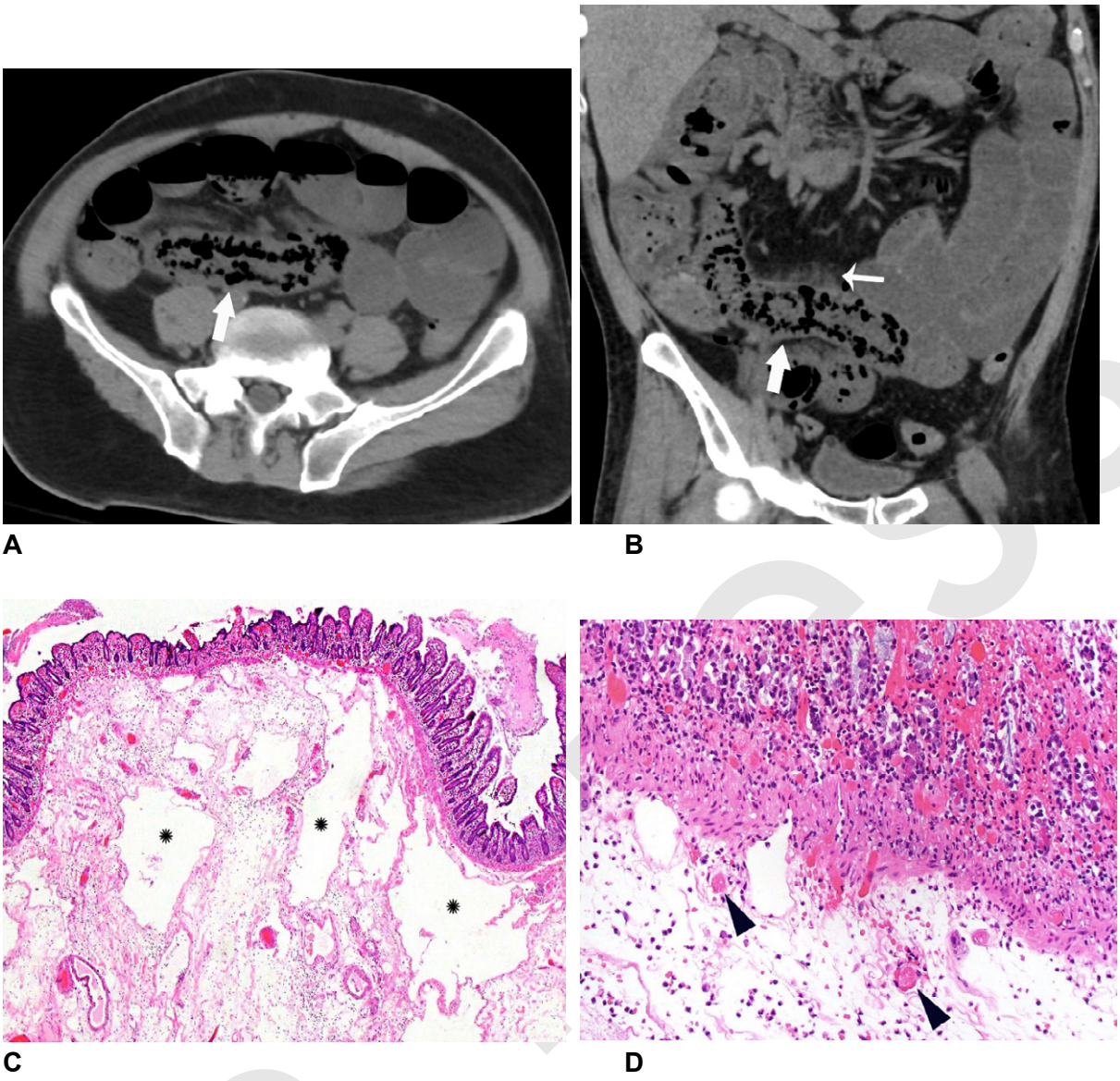


Figure 5. Non-contrast axial (A) and coronal (B) CT performed in a 54-year-old man demonstrates pneumatosis cystoides intestinalis (arrows) in a long segment of ileum. Adjacent mesenteric congestion is also noted (thin arrow). Laparotomy demonstrated no frank bowel necrosis. Low power photomicrograph (H and E, 40x) of the ileum (C) 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 (*). High power view (H and E, 400x) (D) of the superficial submucosa shows arterioles with fibrin thrombi (arrowheads) beneath the damaged mucosa.

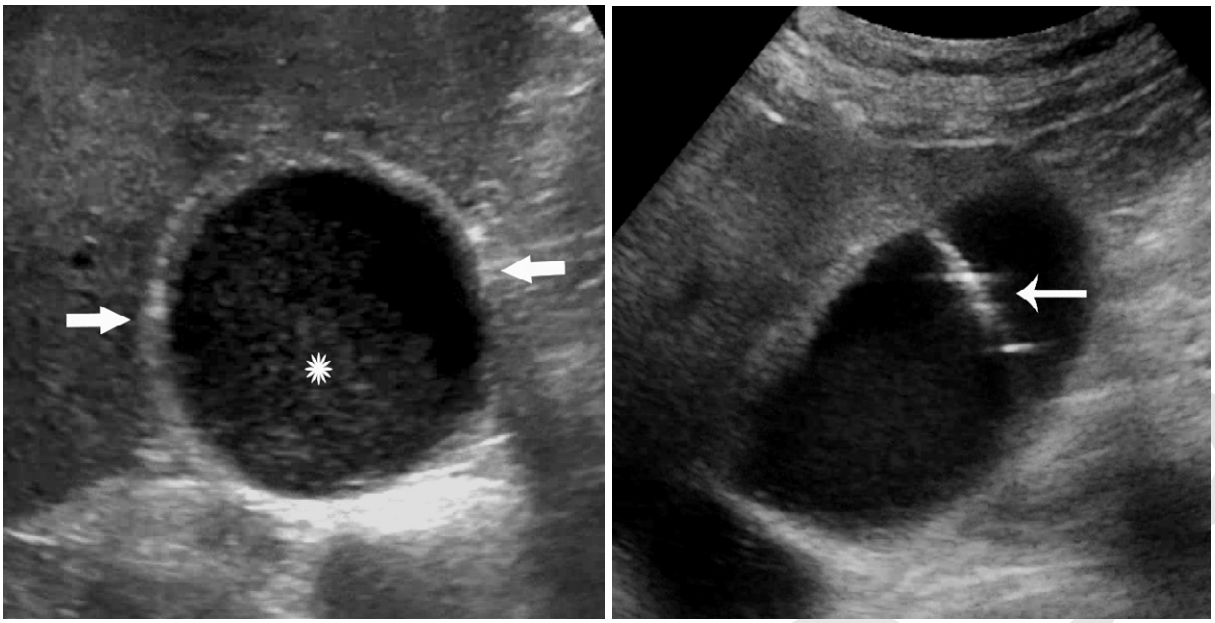


Figure 6. Abdominal ultrasound (A) in an 83-year-old man with elevated liver enzymes and sepsis demonstrated a distended gallbladder (arrows) containing sludge (*), suggestive of cholestasis. Intraprocedural ultrasound images (B) demonstrate a needle within the gallbladder lumen (thin arrow) while placing a cholecystostomy tube under ultrasound guidance. Fluid analysis revealed non-infected bile.