Impact of COVID-19 on Nonpulmonary Critical Illness

Prevalence, Clinical Manifestations, Management, and Outcomes

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KEYWORDS

• COVID-19 • Organ failure • Critical illness • Sepsis

KEY POINTS

- SARS-CoV-2 infection has a significant influence on multiple organ systems in the body, a distinctive feature compared with past viral epidemics.
- It is uncommon for hospitalized patients to need nonpulmonary organ support without respiratory failure.
- Nearly every organ failure is independently associated with poorer outcomes in COVID-19 infection.
- Long-term outcomes of isolated and multiorgan failure are underway.

INTRODUCTION

During the past 2 years, SARS-CoV-2 has infected millions of patients worldwide, contributing to 513 million cases and 6.2 million deaths[1] as of May 1, 2022. Although respiratory manifestations are the most common driver of hospitalization, SARS-CoV-2 infection has a wide range of manifestations, including multisystem organ failure in severe cases (**Fig. 1**, **Table 1**). In this review, we discuss the prevalence, pathophysiology, clinical manifestations, treatment, and outcomes of nonpulmonary organ dysfunction from SARS-CoV-2.

Sepsis and Multiorgan Failure

Prevalence

Before the COVID-19 pandemic, viral sepsis was an underrecognized cause of sepsis in adults.[2] However, sepsis may result from any type of infection, including viruses such as influenza, MERS, SARS, and SARS-CoV-2.[3,4] In a meta-analysis by Karakike *and colleagues* of 151 studies published between August 2020 and March 2021 including 218,184 patients hospitalized with COVID-19 (mostly in Asia, Europe, and North America), the prevalence of sepsis (inferred by SOFA scoring, acute organ dysfunction, or organ support) was 33% among ward-treated patients, 78% among intensive care unit (ICU)-treated patients, and 52% overall (**Table 2**).[2] Among ICU-treated patients, the most common organ supports were mechanical ventilation (60%), vasopressor therapy (50%), and renal replacement therapy (RRT; 20%).[2] Overall, although respiratory support was most common, a large proportion of ICU hospitalizations for COVID-19 required nonpulmonary organ support.

In the Society of Critical Care Medicine (SCCM) VIRUS cohort of 20,608 adult hospitalizations for COVID-19 in 16 countries during February to November 2020, 15,001 (72.3%) patients required

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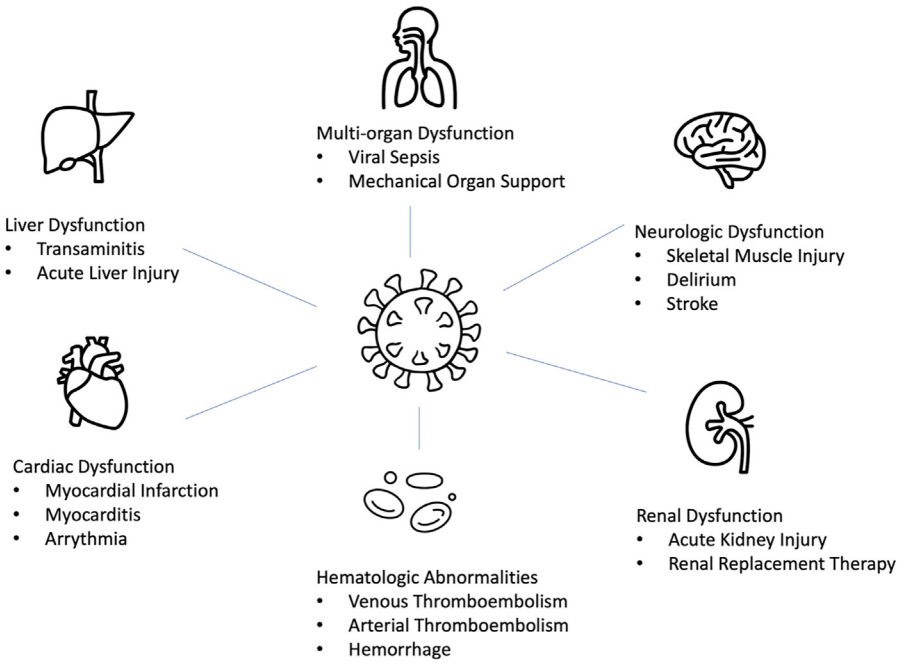

Fig. 1. Nonpulmonary critical organ dysfunctions due to COVID-19 infection.

no organ support, 5005 (24.3%) required invasive mechanical ventilation (IMV), and 602 (2.9%) required vasopressor therapy and/or acute RRT without IMV. Of the 5005 who required IMV, 1749 (34.9%) required IMV only; 2032 (40.6%) required IMV and vasopressors; 655 (13.1%) required IMV, vasopressors, and RRT; 180 (3.6%) required IMV and RRT; and 389 (7.8%) underwent extracorporeal membrane oxygenation.[5] Among 5837 patients in the Health Outcome Predictive Evaluation (HOPE) COVID-19 registry, an international registry of patients hospitalized from March to June 2020 in 8 countries, patients with COVID-19 who developed viral sepsis were older, admitted sooner after symptom onset, and had higher burden of comorbid disease.[6]

Pathophysiology

SARS-COV-2 enters the human host by inhalation. Once viral particles are inhaled, a spike protein on the virus surface attaches to the angiotensin 1 converting enzyme 2 (ACE-2) receptor, then relies on transmembrane protease serine 2 (TMPRSS2) expressed on the surface of respiratory epithelium to enter the cell.[7,8] Once inside the host cell, the virus can replicate. The ACE-2 receptor and TMPRSS2 have been identified in lung alveolar epithelial cells, but also on many other cell types, suggesting that direct viral invasion may be a common mechanism of injury across organs. Beyond direct viral invasion, several other mechanisms may be implicated, including endothelial damage with thrombo-inflammation,[9] dysregulation of the immune response via high serum level of proinflammatory cytokines such as interleukin (IL) 6 and IL-1 beta, and tumor necrosis factor,[8,10] viral sepsis-induced immune paralysis,[6] and dysregulation of the renin-angiotensin-aldosterone system.[9] Mechanisms of specific organ dysfunctions are discussed further in sections specific to each organ.

Clinical Manifestations

Respiratory failure is the most common organ dysfunction in COVID-19, and other organ dysfunctions rarely occur without respiratory dysfunction. In the HOPE-COVID-19 registry, patients with COVID-19-related sepsis had higher levels of D-dimer, procalcitonin, CRP, troponin, transaminases, ferritin, LDH, and creatinine.[6] Prevalence of leukocytopenia and lymphocytopenia, however, were similar among patients with versus without sepsis.[6] The parsimonious HOPE Sepsis Score identified the following risk factors for sepsis during COVID-19 hospitalization: current smoking, respiratory rate, SpO_2, blood pressure, Glasgow Coma Scale, procalcitonin, troponin I, creatinine, and hemoptysis.[6]

Outcomes

Hospital mortality for COVID-19 is strongly associated with the severity and number of acute organ dysfunctions. In the SCCM VIRUS cohort,

Table 1
Prevalence of organ dysfunction by hospitalization status and association with mortality

Organ Dysfunction	General Prevalence in Hospitalized Patients	ICU Prevalence	Association with Mortality
Sepsis[2]	5% (pooled)	Septic shock 36.4%; Lactate elevated (>2 mmol/L) 47.2%	Mortality could not be assessed separately for patients with and without sepsis because none of the studies reported such outcomes
Cardiac[42,43,89]	21%–45% with troponin elevation; 10%–20% with symptomatic dysfunction	Troponin elevation more common in patients requiring >50% Fraction of inspired oxygen support	Troponin elevation has 2.7× risk in-hospital mortality and associated with 2× increase in major complications, including sepsis, acute kidney failure, multiorgan failure, pulmonary embolism, and major bleeding
Renal[2,30,31,39]	37% to 46% with AKI defined by KDIGO[29] criteria	28.6% to 76% with AKI; 19% received renal replacement therapy	3.4× risk in-hospital mortality; 50% with AKI vs 8% without AKI
Liver[2,51,56]	14% (>2–3 UNL transaminitis); 58%–62% (>ULN)	20.3%	Elevation in AST and direct bilirubin on admission associated with 2× increase in hospital mortality
Neurologic[57]	Fatigue (31%) and myalgia (30%) more common in hospitalized COVID-19 cases; stroke 2%	Skeletal muscle injury (5%) and disturbances of consciousness more likely in severe than nonsevere COVID-19 infection; 50% delirium	In patients ≥60 y of age, the presence of any neurologic manifestations was significantly associated with increased mortality (OR 1.80, 95% CI 1.11–2.91); nonsignificant higher odds of mortality in all patients with neurologic manifestations compared with those without them (OR 1.39)
Coagulopathy[71,81,90]	8%–21%	Pooled prevalence of VTE 24%–31%	Pooled odds mortality 74% higher (OR 1.74) for patients with VTE

in-hospital mortality among 5005 IMV-treated patients was 50% versus 8% among 15,001 patients without organ support.[5] In-hospital mortality increased with additional organ supports from 41% among IMV-treated patients to 71.6% among patient receiving IMV, vasopressors, and RRT (n = 655).[5] In the meta-analysis by Karakike *and colleagues*, in-hospital mortality was 33% among ICU-treated patients, and 42% among IMV-treated patients.[2]

Table 2
Multiorgan dysfunction studies in detail

Study Author	Study Characteristics; Patient No.	Dates of Study	Findings	Conclusion
Karakike et al[2] 2021(Meta-analysis)	151 studies; 218,184 patients Forty-seven studies reported results from Asia, mainly China (21 studies), 21 from North America, 7 from Central and South America, 73 across Europe, one from Australia, and 2 were international	104 studies published in 2020 and 47 published in 2021	Sepsis prevalence was 77.9% (95% CI, 75.9–79.8; I2 = 91%; 57 studies) in the ICU, and 33.3% (95% CI, 30.3–36.4; I2 = 99%; 86 studies) in the general ward Pooled prevalence of organ support: vasopressor use 9.5%; Noninvasive ventilation (NIV) 20.9%; IMV 62.4%; Extracorporeal membrane oxygenation 6.2%; Continuous renal replacement therapy/ dialysis 19.9% Pooled prevalence of organ dysfunction: Septic shock 36.4%; lactate elevated (>2 mmol/L) 47.2%; renal dysfunction 28.6%; coagulopathy 17.7%, liver dysfunction 20.3%, CNS dysfunction 8.8%, acute respiratory distress syndrome (ARDS) 87.5%, mild ARDS 21.5%, moderate ARDS 43.7%, severe ARDS 32.1%	The majority COVID-19 patients hospitalized in the ICU meet Sepsis-3 criteria and present with infection-associated organ dysfunction. Awareness and systematic reporting of COVID 19 viral sepsis is crucial to understand prognostic and treatment implications
Domecq et al.[5] 2021(Registry)	16 countries; 168 hospitals (150 from the United States); 20,608 patients	Patient hospitalized from February 15, 2020, to November 30, 2020	Mean age 60.5 y, 54.3% men; 42.4% were admitted to the ICU Organ Support and Mortality: IMV Only 40.8%; IMV + vasopressors 53%; IMV + vasopressors + RRT 71.6%; ECMO 35%; No organ support 8.2%; All patients 19%	Prognosis varies by age and level of organ support. Interhospital variation in mortality of mechanically ventilated patients was not explained by patient characteristics and requires further evaluation

Management

Treatment of COVID-19-related sepsis focuses on resuscitation and supportive therapy, as with other causes of sepsis.[11] Although antibacterial therapy is crucial to the treatment of bacterial sepsis, anti-SARS-CoV-2 therapies such as antivirals and monoclonal antibodies are most effective in earlier phases of SARS-CoV-2 infection, before the onset of acute organ dysfunction.

There has been particular interest in regulating the hyperinflammatory response to SARS-CoV-2 and subsequent viral-induced immunosuppression.[11] High-quality evidence indicate that corticosteroids,[12]IL-6 inhibition,[13] and JAK inhibition[14] reduce mortality, and these therapies are broadly recommended in COVID-19 treatment guidelines.[15] However, timing of initiation is important, and patients should be initiated on these therapies promptly on meeting illness severity criteria. Research is ongoing to clarify the optimal dosing regimens and patient populations for these therapies.

Beyond corticosteroids and IL-6 inhibitors, many other therapies under investigation for treatment/mitigation of disease, including stem cell therapy,[16] short-chain fatty acids,[17] anakinra,[18] infliximab,[19] cytokine therapy (ie, IL-17 inhibitors),[20] vitamin D,[21] vitamin C,[22,23] fecal microbiota transplantation,[24] blood filters,[25] convalescent plasma,[26] plasma exchange,[27] and CRP-apheresis.[28]

Acute Renal Dysfunction

Prevalence

RRT for acute renal failure is the third most common organ support among patients with COVID-19. In a cohort of 3993 patients hospitalized with COVID-19 at 5 hospitals in New York during March to May 2020, 46% had acute kidney injury (AKI, defined by Kidney Disease Improving Global Outcomes criteria[29]), including 76% of ICU-treated patients.[30] About 19% of patients with AKI received RRT.[30] In a separate cohort of 5449 patients hospitalized with COVID-19 at 13 hospitals in New York during March to May 2020, 37% had AKI, including 90% of IMV-treated patients. Renal failure and RRT were largely limited to patients with respiratory failure. Indeed, in the 13-hospital New York cohort, nearly all patients treated with RRT were also receiving IMV.[31] In the meta-analysis by Karakike *and colleagues*, the pooled prevalence of RRT among ICU patients with COVID-19 was 20%.

Histology and pathophysiology

The hypothesized mechanisms of COVID-19-related AKI are largely drawn from biopsy and autopsy studies. In a series of 10 patients with COVID-19-related renal failure requiring RRT, the most common histologic finding was acute tubular injury,[32] with ACE2 highly expressed on proximal tubular cells.[33] In a series of 63 decedents with COVID-19 respiratory infection, SARS-CoV-2 RNA was detected in 60%, including 72% of decedents with AKI.[34] Other findings included thrombotic microangiopathy, pauci-immune crescent glomerulonephritis, widespread myoglobin casts.[32] Several studies found evidence of live virus, suggesting direct kidney tropism through angiotensin-converting enzyme-2 receptors expressed on proximal tubule cells and podocytes.[34] Additionally, microthrombi formation of the capillaries around the renal tubulars was seen on autopsy, suggesting a hypercoagulable effect.[33,35] Whether from direct viral invasion, hypoxia, or hypercoagulability, there may be indirect causes for renal injury including hemodynamic instability, mitochondrial dysfunction,[36] excessive diuresis, nephrotoxic exposure, cytokine storm, and rhabdomyolysis.[34]

Clinical manifestations

COVID-19-related AKI manifests as decreased glomerular filtration, elevated serum creatinine and BUN, frequent proteinuria,[30,33,37] and occasional hematuria and leukocyturia.[30] In a cohort of 182 patients hospitalized with COVID-19-associated AKI, serum creatine was similar, proteinuria was more common, and dialysis was more common than in non–COVID-19-related AKI.[38]

Outcomes

The development of COVID-19-related AKI is associated with worse outcomes, particularly among patients requiring RRT. Although AKI is a marker of worse disease, the association persists after adjustment for illness severity, suggesting that renal injury may also directly contribute to worse outcomes. In the 13-hospital New York cohort, the development of AKI was associated with a 3.4-fold increased risk of in-hospital mortality in adjusted analysis, whereas RRT was associated with 6.4-fold increased risk.[39] In the 5-hospital New York cohort, in-hospital mortality was 50% among patients with COVID-19 and AKI versus 8% among patients without renal injury.[30] Furthermore, among 832 patients with AKI who survived to hospital discharge, 35% had not returned to baseline renal function by discharge.[30] In a single-center telephone follow-up of 300 patients who survived ICU hospitalization for COVID-19 during March to April of 2020 in New York, only 42% survived to 6 months

postdischarge. At 6 months postdischarge, AKI recovered in 74% of survivors, including 77% who liberated from dialysis.[40]

Management

Treatment strategies for COVID-19-related AKI are similar to standard management of AKI from other causes. Management focuses on mitigating further renal injury through avoidance of nephrotoxic medications, renally dosing medications, and maintaining perfusion to the kidney. The threshold for initiating RRT is similar to non–COVID-19-related renal failure. Clotting of continuous renal replacement therapy (CRRT) filters has led to significant resource utilization. In a case series of 65 patients who received CRRT for COVID-19-related renal failure at a single U.S. hospital, 85% lost at least one filter, with a median filter life of only 6.5 hours.[41] Studies are underway testing interventions to mitigate progression of renal disease, including oral medications targeting inflammatory pathways (NCT05038488) and treatments such as CRP-apheresis (NCT04898062) (**Table 3**).

Cardiac Dysfunction

Prevalence

The spectrum of cardiac manifestations of COVID-19 includes asymptomatic cardiac biomarker elevation and symptomatic cardiac dysfunction such as heart failure, arrhythmia, and sudden cardiac arrest. Biomarker elevation occurs in approximately 20% to 35% of patients hospitalized with COVID-19. In a meta-analysis of 35 studies of 22,473 patients hospitalized in 2020 with COVID-19, troponin was elevated in 21% of patients tested on admission.[42] In a cohort of 2736 patients hospitalized in single system in New York, troponin was elevated in 36%.[43] Symptomatic cardiac dysfunction is present in approximately 10% to 20% of hospitalized patients. In a study of 748 patients hospitalized in Europe and Australia during January-October 2020, 141 (19%) had an acute cardiac complication, including cardiovascular death (7%), heart failure (5%), pulmonary embolism (5%), sustained supraventricular tachycardia or ventricular arrhythmia (4%), cardiac arrest (2%), myocarditis (2%), and acute coronary syndrome (1%).[44]

Pathophysiology/mechanisms

SARS-COV-2 is hypothesized to cause cardiac injury via endothelial inflammation, immune activation, direct myocardial injury, acute right heart strain secondary to acute respiratory distress syndrome and/or pulmonary embolism, and hypoxic injury.[45]

Clinical manifestations

Cardiac biomarkers, including troponin and BNP, may be elevated in up to one-third of patients hospitalized with COVID-19. Cardiac arrhythmias, including atrial fibrillation, bradyarrhythmias, and ventricular arrhythmias, occur in a minority of patients. The extent to which arrhythmias are directly mediated by SARS-CoV-2 versus general acute illness is unclear. Myocarditis may be triggered by a variety of viral infections including SARS-CoV-2, but the prevalence of this manifestation is unknown.[46] Most myocarditis occurs simultaneous to acute respiratory disease, but case reports of delayed myocarditis have been reported.[46] Although not common, cardiac manifestations can be the presenting symptom of COVID-19. In a series of 28 patients hospitalized in Italy during February-March 2020 with COVID-19 and ST segment elevation myocardial infarction (STEMI), 24 of 28 patients had the STEMI as the first manifestation of SARS-CoV-2 infection.[47] Seventeen had a culprit lesion and underwent revascularization.[47]

Outcomes

Troponin elevation indicates myocardial injury and is consistently associated with worse outcomes.[44,48] In a meta-analysis of 11 studies of patients hospitalized with COVID-19 during 2020, troponin elevation was associated with 2.7-fold increased risk of in-hospital mortality[42] in adjusted analysis. In a study of 416 patients hospitalized with COVID-19 in China in 2020, cardiac biomarker elevation was associated with increased need for IMV.[49] In a meta-analysis of 3 studies of in-hospital cardiac arrest, SARS-CoV-2 infection was associated with lower rates of shockable rhythm (9.6% vs 19.8%, $P < .001$), lower rates of ROSC (33.9% vs 52.1%, $P < .001$), and higher 30-day mortality (77.2% vs 59.7%, $P = .003$).[50]

Management/treatment

Treatment of COVID-19-related cardiac injury is similar to the management of cardiac injury from other causes. As of May 1, 2022, 253 phase 2 to 4 interventional clinical trials were registered in clinicaltrials.gov to test interventions, prevent or mitigate cardiac complications, including trials of colchicine (NCT04510038), antiplatelet and anticoagulant triple therapy (NCT04333407), angiotensin receptor neprilysin inhibitors (NCT04883528) and anti-IL1b (NCT04365153) antibody therapy.

Table 3
Organ-specific randomized control trials of therapeutics in COVID-19 infections[a]

Organ Function	NCT Number	Name of Study
Cardiac	NCT04883528 NCT04365153	Protecting with ARNI against cardiac consequences of Coronavirus Disease 2019 with Drug: Sacubitril/Valsartan Oral Tablet [Entresto] Canakinumab to Reduce Deterioration of Cardiac and Respiratory Function in SARSCoV2 Associated Acute Myocardial Injury with Heightened Inflammation (completed)
Renal	NCT04402957 NCT04818216	LSALT Peptide vs Placebo to Prevent ARDS and Acute Kidney Injury in Patients Infected With SARS-CoV-2(COVID-19) Nicotinamide Riboside in SARS-CoV-2 (COVID-19) Patients for Renal Protection (NIRVANA)
Liver	NCT04816682	Silymarin, phase 4, Does Silymarin Mitigate Clinical Course of COVID-19 in Patients Admitted to an Internal Medicine Ward with Elevated Liver Enzymes?
Neuro	NCT04904536	An International, Investigator Initiated and Conducted, Pragmatic Clinical Trial to Determine Whether 40 mg Atorvastatin Daily Can Improve Neurocognitive Function in Adults With Long COVID Neurologic Symptoms; Statin TReatment for COVID-19 to OptimiseNeuroloGical recovERy (STRONGER)
Coagulopathy	NCT04650087 NCT04508023	COVID-19 Post-hospital Thrombosis Prevention Trial: An Adaptive, Multicenter, Prospective, Randomized Platform Trial Evaluating the Efficacy and Safety of Antithrombotic Strategies in Patients With COVID-19 Following Hospital Discharge A Study of Rivaroxaban to Reduce the Risk of Major Venous and Arterial Thrombotic Events, Hospitalization and Death in Medically Ill Outpatients With Acute, Symptomatic Coronavirus Disease 2019 (COVID-19) Infection (PREVENT-HD)

[a] Partial list of active interventional phase 2–4 randomized control trials.

Liver Dysfunction

Prevalence

Liver enzymes elevations are common in patients requiring hospitalization for COVID-19 but severe liver dysfunction is a rare manifestation of COVID-19. In a study of 2073 patients hospitalized with COVID-19 in China during January to April 2020, 62% of patients had liver enzymes greater than the upper limit of normal (ULN), including 46% on admission. Liver dysfunction was hepatocellular in 40%, cholestatic in 3%, mixed in 12%, and other in 8%. However, liver injury (>2–3× ULN) occurred in only 14%, including 5% on admission.[51] In a US cohort of 834 patients hospitalized with COVID-19 during April 2020, 12% had significant liver injury (5× ULN) during hospitalization.[52] Acute liver failure (defined as acute liver injury with hepatic encephalopathy) is a rare complication of COVID-19.[51]

Pathophysiology/mechanisms

Similar to other solid organs, the liver is susceptible to hypoxic, ischemic, thrombotic, congestive, and direct viral injury. Several therapies for COVID-19, such as remdesivir and tocilizumab can be hepatotoxic, making drug-induced liver injury a potential cause of liver injury during hospitalization. The ACE2 receptor, where the SARS CoV-2 enters the host is expressed in higher amounts on cholangiocytes than hepatocytes.[53] In series of 40 decedents, macrovesicular steatosis was the most common finding (75%), followed by lobular necroinflammation (50%), portal inflammation (50%), and cholestasis (38%).[54]

Clinical manifestations

Liver enzyme abnormalities in COVID-19 include hepatocellular, cholestatic, and mixed patterns of injury, with most cases being mild (1–2× the ULN). The 834-patient US cohort found that the most common liver abnormalities were AST (63%), ALT (34%), alkaline phosphatase (12%), and total bilirubin (3%).[52] The median time to peak of AST level was 3 days (IQR 1–6 days) postadmission.[52]

Outcomes

Liver injury due to COVID-19 is associated with worse outcomes. In a meta-analysis of 26 studies of patients hospitalized with COVID-19 in China,

baseline AST greater than ULN was associated with increased mortality (odds ratio [OR] = 3.82, P = .05), ICU admission (OR = 2.98, P = .06), and nonfatal complications (OR = 2.95, P = .08).[55] In study of 565 patients hospitalized with COVID-19 on general medicine wards in Italy during 2020, 58% had abnormal liver function, which was associated with higher rates of ICU transfer (20% vs 8%), AKI (22% vs 13%), need for IMV (14% vs 6%), and mortality (21% vs 11%).[56] Abnormal liver function was independently associated with death and/or transfer to the ICU (aOR = 3.5).[56]

Management/treatment

The management of acute liver injury in COVID-19—including hepatocellular, cholestatic, and mixed liver injury—is consistent with current strategies for management of non–COVID-19-related liver injury, including maintaining perfusion, minimizing hepatotoxic medications, optimizing volume status, and ruling out of other causes of hepatic injury. As of May 1, 2022, there was one interventional clinical trial registered on clinicaltrials.gov targeted specifically at patients with elevated liver enzymes in the setting of COVID-19 (NCT04816682).

Neurologic Dysfunction

Prevalence and clinical manifestations

The neurologic manifestations of COVID-19 are varied but can cause severe debility.

A meta-analysis of 48 studies published in the 2020, including 2839 patients with severe/critical COVID and 7493 with nonsevere COVID-19, analyzed neurologic manifestations and their association with COVID-19 severity.[57] Severe COVID-19 was associated with skeletal muscle injury, delirium or impaired consciousness, and fatigue, and less alteration in smell or taste. Myopathy was associated with prolonged hospitalization,[58] and critical illness neuropathy was more prevalent in COVID-19 cohorts than non-COVID-19 cohorts.[59] In a retrospective cohort of 277 patients admitted with a stroke to a large NYC hospital in March to April 2020, 38% were SARS-CoV-2 positive. The COVID-19-positive patients were more likely to have a cryptogenic stroke cause, lobar stroke location, admission to the ICU, and in-hospital mortality.[60] The majority (68%) of COVID-19-positive patients with stroke had parenchymal abnormalities on chest imaging, although stroke has been reported as the presenting sign of COVID-19 in patients without respiratory symptoms.[61] A meta-analysis of 29 studies published in 2020 with 43,024 patients found a 2% pooled prevalence of stroke, which is higher than the prevalence in influenza (0.2%).[62]

Delirium is a common manifestation in critical COVID-19 and known to be associated long-term cognitive impairment.[63] In an international cohort of 2088 ICU-treated patients during January to April 2020, 82% were comatose, for a median of 10 days, and 54.9% experienced delirium, for a median of 3 days.[64]

Pathophysiology/mechanisms

The expression of ACE2 receptor is significantly lower in the central and peripheral nervous system compared with other organs but is found in glial cells in the brain and spinal neurons. In vitro models of the human blood–brain barrier showed a negative impact of SARS CoV-2 spike protein, and brain endothelial cells showed a distinct proinflammatory response.[65,66] Endothelial dysfunction, coagulation abnormalities, direct viral transmission through olfactory nerve, hypoxic brain injury, and disruption of the blood–brain barrier[65] are all postulated to play a role in neurologic manifestation of patients.[8] Loss of taste/smell, meningitis, encephalitis, cerebral vasculitis, and myalgia may all result from direct viral invasion of the nervous system.[16] Encephalopathy from hypoxia, hyperinflammatory response, and hypercoagulability (leading to stroke) are indirect manifestations of COVID-19 infection on the central nervous system.

Outcomes

Similar to other acute organ dysfunction, neurologic dysfunction is associated with increased mortality. In a meta-analysis of 21 studies, 770 of 2982 patients with neurologic manifestations died. The pooled prevalence of mortality among patients with neurologic manifestations was 27% (95% CI 19%–35%).[57] For patients aged older than 60 years, any neurologic manifestation was associated with mortality (OR 1.80, 95% CI 1.11–2.91).[57] Nearly 1 in 50 patients developed a stroke, which has been associated with marked increase in risk of mortality.[67] COVID-19 infection is also associated with significant morbidity in ICU survivors. A multicenter Dutch prospective cohort with follow-up to 1 year post-ICU, physical symptoms were reported in 74.3%, mental symptoms in 26.2%, and cognitive symptoms in 16.2%.[68] The most symptoms were weakened condition (38.9%), joint stiffness (26.3%), joint pain (25.5%), muscle weakness (24.8%), and myalgia (21.3%).[68]

Management/treatment

The management and treatment of neurologic manifestations of COVID-19 mirror strategies used for non–COVID-19-associated symptoms/diseases. Given the known association of delirium

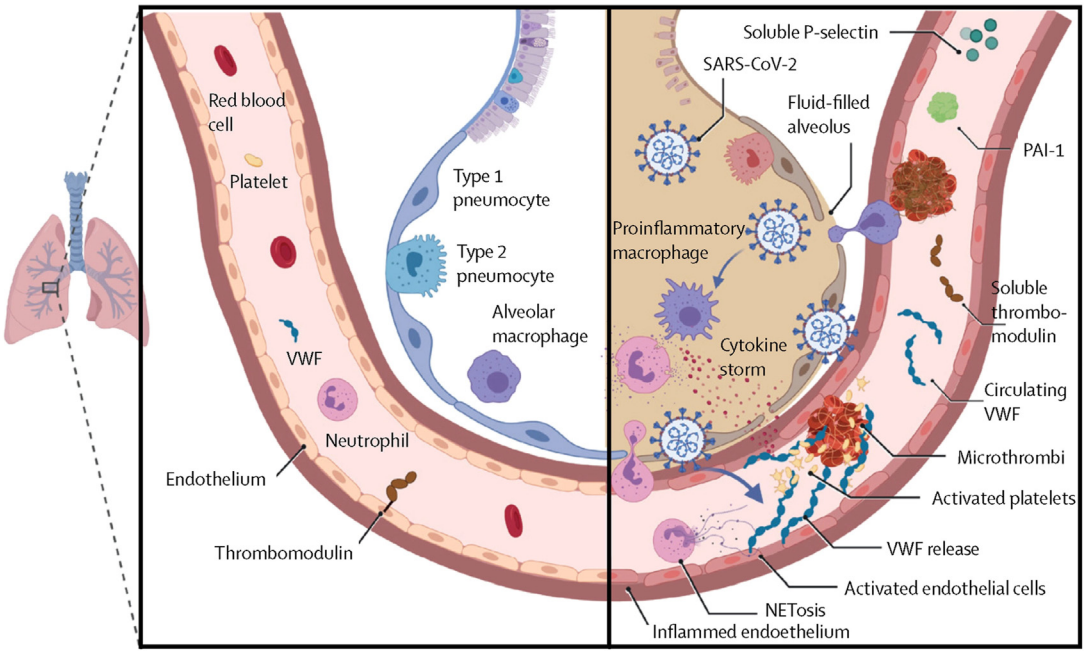

Fig. 2. Endotheliopathy in COVID-19 coagulopathy. (*From* O'Sullivan JM, Gonagle DM, Ward SE, Preston RJS, O'Donnell JS. Endothelial cells orchestrate COVID-19 coagulopathy. The Lancet Haematology. 2020;7(8):e553-e555.)

and poor outcomes,[69] strategies to reduce delirium in mechanically ventilated patients is extremely important. In a large international cohort of 2088 ICU patients, of which 87.5% undergoing mechanical ventilation at some point in their hospitalization, benzodiazepine use was identified as a modifiable risk factor for the development of delirium while the family visitation was associated with decreased risk for delirium. This information should be considered for sedations protocols as well as hospital policies regarding visitation. The treatment of stroke follows guidelines for non–COVID-19 stroke but studies are underway to assess the safety, feasibility, and efficacy of thrombectomy for the management of acute ischemia strokes in patients with COVID-19 (NCT04406090). Early mobility and rehabilitation are crucial to reduce the morbidity associated with COVID-19 disease.

Hematologic Abnormalities (Coagulopathy)

Prevalence

Coagulation abnormalities are a common manifestation of severe and critical COVID-19. In a meta-analysis of 24 studies including 2570 patients with critical COVID-19, the pooled prevalence of clinically detected venous thromboembolism (VTE) was 31% and increased to 48% if using systematic screening (eg, for extremity swelling and/or elevated D-dimer).[70] A subsequent meta-analysis of 19 studies with 1599 patients receiving prophylactic anticoagulation reported pooled prevalences of VTE, deep vein thrombosis (DVT), and PE in 30.1%, 27.2% and 18.3%, respectively.[71] Among studies with routine screening, DVT was identified in 48% versus in 15% with symptom-driven testing ($P < .0001$).[71] The frequent occurrence of VTE when not clinically suspected is corroborated on post-mortem studies.[72] Although rare, aortic thrombosis, occlusion of large vessels, and solid organ infarct have been reported.[73] In the abdomen and pelvis, hemorrhagic complications were more common than thrombotic complications, including hematomas of retroperitoneum and abdominal wall.[73] Overall, rates of VTE among patients hospitalized with COVID-19 are approximately 3-fold higher than among historical matched controls,[74] whereas rates of arterial thromboembolism (ATE) are lower.[75]

Pathophysiology and clinical manifestations

The balance of coagulation and fibrinolysis is deranged in SARS-CoV-2 infection (**Fig. 2**). Abnormal laboratories associated with coagulopathy in COVID-19 are summarized in **Table 4**. Although the exact mechanism is incompletely understood, endothelial dysfunction is widely regarded as the major driver of the prothrombotic state in COVID-19.[73,76] Most patients hospitalized

Table 4
Current and novel biomarkers of hypercoagulability in COVID-19 disease

Serologic Biomarkers	Current Summary of Evidence Supporting Usefulness
C-reactive protein	Strong evidence that levels are associated with disease severity, occurrence of VTE and mortality
IL-6	Strong evidence to guide prognosis but not for prediction of thrombosis
D-dimer	Strong evidence that levels are associated with disease severity and adverse outcomes, including mortality
aPTT/Anti-Xa	Not useful as a marker of COVID-19 severity or prognosis
Neuroendocrine tumors	Potential use in detecting severe vs nonsevere COVID-19 but not in predicting thrombotic risk
Complement factors	Potentially of use in detecting severe COVID-19, longer-term prognostic utility unknown
ACE2	Discrimination of COVID-19 severity not shown
Calprotectin	Potentially of use in detecting severe COVID-19 and assessing the risk of thrombosis

Adapted from Gorog DA, Storey RF, Gurbel PA, et al. Current and novel biomarkers of thrombotic risk in COVID-19: a Consensus Statement from the International COVID-19 Thrombosis Biomarkers Colloquium. Nat Rev Cardiol. 2022;19(7):475-495.

with COVID-19 have elevated D-dimer, mild prolongation of aPTT and/or PT, and mild thrombocytopenia.[77] It is unclear whether these abnormalities indicate hypercoagulability or consumptive disseminated intravascular coagulation (DIC).[77] Hypofibrinogenemia is rare[77] and peripheral smears support a hypercoagulable state.[78] However, in prospective cohort of 98 patients hospitalized in ICU with COVID-19 in the United States during 2020 to 2021 at a single US center, thromboelastographic parameters and conventional coagulation parameters suggested a relative consumptive coagulopathy.[79]

Overall, COVID-19 is associated with a prothrombotic profile that may be driven by excessive inflammation, endothelial activation, platelet activation, impaired fibrinolysis, immune-related molecular events, and systemic hypercoagulability.[80]

Outcomes

Thromboembolism is associated with worse outcomes in COVID-19. In a meta-analysis of 42 studies with 8217 patients hospitalized with COVID-19, the pooled VTE rate in-hospital was 21% (31% among ICU-treated patients).[81] Pooled in-hospital mortality was 23% vs 13% among patients with versus without thromboembolism. The pooled odds of mortality were 74% higher for patients diagnosed with a thromboembolism (OR 1.74, $P = .04$).[81]

Treatment

Several high-quality randomized control trials (RCT) s have addressed the prevention of thrombotic complications in COVID-19. The current evidence supports prophylactic anticoagulation in critically ill patients but therapeutic anticoagulation in ward patients. An open-label trial[82] that randomized 1207 patients to therapeutic heparin anticoagulation versus heparin thromboprophylaxis was stopped for futility. Patients randomized to therapeutic anticoagulation had fewer organ-support free days (median 1 vs 4 days) and similar survival to discharge (62.7% vs 64.5%).[82] However, among noncritically patients, full-dose anticoagulation decreased the need for IMV and other organ supports (aOR = 1.27), without increasing major bleeding (1.9% vs 0.9%).[83] Similarly, a multicenter US trial evaluated the impact of therapeutic anticoagulation for patients hospitalized with COVID-19 with elevated D-dimer levels (>4× ULN) or sepsis-induced coagulopathy score of 4 or more. The study found that—among noncritically ill patients—the combined outcome of VTE, ATE, or mortality was lower (16.7% vs 36.1%, $P = .004$) among patients randomized to therapeutic-dose anticoagulation.[75] However, among critically patients, outcomes were similar between arms (51.1 vs 55.3%, $P = .71$).[75] A multicenter RCT in Iran randomized 562 patients with critical COVID to intermediate-dose thromboprophylaxis (enoxaparin 1 mg/kg daily) vs standard thromboprophylaxis (enoxaparin

40 mg daily).[84] Outcomes, including composite outcome of VTE or ATE, ECMO treatment, and 30-day mortality, were similar among patients randomized to intermediate versus standard enoxaparin dosing. At this time, it is unclear whether continuing anticoagulation after hospital discharge affects short-term or long-term outcomes. However, studies are underway evaluating posthospitalization direct oral anticoagulants to prevent or reduce long-term symptoms associated with COVID-19 infection (NCT04801940).

New biomarkers for tests of coagulation, fibrinolysis, and platelet activation are being studied to support its usefulness for prognostic, diagnostic and management decisions in COVID-19-related thrombosis[80] (**Table 4**). Many advocate for the use of personalized protocol-based titration of heparin anticoagulation,[85,86] as studies consistently show heparin resistance manifested by subtherapeutic anti-Xa levels compared with standard dosing protocols[87,88]; however, the exact biomarker of choice has yet to be determined. In all, the prevalence and severe prognostic implications of thromboembolism should make thrombotic risk assessment and VTE prevention a priority.

SUMMARY

Although SARS-CoV-2 infection most commonly causes respiratory symptoms and impairment, it can also cause nonpulmonary organ dysfunction, most commonly shock, AKI, and hypercoagulability. Neurologic, cardiac, and, to a lesser degree, liver injury may also occur from SARS-CoV-2. Management of extrapulmonary organ dysfunction largely focuses on supportive care practices that are applicable regardless of the cause of organ injury. However, there is emerging evidence to support therapeutic anticoagulation in noncritically ill patients to mitigate risk for VTE.

CLINICS CARE POINTS

- Severe COVID-19 respiratory infection is often accompanied with other organ injuries, which are independently associated with poor outcomes.
- It is important for providers to assess for multi-organ involvement of COVID-19 infection, as each organ injury impacts patient morbidity and mortality.
- At this time, non-pulmonary organ injury is managed with supportive care and follows best practices that are applicable regardless of the cause of injury.
- There is emerging data that supports therapeutic over prophylactic anticoagulation in non-critically ill patients admitted to the general hospital ward.

DISCLOSURE

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