Hepatitis B virus infection and alcohol consumption

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Abstract

Hepatocellular carcinoma (HCC) is the most common type of primary liver cancer, and the second most common cause of cancer deaths worldwide. The top three causes of HCC are hepatitis B virus (HBV), hepatitis C virus (HCV), and alcoholic liver disease. Owing to recent advances in direct-acting antiviral agents, HCV can now be eradicated in almost all patients. HBV infection and alcoholic liver disease are expected, therefore, to become the leading causes of HCC in the future. However, the association between alcohol consumption and chronic hepatitis B in the progression of liver disease is less well understood than with chronic hepatitis C. The mechanisms underlying the complex interaction between HBV and alcohol are not fully understood, and enhanced viral replication, increased oxidative stress and a weakened immune response could each play an important role in the development of HCC. It remains controversial whether HBV and alcohol synergistically increase the incidence of HCC. Herein, we review the currently available literature regarding the interaction of HBV infection and alcohol consumption on disease progression.

Key words: Entecavir; Genetic factors; Hepatocellular carcinoma; Interferon

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Core tip: The mechanisms by which alcohol enhances disease progression are less well understood in chronic hepatitis B than in chronic hepatitis C. The association of light-to-moderate alcohol consumption with clinical outcomes in patients with chronic hepatitis B virus (HBV) infection appears modest. Although the threshold amount of alcohol for increasing hepatocellular carcinoma (HCC) risk remains unknown, heavy alcohol consumption significantly accelerates the progression of liver disease to cirrhosis and, ultimately, HCC. Alcohol abuse could impair the response to interferon-α therapy in chronic hepatitis B patients, although not fully confirmed, and can increase the risk of HCC even in patients with low HBV DNA levels during nucleoside/nucleotide therapy.

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In general, once chronic liver injury of any etiology has occurred, damaged hepatocytes, activated sinusoidal cells, platelets, and recruited inflammatory cells release various profibrogenic cytokines, including transforming growth factor-β, and reactive oxygen species, which activate hepatic stellate cells (Figure 1). This process is responsible for deposition of the majority of excess extracellular matrix (predominantly collagen types I and III).

The mechanisms of alcohol-induced liver damage are complex and multifactorial. Ethanol is oxidized to acetaldehyde, mainly by alcohol dehydrogenase (ADH) in the hepatocyte cytoplasm. This is subsequently oxidized to acetate by acetaldehyde dehydrogenase (ALDH) in mitochondria. Acetaldehyde is highly toxic, and plays an important role in protein, DNA and hybrid adduct formation, prompting release of inflammatory cytokines such as tumor necrosis factor-α (TNF-α) by Kupffer cells, and contributing to immune responses that produce antibodies against aldehyde adducts. Acetaldehyde and aldehydes induce collagen synthesis by activation of transforming growth factor-β-dependent and independent profibrogenic pathways in which cytochrome P450 2E1 (CYP2E1) and osteopontin are involved, activating hepatic stellate cells to promote fibrosis[8]. CYP2E1 is another enzyme involved in the initial steps of alcohol metabolism and its induction is also a key response to alcohol intake, resulting in an increased production of reactive oxidative species, mainly hydrogen peroxide and superoxide anion. Oxygen radicals interact with fat molecules in a process called lipid peroxidation. Lastly, alcohol-induced immune abnormalities lead to increased intestinal permeability to a variety of substances, including endotoxins such as lipopolysaccharide, which stimulate Kupffer cells by binding with the CD14 receptor to promote fibrosis[9].

On the other hand, HBV is not directly cytopathic; the liver injuries seen in chronic HBV infection are considered to be associated with the activity of HBV-specific CD8+ cytotoxic T cells. Cytotoxic T cells are activated through the major histocompatibility complex, and proceed to kill infected cells by discharging interferon-γ and TNF-α. HBV infection usually causes inflammatory reactions characterized by the release of cytokines and chemokines, such as interleukin (IL)-1 and IL-8, and TNF-α. The oxidative stress induced by inflammation triggers Kupffer cells to promote stellate cell activation via nuclear factor-κB and activator protein 1. The persistent activation of these genes promotes fibrosis, leading to cirrhosis, and finally to the development of HCC[10].

Interplay between alcohol and HBV in liver disease progression
Although the mechanisms underlying the complex interaction between alcohol and hepatitis virus infection in the progression of liver disease are not fully understood, possible explanations include effects on viral replication, increases in oxidative stress, and a weakening of the immune response[11].

Larkin et al[12] reported that in HBV transgenic
C.B-17 SCID mice fed a standard Lieber-DeCarli ethanol liquid diet, elevated levels of HBV RNA as replicative intermediates, and increased expression of HBs, core and X antigens were observed in the liver. With ethanol, the level of HBsAg and of viral DNA in serum increased by up to 7-fold compared with mice fed the control diet. These findings may provide a partial explanation for the effects of alcohol on viral replication and the high frequency of HBV markers observed among alcoholics. Similarly, Min et al.\(^\text{[13]}\) showed that in human HepAD38 hepatoma cells infected with HBV, 100 mmol ethanol treatment approximately doubled the transcriptional activity of HBV promoters by increasing the expression of nuclear receptors such as hepatocyte nuclear factor-4α and peroxisome proliferator-activated receptor-α. In addition, CYP2E1-induced oxidative stress potentiates the ethanol-induced transactivation of HBV.

Consistent with clinical observations, Ha et al.\(^\text{[14]}\) showed that alanine aminotransferase (ALT) was elevated in both control C57BL/6J mice and HBx transgenic mice fed a 25% ethanol liquid diet for 12 wk, relative to water-fed controls. HBx mice showed 1.4-fold higher levels of ALT than did controls and, in histological evaluations, ethanol-fed HBx transgenic livers showed more evident hepatocyte enlargement and fatty changes compared to ethanol-fed control livers, suggesting that HBx compromising of antioxidant defenses promotes alcoholic liver injury.

Lastly, Geissler et al.\(^\text{[15]}\) demonstrated that in female BALB/c mice fed the Lieber-DeCarli diet, with 24% of the total caloric intake from ethanol, followed by DNA-based immunization with a plasmid construct containing the pre-S2/S gene, the levels of antibody to hepatitis B surface proteins (anti-HBs) were marginally reduced compared with those in control mice. Cytotoxic T lymphocytes and CD4+ T helper cells derived from ethanol-fed mouse spleens responded poorly to increasing concentrations of envelope protein and peptides \textit{in vitro}, suggesting that chronic ethanol consumption alters the cellular immune responses to a viral structural protein. A weakened immune response may result in not only persistent HBV infection, but also an immune-tolerant state. On the contrary, excess immune response can cause hepatitis exacerbations. The relationship between the protective versus harmful immune response in HBV infection remains to be fully defined in the context of alcohol intervention.

**LIGHT-TO-MODERATE ALCOHOL CONSUMPTION AND DISEASE PROGRESSION**

Although it is well documented that HCV-positive drinkers are 2 to 3 times more likely to develop HCC than abstinent individuals\(^\text{[16-19]}\), whether HBV infection and alcohol consumption synergistically increase the incidence of HCC is still controversial. Table 1 summarizes previous reports concerning the association of light-to-moderate habitual alcohol consumption with risk of HCC in patients with chronic HBV infection. The large-scale, prospective cohort REVEAL-HBV study in Taiwan, which included more than 3500 patients (aged 30-65 years), showed, during a mean follow-up of 11 years, that elevated serum HBV DNA level (> 10000 copies/mL) is an independent risk predictor of disease progression to cirrhosis and HCC\(^\text{[20,21]}\). A regression analysis revealed that male sex, older age, seropositivity for hepatitis B e antigen (HBeAg), and habitual alcohol consumption are also significantly associated with the development of HCC. The adjusted HR (with 95%CI) for HCC was 1.6 (1.1-2.4) for habitual alcohol consumption, defined as drinking alcohol ≥ 4 d per week for ≥ 1 year\(^\text{[20]}\). In contrast, as a predictor of progression to cirrhosis, HBV DNA level was the strongest factor (RR = 10.6; 95%CI: 5.7-19.6) in a Cox proportional hazards model adjusting for HBeAg status and serum ALT level, while habitual alcohol consumption was not associated with the risk for cirrhosis (RR = 0.8; 95%CI: 0.6-1.2)\(^\text{[21]}\). In
Table 1  Light-to-moderate habitual alcohol consumption and risk of hepatocellular carcinoma in patients with chronic hepatitis B virus infection

| Author (year) | Country | Design | n | Follow-up, years | Alcohol intake | Relative risk for HCC | Ref. |
|---------------|---------|--------|---|------------------|----------------|-----------------------|------|
| Chen (2006)   | Taiwan  | Prospective cohort study | 3653 with HBV | 11 | ≥ 4 d/wk for ≥ 1 year | 1.6 | [20] |
| Wang (2003)   | Taiwan  | Prospective cohort study | 2416 men with HBV | 7.8 | ≥ 4 d/wk for ≥ 1 year | 1.28 | [23] |
| Jee (2004)    | South Korea | Prospective cohort study | 4495 men with HBV | 10 | 25 g/d | 1.13 | [24] |

Table 2  Heavy alcohol consumption and risk of hepatocellular carcinoma in patients with chronic hepatitis B virus infection

| Author (year) | Country | Design | n | Follow-up, years | Alcohol intake | Relative risk for HCC | Ref. |
|---------------|---------|--------|---|------------------|----------------|-----------------------|------|
| Donato (2002) | Italy | Case-control study | 464 with HCC (including 92 with HBV) vs 824 controls (including 44 with HBV) | NA | ≥ 60 g/d | 2.13 | [30] |
| Lin (2013)    | Taiwan | Retrospective cohort study | 632 cirrhosis with HBV and alcohol vs 132 cirrhotics with HBV alone | 2.9-5.2 | ≥ 80 g/d for ≥ 5 yr | 1.33 | [31] |
| Ikeda (1998)  | Japan  | Prospective cohort study | 610 with HBV | 4.1 | 500 kg (cumulative) | 8.37 | [32] |

NA: Not applicable; HBV: Hepatitis B virus; HCC: Hepatocellular carcinoma.

HEAVY ALCOHOL CONSUMPTION AND DISEASE PROGRESSION

Table 2 summarizes previous reports concerning the association between heavy alcohol consumption and risk of HCC in patients with chronic HBV infection. Although there is currently no worldwide consensus, heavy drinking is sometimes defined as consuming more than 60 g/d of alcohol for men and 40 g/d for women[29]. In Italy, Donato et al.[30] conducted a case-control study to investigate the dose-effect relationship between alcohol consumption and HCC, separately, in men and women. They enrolled 464 subjects with a first diagnosis of HCC (including 92 with HBV) and 824 subjects unaffected by hepatic diseases (including 44 with HBV), and found a steady linear increase in the odds ratio of HCC with increasing alcohol intake, for values of > 60 g/d in both sexes. In addition, a synergism between alcohol drinking and chronic HBV infection was found, with the odds ratio of 2.13 in HBsAg-positive drinkers consuming > 60 g per day, compared to HBsAg-positive nondrinkers or drinkers of ≤ 60 g/d. Similarly, in a retrospective cohort study of 966 cirrhotic patients in Taiwan, with a mean follow-up period of 2.9-5.2 years, the annual incidence of HCC was significantly higher in 632 cirrhotic patients with HBV infection and heavy alcohol consumption (≥ 80 g/d for ≥ 5 years) than in 132 patients with HBV infection alone (9.9% and 4.1%, respectively, P
< 0.001) for a RR of 1.33[^31]. Likewise, a prospective cohort study in Japan that followed 610 consecutive HBsAg-positive patients for a median observation period of 4.1 years found that cumulative alcohol consumption ≥ 500 kg was independently associated in a multivariate analysis with the carcinogenesis rate, with a RR (95%CI) of 8.37 (2.70-25.93, P = 0.0002[^32]). Regarding mortality, Ribes et al[^33] followed 2352 HBsAg-positive patients for 20 years in a prospective cohort study, and found that lifetime alcohol consumption (> 60 g/d) was associated with a 6-fold increase in the risk of death from cirrhosis and HCC.

These studies indicate that heavy alcohol intake increases the incidence of HCC in patients with chronic HBV infection, although the risk threshold remains uncertain.

### ALCOHOL CONSUMPTION AND OUTCOME OF ANTIVIRAL TREATMENT

Since high HBV DNA levels in serum are associated with a higher risk of HCC, the primary aim of chronic hepatitis B treatment is sustained suppression of viral replication. HBV cannot be completely eradicated, due to the persistence of covalently closed circular DNA in the infected cell nucleus. Current guidelines recommend antiviral therapy with pegylated interferon-α or nucleoside/nucleotide analogues, including entecavir and tenofovir, as first-line treatment[^34-36].

In HBsAg-positive patients, female sex, high serum ALT level, low HBV DNA level, and genotype A were associated with an increased likelihood of sustained response to interferon-α[^27]; there are no strong pre-treatment predictors of viral response in HBsAg-negative patients. In patients with HCV, alcohol abuse appears to decrease responsiveness to interferon therapy, reducing both sensitivity and compliance[^38,39]. It was reported that increased oxidative stress from alcohol consumption can impair the cellular response to interferon-α through interference with the JAK-STAT pathway[^40,41]. Although there are no data concerning an association between alcohol consumption and treatment outcomes in patients with HBV, probably because fewer patients receive interferon for treatment of chronic hepatitis B, excess alcohol could reduce the efficacy of interferon therapy by the same mechanisms reported for patients with HCV.

In patients receiving nucleoside/nucleotide analogues, high serum ALT levels, high histological activity index scores for necroinflammation, and low HBV DNA levels are pre-treatment factors predictive of favorable biochemical, serological and virological responses[^42,43]. Regarding alcohol consumption, Chung et al[^44] reported that hazardous drinking (defined as a score of 8 or more on the Alcohol Use Disorders Identification Test) had no significant impact on the short-term outcome of 12 mo of entecavir treatment, measured as the rate of HBeAg seroconversion and HBV DNA negativity. Long-term treatment with lamivudine for a median duration of 32.4 mo can prevent progression to end-stage liver disease[^45]. Hosaka et al[^46] conducted a retrospective case-control study using propensity matching, and found that patients treated with 0.5 mg entecavir were significantly less likely to develop HCC than those in the control group (HR = 0.37; 95%CI: 0.15-0.91; P = 0.030). However, HCC can develop, even in patients with sustained HBV suppression. In addition to older age, presence of cirrhosis, HBeAg positivity, and low platelet count (< 1.5 × 10^12/mm^3), cumulative alcohol consumption > 200 kg was one of the significant factors associated with HCC development, with a multivariate adjusted HR (95%CI) of 2.21 (1.18-4.0).

In short, alcohol abuse could impair the response to interferon-α therapy in chronic hepatitis B patients as well as in chronic hepatitis C patients, and can increase the risk of HCC even in patients with low HBV DNA levels during nucleoside/nucleotide therapy.

### GENETIC FACTORS

Albeit still controversial, some reports have associated genetic variants with disease progression. Table 3 is a brief summary of reported genetic polymorphisms potentially associated with increased risk of alcoholic liver disease. In subjects with ADH2*1/*2 or ADH2*1/*1, the rate of ethanol metabolism is lower, compared with those having ADH2*2/*2. ADH2 gene polymorphism can determine flushing after ethanol ingestion. Flushing was reported in subjects homozygous for ALDH2*2/*2 and heterozygous for ALDH2*1/*2, but not in those homozygous for ALDH2*2/*1[^47]. Concerning polymorphisms of the CYP2E1 gene, subjects heterozygous for the promoter alleles C1/C2 or homozygous C2/C2 are better able to metabolize alcohol, which might increase free radical generation and lipid peroxidation, and promote fatty change in the liver[^48]. Recently, the isoleucine-to-methionine substitution at position 148 (rs738409 C>G) in the patatin-like phospholipase domain-containing 3 protein (PNPLA3) has been reported to have a strong association with progression of alcoholic liver disease (including cirrhosis and HCC), as well as nonalcoholic fatty liver disease[^49,50]. Polymorphisms in CD14[^50] or TNF-α[^51] are reported to be associated with alcoholic liver injury, but further validation is needed.

Regarding HBV, a number of cohort studies have shown that some single nucleotide polymorphisms (SNPs) in the HLA-DO I polymorphic region were associated with persistent HBV infection. As shown in Table 4, for example, rs3077 SNP near the HLA-DOA1 gene and rs9277535 SNP near the HLA-DPB1 gene were associated with persistent HBV infection in Asian populations[^52]. Among Chinese, Li et al[^53] identified locus at 8p21.3 (index SNP rs7000921) contributing to the susceptibility to persistent HBV infection. They further demonstrated the nearby gene integrator complex subunit 10 at 8p21.3.

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Table 3  Genetic polymorphisms associated with increased risk of alcoholic liver disease progression

| Gene   | Polymorphism         | Reported association                          | Ref. |
|--------|----------------------|----------------------------------------------|------|
| ADH    | ADH2*1/*2            | Decrease the rate of ethanol metabolism      | [47] |
|        | ADH2*1/*1            |                                              |      |
| ALDH   | ALDH2*2/*2           | Increase alcohol sensitivity                 | [47] |
|        | ALDH2*1/*2           |                                              |      |
| CYP2E1 | C1/C1                | Increase free radical generation, lipid peroxidation, and fatty change | [9]  |
|        | C1/C2                |                                              |      |
|        | C2/C2                |                                              |      |
| PNPLA3 | rs738469C>G          | Increase the risk of liver cirrhosis and HCC | [48,49]|
| CD14   | 159TT                | Enhance inflammatory responses               | [50] |
| TNF-α  | 238G>A               | Develop alcoholic liver disease              | [51] |

ADH: Alcohol dehydrogenase; ALDH: Acetaldehyde dehydrogenase; CYP2E1: Cytochrome P450 2E1; HCC: Hepatocellular carcinoma; PNPLA3: Patatin-like phospholipase domain containing 3; TNF-α: Tumor necrosis factor-α.

Table 4  Genetic polymorphisms associated with hepatitis B virus infection

| Gene    | Polymorphism         | Reported association                          | Ref. |
|---------|----------------------|----------------------------------------------|------|
| HLA-DPA1| rs3077 CC            | Persistent HBV infection                     | [52] |
| HLA-DPB1| rs9277535 GG         | Persistent HBV infection                     | [52] |
| INTS10 | rs7009921 TT or CC   | Suppress HBV replication                     | [53] |

HBV: Hepatitis B virus; HLA: Human leukocyte antigen; INTS10: Integrator complex subunit 10.

regard to sex differences, women are more susceptible than men to the toxic effects of alcohol, as they have a significantly higher risk of developing progressive disease for any given level of alcohol intake[53]. In contrast, male patients with HBV are at higher risk of HCC than female patients[58,59]. Previous studies on racial and ethnic differences have found that Hispanic, Black, and Asian subjects are more susceptible to alcohol-related liver damage than are Caucasians[59,60]. Additionally, in most Asian countries, genotype C is the most prevalent type of HBV, which is associated with an increased risk of disease progression[55]. As most large-scale clinical studies of HBV have been conducted in East Asia, it remains to be elucidated whether the obtained results can be applied to other areas, such as the United States and Europe. Lastly, Loomba et al[61] reported that alcohol and obesity synergistically increased the risk of HCC in 2260 HBsAg-positive men from the REVEAL-HBV study cohort (HR = 3.40; 95%CI: 1.24-9.34).

CONCLUSION

The association of light-to-moderate alcohol consumption with clinical outcomes in patients with chronic HBV infection appears modest, with a 1.5-fold increased risk at best, probably smaller than that of viral factors such as HBV DNA load and genotype. However, heavy alcohol consumption significantly accelerates the progression of liver disease to cirrhosis and, finally, HCC, with a 1.3-fold to 8.4-fold increased risk. As the mechanisms by which alcohol enhances disease progression are less well understood in patients with chronic hepatitis B than C, more experimental studies are warranted. In addition, alcohol abuse could impair the response to interferon-α therapy in patients with chronic hepatitis B (as with C), although this is still controversial, and can increase the risk of HCC in patients with low HBV DNA levels suppressed by nucleoside/nucleotide therapy. Although the threshold amount of alcohol for HCC risk remains unknown, heavy alcohol intake is clearly associated with the progression of liver disease. Strict abstinence should suppress HBV replication in an interferon regulatory factor 3-dependent manner in vitro and identified an antiviral gene integrator complex subunit 10 (INTS10) at 8p21.3 as involved in the clearance of HBV infection. A SNP near the IL-28B gene is associated with pegylated interferon-α and ribavirin treatment-induced/spontaneous viral clearance in chronic/acute HCV infection. In contrast, in chronic hepatitis B, previous studies yielded conflicting results of the association of IL-28B with response to interferon-α therapy or long-term outcome[56].

OTHER POSSIBLE FACTORS AFFECTING DISEASE PROGRESSION

Other factors may affect the progression of alcoholic liver injury, including the disease duration, patient sex, ethnicity and obesity[55,56]. Since longer duration of persistent alcohol intake is associated with disease progression in patients with alcoholic liver injury, it is generally accepted that strict abstinence must be recommended. Although a retrospective case-control study unexpectedly indicated that former drinkers who had stopped 1-10 years previously had a higher risk of HCC than current drinkers, the authors speculated the reason might be that many patients with HCC had stopped drinking some years prior to the study[20]. With other factors such as the presence of viral factors such as HBV DNA load and genotype, the association of light-to-moderate alcohol consumption with disease progression is less well understood in patients with chronic hepatitis B than C, more experimental studies are warranted. In addition, alcohol abuse could impair the response to interferon-α therapy in patients with chronic hepatitis B (as with C), although this is still controversial, and can increase the risk of HCC in patients with low HBV DNA levels suppressed by nucleoside/nucleotide therapy. Although the threshold amount of alcohol for HCC risk remains unknown, heavy alcohol intake is clearly associated with the progression of liver disease. Strict abstinence should suppress HBV replication in an interferon regulatory factor 3-dependent manner in vitro and identified an antiviral gene integrator complex subunit 10 (INTS10) at 8p21.3 as involved in the clearance of HBV infection. A SNP near the IL-28B gene is associated with pegylated interferon-α and ribavirin treatment-induced/spontaneous viral clearance in chronic/acute HCV infection. In contrast, in chronic hepatitis B, previous studies yielded conflicting results of the association of IL-28B with response to interferon-α therapy or long-term outcome[56].

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