

11-2003

# Comprehensive Analysis of Class I and Class II HLA Antigens and Chronic Hepatitis B Virus Infection

Chloe L. Thio

*Johns Hopkins Medical Institutions*

David L. Thomas

*Johns Hopkins Medical Institutions*

Peter Karacki

*Johns Hopkins Medical Institutions*

Xiaojiang Gao

*National Cancer Institute at Frederick*

Darlene Marti

*National Cancer Institute at Frederick*

*See next page for additional authors*

Follow this and additional works at: [https://nsuworks.nova.edu/cnso\\_bio\\_facarticles](https://nsuworks.nova.edu/cnso_bio_facarticles)

 Part of the [Biology Commons](#), [Genetics and Genomics Commons](#), and the [Virology Commons](#)

## NSUWorks Citation

Thio, Chloe L.; David L. Thomas; Peter Karacki; Xiaojiang Gao; Darlene Marti; Richard A. Kaslow; James J. Goedert; Margaret Hilgartner; Steffanie A. Strathdee; Priya Duggal; Stephen J. O'Brien; Jacquie Astemborski; and Mary Carrington. 2003. "Comprehensive Analysis of Class I and Class II HLA Antigens and Chronic Hepatitis B Virus Infection." *Journal of Virology* 77, (22): 12083-12087. [https://nsuworks.nova.edu/cnso\\_bio\\_facarticles/208](https://nsuworks.nova.edu/cnso_bio_facarticles/208)

This Article is brought to you for free and open access by the Department of Biological Sciences at NSUWorks. It has been accepted for inclusion in Biology Faculty Articles by an authorized administrator of NSUWorks. For more information, please contact [nsuworks@nova.edu](mailto:nsuworks@nova.edu).

---

**Authors**

Chloe L. Thio, David L. Thomas, Peter Karacki, Xiaojiang Gao, Darlene Marti, Richard A. Kaslow, James J. Goedert, Margaret Hilgartner, Steffanie A. Strathdee, Priya Duggal, Stephen J. O'Brien, Jacquie Astemborski, and Mary Carrington

# Comprehensive Analysis of Class I and Class II HLA Antigens and Chronic Hepatitis B Virus Infection

Chloe L. Thio,<sup>1\*</sup> David L. Thomas,<sup>1</sup> Peter Karacki,<sup>1</sup> Xiaojiang Gao,<sup>2</sup> Darlene Marti,<sup>2</sup> Richard A. Kaslow,<sup>3</sup> James J. Goedert,<sup>4</sup> Margaret Hilgartner,<sup>5</sup> Steffanie A. Strathdee,<sup>6</sup> Priya Duggal,<sup>6</sup> Stephen J. O'Brien,<sup>2</sup> Jacquie Astemborski,<sup>1</sup> and Mary Carrington<sup>2</sup>

Department of Medicine<sup>1</sup> and Department of Epidemiology,<sup>6</sup> Johns Hopkins Medical Institutions, Baltimore, Laboratory of Genomic Diversity, National Cancer Institute, Frederick,<sup>2</sup> and Viral Epidemiology Branch, Division of Cancer Epidemiology and Genetics, National Cancer Institute, Rockville,<sup>4</sup> Maryland; Department of Epidemiology, University of Alabama, Birmingham, Alabama<sup>3</sup>; and Department of Pediatrics, New York Presbyterian Hospital-Cornell Medical Center, New York, New York<sup>5</sup>

Received 12 February 2003/Accepted 9 August 2003

Following an acute hepatitis B virus (HBV) infection, clearance or persistence is determined in part by the vigor and breadth of the host immune response. Since the human leukocyte antigen system (HLA) is an integral component of the immune response, we hypothesized that the highly polymorphic *HLA* genes are key determinants of viral clearance. *HLA* class I and II genes were molecularly typed in 194 Caucasian individuals with viral persistence and 342 matched controls who had cleared the virus. A single class I allele, *A\*0301* (odds ratio [OR], 0.47; 95% confidence interval [CI], 0.30 to 0.72;  $P = 0.0005$ ) was associated with viral clearance. The class II allele *DRB1\*1302* was also associated with clearance (OR, 0.42; 95% CI, 0.19 to 0.93;  $P = 0.03$ ), but its significance decreased in a multivariate model that included other alleles associated with disease outcome as covariates. *B\*08* was associated with viral persistence both independently (OR, 1.59; 95% CI, 1.04 to 2.43;  $P = 0.03$ ) and as part of the conserved Caucasian haplotype *A\*01-B\*08-DRB1\*03*. The *B\*44-Cw\*1601* (OR, 2.23; 95% CI, 1.13 to 4.42;  $P = 0.02$ ) and *B\*44-Cw\*0501* (OR, 1.99; 95% CI, 1.22 to 3.24;  $P = 0.006$ ) haplotypes were also associated with viral persistence. Interestingly, both the *B\*08* haplotype and *DR7*, which forms a haplotype with *B\*44-Cw\*1601*, have been associated with nonresponse to the HBV vaccine. The associations with class I alleles are consistent with a previously implicated role for CD8-mediated cytolytic-T-cell response in determining the outcome of an acute HBV infection.

Worldwide, chronic hepatitis B affects an estimated 350 million persons and is the leading cause of cirrhosis and hepatocellular carcinoma (20). Infection with hepatitis B virus (HBV) in adulthood results in viral persistence and development of chronic hepatitis in 5 to 10% of cases, but factors that determine viral persistence or clearance are not well understood. Certain groups of individuals are known to be at increased risk of developing chronic hepatitis B, including those who are human immunodeficiency virus (HIV) seropositive, male, immunosuppressed, and elderly at the time of infection (17). In addition, the host immune response plays a key role in determining the outcome, since a vigorous, polyclonal cytotoxic-T-lymphocyte (CTL) response correlates with viral clearance (9, 25). These immune responses may be genetically determined, since twin and family studies have suggested an inherited component in the development of chronic hepatitis B (3, 21).

The immune response is coordinated by the human leukocyte antigen (HLA) class I and class II molecules, which present foreign antigens to CD8<sup>+</sup> cytolytic T cells and CD4<sup>+</sup> helper T cells, respectively. The genes encoding these molecules are the most polymorphic in the human genome and are

ideal candidates for the investigation of association with HBV outcomes.

*HLA* class II genes have previously been examined with respect to HBV outcomes. The largest study, which was from The Gambia, demonstrated an association between *DRB1\*1302* and viral clearance (31). This finding was replicated in a small study of Caucasian subjects from Germany (16). We and others have noted a diverse array of additional class II associations (1, 28, 32, 33, 35), whose inconsistencies may be due to small, heterogeneous study populations and variability in typing methods (29). Surprisingly, *HLA* class I alleles have never been comprehensively examined despite their critical role in mediating CTL responses. Thus, using a large cohort of Caucasian individuals with well-defined viral clearance or persistence, we molecularly typed *HLA* class I and class II genes to determine associations of their polymorphisms with the outcome of HBV infection.

## MATERIALS AND METHODS

**Study subjects.** Subjects in this study were participants in one of four studies: (i) AIDS Link to Intravenous Experience, which is an ongoing study of 2,921 injection drug users enrolled in Baltimore from February 1988 to March 1989 (34), (ii) the Multicenter Hemophilia Cohort Study (MHCS), which is a prospectively monitored cohort of 2,056 persons with hemophilia, von Willebrand's disease, or a related coagulation disorder from 16 comprehensive hemophilia treatment centers enrolled between 1982 and 1996 (14), (iii) the Hemophilia Growth and Development Study (HGDS) which is a continuing study of 333 children and adolescents with hemophilia enrolled between March 1989 and May

\* Corresponding author. Mailing address: Johns Hopkins University, 1503 E. Jefferson St., Baltimore, MD 21231-1001. Phone: (410) 955-0349. Fax: (410) 614-7564. E-mail: cthio@jhmi.edu.

1990 (15), and (iv) the Multicenter AIDS Cohort Study (MACS), which is an ongoing study of 5,622 homosexual men enrolled in one of four cities in the United States between 1984 and 1985 and between 1987 and 1991, as previously described (10, 18). A nested case-control design was used such that case patients were subjects persistently infected with HBV and controls were subjects who were able to clear the virus. Each case was matched to two controls from the same cohort based on factors that have been associated with HBV outcomes, including age within 10 years, gender, and HIV status. Subjects were eligible to be tested for viral persistence (cases) if they had (i) a baseline positive hepatitis B surface antigen (HBsAg) test, (ii) a second specimen available for testing, and (iii) peripheral blood mononuclear cells available to be transformed into cell lines. Subjects were considered persistently infected with HBV if they tested positive for HBsAg at two visits separated by a minimum of 6 months. Testing for antibodies against hepatitis B core antigen (anti-HBc) and HBsAg (anti-HBs) was performed as needed to exclude primary HBV infection. Individuals with viral clearance (controls) were positive for anti-HBc and anti-HBs without the presence of HBsAg at two time points separated by a minimum of 6 months. HBV status of the HIV-positive subjects was defined before highly active antiretroviral therapy was available. We restricted our study to Caucasian subjects, since numbers representing other ethnic groups were too small to discriminate a significant effect by race (51 black subjects with viral persistence). Informed consent was obtained from all participants, and the study was approved by the institutional review boards at all participating institutions.

**Serologic testing.** All serum specimens were stored at  $-70^{\circ}\text{C}$  until testing for HBV and HIV serology using commercially available kits and manufacturer's specifications.

**HLA typing.** An Epstein-Barr virus-transformed cell line was established for each subject, and DNA was isolated from these cell lines by phenol-chloroform extraction. High-resolution (allele level) *HLA* class I genotyping was carried out by using the standard sequence-specific oligonucleotide (SSO) probe typing protocols developed by the 13th International Histocompatibility Workshop (<http://www.ihwg.org/protocols/protocol.htm>). *HLA-A*, *-B*, and *-C* genes were amplified by using locus-specific PCR primers flanking exons 2 and 3, the polymorphic segments of the class I genes. The 1-kb PCR products were blotted onto nylon membranes and hybridized with a panel of SSO probes. *HLA* alleles were assigned by the reaction patterns of the SSO probes based on known *HLA* sequences. For samples with ambiguous SSO typing results, exons 2 and 3 were sequenced.

Class II molecular typing was done by single-strand conformational polymorphism (7) in combination with PCR-SSO. For PCR-SSO, the protocol was also based on the 13th International Histocompatibility Workshop and primers were designed to amplify exon 2.

**Statistical analysis.** All analyses were performed with SAS version 6.12 (SAS Institute, Cary, N.C.). In order to reduce the number of comparisons with inadequate power, low-frequency alleles ( $<3\%$ ) were not analyzed. Odds ratios (ORs), which reflect the likelihood of a subject's carrying a specific allele if that subject is persistently HBV infected, and *P* values were calculated by using conditional logistic regression. Known haplotypes composed of alleles that were significantly associated with disease outcome (i.e.,  $P \leq 0.05$ ) were also examined by using conditional logistic regression. We further examined all alleles associated with either persistence or clearance ( $P \leq 0.05$ ) using a forward stepwise multivariate analysis. The allele with the lowest *P* value was placed in the model first, and subsequently each allele with a *P* value of  $\leq 0.05$  was manually added to the model. An allele was retained in the model if its *P* value remained  $\leq 0.05$ .

Potential effects of heterozygosity on HBV outcomes were tested separately for the class I and II loci, using conditional logistic regression with the ORs reflecting the likelihood of persistence if heterozygous. Initially, heterozygosity was defined as having nonidentical alleles at all class I loci tested or at all class II loci tested. Subsequently, heterozygosity was examined at each class II locus individually in a univariate analysis. All of the class II loci were included as separate variables in a multivariate model to assess which locus had a stronger association.

## RESULTS

A total of 194 individuals fulfilled our criteria for a persistent HBV infection and were matched to 342 individuals with viral clearance. Of the persistently HBV-infected individuals, 151 (77.8%) came from the MACS cohort, and the remaining 43 came from one of the other three cohorts. Of 46 individuals with viral persistence (30 from the MACS, 12 from the HGDS,

TABLE 1. *HLA* alleles associated with HBV clearance and persistence and their known haplotypes

Allele or haplotype	Frequency (%) in subjects with:		OR	95% CI	<i>P</i>
	Clearance ( <i>n</i> = 342)	Persistence ( <i>n</i> = 194)			
<b>Alleles associated with clearance</b>					
<i>A*0301</i>	15.7	8.1	0.47	0.30–0.72	0.0005
<i>DRB1*1302</i>	4.9	2.1	0.42	0.19–0.93	0.03
<b>Alleles associated with persistence</b>					
<i>B*08</i>	8.1	12.2	1.59	1.04–2.43	0.03
<i>B*44</i>	11.9	19.4	1.82	1.27–2.60	0.001
<i>Cw*0501</i>	6.8	12.1	1.81	1.16–2.82	0.009
<i>Cw*1601</i>	2.4	5.3	2.14	1.09–4.18	0.03
<i>DQB1*0201</i>	20.1	27.8	1.56	1.15–2.09	0.004
<i>DRB1*0301</i>	9.6	15.1	1.66	1.13–2.42	0.009
<b>Haplotype from alleles associated with clearance</b>					
<i>A*0301-B*07</i>	6.1	4.0	0.64	0.34–1.19	0.16
<b>Haplotypes from alleles associated with persistence</b>					
<i>A*0101-B*08-DQA1*0501-DQB1*0201-DRB1*0301</i>	5.3	8.0	1.58	0.93–2.68	0.09
<i>B*44-Cw*1601</i>	2.4	5.4	2.23	1.13–4.42	0.02
<i>B*44-Cw*0501</i>	5.3	10.4	1.99	1.22–3.24	0.006
<i>B*44-DRB1*0701</i>	4.6	7.8	1.83	1.06–3.15	0.03
<i>B*44-Cw*1601-DRB1*0701</i>	2.0	4.3	2.21	1.04–4.71	0.04

1 from the MHCS, and 3 from AIDS Link to Intravenous Experience), only one control subject met the selection criteria. Although matching criteria allowed a 10-year age difference, 95% of the controls matched cases within a 5-year range, and the mean ages of the cases and controls were similar, 30.7 and 30.5 years, respectively. In addition, the groups were similar with respect to the other matching criteria, with 99% being male and 69% being HIV seropositive.

**Associations with viral clearance.** HBV clearance was associated with only one class I allele, *HLA-A\*0301*, with an OR of 0.47 and a 95% confidence interval (95% CI) of 0.30 to 0.72 ( $P = 0.0005$ ) (Table 1). The *A\*0301* association appeared to be codominant, since the presence of two *A\*0301* alleles was more protective than a single copy (Mantel-Haenszel test for trend,  $P = 0.0007$ ). This allele appeared protective in each cohort, but protection was significant only in members of the MACS, the largest cohort in the study. Of the 13 individuals homozygous for *A\*0301*, 11 experienced viral clearance. The known *A\*0301-B\*07* haplotype was not significantly associated with viral clearance ( $P = 0.16$ ). In a multivariate model, which included the alleles associated with persistence (see below), the OR for *A\*0301* was unchanged ( $P = 0.0008$ ) (Table 2).

An analysis of the class II loci showed an association of the allele *DRB1\*1302* with viral clearance (OR, 0.42; 95% CI, 0.19 to 0.93;  $P = 0.03$ ). However, when *DRB1\*1302* was added to

TABLE 2. Final multivariate model combining alleles associated with clearance and persistence with a *P* value of <0.05 from univariate analysis<sup>a</sup>

Allele	OR	95% CI	<i>P</i>
<i>B*08</i>	1.66	1.08–2.55	0.02
<i>B*44</i>	1.81	1.25–2.60	0.002
<i>A*0301</i>	0.47	0.30–0.73	0.0008
<i>DRB1*1302</i>	0.46	0.21–1.04	0.06

<sup>a</sup> *DRB1\*1302* was borderline significant but has previously been associated with HBV clearance; thus, it is presented here in the final model. Alleles considered in the multivariate model include all alleles significant in univariate analysis, specifically, *A\*0301*, *DRB1\*1302*, *B\*08*, *B\*44*, *Cw\*0501*, *Cw\*1601*, *DQB1\*0201*, *DRB1\*0301*.

the multivariate model the OR was stable (0.46), but it was borderline significant (*P* = 0.06) (Table 2).

**Associations with viral persistence.** Four class I alleles were associated with viral persistence: *B\*08* (OR, 1.59; 95% CI, 1.04 to 2.43; *P* = 0.03), *B\*44* (includes *HLA-B\*4402* and *HLA-B\*4403*) (OR, 1.82; 95% CI, 1.27 to 2.60; *P* = 0.001), *Cw\*0501* (1.81; 95% CI, 1.16 to 2.82; *P* = 0.009), and *Cw\*1601* (OR, 2.14; 95% CI, 1.09 to 4.18; *P* = 0.03) (Table 1). In addition, two class II alleles, *DQB1\*0201* (OR, 1.56; 95% CI, 1.15 to 2.09; *P* = 0.004) and *DRB1\*0301* (OR, 1.66; 95% CI, 1.13 to 2.42; *P* = 0.009), were associated with viral persistence. In the multivariate model, which included alleles associated with viral clearance, only *B\*08* (*P* = 0.02) and *B\*44* (*P* = 0.002) were retained (Table 2).

The two class II alleles significant in the univariate analysis along with *B\*08* are often inherited as the conserved haplotype *A\*01-B\*08-DRB1\*0301-DQA1\*0501-DQB1\*0201*. The association of this haplotype with viral persistence was similar in magnitude to the individual associations of *B\*08*, *DQB1\*0201*, and *DRB1\*0301* (OR, 1.58; 95% CI, 0.93 to 2.68; *P* = 0.09). In order to determine whether *B\*08* or either of these class II alleles had the stronger association, we excluded people with the haplotype and tested the associations of *B\*08*, *DQB1\*0201*, and *DRB1\*0301* individually. *B\*08* alone was the most predictive (OR, 2.03) of persistence compared to *DQB1\*0201* (OR, 1.42) and *DRB1\*0301* (OR, 1.40), concurring with the results of the multivariate analysis.

*B\*44* forms a haplotype with two of the other alleles associated with viral persistence, *Cw\*0501* and *Cw\*1601*. The association of *B\*44-Cw\*0501* (OR, 1.99; *P* = 0.006) and *B\*44-Cw\*1601* (OR, 2.23; *P* = 0.02) with viral persistence was similar in magnitude to that of the individual alleles. The extended haplotype *B\*44-Cw\*1601-DRB1\*0701* was also associated with viral persistence (OR, 2.21; *P* = 0.04). *Cw\*1601* was observed only in the presence of *B\*44*, so it was not possible to examine its effects independent of *B\*44*. However, the strength of the *B\*44* association among individuals without either *C* allele was weaker (OR, 1.10). The same was also true of the association of *Cw\*0501* among individuals without *B\*44* (OR, 1.72).

**HLA heterozygosity and HBV outcomes.** We tested the hypothesis that being fully heterozygous at the *HLA* class I or II loci is advantageous for viral clearance since, on average, heterozygotes are expected to present a wider array of antigenic epitopes to the T cells (13). There was no protection due to complete class I heterozygosity defined either by the two-digit

TABLE 3. Association of HLA class I and class II heterozygosity and hepatitis B virus outcomes

	Frequency (%) of all heterozygous subjects with <sup>a</sup> :		OR	95% CI	<i>P</i>
	Clearance ( <i>n</i> = 342)	Persistence ( <i>n</i> = 194)			
Class I					
2-digit nomenclature	74.9	70.0	0.76	0.50–1.14	0.18
4-digit nomenclature	79.5	73.8	0.69	0.45–1.07	0.10
Class II					
Univariate					
<i>DQA1</i>	81.6	76.2	0.70	0.44–1.01	0.12
<i>DQB1</i>	86.9	78.8	0.50	0.31–0.83	0.008
<i>DRB1</i>	91.4	86.9	0.56	0.32–1.00	0.05
Multivariate					
<i>DQA1</i>	NA	NA	1.12	0.58–2.14	0.74
<i>DQB1</i>	NA	NA	0.50	0.26–2.14	0.05
<i>DRB1</i>	NA	NA	0.80	0.34–1.89	0.61

<sup>a</sup> NA, not applicable.

(serological equivalent) (OR, 0.76; 95% CI, 0.50 to 1.14; *P* = 0.18) or the four-digit (high-resolution) nomenclature (OR, 0.69; 95% CI, 0.45 to 1.07; *P* = 0.10) (Table 3). On the other hand, viral clearance was more common among individuals who were heterozygous at all class II loci (OR, 0.62; 95% CI, 0.40 to 0.95; *P* = 0.03). Next, potential confounding effects of *HLA-DQB1\*0201* and *HLA-DRB1\*0301*, class II alleles associated with viral persistence, were excluded by removing individuals with these alleles from the zygosity analysis. The protective effect of heterozygosity on viral clearance was independently significant (OR, 0.41; 95% CI, 0.19 to 0.85; *P* = 0.02). Heterozygosity at *DQB1* was most strongly associated with viral clearance in a univariate analysis of individual class II loci (OR, 0.50; 95% CI, 0.31 to 0.83; *P* = 0.008) and in a multivariate model of all class II loci (Table 3).

## DISCUSSION

In this comprehensive study of *HLA* class I and class II genetic effects on the outcome of HBV infection in Caucasians, *A\*0301* and *DRB1\*1302* were associated with a 2-fold increase in HBV clearance, whereas *B\*08* and two *B\*44* haplotypes were associated with a >1.5-fold increase in viral persistence. It is notable that overall, the class I alleles have the strongest associations, suggesting that the CD8<sup>+</sup> CTLs are important in determining viral clearance or persistence. These findings concur with the recent demonstration that chimpanzees acutely infected with HBV and then depleted of CD8<sup>+</sup> T cells were unable to eliminate the virus (27).

*B\*08* and its extended haplotype (*A1-B8-DR3-DQ2*) have been associated with other immune-mediated diseases, including autoimmune hepatitis (22, 24). In 57 to 88% of those instances, *B\*08* is observed on this haplotype (24). Here, *B\*08* appeared to be more predictive of outcome than the other alleles in the haplotype. Functional studies of individuals with the *A\*01-B\*08-DR3* haplotype have suggested a defect in early T-cell activation (5) and decreased production of type 1 cytokines, including interleukin 2, gamma interferon, and interleukin 12 (4). Decreased natural killer cell activity has also been

noted in people with this haplotype (8). However, neither the mechanism nor the precise gene responsible for these findings has been elucidated, thus retaining the possibility that *B\*08* may be at least partly responsible for these phenotypes.

Although *B\*44* on haplotypes with both *Cw\*1601* and *Cw\*0501* was associated with viral persistence, *B\*44* in the absence of *Cw\*1601* and *Cw\*0501* was not. The stronger association with the haplotypes may indicate that these alleles are simply markers of the true disease allele through linkage disequilibrium. The *B\*44-Cw\*1601* haplotype often includes the class II allele *DRB1\*0701*, whose serological equivalent (*DR7*) has been associated with viral persistence in a small study from Qatar (1). However, in our study, *DRB1\*0701* alone was not significantly associated with HBV persistence (OR, 1.23; 95% CI, 0.87 to 1.75;  $P = 0.25$ ).

Poor response to the HBsAg recombinant form of HBV vaccine has been associated with some of the same alleles associated with viral persistence in the present study, suggesting similarities in the immune defect leading to viral persistence and vaccine nonresponsiveness. Several studies have demonstrated nonresponse to HBV vaccine among individuals with the extended *A\*01-B\*08* haplotype (2, 11, 19). *DR7* has also been reported to be associated with nonresponse to hepatitis B vaccine (11, 12, 23). In the one study that examined *HLA-A* and *-B* genes, *B\*44* was more common in nonresponders (40.7%) than in responders (23.9%) (23).

*A\*0301* was significantly associated with viral clearance in a multivariate model. Examination of the A3 supertype, which includes *A\*0301* and other *A* alleles with cross-reactive epitopes (26), indicated that it could not account for the *A\*0301* association. The molecule encoded by *A\*0301* may be particularly efficient at presenting HBV epitopes to the CD8<sup>+</sup> T cells, but functional studies are necessary to confirm this hypothesis.

*DRB1\*1302*, an allele that has been associated with HBV clearance in The Gambia (31), was the only other allele associated with viral clearance here. The borderline significance of this allelic effect in the multivariate analysis may have been a consequence of its low frequency (3.8%). Alternatively, the prominence of this allele in the Gambian study may indicate greater importance in certain ethnic groups or in those who acquire infections in infancy or early childhood.

The association of class II heterozygote advantage confirmed findings for the Gambian cohort (30). The multivariate analysis suggested that the effect of class II heterozygosity is due primarily to the *DQB1* locus. Class I zygosity may also be predictive of outcome to HBV infection, and our failure to detect such an association may reflect insufficient statistical power.

There are three primary limitations to this study. First, Bonferroni correction for multiple comparisons would have excluded all but the association of *A\*0301* with viral clearance. However, that statistical maneuver for genetic association studies is controversial; its conservative overcorrection likely leads to type II error (6). Our multivariate analysis, not performed in previous HLA studies, highlighted the alleles that are independently associated with either viral clearance or persistence and strengthens our univariate findings. Furthermore, the biologic plausibility of those associations linked to vaccine nonresponsiveness makes them worthy of further in-

vestigation. Second, despite the large sample size, we had limited power to detect associations with very-low-frequency alleles. Third, we combined several cohorts in this study and acknowledge that we did not have the power to test each allele individually in each cohort. Thus, the associations we detected may not apply to every population and we may also have missed associations that are operative only in certain populations. Further research, such as by replication in another cohort, is needed to confirm our findings.

The data reported herein support a role for *HLA* molecules, particularly class I, in determining the outcome of a HBV infection and may provide clues regarding the pathogenesis of HBV infection. Functional studies are needed to understand the basis for these associations and the link between the genes associated both with viral persistence and with nonresponse to the HBV vaccine.

#### ACKNOWLEDGMENTS

This work was supported by NIH grants DA00441, DA04334, and DA13324. C.L.T. was additionally supported, in part, by the Investigators in the Pathogenesis of Infectious Diseases Award from the Burroughs Wellcome Fund. The MACS is funded by the National Institute of Allergy and Infectious Diseases, with additional supplemental funding from the National Cancer Institute: UO1-AI-35042, 5-MO1-RR-00722 (GCRC), UO1-AI-35043, UO1-AI-37984, UO1-AI-35039, UO1-AI-35040, UO1-AI-37613, UO1-AI-35041. The HGDS is supported by the Bureau of Maternal and Child Health and Resources Development (MCJ-060570), the National Institute of Child Health and Human Development (NO1-HD-4-3200), the Centers for Disease Control and Prevention, and the National Institute of Mental Health. Additional support was provided by grants from the National Center for Research Resources of the National Institutes of Health to the New York Hospital-Cornell Medical Center Clinical Research Center (MO1-RR06020), the Mount Sinai General Clinical Research Center, New York (MO1-RR00071), the University of Iowa Clinical Research Center (MO1-RR00059), and the University of Texas Health Science Center, Houston (MO1-RR02558). The MHCS is supported by National Cancer Institute contract NO1-CP-33002 with Research Triangle Institute. This project was funded in whole or in part with federal funds from the National Cancer Institute, National Institutes of Health, under contract no. NO1-CO-56000.

We thank Karen Nolt for technical assistance, the participants in the study for making this work possible, and Abbott Laboratories for donating HBsAg and anti-HBs kits.

#### REFERENCES

- Almarri, A., and J. R. Batchelor. 1994. HLA and hepatitis B infection. *Lancet* **344**:1194-1195.
- Alper, C. A., M. S. Kruskall, D. Marcus-Bagley, D. E. Craven, A. J. Katz, S. Brink, J. Dienstag, Z. Awdeh, and E. J. Yunis. 1989. Genetic prediction of nonresponse to hepatitis B vaccine. *N. Engl. J. Med.* **321**:708-712.
- Blumberg, B. S., J. S. Friedlaender, A. Woodside, A. I. Sutnick, and W. T. London. 1969. Hepatitis and Australia antigen: autosomal recessive inheritance of susceptibility to infection in humans. *Proc. Natl. Acad. Sci. USA* **62**:1108-1115.
- Candore, G., D. Cigna, F. Gervasi, A. T. Colucci, M. A. Modica, and C. Caruso. 1994. In vitro cytokine production by HLA-B8, DR3 positive subjects. *Autoimmunity* **18**:121-132.
- Candore, G., D. Cigna, M. Todaro, R. De Maria, G. Stassi, C. Giordano, and C. Caruso. 1995. T-cell activation in HLA-B8, DR3-positive individuals. Early antigen expression defect in vitro. *Hum. Immunol.* **42**:289-294.
- Cardon, L. R., and J. I. Bell. 2001. Association study designs for complex diseases. *Nat. Rev. Genet.* **2**:91-99.
- Carrington, M., T. Miller, M. White, B. Gerrard, C. Stewart, M. Dean, and D. Mann. 1992. Typing of HLA-DQA1 and DQB1 using DNA single-stranded conformational polymorphism. *Hum. Immunol.* **33**:208-212.
- Caruso, C., G. Candore, A. T. Colucci, D. Cigna, M. A. Modica, G. Tantillo, and A. Salerno. 1993. Natural killer and lymphokine-activated killer activity in HLA-B8, DR3-positive subjects. *Hum. Immunol.* **38**:226-230.
- Chisari, F. V. 1997. Cytotoxic T cells and viral hepatitis. *J. Clin. Invest.* **99**:1472-1477.

10. Chmiel, J. S., R. Detels, R. A. Kaslow, M. Van Raden, L. A. Kingsley, and R. Brookmeyer. 1987. Factors associated with prevalent human immunodeficiency virus (HIV) infection in the Multicenter AIDS Cohort Study. *Am. J. Epidemiol.* **126**:568–577.
11. Craven, D. E., Z. L. Awdeh, L. M. Kunches, E. J. Yunis, J. Dienstag, B. Werner, F. Polk, D. R. Snyderman, R. Platt, C. S. Crumpacker, G. F. Grady, and C. A. Alper. 1986. Nonresponsiveness to hepatitis B vaccine in health care workers. *Ann. Intern. Med.* **105**:356–360.
12. Desombere, I., A. Willems, and G. Leroux-Roels. 1998. Response to hepatitis B vaccine: multiple HLA genes are involved. *Tissue Antigens* **51**:593–604.
13. Doherty, P. C., and R. M. Zinkernagel. 1975. Enhanced immunological surveillance in mice heterozygous at the H-2 gene complex. *Nature* **256**:50–52.
14. Goedert, J. J., C. M. Kessler, L. M. Aledort, et al. 1989. A prospective study of human immunodeficiency virus type 1 infection and the development of AIDS in subjects with hemophilia. *N. Engl. J. Med.* **321**:1141–1148.
15. Hilgartner, M. W., S. M. Donfield, A. Willoughby, C. F. Contant, Jr., B. L. Evatt, E. D. Gomperts, W. K. Hoots, J. Jason, K. A. Loveland, and S. M. McKinlay. 1993. Hemophilia growth and development study. Design, methods, and entry data. *Am. J. Pediatr. Hematol. Oncol.* **15**:208–218.
16. Hohler, T., G. Gerken, A. Notghi, R. Lubjuhn, H. Taheri, U. Protzer, H. F. Lohr, P. M. Schneider, K. H. Meyer zum Buschenfelde, and C. Rittner. 1997. HLA-DRB1\*1301 and \*1302 protect against chronic hepatitis B. *J. Hepatol.* **26**:503–507.
17. Hyams, K. 1995. Risks of chronicity following acute hepatitis B virus infection: a review. *Clin. Infect. Dis.* **20**:992–1000.
18. Kaslow, R. A., D. G. Ostrow, R. Detels, J. P. Phair, B. F. Polk, and C. R. Rinaldo. 1987. The Multicenter AIDS Cohort Study: rationale, organization, and selected characteristics of the participants. *Am. J. Epidemiol.* **126**:310–318.
19. Kruskall, M. S., C. A. Alper, Z. Awdeh, E. J. Yunis, and D. Marcus-Bagley. 1992. The immune response to hepatitis B vaccine in humans: inheritance patterns in families. *J. Exp. Med.* **175**:495–502.
20. Lee, W. M. 1997. Medical progress—hepatitis B virus infection. *N. Engl. J. Med.* **337**:1733–1745.
21. Lin, T. M., C. J. Chen, and M. M. Wu. 1989. Hepatitis B virus markers in Chinese twins. *Anticancer Res.* **9**:737–742.
22. Manns, M. P., and M. Kruger. 1994. Immunogenetics of chronic liver disease. *Gastroenterology* **106**:1676–1697.
23. McDermott, A. B., J. N. Zuckerman, C. A. Sabin, S. G. Marsh, and J. A. Madrigal. 1997. Contribution of human leukocyte antigens to the antibody response to hepatitis B vaccination. *Tissue Antigens* **50**:8–14.
24. Price, P., C. Witt, R. Allcock, D. Sayer, M. Garlepp, C. C. Kok, M. French, S. Mallal, and F. Christiansen. 1999. The genetic basis for the association of the 8.1 ancestral haplotype (A1, B8, DR3) with multiple immunopathological diseases. *Immunol. Rev.* **167**:257–274.
25. Rehmann, B., P. Fowler, J. Sidney, J. Person, A. Redeker, M. Brown, B. Moss, A. Sette, and F. V. Chisari. 1995. The cytotoxic T lymphocyte response to multiple hepatitis B virus polymerase epitopes during and after acute viral hepatitis. *J. Exp. Med.* **181**:1047–1058.
26. Sidney, J., H. M. Grey, R. T. Kubo, and A. Sette. 1996. Practical, biochemical and evolutionary implications of the discovery of HLA class I supermotifs. *Immunol. Today* **17**:261–266.
27. Thimme, R., S. Wieland, C. Steiger, J. Ghreyeb, K. A. Reimann, R. H. Purcell, and F. V. Chisari. 2003. CD8<sup>+</sup> T cells mediate viral clearance and disease pathogenesis during acute hepatitis B virus infection. *J. Virol.* **77**:68–76.
28. Thio, C. L., M. Carrington, S. J. O'Brien, D. Vlahov, K. E. Nelson, J. A. Astemborski, and D. L. Thomas. 1999. The association of HLA alleles and clearance of hepatitis B among African Americans. *J. Infect. Dis.* **179**:1004–1006.
29. Thio, C. L., D. L. Thomas, and M. Carrington. 2000. Chronic viral hepatitis and the human genome. *Hepatology* **31**:819–827.
30. Thursz, M., H. C. Thomas, B. M. Greenwood, and A. V. S. Hill. 1997. Heterozygote advantage for HLA class-II type in hepatitis B virus infection. *Nat. Genet.* **17**:11–12.
31. Thursz, M. R., D. Kwiatkowski, C. E. M. Allsopp, B. M. Greenwood, H. C. Thomas, and A. V. S. Hill. 1995. Association between an MHC class II allele and clearance of hepatitis B virus in The Gambia. *N. Engl. J. Med.* **332**:1065–1069.
32. Van Hattum, J., G. M. Schreuder, and S. W. Schalm. 1987. HLA antigens in patients with various courses after hepatitis B virus infection. *Hepatology* **7**:11–14.
33. Verdon, R., S. Pol, P. Landais, B. Mattlinger, F. Carnot, C. Brechot, M. Busson, and H. Kreis. 1994. Absence of association between HLA antigens and chronicity of viral hepatitis in haemodialyzed patients. *J. Hepatol.* **21**:388–393.
34. Vlahov, D., J. C. Anthony, A. Munoz, J. Margolick, K. E. Nelson, D. D. Celentano, L. Solomon, and B. F. Polk. 1991. The ALIVE study, a longitudinal study of HIV-1 infection in intravenous drug users: description of methods and characteristics of participants. *NIDA Res. Monogr.* **109**:75–100.
35. Zavaglia, C., C. Bortolon, G. Ferrioli, A. Rho, L. Mondazzi, R. G. A. Bottelli, F. Gelosa, G. Iamoni, and G. Ideo. 1996. HLA typing in chronic type B, D and C hepatitis. *J. Hepatol.* **24**:658–665.