Liver injury in COVID-19: The hepatic aspect of the respiratory syndrome — what we know so far

Prajna Anirvan, Pankaj Bharali, Mrinal Gogoi, Paul J Thuluvath, Shivaram P Singh, Sanjaya K Satapathy

ORCID number: Prajna Anirvan 0000-0003-4494-0865; Pankaj Bharali 0000-0001-6609-2460; Mrinal Gogoi 0000-0001-7937-1223; Paul J Thuluvath 0000-0002-4374-4507; Shivaram P Singh 0000-0002-8197-2674; Sanjaya K Satapathy 0000-0003-0153-2829.

Author contributions: Singh SP and Satapathy SK contributed to the conception and design of the manuscript; Singh SP, Satapathy SK, Thuluvath PJ, Anirvan P, Bharali P and Gogoi M drafted the initial manuscript; All authors participated in the critical revision of the manuscript for important intellectual contents and approved the final manuscript.

Supported by Kalinga Gastroenterology Foundation, Cuttack, India.

Conflict-of-interest statement: The authors have no conflicts of interest to declare.

Open-Access: This article is an open-access article that was selected by an in-house editor and fully peer-reviewed by external reviewers. It is distributed in accordance with the Creative Commons Attribution NonCommercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, ©The Author(s) 2020. Published by Baishideng Publishing Group Inc. All rights reserved.

Abstract

The 2019 novel coronavirus disease (COVID-19) pandemic due to severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has posed a serious threat to global public health. Although primarily, the infection causes lung injury, liver enzyme abnormalities have also been reported to occur during the course of the disease. We conducted an extensive literature review using the PubMed database on articles covering a broad range of issues related to COVID-19 and hepatic injury. The present review summarizes available information on the spectrum of liver involvement, the possible mechanisms and risk factors of liver injury due to SARS-CoV-2 infection, and the prognostic significance of the presence of liver injury. Hopefully, this review will enable clinicians, especially the hepatologists, to understand and manage the liver derangements they may encounter in these patients better and provide guidance for further studies on the liver injury of COVID-19.

Key Words: COVID-19; Hepatitis; Infectious disease; Liver injury; SARS-CoV-2; Management
and license their derivative works on different terms, provided the original work is properly cited and the use is non-commercial. See: http://creativecommons.org/License/s/by-nc/4.0/

**Manuscript source:** Unsolicited manuscript

**Specialty type:** Gastroenterology and hepatology

**Country/Territory of origin:** India

**Peer-review report’s scientific quality classification**
- Grade A (Excellent): 0
- Grade B (Very good): B, B
- Grade C (Good): C
- Grade D (Fair): 0
- Grade E (Poor): 0

**Received:** September 6, 2020

**Peer-review started:** September 6, 2020

**First decision:** October 5, 2020

**Revised:** October 21, 2020

**Accepted:** November 17, 2020

**Article in press:** November 17, 2020

**Published online:** December 27, 2020

**P-Reviewer:** Carnevale S, De Ponti F

**S-Editor:** Gao CC

**L-Editor:** A

**P-Editor:** Wu YXJ

---

**Core Tip:** Hepatic injury in coronavirus disease 2019 (COVID-19) has been widely observed. Although the pathogenic mechanisms still remain unclear, it is believed to be due to interplay of multiple factors. In this review, we have tried to discuss the pathophysiological mechanisms of hepatic injury in the context of COVID-19 and have proposed a management outline of such injury.

**Citation:** Anirvan P, Bharali P, Gogoi M, Thuluvath PJ, Singh SP, Satapathy SK. Liver injury in COVID-19: The hepatic aspect of the respiratory syndrome — what we know so far. World J Hepatol 2020; 12(12): 1182-1197

**URL:** https://www.wjgnet.com/1948-5182/full/v12/i12/1182.htm

**DOI:** https://dx.doi.org/10.4254/wjh.v12.i12.1182

---

**INTRODUCTION**

An outbreak of novel coronavirus (severe acute respiratory syndrome coronavirus 2, SARS-CoV-2) infection occurred in Hubei province of Wuhan, China in December, 2019 and since then it has assumed the form of a pandemic spanning 213 countries with more than 26.3 million confirmed cases worldwide and causing 869000 deaths as of September 3, 2020[1]. The syndrome caused by the virus SARS-CoV-2 has been named coronavirus disease 2019 (COVID-19). The virus can cause an acute respiratory illness which resolves quickly but may also lead to massive alveolar damage with respiratory failure. Although the presenting complaints are chiefly respiratory, the gastrointestinal system and the liver, in particular have also been found to be affected[2]. This is evident in a large series of 5700 cases from New York where the authors reported liver enzymes abnormalities in more than half of the cases[3].

**CLINICAL PROFILE OF PATIENTS OF COVID-19**

SARS-CoV-2 primarily causes a respiratory syndrome heralded by fever, myalgia, sore throat, runny nose and dyspnea in severe cases. COVID-19 has been reported to have a slight male predilection of around 73% and a median age of presentation of 49 years[4]. Amongst other atypical symptoms, diarrhea has also been reported to occur as a presenting complaint in the absence of respiratory symptoms. What is also concerning is that 32% of the patients required intensive care unit (ICU) admission, of which 15% expired. Another study reported by Wang et al[5] that included 138 patients also reported similar clinical characteristics. It has also been reported that many of the patients belonging to the elderly age group who become severely ill have evidence of underlying illness such as cardiovascular disease, liver disease, kidney disease, or malignancies[6].

A significant proportion of the patients with COVID-19 have also been found to have a number of digestive disorders like anorexia, nausea, vomiting, diarrhea and abdominal pain[7]. The involvement of the gastrointestinal system, and the hepatobiliary system in particular, is significant in view of the fact that the case studies and data from The Fifth Medical Centre of PLS General Hospital, Beijing, China indicate that 2%-11% of patients with COVID-19 had liver comorbidities and 14%-53% cases reported abnormal levels of alanine aminotransferase and aspartate aminotransferase (AST) during disease progression[8]. Also, it was observed that the synthetic function of the liver was affected, being evident in the fact that prothrombin time prolongation was more significant in patients with digestive symptoms[9].

**CORONAVIRUSES AND LIVER INJURY**

Similar to the current pandemic, studies had showed that liver injury also occurred in patients with SARS—which broke out two decades ago—manifesting mainly as transaminitis along with increases in serum bilirubin and decreased serum albumin[10]. It was found that, apart from causing alveolar injury, SARS also caused direct hepatocyte injury by using angiotensin converting enzyme 2 (ACE2) receptor for
cellular entry, which is abundantly expressed in the liver\[^4\]. Further confirmation of this came from reverse transcription polymerase chain reaction (RT-PCR) based evidence of SARS-associated coronavirus in the liver tissues despite electron microscopy failing to identify viral particles\[^9\].

Similarly, Middle East respiratory syndrome (MERS) caused by Middle East respiratory syndrome coronavirus (MERS-CoV) was characterised by fever, which also progressed to respiratory and multiorgan failure, in severe cases. These patients also had hyperbilirubinemia, hypoalbuminemia and transaminisits. In contrast to the SARS-CoV, MERS-CoV was found to have specific affinity for the Dipeptidyl Peptidase-4 (DPP-4) receptor which is abundantly expressed in the liver and thus was presumed to have gained entry into hepatocytes\[^10]\]. In this case, too, viral particles could not be demonstrated in the liver tissue of patients with MERS\[^10\].

In a study involving 1099 patients with laboratory-confirmed COVID-19 from 552 hospitals in China, nausea or vomiting, or both, and diarrhoea were reported in 55 (5.6%) and 42 (3.8%) patients respectively\[^10\]. Interestingly, SARS-CoV-2 RNA was first detected in a stool specimen of the first reported COVID-19 case in the United States\[^13\].

It has been shown that SARS-CoV-2 shares 82% genomic sequence similarity with SARS-CoV and has also been found to have affinity for the ACE2 receptor\[^11\]. Therefore, it is not at all surprising that 14%-53% of patients with COVID-19 have abnormalities in transaminase levels\[^12\]. In the past too, liver impairment was reported in 60% of patients with SARS\[^13\].

Liver dysfunction in COVID-19 is manifested by abnormal transaminase levels and this has also been linked to the severity of the disease as well as the outcome. For example, in one study published by Huang et al\[^14\]\] elevation of AST was observed in eight (62%) of 13 patients in the ICU compared with seven (25%) of 28 patients who did not require care in the ICU. In another comparatively bigger cohort of 1099 patients from 552 hospitals in 31 provinces in China, patients with more severe disease had abnormal liver aminotransferase levels than did patients with less severe disease\[^12\]. In one more study, 8 patients who had a diagnosis of COVID-19 confirmed by computed tomography (CT) scan while in the asymptomatic phase had significantly lower incidence of AST abnormality compared to patients diagnosed after the onset of symptoms\[^14\]. All these figures indicate that liver injury manifested by transaminisits is probably more prevalent in severe cases than in mild cases of COVID-19.

**RISK FACTORS FOR LIVER INJURY**

There are not many studies addressing the risk factors associated with liver injury in COVID-19. It is quite natural that a thorough and comprehensive evaluation of possible risk factors that can cause or exacerbate liver injury has not been possible in such a short span of time.

An important observation in a study by Li et al\[^15\]\] was that among patients with abnormal liver function, patients with moderate and severe disease were more likely to have liver injury, accounting for 58.8% and 66.7% respectively. This indicates that hepatic injury is more common and is more severe during the period of critical care, where the patient is exposed to multiple insults in the form of medications, hemodynamic instability and cytokine storm. This is in addition to the fact that a significant number of patients in China have underlying hepatitis B infection.

The authors, in the same study, performed multivariate logistic regression analysis to study the association of several factors that included age, drinking history, baseline albumin, lactic acid, C-reactive protein (CRP), neutrophils, lymphocyte and myoglobin. It was found that CRP levels greater than 20 mg/L and a lymphocyte count less than 1.1 × 10^9/L were independently related to alanine aminotransferase (ALT) elevation. This study, importantly, excluded the effects of drugs that might cause hepatic injury and suggested that cytokine storm may be the major mechanism behind lymphopenia and elevation in CRP, heralding liver injury.

In addition, herbal medicines, which are a major cause of liver injury in the developing nations\[^16\], complicate the problem further as they have been indiscriminately used in these cases in China. A dataset processed by Ou et al\[^17\]\] from between 2011 and 2014 in China identified Chinese herbal medicine as the primary cause of liver injury in 36% of the patients investigated in their study. Therefore, in such a background of widespread consumption of herbal products which is an established risk factor for liver injury, patients with COVID-19 seem to be at high risk for exacerbation of hepatic injury due to a combination of multiple factors.
PATHOGENESIS OF LIVER INJURY

As discussed earlier, it has been observed that SARS-CoV-2, by virtue of its affinity for ACE2 receptor gains access to hepatocytes and causes direct liver injury. However, what is puzzling is that the ACE2 expression of bile duct cells is reportedly much higher than that of liver cells, and is comparable to alveolar type 2 cells in the lungs. As bile duct epithelial cells are known to play important roles in liver regeneration and immune responses, it is believed that the liver injury in COVID-19 patients may be due to the damage to bile duct cells by the virus, and not the liver cells, and in such a scenario, it would be expected that COVID-19 patients should have evidence of cholestatic liver injury. However, the normal ALP levels and elevated AST/ALT levels do not favour the injury hypothesis, and our understanding with regards to liver injury related to SARS-CoV-2 continues to evolve. Besides, histopathological analysis of liver tissue from a deceased patient also did not show the presence of viral inclusion bodies in the liver.

It is in this context that other factors apart from direct viral cytopathic injury need to be considered. In addition to direct hepatotoxicity, it is clear that immune dysregulation does occur in COVID-19 in varying forms. Systemic Inflammatory Response Syndrome (SIRS) and accompanying release of interleukins and other mediators of inflammation lead to a form of cytokine storm that can cause and exacerbate hepatocellular injury. Furthermore, a metanalytic study investigating the relationship between liver damage and COVID-19 suggests that SARS-CoV-2 may produce a relevant hepatic damage probably through the immune interactions requiring the action of intrahepatic cytotoxic T cells and Kupffer cells.

Another factor that needs to be kept in mind while dealing with hepatic dysfunction in COVID-19 is the possibility of pneumonitis associated hypoxia and fall in mean arterial pressure that can cause ischemic hepatitis. Besides, the fact that patients in ICU had higher levels of transaminases might also be due to the higher degrees of hypoxia requiring mechanical ventilation. Levels of AST and ALT in thousands are an established feature of ischemic hepatitis, and hypoxia may in fact exacerbate the liver injury along with other causes of liver dysfunction.

Drug induced liver injury during COVID-19 related illness should be considered in the differential diagnosis considering many of the unapproved drugs are being tested either empirically or are undergoing clinical trials. While there is no specific treatment for COVID-19 till date, there has been a frenetic attempt to use various existing combinations of antivirals, immunomodulators, antibiotics and steroids in addition to ‘hepatoprotective’ drugs. The indiscriminate use of such cocktails might, in fact, be perpetuating hepatic dysfunction observed in these cases. Biopsies performed post mortem in SARS-CoV-2 infection revealed microvascular steatosis and mild lobular and portal activity, indicating that the injury could have been caused by drug-induced liver injury in addition to the SARS-CoV-2 infection. Use of steroids, antibiotics and antivirals have all been associated with liver injury. It has also been reported that the liver injury observed in COVID-19 patients might be caused by lopinavir/ritonavir, which is being used as an antiviral for the treatment of SARS-CoV-2 infection. The drug Remdesivir, widely used in COVID-19, has been reported to cause hepatocellular injury and derangement of liver function. Use of biologics like Tocilizumab has been associated with Hepatitis B reactivation. Azithromycin which is commonly prescribed in COVID-19 is a known cause of idiosyncratic liver injury while hydroxychloroquine may also rarely cause idiosyncratic hepatotoxicity. Therefore, it is amply clear that the sheer number of medications being tried in COVID-19 is highly likely to cause liver injury ranging from asymptomatic transaminitis to greater degrees of hepatotoxicity. The APASL expert panel consensus recommendations advise careful investigation of drug induced liver injury in COVID-19 and specifically mention against using certain drugs like Remdesivir in patients with decompensated chronic liver disease and ALT elevations more than 5 times the upper limit of normal. Close monitoring of liver function tests has been advised. In addition, it has also been suggested that use of herbal products and nutraceuticals in COVID-19 may interfere with the body’s natural immune mechanisms and hence the French Agency for Food, Environmental and Occupational Health and Safety (ANSES) has advised against using these substances derived from plants like poplar, birch, willow, goldenrod, curcuma etc. A summary of the spectrum of drugs used in COVID-19 likely to induce liver injury is shown in Figure 1.

To add to this growing concern over liver injury in COVID-19, the presence of chronic liver disease adds to the burden of the problem worldwide. The prevalence of liver disease varies globally and so do the etiologies. Viral hepatitis, alcohol related liver disease and non-alcoholic fatty liver disease are prevalent in epidemic...
proportions worldwide and the impact of COVID-19 in patients with these pre-existing diseases is largely unknown. A recent case series from China reported that decompensated cirrhosis may be a risk factor for a poor outcome in patients with COVID-19[33]. The use of complementary, herbal and indigenous drugs that can exacerbate liver injury, especially in countries like China where the infection originated and in India, where the incidence of new cases has been steadily rising, poses great challenges.

The presence of co-morbidities makes the pathogenic processes complex and at the moment, there are very few studies that have looked at this problem. A systematic review and meta-analysis by Yang et al[34] has shown that the most prevalent comorbidities were hypertension and diabetes, followed by cardiovascular diseases and respiratory system disease. It is well known that both hypertension and diabetes are commonly treated with ACE inhibitors. The expression of ACE2 is substantially increased in patients with type 1 or type 2 diabetes, who are treated with ACE inhibitors and angiotensin II type-I receptor blockers (ARBs). This results in an upregulation of ACE2. Consequently, it has been hypothesised that the increased expression of ACE2 in different organs like the lung and the liver might facilitate infection with SARS-CoV-2. Thus, it has been assumed that diabetes and hypertension treatment with ACE2-stimulating drugs increases the risk of developing severe and fatal COVID-19[26]. Further, these studies suggest that patients with co-morbidities having SARS-CoV-2 infection might have multiple pathogenic mechanisms of host injury and inflammatory response proceeding simultaneously. Given the high burden of co-morbidities, especially among the elderly population, this area needs to be meticulously investigated. The potential mechanisms of liver injury in COVID 19 are summarized in Figure 2.

**PATTERN OF LIVER INJURY IN SARS-COV-2 INFECTION**

Liver injury in SARS-CoV-2 infection has a variable incidence of 14%-53% as indicated by elevated AST and ALT levels. There is also an accompanying mild increase of serum bilirubin levels[35]. However, from the existing data, the pattern of bilirubin rise (direct vs indirect) and its relationship to the disease process is not very clear. Also, no correlation between the rise in transaminases and bilirubin levels have been found. Hypoalbuminemia has also been found to occur with the serum albumin levels around 2.63-3.09 mg/dL according to one study[36]. A recent study including 417 patients with COVID-19, 318 (76.3%) had abnormal liver test results and 90 (21.5%) had liver injury during the hospitalization. Ninety-one (21.8%) developed severe disease and 326 (78.2%) had mild disease during hospitalization (Figure 2)[36]. A recent study has noted that AST-dominant aminotransferase elevation is common in COVID-19, mirrors
Interestingly, COVID-19 infection presenting as acute non-icteric hepatitis which preceded the development of fever and respiratory symptoms has recently been reported in a patient[38]. This particular case report assumes importance in view of the fact that the patient did not have typical features of COVID-19 at presentation and was worked up as a case of acute viral hepatitis. All possible causes of acute hepatitis were ruled out. After 2 d, she developed respiratory signs and symptoms and was found positive for SARS CoV-2. She responded to treatment with supportive measures and hydroxychloroquine[38]. Furthermore, a case of COVID-19 hepatitis in a living donor liver allograft recipient whose donor subsequently tested positive for COVID-19 has been reported with unique histopathological findings[39].

The proportion of patients developing liver injury in severe COVID-19 has been found to be significantly higher than that in patients with milder disease. In a metaanalytic study by Mantovani et al[24], patients with severe COVID-19 disease tended to have higher levels of liver enzymes, as well as a greater activation of coagulative and fibrinolytic pathways. While the elevation in AST and ALT have been around three to four times and has varied across studies, one study reported elevations in AST and ALT to be in the range of thousands. In another study, although serum gamma glutamyl transpeptidase (GGT) was found to be increased in severe cases, serum alkaline phosphatase (ALP) level was in the normal range in both mild and severe cases[20]. Table 1 summarizes the pattern of liver dysfunction in COVID-19 patients reported in various studies[35,40-70].

**SARS-COV-2 INFECTION IN THE SETTING OF PRE-EXISTING LIVER DISEASE**

Patients with pre-existing chronic liver disease have a wide spectrum of immune dysfunction starting from cytopenia to cytokine storm. The proportion of COVID-19 patients with pre-existing liver conditions ranged from 2% to 11% in one study[41]. In patients with chronic hepatitis B and C infection, it is not known as to what kind of effect co-infection with SARS-CoV-2 might have. Such patients who remain as inactive...
### Table 1 Summary of the pattern of liver injury reported in coronavirus disease 2019 in various studies

| Ref. | Number of patients | Pattern of liver injury | Pre-existing liver diseases | Comments | Place of study |
|------|--------------------|-------------------------|-----------------------------|----------|----------------|
| Richardson et al[3] | 5700 | Elevated AST: 58.4%; elevated ALT: 39% | Cirrhosis: 0.4%; chronic hepatitis B: 0.1%; chronic hepatitis C: 0.1% | Elevated AST observed in 62% of patients in ICU compared with only 25% of patients not in ICU | Northwell Health System, New York, United States |
| Huang et al[4] | 41 | 15(31%) | 1 (2%) | | Wuhan, China |
| Wang et al[5] | 138 | Mild elevation of AST and ALT | - | | Wuhan, China |
| Guan et al[6] | 1099 | Elevated AST: 22.2%; elevated ALT: 21.3%; elevated total bilirubin: 10.3% | AST elevated in 18.2% of non-severe disease but in 39.4% of severe disease; ALT elevated in 19.8% with non-severe disease and 28.1% of severe disease | 552 hospitals in 30 provinces, autonomous regions, and municipalities in mainland China |
| Shi et al[7] | 81 | Transaminitis in 43 (53.1%) | 7 (8.6%) | Patients with subclinical infection had lower AST | Wuhan, China |
| Fan et al[8] | 148 | Abnormal LFT in 50.7%; elevated ALT in 18.2%; elevated AST in 21.6% | Higher proportion (56.1%) with liver injury received lopinavir/ ritonavir than those without liver injury (25%) | | Shanghai Public health Clinical Centre, China |
| Chen et al[9] | 99 | 43(43%); elevated AST: 35%; elevated ALT: 28%; elevated total bilirubin: 98% | One patient had severe liver injury with ALT 7590U/L | | Wuhan, China |
| Cai et al[10] | 417 | During hospitalisation, rise in liver enzymes > 3 times of upper limit seen; elevated ALT: 49 (23.4%); elevated AST: 31 (14.8%); elevated total bilirubin: 24 (11.5%); elevated GGT: 51 (24.4%) | 318 (76.3%) had abnormal liver biochemistries and 90 (21.5%) had liver injury during hospitalization; 91 (21.8%) developed severe disease and 326 (78.2%) had mild disease during hospitalization; use of lopinavir/ritonavir increased the odds of liver injury by 7-fold | Shenzhen, China |
| Tabata et al[11] | 104 | Elevated AST: 17.5%; elevated ALT: 16.3% | - | | Diamond Princess Cruise, Japan |
| Huang et al[12] | 36 | Elevated ALT: 13.35%; elevated AST: 58.06%; elevated total bilirubin: 12.90% | All fatal cases only | | Wuhan, China |
| Zhang et al[13] | 82 | Liver dysfunction in 64 (78%) | 2 (2.4%) | All fatal cases only | Wuhan, China |
| Yang et al[14] | 52 | 15 (29%) | No difference in incidence of liver injury between survivors and non-survivors | Wuhan, China |
| Cao et al[15] | 128 | Transaminitis present only in severe disease | | | Xiangyang, China |
| Xu et al[16] | 62 | Elevated AST in only 16.1% | 7 (11.0%) | No patient had elevated ALT while a sixth had elevated AST | Zhejiang Province, China |
| Cai et al[17] | 298 | 44 (14.8%) | 8 (2.7%) | Transaminitis 4 times commoner in severe disease (36.2%) compared to mild disease (9.6%) | Shenzhen, China |
| Kujawski et al[18] | 12 | Elevated AST: 58.3%; elevated ALT: 58.3% | 8.3% had HBV and 8.3% had fatty liver disease | | Center of Disease Control California, Illinois, Arizona, Massachusetts, Washington, Wisconsin, |
| Authors            | Median AST (range) | Median ALT (range) | Elevated AST and ALT | Elevated Bilirubin | Elevated ALP | Elevated total bilirubin | Elevated Direct bilirubin | Risk of being transferred to the intensive care unit | Associated with elevated levels of AST and direct bilirubin |
|--------------------|--------------------|--------------------|-----------------------|---------------------|-------------|--------------------------|---------------------------|-----------------------------------------------------|----------------------------------------------------------|
| Arentz et al.      | 273 (14-4432)      | 108 (11-1414)      | 4.8% had cirrhosis of liver |                     |             |                          |                           |                                                     |                                                          |
| Jin et al.         | 651                |                    | Liver injury seen in 13 out of 74 with GI symptoms vs 51 out of 577 without GI symptoms | Rate of increased AST, but not ALT, was significantly higher in patients with GI symptoms than in those without GI symptoms |                     |                          |                           |                                                     |                                                          |
| Qi et al.          | 267                | Elevated AST: 7.2%; elevated ALT: 7.5%; elevated total bilirubin: 2.2% | Elevated AST seen in 9 out of 217 patients with non-severe disease and 10 out of 50 patients with severe disease. Elevated ALT seen in 10 out of 217 patients with non-severe disease and 10 out of 50 patients with severe disease. Elevated bilirubin in 3 out of 217 patients with non-severe disease and 3 out of 50 patients with severe disease |                     |             |                          |                           |                                                     |                                                          |
| Omranian-Nava et al| 93                 | Elevated AST: 29.2%; elevated ALT: 30.3%; elevated total bilirubin: 10.2%; elevated direct bilirubin: 45.8% | Risk of being transferred to the intensive care unit strongly associated with the elevated levels of AST and direct bilirubin |                     |             |                          |                           |                                                     |                                                          |
| Mao et al.         | 214                | Median AST 26 (8-8191); median ALT 26 (5-1933) | Liver enzymes were significantly higher in severe cases compared to non-severe cases |                     |             |                          |                           |                                                     |                                                          |
| Xu et al.          | 45                 | Elevated AST/ALT: 37.8%; median Bilirubin: 0.91 (IQR 0.61-1.3) |                      |                     |             |                          |                           |                                                     |                                                          |
| Tian et al.        | 24                 | Elevated AST: 8.33%; elevated ALT: 4.17% | 4.17 % had cirrhosis |                     |             |                          |                           |                                                     |                                                          |
| Chen et al.        | 291                | Elevated AST: 15.1%; elevated ALT: 10.3%; elevated bilirubin: 9.3% | 5.2% chronic liver disease |                     |             |                          |                           |                                                     |                                                          |
| Wang et al.        | 18                 | Elevated AST or ALT in 25% |                      |                     |             |                          |                           |                                                     |                                                          |
| Yan et al.         | 168                | Elevated AST: 17.3%; elevated ALT: 8.0% |                     |                     |             |                          |                           |                                                     |                                                          |
| Lin et al.         | 95                 | Elevated AST: 4.2%; elevated ALT: 5.3% |                     |                     |             |                          |                           |                                                     |                                                          |
| Zhao et al.        | 77                 | Elevated AST: 26.0%; elevated ALT: 33.8% |                     |                     |             |                          |                           |                                                     |                                                          |
| Chen et al.        | 274                | Elevated AST: 30.7%; elevated ALT: 21.9%; median bilirubin: 0.6 (IQR 0.4-0.8) | 4 % were HbsAg positive |                     |             |                          |                           |                                                     |                                                          |
| Rubin et al.       | 54                 | Elevated AST: 42.59%; elevated ALT: 40.7% | 1.8 % were HBV infected | AST: mean/SD=73.4 ± 61.8 (females); 45.1 ± 19.5 (males) ALT: mean/SD= 69.6 ± 65.2 (females); 43.9 ± 25.8 (males) |                     |             |                          |                           |                                                     |                                                          |
| Cholankeril et al. | 116                | Deranged LFT in 26 out of 65 cases (40%). Higher levels of AST compared to ALT. Median bilirubin: 0.4 (IQR 0.3-0.7) | 2.6 % chronic liver disease | 22 of the 26 patients with liver enzyme elevations had normal baseline liver enzymes |                     |             |                          |                           |                                                     |                                                          |
| Yao et al.         | 40                 | Elevated AST: 40%; elevated ALT: 52.5% Elevated Bilirubin: 25% | Out of 22 critical cases, 17 had hepatic dysfunction. Out of 18 noncritical cases, 5 had hepatic dysfunction |                     |             |                          |                           |                                                     |                                                          |
Anirvan P et al. Liver injury in COVID-19

| Study | n | AST Elevated (%) | ALT Elevated (%) | Bilirubin Elevated (%) | Chronic Liver Disease | Location |
|-------|---|------------------|------------------|------------------------|-----------------------|---------|
| Zhao et al | 75 | Elevated AST: 18.7%; elevated ALT: 20%; elevated Bilirubin: 16% | 5.3 % had chronic liver disease | | Hefei, Anhui Province, China |
| Ai et al | 102 | Elevated AST: 25.5%; elevated ALT: 19.6% | | | Xiangyang, China |
| Ma et al | 81 | Deranged AST/ALT: 38.2% | | | Wuhan, China |
| Xu et al | 355 | Elevated AST: 28.7%; elevated ALT: 25.6%; elevated Total bilirubin: 18.6% | | | Wuhan, China |
| Shi et al | 416 | Median AST: 30 (IQR 22-43); median ALT: 28 (IQR 18-46) | 1% had HBV infection | | Wuhan, China |
| Luo et al | 1141 | Among 183 patients, median AST: 65.8 ± 12.7, median ALT: 66.4 ± 13.2 | | | Wuhan, China |
| Qi et al | 21 | Elevated AST: 38.1%; elevated ALT: 23.8%; elevated GGT: 23.8% | | | 16 designated hospitals in China |

AST: Aspartate aminotransferase; ALT:Alanine aminotransferase; GGT: Gamma glutamyl transpeptidase; IQR: Interquartile range; HBV: Hepatitis B virus; LEF: Liver function tests; GI: Gastrointestinal; ICU: Intensive care unit; SD: Standard deviation.

Carriers or in the immunotolerant phase might have reactivation of the virus and hepatic injury. Mantovani et al[24], in their metanalytic study, have suggested that patients with pre-existing chronic liver disease may be more susceptible to liver damage from SARS-CoV-2. Implications of underlying non-alcoholic fatty liver disease (NAFLD) has been recently evaluated. The authors have noted that patients with NAFLD had higher risk of disease progression [6.6% (5/126) vs 44.7% (34/76), P < 0.0001], higher likelihood of abnormal liver function from admission to discharge [70% (53/76) vs 11.1% (14/126), P < 0.0001] and longer viral shedding time [17.5 ± 5.2 d vs 12.1 ± 4.4 d, P < 0.0001] when compared with non-NAFLD subjects[71]. Patients with autoimmune hepatitis and primary biliary cholangitis on steroids and other immunosuppressive therapy might be at higher risk of developing severe disease and may pose dilemma in treatment, considering the fact that use of medications like antivirals and antibiotics might worsen liver injury. This issue also requires further investigation. An interesting case series of three patients of COVID-19 with chronic liver disease showed that while two of the patients with Child-Pugh C disease died, the patient with Child-Pugh class B did not[33]. In addition, the patient with the highest Model for End-stage Liver Disease (MELD) score survived compared to the ones with lower MELD scores who did not, possibly indicating that clinical decompensating events may be more important in predicting outcome of patients with COVID-19 and pre-existing cirrhosis[33].

In a multicentric study in China evaluating the clinical course and risk factors for mortality of COVID-19 patients with pre-existing cirrhosis, most patients were found to have compensated cirrhosis while chronic HBV infection was found to be the most common aetiology[70]. The study did not report any significant differences between...
survivors and non-survivors in terms of age, sex, comorbidities, aetiology of cirrhosis, Child-Pugh class, MELD score, interval between onset and admission, or onset symptoms of COVID-19\[70\]. Further, COVID-19 patients who died had lower total lymphocyte and platelet counts, and higher direct bilirubin levels than patients who survived, while the frequency of acute respiratory distress syndrome (ARDS) and gastrointestinal (GI) bleeding were higher in non-survivors compared to survivors\[70\]. Importantly, the cause of death in most patients was respiratory failure rather than acute on chronic liver failure\[70\]. Further studies need to be carried out across different population groups to determine the exact impact of SARS-CoV-2 co-infection in patients with chronic liver disease.

### SARS-COV-2 INFECTION IN THE SETTING OF LIVER TRANSPLANTATION

Taking a cue from the previous SARS outbreak of 2002, it has been hypothesised that liver transplantation might involve a risk of transmission of viral infection from donor to recipient. Hence, donor screening and testing might prove to be extremely crucial\[72\]. However, at this juncture, there is a lack of evidence to justify this hypothesis. A case series of patients with COVID-19 had several patients with various comorbidities, but none of them had been a transplant recipient\[72\]. A recent study from Italy reported experience from a single transplant centre, and noted 3 deaths out of their 111 Long-term liver transplant survivors (transplanted more than 10 years ago) compared to none of the three infected with SARS-CoV-2 transplanted within the last 2 years. All three who died were male, older than 65 years, receiving antihypertensive drugs, overweight (body mass index > 28 kg/m\(^2\)), with hyperlipidaemia, and diabetes (median Hemoglobin A1c of 6.9\%)\[71\]. In the present circumstances, in the event of a liver transplantation, the hepatologists have to follow the guidance issued by the Transplantation Society\[74\], as well as local health department guidelines for isolating, quarantining, testing, and monitoring returned travellers from endemic areas. Recent AASLD guidance reports that there is a significant false negative rate and transplant programs should consider symptoms of COVID-19 to be strongly suggestive of infection despite negative testing. Transplantation in SARS-CoV-2-positive recipients is currently not recommended.

### PREVENTION AND TREATMENT

Liver injury in COVID-19 infection can be fleeting and mild and enzyme levels can normalise spontaneously. As of now, there is no specific therapy for liver injury in COVID-19 infection. In addition to managing the respiratory syndrome in COVID-19, monitoring of the liver function tests (LFT) should be done and all factors known to cause or exacerbate liver injury should be taken into consideration while treating the patient. A proper history especially with regard to recent or long-term intake of herbal preparations and hepatotoxic drugs must be taken. Drugs known to cause liver injury must be used with caution and LFT should be repeated at regular intervals. All the studies concerning COVID 19 and liver injury are from China and one thing common in these studies is the use of a cocktail of drugs that include steroids, antivirals, antibiotics and compounds like ammonium glycyrrhizinate which should be viewed with caution as some of these are known to cause hepatic injury. Especially in the setting of hypoxia and cytokine storm, use of these drugs can exacerbate any existing hepatic insult. Special caution is warranted for patients with pre-existing liver disease. At the moment, there is lack of robust data to support the use of specific hepatoprotective agents. However, in cases of severe liver injury, liver protective agents have been used in COVID-19. Figure 3 succinctly delineates the diagnostic approach to COVID-19 patients with abnormal liver biochemistries, investigations to be performed and monitoring of such patients.

In the face of this pandemic, management of patients with chronic liver disease has also posed problems. Recently, the AASLD and EASL have come up with recommendations for patients with compensated as well as decompensated liver disease. In case of compensated liver disease, AASLD recommends limiting outpatient visits and to consider seeing in person only new adult and paediatric patients with urgent issues and clinically significant liver disease (e.g., jaundice, elevated ALT or AST > 500 U/L, recent onset of hepatic decompensation), to continue treatment for hepatitis B and hepatitis C if already on treatment, to continue monitoring in those on or off therapy for hepatocellular carcinoma (HCC), to continue surveillance in those at
Figure 3 Approach to a coronavirus disease 2019 patient with liver dysfunction. COVID-19: Coronavirus disease 2019; AST: Aspartate aminotransferase; ALT: Alanine aminotransferase; ACLF: Acute-on-chronic liver failure; USG: Ultrasonography.

risk for HCC and to proceed with HCC treatments when able rather than delaying them due to the pandemic\(^7\). In those with decompensated liver disease, AASLD recommends evaluating only patients with HCC or those patients with severe disease and high MELD scores who are likely to benefit from immediate liver transplant listing\(^7\). In autoimmune liver disease too, EASL recommends against reducing immunosuppressive therapy unless indicated in special circumstances\(^7\).

LIVER DYSFUNCTION AND PROGNOSIS

The prognostic variables of hepatic dysfunction in COVID-19 are still being worked out. As previously mentioned, patients with more severe disease have abnormal levels of transaminase levels, suggesting that elevated transaminase levels may be viewed as a prognostic factor and these patients need to be treated with caution. However, the causality association of this factor might be subject to bias. In a retrospective study from Wuhan by Zhou et al\(^7\), several factors were identified that might be associated with higher mortality in adults who were hospitalised with COVID-19. Older age, d-dimer levels greater than 1 μg/mL, and higher Sequential Organ Failure Assessment (SOFA) score on admission were associated with higher odds of in-hospital death. Also, levels of interleukin 6 (IL-6), high-sensitivity cardiac troponin I, and lactate dehydrogenase (LDH) were elevated and lymphopenia was more common in severe COVID-19 illness. Preliminary data suggests the reported death rate varies depending on the study and country. However, the mortality rate estimates are based on the number of deaths relative to the number of confirmed cases of infection, which is not representative of the actual death rate. Extrapulmonary involvement like hepatic and renal injury could indicate more severe inflammatory responses and might have a bearing on the mortality rates. Furthermore, it is not clear at this point of time whether the algorithms and scores that are commonly used to assess prognosis in patients with acute hepatic failure are applicable to liver injury in COVID-19, considering the multiple factors involved in the pathogenesis. This, therefore, warrants extreme degree of caution and an individually tailored approach while dealing with such patients.
CONCLUSION

SARS-CoV-2 infection has taken the world by storm. The pandemic is yet to reach a plateau, with the incidence rising and newer populations getting infected. However, physicians, researchers and scientists have left no stone unturned to understand the pathogenesis of this multi-system afflicting disease, find out effective therapies and contain the pandemic. While the disease primarily affects the respiratory system, liver injury does pose problems in the management of COVID-19 patients. Both direct virus-mediated cytopathic effects and indirect immune mediated, drug induced or hypoxic states are probably responsible for causing and perpetuating the liver injury. However, a word of caution: Transaminitis in patients with COVID-19 should not be overly investigated. Only in those patients where there is suspicion of cholestatic injury does pose problems in the management of COVID-19 patients. Both direct virus-mediated cytopathic effects and indirect immune mediated, drug induced or hypoxic states are probably responsible for causing and perpetuating the liver injury. Intensive monitoring and evidence trickles in and more facts come to light, we will be in a better position to understand and tackle liver injury in COVID-19. Intensive monitoring and individually tailored approach are the need of the hour to treat patients with severe liver injury or patients with pre-existing liver diseases.

REFERENCES

1. World Health Organization. Coronavirus Disease (COVID-19) Dashboard. [Cited 2020 May 24]. Available from: https://covid19.who.int/

2. Zhang C, Shi L, Wang FS. Liver injury in COVID-19: management and challenges. Lancet Gastroenterol Hepatol 2020; 5: 428-430 [PMID: 32145190 DOI: 10.1016/S2468-1253(20)30057-1]

3. Richardson S, Hirsch JS, Narasimhan M, Crawford JM, McGinn T, Davidson KW; the Northwell COVID-19 Research Consortium, Barnaby DP, Becker LB, Chelico JD, Cohen SL, Cookingham J, Coppa K, Diefenbach MA, Dominoello AJ, Duer-Helele J, Falzon L, Gitlin J, Hajizadeh N, Harvin TG, Hirschwerk DA, Kim EJ, Kozel ZM, Marrast LM, Mogavero JN, Osorio GA, Qi M, Zanos TP. Presenting Characteristics, Comorbidities, and Outcomes Among 5700 Patients Hospitalized With COVID-19 in the New York City Area. JAMA 2020; 323: 2052-2059 [PMID: 32320603 DOI: 10.1001/jama.2020.6775]

4. Huang C, Wang Y, Li X, Ren L, Zhao J, Hu Y, Zhang L, Fan G, Xu J, Gu X, Cheng Z, Yu T, Xia J, Wei Y, Wu W, Xie X, Yin W, Li H, Liu M, Xiao Y, Gao H, Guo L, Xie J, Wang G, Jiang R, Gao Z, Jin Q, Wang J, Cao B. Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. Lancet 2020; 395: 497-506 [PMID: 31986264 DOI: 10.1016/S0140-6736(20)30183-5]

5. Wang D, Hu B, Hu C, Zhu F, Liu X, Zhang J, Wang B, Xiang H, Cheng Z, Xiong Y, Zhao Y, Li Y, Wang X, Peng Z. Clinical Characteristics of 138 Hospitalized Patients With 2019 Novel Coronavirus-Infected Pneumonia in Wuhan, China. JAMA 2020; 323: 1061-1069 [PMID: 32031570 DOI: 10.1001/jama.2020.1585]

6. Pan L, Mu M, Yang P, Sun Y, Wang R, Yan J, Li P, Hu B, Wang J, Hu C, Jin Y, Niu X, Ping R, Du Y, Li T, Xu G, Hu Q, Tu L. Clinical Characteristics of COVID-19 Patients With Digestive Symptoms in Hubei, China: A Descriptive, Cross-Sectional, Multicenter Study. Am J Gastroenterol 2020; 115: 766-773 [PMID: 32287140 DOI: 10.14309/ajg.0000000000000620]

7. Lu Y, Yin C, Tang X, Yang Z, Lei C, Chen W, Gong L, Jia W. Clinical characteristics and mechanism of liver function injury in 250 patients with severe acute respiratory syndrome. Zhongguo Xian Dai Yi Xue Za Zhi 2004; 14: 121-123

8. Li W, Moore MJ, Vasilieva N, Sai J, Wong SK, Berne MA, Somasundaran M, Sullivan JL, Luzuriaga K, Greenough TC, Choe H, Farzan M. Angiotensin-converting enzyme 2 is a functional receptor for the SARS coronavirus. Nature 2003; 426: 450-454 [PMID: 14647384 DOI: 10.1038/nature02145]

9. Chau TN, Lee KC, Yao H, Tsang TY, Chow TC, Yeung YC, Choi KW, Tso YK, Lau T, Lai ST, Lai CL. SARS-associated viral hepatitis caused by a novel coronavirus: report of three cases. Hepatology 2004; 39: 302-310 [PMID: 14767982 DOI: 10.1002/hep.20111]

10. Song W, Wang Y, Wang N, Wang D, Guo J, Fu L, Shi X. Identification of residues on human receptor DPP4 critical for MERS-CoV binding and entry. Virolology 2014; 471: 49-53 [PMID: 24561530 DOI: 10.1016/j.virol.2014.10.006]

11. Alsaaed KO, Hajeer AH, Al Balwi M, Al Moaiqel M, Al Oudah N, Al Ajlan A, Allohami S, Alsalamy S, Gmati GE, Balkhy H, Al-Jahdali HH, Baharoon SA, Arabi YM. Histopathology of Middle East respiratory syndrome coronavirus (MERS-CoV) infection - clinicopathological and ultrastructural study. Histopathology 2018; 72: 516-524 [PMID: 28588401 DOI: 10.1111/his.13379]

12. Guan WJ, Ni ZY, Hu Y, Liang WH, Ou CQ, He JX, Liu Z, Shan H, Lei CL, Hui DSC, Du B, Li LJ, Zeng G, Yuen KY, Chen RC, Tang CL, Wang T, Shen PY, Xiang J, Li SY, Wang JL, Liang ZJ, Peng YX, Wei L, Liu Y, Hu YH, Peng P, Wang JM, Liu JY, Chen Z, Li G, Zheng ZJ, Qiu SQ, Luo J, Ye...
Anirvan P et al. Liver injury in COVID-19

Cl, Zhu SY, Zhong NS; China Medical Treatment Expert Group for Covid-19. Clinical Characteristics of Coronavirus Disease 2019 in China. N Engl J Med 2020; 382: 1708-1720 [PMID: 32109013 DOI: 10.1056/NEJMoa2002032]

Holshue ML, DeBolt C, Lindquist S, Lofy KH, Wiesman J, Bruce H, Sperites C, Ericson K, Wilkerson S, Tural A, Díaz G, Cohn A, Fox L, Patel A, Gerber SL, Kim L, Tong S, Lu X, Lindstrom S, Pallansch MA, Weldon WC, Biggs HM, Uyeki TM, Pililai SK; Washington State 2019-ncov Case Investigation Team. First Case of 2019 Novel Coronavirus in the United States. N Engl J Med 2020; 382: 929-936 [PMID: 32004427 DOI: 10.1056/NEJMoa2001191]

Zhou P, Yang XL, Wang XG, Hu B, Zhang L, Zhang W, Si HR, Zhu Y, Li B, Huang CL, Chen HD, Chen J, Luo Y, Guo H, Jiang RD, Liu MQ, Chen Y, Shen XR, Wang X, Zheng XS, Zhao K, Chen QJ, Deng F, Liu LL, Yan B, Zhan FX, Wang YY, Xiao GF, Shi ZL. A pneumonia outbreak associated with a new coronavirus of probable bat origin. Nature 2020; 579: 270-273 [PMID: 32015507 DOI: 10.1038/s41586-020-2174-7]

Yang Z, Xu M, Yi JQ, Jia WD. Clinical characteristics and mechanism of liver damage in patients with severe acute respiratory syndrome. Hepatobiliary Pancreatic Dis Int 2005; 4: 60-63 [PMID: 15739021]

Shi H, Han X, Jiang N, Cao Y, Al-Walid O, Gu J, Fan Y, Zheng C. Radiological findings from 81 patients with COVID-19 pneumonia in Wuhan, China: a descriptive study. Lancet Infect Dis 2020; 20: 425-434 [PMID: 32105637 DOI: 10.1016/S1473-3099(20)30086-4]

Li L, Li S, Xu M, Yu F, Zheng S, Duan Z, Liu J, Chen Y, Li J. Risk factors related to hepatic injury in patients with corona virus disease 2019. medRxiv. Published online January 1, 2020: 2020.02.28.20028514 [DOI: 10.1016/j.gastro.2020.09.011]

Chalasani N, Fontana RJ, Bonkovsky HL, Watkins PB, Duvvern T, Serrano J, Yang H, Rochon J; Drug Induced Liver Injury Network (DILIN). Causes, clinical features, and outcomes from a prospective study of drug-induced liver injury in the United States. Gastroenterology 2008; 135: 1924-1934, 1934.e1-1934. e4 [PMID: 18955056 DOI: 10.1053/j.gastro.2008.09.011]

Ou P, Chen Y, Li B, Zhang M, Liu X, Li F, Li Y, Chen C, Mao Y, Chen J. Causes, clinical features and outcomes of drug-induced liver injury in hospitalized patients in a Chinese tertiary care hospital. Springerplus 2015; 4: 802 [PMID: 26702391 DOI: 10.1186/s40064-015-1600-8]

Xu L, Liu J, Lu M, Yang D, Zheng X. Liver injury during highly pathogenic human coronavirus infections. Liver Int 2020; 40: 998-1004 [PMID: 32170806 DOI: 10.1111/1445-225X.14435]

Banales JM, Huerec RT, Karlsten T, Strazzabosco M, LaRusso NF, Gores GJ. Cholangiocyte pathobiology. Nat Rev Gastroenterol Hepatol 2019; 16: 269-281 [PMID: 30850822 DOI: 10.1038/s41575-019-0125-y]

Xu Z, Shi L, Wang Y, Zhang J, Huang L, Zhang C, Liu S, Zhao P, Liu H, Zhu L, Tai Y, Bai C, Gao T, Song J, Xia F, Dong J, Zhao J, Wang FS. Pathological findings of COVID-19 associated with acute respiratory distress syndrome. Lancet Respir Med 2020; 8: 420-422 [PMID: 32085846 DOI: 10.1016/S2213-2600(20)30076-X]

Liu J, Li S, Liu J, Liang B, Wang X, Wang H, Li W, Tong Q, Yi J, Zhao L, Xiong L, Guo C, Tian J, Luo J, Yao J, Pang R, Shen H, Peng C, Liu T, Zhang Q, Wu J, Xu L, Lu S, Wang B, Weng Z, Han C, Zhu H, Zhou R, Zhou H, Chen X, Ye P, Zhu B, Wang L, Zhou W, He S, He Y, Jie S, Wei P, Zhang J, Lu Y, Wang W, Zhang L, Li Z, Zhou F, Wang J, Dittmer U, Lu M, Hu Y, Yang D, Zheng X. Longitudinal characteristics of lymphocyte responses and cytokine profiles in the peripheral blood of SARS-CoV-2 infected patients. ElBioMedicine 2020; 55: 102763 [PMID: 32361250 DOI: 10.1016/j.ebiom.2020.102763]

Mantovani A, Beatrice G, Dalbeni A. Coronavirus disease 2019 and prevalence of chronic liver disease: A meta-analysis. Liver Int 2020; 40: 1316-1320 [PMID: 32329563 DOI: 10.1111/lil.14465]

Fan Z, Chen L, Li J, Cheng X, Yang J, Tian C, Zeng Y, Huang S, Liu Z, Cheng J. Clinical Features of COVID-19-Related Liver Functional Abnormality. Clin Gastroenterol Hepatol 2020; 18: 1561-1566 [PMID: 32283325 DOI: 10.1016/j.cgh.2020.04.002]

Zampino R, Mele F, Florio LL, Bertolino L, Andini R, Galdol M, De Rosa R, Corcione A, Durante-Mangoni E. Liver injury in remdesivir-treated COVID-19 patients. Hepatol Int 2020; 14: 881-883 [PMID: 32725454 DOI: 10.1007/s12072-020-0077-3]

APASL Covid-19 Task Force, Lau G, Sharma M. Clinical practice guidance for hepatology and liver transplant providers during the COVID-19 pandemic: APASL expert panel consensus recommendations. Hepatol Int 2020; 14: 415-428 [PMID: 32447721 DOI: 10.1007/s12072-020-10054-w]

Chen LF, Mo YQ, Jing J, Ma JD, Zheng DH, Dai L. Short-course tocilizumab increases risk of hepatitis B virus reactivation in patients with rheumatoid arthritis: a prospective clinical observation. Int J Rheum Dis 2017; 20: 859-869 [PMID: 28160426 DOI: 10.1111/1654-213X.13010]

Azithromycin. In: LiverTox: Clinical and Research Information on Drug-Induced Liver Injury. National Institute of Diabetes and Digestive and Kidney Diseases; 2012. [Cited 2020 May 31]. Available from: http://www.ncbi.nlm.nih.gov/books/NBK548434/30

Hydroxychloroquine. In: LiverTox: Clinical and Research Information on Drug-Induced Liver Injury. National Institute of Diabetes and Digestive and Kidney Diseases; 2012. [Cited 2020 October 10]. Available from: http://www.ncbi.nlm.nih.gov/books/NBK548738/30

Olney A, Meunier L, Delire B, Larrey D, Horsmans Y, Le Louët H. Drug-Induced Liver Injury and COVID-19 Infection: The Rules Remain the Same. Drug Saf 2020; 43: 615-617 [PMID: 32514859 DOI: 10.1007/s40264-020-00954-z]
32 ANSES warns against taking food supplements that could lower the body's immune response. Anses - Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail. [Cited 2020 October 11]. Available from: https://www.anses.fr/en/content/anses-war...nutrition-supplements-could-boost-lower-body%E2%80%99s-immune-response

33 Qi X, Wang J, Li X, Wang Z, Liu Y, Yang H, Li X, Shi J, Xiang H, Liu T, Kawada N, Maruyama H, Jiang Z, Wang F, Takeharu T, Rockey DC, Sarin SK. COVID-Cirrhosis-CHESS Group. Clinical course of COVID-19 in patients with pre-existing decompensated cirrhosis: initial report from China. Hepatol Int 2020; 14: 478-482 [PMID: 32440857 DOI: 10.1007/s12072-020-10051-2]

34 Yang J, Zheng Y, Gou X, Pu K, Chen Z, Guo Q, Ji R, Wang H, Wang Y, Zhou Y. Prevalence of comorbidities and its effects in patients infected with SARS-CoV-2: a systematic review and meta-analysis. Int J Infect Dis 2020; 94: 91-95 [PMID: 32173574 DOI: 10.1016/j.ijid.2020.03.017]

35 Chen N, Zhou M, Dong X, Qu J, Gong F, Han Y, Qiu Y, Wang J, Liu Y, Wei Y, Xia J, Yu T, Zhang X, Zhang L. Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: a descriptive study. Lancet 2020; 395: 507-513 [PMID: 32007143 DOI: 10.1016/S0140-6736(20)30211-7]

36 Cai Q, Huang D, Yu H, Zhu Z, Xia Z, Su Y, Li Z, Zhou G, Gou J, Qu J, Sun Y, Liu Y, He Q, Chen J, Liu X, Yu L. COVID-19: Abnormal liver function tests. J Hepatol 2020; 73: 566-574 [PMID: 32298767 DOI: 10.1016/j.jhep.2020.04.006]

37 Bloom PP, Meyerowitz EA, Reinus Z, Daidone M, Gustafson J, Kim AY, Schaefer E, Chung RT. Liver Biochemistries in Hospitalized Patients With COVID-19. Hepatology 2020; Online ahead of print [PMID: 32415866 DOI: 10.1002/hep.31326]

38 Wander P, Epstein M, Bernstein D. COVID-19 Presenting as Acute Hepatitis. Am J Gastroenterol 2020; 115: 941-942 [PMID: 32301760 DOI: 10.14309/eag.0000000000000660]

39 Pagana SM, De Michele S, Lee MJ, Emend JC, Griesemer AD, Tullin-Silver SA, Verna EC, Martinez M, Leftkowitz H. COVID-19 Associated Hepatitis Correlating Recent Living Donor Liver Transplantation. Arch Pathol Lab Med 2020; Online ahead of print [PMID: 33202212 DOI: 10.5858/arpa.2020-0186-SA]

40 Tabata S, Imai K, Kawano S, Ikeda M, Kodama T, Miyoshi K, Obinata H, Mimura S, Kodera T, Kitakagi M, Sato M, Suzuki S, Ito T, Uwabe Y, Tamura K. Clinical characteristics of COVID-19 in 104 people with SARS-CoV-2 infection on the Diamond Princess cruise ship: a retrospective analysis. BMJ 2020; 368: m2029009 [PMID: 10.1136/bmj.m2029009]

41 Huang Y, Yang R, Xu Y, Gong P. Clinical characteristics of 36 non-survivors with COVID-19 in Wuhan, China. medRxiv. Published online March 5, 2020;2020.02.27.20029009 [DOI: 10.1101/2020.02.27.20029009]

42 Zhang B, Zhou X, Qiu Y, Feng F, Feng J, Jia Y, Zhu H, Hu K, Liu J, Liu Z, Wang S, Gong Y, Zhou C, Zhu T, Cheng Y, Liu Z, Deng H, Tao F, Ren Y, Cheng B, Gao L, Wu X, Yu L, Huang Z, Mao Z, Song Q, Zhu B, Wang J. Clinical characteristics of 82 death cases with COVID-19. medRxiv. Published online February 27, 2020;2020.02.26.20028191 [DOI: 10.1101/2020.02.26.20028191]

43 Yang X, Yu Y, Xu J, Shu H, Xia J, Liu H, Wu Y, Zhang L, Yu Z, Fang M, Yu T, Wang Y, Pan S, Sot X, Yuan S, Shang Y. Clinical course and outcomes of critically ill patients with SARS-CoV-2 pneumonia in Wuhan, China: a single-centered, retrospective, observational study. Lancet Respir Med 2020; 8: 475-481 [PMID: 32105632 DOI: 10.1016/S2213-2600(20)30079-5]

44 Cao W. Clinical features and laboratory inspection of novel coronavirus pneumonia (COVID-19) in Xiangyang, Hubei. medRxiv. Published online February 5, 2020;2020.02.27.20026963 [DOI: 10.1101/2020.02.23.20026963]

45 Xu XW, Wu XX, Jiang XG, Xu KJ, Ying LJ, Ma CL, Li SB, Wang HY, Zhang S, Gao HN, Sheng JF, Cai HL, Qiu YQ, Li LJ. Clinical findings in a group of patients infected with the 2019 novel coronavirus (SARS-CoV-2) outside Wuhan, China: retrospective case series. BMJ 2020;368: m6066 [PMID: 32075786 DOI: 10.1136/bmj.m6066]

46 Cai Q, Huang D, Ou P, Yu H, Zhu Z, Xia Z, Su Y, Ma Z, Zhang y, Li Z, He Q, Fu Y, Liu L, Chen J. COVID-19 in a Designated Infectious Diseases Hospital Outside Hubei Province, China. medRxiv. Published online February 19, 2020;2020.02.19.20024018 [DOI: 10.1101/2020.02.19.20024018]

47 Kujawski SA, Wong KK, Collins JP, Epstein L, Killip J, Chetty S, Javed M, Ahmed N, Almenara SO, Alvarez-FN, Anderson KN, Balter S, Barry V, Bartlett K, Beer K, Ben-Aderet M A, Benowitz I, Biggs H, Binder AM, Black SR, Bonin B, Brown CM, Bruce H, Bryant-Geniever J, Budd A, Buell D, Butty J, Crites J, Charles EM, Chathan-Singh S, Chea N, Chiao H, Christiansen D, Chiu WC, Cody S, Cohen M, Conners E, Curns A, Daasri Y, Dawson P, DeSalvo T, Diaz G, Donahue M, Donovan S, Du LM, Erickson K, Esouna M, Evans S, Fark J, Feldstein LE, Fenstersheib M, Fischer M, Fisher R, Foo C, Frichchione M J, Friedman O, Fry AM, Galang R R, Garcia M, Gerber S I, Gherardini G, Ghina I, Gounder P, Grein J, Grigg C, Gunzenhauser J D, Gutkin G I, Haddix M, Hall A J, Han G, Harcourt J, Harriman K, Haupt T, Haynes A, Holmoe H, Hoover C, Hunter JC, Jacobs MW, Jarashow C, Jiuh M A, Joshi K, Kamali T, Kamili S, Kim L, Kim M, King J, Kirkling HL, Kita-Yarbro A, Klos R, Kobayashi M, Koccharian A, Komatsa K K, Koppaka R, Layden J, Li Y, Lindquist S, Lindstrom S, Linkel-Gelles R, Lively J, Livingston M, L K, Lo J, Lu X, Lynch B, Madoff L, Malapati L, Marks G, Marlow M, Mathiesen G E, McClung N, McGovern O, McPherson TD, Mehta M, Meier A, Mello L, Moon S, Morgan M, Moro RN, Murray J, Murthy R, Nosvad S, Oliver SE, O'Shea J, Pacilli M, Paden CR, Pallansch M A, Patel M, Patel S, Pedraza I, Pillai SK, Pindyck T, Pray I, Queen K, Quick N, Reese H, Rha B, Rhodes H, Robinson S, Robinson P, Rolfs M, Rout J, Rubin R, Rudman S L, Sakhivel S K, Scott S, Shepherd C, Shetty V,
Liver injury in COVID-19

Smith E A, Smith S, Stierman B, Stoecker W, Sunenshine R, Sy-Santos R, Tamin A, Tao Y, Terasita D, Thornburg N J, Tong S, Traub E, Turali A, Uehara A, Uyeki T M, Vahey G, Verani J R, Villarino E, Wallace M, Wang L, Watson J T, Westercamp M, Whitaker B, Wilkerson S, Woodruff R C, Wortham J M, Wu T, Xie A, Yousaf A, Zahn M, Zhang J. First 12 Patients with Coronavirus Disease 2019 (COVID-19) in the United States. medRxiv. Public and Global Health, 2020 [DOI: 10.1101/2020.03.09.20032896]

Arentz M, Yim E, Klaff L, Lohandwala S, Riedo FX, Chong M, Lee M. Characteristics and Outcomes of 21 Critically Ill Patients With COVID-19 in Washington State. JAMA 2020; 323: 1612-1614 [PMID: 32191259 DOI: 10.1001/jama.2020.4326]

Jin X, Lian JS, Hu JH, Gao J, Zheng L, Zhang YM, Hao SR, Jia HY, Cai H, Zhang XL, Yu GD, Xu KJ, Wang XY, Gu JQ, Zhang SY, Ye CY, Jin CL, Lu YF, Yu X, Yu XP, Huang JR, Xu KL, Ni Q, Yu CB, Zhu B, Li YT, Liu J, Zhao H, Zhang X, Yu L, Guo YZ, Su JW, Tao JJ, Lang GJ, Wu XX, Wu WR, Qv, Xiang DR, Yi P, Shi D, Chen Y, Ren Y, Qiu YQ, Li LJ, Sheng J, Yang Y. Epidemiological, clinical and virological characteristics of 74 cases of coronavirus-infected disease 2019 (COVID-19) with gastrointestinal symptoms. Gut 2020; 69: 1002-1009 [PMID: 32213556 DOI: 10.1136/gutjnl-2020-320926]

Qi D, Yan X, Tang X, Peng J, Yu Q, Feng L, Yuan G, Zhang A, Chen Y, Yuan J, Huang X, Zhang X, Hu P, Song Y, Qian C, Sun Q, Wang D, Tong J, Xiang J. Epidemiological and clinical features of 2019-nCoV acute respiratory disease cases in Chongqing municipality, China: a retrospective, descriptive, multiple-center study. medRxiv. Published online January 1, 2020:2020.03.01.20029397

Omran-Nava V, Maleki I, Ahmadi A, Moosazadeh M, Alizadeh-Navaei R. Evaluation of Hepatic Enzymes Changes and Association with Prognosis in COVID-19 Patients. Hepat Mon 2020; 20 [DOI: 10.5812/hepatomon.103179]

Mao L, Wang M, Chen S, He Q, Chang J, Hong C, Zhou Y, Wang D, Li Y, Jin H, Hu B. Neurological Manifestations of Hospitalized Patients with COVID-19 in Wuhan, China: A Retrospective Case Series Study. medRxiv. Infectious Diseases (except HIV/AIDS); 2020 [DOI: 10.1101/2020.02.22.20026500]

Xu Y, Xu Z, Liu X, Cai L, Zheng H, Huang Y, Zhou L, Huang L, Lin Y, Deng L, Li J, Chen S, Liu D, Lin Z, Zhou L, He W, Liu X, Li Y. Clinical findings in critical ill patients infected with SARS-CoV-2 in Guangdong Province, China: a multi-center, retrospective, observational study. medRxiv. Published online January 1, 2020:2020.03.03.20030668 [DOI: 10.1101/2020.03.03.20030668]

Tian S, Wu M, Chang Z, Wang Y, Zhou G, Zhang W, Xing J, Tian H, Zhang X, Zou X, Zhang L, Liu M, Chen J, Han J, Ning K, Chen S, Wu T. Epidemiological Investigation and Intergenerational Clinical Characteristics of 24 COVID-19 Patients Associated with Supermarket Cluster. medRxiv. Published online April 11, 2020:2020.04.11.20058891

Chen X, Zheng F, Qing Y, Ding S, Yang D, Lei C, Yin Z, Zhou X, Jiang D, Zuo Q, He J, Lv J, Chen P, Chen Y, Peng H, Li H, Xie Y, Liu J, Zhou Z, Luo H. Epidemiological and Clinical Features of 291 Cases with Coronavirus Disease 2019 in Areas Adjacent to Hubei, China: A Double-Center Observational Study. medRxiv. Respiratory Medicine; 2020 [DOI: 10.1101/2020.03.03.2003353]

Wang L, Gao YH, Lou LL, Zhang GJ. The clinical dynamics of 18 cases of COVID-19 outside of Wuhan, China. Eur Respir J 2020; 55 [PMID: 32139464 DOI: 10.1183/13993003.00398-2020]

Yan S, Song X, Lin F, Zhu H, Wang X, Li M, Ruan J, Lin C, Liu X, Wu Q, Luo Z, Fu W, Chen S, Yuan Y, Liu S, Yao J, Lv C. Clinical Characteristics of Coronavirus Disease 2019 in Hainan, China. medRxiv. Infectious Diseases (except HIV/AIDS); 2020 [DOI: 10.1101/2020.03.19.20038539]

Lin L, Jiang X, Zhang Z, Huang S, Zhang Z, Fang Z, Gu Z, Gao L, Shi H, Mai L, Liu Y, Lin X, Lai R, Yan Z, Li X, Shan H. Gastrointestinal symptoms of 95 cases with SARS-CoV-2 infection. Gut. medRxiv. Published online April 2, 2020 [DOI: 10.1136/gutjnl-2020-321013]

Zhao W, Yu S, Zha X, Wang N, Pang Q, Li T, Li A. Clinical characteristics and durations of hospitalized patients with COVID-19 in Beijing: a retrospective cohort study. medRxiv. Published online March 30, 2020:2020.03.13.20035436 [DOI: 10.1101/2020.03.13.20035436]

Chen T, Wu D, Chen H, Yan W, Yang D, Chen G, Ma K, Xu D, Yu H, Wang H, Tang T, Guo W, Chen J, Ding C, Zhang X, Huang J, Han M, Li S, Luo X, Zhao J, Ning Q. Clinical characteristics of 113 deceased patients with coronavirus disease 2019: retrospective study. BMJ 2020; 368: m1091 [PMID: 32217556 DOI: 10.1136/bmj.m1091]

Rubin SJ, Falkson SR, Degner N, Blish C. Clinical Characteristics Associated with COVID-19 Severity in California. J Clin Transl Sci 2020; 1-4 [DOI: 10.1136/jctjs-2020-004361]

Cholankeril G, Podboy A, Aivaliotis VI, Tarlow B, Pham EA, Spencer SP, Kim D, Hsing A, Ahmed A. High Prevalence of Concurrent Gastrointestinal Manifestations in Patients With Severe Acute Respiratory Syndrome Coronavirus 2: Early Experience From California. Gastroenterology 2020; 159: 775-777 [PMID: 32283101 DOI: 10.1053/j.gastro.2020.04.008]

Yao N, Wang SN, Lian JQ, Sun YT, Zhang GF, Kang WZ, Kang W. [Clinical characteristics and influencing factors of patients with novel coronavirus pneumonia combined with liver injury in Shaanxi region]. Zhonghua Gan Zang Bing Za Zhi 2020; 28: 234-239 [PMID: 32153170 DOI: 10.3760/cma.j.cn501113-20200226-00070]

Zhao Z, Xie J, Yin M, Yang Y, He H, Jin T, Li W, Zhu X, Xu J, Zhao C, Li L, Li Y, Mengist H M, Zahid A, Yao Z, Ding C, Qi Y, Gao Y, Ma X. Clinical and Laboratory Profiles of 75 Hospitalized Patients with Novel Coronavirus Disease 2019 in Hefei, China. medRxiv. Published online March 6, 2020:2020.03.01.20029785 [DOI: 10.1101/2020.03.01.20029785]
Anirvan P et al. Liver injury in COVID-19

65 Ai J, Chen J, Wang Y, Liu X, Fan W, Qu G, Zhang M, Pei S P, Tang B, Yuan S, Li Y, Wang L, Huang G, Pei B. The cross-sectional study of hospitalized coronavirus disease 2019 patients in Xiangyang, Hubei province. medRxiv. Published online January 1, 2020;2020.02.19.20025023 [DOI: 10.1101/2020.02.19.20025023]

66 Ma L, Xie W, Li D, Shi L, Mao Y, Xiong Y, Zhang Y, Zhang M. Effect of SARS-CoV-2 infection upon male gonadal function: A single center-based study. medRxiv. Published online January 1, 2020; 2020.03.21.20037267 [DOI: 10.1101/2020.03.21.20037267]

67 Xu S, Fu L, Fei J, Xiang H-X, Xiang Y, Tan Z-X, Li M-D, Liu F-F, Li Y, Han M-F, Li X-Y, Yu D-X, Zhao H, Xu D-X. Acute kidney injury at early stage as a negative prognostic indicator of patients with COVID-19: a hospital-based retrospective analysis. medRxiv. Published online January 1, 2020;2020.03.24.20042408 [DOI: 10.1101/2020.03.24.20042408]

68 Shi S, Qin M, Shen B, Cai Y, Liu T, Yang F, Gong W, Liu X, Liang J, Zhao Q, Huang H, Yang B, Huang C. Association of Cardiac Injury With Mortality in Hospitalized Patients With COVID-19 in Wuhan, China. JAMA Cardiol 2020; 5: 802-810 [PMID: 32211816 DOI: 10.1001/jamacardio.2020.0950]

69 Luo S, Zhang X, Xu H. Don't Overlook Digestive Symptoms in Patients With 2019 Novel Coronavirus Disease (COVID-19). Clin Gastroenterol Hepatol 2020; 18: 1636-1637 [PMID: 32205220 DOI: 10.1016/j.cgh.2020.03.043]

70 Qi X, Liu Y, Wang J, Fallowfield JA, Wang J, Li X, Shi J, Pan H, Zou S, Zhang H, Chen Z, Li F, Luo Y, Mei M, Liu H, Wang Z, Li J, Yang H, Xiang H, Li X, Liu T, Zheng MH, Liu C, Huang Y, Xu D, Li X, Kang N, He Q, Gu Y, Zhang G, Shao C, Liu D, Zhang L, Li X, Kawada N, Jiang Z, Wang F, Xiong B. Takehara T, Rockey DC; COVID-Cirrhosis-CHESS Group. Clinical course and risk factors for mortality of COVID-19 patients with pre-existing cirrhosis: a multicentre cohort study. Gut 2020; Online ahead of print [PMID: 32434831 DOI: 10.1136/gutjnl-2020-321666]

71 Ji D, Qin E, Xu J, Zhang D, Cheng G, Wang Y, Lau G. Non-alcoholic fatty liver diseases in patients with COVID-19: A retrospective study. J Hepatol 2020; 73: 451-453 [PMID: 32278005 DOI: 10.1016/j.jhep.2020.03.044]

72 Kumar D, Tellier R, Draker R, Levy G, Humar A. Severe Acute Respiratory Syndrome (SARS) in a liver transplant recipient and guidelines for donor SARS screening. Am J Transplant 2003; 3: 977-981 [PMID: 12859532 DOI: 10.1034/j.1600-6143.2003.00197.x]

73 Bhoori S, Rossi RE, Citterio D, Mazzaferro V. COVID-19 in long-term liver transplant patients: preliminary experience from an Italian transplant centre in Lombardy. Lancet Gastroenterol Hepatol 2020; 5: 532-533 [PMID: 32278366 DOI: 10.1016/S2468-1253(20)30116-3]

74 The Transplantation Society. An Update and Guidance on 2019 Novel Coronavirus (2019-nCov) for Transplant ID Clinicians. [Cited 2020 May 6]. Available from: https://tts.org/23-tid/tid-news/657-tid-update-and-guidance-on-2019-novel-coronavirus-2019-ncov-for-transplant-id-clinicians

75 American Association for the Study of Liver Diseases. Clinical insights for hepatology and liver transplant providers during the covid-19 pandemic. [Cited 2020 May 6]. Available from: https://www.aasld.org/sites/default/files/2020-04/AASLD-COVID19-ClinicalInsights-4.07.2020-Final.pdf

76 The European Association for the Study of the Liver. COVID-19 and the Liver. EASL-The Home of Hepatology. [Cited 2020 May 6]. Available from: https://easl.eu/covid-19-and-the-liver/

77 Zhou F, Yu T, Du R, Fan G, Liu Y, Liu Z, Xiang J, Wang Y, Song B, Gu X, Guan L, Wei Y, Li H, Wu X, Xu J, Tu S, Zhang Y, Chen H, Cao B. Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort study. Lancet 2020; 395: 1054-1062 [PMID: 32171076 DOI: 10.1016/S0140-6736(20)30566-3]
