



COVID-19 and Liver Dysfunction: Current Insights and Emergent Therapeutic Strategies

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Abstract

The outbreak of coronavirus disease 2019 (COVID-19), caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has attracted increasing worldwide attention. Cases of liver damage or dysfunction (mainly characterized by moderately elevated serum aspartate aminotransferase levels) have been reported among patients with COVID-19. However, it is currently uncertain whether the COVID-19-related liver damage/dysfunction is due mainly to the viral infection per se or other coexisting conditions, such as the use of potentially hepatotoxic drugs and the coexistence of systemic inflammatory response, respiratory distress syndrome-induced hypoxia, and multiple organ dysfunction. Based on the current evidence from case reports and case series, this review article focuses on the demographic and clinical characteristics, potential mechanisms, and treatment options for COVID-19-related liver dysfunction. This review also describes the geographical and demographic distribution of COVID-19-related liver dysfunction, as well as possible underlying mechanisms linking COVID-19 to liver dysfunction, in order to facilitate future drug development, prevention, and control measures for COVID-19.

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Keywords: COVID-19; Liver dysfunction; SARS-CoV-2.

Abbreviations: ACE, angiotensin converting enzyme; ALT, alanine aminotransferase; AST, aspartate aminotransferase; COVID-19, coronavirus disease 2019; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2; TLR, toll-like receptor.

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Introduction

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has become a serious threat to global public health.^{1,2} Although the virus appears to be only partially similar to severe acute respiratory syndrome coronavirus and Middle East respiratory syndrome coronavirus, all of these viral infections are responsible for severe and potentially lethal acute respiratory syndromes in humans.³ Unfortunately, to date, there are no specific/targeted drugs, or vaccines, and the number of SARS-CoV-2-positive patients is growing in many parts of the world. The world and China map showing the geographical distribution of coronavirus disease 2019 (COVID-19) is shown in Figure 1; the cut-off date for this data extraction was March 5, 2020.⁴

Surprisingly, in addition to the acute respiratory symptoms, patients with COVID-19 also have varying degrees of liver damage/dysfunction. For example, Chen *et al.*⁵ showed that more than a third of COVID-19 patients have some liver function test abnormalities. Most of these infected patients had mild-to-moderate elevations of serum alanine aminotransferase (ALT) or aspartate aminotransferase (AST) levels; one patient had severely elevated serum aminotransferases (ALT of 7590 U/L, AST of 1445 U/L).⁵ Since COVID-19-related liver dysfunction is now attracting widespread attention, this review discusses the epidemiological characteristics, the potential mechanisms, and the treatment options for liver dysfunction induced by COVID-19.

Epidemiological characteristics of COVID-19-related liver dysfunction

To better understand the distribution of COVID-19-related liver dysfunction in different regions of the world, we searched the available literature between December 11, 2019 and February 20, 2020. The literature search focused on initial case reports and case series covering COVID-19 patients, with a clear description of liver function tests and results. All case reports without any data on patients' liver function tests were excluded. Finally, we included 14 eligible studies, including 5 case reports (Table 1) and 9 case series (Table 2).^{5–18} By reviewing these 14 studies, we have

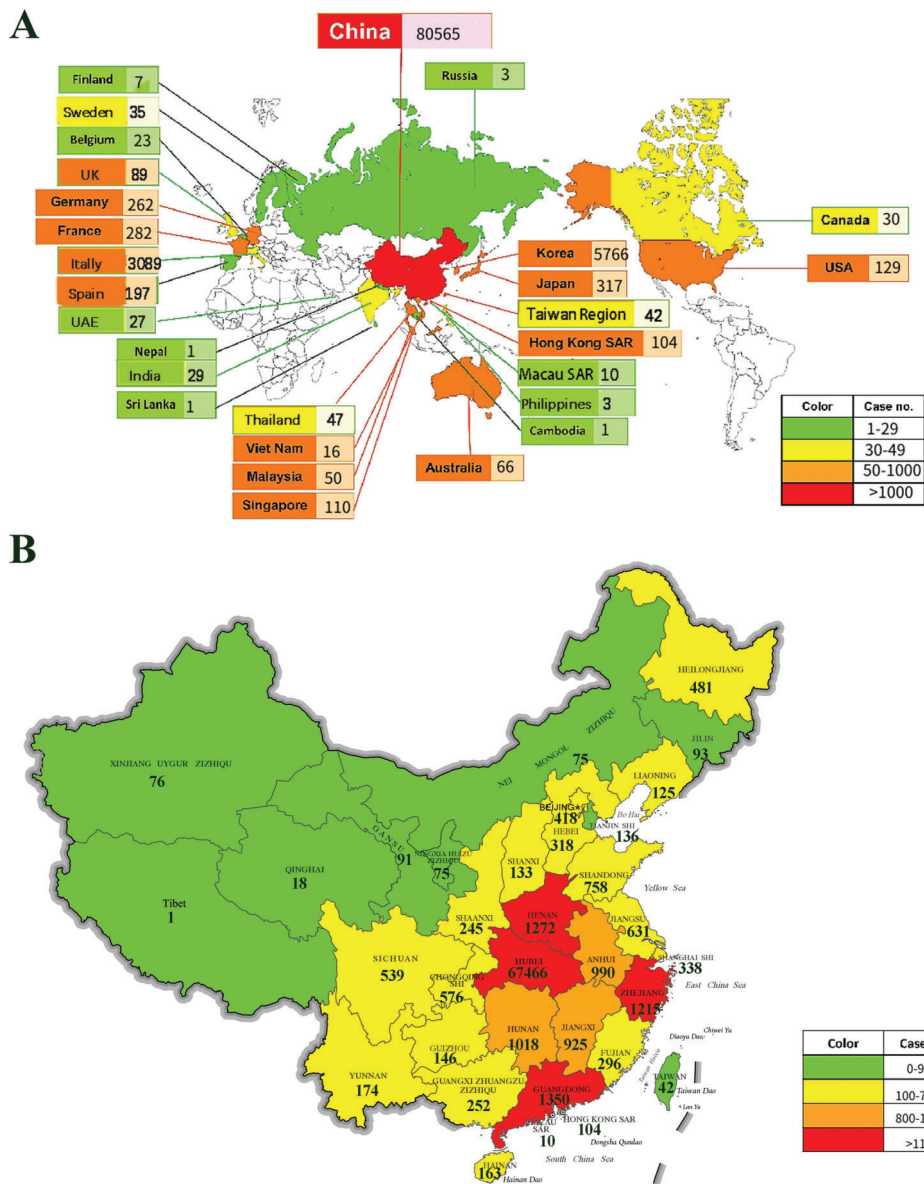


Fig. 1. Geographical distribution of COVID-19, using the cut-off date for data extraction of March 5, 2020.

described geographical and demographic characteristics of COVID-19-related liver dysfunction (as summarized below).

Geographical distribution of COVID-19-related liver dysfunction

In two Chinese multicenter surveys, one of which was led by the First Affiliated Hospital of Guangzhou Medical University, including 552 hospitals in 31 provinces/provincial municipalities through January 29th, 2020 and the other was led by the First Hospital of Lanzhou University including 7 hospitals, a considerable number of patients with COVID-19 had some abnormalities in liver function tests.^{11,16} In particular, 6.2% to 22.2% of patients had increased serum AST levels (Fig. 2) and 21.3% to 28.1% of patients had increased serum ALT

levels, respectively.^{11,16} Of the six studies performed in Wuhan, China,^{5,13-15,17,18} only four included data on the proportion of patients with abnormal liver function test results. Specifically, in these four studies, the proportion of infected patients with increased serum AST levels ranged from 24.1% to 36.6% (Fig. 2).^{5,13,17,18} In a survey from Zhejiang Province, China, the proportion of patients with increased serum AST levels was only 16.1%, whereas the proportion of those with increased serum ALT levels was not specified.¹² It seems likely that the proportion of infected patients with increased serum AST levels in Wuhan (i.e. the area in which the epidemic of COVID-19 started) is much greater than cases reported outside Wuhan. It is plausible to speculate that there may have been a higher viral load of COVID-19 in

Table 1. Demographic and liver function characteristics of patients with COVID-19 based on the first case reports in three countries

Author, Year	Country	Age (years)	Sex	AST (IU/L)	ALT (IU/L)	COVID-19 Disease severity	Prior history of liver diseases	Drugs		
								Antibiotic drugs	Antiviral drugs	Antifungal drugs
Zhang YH, 2020 ⁶	China (Haikou)	3 months	Female	Normal	Normal	Non-severe	No	Azithromycin, Ceftriaxime	Paramivir	NA
Chen F, 2020 ⁷	China (Wuhan)	1	Male	Normal	Normal	Severe	NA	Meropenem, Linezolid, Oseltamivir	NA	NA
Cai JH, 2020 ⁸	China (Shanghai)	7	Male	33	17	Non-severe	No	Levofloxacin	NA	NA
Holshue ML, 2020 ⁹	United States	35	Male	72 (16.4) _{1*}	124 (30.3) _{2*}	Non-severe	No	NA	NA	NA
Silverstein WK, 2020 ¹⁰	Canada	56	Male	NA	29	Non-severe	NA	NA	NA	NA

AST: aspartate aminotransferase. ALT: alanine aminotransferase. Liver diseases: any liver disease that can cause serum liver enzyme changes, such as viral hepatitis, autoimmune hepatitis, etc. NA: not available. Normal ranges for AST and ALT: AST < 40 IU/L and ALT < 40 IU/L.

* Standard deviation of liver enzyme fluctuations during hospitalization

exposed patients in Wuhan, where the infection began and was concentrated in a greater proportion of the population.

Sex distribution of COVID-19-related liver dysfunction

A total of six case series reporting the percentage of abnormal liver function test results amongst COVID-19 patients suggested that the proportion of infected men with increased serum AST levels was higher than that observed in infected women.^{5,11-13,16,17} In fact, in these case series, the proportions of infected men with increased serum AST levels were, respectively, 68.7%, 58.2%, 58.1%, 72.4%, 62.8% and 73.2%, whereas the proportions of infected women were, respectively, 31.3%, 41.8%, 41.9%, 27.6%, 37.2% and 26.8%. It is possible to hypothesize that infected men are more predisposed to develop COVID-19-associated liver dysfunction than infected women, and we suggest that further research is required to better understand this sex-related difference.

Age distribution of COVID-19-related liver dysfunction

Of the five case reports, three were in children and two were in adults. The age of children ranged from 3 months to 7 years, whereas the age of adult patients ranged from 35 to 56 years. None of these children had abnormal serum liver enzymes and, therefore, it is possible to hypothesize that older age is associated with a higher likelihood of liver damage/dysfunction. However, further studies are needed to confirm this finding. We look forward to more case reports/case series on COVID-19-related liver damage/dysfunction in different age groups in the future.

Putative mechanisms of COVID-19-related liver dysfunction

Angiotensin-converting enzyme (ACE)2-mediated liver dysfunction

Whether SARS-CoV-2 has direct adverse effects on liver function is currently not known. Some studies have suggested that SARS-CoV-2 predominantly enters alveolar epithelial cells through the human ACE2 receptor.^{19,20} Therefore, the lung is considered the main target organ of SARS-CoV-2 infection. However, previous studies have found that bile duct epithelial cells may also express ACE2 receptor at a concentration 20 times higher than in hepatocytes and these findings suggest that SARS-CoV-2 infection might also cause bile duct epithelial cell damage.^{21,22} However, significant increases in circulating levels of serum alkaline phosphatase, bilirubin or gamma-glutamyltransferase (that may reflect bile duct injury) have been rarely reported in COVID-19 patients.⁹ Liver histopathologic features from COVID-19 patients also did not show any significant damage in hepatocytes or bile duct cells.²³ For this reason, it is reasonable to assume that COVID-19-related liver dysfunction is more likely due to secondary liver damage than the use of hepatotoxic therapies or the coexistence of systemic inflammatory response, respiratory distress syndrome-induced hypoxia, or multiple organ dysfunction.

Table 2. Main characteristics related to liver disease in patients with COVID-19 infection in different Chinese regions based on a series of case reports

Author, Year	Country	Sample size (n)	Abnormal AST (%)	AST (IU/L)	Abnormal ALT (%)	ALT (IU/L)	Male, n (%)	Age (years)	Disease severity				Drugs			
									Severe (%)	Non-severe (%)	History of liver diseases (%)	Antibiotic drugs (%)	Antiviral drugs (%)	Antifungal drugs (%)		
Guan WJ 2020 ¹¹	China (Multi-center)	1099	168 (22.2)	NA	158 (21.3)	NA	640 (58.2)	47.0 (35.0–58.0)	173 (15.7)	926 (84.3)	23 (2.1)	632 (57.5)	393 (35.8)	30 (2.7)		
Xu XW 2020 ¹²	China (Zhejiang)	62	10 (16.1)	26 (20–32)	NA	22 (14–34)	36 (58.1)	41.0 (32.0–52.0)	NA	NA	7 (11.3)	28 (45.2)	55 (88.7)	NA		
Chen NS, 2020 ⁵	China (Wuhan)	99	35 (35.3)	34 (26–48)	28 (28.2)	39 (22–53)	67 (68.7)	55.5 ± 35.1	NA	NA	11 (11.1)	70 (70.7)	75 (75.8)	15 (15.2)		
Chen L, 2020 ¹³	China (Wuhan)	29	7 (24.1)	NA	5 (17.2)	NA	21 (72.4)	56.0 [±] *	14 (48.3)	15 (51.7)	NA	NA	NA	NA		
Wang DW, 2020 ¹⁴	China (Wuhan)	138	NA	31 (24–51)	NA	24 (16–40)	75 (54.3)	56.0 (42.0–68.0)	36 (26.1)	102 (73.9)	4 (2.9)	89 (64.5)	124 (89.9)	NA		
Pan F, 2020 ¹⁵	China (Wuhan)	21	NA	32 ± 20 (15–95)	NA	42 ± 31 (12–107)	6 (28.6)	40.0 ± 9.0	0 (0.0)	21 (100.0)	NA	NA	NA	NA		
Liu C, 2020 ¹⁶	China (Multi-center)	32	2 (6.2)	25 (19–32)	9 (28.1)	26 (17–46)	20 (62.5)	38.5 (26.3–45.8)	4 (12.5)	28 (87.5)	1 (3.13)	NA	NA	NA		
Huang C 2020 ¹⁷	China (Wuhan)	41	15 (36.6)	34 (26–48)	NA	32 (21–50)	30 (73.2)	49.0 (41.0–58.0)	13 (31.7)	28 (68.3)	1 (2.4)	41 (100.0%)	38 (92.7%)	NA		
Chen HJ 2020 ¹⁸	China (Wuhan)	9	3 (33.3)	24 (21–119)	3 (33.3)	16 (11–58)	0 (0)	28 (26–34)	0 (0.0)	9 (100.0)	NA	9 (100.0%)	6 (66.7%)	NA		

Abbreviations: AST, aspartate aminotransferase; ALT, alanine aminotransferase; NA, not available. Liver diseases: any liver disease that can cause liver enzyme changes, such as viral hepatitis, autoimmune hepatitis, etc. Normal range for AST and ALT: AST < 40 IU/L and ALT < 40 IU/L.
^{*} Median, no interquartile range

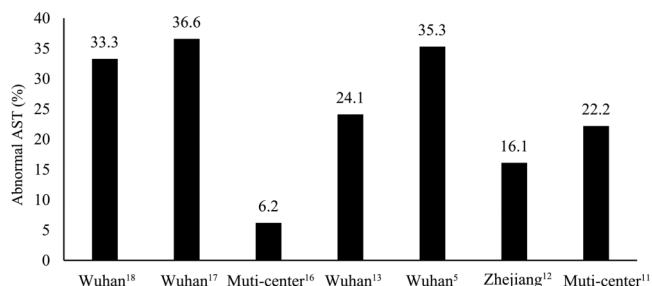


Fig. 2. Proportion of patients with liver dysfunction in Chinese regions: Wuhan and outside Wuhan.

Drugs

During the course of the COVID-19 epidemic, many infected patients have been treated with antipyretic agents. Most of these medications contain acetaminophen, which is a drug recognized as being able to cause significant liver damage or induce liver failure.²³ It is known that an acute ingestion of >7.5 to 10 g of acetaminophen in adults or 150 to 200 mg/kg in children is likely to cause hepatotoxicity.²⁴ Although the US Food and Drug Administration Advisory Committee has proposed a decrease in the maximum daily dosage of acetaminophen from 4 to 3 g, and the maximum individual dosage from 1 to 0.65 g, (relegating 500-mg tablets to prescription status), these recommendations have not been implemented worldwide.²⁵ In addition, although there is currently no targeted antiviral treatment for COVID-19, many infected patients have also been treated with some antiviral drugs, such as oseltamivir, abidol or lopinavir, which may have some hepatotoxic effects.

Systemic inflammatory response syndrome

Although many COVID-19 patients were not too unwell, this infection in some patients has resulted in sudden deterioration, ending in multiple organ failure. Most experts believe that the occurrence of multiple organ failure is mainly related to the sudden initiation of an inflammatory "storm" in the critically ill COVID-19 patients.²⁶ The so-called inflammatory "storm", or systemic inflammatory response syndrome, is strongly related to activation of both natural and cellular immunity that is triggered by COVID-19 infection.²⁷ In fact, the virus is able to directly induce multiple proinflammatory signals via toll-like receptors (TLRs) and activation of killer T lymphocytes.²⁸ The activated T lymphocytes then attack the infected body cells, leading to their apoptosis and necrosis, until T lymphocytes are depleted. Damage-related pattern molecules released by dead infected cells can further amplify some inflammatory signals, such as TLRs. At the same time, T-lymphocyte depletion cannot control viral and bacterial infections, thereby activating multiple inflammatory signaling pathways, which lead to macrophage activation and secondary inflammatory reactions. Subsequently, when more inflammatory cytokines are released, more cell damage and necrosis are observed (Fig. 3). Such a vicious cycle is capable of causing multiple injuries, not only to the lungs but also to the liver, heart, and kidneys.

Hypoxia-reperfusion dysfunction

Hypoxia and shock induced by COVID-19-related complications (such as respiratory distress syndrome, systemic

inflammatory response syndrome, and multiple organ failure) may also cause hepatic ischemia and hypoxia-reperfusion dysfunction. Experimental data showed that hepatic cell death and inflammatory cell infiltration caused by hypoxia can be seen both *in vivo* and *in vitro* models of hepatic ischemia and hypoxia.²⁹ This suggests that oxygen reduction and lipid accumulation in hepatocytes during shock and hypoxic conditions may lead to cell death. The subsequent marked increase in reactive oxygen species and their peroxidation products can act as a second messenger, activating redox-sensitive transcription factors, and further amplifying the release of multiple proinflammatory factors, causing liver damage.³⁰ All the aforementioned findings suggest that pneumonia-associated hypoxia is one of the most important factors causing secondary liver injury in COVID-19 patients.

In summary, the COVID-19-related liver dysfunction may be considered as the result of secondary liver damage caused mainly by several factors, such as the use of potentially hepatotoxic drugs, systemic inflammatory response, respiratory distress syndrome-induced hypoxia, and multiple organ failure. In addition, critically ill COVID-19 patients with severe liver dysfunction are also more likely to have a poorer prognosis.

Treatment options for COVID-19-related liver dysfunction

Presently, there is no specific treatment for COVID-19 infection.³¹ Therefore, the cornerstone of COVID-19 management is patient isolation and supportive medical care where necessary, including pulmonary ventilation and prevention of the underlying inflammatory "storm" as well.³²

From the findings discussed above, however, we believe that it is also reasonable to explore novel treatments for COVID-19 targeting of the ACE2 receptor. The ACE2 cellular receptor is highly expressed in human lung tissues, gastrointestinal tract, liver, vascular endothelial cells, and arterial smooth muscle cells.³³ In addition, skin, nasal cavity, and oral mucosa basal cells also express the ACE2 receptor.²⁷ All organs with high expression of the ACE2 receptor may be targeted by SARS-CoV-2 infection.³⁴ Activation of the ACE2/Ang

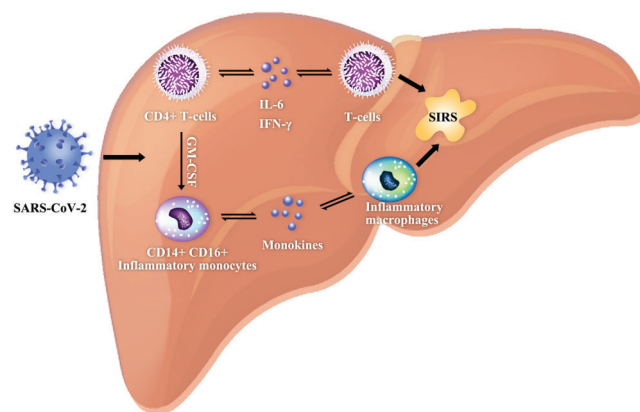


Fig. 3. Schematic diagram showing the systemic inflammatory response syndrome induced by SARS-CoV2. After the SARS-CoV-2 infection, pathogenic T cells are rapidly activated, producing granulocyte-macrophage colony-stimulating factor (GM-CSF), interleukin (IL)-6 and other proinflammatory factors. GM-CSF will further activate CD14⁺CD16⁺ inflammatory monocytes, producing a larger amount of IL-6 and other proinflammatory factors, and thereby inducing an inflammatory "storm" that leads to immune damage to other organs, such as the lungs and the liver. Both IL-6 and GM-CSF are two key proinflammatory factors that trigger the inflammatory "storm" in patients with COVID-19.

(1-7)/Mas signaling pathway or inhibition of the ACE/Ang II/AT1R pathway could be potential pathways for the treatment of COVID-19. For SARS-CoV-2-infected patients, both ACE-inhibitors and angiotensin-II-receptor antagonists might be used not only for treating high blood pressure but also for reducing systemic inflammatory response and improving patient mortality.³⁵

Recently, Chen *et al.*³⁶ reported that glycyrrhizic acid derivatives might also have antiviral activity against SARS-CoV-2. Glycyrrhizic acid is one of the first-line drugs for anti-inflammatory protection in liver disease, and it has been used in clinical practice for many years.³⁷ In particular, glycyrrhizic acid is a triterpene glycoside isolated from the root of the licorice plant. ACE2 is a cellular type I membrane protein that is mostly expressed in the lungs, heart, kidneys, and intestine. Full-length ACE2 consists of an N-terminal peptidase domain and a C-terminal collectrin-like domain that ends with a single trans-membrane helix and a ~40-residue intracellular segment.³⁸ Glycyrrhizin has the potential to bind to ACE2 receptor with an estimated ΔG (kcal/mol) of -9, with the binding sites of ARG-559, GLN-388, ARG-393, and ASP-30.³⁶

Conclusions

Our review shows the following: (1) In highly epidemic areas of COVID-19 infection, such as Wuhan, China, the proportion of infected patients with abnormal liver function test results (mainly elevated serum AST levels) is greater than that observed in regions where a smaller proportion of cases of COVID-19 infection in the population have occurred. (2) The proportion of infected patients with elevated serum transaminase levels is higher in adults than in children and in men than in women, respectively. However, we suggest that further studies are needed to confirm these preliminary observations. In the meantime, we believe that the front-line medical staff should pay attention to liver function tests in patients infected with COVID-19. For those patients with a pre-existing history of liver diseases (especially older patients), special attention should be paid to monitoring hepatic changes caused by COVID-19, whilst carefully identifying the cause of the liver dysfunction.³⁹ We also recommend that front-line medical staff should assess the use of appropriate hepatoprotective therapies, especially in patients with pre-existing liver disease, in order to attenuate the potentially deleterious impact of COVID-19-related liver damage/dysfunction.

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Conflict of interest

The authors have no conflict of interests related to this article.

Author contributions

Design and data interpretation (MHZ, GF, KIZ, QQY, WYL), manuscript writing (GF, KIZ, RSR), critical revision of the

manuscript (MHZ, GT, CDB, SVP). All authors reviewed and commented on the manuscript and approved the final version.

References

- [1] Zhu N, Zhang D, Wang W, Li X, Yang B, Song J, *et al.* A novel coronavirus from patients with pneumonia in China, 2019. *N Engl J Med* 2020;382:727–733. doi: 10.1056/NEJMoa2001017.
- [2] Li Q, Guan X, Wu P, Wang X, Zhou L, Tong Y, *et al.* Early transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia. *N Engl J Med* 2020. doi: 10.1056/NEJMoa2001316.
- [3] Zhang C, Shi L, Wang FS. Liver injury in COVID-19: management and challenges. *Lancet Gastroenterol Hepatol* 2020. doi: 10.1016/S2468-1253(20)30057-1.
- [4] WHO. Coronavirus disease 2019 (COVID-19) situation report-49. 2020. Available from: https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200309-sitrep-49-covid-19.pdf?sfvrsn=70dabe61_4
- [5] Chen N, Zhou M, Dong X, Qu J, Gong F, Han Y, *et al.* Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: a descriptive study. *Lancet* 2020;395:507–513. doi: 10.1016/S0140-6736(20)30211-7.
- [6] Zhang YH, Lin DJ, Xiao MF, Wang JC, Wei Y, Lei ZX, *et al.* [2019-novel coronavirus infection in a three-month-old baby]. *Zhonghua Er Ke Za Zhi* 2020; 58:E006. doi: 10.3760/cma.j.issn.0578-1310.2020.0006.
- [7] Chen F, Liu ZS, Zhang FR, Xiong RH, Chen Y, Cheng XF, *et al.* [First case of severe childhood novel coronavirus pneumonia in China]. *Zhonghua Er Ke Za Zhi* 2020;58:E005. doi: 10.3760/cma.j.issn.0578-1310.2020.0005.
- [8] Cai JH, Wang XS, Ge YL, Xia AM, Chang HL, Tian H, *et al.* [First case of 2019 novel coronavirus infection in children in Shanghai]. *Zhonghua Er Ke Za Zhi* 2020;58:86–87. doi: 10.3760/cma.j.issn.0578-1310.2020.02.002.
- [9] Holshue ML, DeBolt C, Lindquist S, Lofy KH, Wiesman J, Bruce H, *et al.* First case of 2019 novel coronavirus in the United States. *N Engl J Med* 2020;382:929–936. doi: 10.1056/NEJMoa2001191.
- [10] Silverstein WK, Stroud L, Cleghorn GE, Leis JA. First imported case of 2019 novel coronavirus in Canada, presenting as mild pneumonia. *Lancet* 2020; 395:734. doi: 10.1016/S0140-6736(20)30370-6.
- [11] Guan WJ, Ni ZY, Hu Y, Liang WH, Ou CQ, He JX, *et al.* Clinical characteristics of coronavirus disease 2019 in China. *N Engl J Med* 2020. doi: 10.1056/NEJMoa2002032.
- [12] Xu XW, Wu XX, Jiang XG, Xu KJ, Ying LJ, Ma CL, *et al.* Clinical findings in a group of patients infected with the 2019 novel coronavirus (SARS-Cov-2) outside of Wuhan, China: retrospective case series. *BMJ* 2020;368:m606. doi: 10.1136/bmj.m606.
- [13] Chen L, Liu HG, Liu W, Liu J, Liu K, Shang J, *et al.* [Analysis of clinical features of 29 patients with 2019 novel coronavirus pneumonia]. *Zhonghua Jie He He Hu Xi Za Zhi* 2020;43:E005. doi: 10.3760/cma.j.issn.1001-0939.2020.0005.
- [14] Wang D, Hu B, Hu C, Zhu F, Liu X, Zhang J, *et al.* Clinical characteristics of 138 hospitalized patients with 2019 novel coronavirus-infected pneumonia in Wuhan, China. *JAMA* 2020. doi: 10.1001/jama.2020.1585.
- [15] Pan F, Ye T, Sun P, Gui S, Liang B, Li L, *et al.* Time course of lung changes on chest CT during recovery from 2019 novel coronavirus (COVID-19) pneumonia. *Radiology* 2020;200370. doi: 10.1148/radiol.2020200370.
- [16] Liu C, Jiang ZC, Shao CX, Zhang HG, Yue HM, Chen ZH, *et al.* [Preliminary study of the relationship between novel coronavirus pneumonia and liver function damage: a multicenter study]. *Zhonghua Gan Zang Bing Za Zhi* 2020;28:148–152. doi: 10.3760/cma.j.issn.1007-3418.2020.02.003.
- [17] Huang C, Wang Y, Li X, Ren L, Zhao J, Hu Y, *et al.* Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *Lancet* 2020;395:497–506. doi: 10.1016/S0140-6736(20)30183-5.
- [18] Chen H, Guo J, Wang C, Luo F, Yu X, Zhang W, *et al.* Clinical characteristics and intrauterine vertical transmission potential of COVID-19 infection in nine pregnant women: a retrospective review of medical records. *Lancet* 2020; 395:809–815. doi: 10.1016/S0140-6736(20)30360-3.
- [19] Li R, Qiao S, Zhang G. Analysis of angiotensin-converting enzyme 2 (ACE2) from different species sheds some light on cross-species receptor usage of a novel coronavirus 2019-nCoV. *J Infect* 2020. doi: 10.1016/j.jinf.2020.02.013.
- [20] Xu H, Zhong L, Deng J, Peng J, Dan H, Zeng X, *et al.* High expression of ACE2 receptor of 2019-nCoV on the epithelial cells of oral mucosa. *Int J Oral Sci* 2020;12:8. doi: 10.1038/s41368-020-0074-x.
- [21] Chai X, Hu L, Zhang Y, Han W, Lu Z, Ke A, *et al.* Specific ACE2 expression in cholangiocytes may cause liver damage after 2019-nCoV infection. *bioRxiv* 2020(v1). doi: 10.1101/2020.02.03.931766.
- [22] Guan GW, Gao L, Wang JW, Wen XJ, Mao TH, Peng SW, *et al.* [Exploring the mechanism of liver enzyme abnormalities in patients with novel coronavirus-infected pneumonia]. *Zhonghua Gan Zang Bing Za Zhi* 2020;28:E002. doi: 10.3760/cma.j.issn.1007-3418.2020.02.002.

- [23] Xu Z, Shi L, Wang Y, Zhang J, Huang L, Zhang C, *et al*. Pathological findings of COVID-19 associated with acute respiratory distress syndrome. *Lancet Respir Med* 2020. doi: 10.1016/s2213-2600(20)30076-x.
- [24] Hodgman MJ, Garrard AR. A review of acetaminophen poisoning. *Crit Care Clin* 2012;28:499–516. doi: 10.1016/j.ccc.2012.07.006.
- [25] Krenzelok EP. The FDA Acetaminophen Advisory Committee Meeting - what is the future of acetaminophen in the United States? The perspective of a committee member. *Clin Toxicol (Phila)* 2009;47:784–789. doi: 10.1080/15563650903232345.
- [26] Prompetchara E, Ketloy C, Palaga T. Immune responses in COVID-19 and potential vaccines: Lessons learned from SARS and MERS epidemic. *Asian Pac J Allergy Immunol* 2020;38:1–9. doi: 10.12932/ap-200220-0772.
- [27] Klimstra WB, Ryman KD, Bernard KA, Nguyen KB, Biron CA, Johnston RE. Infection of neonatal mice with sindbis virus results in a systemic inflammatory response syndrome. *J Virol* 1999;73:10387–10398.
- [28] Tartey S, Takeuchi O. Pathogen recognition and Toll-like receptor targeted therapeutics in innate immune cells. *Int Rev Immunol* 2017;36:57–73. doi: 10.1080/08830185.2016.1261318.
- [29] Yang L, Wang W, Wang X, Zhao J, Xiao L, Gui W, *et al*. Creg in hepatocytes ameliorates liver ischemia/reperfusion injury in a TAK1-dependent manner in mice. *Hepatology* 2019;69:294–313. doi: 10.1002/hep.30203.
- [30] Zhang XJ, Cheng X, Yan ZZ, Fang J, Wang X, Wang W, *et al*. An ALOX12-12-HETE-GPR31 signaling axis is a key mediator of hepatic ischemia-reperfusion injury. *Nat Med* 2018;24:73–83. doi: 10.1038/nm.4451.
- [31] Zhang Z, Li X, Zhang W, Shi ZL, Zheng Z, Wang T. Clinical features and treatment of 2019-nCoV pneumonia patients in Wuhan: report of a couple cases. *Virology* 2020. doi: 10.1007/s12250-020-00203-8.
- [32] Zhang L, Liu Y. Potential interventions for novel coronavirus in China: A systematic review. *J Med Virol* 2020;92:479–490. doi: 10.1002/jmv.25707.
- [33] Santos RAS, Sampaio WO, Alzamora AC, Motta-Santos D, Alenina N, Bader M, *et al*. The ACE2/Angiotensin-(1-7)/MAS axis of the renin-angiotensin system: focus on angiotensin-(1-7). *Physiol Rev* 2018;98:505–553. doi: 10.1152/physrev.00023.2016.
- [34] Ding Y, Wang H, Shen H, Li Z, Geng J, Han H, *et al*. The clinical pathology of severe acute respiratory syndrome (SARS): a report from China. *J Pathol* 2003;200:282–289. doi: 10.1002/path.1440.
- [35] Sun ML, Yang JM, Sun YP, Su GH. [Inhibitors of RAS Might Be a Good Choice for the Therapy of COVID-19 Pneumonia]. *Zhonghua Jie He He Hu Xi Za Zhi* 2020;43:E014. doi: 10.3760/cma.j.issn.1001-0939.2020.0014.
- [36] Chen H, Du Q. Potential natural compounds for preventing 2019-nCoV infection. *Preprints* 2020;2020010358(v3). doi: 10.20944/preprints202001.0358.v3.
- [37] Li JY, Cao HY, Liu P, Cheng GH, Sun MY. Glycyrrhizic acid in the treatment of liver diseases: literature review. *Biomed Res Int* 2014;2014:872139. doi: 10.1155/2014/872139.
- [38] Yan R, Zhang Y, Li Y, Xia L, Zhou Q. Structure of dimeric full-length human ACE2 in complex with B0ATI. *bioRxiv* 2020(v1). doi: 10.1101/2020.02.17.951848.
- [39] Cheng ZJ, Shan J. 2019 novel coronavirus: where we are and what we know. *Infection* 2020. doi: 10.1007/s15010-020-01401-y.