Scoping Review: Ultrasonographic evidence of intraabdominal manifestations of COVID-19 infection

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Introduction

We are confronted with a global pandemic caused by the novel SARS-CoV-2 coronavirus that in the majority of patients will only cause mild symptoms. The most common serious complication is COVID-19 pneumonia, however, gastrointestinal (GI) COVID-19 is also a frequent presentation and likely due to the high expression of the ACE2 receptor in the GI tract. As diagnostic ultrasound has been frequently used in the management of this patient cohort, we conducted a literature search with the aim to present and review the currently published evidence of using ultrasound examinations in the management of intraabdominal manifestations of COVID-19. Our analysis showed that sonographic abnormalities of the hepatobiliary system are the most commonly reported findings in adults, while gastrointestinal abnormalities are the most common findings in children. The most severe complications are related to thromboembolic complications in the intensive care unit.

Keywords: SARS-COV-2; COVID-19; gastrointestinal; liver; spleen; kidney

Abstract

COVID-19 is an infectious disease caused by the novel SARS-CoV-2 coronavirus that in the majority of patients will only cause mild symptoms. The most common serious complication is COVID-19 pneumonia, however, gastrointestinal (GI) COVID-19 is also a frequent presentation and likely due to the high expression of the ACE2 receptor in the GI tract. As diagnostic ultrasound has been frequently used in the management of this patient cohort, we conducted a literature search with the aim to present and review the currently published evidence of using ultrasound examinations in the management of intraabdominal manifestations of COVID-19. Our analysis showed that sonographic abnormalities of the hepatobiliary system are the most commonly reported findings in adults, while gastrointestinal abnormalities are the most common findings in children. The most severe complications are related to thromboembolic complications in the intensive care unit.

Keywords: SARS-COV-2; COVID-19; gastrointestinal; liver; spleen; kidney

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been infected and over 3 million people have died from COVID-19 by the end of 2021 [2]. Typical symptoms of the disease include dry cough and dyspnea, as well as fever and fatigue [3-5]. Severe infection of the lungs, which progresses to ARDS, occurs in up to 12% of hospitalized patients and most cases require intensive care [6]. In this population, lung ultrasound (US) has been frequently used because it is readily available at bedside, and has high diagnostic accuracy for a number of conditions without the use of intravenous iodinated contrast agent [5,7-13]. Typical US signs of pneumonia and acute respiratory distress syndrome (ARDS) in the course of COVID-19 were described. These included thickened and irregular pleural lines, B-lines as well as sub pleural consolidations with or without air bronchogram [7,14,15]. Pathophysiological mechanisms of COVID-19 appear to involve immunological, vascular and prothrombotic factors which lead to endothelial damage and thrombosis in the context of a cytokine storm, accompanied by remod-
eling of the vascular tissue and resulting hypoperfusion play a crucial role [16-18].

However, COVID-19 is not limited to the respiratory tract with emerging evidences suggest it rather represents a systemic disease with a variety of clinical manifestations [19]. Up to 50% of children as well as adults have been shown to experience gastrointestinal (GI) symptoms, which include diarrhea, nausea, vomiting, anorexia, and abdominal pain [20]. GI symptoms might precede other symptoms or even be the only manifestation of the disease, and thus can complicate the diagnostic process [21-23]. Involvement of the hepatobiliary system in COVID-19 may lead to abnormal liver function testing in up to 76% of hospitalized patients, regardless of preexisting hepatic conditions. It can be accompanied by symptoms of hepatitis or acute hepatic failure, especially during intensive care therapy [24,25]. Furthermore, involvement of the pancreas has been reported in up to 17% of cases ranging from asymptomatic elevation of serum amylase to fulminant pancreatitis [26,27]. Moreover, acute or chronic failure of renal function was observed in both children and adults in up to 46% of cases [28,29]. Symptoms comprise hematuria, proteinuria, but also oliguria and anuria and are most likely the result of immunological and micro thrombotic phenomena [29]. Finally, the lymphatic tissue and spleen may also be affected causing unspecific abdominal complaints and has been detected in children diagnosed with COVID-19 [30,31].

While US is usually a well-established imaging method for abdominal complaints, data concerning abdominal manifestation of COVID-19 appear scarce [7,32]. Therefore, our aim is to review and summarize the results of existing published data and to identify specific sonographic findings facilitating the diagnosis of abdominal COVID-19.

Methods

The Electronic Databases PubMed, Cochrane library and Google scholar were systematically searched. The MeSH key words used were “SARS-COV-2”, “COVID-19”, “ultrasound”, “ultrasonography”, “extrapulmonary”, “abdominal”, “gastrointestinal”, “hepatic”, “biliary”, “pancreatic”, “spleenic” and “renal” to identify publications related to gastrointestinal and abdominal (extra pulmonary) ultrasonographic findings of COVID-19. We included all types of clinical prospective and retrospective studies and single or multiple case studies. There was no restriction on age or gender for the search. Clinical symptoms and results of US had to be stated in the article; otherwise we excluded the publication from the analysis (table 1).

Results

The review comprised a total of 39 publications including two prospective and four retrospective studies, as well as several single or multiple case reports. In total, data of 175 patients were analyzed. The diagnosis of COVID-19 was confirmed in all patients with reverse-transcription polymerase chain reaction (RT-PCT). The mean age was 27 years (range: 2 months - 78 years) and about 90% of patients were male. All patients received an abdominal US. Out of 138 patients with available information, 96 patients (70%) showed abdominal symptoms. Notably, multiple patients experienced these prior to any respiratory complaints. In single and multiple case studies, there was a correlation of symptoms and US findings. In the prospective and retrospective trials, a clear correlation between US and clinical findings was not as clearly found.

Gastrointestinal tract

Overall we found that unspecific GI abnormalities detected by US were frequently reported, especially for children. We found 8 cases of ileocolic intussusception in infants up to ten months of age, hereof one with necrosis of the intestine. US examinations showing ileocolic intussusception reported typical findings such as “telescoping of bowl into bowl”, “doughnut sign” or a “swirl” of the intestines with layers of different echogenicity (fig 1). One case of pediatric intestinal necrosis presented with a significant amount of free intraperitoneal fluid on examination [40].

A single center study enrolling 44 patients with multisystem inflammatory syndrome in children (MIS-C) related to COVID-19 described US findings of thickened...
## Overview of ultrasonographic and clinical findings concerning abdominal manifestation of COVID-19

| Publication          | N  | Age             | Results of ultrasonography                                                                 | Clinical symptoms | Diagnosis                                      |
|----------------------|----|-----------------|------------------------------------------------------------------------------------------|-------------------|------------------------------------------------|
| **Gastrointestinal tract** |
| Ahtamnah [33]        | 1  | 2 mo            | Target sign of bowel                                                                      | Yes               | Ileocolic intussusception                       |
| Bazuaeye-Ekwuyasi [38]| 1  | 9 mo            | Concentric alternating echogenic and hypoechoic bands (target sign)                       | Yes, Yes          | Ileocolic intussusception                       |
| Cabrero-Hernández [45]| 3  | 9-12 y          | Signs of ileitis and colitis, intestinal inflammation                                    | Yes               | PIMS-TS                                         |
| Cai [40]             | 1  | 10 mo           | Free intraperitoneal liquid                                                                | Yes               | Ileocolic intussusception with necrosis         |
| Carducci [44]        | 2  | 13 y            | Widespread thickening of distal small intestine, small amount of ascites                  | Yes               | PIMS-TS                                         |
| Ekbatani [41]        | 2  | 10 y            | Acute appendicitis, multiple reactive mesenteric lymph nodes                              | Yes               | Acute appendicitis                             |
| Gutierrez-Jimeno [42]| 1  | 13 y            | Thickened appendix with destructured layers                                               | Yes, No           | MIS-C with acute appendicitis                  |
| Hameed [31]          | 18 | 1-17y           | 37% echogenic expanded mesenteric fat, 21% bowl wall thickening                           | Yes               | MIS-C                                          |
| Ibrahim [47]         | 1  | 33 y            | Dilatated fluid-filled intestinal loops in left lower quadrant                             | Yes               | Paralytic Ileus of large intestine             |
| Kangas-Dick [46]     | 1  | 74 y            | Free intraperitoneal liquid                                                                | Yes               | Upper gastrointestinal perforation             |
| Makrinioti [35]      | 2  | 10 mo           | Signs of ileocolic intussusception not further specified                                  | Yes               | Ileocolic intussusception                      |
| Martinez-Castano [36]| 1  | 8 mo            | “Swirl” of intestines with alternating hyper- and hypoechogetic layers                    | Yes               | Ileocolic intussusception                      |
| Miller [30]          | 12 | NA              | 16.7% thickened intestine in right upper quadrant, 8.3% prominent appendix vermiformis   | Yes               | MIS-C                                          |
| Moazzam [37]         | 1  | 4 mo            | Telescoping of bowel into bowl with doughnut sign in right upper quadrant                 | Yes               | Ileocolic intussusception                      |
| Morparia [43]        | 1  | 11 y            | Non-compressible, dilated appendix                                                        | Yes, No           | MIS-C with acute appendicitis                  |
| Rajalakshmi [39]     | 1  | 6 mo            | Signs of ileocolic intussusception not further specified                                  | Yes, No           | Ileocolic intussusception                      |
| **Hepatobiliary tract** |
| Abeysekera [60]      | 1  | 42 y            | No flow detectable in portal vein                                                         | Yes               | Thrombosis of portal vein                      |
| Bhayana [58]         | 37 | NA              | 54% dilatation of gallbladder with sludge, 5.4% thickening of gallbladder wall, 2.7% liquid in gallbladder base, 2.7% gas in portal vein | NA, NA           | NA                                              |
| Blumfield [49]       | 8  | 1-20y           | 75% Hepatomegaly, ascites                                                                 | Yes               | MIS-C                                          |
| Culver [51]          | 1  | 71 y            | Massive amount of free intraperitoneal liquid                                              | Yes, Yes          | Acute hepatic decompensation, Ascites Sars-CoV-2-positive |
| Dane [39]            | 1  | NA              | Thrombosis of portal vein tree                                                            | NA, NA           | Hypercoagulability                              |
| Effenberger [54]     | 32 | NA              | 50% increased liver stiffness in elastography                                             | Yes               | Acute hepatitis                                 |
| Hameed [31]          | 18 | 1-17y           | 16% periportal echogenicity, pericholecystic edema, mild gallbladder wall thickening and gallbladder sludge, 11% mild hepatomegaly | Yes               | MIS-C                                          |
| Hassani [57]         | 1  | 65 y            | Increased gallbladder wall thickness                                                      | Yes               | Acute cholecystitis                             |
| Lamazou [53]         | 1  | 35 y            | Sludge in gallbladder with no signs of inflammation                                        | Yes               | Liver cytolysis                                 |
| Mieczkowska [52]     | 1  | 43 y            | Hepatomegaly, hepatic steatosis and trace pericholecystic fluid                           | Yes               | Multisystemic inflammation syndrome            |
| Publication | N  | Age | Results of ultrasonography                                                                 | Clinical symptoms | Diagnosis                        |
|-------------|----|-----|--------------------------------------------------------------------------------------------|-------------------|----------------------------------|
| Miller [30] | 12 | NA  | 25% thickened gallbladder wall  
25% sludge in gallbladder  
25% ascites  
8.3% heterogenous coarse parenchyma of liver without focal lesion  
8.3% hepatomegaly with normal parenchyma and vascularity | Yes              | Yes                             | MIS-C              |
| Paz [62]    | 1  | 14 y| Biliary sludge, distended gallbladder with diffuse wall thickening, surrounding free fluid, meteorism | Yes               | No                              | Acute pancreatitis  |
| Tirumani [55]| 4 | NA  | 50% signs of hepatitis not further specified  
25% sludge in gallbladder | NA               | NA                              | NA                 |
| Ying [56]   | 1  | 68 y| Ultrasound-guided percutaneous transhepatic gallbladder drainage | Yes             | Yes                             | Acute cholecystitis  |
| Alloway [63]| 1  | 7 y | Diffuse pancreatic enlargement and heterogeneous pancreatic echogenicity | Yes             | No                              | Necrotizing pancreatitis |

**Pancreas**

| Publication | N  | Age | Results of ultrasonography                                                                 | Clinical symptoms | Diagnosis                        |
|-------------|----|-----|--------------------------------------------------------------------------------------------|-------------------|----------------------------------|
| Dietrich [21]| 1 | 72 y| Cholecystolithiasis without signs of obstruction, inhomogeneous pancreas                  | Yes               | Yes                             | Acute pancreatitis  |
| Hadi [64]   | 2  | 47 y| Diffuse increase in pancreatic volume without focal lesions or gallstones                | Yes             | Yes                             | Acute pancreatitis  |
| Samies [61] | 1  | 16 y| Mild hepatomegaly, one gallstone, prominent pancreatic head, tail and duct              | Yes             | No                              | Acute pancreatitis  |

**Renal and urinary tract**

| Publication | N  | Age | Results of ultrasonography                                                                 | Clinical symptoms | Diagnosis                        |
|-------------|----|-----|--------------------------------------------------------------------------------------------|-------------------|----------------------------------|
| Berteloot [65]| 7 | 3-17 y| Spectral Doppler: stenosis of renal artery, increased peak systolic velocity | No               | No                              | Immune postviral vasculitis in renal graft after transplant |
| Blumfield [49]| 8 | 1-20 y| 63% hyperechogenic kidneys  
13% urinary bladder wall thickening | Yes             | Yes                             | MIS-C              |
| Fogagnolo [66]| 15| 55-69 y| Doppler: increased renal resistance index,  
71% not continuous venous flow | Yes             | Yes                             | Acute kidney injury in 53% |
| Gopalakrishna [70]| 1| 49 y| Slightly echogenic kidneys              | Yes             | Yes                             | Acute kidney injury  |
| Jung [67]    | 5  | 51-74 y| Color Doppler: increased renal resistance index  
CEUS: segmental infarction 20%, partially reduced cortical microcirculation | Yes             | Yes                             | Acute or acute on chronic kidney disease  |
| Hameed [31]  | 18 | 1-17 y| 5.5% echogenic kidneys                  | Yes             | Yes                             | MIS-C              |
| Tancredi [69]| 1  | 38 y| Increased renal parenchymal echogenicity  
Color Doppler: decreased global signal, elevated resistance indices | Yes             | Yes                             | Acute kidney injury  |
| Harwood [71]| 2  | 14 y| 25% increased renal cortical echogenicity  
Echo-dense and enlarged kidneys with high resistance indices (>0.8)  
CEUS: delayed renal perfusion | Yes             | Yes                             | NA                 |
| Miller [30]  | 12 | NA  | 16.7% mesenterial lymphadenopathy in right hemiabdomen                                    | Yes             | Yes                             | MIS-C              |

**Spleen and lymphatic system**

| Publication | N  | Age | Results of ultrasonography                                                                 | Clinical symptoms | Diagnosis                        |
|-------------|----|-----|--------------------------------------------------------------------------------------------|-------------------|----------------------------------|
| Blumfield [30]| 8 | 1-20 y| 13% splenomegaly  
11% borderline splenomegaly, subcortical and hypoechoic splenic lesions | Yes             | Yes                             | MIS-C              |
| Hameed [31]  | 18 | 1-17 y| 47% enlarged lymph nodes  
11% borderline splenomegaly, subcortical and hypoechoic splenic lesions | Yes             | Yes                             | MIS-C              |
| Harwood [71]| 2  | 14 y| Mesenteric adenitis                                                                       | Yes             | Yes                             | PIMS-TS            |

N: Number of cases; Abd.: Abdominal; Resp.: Respiratory; PIMS-TS: Pediatric Inflammatory Multisystem Syndrome temporally associated with SARS-CoV-2-infection; MIS-C: Multisystemic inflammatory syndrome in children; NA: not available
intestinal walls within the right upper quadrant in 16.7% and a prominent appendix vermiformis in 8.3% of their participants [30] (fig 2). US evidence of appendicitis in three more cases was reported in children with non-specific malaise due to COVID-19 [41-43].

More general signs of inflammation concerning the small and large intestines, such as bowel wall thickening or fluid surrounding the loops were reported in children presenting with generalized illness, abdominal symptoms or acute abdomen as a part of the Pediatric Inflammatory Multisystem Syndrome temporally associated with SARS-CoV-2 infection (PIMS-TS) [31,44,45]. Two case reports showed US findings of gastrointestinal involvement in critically ill adult males with COVID-19. One case showed a significant amount of free intraperitoneal fluid that was later identified as enteric content due to upper GI perforation [46]. The other case showed signs of an ileus such as dilatation of multiple fluid-filled bowel loops in a patient requiring intensive care [47].

**Hepatobiliary tract**

Hepatic laboratory anomalies are often observed in SARS-CoV-2 infection [48]. Hepatobiliary abnormalities on US of children were so far only described in MIS-C. According to Miller et al, 25% of children with MIS-C presented with a thickened gallbladder wall and sludge on US. Another 8.3% showed either parenchymatous abnormalities of the liver without specific lesions or liver enlargement with normal liver echo texture and vasculature. Presence of any abdominal symptoms was documented in 84% of the included cases [30]. Hameed et al revealed significant ascites in 53% of the included children with MIS-C and 16% were reported to have biliary abnormalities such as gallbladder sludge or wall thickening, pericholecystic edema and increased portal echogenicity. In 11% of the cases, the liver was enlarged on US [31]. A retrospective study of the same population reported even higher odds of hepatobiliary involvement, with up to 75% of patients showing hepatomegaly and ascites and 38% presenting with a thickened gallbladder wall [49]. Meanwhile, evidence of hepatobiliary manifestation of COVID-19 is frequently reported in adult patients. A retrospective study of 30 ICU patients revealed solitary hepatomegaly in 56% of their patients [50]. Acute hepatic decompensation was found to be diagnosed in cases with and without preexisting liver conditions. However, one single case study of an elderly male patient with liver cirrhosis Child-Pugh-B showed massive new ascites and RT-PCR of the fluid was positive for Sars-CoV-2 [51]. Particularly in cases of severe COVID-19, the risk of acute liver injury appears to be increased [52,53]. As acute liver injury is associated with increasing liver stiffness and elevated liver enzymes, an association between these two measures and disease severity could be found in COVID-19 [54]. Moreover, several investigators reported patients with US signs of hepatobiliary tract inflammation. A retrospective study on 73 patients with COVID-19 described non-specific signs of hepatitis in 50% and gallbladder sludge in 25% of the patients. Interestingly, the bowel abnormalities were the most frequent finding in the abdomen, but the majority of patients had no abdominal complaints. GI findings appeared independent of the severity of pulmonary involvement or laboratory markers [55]. Two other case reports of US findings of acute cholecystitis showed increased gallbladder wall thickness and one required percutaneous transhepatic gallbladder drainage with US guidance [56,57]. Gallbladder dilatation and sludge were further reported in 54% of patients of a retrospective cross-sectional study of 134 patients. Within the same population, 27% of participants presented with a fatty liver and 2.7% revealed a thickened gallbladder wall or fluid surrounding the gallbladder, or signs of gas in the portal vein [58]. Venous thrombosis of abdominal vasculature, such as thrombosis of the portal vein, has also been reported [59,60]. One patient was a middle-aged man with both abdominal and respiratory symptoms, while the other
case was described as part of a larger retrospective trial without additional information.

**Pancreas**

Three cases of acute pancreatitis associated with COVID-19 in children and two cases in adults were identified. In a 14 year old boy, US revealed prominence of the whole pancreas as well as its duct, associated with mild hepatomegaly and a solitary gallstone [61]. In the other case, an adolescent male patient had a distended gallbladder with thickened walls, biliary sludge and a small amount of free fluid, but no pancreatic abnormalities [62]. In another young and otherwise healthy 7 year old girl, US revealed diffuse pancreatic enlargement and heterogeneous pancreatic echogenicity [63]. Moreover, the three children with COVID-19 associated pancreatitis did not present with any respiratory manifestation of the disease [62,63].

In adult patients, a case series reported acute pancreatitis in two of three family members with severe COVID-19. Here, US revealed an increased pancreatic volume without signs of necrosis, focal lesions, or gallstones [64].

**Kidneys and urinary tract**

US renal abnormalities in children and adults were mostly related to disturbances of the renal perfusion going along with acute or acute on chronic kidney disease. In children with MIS-C, the main US findings were echogenic kidneys in up to 63% in one study, but only reported in 5% in another [31,49]. Berteloot et al performed US in children after kidney transplantation, which were diagnosed with immune post viral graft vasculitis related to COVID-19. They found stenosis of the renal artery with increased peak systolic velocity using spectral Doppler US [65]. Furthermore, a thickened wall of the urinary bladder was described in a child with MIS-C [49]. Similar results were obtained in adult patients with COVID-19. A prospective study found an increased renal resistance index measured with Doppler US in all their patients and additionally a not continuous pattern of venous flow in 71% of their study sample of 15 patients [66]. The same result was reported by Jung et al, who also performed contrast enhanced US (CEUS) in 5 COVID-19 patients, which additionally revealed a segmental renal infarction with reduced cortical microcirculation in one patient [67]. Elevated resistance indices were also reported in one case where US discovered decreased global perfusion of the enlarged and echogenic kidney on CEUS [68,69]. Echogenic kidneys on US were found in one retrospective study of 73 patients and one case report described a previous healthy young adult male progressing to acute kidney injury in the setting of worsening COVID-19 [55,70]. Acute kidney injury due to COVID-19 is thought to be multifactorial, including from micro thrombi formation leading to tissue ischemia, virus-mediated cytokine storm and direct viral effects on renal parenchyma as ACE-2 expression in urinary organs are nearly 100-fold higher than in respiratory organs [68].

**Spleen and lymphatic system**

Splenic manifestations detected on US were reported in children with MIS-C due to COVID-19. Two studies of 35 and 16 pediatric patients found an enlarged spleen in 11–13% of the included patients, in one case even with focal hypoechoic splenic lesions [31,49]. Lymphadenopathy was frequently described on abdominal US of children with COVID-19. Miller et al found prominent lymphatic tissue in the right hemi abdomen in 16.7% of their 40 included patients [30]. Mesenterial lymphadenitis was further reported in two girls with PIMS-TS [71]. Moreover, Hameed et al revealed enlarged intraabdominal lymph nodes in 47% of their patients, with 37% showing echogenic expansion of the mesenteric tissue [31].

**CEUS for abdominal imaging of COVID-19 infection**

CEUS offers the possibility to analyze dynamic microcirculatory disturbances in real time dynamically without any risk for kidneys and thyroid gland even in severe progressing disease bedside. Based on severe COVID-19 infections, first experiences with abdominal CEUS examinations are presented. In the stage of an imminent organ failure with significantly reduced kidney and liver function, CEUS can be used to show a narrowing of the organ-supplying arteries, as well as a delayed capillary filling of vessels near the capsule, a regional reduced parenchymal perfusion or an inflammatory hyperemia with capillary hyper circulation. It is possible to quickly rule out organ infarction and to dynamically record the mesenterial arterial and venous blood flow [67]. The first results on abdominal diagnostics confirm the assessment that CEUS can also detect peripheral reduced blood flow, embolisms in the context of pulmonary artery embolism, micro infarctions and reactive hyperemia in the case of consolidations and pleural irritation in the periphery of the lungs. In this way, CEUS can contribute to improving follow-up checks in the event of severe infection constellations and embolisms in the case of COVID-19 infections [9,12,13,72] (fig 3).

In the case of COVID-19, CEUS is restricted in the event of severe disease progression by the fact that the use of Sulfur hexafluoride Microbubbles (SonoVue®) as US contrast agent can lead to right heart stress with pulmonary hypertension. A restricted right heart function is often part of the serious course of the disease with COVID-19 infections. For a seriously ill COVID-19 patient, examinations with computed tomography (CT) also meant complex repositioning and transport with a
high level of personnel care. In addition, the contrast agent used in CT imaging can pose a not inconsiderable risk for the kidneys, which are often already functionally impaired. This would be one of the starting points for CEUS, since the use of SonoVue® does not impair kidney function. In preliminary investigations, the potential of CEUS for dynamic recording of organ micro perfusion in the case of a severe course of a COVID-19 infection with regard to abdominal US could be shown. Our initial experience indicate reactive changes with hyperemia, peripheral mosaic perfusion, peripheral micro embolism, infarcts and vascular thrombosis (fig 4-6). This enables a targeted control with CEUS in correlation to the CT. In addition, CEUS also enables the dynamic assessment of organ micro perfusion, especially of the liver, spleen and kidneys. Here, hypoperfusions are common in severe infectious to septic clinical pictures and, as with COVID-19 patients, may require the use of an ECMO treatment.

The use of CEUS for lung diagnostics is reserved for individual cases. However, especially in the stage of increasing kidney function restriction, CEUS can open up new diagnostic possibilities with regard to changes in microvascularisation. These must be examined multicentrically before a final assessment is possible. Acute kidney injury (AKI) is a common complication of COVID-19 critical illness but the pathophysiology is uncertain. CEUS-derived parameters were reduced in COVID-19 associated AKI compared with healthy controls (perfusion index 3.415 vs. 548, p=0.001; renal blood volume 7.794 vs. 3.338, p=0.04). Renal arterial flow quantified using time averaged peak velocity was also reduced compared with healthy controls (36.6 cm/s vs. 20.9 cm/s, p=0.004) despite cardiac index being similar between groups (2.8 l/min/m² vs. 3.7 l/min/m², p=0.07). Patients with septic shock had more heterogeneous perfusion variables. Both large and small vessel blood flow was reduced in patients with COVID-19 associated AKI compared with healthy controls, which does not appear to be a consequence of right or left heart dysfunction. A reno-vascular pathogenesis of COVID-19 AKI seems likely [73].

**Point of care US**

Due to its easy application and its high diagnostic reliability, point-of-care US systems of the latest generation represent a valuable imaging method for the primary

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**Fig 4.** A 69 years old patient with severe symptoms of a COVID-19 infection: thrombosis of the inferior caval vein with echo-inhomogeneous material inside of the lumen without contrast enhancement (arrow).

**Fig 5.** A 65 years old patient with severe symptoms of a COVID-19 infection: echo-inhomogeneous parenchymal kidney structures, partial edema, local inflammatory reaction by micro-embolic changes (arrow).
assessments of abdominal and thoracic findings, especially in patients on geriatric and intensive care units or in emergency situations [74-77].

**Discussion**

This review identified 39 studies reporting US findings of intraabdominal manifestations of COVID-19. We structured these findings according to the corresponding anatomy of GI, hepatobiliary, kidneys, and the lymphatic system. If available, additional clinical information was provided. Although according to the current literature, children and adults suffer similarly from GI symptoms due to COVID-19, we found more results were reported concerning children. Pathologies such as intussusception in infants seem to be of great clinical relevance and can readily be detected using US. Avoidance of ionizing radiation and potentially harmful contrast agents are important factors to consider in this population [32]. On the contrary, hepatic and biliary abnormalities appear to be more common findings in adults. However, the clinical importance of findings such as gallbladder sludge is not clear, as it may not necessarily be linked to COVID-19. Remarkably, many hepatobiliary pathologies were detected in clinically severe cases of both children and adults [30,49,53]. A possible explanation might be virally induced decompensation of a preexisting condition [51]. Similar results were found concerning acute pancreatitis and AKI [21,31,49,61,63,64,66]. The latter can also be observed in the context of acute on chronic failure of renal function. Here, renal perfusion appears compromised and thus limiting the functional capacity of the organ [66,67]. This might be due to hyper inflammation promoting a prothrombotic state not only affecting the kidneys but also other organ systems [16]. Hypercoagulability might eventually lead to end organ ischemia due to the resulting micro- and macroangiopathy, as well as manifest as thrombosis and embolism [17,18]. Although similar phenomena are known in sepsis, the mechanisms involved in COVID-19 might be particular because of their linkage to the ACE-2 receptor, which contributes to the widespread endothelial dysfunction [18]. These mechanisms might also have an impact on changes in the lymphatic organs and the spleen. However, due to their role in immune response, they might also experience unspecific alterations linked to the state of infection in general [49].

While rather specific signs of pneumonia and ARDS due to COVID-19 could be identified using lung US, the results concerning the abdomen do not appear to offer the same specificity [7,14,15]. Nevertheless, they often reflect the general clinical state and correspond to certain symptoms, e.g. an edematous pancreas in Sars-CoV-2-induced pancreatitis [61]. Hence, US provided valuable information for the clinician, often relevant for further therapy and course of the disease. To determine potentially more specific intraabdominal US findings linked to COVID-19, larger cohort studies are required.

**Conclusion**

Intraabdominal manifestations of COVID-19 are common and end organ abnormalities can be readily diagnosed on multiparametric US examinations at bedside. COVID-19 specific US findings within the abdomen have not yet been reported, but the reported results often correlated with the clinical presentation. Thus, US has the potential to impact a patient’s clinical course and therapy, and is therefore of great value.

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