Association of non-alcoholic fatty liver disease and COVID-19: A literature review of current evidence

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Abstract

The coronavirus disease 2019 (COVID-19) pandemic has swept through nations, crippled economies and caused millions of deaths worldwide. Many people diagnosed with COVID-19 infections are often found to develop liver injury, which, in a small portion of patients, progresses to severe liver disease. Liver injury in the form of elevated transaminases, hyperbilirubinemia and alterations in serum albumin has been observed to be higher in patients with severe forms of the disease. Those who already have insult to the liver from chronic disease, such as nonalcoholic fatty liver disease (NAFLD) may be at the greatest disadvantage. The severity of COVID-19 also seems to be driven by the presence of NAFLD and other co-morbidities. About 25% of the global population has NAFLD. With such a widespread prevalence of NAFLD, understanding the disease progression of COVID-19 and the occurrence of liver injury in this vulnerable population assumes great significance. In this review, we present an overview of COVID-19 infection in patients with NAFLD.

Key Words: SARS-CoV-2; Fatty liver; Mitochondria; Nitrosative stress; Oxidative stress; COVID-19; Metabolic associated fatty liver disease; Nonalcoholic fatty liver disease; Progressive liver disease; Nonalcoholic steatohepatitis

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INTRODUCTION

The worldwide figures of coronavirus disease 2019 (COVID-19) presently stand at 154640649 confirmed cases with 3232285 deaths[1]. Although primarily a respiratory syndrome, COVID-19 has been reported to cause liver injury in multiple studies, including metaanalyses[2-4]. The incidence of liver injury as assessed by several indicators like transaminases, bilirubin and albumin has been found to be higher in patients with severe COVID-19 infection[3,5]. Increasing severity of liver chemistry abnormalities on hospital admission predicts early in-hospital mortality in COVID-19 patients[4].

There is a high global burden of pre-existing liver disease[6], including chronic viral hepatitis, nonalcoholic fatty liver disease (NAFLD) and alcohol-associated liver disease (ALD). For example, in China, where the pandemic originated, liver cirrhosis affects around 7 million people[7]. Similarly, in the United States which has the highest number of recorded COVID 19 cases, about 4.5 million of adults are diagnosed with chronic liver disease[8]. In a cross-sectional analysis based on data from National Health and Nutrition Examination Surveys (NHANES), it was observed that the prevalence of NAFLD (by US-Fatty Liver Index) spiked from 20.0% (1988-1994) to 28.3% (1999-2004) to 33.2% (2009-2012) and 31.9% (2013-2016)[9]. This increasing trend is in concurrence with increases in obesity, diabetes mellitus, hypertension and insulin resistance[9]. It is also to be noted that many patients with fatty liver disease remain undiagnosed and are incidentally detected. Therefore, the actual prevalence of NAFLD may be much higher. In such a background of widespread prevalence of chronic liver disease especially NAFLD, the incidence of liver injury in COVID-19 and its impact on disease progression assumes greater significance. In a recent study, we found that mortality associated with the known risk factors of COVID19 (hypertension, diabetes, male sex, and old age) was accentuated in the presence of liver chemistry abnormalities in those diagnosed with COVID-19[4].

PATHOGENESIS AND PATTERN OF LIVER INJURY IN COVID-19

The pathogenesis of liver injury in COVID-19 is multifactorial. A number of factors have been identified for perpetuating and potentiating liver injury in COVID-19. Direct viral-mediated hepatocyte injury, liver injury ensuing from cytokine release syndrome, drug-induced liver injury and ischemic hepatitis are just some of the mechanisms responsible for hepatic dysfunction in COVID-19[10]. The pattern of liver injury in COVID-19, as evidence from multiple studies, is a rise in liver enzymes [primarily aspartate aminotransferase and alanine aminotransferase (ALT)] with mild increases in bilirubin[10]. In a study by Cai et al[11] from China, among 417 patients, 20.75% had hepatocellular pattern of liver injury, 29.25% had a cholestatic pattern, while 43.4% had a mixed type of liver injury. Liver injury is transient in most cases and liver enzymes usually return to normal with recovery from COVID-19[2]. The rampant use of multiple medications-antibiotics, antivirals, nonsteroidal anti-inflammatory drugs, herbal medications, interferon and other immunomodulators has been as-
associated with increased liver test abnormalities[11]. To add to this is the presence of pre-existing liver disease in patients with COVID-19 which makes the pathogenesis of hepatic dysfunction even more complex. In the largest reported cohort of 745 chronic liver disease and cirrhotic patients with COVID-19, it was observed that baseline liver disease stage and ALD were independent risk factors for death from COVID-19[12]. The APASL COVID19 Liver Injury Spectrum (APCOLIS) Study has shown that pre-existing liver disease is associated with poor outcome in patients with SARS CoV2 infection. Additionally, if these patients also have chronic liver disease, diabetes and/or obesity, they are more vulnerable and should be closely monitored[13]. In a study on 12 COVID-19 patients with pulmonary embolism on autopsy, hepatic steatosis involving 50-60 percent of hepatocytes was found in all patients. This data supports the fact that pre-existing liver diseases like ALD and NAFLD could play significant roles in COVID-19 progression[14].

COVID-19 IN THE SETTING OF NAFLD

Whether NAFLD is an independent or dependent determinant for worse outcomes in COVID-19 has been a hot topic of debate in recent times. A look at the figures and the results of several studies done in the midst of this pandemic opens up conflicting and debatable viewpoints in this regard. Interestingly, in this above-mentioned cohort of 745 patients, 43% of patients had NAFLD, while hypertension, diabetes and obesity — established risk factors for developing severe COVID-19 — constituted the major comorbidities[12]. While one can argue that it is ALD and not NAFLD which has been observed to be a significant predictor of mortality in COVID-19, it would be worthwhile to take note of the fact that patients with ALD had more severe underlying liver disease compared to those with NAFLD. In a retrospective study on 202 patients with confirmed COVID-19, it was observed that patients with NAFLD had a higher risk of disease progression, greater likelihood of abnormal liver function from admission to discharge and longer viral shedding time[15]. An association between the presence of metabolic associated fatty liver disease (MAFLD) and COVID-19 severity was observed in younger patients[16]. In another study on 589 patients from the eastern Mediterranean region, NAFLD has been found to be a predictor of liver injury in COVID-19. However, quite contrary to the results of other studies, NAFLD did not seem to be an independent predictor of mortality, disease severity, or markers of disease progression[17]. Similarly, in another study by Huang et al[18], although more patients with NAFLD developed abnormal liver function tests, concurrent NAFLD was not found to be associated with adverse clinical outcomes in patients with COVID-19. Table 1 shows a summary of the various studies describing the association between NAFLD and COVID-19.

MECHANISM OF COVID-19 PROGRESSION IN PATIENTS WITH NAFLD

The role of inflammation in the pathophysiology of NAFLD has been well recognized[19]. It has been hypothesized that hepatic inflammation resulting from pro-inflammatory cytokines released by adipose tissue is even furthered by COVID-19[15]. The liver is a major site of lipid metabolism and the generation of lipid species plays an important role in regulating metabolic inflammation. The complex pathways in lipid metabolism drive innate immunity and have been found to affect the progression to steatohepatitis and fibrosis in NAFLD[20]. Additionally, NAFLD patients are found to have elevated plasma levels of von Willebrand factor and circulating plasminogen activator inhibitor type 1[21]. This has been hypothesized to predispose such patients to higher risks of adverse cardiovascular events. It has also been postulated that hepatic and systemic immune responses due to underlying NAFLD could contribute to the cytokine storm in younger patients with COVID-19[16,22]. While severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) binds to angiotensin-converting enzyme 2 (ACE2) receptors and attaches to the cell, cellular entry is made possible by cleavage of the SARS-CoV-2 spike protein by transmembrane serine protease 2 (TMPRSS2)[23]. Interestingly, it has been seen that while there were no differences in liver mRNA expression of both ACE2 and TMPRSS2 between subjects without liver injury and patients with only steatosis, upregulation of these genes occurred in obese patients with nonalcoholic steatohepatitis (NASH). Additionally, there was positive correlation of ACE2 and TMPRSS2 with NAFLD activity score and TMPRSS2 positively correlated with weight, body mass index (BMI) and cholesterol[24]. However,
| Ref. | Type of study | Study origin | Number of COVID patients/number of NAFLD/NASH patients | Overall impact of occurrence of concomitant NAFLD and COVID-19 | Impact of NAFLD on COVID-19 liver injury |
|------|--------------|--------------|------------------------------------------------------|-------------------------------------------------------------|----------------------------------------|
| Marjet et al.[13] | Retrospective | Multinational Cohort | No. of COVID patients with CLD: 745; No. of NAFLD patients: 322 | Baseline liver disease stage and ALD are independent risk factor for death from COVID-19 | NA |
| Sarin et al.[13] | Retrospective | Multinational Cohort | No. of COVID patients with CLD: 226; No. of fatty liver disease patients: 113 | CLD patients with diabetes and obesity are more vulnerable and should be closely monitored | Comorbidities like NAFLD, obesity and diabetes were present in 80% of the patients. NAFLD was the commonest cause for CLD without cirrhosis. Obese cirrhotics had more acute liver injury than normal weight patients [OR 8.9 (95% CI: 1.9-38.8); P = 0.02]. Patients of CLD with diabetes had higher risk [57.7% vs 39.7%, P = 0.01, OR = 2.061.14-3.73] of liver injury |
| Ji et al.[15] | Retrospective | China | No. of COVID patients: 202; No. of NAFLD patients: 76 | Patients with NAFLD also had a higher risk of progression to severe COVID-19 and longer viral shedding time | Patients with NAFLD had a higher likelihood of abnormal liver function from admission to discharge [70% (53.76% vs 11.1% (14/126); P < 0.0001) compared to patients without NAFLD |
| Zhou et al.[16] | Retrospective | Wenzhou, China | No. of COVID patients: 327; No. of patients with fatty liver disease: 93 | In patients younger than 60 yr, a more than 2-fold higher prevalence of severe COVID-19 was observed in those with MAFLD compared to those without. MAFLD was not associated with disease severity in multivariable analysis in elderly patients | NA |
| Munshitaq et al.[17] | Retrospective | Qatar | No. of COVID patients: 589; No. of NAFLD patients: 320 | NAFLD was not an independent predictor of mortality, disease severity on presentation, or disease progression in patients with COVID-19 | Presence of NAFLD was a predictor of the development of mild liver injury (OR 2.99; 95%CI: 1.62-4.57; P = 0.000) and moderate liver injury (OR 5.13; 95%CI: 3.21-6.99; P = 0.000) |
| Huang et al.[18] | Retrospective | Jiangsu, China | No. of COVID patients: 280; No. of NAFLD patients: 86 | No patient developed severe liver-related complications during hospitalization | Concurrent NAFLD was identified as a risk factor of elevated ALT (OR, 2.962; 95%CI: 1.745-5.028; P < 0.001) on univariate analysis. Concurrent NAFLD (OR, 2.956; 95%CI: 1.526-5.726; P = 0.000) was an independent risk factor of ALT elevation on multivariate analysis |
| Fondevila et al.[24] | Retrospective | Spain | No. of patients without NAFLD: 17; No. of patients with NAFLD: 77 | Obese patients with NASH show markedly higher expression of ACE2 and TMPRSS2, suggesting that advanced stages of NAFLD might predispose individuals to COVID-19 | NA |
| Biquard et al.[25] | Retrospective | France | No. of patients without fatty liver disease: 28; No. of patients with fatty liver disease: 26 | MAFLD is not associated with changes in liver expression of genes implicated in SARS-CoV-2 infection | NA |
| Zheng et al.[28] | Retrospective | Wenzhou, China | No. of COVID patients: 214; No. of NAFLD patients: 66 | Risk of obesity to COVID-19 severity is greater in those with compared to those without MAFLD | NA |
| Ghoneim et al.[29] | Retrospective | Multination electronic health records | No. of COVID patients: 8885; No. of NAFLD patients: 102 | The adjusted odds ratio of having COVID-19 were higher in patients if they were diagnosed with NASH | NA |
| Targher et al.[30] | Retrospective | Zhejiang Province, China | No. of COVID patients: 310; No. of NAFLD patients: 94 | Patients with MAFLD with increased FIB-4 or NFS are at higher likelihood of having severe COVID-19 illness, irrespective of metabolic | COVID-19 patients with MAFLD with intermediate or high FIB-4 scores were more likely to have higher liver enzymes [AST > 40 IU/L (%) -27.8/57.1, ALT > 40 IU/L (%) -30.6/42.9], |
to complicate matters, in another study by Biquard et al. [25], none of the genes necessary for SARS-CoV-2 infection-TMPRSS2 and ACE2 included- were differentially expressed between lean or obese controls and patients with simple steatosis or with NASH. Hence the role of underlying NAFLD on the outcomes of COVID-19 infection is still up for debate.

**IS NAFLD INDEPENDENTLY ASSOCIATED WITH COVID-19 SEVERITY?**

In the population-based study by Ghoneim et al. [29], among different components of MS, NASH was found to be associated with the highest risk of COVID-19 after calculating the adjusted odds ratio. A study by Targher et al. [33] sheds some light on

**ROLE OF COMORBIDITIES**

In such a background of conflicting data, it is worthwhile to analyze the role of comorbidities that are present in patients with NAFLD which might lead to disease progression in COVID-19. It needs no reiteration that NAFLD is usually accompanied by a cluster of several other conditions such as obesity, insulin resistance, dyslipidemia and hypertension, collectively reflecting underlying metabolic syndrome (MS). According to the ATP III criteria, the prevalence of the MS in patients with NAFLD is 22.8% [26]. The strong association between MS and NAFLD has led investigators to term NAFLD the hepatic component of MS [27]. Thus, it is entirely understandable that the presence of these components would potentially cause increased severity of COVID-19. This has been validated by a multicentric study by Zheng et al. [28] which showed that obesity conferred a nearly sixfold higher risk of severe COVID-19 in patients with NAFLD. A strong positive association between the different components of MS and COVID-19 has also been reported in a population-based study [29]. Obesity and a state of insulin resistance impairs the ability to mount an effective immune response and predisposes to viral infections and respiratory diseases [30,31]. The questions that naturally arise from these observations are: (1) Do the different components of MS drive outcomes in COVID-19 infection and is NAFLD merely a bystander? and (2) Does NAFLD independently drive inflammation and disease progression in COVID-19? The latter is supported by the finding that NAFLD is associated with 30-d all-cause mortality in patients with community-acquired pneumonia with a significant higher degree of association in patients with advanced hepatic fibrosis [32].

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**Table:**

| Study Authors | Study Type | Setting | No. of COVID patients | No. of NAFLD patients | Findings |
|---------------|------------|---------|----------------------|-----------------------|----------|
| Forlano et al. [34] | Retrospective | Imperial College Healthcare NHS Trust (London, United Kingdom) | 193 | 61 | Presence of NAFLD per se was not associated with worse outcomes in hospitalised patients. Mortality was associated with pronounced inflammatory response in NAFLD group |
| Gao et al. [35] | Retrospective | 3 Chinese hospitals: (the First Affiliated Hospital of Wenzhou Medical University, the Ningbo No. 2 Hospital, and the Ruian People’s Hospital) | 167 | 46 | NAFLD patients with elevated serum IL-6 levels at admission are at higher risk for severe illness from COVID-19 |
| Sachdeva et al. [37] | Pooled analysis | - | 8142 | 833 | NAFLD is a predictor of severe COVID-19, even after adjusting for the presence of obesity |
This conundrum. In this study on 310 COVID-19 patients, subjects with MAFLD with increased fibrosis-4 (FIB-4) or NAFLD fibrosis score were more likely to have severe COVID-19 illness, irrespective of metabolic comorbidities like obesity and diabetes. Forlano et al [34] showed that although NAFLD patients have higher levels of inflammatory markers like CRP compared to the non-NAFLD group, the presence of NAFLD per se was not associated with adverse outcomes in the whole study population. Additionally, the presence of intermediate/high-risk FIB-4 scores as well as the presence of liver cirrhosis did not demonstrate any association with adverse outcomes in the NAFLD cohort [34]. Furthermore, a study by Gao et al [35] showed that patients with MAFLD and elevated serum interleukin-6 levels at admission are at higher risk for severe illness from COVID-19. However, mortality in the NAFLD cohort was associated with a pronounced inflammatory response. Therefore, what could be inferred from these results is that rather than attributing the severity of COVID-19 to underlying liver disease, it might possibly be a result of the general state of host inflammation in NAFLD patients. Increased liver fat has been independently associated with a higher likelihood of testing positive for COVID-19 in a United Kingdom based study [36]. In a pooled analysis on the association of fatty liver and COVID-19, it was found that NAFLD was associated with an increased risk of severe COVID-19, even after adjusting for obesity as a possible confounding factor [37]. From these results, one is led to believe that NAFLD is indeed independently associated with increased severity in COVID-19. Whether it is the liver disease that is responsible for this increasing severity, the general state of inflammation that accompanies NAFLD or the associated comorbidities that drives the outcome is a matter of debate. Interestingly, a recent study showed that the presence of fibrosis rather than the presence of MAFLD is associated with increased risk for mechanical ventilation, development of acute kidney injury, and higher mortality in COVID-19 patients [38].

LEAN VS OBESE NAFLD IN COVID-19

While a BMI greater than 23 kg/sq. metres increases the risk of developing fatty liver disease [39], many people with normal BMI’s are capable of developing NAFLD. Additionally, significant proportion of NAFLD patients do not have insulin resistance either [40,41]. Termed ‘lean’ NAFLD, this so-called ‘entity’ indicates that there is more to NAFLD than just the mere presence of MS. Zheng et al [28] showed that compared to MAFLD patients without obesity those with obesity were at a 6-fold increased risk of severe COVID-19 illness and this association was significant even after adjusting for various parameters like diabetes, hypertension and dyslipidemia. This raises an important question as to whether the worse outcome in NAFLD patients is related to underlying liver disease or related to associated obesity? However, the small sample size of this study makes it difficult to arrive at such sweeping conclusions. Also, the cut-off for obesity in this study has been taken as 25 kg/m².

INFLAMMATION IN NAFLD

The bidirectional relationship between hepatic steatosis and insulin resistance is well established [42]. Hepatic steatosis can itself be a driver of insulin resistance and MS has opened avenues for further investigation in the pathophysiology of inflammation in NAFLD. There has been increasing evidence of the presence of significant cross-talk between the liver and other extrahepatic tissues and organs mediated by cytokines, hepatokines. It also involves nuclear factor-xB and c-Jun N-terminal kinase pathways which implies that hepatic inflammation could be a potential driver of cellular dysfunction, cell death and deleterious remodelling in various body tissues and organs [43]. This state of chronic inflammation may directly impact disease severity by adding up to the dysregulated immune response in COVID-19. In a peripheral blood genome-wide gene expression analysis among 1650 participants, it was observed that after adjustment for known risk factors, fatty liver was associated with blood gene sets of extracellular matrix turnover, inflammatory response, immune system activation and a prothrombotic state [44]. This could lead to morbidities in multiple organs including the cardiovascular system, and may, in our opinion, exacerbate disease processes in COVID-19.
LIVER INJURY IN NAFLD PATIENTS WITH COVID-19

NAFLD patients have been reported to be more likely to develop liver injury when infected by COVID-19[18]. Median ALT levels and the proportion of elevated ALT were found to be significantly greater in patients with NAFLD than in patients without NAFLD on admission. In addition, the proportion of elevated ALT in patients with NAFLD was significantly higher than patients without NAFLD during hospitalization. However, severe liver-related complications during hospitalization were not observed in any of the patients. Mushtaq et al[17] found that NAFLD is an independent predictor of the development of mild to moderate liver injury in hospitalized patients with COVID-19. Moreover, COVID-19 patients with persistent liver injury have been found to have NAFLD and high BMI in one particular study[15]. The APCOLIS study also found that the presence of MAFLD aggravates the risk of liver injury in COVID-19[13]. In the study by Targher et al[33], COVID-19 patients with MAFLD with intermediate or high FIB-4 scores were more likely to have higher liver enzymes, compared with their counterparts with low FIB-4 score or those without MAFLD. The reasons for this increased likelihood of liver injury in NAFLD patients affected by COVID-19 could be multifactorial-pre-existing steatohepatitis, systemic inflammation, the severity of COVID-19 itself and a combination of any of these. The ‘cocktail’ of medications used in this pandemic deserves special attention while evaluating the relationship between NAFLD and COVID-19. Antivirals, antibiotics and glucocorticoids have been the most rampantly used medications in the quest to control COVID-19 and may contribute to liver injury, especially in those with NAFLD.

A summary of the pathophysiological processes that could presumably drive disease progression in patients of NAFLD with COVID-19 and the resulting impact on hepatic status is illustrated in Figure 1.

CONCLUSION

The bulk of the evidence-based on pooled analysis so far shows NAFLD patients are at increased risk of severe COVID-19 infection. However, judging by the results based on few studies that have been carried out to date, it seems the disease severity is determined more by the presence of co-morbidities like obesity, insulin resistance and dyslipidemia which are frequent accompaniments of NAFLD. The studies showing the
association of NAFLD/MAFLD with severity of COVID-19 independent of associated comorbidities have shown conflicting results. The presence of fibrosis rather than the presence of MAFLD/NAFLD is associated with worse clinical outcomes and higher mortality in COVID-19 patients. Additionally, there seems to be an increased likelihood of liver injury in NAFLD patients with COVID-19. Further studies are required to delineate these pathophysiological details.

REFERENCES

1 World Health Organization. WHO Coronavirus (COVID-19) Dashboard. [cited 6 May 2021]. In: World Health Organization [Internet]. 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 Parohan M, Yaghoubi S, Seraji A. Liver injury is associated with severe coronavirus disease 2019 (COVID-19) infection: A systematic review and meta-analysis of retrospective studies. Hepatol Res 2020; 50: 924-935 [PMID: 32386449 DOI: 10.1111/hepr.13510]
4 Satapathy SK, Kuntzen C, Qiu H, Jiang Y, Bodenheimer HC, Roth NC, Lee TP, Hirsch JS, Trindade AJ, Bernstein DE; Northwell Health COVID-19 Research Consortium. Severity of liver test abnormalities in coronavirus disease 2019 depends on comorbidities and predicts early in-hospital mortality. Eur J Gastroenterol Hepatol 2021 [PMID: 33560687 DOI: 10.1097/MEG.0000000000002053]
5 Kovalic AJ, Huang G, Thuluvath PJ, Satapathy SK. Elevated Liver Biochemistries in Hospitalized Chinese Patients With Severe COVID-19: Systematic Review and Meta-analysis. Hepatology 2021; 73: 1521-1530 [PMID: 32902464 DOI: 10.1002/hep.31472]
6 GBD 2017 Cirrhosis Collaborators. The global, regional, and national burden of cirrhosis by cause in 195 countries and territories, 1990-2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet Gastroenterol Hepatol 2020; 5: 245-266 [PMID: 31981519 DOI: 10.1016/S2468-1253(19)30349-8]
7 Xiao J, Wang F, Wong NK, He J, Zhang R, Sun R, Xu Y, Liu Y, Li W, Koike K, He W, You H, Miao Y, Liu X, Meng M, Gao B, Wang H, Li C. Global liver disease burdens and research trends: Analysis from a Chinese perspective. J Hepatol 2019; 71: 212-221 [PMID: 30871980 DOI: 10.1016/j.jhep.2019.03.004]
8 Centers for Disease Control and Prevention. FastStats. [cited 6 Dec 2020]. In: Centers for Disease Control and Prevention [Internet]. Available from: https://www.cdc.gov/nchs/fastats/Liver-disease.htm
9 Younossi ZM, Stepanova M, Younossi Y, Golabi P, Mishra A, Rafiq N, Henry L. Epidemiology of chronic liver diseases in the USA in the past three decades. Gut 2020; 69: 564-568 [PMID: 31366455 DOI: 10.1136/gutjnl-2019-318813]
10 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: 1182-1197 [PMID: 33442447 DOI: 10.4254/wjh.v12i12.1182]
11 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 L, Xu L. COVID-19: Abnormal liver function tests. J Hepatol 2020; 73: 566-574 [PMID: 32298876 DOI: 10.1016/j.jhep.2020.04.006]
12 Marjot T, Moon AM, Cook JA, Abd-Elsalam S, Aloman C, Armstrong MJ, Pose E, Brenner EJ, Cargill T, Catana MA, Dhanasekaran R, Eshraghian A, García-Juárez I, Gill US, Jones PD, Kennedy J, Marshall A, Matthews C, Mells G, Mercer C, Perumalswami PV, Avitabile E, Qi X, Su F, Ufere NN, Wong YJ, Zheng MH, Barnes E, Barratt AS 4th, Webb GJ. Outcomes following SARS-CoV-2 infection in patients with chronic liver disease: An international registry study. J Hepatol 2021; 74: 567-577 [PMID: 33035628 DOI: 10.1016/j.jhep.2020.09.024]
13 Sarin SK, Choudhury A, Lau GK, Zheng MH, Ji D, Abd-Elsalam S, Hwang J, Qi X, Cua H, Suh JI, Park JG, Patcharoen O, Kaewdech A, Piratvisuth T, Treeprasertsuk S, Park S, Wejnaruemarn S, Payawal DA, Baatarkhuu O, Ahn SH, Yeo CD, Aloman C, Chinchayar T, Loh M, Yokosuka O, Jafri W, Tan S, Soo LI, Tanwandee T, Gani R, Anand L, Esmail ES, Khalaf M, Alam S, Lin CY, Chiang WL, Soin AS, Garg HK, Kalista K, Batsukh B, Purnomo HD, Dara VP, Rathi P, Al Mahtab M, Shukla A, Sharma MK, Omata M. APASL COVID Liver Injury Spectrum Study (APCOLIS Study-NCT 04345640). Pre-existing liver disease is associated with poor outcome in patients with SARS CoV2 infection: The APCOLIS Study (APASL COVID-19 Liver Injury Spectrum Study). Hepatol Int 2020; 14: 690-700 [PMID: 32623632 DOI: 10.1007/s12072-020-10072-8]
14 Lax SF, Skok K, Zecheh P, Kessler HH, Kaufmann N, Koellbinger C, Yandor K, Bargfrieder U, Trauner M. Pulmonary Arterial Thrombosis in COVID-19 With Fatal Outcome: Results From a Prospective, Single-Center, Clinicoepidemiologic Case Series. Ann Intern Med 2020; 173: 350-361 [PMID: 32422076 DOI: 10.7326/M20-2566]
15 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]
Zhou YJ, Zheng KJ, Wang XB, Yan HD, Sun QF, Pan KH, Wang TY, Ma HL, Chen YP, George J, Zheng MH. Younger patients with NAFLD are at increased risk of severe COVID-19 illness: A multicenter preliminary analysis. *J Hepatol* 2020; 73: 719-721 [PMID: 32348790 DOI: 10.1016/j.jhep.2020.04.027]

Mushkat K, Khan MU, Iqbal F, Alsoub DH, Chaudhry HS, Ata F, Iqbal P, Elref K, Balaraju G, Alsalmamani M, Al-Ejji K, AlKabi S, Kamel YM. NAFLD is a predictor of liver injury in 2019-hospitalized patients but not of mortality, disease severity on the presentation or progression - The debate continues. *J Hepatol* 2021; 74: 482-484 [PMID: 33223215 DOI: 10.1016/j.jhep.2020.09.006]

Huang R, Zhu L, Wang J, Xue L, Liu L, Yan X, Huang S, Li Y, Zhang B, Xu T, Li C, Ji F, Ming F, Zhao Y, Cheng J, Wang Y, Zhao H, Hong S, Chen K, Zhao XA, Zou L, Sang D, Shao H, Guan X, Chen X, Chen Y, Wei J, Zhu C, Wu C. Clinical features of COVID-19 patients with non-alcoholic fatty liver disease. *Hepatol Commun* 2020 [PMID: 32838108 DOI: 10.1002/hep.1592]

Gao B, Tsukamoto H. Inflammation in Alcoholic and Nonalcoholic Fatty Liver Disease: Friend or Foe? *Immune Netw* 2016; 15: 1704-1709 [PMID: 26826669 DOI: 10.1033/j.gastro.2016.01.025]

Bai L, Li H. Innate immune regulatory networks in hepatic lipid metabolism. *J Mol Med (Berl)* 2019; 97: 593-604 [PMID: 30891617 DOI: 10.1007/s00109-019-01765-1]

Verrijken A, Franqué S, Mertens I, Prawitt J, Caron S, Hubens G, Van Marck E, Staels B, Michielsen P, Van Gaal L. Prothrombotic factors in histologically proven nonalcoholic fatty liver disease and nonalcoholic steatohepatitis. *Hepatology* 2014; 59: 121-129 [PMID: 24375485 DOI: 10.1002/hep.26510]

Narayaanan S, Surette FA, Hahn YS. The Immune Landscape in Nonalcoholic Steatohepatitis. *Immune Netw* 2016; 16: 147-158 [PMID: 27340383 DOI: 10.4110/ln.2016.16.3.147]

Soffmann M, Kleine-Weber H, Schroeder S, Krüger N, Harrler T, Erichsen S, Schergens TS, Harrler G, Wu NH, Nitsche A, Müller MA, Drosten C, Pöhlmann S. SARS-CoV-2 Cell Entry Depends on ACE2 and TMPRSS2 and Is Blocked by a Clinically Proven Protease Inhibitor. *Cell* 2020; 181: 271-280.e8 [PMID: 32142651 DOI: 10.1016/j.cell.2020.02.052]

Fondevila MF, Mercado-Gómez M, Rodriguez A, Gonzalez-Rellán MJ, Inzúbieta P, Valenti V, Escalada J, Schwaninger M, Prevot V, Dieuguez C, Crespo J, Frühbeck G, Martinez-Chantar ML, Nogueiras R. Obese patients with NASH have increased hepatic expression of SARS-CoV-2 critical entry points. *J Hepatol* 2021; 74: 469-471 [PMID: 33096086 DOI: 10.1016/j.jhep.2020.09.097]

Biquard L, Valla D, Rautou PE. No evidence for an increased liver uptake of SARS-CoV-2 in metabolic-associated fatty liver disease. *J Hepatol* 2020; 73: 717-718 [PMID: 33260925 DOI: 10.1016/j.jhep.2020.04.035]

Lizardi-Cervera J, Laparra DJ, Chávez-Tapia NC, Ostos ME, Esquivel MU. [Prevalence of NAFLD and metabolic syndrome in asymptomatic subjects]. *Rev Gastroenterol Mex 2006; 71: 435-459 [PMID: 17582278]

Chalasani N, Younossi Z, Lavine JE, Charlton M, Cusi K, Rigacci L, Harrison SA, Carraro E, Xing Y, Lavine JE, Cusi K. The diagnosis and management of nonalcoholic fatty liver disease: Practice guidance from the American Association for the Study of Liver Diseases. *Hepatology* 2018; 67: 328-357 [PMID: 29714183 DOI: 10.1002/hep.29367]

Zheng KI, Gao F, Wang XB, Sun QF, Pan KH, Wang TY, Ma HL, Chen YP, Liu WY, George J, Zheng MH. Letter to the Editor: Obesity as a risk factor for greater severity of COVID-19 in patients with metabolic associated fatty liver disease. *Metabolism* 2020; 108: 154244 [PMID: 32320741 DOI: 10.1016/j.metabol.2020.154244]

Ghoneim S, Butt MU, Hamid O, Shah A, Asaad I. The incidence of COVID-19 in patients with metabolic syndrome and non-alcoholic steatohepatitis: A population-based study. *Metabol Open* 2020; 8: 100057 [PMID: 32922000 DOI: 10.1016/j.metopen.2020.100057]

Portincasa P, Krawczyk M, Smyk W, Lammert F, Di Ciaula A. COVID-19 and non-alcoholic fatty liver disease: Two intersecting pandemics. *Eur J Clin Invest* 2020; 50: e13338 [PMID: 32589264 DOI: 10.1111/eci.13338]

Moser JS, Galindo-Fraga A, Ortiz-Hernández AA, Gu W, Hunsberger S, Galán-Herrera JF, Guerrero ML, Ruiz-Palacios GM, Beigel JH, La Red ILI002 Study Group. Underweight, overweight, and obesity as independent risk factors for hospitalization in adults and children from influenza and other respiratory viruses. *Influenza Other Respir Viruses* 2019; 13: 3-9 [PMID: 30315985 DOI: 10.1111/irv.12615]

Nseir WB, Mograbi JM, Amara AE, Abu Elheja OH, Mamidad MN. Non-alcoholic fatty liver disease and 30-day all-cause mortality in adult patients with community-acquired pneumonia. *QJM* 2019; 112: 95-99 [PMID: 30325458 DOI: 10.1093/qjmed/hcy227]

Targher G, Mantovani A, Byrne CD, Wang XB, Yan HD, Sun QF, Pan KH, Zheng KL, Chen YP, Eslam M, George J, Zheng MH. Risk of severe illness from COVID-19 in patients with metabolic dysfunction-associated fatty liver disease and increased fibrosis scores. *Gut* 2020; 69: 1545-1547 [PMID: 32414813 DOI: 10.1136/gutjnl-2020-321611]

Forlano R, Mullish BH, Mulkherjee SK, Nathwani R, Harlow C, Crook P, Judge R, Soubieres A, Middleton P, Daunt A, Perez-Guzman P, Selvapatt N, Lemoine M, Dhar A, Thursz MR, Nayagam S, Manoussou P. In-hospital mortality is associated with inflammatory response in NAFLD patients admitted for COVID-19. *PLoS One* 2020; 15: e0240400 [PMID: 33031439 DOI: 10.1371/journal.pone.0240400]

Gao F, Zheng KI, Yan HD, Sun QF, Pan KH, Wang TY, Chen YP, Targher G, Byrne CD, George J, Zheng MH. Association and Interaction Between Serum Interleukin-6 Levels and Metabolic
Dysfunction-Associated Fatty Liver Disease in Patients With Severe Coronavirus Disease 2019. *Front Endocrinol (Lausanne)* 2021; 12: 604100 [PMID: 33763027 DOI: 10.3389/fendo.2021.604100]

**Roca-Fernández** A, Dennis A, Nicholls R, McGonigle J, Kelly M, Banerjee R, Banerjee A, Sanyal AJ. Hepatic Steatosis, Rather Than Underlying Obesity, Increases the Risk of Infection and Hospitalization for COVID-19. *Front Med (Lausanne)* 2021; 8: 636637 [PMID: 33855033 DOI: 10.3389/fmed.2021.636637]

**Sachdeva** S, Khandait H, Kopel J, Aloysius MM, Desai R, Goyal H. NAFLD and COVID-19: a Pooled Analysis. *SN Compr Clin Med* 2020; 1-4 [PMID: 33173850 DOI: 10.1007/s42399-020-00631-3]

**Campos-Murguía** A, Román-Calleja BM, Toledo-Coronado IV, González-Regueiro JA, Solís-Ortega AA, Kusiulas-Delint D, Cruz-Contreras M, Cruz-Yedra N, Cubero FJ, Nezvorova YA, Martínez-Cabrera CF, Moreno-Guillén P, Lozano-Cruz OA, Chapa-Ibargüengoitia M, Gilias-Herrero A, Aguilar-Salinas CA, Ruiz-Margáin A, Macías-Rodríguez RU. Liver fibrosis in patients with metabolic associated fatty liver disease is a risk factor for adverse outcomes in COVID-19. *Dig Liver Dis* 2021; 53: 525-533 [PMID: 33551355 DOI: 10.1016/j.dld.2021.01.019]

**Fan** R, Wang J, Du J. Association between body mass index and fatty liver risk: A dose-response analysis. *Sci Rep* 2018; 8: 15273 [PMID: 30323178 DOI: 10.1038/s41598-018-33419-6]

**Alam** S, Fahim SM, Chowdhury MAB, Hassan MZ, Azam G, Mustafà G, Ahsan M, Ahmad N. Prevalence and risk factors of non-alcoholic fatty liver disease in Bangladesh. *JGH Open* 2018; 2: 39-46 [PMID: 30483562 DOI: 10.1002/jgh3.12044]

**Singh** SP, Misra B, Kar SK, Panigrahi MK, Misra D, Bhuayan P, Pattnaik K, Meher C, Agrawal O, Rout N, Swain M. Nonalcoholic fatty liver disease (NAFLD) without insulin resistance: Is it different? *Clin Res Hepatol Gastroenterol* 2015; 39: 482-488 [PMID: 25543522 DOI: 10.1016/j.clinre.2014.08.014]

**Wainwright** P, Byrne CD. Bidirectional Relationships and Disconnects between NAFLD and Features of the Metabolic Syndrome. *Int J Mol Sci* 2016; 17: 367 [PMID: 26978356 DOI: 10.3390/ijms17030367]

**Gehrke** N, Schattenberg JM. Metabolic Inflammation-A Role for Hepatic Inflammatory Pathways as Drivers of Comorbidities in Nonalcoholic Fatty Liver Disease? *Gastroenterology* 2020; 158: 1929-1947.e6 [PMID: 32068022 DOI: 10.1053/j.gastro.2020.02.020]

**Taipale** T, Seppälä I, Raitoharju E, Mononen N, Lyytikäinen LP, Ilig T, Waldenberger M, Jaonala M, Hutri-Kähönen N, Oksala N, Kähönen M, Raikäari O, Lehtimäki T. Fatty liver is associated with blood pathways of inflammatory response, immune system activation and prothrombotic state in Young Finns Study. *Sci Rep* 2018; 8: 10358 [PMID: 29985430 DOI: 10.1038/s41598-018-28563-2]
