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Myeloid-DerivedSuppressor Cells Regulate Immune Response in Patients with Chronic Hepatitis B Virus Infection through PD-1–Induced IL-10

Ang Huang,*†,1 Bo Zhang,‡,1 WeiWei Yan,† Bo Wang,* Huafeng Wei,‡ Fan Zhang,* Lang Wu,‡ KeXing Fan,*† and YaJun Guo*‡

Although myeloid-suppressor cells (MDSCs) are well known for their immunosuppressive function in several pathological conditions, the role of MDSCs in hepatitis B virus infection remains obscure. In this study, we investigated the frequency and function of MDSCs in the peripheral blood and liver of 91 chronic hepatitis B (CHB) patients. A higher percentage of MDSCs, defined as CD14+HLA-DR–/low, was detected in peripheral blood of CHB patients than that of the healthy controls. Moreover, high expression of programmed death 1 (PD-1) and secretion of IL-10 in this population were determined. The frequency of MDSCs was positively correlated with serum viral load, but it was negatively correlated with liver inflammatory injury. These cells were also abundant in liver tissue of CHB patients and were related to necroinflammatory activity. Furthermore, we found that these cells could suppress hepatitis B virus–specific CD8+ T cell response, including reduced proliferation and IFN-γ production, and inhibit degranulation of CD8+ T cells, including reduced production of granzyme B and perforin. Importantly, PD-1–induced IL-10 production by MDSCs was responsible for the suppressive activity. To our knowledge, for the first time our study proved that CD14+HLA-DR–/low–PD-1+ MDSCs in CHB patients contribute to an inadequate immune response against the virus and lead to chronic infection, which represents a potential target for therapeutic intervention. The Journal of Immunology, 2014, 193: 5461–5469.

Hepatitis B virus (HBV) infection has major global health problems, especially in Asia. There are >350 million people chronically infected with this virus worldwide, and in China ~22 million people suffer from chronic hepatitis B (CHB) virus (1). Accumulating evidence suggests that immune dysregulation occurs in CHB patients, and that persistent HBV infection could lead to increased risk of developing liver cirrhosis, liver failure, and liver cancer (2). HBV-specific CD8+ CTLs are essential for the control of HBV infection, but suppression of virus-specific T cells, demonstrated as functional impairment of proliferation and exhausted cytokine production, has been observed in patients with persistent HBV infection (3, 4). Thus, a better understanding of the mechanisms behind T cell suppression is critical for identifying effective strategies for HBV immunotherapy.

Recently, the focus of this area of research has shifted to myeloid-suppressor cells (MDSCs) owing to their prominent role in immunoregulation. MDSCs are a heterogeneous population of cells composed of precursors of macrophages, granulocytes, dendritic cells, and myeloid cells at earlier stages of differentiation (5). These cells have been demonstrated to have the potential to suppress immune responses of T cells by way of TGF-β, Arg1, programmed death ligand (PD-L) 1, and reactive oxygen species (ROS), as well as by regulatory T cell induction (6–11). In mice, MDSCs are characterized by the coexpression of Gr-1 and CD11b. Human MDSCs, although being mostly described as Lin+HLA-DR–CD33+, have not been well characterized owing to lack of specific markers (12). Recently, a novel subset of monocytes defined as CD14+HLA-DR–/low–PD-1+ MDSCs in cancer patients (13–15), supporting the heterogeneity and plasticity of MDSCs. Accumulating evidence has demonstrated that MDSCs were closely associated with disease progression in malignancy and some inflammation-mediated pathological conditions (7, 16). Although recent studies report MDSC expansion in viral infections (17–22), phenotypic and functional features of MDSCs are still poorly defined in patients with CHB.

The aim of this study was to determine whether MDSCs are involved in the impaired immune response leading to chronic HBV infection. We hypothesized that patients with chronic HBV infection have a higher proportion of MDSCs compared with healthy controls and that MDSCs are responsible for the inability of infection clearance for patients. For this purpose, we investigated the frequency, phenotype, and function of MDSCs in chronic HBV patients and evaluated the association of MDSCs with disease

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The online version of this article contains supplemental material.

Abbreviations used in this article: ALT, alanine aminotransferase; CHB, chronic hepatitis B; GrB, granzyme B; HAI, histological activity index; HBeAg, hepatitis B e antigen; HBV, hepatitis B virus; HCV, hepatitis C virus; IA, immune-activated; iNOS, inducible NO synthase; IT, immune-tolerant; MDSC, myeloid-derived suppressor cell; PD-1, programmed death 1; PD-L, programmed death ligand; ROS, reactive oxygen species.

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activity and viral clearance. These findings may provide new insights for understanding the impaired immune response in humans with virus infection.

Materials and Methods

Patients and healthy controls

Blood samples were obtained from 91 HBV-infected hepatitis B e Ag (HBeAg)+ subjects, including 70 immune-activated (IA) patients and 21 immune-tolerant (IT) carriers. All patients were diagnosed according to previously described criteria (23). Briefly, the IT group was defined as patients with minimal liver damage, normal alanine aminotransferase (ALT) levels (<40 U/l), and no inflammation in the liver. The IA group included patients with high levels of inflammation in the liver, elevated serum ALT levels (>40 U/l), but decreased viral replication (>100 IU/ml). None of the subjects with HBV infection included in the study had received antiviral therapy or immunosuppressive drugs within 6 mo before sampling. Liver biopsies were collected from 21 IA patients, and the degree of hepatic inflammation was graded by the modified histological activity index (HAI) (24). Briefly, two components, grading and staging, were given in a numerical value ranging from 0 to 4; grading was used to describe the intensity of necroinflammatory activity, and staging was a measure of fibrosis and architectural alteration in chronic hepatitis. Increased numerical values indicated a greater severity of disease. Individuals with coinfections of hepatitis C virus (HCV), hepatitis D virus, and HIV infections were excluded from enrollment. The study protocol was in accordance with the ethical guidelines of the 1975 Declaration of Helsinki and was approved by the Beijing 302 Hospital Research Ethics Committee. Written informed consent was obtained from all participants. Baseline clinical data are shown in Table I. For comparison, 37 uninfected healthy controls were age and sex matched to the enrolled patients.

Cell isolation and sorting

PBMCs were isolated from heparinized blood by Ficoll-Hypaque (Pharmacia, Uppsala, Sweden) density gradient centrifugation. Monocyte counts of these patients were determined by an automated hematology analyzer (KX-21N, Sysmex). PBMCs were stained with Abs to human CD14 and HLA-DR. In selected assays, PBMCs were sorted into CD14+HLA-DR−/low–depleted PBMCs, CD14+HLA-DR− cells, or CD14+HLA-DR−/low cells by using a MoFlo XDP cell sorter (Beckman Coulter). The purity of the CD14+HLA-DR−/low cells, a novel population of MDSCs, in CHB patients as compared to healthy controls was determined by an automated hematology analyzer.

Flow cytometric analysis

For surface marker staining, fresh heparinized peripheral blood (100 μl) was labeled with the following mAbs: PE-Cy5–conjugated CD74, PE-Cy5–conjugated HLA-DR, FITC-conjugated CD11b, FITC-conjugated CD11c, PE-conjugated CD33, PE-conjugated CD80, FITC-conjugated CD86, PE-conjugated PD-L1, PE-conjugated programmed death 1 (PD-1), PE-Cy5–conjugated CD11b, and FITC-conjugated LIn1 (CD3, 14, 16, 19, 20, 56) (BioLegend, San Diego, CA). After the cells were incubated for 30 min at 4°C in the dark, they were lysed with RBC lysis solution (BioLegend). Data acquisition and analysis were performed using a flow cytometer (FC500 MPL, Beckman Coulter) and FlowJo software (Tree Star, Ashland, OR). Isotype-matched Abs were used with all samples as controls.

Cell culture supernatants were tested for levels of various cytokines as indicated. This was done using cytokine bead array (Bender MedSystems, Copenhagen, Denmark) according to the manufacturer’s protocol.

Detection of granzyme B and perforin production

For intracellular granzyme B (GrB) and perforin detection, cells cocultured were stimulated with PMA (50 ng/ml, Sigma-Aldrich), ionomycin (1 μg/ml, Sigma-Aldrich), and monensin (1 μg/ml, BD Biosciences) for 5 h as described previously (10). Cells were then stained with PE-Cy5–conjugated CD8, further permeabilized with a Cytofix/Cytoperm kit (BD Biosciences), and labeled with intracellular Ab FITC-conjugated perforin and PE-conjugated GrB (BD Biosciences).

Analysis of degranulation of CD8+ T cells

For determination of degranulation of CD8+ T cells, a CD107a mobilization assay was performed as described previously (28). After that, cells were washed, stained with PE-Cy7–conjugated CD8, and subjected to flow cytometric analysis.

Proliferation and IFN-γ secretion assays

For intracellular cytokine IFN-γ detection, cells cocultured were stimulated with PMA (50 ng/ml, Sigma-Aldrich), ionomycin (1 μg/ml, Sigma-Aldrich), and monensin (1 μg/ml, BD Biosciences) for 5 h as described previously (10). Cells were then stained with PE-Cy5–conjugated CD8, further permeabilized with a Cytofix/Cytoperm kit (BD Biosciences), and labeled with intracellular Ab FITC-conjugated IFN-γ (BD Biosciences).

For proliferation assays, PBMCs with CD14+HLA-DR−/low cells, PBMCs were labeled with CFSE according to the manufacturer’s instructions (Invitrogen). CFSE in the form of a 5 mM stock solution in DMSO was added to give a final concentration of 5 μM in the cell suspension. PBMCs cocultured with CD14+HLA-DR−/low cells at different ratios were then stimulated with anti-human CD3 and CD28 (both 1 μg/ml) or HBV core Ag (5 μg/ml) according to previous description (7). Cells were then washed, stained with PE-Cy7–conjugated CD8 at day 5, and subjected to flow cytometric analysis.

To further investigate the potential suppressive mechanisms by MDSCs, 10 μg/ml neutralizing anti-human PD-L1 Ab (BioLegend) or 10 μg/ml neutralizing anti-human IL-10 Ab (BioLegend) was added in the culture system. PBMCs and MDSCs were cocultured in Transwell plates (Corning) in indicated experiments.

Quantitative PCR

Total RNA from CD14+ HLA-DR−/low cells was extracted using the RNeasy Mini kit (Qiagen, Hilden, Germany), and genomic DNA was removed using the RNase-free DNase set (Promega, Madison, WI). Quantitative PCR (SYBR Green Supermix, iCycler, Bio-Rad) was performed according to previously described protocols (29). Primer sequences for gene-specific amplifications were previously reported (7, 29). Relative gene expression was determined by normalizing to β-actin in each sample.

Serum HBV DNA, HBsAg, and HBeAg assays

The serum HBV DNA, HBsAg, and HBeAg assays were performed according to previous descriptions (25, 30, 31). The cut-off value was 100 IU/ml.

Statistical analysis

All data were analyzed using SPSS version 16.0 for Windows software (SPSS, Chicago, IL). Multiple comparisons were made between different groups with the Kruskal–Wallis H nonparametric test. Comparisons between various individuals were performed using the Mann–Whitney U test. Comparison between values within the same individual was performed using the Wilcoxon matched pairs t test. Correlation analysis was performed using Spearman rank correlation tests. For all tests, two-sided p < 0.05 was considered to be significant.

Results

Frequency and phenotype of MDSCs in CHB patients

We first compared the percentage of CD14+ monocytes present in the peripheral blood of chronic HBV patients (n = 91) with the percentage of those in healthy controls (n = 37) (Table I). As shown in Fig. 1A, there was a mild increase in the frequency of CD14+ monocytes in peripheral blood from patients with CHB, compared with that of healthy controls (Fig. 1A). Furthermore, when the CD14+ cells were analyzed for HLA-DR expression, we noticed a significant increase in the percentage of HLA-DR−/low cells, a novel population of MDSCs, in CHB patients as compared with healthy controls (Fig. 1B, 1C). Moreover, both IA and IT patients have an increased percentage of CD14+HLA-DR−/low cells in monocytes compared with healthy controls, whereas there...
was no significant difference between the two groups (Fig. 1D). The Lin- HLA-DR-CD33+ cells in CHB patients, a phenotype most commonly described for human cancer-associated MDSCs, was found at low percentage and at similar levels as in healthy controls (Supplemental Fig. 1).

The distribution of this subpopulation in liver tissue was further determined in 21 patients with chronic infection. The frequency of these cells was slightly higher in liver than that in the periphery (8.97 ± 3.37% versus 7.52 ± 3.95%), albeit there is no statistical significant difference, indicating that these cells were also abundant in liver tissue (Fig. 1E).

**Characterization of MDSCs in CHB patients**

To further characterize the MDSCs in CHB patients, we compared their phenotype with CD14+HLA-DR+ monocytes (Fig. 2A). Most of the myeloid markers and surface activation markers such as CD11b, Table I. Clinical features of enrolled subjects

<table>
<thead>
<tr>
<th>Group</th>
<th>IA</th>
<th>IT</th>
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<tbody>
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<td>37</td>
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<td>15/6</td>
<td>20/17</td>
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<tr>
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<td>30.56 ± 8.37</td>
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<tr>
<td>Cases with liver biopsy</td>
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<td>8</td>
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HC, healthy controls; ND, not determined.

**FIGURE 1.** Frequency and phenotype of MDSCs in CHB patients. (A) Frequency of circulating CD14+ monocytes in CHB patients and health controls. (B) Frequency of circulating CD14+HLA-DR-Flow monocytes in CHB patients and health controls. (C) Representative dot plots of a healthy control and a CHB patient. Whole blood was stained for monocyte markers, including CD14 and HLA-DR. CD14 cells in whole blood were identified based on side scatter (SSC) and CD14 expression pattern. CD14 cells were further categorized into the CD14+HLA-DR+ subset and the CD14+HLA-DR-Flow subset for HLA-DR expression. (D) Frequency of circulating CD14+HLA-DR-Flow monocytes in IA and IT patients. (E) Comparison of CD14+HLA-DR-Flow monocyte frequency in the liver and peripheral blood of subjects with chronic infection.
CD16, CD33, CD80, and PD-L1 were expressed at similar levels in both populations. The CD14+HLA-DR−/low MDSCs from CHB patients, similar to CD14+HLA-DR+ cells, expressed positive CD11b and CD33. CD86 expression was rather decreased on CD14+HLA-DR−/low MDSCs, compared with CD14+HLA-DR+ monocytes. Notably, high expression of PD-1 was detected on MDSCs, but not on CD14+HLA-DR+ monocytes (Fig. 2B, bottom panel). Furthermore, we observed a significant positive correlation between MDSC frequency and PD-1 expression on total CD14+ monocytes ($r = 0.631, p = 0.002$). Increased PD-1 expression on total CD14+ monocytes was associated with increased percentage of CD14+HLA-DR−/low MDSCs in CHB patients (Fig. 2B, top panel). To further confirm the expression of PD-1 on MDSCs, Western blotting was used to determine the expression of PD-1. The results demonstrated that upregulation of PD-1 expression in MDSCs was detected, compared with that of CD14+HLA-DR+ monocytes (Supplemental Fig. 2). The data were consistent with those of FACS analysis.

We next examined the production of cytokines including IL-1β, IL-6, IL-10, and TNF-α in subsets of CD14+ cells under LPS stimulation in vitro (Fig. 2C, 2D). We found that CD14+HLA-DR−/low MDSCs from CHB patients expressed significantly more IL-10 than CD14+HLA-DR+ cells. However, MDSCs seemed to have decreased secretion of IL-1β, IL-6, and TNF-α compared with CD14+HLA-DR+ cells in these CHB patients. The similar results also were observed in the cell culture supernatants by cytokine bead array (Supplemental Fig. 3).

MDSCs in relationship to clinical parameters

To analyze whether the frequency of MDSCs are correlated with serum ALT levels and HBV DNA load, IA patients were divided into two groups based on their serum HBV DNA load or ALT level, respectively. As shown in Fig. 3A, patients with serum HBV DNA load of $>10^7$ IU/ml had a higher mean frequency of circulating MDSCs than did patients with a serum HBV DNA load of $<10^5$ IU/ml. However, patients with a serum ALT level of $>200$ U/l had a lower frequency of these cells, compared with subjects with an ALT level of $<200$ U/l (Fig. 3B). Interestingly, Spearman rank correlation analysis also showed a positive correlation between frequency of MDSCs and the viral load (Fig. 3A) but a negative relationship between frequency of MDSCs and ALT levels (Fig. 3B). These results suggested that increased circulating MDSCs may be associated with a negative immune response leading to poor viral clearance and, in contrast, contribute to protect liver inflammation injury. Additionally, we found that the percentage of this population was not correlated with HBeAg or HBsAg levels.

The relationship between intrahepatic MDSCs and liver HAI, including grading and staging, was further analyzed. The results showed that IA patients with HAI grade 1 had a higher frequency of MDSCs in the liver than did patients with HAI grades 2–4 (Fig. 3C), whereas no such difference was observed between HAI staging 1 and staging 2–4 groups (Fig. 3D), further suggesting these cells are negatively related to necroinflammatory activity, but not to fibrosis alteration.

MDSCs suppress cytolytic molecule release and production of CD8+ T cells in CHB patients

It is well known that hepatocyte injury in CHB patients results from the killing capability of CD8+ T cells. In this study, degranulation of cytolytic molecules by CD8+ T cells was measured by detecting the expression of the perforin-release marker, CD107a. After 6 h
of anti-CD3/CD28 stimulation, CHB patients showed a significant decrease of CD107a expression in CD8+ T cells compared with normal controls (Fig. 4A). Dynamic analysis showed that the CD107a expression was much lower in HBC patients than in normal controls after stimulation (Fig. 4B). When MDSCs were depleted, CD107a expression was restored significantly (Fig. 4B). Degranulation analysis showed that CHB patients with a serum ALT level of 200 U/l had lower levels of GrB and perforin, compared with subjects with an ALT level of >200 U/l (Fig. 4C). Production of GrB and perforin in CD8+ T cells of CHB patients

![Figure 3](http://www.jimmunol.org/)

**Figure 3.** Correlation analysis between the frequency of MDSCs and clinical parameters. (A and B) The significance of difference between this subset of monocyte frequency and serum HBV DNA (A) or ALT level (B) was analyzed using a nonparametric Mann–Whitney U test. The correlation between MDSC frequency and serum HBV DNA load or ALT level was analyzed using Spearman correlation. (C and D) Correlation analysis between the frequency of intrahepatic MDSCs in CHB and histological activity index, including grading (C) and staging (D). G, grading; S, staging.

![Figure 4](http://www.jimmunol.org/)

**Figure 4.** MDSCs suppress degranulation of CD8+ T cells of CHB patients. (A) The degranulation marker, that is, CD107a expression on CD8+ T cells of CHB patients, was compared with normal controls after 6 h of anti-CD3/CD28 stimulation. (B) Dynamic analysis of CD107a expression on CD8+ T cells, as well as the effect of depletion of MDSCs from PBMCs of CHB patients on CD107a expression. (C) Levels of GrB and perforin production by CD8+ T cells in CHB patients with various ALT levels. (D and E) Depletion of MDSCs from PBMCs restores the production of GrB and perforin in CD8+ T cells. Means ± SD are shown. *p < 0.05, **p < 0.01.
increased obviously in MDSC-depleted PBMCs (Fig. 4D, 4E). Overall, our findings suggest that MDSCs may suppress CD8+ T cell killing capability by inhibiting the release and production of GrB and perforin, which contributes to the improvement of liver inflammation.

MDSCs suppress CD8+ T cell response in CHB patients

For further functional analysis, we tested whether MDSCs from CHB patients could suppress autologous CD8+ T cell responses. Sorted MDSCs were added at different ratios to autologous PBMCs. We detected that MDSCs suppressed the proliferation and IFN-γ production of autologous CD8+ T cells in a dose-dependent manner. Moreover, depletion of these cells from PBMCs of CHB patients resulted in a significantly stronger proliferation upon stimulation with anti-CD3/CD28 or higher IFN-γ production after stimulation with PMA compared with PBMCs (Fig. 5A, 5B). Furthermore, we observed that these cells inhibited the HBcAg-specific proliferation of CD8+ T cells in a dose-dependent manner, and autologous CD8+ T cell response was enhanced when these cells were depleted from PBMCs (Fig. 5C). Moreover, Transwell assays showed that the suppressive activity of these cells was mediated by soluble factors and was not cell contact-dependent (Fig. 5). We also evaluated the immunosuppressive activities of CD14+HLA-DR+ monocytes on autologous T cell proliferation and IFN-γ production. As expected, CD14+ HLA-DR+ monocytes failed to inhibit CD8+ T cell proliferation or IFN-γ production in autologous PBMCs even at a 1:1 ratio (data not shown). Thus, the suppressive function was restricted to the HLA+DRlow population.

PD-1–induced IL-10 production is responsible for MDSC-mediated suppression of T cell response

We further investigated the underlying mechanism by which MDSCs suppress CD8+ T cell response. Although inducible NO synthase (iNOS) and arginase have been linked to MDSC activity of immunosuppression, in the current study we could not detect any arginase expression or activity in MDSCs from CHB patients, thereby excluding a role of arginase and iNOS metabolism products (Fig. 6A). Additionally, no obvious difference was found for the expression of p47phox and gp91phox, the most important subunits of the NADPH oxidase complex responsible for ROS production, between CHB patients and healthy controls (Fig. 6A). However, the level of IL-10 transcription was significantly higher in CHB MDSCs compared with levels of those in healthy controls (Fig. 6A), consistent with the results in Fig. 2C. The mRNA expression of TGF-β was also not detected in MDSCs. Furthermore, suppression of T cell response, including T cell proliferation and IFN-γ production, was prevented by treatment with IL-10–specific mAbs (Fig. 6B, 6C). However, inhibition of arginase, iNOS, and ROS had no observed effect on MDSC-mediated suppression of CD8+ T cell response (data not shown). Interestingly, we also observed similar results when we...
added the neutralizing Ab for PD-L1 to cell cultures. Moreover, after pretreatment with anti–PD-L1 mAb for these cell cultures, addition of anti–IL-10 mAb could not effectively restore T cell proliferation and IFN-γ production (Fig. 6B, 6C). These results strongly suggest that the PD-1 signaling might play an important role in inducing IL-10 production by MDSCs.

We further investigated whether triggering of PD-1 can induce IL-10 production by MDSCs. Stimulation of MDSCs with a PD-1–specific agonist induced a 10-fold increase in IL-10 production as compared with control IgG (Fig. 6D), providing further evidence that expression of PD-1 by MDSCs and IL-10 production were interrelated. We confirmed that IL-10 is secreted at 24 h in a dose-dependent manner upon PD-1 triggering (Fig. 6E). Moreover, MDSCs triggered via anti–PD-1 Ab produced IL-10 as early as 6 h after treatment and reached peak concentration at 24 h (Fig. 6F). In contrast, we did not detect IL-10 production upon PD-1 triggering of CD3− and CD28-preactivated T cells and CD14+ HLA-DR+ cells (data not shown), suggesting that IL-10 production was from PD-1–triggered MDSCs and that it mediated suppression of T cell response.

To further confirm the impact of PD-1 interaction with PD-L1 or PD-L2 on IL-10 production by MDSCs. We transduced COS-7 cells with pcDNA3.1 encoding GFP (COS-mock cells), PD-L1 (COS–PD-L1 cells), and PD-L2 (COS–PD-L2 cells). MDSCs produced more IL-10 when cocultured with COS–PD-L1 cells than did MDSCs cocultured with COS-mock cells. Addition of anti–PD-L1 mAb into the coculture inhibited the IL-10 production by MDSCs. Additionally, MDSCs cocultured with COS–PD-L2 did not produce much IL-10 (Supplemental Fig. 4). Overall, these data demonstrated that PD-1/PD-L1 signaling was responsible for IL-10 production in MDSCs.

FIGURE 6. PD-1–induced IL-10 production mediates the suppressive effect of MDSCs on T cell response. (A) mRNA expression levels of candidate suppressive molecules in MDSCs of healthy controls and CHB patients (n = 8). (B and C) Effect of neutralization of PD-L1 and IL-10 on CD8+ T cell proliferation (B) and IFN-γ production (C) in the coculture MDSCs and CD8+ T cells (n = 10). (D) IL-10 concentrations, as measured by ELISA 24 h after incubation of MDSCs with 10 μg/ml Ab to PD-1, polyclonal goat IgG (n = 10). (E and F) IL-10 secreted by MDSCs incubated for 24 h with a range of concentrations of Ab to PD-1 (E) or with 10 μg/ml Ab to PD-1 for various time (F) (n = 10). Data were from at least five CHB individuals. Means ± SD are shown. *p < 0.05, **p < 0.01.

Discussion
There has been rapid progress in the understanding of the contribution of MDSCs in tumor progression and antitumor immune response (32). However, the immunological and clinical significances of MDSCs in viral diseases are far from clear. In this study, we have identified, to our knowledge for the first time, a novel subset of monocytes from CHB patients that are capable of suppressing T cell responses. These cells, which were CD14+, did not express molecules that are associated with activation or costimulation, such as HLA-DR or CD80. The suppressive monocyte population has been identified in the microenvironment of tumor systems (14, 15), which was also named “MDSCs.” In the current study, we found a significantly higher proportion of this subset in CHB patients compared with healthy controls. We also detected that increased MDSCs were positively correlated with HBV viral load, but negatively correlated with liver damage, suggesting that increased MDSCs could be associated with disease progression. Furthermore, our results indicate that these cells suppress IFN-γ secretion and proliferation of HBV-specific T cells in a cell contact–independent fashion, which required production of IL-10. Overall, our data provide a novel mechanism of viral escape from effective immune response, and it could also be a response of the host to avoid further organ damage.
effects of MDSCs on CD8+ T cell proliferation and IFN-
function of MDSCs (27, 40, 41). Indeed, we observed that neu-
weases (27, 38, 39). These cells could spontaneously secrete bio-
patients, similar to previous reports for several other human dis-
represents the major mechanism for suppressive MDSCs in CHB
nism of suppression in CHB is not known. Previous studies have
MDSCs and liver injury.
spressing T cell proliferation, activation, and degranulation in CHB
HCV, HIV, and lymphocytic choriomeningitis virus (20–22, 45).
sugest that MDSCs may impair CD8+ T cell function by sup-
1). The persistence of viral infections has been found to be asso-
ated with diminished CD8+ T cell number and function in both
humans and mice (35). Several studies have demonstrated that the
acellular immune response to HBcAg is generally low to unde-
cumulation of MDSCs in CHB are being investigated in our
may contribute to the increased percentage of MDSCs in their peripheral
blood compared with healthy controls. These MDSCs could contribute to
persistence of HBV infection by impairing HBV-specific immune
response, but also inhibited serious inflammatory response resulting in
further liver damage. Our findings provide new insights into the
mechanisms of MDSCs in CHB patients. Our study might
support the potential of targeting MDSCs for developing effective
immunotherapy for HBV infection.

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Disclosures
The authors have no financial conflicts of interest.

References
induce IDO\textsuperscript{43} CD14\textsuperscript{+}HLA-DR\textsuperscript{+} myeloid-derived suppressor cells that inhibit T-cell responses and promote Treg cell expansion. Blood 124: 750–760.


Supplementary Figure 1  Frequencies of Lin^HLA-DR^-CD33^+ cells in CHB (n=21) as compared to HC (n=14) PBMC. Bars indicate mean ± SD.
**Supplementary Figure 2** The expression of PD-1 on MDSCs was determined by western blotting. MDSCs and CD14⁻HLA-DR⁺ monocytes derived from three patients were sorted, and the cell samples were used to determined the PD-1 expression by western blotting.

<table>
<thead>
<tr>
<th>Patient 1</th>
<th>Patient 2</th>
<th>Patient 3</th>
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<tbody>
<tr>
<td>CD14⁺HLA-DR⁻</td>
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<td>CD14⁺HLA-DR⁺</td>
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<td>CD14⁺HLA-DR⁺</td>
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**Western Blot Analysis**

- **PD-1**
- **Beta-actin**
Supplementary Figure 3  Cytometric Bead Assays were performed to quantify IL-1β, IL-6, and TNF-α production in the supernatants. Bars indicate mean ± SD.
Supplementary Figure 4  IL-10 expression was measured by ELISA at 48 h after MDSCs incubation with PD-L1-expressing (in the presence or absence of antibody to PD-L1), PD-L2-expressing or Mock (empty vector)-expressing Cos-7 cells at a ratio of 1:4.