



(12) **DEMANDE DE BREVET CANADIEN**
CANADIAN PATENT APPLICATION

(13) **A1**

(86) Date de dépôt PCT/PCT Filing Date: 2020/06/18
(87) Date publication PCT/PCT Publication Date: 2020/12/24
(85) Entrée phase nationale/National Entry: 2021/12/09
(86) N° demande PCT/PCT Application No.: IB 2020/055709
(87) N° publication PCT/PCT Publication No.: 2020/255018
(30) Priorité/Priority: 2019/06/18 (EP19180926.8)

(51) Cl.Int./Int.Cl. *A61K 39/12* (2006.01),
A61K 39/29 (2006.01), *A61K 39/295* (2006.01),
A61P 31/20 (2006.01)
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(54) Titre : VACCINS CONTRE LE VIRUS DE L'HEPATITE B (VHB) ET UTILISATIONS ASSOCIEES
(54) Title: HEPATITIS B VIRUS (HBV) VACCINES AND USES THEREOF

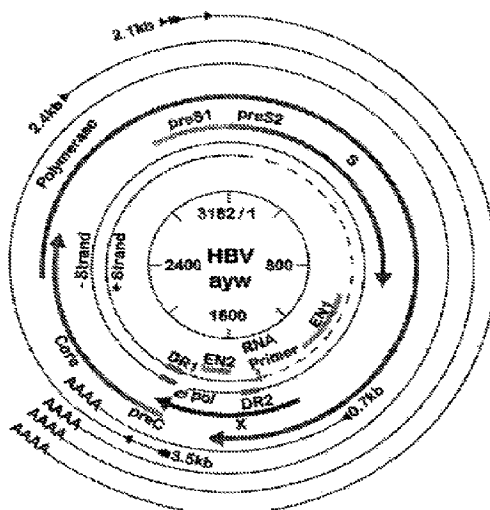


FIG 1A

(57) **Abrégé/Abstract:**

Polynucleotides encoding hepatitis B virus (HBV) surface antigens, and related combinations are described. Also described are vectors, such as DNA plasmids or viral vectors, expressing the HBV surface antigens, and immunogenic compositions containing the expression vectors. Methods of inducing an immune response against HBV or treating an HBV-induced disease, particularly in individuals having chronic HBV infection, using the immunogenic compositions are also described.

Date Submitted: 2021/12/09

CA App. No.: 3141238

Abstract:

Polynucleotides encoding hepatitis B virus (HBV) surface antigens, and related combinations are described. Also described are vectors, such as DNA plasmids or viral vectors, expressing the HBV surface antigens, and immunogenic compositions containing the expression vectors. Methods of inducing an immune response against HBV or treating an HBV-induced disease, particularly in individuals having chronic HBV infection, using the immunogenic compositions are also described.

TITLE OF THE INVENTION**Hepatitis B Virus (HBV) Vaccines and Uses Thereof****CROSS REFERENCE TO RELATED APPLICATION**

5 This application claims priority to European Application No. EP19180926.8 filed on June 18, 2019, the disclosure of which is incorporated herein by reference in its entirety.

REFERENCE TO SEQUENCE LISTING SUBMITTED ELECTRONICALLY

10 This application contains a sequence listing, which is submitted electronically via EFS-Web as an ASCII formatted sequence listing with a file name "Sequence Listing" and a creation date of June 11, 2020 and having a size of 57.6 kb. The sequence listing submitted via EFS-Web is part of the specification and is herein incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

15 Hepatitis B virus (HBV) is a small 3.2-kb hepatotropic DNA virus that encodes four open reading frames and seven proteins. About two billion people are infected with HBV, and approximately 240 million people have chronic hepatitis B infection (chronic HBV), characterized by persistent virus and subvirus particles in the blood for more than 6 months (1). Persistent HBV infection leads to T-cell exhaustion in circulating and intrahepatic HBV-specific
20 CD4+ and CD8+ T-cells through chronic stimulation of HBV-specific T-cell receptors with viral peptides and circulating antigens. As a result, T-cell polyfunctionality is decreased (i.e., decreased levels of IL-2, tumor necrosis factor (TNF)- α , IFN- γ , and lack of proliferation). A safe and effective prophylactic vaccine against HBV infection has been available since the 1980s and is the mainstay of hepatitis B prevention (3). The World Health Organization
25 recommends vaccination of all infants, and, in countries where there is low or intermediate hepatitis B endemicity, vaccination of all children and adolescents (<18 years of age), and of people of certain at-risk population categories. Due to vaccination, worldwide infection rates have dropped dramatically. However, prophylactic vaccines do not cure established HBV infection.

30 Chronic HBV is currently treated with IFN- α and nucleoside or nucleotide analogs, but there is no ultimate cure due to the persistence in infected hepatocytes of an intracellular viral replication intermediate called covalently closed circular DNA (cccDNA), which plays a fundamental role as a template for viral RNAs, and thus new virions. It is thought that induced

virus-specific T-cell and B-cell responses can effectively eliminate cccDNA-carrying hepatocytes. Current therapies targeting the HBV polymerase suppress viremia, but offer limited effect on cccDNA that resides in the nucleus and related production of circulating antigen. The most rigorous form of a cure may be elimination of HBV cccDNA from the organism, which has
5 neither been observed as a naturally occurring outcome nor as a result of any therapeutic intervention. However, loss of HBV surface antigens (HBsAg) is a clinically credible equivalent of a cure, since disease relapse can occur only in cases of severe immunosuppression, which can then be prevented by prophylactic treatment. Thus, at least from a clinical standpoint, loss of HBsAg is associated with the most stringent form of immune reconstitution against HBV.

10 For example, immune modulation with pegylated interferon (pegIFN)- α has proven better in comparison to nucleoside or nucleotide therapy in terms of sustained off-treatment response with a finite treatment course. Besides a direct antiviral effect, IFN- α is reported to exert epigenetic suppression of cccDNA in cell culture and humanized mice, which leads to reduction of virion productivity and transcripts (4). However, this therapy is still fraught with side-effects
15 and overall responses are rather low, in part because IFN- α has only poor modulatory influences on HBV-specific T-cells. In particular, cure rates are low ($< 10\%$) and toxicity is high. Likewise, direct acting HBV antivirals, namely the HBV polymerase inhibitors entecavir and tenofovir, are effective as monotherapy in inducing viral suppression with a high genetic barrier to emergence of drug resistant mutants and consecutive prevention of liver disease progression.
20 However, cure of chronic hepatitis B, defined by HBsAg loss or seroconversion, is rarely achieved with such HBV polymerase inhibitors. Therefore, these antivirals in theory need to be administered indefinitely to prevent reoccurrence of liver disease, similar to antiretroviral therapy for human immunodeficiency virus (HIV).

Therapeutic vaccination has the potential to eliminate HBV from chronically infected
25 patients (5). Many strategies have been explored, but to date therapeutic vaccination has not proven successful.

BRIEF SUMMARY OF THE INVENTION

Accordingly, there is an unmet medical need in the treatment of hepatitis B virus (HBV),
30 particularly chronic HBV, for a finite well-tolerated treatment with a higher cure rate. The invention satisfies this need by providing immunogenic compositions and methods for inducing an immune response against hepatitis B virus (HBV) infection. The immunogenic compositions and methods of the invention can be used to provide therapeutic immunity to a subject, such as a subject having chronic HBV infection.

In a general aspect, the application relates to a non-naturally occurring nucleic acid molecule comprising a polynucleotide sequence encoding an HBV surface antigen.

In an embodiment, provided is a non-naturally occurring nucleic acid molecule comprising a first polynucleotide sequence encoding a first HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to the amino acid sequence of SEQ ID NO: 29.

In an embodiment, provided is a non-naturally occurring nucleic acid molecule comprising a first polynucleotide sequence encoding a first HBV surface antigen consisting of the amino acid sequence of SEQ ID NO: 29.

In an embodiment, provided is a non-naturally occurring nucleic acid molecule comprising a first polynucleotide sequence that is at least 90% identical to the polynucleotide sequence of SEQ ID NO: 28.

In an embodiment, provided is a non-naturally occurring nucleic acid molecule comprising a first polynucleotide sequence consisting of the polynucleotide sequence of SEQ ID NO: 28.

In an embodiment, provided is a non-naturally occurring nucleic acid molecule comprising a first polynucleotide sequence encoding a first HBV surface antigen and further comprising a polynucleotide sequence encoding a signal sequence operably linked to the first HBV surface antigen. In some embodiments, the signal sequence comprises the amino acid sequence of SEQ ID NO: 6 or SEQ ID NO: 19, preferably the signal sequence is encoded by the polynucleotide sequence of SEQ ID NO: 5 or SEQ ID NO: 19.

In an embodiment, provided is a non-naturally occurring nucleic acid molecule comprising a second polynucleotide sequence encoding a second HBV surface antigen consisting of an amino acid sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 27.

In an embodiment, provided is a non-naturally occurring nucleic acid molecule comprising a second polynucleotide sequence encoding a second HBV surface antigen consisting of the amino acid sequence of SEQ ID NO: 27.

In an embodiment, provided is a non-naturally occurring nucleic acid molecule comprising a second polynucleotide sequence that is at least 90% identical to the polynucleotide sequence of SEQ ID NO: 26.

In an embodiment, provided is a non-naturally occurring nucleic acid molecule comprising a second polynucleotide sequence consisting of the polynucleotide sequence of SEQ ID NO: 26.

In an embodiment, provided is a non-naturally occurring nucleic acid molecule comprising a second polynucleotide sequence encoding a second HBV surface antigen and further comprising a polynucleotide sequence encoding a signal sequence operably linked to the second HBV surface antigen. In some embodiments, the signal sequence comprises the amino acid sequence of SEQ ID NO: 6 or SEQ ID NO: 19, preferably the signal sequence is encoded by the polynucleotide sequence of SEQ ID NO: 5 or SEQ ID NO: 18.

In an embodiment, provided is a non-naturally occurring nucleic acid molecule as described herein, further comprising a promoter sequence, optionally one or more additional regulatory sequences, preferably the promoter sequence comprises the polynucleotide sequence of SEQ ID NO: 7, and the additional regulatory sequence is selected from the group consisting of SEQ ID NO: 8 or SEQ ID NO: 23, and a polyadenylation signal sequence of SEQ ID NO: 11 or SEQ ID NO: 24.

In an embodiment, provided is a vector comprising a non-naturally occurring nucleic acid molecule as described herein.

In an embodiment, provided is a vector comprising a non-naturally occurring nucleic acid molecule comprising, from 5' end to 3' end, a promoter sequence, an enhancer sequence, a signal peptide coding sequence, the first polynucleotide sequence, and a polyadenylation signal sequence, optionally, the non-naturally occurring nucleic acid molecule further comprises the second polynucleotide sequence.

In some embodiments, a vector is a plasmid DNA vector, and the plasmid DNA vector further comprises an origin of replication and an antibiotic resistance gene.

In some embodiments, provided is a plasmid DNA vector containing an origin of replication comprising the polynucleotide sequence of SEQ ID NO: 10, an antibiotic resistance gene comprising the polynucleotide sequence of SEQ ID NO: 12, a promoter sequence comprising the polynucleotide sequence of SEQ ID NO: 7, an enhancer sequence comprising the polynucleotide sequence of SEQ ID NO: 8, a signal peptide coding sequence comprising the polynucleotide sequence of SEQ ID NO: 5, a first polynucleotide sequence comprising the polynucleotide sequence of SEQ ID NO: 28, and a polyadenylation signal sequence comprising the polynucleotide sequence of SEQ ID NO: 11.

In some embodiments, a vector is an adenoviral vector, preferably an Ad26 or Ad35 vector.

In another general aspect, the application relates to non-naturally occurring (e.g., recombinant or isolated) HBV surface antigen.

In an embodiment, provided is a non-naturally occurring first HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to the amino acid sequence of SEQ ID NO: 29.

5 In an embodiment, provided is a non-naturally occurring first HBV surface antigen consisting of the amino acid sequence of SEQ ID NO: 29.

In an embodiment, provided is a non-naturally occurring second HBV surface antigen consisting of the amino acid sequence of SEQ ID NO: 27.

In another general aspect, the application relates to host cells comprising a non-naturally occurring nucleic acid molecule and/or vector as described herein.

10 In another general aspect, the application relates to a composition comprising a non-naturally occurring nucleic acid molecule, a vector, a non-naturally occurring first HBV surface antigen, and/or a non-naturally occurring second HBV surface antigen as described herein, and a pharmaceutically acceptable carrier.

15 In an embodiment, provided is a composition comprising a first non-naturally occurring nucleic acid molecule comprising a first polynucleotide encoding a first HBV surface antigen as described herein, a second non-naturally occurring nucleic acid molecule comprising a second polynucleotide encoding a second HBV surface antigen as described herein, and a pharmaceutically acceptable carrier, wherein the first and second polynucleotides are not comprised in the same nucleic acid molecule or in the same nucleic acid vector.

20 In another general aspect, the application relates to a vaccine combination.

In an embodiment, provided is a vaccine combination comprising:

- (a) a first non-naturally occurring nucleic acid molecule comprising a first polynucleotide encoding a first HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to the amino acid sequence of SEQ ID NO: 29;
 - 25 (b) a second non-naturally occurring nucleic acid molecule comprising a second polynucleotide encoding a second HBV surface antigen consisting of an amino acid sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 27; and
 - (c) a pharmaceutically acceptable carrier,
- 30 wherein the first non-naturally occurring nucleic acid molecule and the second non-naturally occurring nucleic acid molecule are present in the same non-naturally occurring nucleic acid molecule or two different non-naturally occurring nucleic acid molecules, preferably in two different non-naturally occurring nucleic acid molecules.

In an embodiment, provided is a vaccine combination, wherein the first HBV surface antigen consists of the amino acid sequence of SEQ ID NO: 29 and the second HBV surface antigen consists of the amino acid sequence of SEQ ID NO: 27.

5 In an embodiment, provided is a vaccine combination, wherein at least one of the first non-naturally occurring nucleic acid molecule and the second non-naturally nucleic acid molecule further comprises a polynucleotide sequence encoding a signal sequence operably linked to at least one of the first HBV surface antigen and the second HBV surface antigen.

10 In an embodiment, provided is a vaccine combination, wherein the signal sequence independently comprises the amino acid sequence of SEQ ID NO: 6 or SEQ ID NO: 19, preferably the signal sequence is independently encoded by the polynucleotide sequence of SEQ ID NO: 5 or SEQ ID NO: 18.

In an embodiment, provided is a vaccine combination, wherein the first polynucleotide sequence is at least 90% identical to SEQ ID NO: 28.

15 In an embodiment, provided is a vaccine combination, wherein the first polynucleotide sequence comprises the polynucleotide sequence of SEQ ID NO: 28.

In an embodiment, provided is a vaccine combination, wherein the second polynucleotide sequence is at least 90% identical to the polynucleotide sequence of SEQ ID NO: 26.

In an embodiment, provided is a vaccine combination, wherein the second polynucleotide sequence comprises the polynucleotide sequence of SEQ ID NO: 26.

20 In an embodiment, provided is a vaccine combination, wherein at least one of the first non-naturally occurring nucleic acid molecule and the second non-naturally nucleic acid molecule further comprises a promoter sequence, optionally an enhancer sequence, and further optionally a polyadenylation signal sequence, preferably the promoter sequence has the polynucleotide sequence of SEQ ID NO: 7 or SEQ ID NO: 25, the enhancer sequence
25 independently has the polynucleotide sequence of SEQ ID NO: 8 or SEQ ID NO: 23, and the polyadenylation signal sequence independently has the polynucleotide sequence of SEQ ID NO: 11 or SEQ ID NO: 24.

30 In an embodiment, provided is a vaccine combination, wherein the first non-naturally occurring nucleic acid molecule is present in a first vector, preferably a first plasmid DNA vector, and the second non-naturally occurring nucleic acid molecule is present in a second vector, preferably a second plasmid DNA vector.

In an embodiment, provided is a vaccine combination, wherein each of the first and second plasmid DNA vectors comprises an origin of replication, an antibiotic resistance gene, and from 5' end to 3' end, a promoter sequence, a regulatory sequence, a signal peptide coding

sequence, the first polynucleotide sequence or the second polynucleotide sequence, and a polyadenylation signal sequence.

In an embodiment, provided is a vaccine combination, wherein the antibiotic resistance gene is a kanamycin resistance gene having a polynucleotide sequence at least 90% identical to the polynucleotide sequence of SEQ ID NO: 12, preferably 100% identical to the polynucleotide sequence of SEQ ID NO: 12.

In an embodiment, provided is a vaccine combination comprising:

(a) a first vector, preferably a first plasmid DNA vector, comprising the promoter sequence comprising the polynucleotide sequence of SEQ ID NO: 25, the regulatory sequence comprising the polynucleotide sequence of SEQ ID NO: 8, the signal peptide coding sequence comprising the polynucleotide sequence of SEQ ID NO: 5, the first polynucleotide sequence comprising the polynucleotide sequence of SEQ ID NO: 28, and the polyadenylation signal sequence comprising the polynucleotide sequence of SEQ ID NO: 11;

(b) a second vector, preferably a second plasmid DNA vector, comprising the promoter sequence comprising the polynucleotide sequence of SEQ ID NO: 25, the regulatory sequence comprising the polynucleotide sequence of SEQ ID NO: 8, the signal peptide coding sequence comprising the polynucleotide sequence of SEQ ID NO: 5, the second polynucleotide sequence comprising the polynucleotide sequence of SEQ ID NO: 26, and the polyadenylation signal sequence comprising the polynucleotide sequence of SEQ ID NO: 11; and

(c) a pharmaceutically acceptable carrier, wherein each of the first plasmid DNA vector and the second plasmid DNA vector further comprises a kanamycin resistance gene having the polynucleotide sequence of SEQ ID NO: 12, and an origin of replication having the polynucleotide sequence of SEQ ID NO: 10, and wherein the first plasmid DNA vector and the second plasmid DNA vector are present in the same composition or two different compositions.

In an embodiment, provided is a vaccine combination further comprising a third non-naturally occurring nucleic acid molecule comprising a third polynucleotide sequence encoding an HBV polymerase antigen comprising an amino acid sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 4.

In an embodiment, provided is a vaccine combination, wherein the HBV polymerase antigen comprises the amino acid sequence of SEQ ID NO: 4.

In an embodiment, provided is a vaccine combination, wherein the third polynucleotide sequence is at least 90% identical to the polynucleotide sequence of SEQ ID NO: 3 or SEQ ID NO: 16, preferably SEQ ID NO: 3.

5 In an embodiment, provided is a vaccine combination, wherein the third polynucleotide sequence comprises the polynucleotide sequence of SEQ ID NO: 3 or SEQ ID NO: 16, preferably SEQ ID NO: 3.

In an embodiment, provided is a vaccine combination, further comprising a fourth non-naturally occurring nucleic acid molecule comprising a fourth polynucleotide sequence encoding a truncated HBV core antigen consisting of the amino acid sequence of SEQ ID NO: 2 or SEQ
10 ID NO: 14.

In an embodiment, provided is a vaccine combination, wherein the fourth polynucleotide sequence is at least 90% identical to the polynucleotide sequence of SEQ ID NO: 1 or SEQ ID NO: 15.

15 In an embodiment, provided is a vaccine combination, wherein the fourth polynucleotide sequence comprises the polynucleotide sequence of SEQ ID NO: 1 or SEQ ID NO: 15.

In an embodiment, provided is a vaccine combination, wherein the third non-naturally occurring nucleic acid molecule and the fourth non-naturally occurring nucleic acid molecule are present in non-naturally occurring nucleic acid molecules separate from the first and second non-naturally occurring nucleic acid molecules.

20 In an embodiment, provided is a vaccine combination, wherein the third non-naturally occurring nucleic acid molecule is present in a third plasmid DNA vector and the fourth non-naturally occurring nucleic acid molecule is present in a fourth plasmid DNA vector.

In an embodiment, provided is a vaccine combination comprising:

25 (a) a first plasmid DNA vector comprising the promoter sequence comprising the polynucleotide sequence of SEQ ID NO: 25, the regulatory sequence comprising the polynucleotide sequence of SEQ ID NO: 8, the signal peptide coding sequence comprising the polynucleotide sequence of SEQ ID NO: 5, the first polynucleotide sequence comprising the polynucleotide sequence of SEQ ID NO: 28, and the polyadenylation signal sequence comprising the polynucleotide sequence of SEQ ID
30 NO: 11;

(b) a second plasmid DNA vector comprising the promoter sequence comprising the polynucleotide sequence of SEQ ID NO: 25, the regulatory sequence comprising the polynucleotide sequence of SEQ ID NO: 8, the signal peptide coding sequence comprising the polynucleotide sequence of SEQ ID NO: 5, the second polynucleotide

sequence comprising the polynucleotide sequence of SEQ ID NO: 26, and the polyadenylation signal sequence comprising the polynucleotide sequence of SEQ ID NO: 11;

(c) a third plasmid DNA vector comprising the promoter sequence comprising the polynucleotide sequence of SEQ ID NO: 7, the regulatory sequence comprising the polynucleotide sequence of SEQ ID NO: 8, the signal peptide coding sequence comprising the polynucleotide sequence of SEQ ID NO: 5, the third polynucleotide sequence comprising the polynucleotide sequence of SEQ ID NO: 3, and the polyadenylation signal sequence comprising the polynucleotide sequence of SEQ ID NO: 11;

(d) a fourth plasmid DNA vector comprising the promoter sequence comprising the polynucleotide sequence of SEQ ID NO: 7, the regulatory sequence comprising the polynucleotide sequence of SEQ ID NO: 8, the signal peptide coding sequence comprising the polynucleotide sequence of SEQ ID NO: 5, the fourth polynucleotide sequence comprising the polynucleotide sequence of SEQ ID NO: 1, and the polyadenylation signal sequence comprising the polynucleotide sequence of SEQ ID NO: 11; and

(e) a pharmaceutically acceptable carrier, wherein each of the first plasmid DNA vector, the second plasmid DNA vector, the third plasmid DNA vector, and the fourth plasmid DNA vector further comprises a kanamycin resistance gene having the polynucleotide sequence of SEQ ID NO: 12, and an origin of replication having the polynucleotide sequence of SEQ ID NO: 10, and

wherein the first plasmid DNA vector, the second plasmid DNA vector, the third plasmid DNA vector, and the fourth plasmid DNA vector are present in the same composition or two or more different compositions.

In another general aspect, the application relates to use of a composition or vaccine combination as described herein for inducing an immune response against HBV or treating a hepatitis B virus (HBV)-induced disease.

In an embodiment, provided is a composition or vaccine combination as described herein for use in inducing an immune response against a hepatitis B virus (HBV) in a subject in need thereof, preferably the subject has chronic HBV infection.

In an embodiment, provided is a combination of another immunogenic agent, preferably another anti-HBV agent, with a composition or vaccine combination as described herein, for use

in inducing an immune response against a hepatitis B virus (HBV) in a subject in need thereof, preferably the subject has chronic HBV infection.

In an embodiment, provided is a composition or vaccine combination as described herein for use in treating a hepatitis B virus (HBV)-induced disease in a subject in need thereof, preferably the subject has chronic HBV infection, and the HBV-induced disease is selected from the group consisting of advanced fibrosis, cirrhosis and hepatocellular carcinoma (HCC).

In an embodiment, provided is a combination of another immunogenic agent, preferably another anti-HBV agent, with a composition or vaccine combination as described herein, for use in treating a hepatitis B virus (HBV)-induced disease in a subject in need thereof, preferably the subject has chronic HBV infection, and the HBV-induced disease is selected from the group consisting of advanced fibrosis, cirrhosis and hepatocellular carcinoma (HCC).

Other aspects, features and advantages of the invention will be apparent from the following disclosure, including the detailed description of the invention and its preferred embodiments and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing summary, as well as the following detailed description of the invention, will be better understood when read in conjunction with the appended drawings. It should be understood that the invention is not limited to the precise embodiments shown in the drawings.

In the drawings:

FIGS. 1A-1E depict the genome, viral particle, and viral life cycle of hepatitis B virus; **FIG. 1A** is a diagram of the genome of hepatitis B virus (HBV); in the native virus, the polymerase protein (Pol) contains the coding sequence for the envelope proteins in a different open reading frame; the envelope proteins (pre-S1, pre-S2, and S) are in the same open reading frame; **FIG. 1B** depicts a portion of the genome of HBV, particularly the coding sequences for the core, polymerase, envelope proteins, and HBx protein; **FIG. 1C** shows a schematic of the structure of an HBV viral particle; the surface antigens L, M, and S proteins are indicated as "L", "M", and "S", respectively; **FIG. 1D** depicts the viral life cycle of HBV; **FIG. 1E** depicts HBV Env or surface antigen transcription; **FIG. 1F** shows a schematic representation of the L-, M-, and S-surface antigen domains and an exemplary HBV surface antigen consensus sequence according to an embodiment of the application (SEQ ID NO: 30); the L-surface antigen domain sequence is indicated in bold/italic/underlined typeface, the M-surface antigen domain sequence is indicated in bold/italic typeface, and the S-surface antigen domain sequence is indicated in underlined typeface; the amino acid sequence of the L-surface antigen is in-frame with the M

and S-surface antigen sequences, such that the L-surface antigen contains the M- and S-surface antigen domains and the M-surface antigen includes the S-surface antigen domain; the L-surface antigen and M-surface antigen are different domains that make up the entire HBV envelope protein or surface antigen in conjunction with the S-surface antigen domain.

FIGS. 2A-2H show the design and optimization of expression cassettes and DNA plasmids encoding HBV pol and core antigens as described in Example 1; **FIG. 2A** is a schematic representation of an expression strategy in which coding sequences of the HBV core and pol antigens are fused in frame; **FIG. 2B** is a schematic representation of an expression strategy in which coding sequences of both the core and pol antigens are expressed from a single plasmid by means of the ribosomal FA2 slippage site; **FIG. 2C** is a schematic representation of an expression strategy in which the core and pol antigens are expressed from two separate plasmids; **FIG. 2D** is a Western blot of core antigen expression in HEK293T cells transfected with a plasmid expressing core with and without the post-transcriptional regulatory element WPRE; expression was tested in cell lysate (left) and supernatant (sup; right) using an α -core antibody; **FIG. 2E** is a Western blot analysis showing a comparison of core expression in HEK293T cells transfected with a core expressing plasmid including the intron/exon sequence derived from human apolipoprotein A1 precursor ("AI intron"), untranslated R-U5 domain of the human T-cell leukemia virus type 1 (HTLV-1) long terminal repeat (LTR) ("HTLV R"), or triple enhancer composite sequence of the HTLV-1 LTR, synthetic rabbit β -globin intron, and a splicing enhancer ("triple"); the unlabeled lane is purified core protein as a size marker; expression was tested in both lysate (left) and supernatant (sup; right); core antigen expression was highest with the triple enhancer composite sequence; **FIG. 2F** is a Western blot analysis of core antigen secretion using different signal peptides fused to the N-terminus of the HBV core antigen; the most efficient protein secretion was observed with the Cystatin S signal peptide; **FIG. 2G** is a schematic representation of optimized HBV core/pol antigen expression cassettes for each of the three expression strategies illustrated in **FIGS. 2A-2C**; CMVpr: human CMV-IE promoter; TRE: triple enhancer sequence; SP: cystatin S signal peptide; FA2: FMDV ribosomal slippage site; pA: BGH polyadenylation signal; **FIG. 2H** is a Western blot analysis of HBV core and pol antigen expression of pDK vectors containing each of the expression cassettes shown in **FIG. 2G**; lanes 1 and 2: pDK-core; lanes 3 and 4: pDK-pol; lanes 5 and 6: pDK-coreFA2Pol; lanes 7 and 8: pDK-core-pol fusion: the most consistent expression profile for cellular and secreted core and pol antigens was observed when the antigens were encoded by separate vectors;

FIGS. 3A-3D show schematic representations of DNA plasmids according to embodiments of the application; **FIG. 3A** shows a DNA plasmid encoding an HBV core antigen according to an embodiment of the application; **FIG. 3B** shows a DNA plasmid encoding an HBV polymerase (pol) antigen according to an embodiment of the application; **FIG. 3C** shows a DNA plasmid encoding an HBV S-surface antigen according to an embodiment of the application; **FIG. 3D** shows a DNA plasmid encoding an HBV surface antigen according to an embodiment of the application consisting of the L-surface antigen domain, M-surface antigen domain and portion of the S-surface antigen domain; the HBV antigens are expressed under control of a CMV promoter with an N-terminal cystatin S signal peptide that is cleaved from the expressed antigen upon secretion from the cell; transcriptional regulatory elements of the plasmid include an enhancer sequence located between the CMV promoter and the polynucleotide sequence encoding the HBV antigen and a bGH polyadenylation sequence located downstream of the polynucleotide sequence encoding the HBV antigen; a second expression cassette is included in the plasmid in reverse orientation including a kanamycin resistance gene under control of an Amp^r (bla) promoter; an origin of replication (pUC) is also included in reverse orientation;

FIG. 4 shows ELISPOT responses of Balb/c mice immunized with different DNA plasmids expressing HBV core antigen or HBV pol antigen, as described in Example 2; peptide pools used to stimulate splenocytes isolated from the various vaccinated animal groups are indicated in gray scale; the number of responsive T-cells are indicated on the y-axis expressed as spot forming cells (SFC) per 10⁶ splenocytes;

FIG. 5 shows ELISPOT responses of Balb/C mice immunized with a combination of DNA plasmids expressing HBV core antigen and HBV pol antigen according to the dose-finding study described in Example 3; peptide pools used to stimulate splenocytes isolated from the various vaccinated animal groups are indicated in gray scale; the number of responsive T-cells are indicated on the y-axis expressed as spot forming cells (SFC) per 10⁶ splenocytes;

FIG. 6 shows ELISPOT responses of Balb/c mice immunized with DNA plasmids (pDNA) expressing HBV core antigen and HBV pol antigen according to the immune interference study as described in Example 4; Group 1, single *Core* pDNA; Group 2, single *Pol* pDNA; Group 3, mixed *Core* and *Pol* pDNA; Group 4, *Core* and *Pol* pDNA applied separately at different sites; peptide pools used to stimulate splenocytes isolated from the various vaccinated animal groups are indicated in gray scale; the number of responsive T-cells are indicated on the y-axis expressed as spot forming cells (SFC) per 10⁶ splenocytes;

FIGS. 7A and 7B show the immunogenicity of a DNA vaccine according to an embodiment of the application in NHPs as described in Example 5; **FIG. 7A** shows the IFN- γ cytokine response after immunization with DNA plasmids expressing HBV Core and Pol antigens; peptide pools used to stimulate PBMCs isolated from the vaccinated animal groups are indicated in gray scale; the number of responsive T-cells are indicated on the y-axis expressed as spot forming cells (SFC) per 10^6 PBMC; **FIG. 7B** shows CD4 and CD8 T-cell memory immune response against Core, Pol-1, and Pol-2 peptide pools as measured by flow cytometry; the graph shows the results from Day 76 as % CD4 or CD8 T-cell response (IFN- γ , IL-2 and TNF- α) to the 3 pools after the DMSO media-only background was subtracted for each pool; CD4 response is shown on the left and CD8 response is shown on the right;

FIGS. 8A and 8B show the schematic representations of the expression cassettes in adenoviral vectors according to embodiments of the application; **FIG. 8A** shows the expression cassette for a truncated HBV core antigen, which contains a CMV promoter, an intron (a fragment derived from the human ApoAI gene - GenBank accession X01038 base pairs 295 – 523, harboring the ApoAI second intron), a human immunoglobulin secretion signal, followed by a coding sequence for a truncated HBV core antigen and a SV40 polyadenylation signal; **FIG. 8B** shows the expression cassette for a fusion protein of a truncated HBV core antigen operably linked to a HBV polymerase antigen, which is otherwise identical to the expression cassette for the truncated HBV core antigen except the HBV antigen; and

FIG. 9 shows ELISPOT responses in F1 mice (C57BL/6 x Balb/C) immunized with HBV adenoviral vectors, as described in Example 8; HBV core or polymerase peptide pools used to stimulate splenocytes isolated from the various vaccinated animal groups are indicated in black (core) and grey (pol); Pol1 and pol2 responses were summed; the X-axis shows the adenovector dose and experimental groups. The number of responsive T-cells are indicated on the y-axis expressed as spot forming cells (SFC) per 10^6 splenocytes.

FIG. 10 shows ELISPOT responses in Balb/C mice immunized with DNA vaccines containing DNA plasmids encoding an S-surface antigen or surface antigen containing the L- and M-surface antigen domains, as described in Example 9; the X-axis shows the plasmid dose and experimental groups. The number of responsive T-cells are indicated on the y-axis expressed as spot forming cells (SFC) per 10^6 splenocytes.

DETAILED DESCRIPTION OF THE INVENTION

Various publications, articles and patents are cited or described in the background and throughout the specification; each of these references is herein incorporated by reference in its

entirety. Discussion of documents, acts, materials, devices, articles or the like which has been included in the present specification is for the purpose of providing context for the invention. Such discussion is not an admission that any or all of these matters form part of the prior art with respect to any inventions disclosed or claimed.

5 Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood to one of ordinary skill in the art to which this invention pertains. Otherwise, certain terms used herein have the meanings as set forth in the specification. All patents, published patent applications and publications cited herein are incorporated by reference as if set forth fully herein.

10 It must be noted that as used herein and in the appended claims, the singular forms “a,” “an,” and “the” include plural reference unless the context clearly dictates otherwise.

Unless otherwise indicated, the term “at least” preceding a series of elements is to be understood to refer to every element in the series. Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation, many equivalents to the specific
15 embodiments of the invention described herein. Such equivalents are intended to be encompassed by the invention.

Throughout this specification and the claims which follow, unless the context requires otherwise, the word “comprise”, and variations such as “comprises” and “comprising”, will be understood to imply the inclusion of a stated integer or step or group of integers or steps but not
20 the exclusion of any other integer or step or group of integer or step. When used herein the term “comprising” can be substituted with the term “containing” or “including” or sometimes when used herein with the term “having”.

When used herein “consisting of” excludes any element, step, or ingredient not specified in the claim element. When used herein, “consisting essentially of” does not exclude materials or
25 steps that do not materially affect the basic and novel characteristics of the claim. Any of the aforementioned terms of “comprising”, “containing”, “including”, and “having”, whenever used herein in the context of an aspect or embodiment of the application can be replaced with the term “consisting of” or “consisting essentially of” to vary scopes of the disclosure.

As used herein, the conjunctive term “and/or” between multiple recited elements is
30 understood as encompassing both individual and combined options. For instance, where two elements are conjoined by “and/or,” a first option refers to the applicability of the first element without the second. A second option refers to the applicability of the second element without the first. A third option refers to the applicability of the first and second elements together. Any one of these options is understood to fall within the meaning, and therefore satisfy the requirement of

the term “and/or” as used herein. Concurrent applicability of more than one of the options is also understood to fall within the meaning, and therefore satisfy the requirement of the term “and/or.”

Unless otherwise stated, any numerical value, such as a concentration or a concentration range described herein, are to be understood as being modified in all instances by the term “about.” Thus, a numerical value typically includes $\pm 10\%$ of the recited value. For example, a concentration of 1 mg/mL includes 0.9 mg/mL to 1.1 mg/mL. Likewise, a concentration range of 1 mg/mL to 10 mg/mL includes 0.9 mg/mL to 11 mg/mL. As used herein, the use of a numerical range expressly includes all possible subranges, and all individual numerical values within that range, including integers within such ranges and fractions of the values unless the context clearly indicates otherwise.

The phrases “percent (%) sequence identity” or “% identity” or “% identical to” when used with reference to an amino acid sequence describe the number of matches (“hits”) of identical amino acids of two or more aligned amino acid sequences as compared to the number of amino acid residues making up the overall length of the amino acid sequences. In other terms, using an alignment, for two or more sequences the percentage of amino acid residues that are the same (e.g. 90%, 91%, 92%, 93%, 94%, 95%, 97%, 98%, 99%, or 100% identity over the full-length of the amino acid sequences) may be determined, when the sequences are compared and aligned for maximum correspondence as measured using a sequence comparison algorithm as known in the art, or when manually aligned and visually inspected. The sequences which are compared to determine sequence identity may thus differ by substitution(s), addition(s) or deletion(s) of amino acids. Suitable programs for aligning protein sequences are known to the skilled person. The percentage sequence identity of protein sequences can, for example, be determined with programs such as CLUSTALW, Clustal Omega, FASTA or BLAST, e.g., using the NCBI BLAST algorithm (Altschul SF, et al (1997), *Nucleic Acids Res.* 25:3389-3402).

As used herein, the terms and phrases “in combination,” “in combination with,” “co-delivery,” and “administered together with” in the context of the administration of two or more therapies or components to a subject refers to simultaneous administration of two or more therapies or components, such as two vectors, e.g., DNA plasmids, or an immunogenic combination and an adjuvant. “Simultaneous administration” can be administration of the two components at least within the same day. When two components are “administered together with” or “administered in combination with,” they can be administered in separate compositions sequentially within a short time period, such as 24, 20, 16, 12, 8 or 4 hours, or within 1 hour, or they can be administered in a single composition at the same time. The use of the term “in combination with” does not restrict the order in which therapies or components are administered

to a subject. For example, a first therapy or component (e.g. first DNA plasmid encoding an HBV antigen) can be administered prior to (e.g., 5 minutes to one hour before), concomitantly with or simultaneously with, or subsequent to (e.g., 5 minutes to one hour after) the administration of a second therapy or component (e.g., second DNA plasmid encoding an HBV antigen). In some embodiments, a first therapy or component (e.g. first DNA plasmid encoding an HBV antigen) and a second therapy or component (e.g., second DNA plasmid encoding an HBV antigen) are administered in the same composition. In other embodiments, a first therapy or component (e.g. first DNA plasmid encoding an HBV antigen) and a second therapy or component (e.g., second DNA plasmid encoding an HBV antigen) are administered in separate compositions.

As used herein, a “non-naturally occurring” nucleic acid or polypeptide, refers to a nucleic acid or polypeptide that does not occur in nature. A “non-naturally occurring” nucleic acid or polypeptide can be synthesized, treated, fabricated, and/or otherwise manipulated in a laboratory and/or manufacturing setting. In some cases, a non-naturally occurring nucleic acid or polypeptide can comprise a naturally-occurring nucleic acid or polypeptide that is treated, processed, or manipulated to exhibit properties that were not present in the naturally-occurring nucleic acid or polypeptide, prior to treatment. As used herein, a “non-naturally occurring” nucleic acid or polypeptide can be a nucleic acid or polypeptide isolated or separated from the natural source in which it was discovered, and it lacks covalent bonds to sequences with which it was associated in the natural source. A “non-naturally occurring” nucleic acid or polypeptide can be made recombinantly or via other methods, such as chemical synthesis.

As used herein, “subject” means any animal, preferably a mammal, most preferably a human, to whom will be or has been treated by a method according to an embodiment of the application. The term “mammal” as used herein encompasses any mammal. Examples of mammals include, but are not limited to, cows, horses, sheep, pigs, cats, dogs, mice, rats, rabbits, guinea pigs, non-human primates (NHPs) such as monkeys or apes, humans, etc., more preferably a human.

As used herein, the term “operably linked” refers to a linkage or a juxtaposition wherein the components so described are in a relationship permitting them to function in their intended manner. For example, a regulatory sequence operably linked to a nucleic acid sequence of interest is capable of directing the transcription of the nucleic acid sequence of interest, or a signal sequence operably linked to an amino acid sequence of interest is capable of secreting or translocating the amino acid sequence of interest over a membrane.

In an attempt to help the reader of the application, the description has been separated in various paragraphs or sections, or is directed to various embodiments of the application. These separations should not be considered as disconnecting the substance of a paragraph or section or embodiments from the substance of another paragraph or section or embodiments. To the contrary, one skilled in the art will understand that the description has broad application and encompasses all the combinations of the various sections, paragraphs and sentences that can be contemplated. The discussion of any embodiment is meant only to be exemplary and is not intended to suggest that the scope of the disclosure, including the claims, is limited to these examples. For example, while embodiments of HBV vectors of the application (e.g., plasmid DNA or viral vectors) described herein may contain particular components, including, but not limited to, certain promoter sequences, enhancer or regulatory sequences, signal peptides, coding sequence of an HBV antigen, polyadenylation signal sequences, etc. arranged in a particular order, those having ordinary skill in the art will appreciate that the concepts disclosed herein may equally apply to other components arranged in other orders that can be used in HBV vectors of the application. The application contemplates use of any of the applicable components in any combination having any sequence that can be used in HBV vectors of the application, whether or not a particular combination is expressly described.

Hepatitis B Virus (HBV)

As used herein “hepatitis B virus” or “HBV” refers to a virus of the hepadnaviridae family. HBV is a small hepatotropic DNA virus that encodes four open reading frames and seven proteins. See FIG. 1A. The seven proteins encoded by HBV include small (S), medium (M), and large (L) surface antigen or envelope (Env) proteins, pre-Core protein, core protein, viral polymerase (Pol), and HBx protein. HBV expresses three surface antigens, or envelope proteins, L, M, and S, with S being the smallest and L being the largest. The extra domains in the M and L proteins are named Pre-S2 and Pre-S1, respectively. Core protein is the subunit of the viral nucleocapsid. Pol is needed for synthesis of viral DNA (reverse transcriptase, RNaseH, and primer), which takes place in nucleocapsids localized to the cytoplasm of infected hepatocytes. PreCore is the core protein with an N-terminal signal peptide and is proteolytically processed at its N and C termini before secretion from infected cells, as the so-called hepatitis B e-antigen (HBeAg). HBx protein is required for efficient transcription of covalently closed circular DNA (cccDNA). HBx is not a viral structural protein. All viral proteins of HBV have their own mRNA except for core and polymerase, which share an mRNA. With the exception of the protein pre-Core, none of the HBV viral proteins are subject to post-translational proteolytic processing.

The HBV virion contains a viral envelope, nucleocapsid, and single copy of the partially double-stranded DNA genome. The nucleocapsid comprises 120 dimers of core protein and is covered by a capsid membrane embedded with the S, M, and L viral envelope or surface antigen proteins. After entry into the cell, the virus is uncoated and the capsid-containing relaxed circular DNA (rcDNA) with covalently bound viral polymerase migrates to the nucleus. During that process, phosphorylation of the core protein induces structural changes, exposing a nuclear localization signal enabling interaction of the capsid with so-called importins. These importins mediate binding of the core protein to nuclear pore complexes upon which the capsid disassembles and polymerase/rcDNA complex is released into the nucleus. Within the nucleus the rcDNA becomes deproteinized (removal of polymerase) and is converted by host DNA repair machinery to a covalently closed circular DNA (cccDNA) genome from which overlapping transcripts encode for HBeAg, surface antigens, Core protein, viral polymerase and HBx protein. Core protein, viral polymerase, and pre-genomic RNA (pgRNA) associate in the cytoplasm and self-assemble into immature pgRNA-containing capsid particles, which further convert into mature rcDNA-capsids and function as a common intermediate that is either enveloped and secreted as infectious virus particles or transported back to the nucleus to replenish and maintain a stable cccDNA pool. See FIG. 1D.

To date, HBV is divided into four serotypes (adr, adw, ayr, ayw) based on antigenic epitopes present on the envelope proteins, and into eight genotypes (A, B, C, D, E, F, G, and H) based on the sequence of the viral genome. The HBV genotypes are distributed over different geographic regions. For example, the most prevalent genotypes in Asia are genotypes B and C. Genotype D is dominant in Africa, the Middle East, and India, whereas genotype A is widespread in Northern Europe, sub-Saharan Africa, and West Africa.

HBV Antigens

As used herein, the terms “HBV antigen,” “antigenic polypeptide of HBV,” “HBV antigenic polypeptide,” “HBV antigenic protein,” “HBV immunogenic polypeptide,” and “HBV immunogen” all refer to a polypeptide capable of inducing an immune response, e.g., a humoral and/or cellular mediated response, against an HBV in a subject. The HBV antigen can be a polypeptide of HBV, a fragment or epitope thereof, or a combination of multiple HBV polypeptides, portions or derivatives thereof. An HBV antigen is capable of raising in a host a protective immune response, e.g., inducing an immune response against a viral disease or infection, and/or producing an immunity (i.e., vaccinates) in a subject against a viral disease or infection, that protects the subject against the viral disease or infection. For example, an HBV antigen can comprise a polypeptide or immunogenic fragment(s) thereof from any HBV protein,

such as HBeAg, pre-core protein, surface antigens (S, M, or L proteins), core protein, viral polymerase, or HBx protein derived from any HBV genotype, e.g., genotype A, B, C, D, E, F, G, and/or H, or a combination thereof.

(1) HBV Core Antigen

As used herein, each of the terms “HBV core antigen,” “HBcAg” and “core antigen” refers to an HBV antigen capable of inducing an immune response, e.g., a humoral and/or cellular mediated response, against an HBV core protein in a subject. Each of the terms “core,” “core polypeptide,” and “core protein” refers to the HBV viral core protein. Full-length core antigen is typically 183 amino acids in length and includes an assembly domain (amino acids 1 to 149) and a nucleic acid binding domain (amino acids 150 to 183). The 34-residue nucleic acid binding domain is required for pre-genomic RNA encapsidation. This domain also functions as a nuclear import signal. It comprises 17 arginine residues and is highly basic, consistent with its function. HBV core protein is dimeric in solution, with the dimers self-assembling into icosahedral capsids. Each dimer of core protein has four α -helix bundles flanked by an α -helix domain on either side. Truncated HBV core proteins lacking the nucleic acid binding domain are also capable of forming capsids.

In an embodiment of the application, an HBV antigen is a truncated HBV core antigen. As used herein, a “truncated HBV core antigen,” refers to an HBV antigen that does not contain the entire length of an HBV core protein, but is capable of inducing an immune response against the HBV core protein in a subject. For example, an HBV core antigen can be modified to delete one or more amino acids of the highly positively charged (arginine rich) C-terminal nucleic acid binding domain of the core antigen, which typically contains seventeen arginine (R) residues. A truncated HBV core antigen of the application is preferably a C-terminally truncated HBV core protein which does not comprise the HBV core nuclear import signal and/or a truncated HBV core protein from which the C-terminal HBV core nuclear import signal has been deleted. In an embodiment, a truncated HBV core antigen comprises a deletion in the C-terminal nucleic acid binding domain, such as a deletion of 1 to 34 amino acid residues of the C-terminal nucleic acid binding domain, e.g., 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, or 34 amino acid residues, preferably a deletion of all 34 amino acid residues. In a preferred embodiment, a truncated HBV core antigen comprises a deletion in the C-terminal nucleic acid binding domain, preferably a deletion of all 34 amino acid residues.

An HBV core antigen of the application can be a consensus sequence derived from multiple HBV genotypes (e.g., genotypes A, B, C, D, E, F, G, and H). As used herein,

“consensus sequence” means an artificial sequence of amino acids based on an alignment of amino acid sequences of homologous proteins, e.g., as determined by an alignment (e.g., using Clustal Omega) of amino acid sequences of homologous proteins. It can be the calculated order of most frequent amino acid residues, found at each position in a sequence alignment, based upon sequences of HBV antigens (e.g., core, pol, surface antigens, etc.) from at least 100 natural HBV isolates. A consensus sequence can be non-naturally occurring and different from the native viral sequences. Consensus sequences can be designed by aligning multiple HBV antigen sequences from different sources using a multiple sequence alignment tool, and at variable alignment positions, selecting the most frequent amino acid. Preferably, a consensus sequence of an HBV antigen is derived from HBV genotypes B, C, and D. The term “consensus antigen” is used to refer to an antigen having a consensus sequence.

An exemplary truncated HBV core antigen according to the application lacks the nucleic acid binding function, and is capable of inducing an immune response in a mammal against at least two HBV genotypes. Preferably a truncated HBV core antigen is capable of inducing a T cell response in a mammal against at least HBV genotypes B, C and D. More preferably, a truncated HBV core antigen is capable of inducing a CD8 T cell response in a human subject against at least HBV genotypes A, B, C and D.

Preferably, an HBV core antigen of the application is a consensus antigen, preferably a consensus antigen derived from HBV genotypes B, C, and D, more preferably a truncated consensus antigen derived from HBV genotypes B, C, and D. An exemplary truncated HBV core consensus antigen according to the application consists of an amino acid sequence that is at least 90% identical to SEQ ID NO: 2 or SEQ ID NO: 14, such as at least 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9%, or 100% identical to SEQ ID NO: 2 or SEQ ID NO: 14. SEQ ID NO: 2 and SEQ ID NO: 14 are core consensus antigens derived from HBV genotypes B, C, and D. SEQ ID NO: 2 and SEQ ID NO: 14 contain a 34-amino acid C-terminal deletion of the highly positively charged (arginine rich) nucleic acid binding domain of the native core antigen.

In a particular embodiment of the application, an HBV core antigen is a truncated HBV antigen consisting of the amino acid sequence of SEQ ID NO: 2. In another particular embodiment, an HBV core antigen is a truncated HBV antigen consisting of the amino acid sequence of SEQ ID NO: 14.

(2) HBV Polymerase Antigen

As used herein, the term “HBV polymerase antigen,” “HBV Pol antigen” or “HBV pol antigen” refers to an HBV antigen capable of inducing an immune response, e.g., a humoral and/or cellular mediated response, against an HBV polymerase in a subject. Each of the terms “polymerase,” “polymerase polypeptide,” “Pol” and “pol” refers to the HBV viral DNA polymerase. The HBV viral DNA polymerase has four domains, including, from the N terminus to the C terminus, a terminal protein (TP) domain, which acts as a primer for minus-strand DNA synthesis; a spacer that is nonessential for the polymerase functions; a reverse transcriptase (RT) domain for transcription; and a RNase H domain.

In an embodiment of the application, an HBV antigen comprises an HBV Pol antigen, or any immunogenic fragment or combination thereof. An HBV Pol antigen can contain further modifications to improve immunogenicity of the antigen, such as by introducing mutations into the active sites of the polymerase and/or RNase domains to decrease or substantially eliminate certain enzymatic activities.

Preferably, an HBV Pol antigen of the application does not have reverse transcriptase activity and RNase H activity, and is capable of inducing an immune response in a mammal against at least two HBV genotypes. Preferably, an HBV Pol antigen is capable of inducing a T cell response in a mammal against at least HBV genotypes B, C and D. More preferably, a HBV Pol antigen is capable of inducing a CD8 T cell response in a human subject against at least HBV genotypes A, B, C and D.

Thus, in some embodiments, an HBV Pol antigen is an inactivated Pol antigen. In an embodiment, an inactivated HBV Pol antigen comprises one or more amino acid mutations in the active site of the polymerase domain. In another embodiment, an inactivated HBV Pol antigen comprises one or more amino acid mutations in the active site of the RNaseH domain. In a preferred embodiment, an inactivated HBV pol antigen comprises one or more amino acid mutations in the active site of both the polymerase domain and the RNaseH domain. For example, the “YXDD” motif in the polymerase domain of an HBV pol antigen that can be required for nucleotide/metal ion binding can be mutated, e.g., by replacing one or more of the aspartate residues (D) with asparagine residues (N), eliminating or reducing metal coordination function, thereby decreasing or substantially eliminating reverse transcriptase function.

Alternatively, or in addition to mutation of the “YXDD” motif, the “DEDD” motif in the RNaseH domain of an HBV pol antigen required for Mg^{2+} coordination can be mutated, e.g., by replacing one or more aspartate residues (D) with asparagine residues (N) and/or replacing the glutamate residue (E) with glutamine (Q), thereby decreasing or substantially eliminating RNaseH function. In a particular embodiment, an HBV pol antigen is modified by (1) mutating

the aspartate residues (D) to asparagine residues (N) in the “YXDD” motif of the polymerase domain; and (2) mutating the first aspartate residue (D) to an asparagine residue (N) and the first glutamate residue (E) to a glutamine residue (N) in the “DEDD” motif of the RNaseH domain, thereby decreasing or substantially eliminating both the reverse transcriptase and RNaseH functions of the pol antigen.

In a preferred embodiment of the application, an HBV pol antigen is a consensus antigen, preferably a consensus antigen derived from HBV genotypes B, C, and D, more preferably an inactivated consensus antigen derived from HBV genotypes B, C, and D. An exemplary HBV pol consensus antigen according to the application comprises an amino acid sequence that is at least 90% identical to SEQ ID NO: 4, such as at least 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 4, preferably at least 98% identical to SEQ ID NO: 4, such as at least 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 4. SEQ ID NO: 4 is a pol consensus antigen derived from HBV genotypes B, C, and D comprising four mutations located in the active sites of the polymerase and RNaseH domains. In particular, the four mutations include mutation of the aspartic acid residues (D) to asparagine residues (N) in the “YXDD” motif of the polymerase domain; and mutation of the first aspartate residue (D) to an asparagine residue (N) and mutation of the glutamate residue (E) to a glutamine residue (Q) in the “DEDD” motif of the RNaseH domain.

In a particular embodiment of the application, an HBV pol antigen comprises the amino acid sequence of SEQ ID NO: 4. In other embodiments of the application, an HBV pol antigen consists of the amino acid sequence of SEQ ID NO: 4.

(3) Fusion of HBV Core Antigen and HBV Polymerase Antigen

As used herein the term “fusion protein” or “fusion” refers to a single polypeptide chain having at least two polypeptide domains that are not normally present in a single, natural polypeptide.

In an embodiment of the application, an HBV antigen comprises a fusion protein comprising a truncated HBV core antigen operably linked to an HBV Pol antigen, or an HBV Pol antigen operably linked to a truncated HBV core antigen, preferably via a linker.

As used herein, the term “linker” refers to a compound or moiety that acts as a molecular bridge to operably link two different molecules, wherein one portion of the linker is operably linked to a first molecule, and wherein another portion of the linker is operably linked to a second molecule. For example, in a fusion protein containing a first polypeptide and a second

heterologous polypeptide, a linker serves primarily as a spacer between the first and second polypeptides. In an embodiment, a linker is made up of amino acids linked together by peptide bonds, preferably from 1 to 20 amino acids linked by peptide bonds, wherein the amino acids are selected from the 20 naturally occurring amino acids. In an embodiment, the 1 to 20 amino acids are selected from glycine, alanine, proline, asparagine, glutamine, and lysine. Preferably, a linker is made up of a majority of amino acids that are sterically unhindered, such as glycine and alanine. Exemplary linkers are polyglycines, particularly (Gly)₅, (Gly)₈, poly(Gly-Ala), and polyalanines. One exemplary suitable linker as shown in the Examples below is (AlaGly)_n, wherein n is an integer of 2 to 5.

Preferably, a fusion protein of the application is capable of inducing an immune response in a mammal against HBV core and HBV Pol of at least two HBV genotypes. Preferably, a fusion protein is capable of inducing a T cell response in a mammal against at least HBV genotypes B, C and D. More preferably, the fusion protein is capable of inducing a CD8 T cell response in a human subject against at least HBV genotypes A, B, C and D.

In an embodiment of the application, a fusion protein comprises a truncated HBV core antigen having an amino acid sequence at least 90%, such as at least 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9%, or 100% identical to SEQ ID NO: 2 or SEQ ID NO: 14, a linker, and a HBV Pol antigen having an amino acid sequence at least 90%, such as at least 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9%, or 100%, identical to SEQ ID NO: 4.

In a preferred embodiment of the application, a fusion protein comprises a truncated HBV core antigen consisting of the amino acid sequence of SEQ ID NO: 14, a linker comprising (AlaGly)_n, wherein n is an integer of 2 to 5, and a HBV Pol antigen having the amino acid sequence of SEQ ID NO: 4. More preferably, a fusion protein according to an embodiment of the application comprises the amino acid sequence of SEQ ID NO: 20.

In an embodiment of the application, a fusion protein further comprises a signal sequence. Preferably, the signal sequence has the amino acid sequence of SEQ ID NO: 6 or SEQ ID NO: 19. More preferably, a fusion protein comprises the amino acid sequence of SEQ ID NO: 21.

(4) HBV Surface Antigens

As used herein, each of the terms “HBV surface antigen,” “surface antigen,” “HBV envelope antigen,” “envelope antigen,” and “env antigen” refers to an HBV antigen capable of

inducing or eliciting an immune response, e.g., a humoral and/or cellular mediated response, against one or more HBV surface antigens or envelope proteins in a subject. Each of the terms “HBV surface protein,” “surface protein,” “HBV envelope protein” and “envelope protein” refers to HBV viral surface or envelope proteins. HBV expresses three surface antigens, or envelope proteins. Gene S is the gene of the HBV genome that encodes the surface antigens. The surface antigen gene is one long open reading frame but contains three in frame “start” (ATG) codons that divide the gene into three sections, pre-S1, pre-S2, and S. Because of the multiple start codons, polypeptides of three different sizes called large (L) or L-surface antigen, middle (M) or M-surface antigen, and small (S) or S-surface antigen are produced. Two different promoters (PreS1 and PreS2) drive transcription of the L, M, and S- surface antigen coding sequences resulting in three different translated proteins. The PreS2 promoter is sometimes referred to as the PreS2/S promoter since it is driving M-surface antigen and S-surface antigen transcription separately. The amino acid sequence of the L-surface antigen is in-frame with the M and S-surface antigen sequences. Thus, the L-surface antigen contains the M- and S-surface antigen domains and the M-surface antigen includes the S-surface antigen domain. The L-surface antigen and M-surface antigen are different domains that make up the entire HBV envelope protein or surface antigen in conjunction with the S-surface antigen domains. See FIGs. 1E and 1F.

In an embodiment of the application, an HBV antigen comprises an HBV surface antigen, or any immunogenic fragment or combination thereof. An HBV surface antigen is capable of inducing an immune response in a subject against at least one of L-surface antigen, M-surface antigen, and S-surface antigen proteins. Preferably, an HBV surface antigen is a consensus antigen, preferably a consensus antigen derived from HBV genotypes B, C, and D, and more preferably a consensus antigen derived from HBV genotypes A, B, C, and D.

Preferably, an HBV surface antigen of the application is capable of inducing an immune response in a mammal against at least one of L-surface antigen, M-surface antigen, and S-surface antigen of at least two HBV genotypes. Preferably, an HBV surface antigen is capable of inducing a T cell response in a mammal against at least HBV genotypes B, C and D. More preferably, the HBV surface antigen is capable of inducing a CD8 T cell response in a human subject against at least HBV genotypes A, B, C and D.

In some embodiments, an HBV surface antigen is S-surface antigen, or any immunogenic fragment or combination thereof. Preferably, the S-surface antigen is a consensus antigen, preferably a consensus antigen derived from HBV genotypes B, C, and D, and more preferably a consensus antigen derived from HBV genotypes A, B, C, and D. Preferably, the S-surface

antigen is capable of inducing or eliciting an immune response against S-surface antigen in a subject.

An exemplary S-surface antigen according to the application consists of an amino acid sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 27, such as at least 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to the amino acid sequence of SEQ ID NO: 27. SEQ ID NO: 27 is an HBV consensus S-surface antigen derived from HBV genotypes A, B, C, and D.

In a particular embodiment of the application, an S-surface antigen consists of the amino acid sequence of SEQ ID NO: 27.

In some embodiments, an HBV surface antigen is M-surface antigen, or any immunogenic fragment or combination thereof. Preferably, the M-surface antigen is a consensus antigen, preferably a consensus antigen derived from HBV genotypes B, C, and D, and more preferably a consensus antigen derived from HBV genotypes A, B, C, and D. Preferably, the M-surface antigen is capable of inducing or eliciting an immune response against M-surface antigen in a subject.

An exemplary M-surface antigen according to the application comprises or consists of an amino acid sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 30, such as at least 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to the amino acid sequence of SEQ ID NO: 30. SEQ ID NO: 30 is an HBV consensus M-surface antigen derived from HBV genotypes A, B, C, and D.

In some embodiments, an HBV surface antigen is an L-surface antigen, or any immunogenic fragment or combination thereof. Preferably, the L-surface antigen is a consensus antigen, preferably a consensus antigen derived from HBV genotypes B, C, and D, and more preferably a consensus antigen derived from HBV genotypes A, B, C, and D. Preferably, the L-surface antigen is capable of inducing or eliciting an immune response against L-surface antigen in a subject.

An exemplary L-surface antigen according to the application comprises or consists of an amino acid sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 31, such as at least 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to the amino acid sequence of SEQ ID NO: 31. SEQ ID NO: 31 is an HBV consensus L-surface antigen derived from HBV genotypes A, B, C, and D.

In some embodiments, an HBV surface antigen comprises a portion of any one of the L-, M-, and S-surface antigens, or any combination thereof. For example, an HBV surface antigen

can comprise or consist of the N-terminal L-surface antigen domain. An HBV surface antigen can also comprise or consist of the M-surface antigen domain. An HBV surface antigen can also comprise or consist of the N-terminal L-surface antigen domain and the M-surface antigen domain. An HBV surface antigen can also comprise or consist of the N-terminal L-surface antigen domain, the M-surface antigen domain, and a portion of the S-surface antigen domain.

An exemplary example of such a surface antigen according to the application consists of an amino acid sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 29, such as at least 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 29, preferably at least 98% identical to SEQ ID NO: 29, such as at least 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 29. SEQ ID NO: 29 is a consensus antigen derived from HBV genotypes A, B, C, and D, containing the N-terminal L-surface antigen domain, the entire M-surface antigen domain, and a 15-amino acid C-terminal tail from the S-surface antigen domain. See FIG. 3F.

In a particular embodiment of the application, an HBV surface antigen consists of the amino acid sequence of SEQ ID NO: 27.

Polynucleotides and Vectors

In another general aspect, the application provides a non-naturally occurring nucleic acid molecule encoding an HBV antigen according to the application, and a vector comprising the non-naturally occurring nucleic acid. A non-naturally occurring nucleic acid molecule can comprise any polynucleotide sequence encoding an HBV antigen of the application, which can be made using methods known in the art in view of the present disclosure. Preferably, a polynucleotide encodes at least one of a truncated HBV core antigen, an HBV polymerase antigen, and an HBV surface antigen of the application. A polynucleotide can be in the form of RNA or in the form of DNA obtained by recombinant techniques (e.g., cloning) or produced synthetically (e.g., chemical synthesis). The DNA can be single-stranded or double-stranded, or can contain portions of both double-stranded and single-stranded sequence. The DNA can, for example, comprise genomic DNA, cDNA, or combinations thereof. The polynucleotide can also be a DNA/RNA hybrid. The polynucleotides and vectors of the application can be used for recombinant protein production, expression of the protein in a host cell, or the production of viral particles. Preferably, a polynucleotide is DNA.

In an embodiment of the application, a non-naturally occurring nucleic acid molecule comprises a polynucleotide encoding a truncated HBV core antigen consisting of an amino acid sequence that is at least 90% identical to SEQ ID NO: 2 or SEQ ID NO: 14, such as at least 90%,

91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 2, preferably 98%, 99% or 100% identical to SEQ ID NO: 2 or SEQ ID NO: 14. In a particular embodiment of the application, a non-naturally occurring nucleic acid molecule encodes a truncated HBV core antigen consisting of the amino acid sequence of SEQ ID NO: 2 or SEQ ID NO: 14.

Examples of polynucleotide sequences of the application encoding a truncated HBV core antigen consisting of the amino acid sequence of SEQ ID NO: 2 or SEQ ID NO: 14 include, but are not limited to, a polynucleotide sequence at least 90% identical to SEQ ID NO: 1 or SEQ ID NO: 15, such as at least 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 1 or SEQ ID NO: 15, preferably 98%, 99% or 100% identical to SEQ ID NO: 1 or SEQ ID NO: 15. Exemplary non-naturally occurring nucleic acid molecules encoding a truncated HBV core antigen have the polynucleotide sequence of SEQ ID NOs: 1 or 15.

In an embodiment of the application, a non-naturally occurring nucleic acid molecule encodes a HBV polymerase antigen comprising an amino acid sequence that is at least 90% identical to SEQ ID NO: 4, such as at least 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 4, preferably 100% identical to SEQ ID NO: 4. In a particular embodiment of the application, a non-naturally occurring nucleic acid molecule encodes a HBV polymerase antigen consisting of the amino acid sequence of SEQ ID NO: 4.

Examples of polynucleotide sequences of the application encoding a HBV Pol antigen comprising the amino acid sequence of SEQ ID NO: 4 include, but are not limited to, a polynucleotide sequence at least 90% identical to SEQ ID NO: 3 or SEQ ID NO: 16, such as at least 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 3 or SEQ ID NO: 16, preferably 98%, 99% or 100% identical to SEQ ID NO: 3 or SEQ ID NO: 16. Exemplary non-naturally occurring nucleic acid molecules encoding a HBV pol antigen have the polynucleotide sequence of SEQ ID NOs: 3 or 16.

In another embodiment of the application, a non-naturally occurring nucleic acid molecule encodes a fusion protein comprising a truncated HBV core antigen operably linked to a HBV Pol antigen, or a HBV Pol antigen operably linked to a truncated HBV core antigen. In a particular embodiment, a non-naturally occurring nucleic acid molecule of the application

encodes a truncated HBV core antigen consisting of an amino acid sequence that is at least 90% identical to SEQ ID NO: 2 or SEQ ID NO: 14, such as at least 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 2 or SEQ ID NO: 14, preferably 100% identical to SEQ ID NO: 2 or SEQ ID NO: 14, more preferably 100% identical to SEQ ID NO: 14; a linker; and a HBV polymerase antigen comprising an amino acid sequence that is at least 90% identical to SEQ ID NO: 4, such as at least 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 4, preferably 98%, 99% or 100% identical to SEQ ID NO: 4. In a particular embodiment of the application, a non-naturally occurring nucleic acid molecule encodes a fusion protein comprising a truncated HBV core antigen consisting of the amino acid sequence of SEQ ID NO: 14, a linker comprising (AlaGly)_n, wherein n is an integer of 2 to 5; and a HBV Pol antigen comprising the amino acid sequence of SEQ ID NO: 4. In a particular embodiment of the application, a non-naturally occurring nucleic acid molecule encodes a fusion protein comprising the amino acid sequence of SEQ ID NO: 20.

Examples of polynucleotide sequences of the application encoding a fusion protein comprising a truncated HBV core antigen operably linked to a HBV Pol antigen include, but are not limited to, a polynucleotide sequence at least 90% identical to SEQ ID NO: 1 or SEQ ID NO: 15, such as at least 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 1 or SEQ ID NO: 15, preferably 98%, 99% or 100% identical to SEQ ID NO: 1 or SEQ ID NO: 15, operably linked to a linker coding sequence at least 90% identical to SEQ ID NO: 22, such as at least 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 22, preferably 98%, 99% or 100% identical to SEQ ID NO: 22, which is further operably linked to a polynucleotide sequence at least 90% identical to SEQ ID NO: 3 or SEQ ID NO: 16, such as at least 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 3 or SEQ ID NO: 16, preferably 98%, 99% or 100% identical to SEQ ID NO: 3 or SEQ ID NO: 16. In particular embodiments of the application, a non-naturally occurring nucleic acid molecule encoding a fusion protein comprises SEQ ID NO: 1 or SEQ ID NO: 15, operably linked to SEQ ID NO: 22, which is further operably linked to SEQ ID NO: 3 or SEQ ID NO: 16.

In an embodiment of the application, a non-naturally occurring nucleic acid molecule comprises a polynucleotide encoding an S-surface antigen consisting of an amino acid sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 27, such as at least 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 27, preferably 99% or 100% identical to SEQ ID NO: 27. In a particular embodiment of the application, a non-naturally occurring nucleic acid molecule encodes an S-surface antigen consisting of the amino acid sequence of SEQ ID NO: 27.

Examples of polynucleotide sequences of the application encoding an S-surface antigen consisting of the amino acid sequence of SEQ ID NO: 27 include, but are not limited to, a polynucleotide sequence at least 90% identical to SEQ ID NO: 26, such as at least 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 26, preferably 98%, 99% or 100% identical to SEQ ID NO: 26. Exemplary non-naturally occurring nucleic acid molecules encoding an S-surface antigen have the polynucleotide sequence of SEQ ID NO: 26.

In an embodiment of the application, a non-naturally occurring nucleic acid molecule comprises a polynucleotide encoding an HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to the amino acid sequence of SEQ ID NO: 29, such as at least 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 29, preferably 98%, 99% or 100% identical to SEQ ID NO: 29. In a particular embodiment of the application, a non-naturally occurring nucleic acid molecule encodes an HBV surface antigen consisting of the amino acid sequence of SEQ ID NO: 29.

Examples of polynucleotide sequences of the application encoding an HBV surface antigen consisting of the amino acid sequence of SEQ ID NO: 29 include, but are not limited to, a polynucleotide sequence at least 90% identical to SEQ ID NO: 28, such as at least 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 28, preferably 98%, 99% or 100% identical to SEQ ID NO: 28. Exemplary non-naturally occurring nucleic acid molecules encoding such HBV surface antigen have the polynucleotide sequence of SEQ ID NO: 28.

The application also relates to a vector comprising an isolated polynucleotide encoding an HBV antigen. As used herein, a "vector" is a nucleic acid molecule used to carry genetic material into another cell, where it can be replicated and/or expressed. Any vector known to

those skilled in the art in view of the present disclosure can be used. Examples of vectors include, but are not limited to, plasmids, viral vectors (bacteriophage, animal viruses, and plant viruses), cosmids, and artificial chromosomes (e.g., YACs). Preferably, a vector is a DNA plasmid. A vector can be a DNA vector or an RNA vector. One of ordinary skill in the art can
5 construct a vector of the application through standard recombinant techniques in view of the present disclosure.

A vector of the application can be an expression vector. As used herein, the term “expression vector” refers to any type of genetic construct comprising a nucleic acid coding for an RNA capable of being transcribed. Expression vectors include, but are not limited to, vectors
10 for recombinant protein expression, such as a DNA plasmid or a viral vector, and vectors for delivery of nucleic acid into a subject for expression in a tissue of the subject, such as a DNA plasmid or a viral vector. It will be appreciated by those skilled in the art that the design of the expression vector can depend on such factors as the choice of the host cell to be transformed, the level of expression of protein desired, etc.

Vectors of the application can contain a variety of regulatory sequences. As used herein, the term “regulatory sequence” refers to any sequence that allows, contributes or modulates the functional regulation of the nucleic acid molecule, including replication, duplication,
15 transcription, splicing, translation, stability and/or transport of the nucleic acid or one of its derivatives (i.e. mRNA) into the host cell or organism. In the context of the disclosure, this term encompasses promoters, enhancers and other expression control elements (e.g., polyadenylation signals and elements that affect mRNA stability).
20

In some embodiments of the application, a vector is a non-viral vector. Examples of non-viral vectors include, but are not limited to, DNA plasmids, bacterial artificial chromosomes, yeast artificial chromosomes, bacteriophages, etc. Examples of non-viral vectors include, but are
25 not limited to, RNA replicon, mRNA replicon, modified mRNA replicon or self-amplifying mRNA, closed linear deoxyribonucleic acid, e.g., a linear covalently closed DNA, e.g., a linear covalently closed double stranded DNA molecule. Preferably, a non-viral vector is a DNA plasmid. A “DNA plasmid”, which is used interchangeably with “DNA plasmid vector,” “plasmid DNA” or “plasmid DNA vector,” refers to a double-stranded and generally circular
30 DNA sequence that is capable of autonomous replication in a suitable host cell. DNA plasmids used for expression of an encoded polynucleotide typically comprise an origin of replication, a multiple cloning site, and a selectable marker, which for example, can be an antibiotic resistance gene. Examples of suitable DNA plasmids that can be used include, but are not limited to, commercially available expression vectors for use in well-known expression systems (including

both prokaryotic and eukaryotic systems), such as pSE420 (Invitrogen, San Diego, Calif.), which can be used for production and/or expression of protein in *Escherichia coli*; pYES2 (Invitrogen, Thermo Fisher Scientific), which can be used for production and/or expression in *Saccharomyces cerevisiae* strains of yeast; MAXBAC[®] complete baculovirus expression system (Thermo Fisher Scientific), which can be used for production and/or expression in insect cells; pcDNA[™] or pcDNA3[™] (Life Technologies, Thermo Fisher Scientific), which can be used for high level constitutive protein expression in mammalian cells; and pVAX or pVAX-1 (Life Technologies, Thermo Fisher Scientific), which can be used for high-level transient expression of a protein of interest in most mammalian cells. The backbone of any commercially available DNA plasmid can be modified to optimize protein expression in the host cell, such as to reverse the orientation of certain elements (e.g., origin of replication and/or antibiotic resistance cassette), replace a promoter endogenous to the plasmid (e.g., the promoter in the antibiotic resistance cassette), and/or replace the polynucleotide sequence encoding transcribed proteins (e.g., the coding sequence of the antibiotic resistance gene), by using routine techniques and readily available starting materials. (See e.g., Sambrook et al., *Molecular Cloning a Laboratory Manual*, Second Ed. Cold Spring Harbor Press (1989)).

Preferably, a DNA plasmid is an expression vector suitable for protein expression in mammalian host cells. Expression vectors suitable for protein expression in mammalian host cells include, but are not limited to, pcDNA[™], pcDNA3[™], pVAX, pVAX-1, ADVAX, NTC8454, etc. Preferably, an expression vector is based on pVAX-1, which can be further modified to optimize protein expression in mammalian cells. pVAX-1 is a commonly used plasmid in DNA vaccines, and contains a strong human immediate early cytomegalovirus (CMV-IE) promoter followed by the bovine growth hormone (bGH)-derived polyadenylation sequence (pA). pVAX-1 further contains a pUC origin of replication and a kanamycin resistance gene driven by a small prokaryotic promoter that allows for bacterial plasmid propagation.

A vector of the application can also be a viral vector. In general, viral vectors are genetically engineered viruses carrying modified viral DNA or RNA that has been rendered non-infectious, but still contains viral promoters and transgenes, thus allowing for translation of the transgene through a viral promoter. Because viral vectors are frequently lacking infectious sequences, they require helper viruses or packaging lines for large-scale transfection. Examples of viral vectors that can be used include, but are not limited to, adenoviral vectors, adeno-associated virus vectors, pox virus vectors, enteric virus vectors, Venezuelan Equine Encephalitis virus vectors, Semliki Forest Virus vectors, Tobacco Mosaic Virus vectors, lentiviral vectors, arenavirus viral vectors, replication-deficient arenavirus viral vectors or replication-competent

arenavirus viral vectors, bi-segmented or tri-segmented arenavirus, infectious arenavirus viral vectors, nucleic acids which comprise an arenavirus genomic segment wherein one open reading frame of the genomic segment is deleted or functionally inactivated (and replaced by a nucleic acid encoding an HBV antigen as described herein), arenavirus such as lymphocytic
5 choriomeningitidis virus (LCMV), e.g., clone 13 strain or MP strain, and arenavirus such as Junin virus e.g., Candid #1 strain, etc. The vector can also be a non-viral vector.

Preferably, a viral vector is an adenovirus vector, e.g., a recombinant adenovirus vector. A recombinant adenovirus vector can for instance be derived from a human adenovirus (HAdV, or AdHu), or a simian adenovirus such as chimpanzee or gorilla adenovirus (ChAd, AdCh, or
10 SAdV) or rhesus adenovirus (rhAd). Preferably, an adenovirus vector is a recombinant human adenovirus vector, for instance a recombinant human adenovirus serotype 26, or any one of recombinant human adenovirus serotype 5, 4, 35, 7, 48, etc. In other embodiments, an adenovirus vector is a rhAd vector, e.g. rhAd51, rhAd52 or rhAd53. A recombinant viral vector useful for the application can be prepared using methods known in the art in view of the present
15 disclosure. For example, in view of the degeneracy of the genetic code, several nucleic acid sequences can be designed that encode the same polypeptide. A polynucleotide encoding an HBV antigen of the application can optionally be codon-optimized to ensure proper expression in the host cell (e.g., bacterial or mammalian cells). Codon-optimization is a technology widely applied in the art, and methods for obtaining codon-optimized polynucleotides will be well
20 known to those skilled in the art in view of the present disclosure.

A vector of the application, e.g., a DNA plasmid or a viral vector (particularly an adenoviral vector), can comprise any regulatory elements to establish conventional function(s) of the vector, including but not limited to replication and expression of the HBV antigen(s) encoded by the polynucleotide sequence of the vector. Regulatory elements include, but are not limited
25 to, a promoter, an enhancer, a polyadenylation signal, translation stop codon, a ribosome binding element, a transcription terminator, selection markers, origin of replication, etc. A vector can comprise one or more expression cassettes. An “expression cassette” is part of a vector that directs the cellular machinery to make RNA and protein. An expression cassette typically comprises three components: a promoter sequence, an open reading frame, and a 3'-untranslated
30 region (UTR) optionally comprising a polyadenylation signal. An open reading frame (ORF) is a reading frame that contains a coding sequence of a protein of interest (e.g., HBV antigen) from a start codon to a stop codon. Regulatory elements of the expression cassette can be operably linked to a polynucleotide sequence encoding an HBV antigen of interest. As used herein, the term “operably linked” is to be taken in its broadest reasonable context, and refers to a linkage of

polynucleotide elements in a functional relationship. A polynucleotide is “operably linked” when it is placed into a functional relationship with another polynucleotide. For instance, a promoter is operably linked to a coding sequence if it affects the transcription of the coding sequence. Any components suitable for use in an expression cassette described herein can be used in any combination and in any order to prepare vectors of the application.

A vector can comprise a promoter sequence, preferably within an expression cassette, to control expression of an HBV antigen of interest. The term “promoter” is used in its conventional sense, and refers to a nucleotide sequence that initiates the transcription of an operably linked nucleotide sequence. A promoter is located on the same strand near the nucleotide sequence it transcribes. Promoters can be constitutive, inducible, or repressible. Promoters can be naturally occurring or synthetic. A promoter can be derived from sources including viral, bacterial, fungal, plants, insects, and animals. A promoter can be a homologous promoter (i.e., derived from the same genetic source as the vector) or a heterologous promoter (i.e., derived from a different vector or genetic source). For example, if the vector to be employed is a DNA plasmid, the promoter can be endogenous to the plasmid (homologous) or derived from other sources (heterologous). Preferably, the promoter is located upstream of the polynucleotide encoding an HBV antigen within an expression cassette.

Examples of promoters that can be used include, but are not limited to, a promoter from simian virus 40 (SV40), a mouse mammary tumor virus (MMTV) promoter, a human immunodeficiency virus (HIV) promoter such as the bovine immunodeficiency virus (BIV) long terminal repeat (LTR) promoter, a Moloney virus promoter, an avian leukosis virus (ALV) promoter, a cytomegalovirus (CMV) promoter such as the CMV immediate early promoter (CMV-IE), Epstein Barr virus (EBV) promoter, or a Rous sarcoma virus (RSV) promoter. A promoter can also be a promoter from a human gene such as human actin, human myosin, human hemoglobin, human muscle creatine, or human metallothionein. A promoter can also be a tissue specific promoter, such as a muscle or skin specific promoter, natural or synthetic.

Preferably, a promoter is a strong eukaryotic promoter, preferably a cytomegalovirus immediate early (CMV-IE) promoter. Nucleotide sequences of exemplary CMV-IE promoters are shown in SEQ ID NO: 7, SEQ ID NO: 17, and SEQ ID NO: 25.

A vector can comprise additional polynucleotide sequences that stabilize the expressed transcript, enhance nuclear export of the RNA transcript, and/or improve transcriptional-translational coupling. Examples of such sequences include polyadenylation signals and enhancer sequences. A polyadenylation signal is typically located downstream of the coding sequence for a protein of interest (e.g., an HBV antigen) within an expression cassette of the

vector. Enhancer sequences are regulatory DNA sequences that, when bound by transcription factors, enhance the transcription of an associated gene. An enhancer sequence is preferably located upstream of the polynucleotide sequence encoding an HBV antigen, but downstream of a promoter sequence within an expression cassette of the vector.

5 Any polyadenylation signal known to those skilled in the art in view of the present disclosure can be used. For example, the polyadenylation signal can be a SV40 polyadenylation signal, LTR polyadenylation signal, bovine growth hormone (bGH) polyadenylation signal, human growth hormone (hGH) polyadenylation signal, or human β -globin polyadenylation signal. Preferably, a polyadenylation signal is a bovine growth hormone (bGH) polyadenylation
10 signal or a SV40 polyadenylation signal. A nucleotide sequence of an exemplary bGH polyadenylation signal is shown in SEQ ID NO: 11. A nucleotide sequence of an exemplary SV40 polyadenylation signal is shown in SEQ ID NO: 24.

Any enhancer sequence known to those skilled in the art in view of the present disclosure can be used. For example, an enhancer sequence can be a human actin, human myosin, human
15 hemoglobin, human muscle creatine, or a viral enhancer, such as one from CMV, HA, RSV, or EBV. Examples of particular enhancers include, but are not limited to, Woodchuck HBV Post-transcriptional regulatory element (WPRE), intron/exon sequence derived from human apolipoprotein A1 precursor (ApoA1), untranslated R-U5 domain of the human T-cell leukemia virus type 1 (HTLV-1) long terminal repeat (LTR), a splicing enhancer, a synthetic rabbit β -
20 globin intron, or any combination thereof. Preferably, an enhancer sequence is a composite sequence of three consecutive elements of the untranslated R-U5 domain of HTLV-1 LTR, rabbit β -globin intron, and a splicing enhancer, which is referred to herein as “a triple enhancer sequence.” A nucleotide sequence of an exemplary triple enhancer sequence is shown in SEQ ID NO: 8. Another exemplary enhancer sequence is an ApoA1 gene fragment shown in SEQ ID
25 NO: 23.

A vector can comprise a polynucleotide sequence encoding a signal peptide sequence. Preferably, the polynucleotide sequence encoding the signal peptide sequence is located upstream of the polynucleotide sequence encoding an HBV antigen. Signal peptides typically direct localization of a protein, facilitate secretion of the protein from the cell in which it is
30 produced, and/or improve antigen expression and cross-presentation to antigen-presenting cells. A signal peptide can be present at the N-terminus of an HBV antigen when expressed from the vector, but is cleaved off by signal peptidase, e.g., upon secretion from the cell. An expressed protein in which a signal peptide has been cleaved is often referred to as the “mature protein.” Any signal peptide known in the art in view of the present disclosure can be used. For example,

a signal peptide can be a cystatin S signal peptide; an immunoglobulin (Ig) secretion signal, such as the Ig heavy chain gamma signal peptide SPIgG or the Ig heavy chain epsilon signal peptide SPIgE.

Preferably, a signal peptide sequence is a cystatin S signal peptide. Exemplary nucleic acid and amino acid sequences of a cystatin S signal peptide are shown in SEQ ID NOs: 5 and 6, respectively. Exemplary nucleic acid and amino acid sequences of an immunoglobulin (Ig) secretion signal are shown in SEQ ID NOs: 18 and 19, respectively.

A vector, such as a DNA plasmid, can also include a bacterial origin of replication and an antibiotic resistance expression cassette for selection and maintenance of the plasmid in bacterial cells, e.g., *E. coli*. Bacterial origins of replication and antibiotic resistance cassettes can be located in a vector in the same orientation as the expression cassette encoding an HBV antigen, or in the opposite (reverse) orientation. An origin of replication (ORI) is a sequence at which replication is initiated, enabling a plasmid to reproduce and survive within cells. Examples of ORIs suitable for use in the application include, but are not limited to ColE1, pMB1, pUC, pSC101, R6K, and 15A, preferably pUC. An exemplary nucleotide sequence of a pUC ORI is shown in SEQ ID NO: 10.

Expression cassettes for selection and maintenance in bacterial cells typically include a promoter sequence operably linked to an antibiotic resistance gene. Preferably, the promoter sequence operably linked to an antibiotic resistance gene differs from the promoter sequence operably linked to a polynucleotide sequence encoding a protein of interest, e.g., HBV antigen. The antibiotic resistance gene can be codon optimized, and the sequence composition of the antibiotic resistance gene is normally adjusted to bacterial, e.g., *E. coli*, codon usage. Any antibiotic resistance gene known to those skilled in the art in view of the present disclosure can be used, including, but not limited to, kanamycin resistance gene (Kan^r), ampicillin resistance gene (Amp^r), and tetracycline resistance gene (Tet^r), as well as genes conferring resistance to chloramphenicol, bleomycin, spectinomycin, carbenicillin, etc.

Preferably, an antibiotic resistance gene in the antibiotic expression cassette of a vector is a kanamycin resistance gene (Kan^r). The sequence of Kan^r gene is shown in SEQ ID NO: 13. Preferably, the Kan^r gene is codon optimized. An exemplary nucleic acid sequence of a codon optimized Kan^r gene is shown in SEQ ID NO: 12. The Kan^r can be operably linked to its native promoter, or the Kan^r gene can be linked to a heterologous promoter. In a particular embodiment, the Kan^r gene is operably linked to the ampicillin resistance gene (Amp^r) promoter, known as the bla promoter. An exemplary nucleotide sequence of a bla promoter is shown in SEQ ID NO: 9.

In a particular embodiment of the application, a vector is a DNA plasmid comprising an expression cassette including:

- (i) a polynucleotide encoding at least one of an HBV antigen selected from the group consisting of an HBV pol antigen comprising an amino acid sequence at least 98% identical to the amino acid sequence of SEQ ID NO: 4, such as at least 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 4; a truncated HBV core antigen consisting of the amino acid sequence of SEQ ID NO: 2; a first HBV surface antigen consisting of an amino acid sequence this is at least 95% identical to the amino acid sequence of SEQ ID NO: 29, such as at least 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9%, or 100% identical to the amino acid sequence of SEQ ID NO: 29; and a second HBV surface antigen consisting of an amino acid sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 27, such as at least 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to the amino acid sequence of SEQ ID NO: 27;
- (ii) an upstream sequence operably linked to the polynucleotide encoding the HBV antigen comprising, from 5' end to 3' end, a promoter sequence, preferably a CMV promoter sequence of SEQ ID NO: 7 or SEQ ID NO: 25, an enhancer sequence, preferably a triple enhancer sequence of SEQ ID NO: 8, and a polynucleotide sequence encoding a signal peptide sequence, preferably a cystatin S signal peptide having the amino acid sequence of SEQ ID NO: 6; and
- (iii) a downstream sequence operably linked to the polynucleotide encoding the HBV antigen comprising a polyadenylation signal, preferably a bGH polyadenylation signal of SEQ ID NO: 11.

Such vector further comprises an antibiotic resistance expression cassette including a polynucleotide encoding an antibiotic resistance gene, preferably a Kan^r gene, more preferably a codon optimized Kan^r gene that is at least 90% identical to SEQ ID NO: 12, such as at least 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 12, preferably 100% identical to SEQ ID NO: 12, operably linked to an Amp^r (bla) promoter of SEQ ID NO: 9, upstream of and operably linked to the polynucleotide encoding the antibiotic resistance gene; and an origin of replication, preferably a pUC ori of SEQ ID NO: 10. Preferably, the antibiotic resistance cassette and the origin of replication are present in the

plasmid in the reverse orientation relative to the HBV antigen expression cassette. Exemplary DNA plasmids comprising the above-mentioned features are shown in FIGS. 3A-3D.

In another particular embodiment of the application, a vector is a viral vector, preferably an adenoviral vector, more preferably an Ad26 or Ad35 vector, comprising an expression cassette including:

- (i) a polynucleotide encoding at least one of an HBV antigen selected from the group consisting of an HBV pol antigen comprising an amino acid sequence at least 98% identical to the amino acid sequence of SEQ ID NO: 4, such as at least 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 4; a truncated HBV core antigen consisting of the amino acid sequence of SEQ ID NO: 4; a first HBV surface antigen consisting of an amino acid sequence this is at least 95% identical to the amino acid sequence of SEQ ID NO: 29, such as at least 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9%, or 100% identical to the amino acid sequence of SEQ ID NO: 29; and a second HBV surface antigen consisting of an amino acid sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 27, such as at least 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to the amino acid sequence of SEQ ID NO: 27;
- (ii) an upstream sequence operably linked to the polynucleotide encoding the HBV antigen comprising, from 5' end to 3' end, a promoter sequence, preferably a CMV promoter sequence of SEQ ID NO: 17, an enhancer sequence, preferably an ApoAI gene fragment sequence of SEQ ID NO: 23, and a polynucleotide sequence encoding a signal peptide sequence, preferably an immunoglobulin secretion signal having the amino acid sequence of SEQ ID NO: 19; and
- (iii) a downstream sequence operably linked to the polynucleotide encoding the HBV antigen comprising a polyadenylation signal, preferably a SV40 polyadenylation signal of SEQ ID NO: 24.

In an embodiment of the application, a vector, such as a plasmid DNA vector or a viral vector (preferably an adenoviral vector, more preferably an Ad26 or Ad35 vector), encodes an HBV Pol antigen having the amino acid sequence of SEQ ID NO: 4. Preferably, the vector comprises a coding sequence for the HBV Pol antigen that is at least 90% identical to the polynucleotide sequence of SEQ ID NO: 3, such as 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%,

99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 3, preferably 100% identical to SEQ ID NO: 3.

In an embodiment of the application, a vector, such as a plasmid DNA vector or a viral vector (preferably an adenoviral vector, more preferably an Ad26 or Ad35 vector), encodes a truncated HBV core antigen consisting of the amino acid sequence of SEQ ID NO: 2 or SEQ ID NO: 14. Preferably, the vector comprises a coding sequence for the truncated HBV core antigen that is at least 90% identical to the polynucleotide sequence of SEQ ID NO: 1 or SEQ ID NO: 15, such as 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 1 or SEQ ID NO: 15, preferably 100% identical to SEQ ID NO: 1 or SEQ ID NO: 15.

In yet another embodiment of the application, a vector, such as a plasmid DNA vector or a viral vector (preferably an adenoviral vector, more preferably an Ad26 or Ad35 vector), encodes a fusion protein comprising an HBV Pol antigen having the amino acid sequence of SEQ ID NO: 4 and a truncated HBV core antigen consisting of the amino acid sequence of SEQ ID NO: 2 or SEQ ID NO: 14. Preferably, the vector comprises a coding sequence for the fusion, which contains a coding sequence for the truncated HBV core antigen at least 90% identical to SEQ ID NO: 1 or SEQ ID NO: 15, such as at least 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 1 or SEQ ID NO: 15, preferably 98%, 99% or 100% identical to SEQ ID NO: 1 or SEQ ID NO: 15, more preferably SEQ ID NO: 15, operably linked to a coding sequence for the HBV Pol antigen at least 90% identical to SEQ ID NO: 3 or SEQ ID NO: 16, such as at least 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 3 or SEQ ID NO: 16, preferably 98%, 99% or 100% identical to SEQ ID NO: 3 or SEQ ID NO: 16, more preferably SEQ ID NO: 16.

Preferably, the coding sequence for the truncated HBV core antigen is operably linked to the coding sequence for the HBV Pol antigen via a coding sequence for a linker that is at least 90% identical to SEQ ID NO: 22, such as at least 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 22, preferably 98%, 99% or 100% identical to SEQ ID NO: 22. In particular embodiments of the application, a vector comprises a coding sequence for the fusion having SEQ ID NO: 15 operably linked to SEQ ID NO: 22, which is further operably linked to SEQ ID NO: 16.

In an embodiment of the application, a vector, such as a plasmid DNA vector or a viral vector (preferably an adenoviral vector, more preferably an Ad26 or Ad35 vector), encodes an S-surface antigen consisting of an amino acid sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 27, such as at least 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 27, preferably 98%, 99% or 100% identical to SEQ ID NO: 27. Preferably, the vector comprises a coding sequence for the S-surface antigen that is at least 90% identical to the polynucleotide sequence of SEQ ID NO: 26, such as 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 26, preferably 100% identical to SEQ ID NO: 26.

In an embodiment of the application, a vector, such as a plasmid DNA vector or a viral vector (preferably an adenoviral vector, more preferably an Ad26 or Ad35 vector), encodes an HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to the amino acid sequence of SEQ ID NO: 29, such as at least 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 29, preferably 98%, 99% or 100% identical to SEQ ID NO: 29. Preferably, the vector comprises a coding sequence for the HBV surface antigen that is at least 90% identical to the polynucleotide sequence of SEQ ID NO: 28, such as 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 28, preferably 100% identical to SEQ ID NO: 28.

The polynucleotides and expression vectors encoding the HBV antigens of the application can be made by any method known in the art in view of the present disclosure. For example, a polynucleotide encoding an HBV antigen can be introduced or “cloned” into an expression vector using standard molecular biology techniques, e.g., polymerase chain reaction (PCR), etc., which are well known to those skilled in the art.

Cells, Polypeptides and Antibodies

The application also provides cells, preferably isolated cells, comprising any of the polynucleotides and vectors described herein. The cells can, for instance, be used for recombinant protein production, or for the production of viral particles.

Embodiments of the application thus also relate to a method of making an HBV antigen of the application. The method comprises transfecting a host cell with an expression vector comprising a polynucleotide encoding an HBV antigen of the application operably linked to a promoter, growing the transfected cell under conditions suitable for expression of the HBV

antigen, and optionally purifying or isolating the HBV antigen expressed in the cell. The HBV antigen can be isolated or collected from the cell by any method known in the art including affinity chromatography, size exclusion chromatography, etc. Techniques used for recombinant protein expression will be well known to one of ordinary skill in the art in view of the present disclosure. The expressed HBV antigens can also be studied without purifying or isolating the expressed protein, e.g., by analyzing the supernatant of cells transfected with an expression vector encoding the HBV antigen and grown under conditions suitable for expression of the HBV antigen.

Thus, also provided are non-naturally occurring or recombinant polypeptides comprising an amino acid sequence of an HBV antigen as described herein. As described above and below, isolated nucleic acid molecules encoding these sequences, vectors comprising these sequences operably linked to a promoter, and compositions comprising the polypeptide, polynucleotide, or vector are also contemplated by the application.

In an embodiment of the application, a non-naturally occurring or recombinant polypeptide comprises an amino acid sequence that is at least 90% identical to the amino acid sequence of SEQ ID NO: 2, such as 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 2. Preferably, a non-naturally occurring or recombinant polypeptide consists of SEQ ID NO: 2.

In another embodiment of the application, a non-naturally occurring or recombinant polypeptide comprises an amino acid sequence that is at least 90% identical to the amino acid sequence of SEQ ID NO: 4, such as 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 4. Preferably, a non-naturally occurring or recombinant polypeptide comprises SEQ ID NO: 4.

In another embodiment of the application, a non-naturally occurring or recombinant polypeptide comprises an amino acid sequence that is at least 90% identical to the amino acid sequence of SEQ ID NO: 14, such as 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 14. Preferably, a non-naturally occurring or recombinant polypeptide consists of SEQ ID NO: 14.

In an embodiment of the application, a non-naturally occurring or recombinant polypeptide consists of an amino acid sequence that is at least 95% identical to the amino acid sequence of SEQ ID NO: 29, such as 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%,

99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 29. Preferably, a non-naturally occurring or recombinant polypeptide consists of SEQ ID NO: 29.

In another embodiment of the application, a non-naturally occurring or recombinant polypeptide consists of an amino acid sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 27, such as 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 27. Preferably, a non-naturally occurring or recombinant polypeptide consists of the amino acid sequence of SEQ ID NO: 27.

Also provided are antibodies or antigen binding fragments thereof that specifically bind to a non-naturally occurring polypeptide of the application. In an embodiment of the application, an antibody specific to a non-naturally occurring HBV antigen of the application does not bind specifically to another HBV antigen. For example, an antibody of the application that binds specifically to an S-surface antigen having the amino acid sequence of SEQ ID NO: 27 will not bind specifically to an S-surface antigen not having the amino acid sequence of SEQ ID NO: 27.

As used herein, the term “antibody” includes polyclonal, monoclonal, chimeric, humanized, Fv, Fab and F(ab')₂; bifunctional hybrid (e.g., Lanzavecchia et al., *Eur. J. Immunol.* 17:105, 1987), single-chain (Huston et al., *Proc. Natl. Acad. Sci. USA* 85:5879, 1988; Bird et al., *Science* 242:423, 1988); and antibodies with altered constant regions (e.g., U.S. Pat. No. 5,624,821).

As used herein, an antibody that “specifically binds to” an antigen refers to an antibody that binds to the antigen with a KD of 1×10^{-7} M or less. Preferably, an antibody that “specifically binds to” an antigen binds to the antigen with a KD of 1×10^{-8} M or less, more preferably 5×10^{-9} M or less, 1×10^{-9} M or less, 5×10^{-10} M or less, or 1×10^{-10} M or less. The term “KD” refers to the dissociation constant, which is obtained from the ratio of K_d to K_a (i.e., K_d/K_a) and is expressed as a molar concentration (M). KD values for antibodies can be determined using methods known in the art in view of the present disclosure. For example, the KD of an antibody can be determined by using surface plasmon resonance, such as by using a biosensor system, e.g., a Biacore® system, or by using bio-layer interferometry technology, such as an Octet RED96 system.

The smaller the value of the KD of an antibody, the higher affinity that the antibody binds to a target antigen.

Compositions, Immunogenic Combinations, and Vaccines

The application also relates to compositions, immunogenic combinations, more particularly kits, and vaccines comprising one or more HBV antigens, polynucleotides, and/or

vectors encoding one or more HBV antigens according to the application. Any of the HBV antigens, polynucleotides (including RNA and DNA), and/or vectors of the application described herein can be used in the compositions, immunogenic combinations or kits, and vaccines of the application.

- 5 The application provides a composition comprising an isolated or non-naturally occurring nucleic acid molecule (DNA or RNA) encoding a truncated HBV core antigen consisting of an amino acid sequence that is at least 90% identical to SEQ ID NO: 2 or SEQ ID NO: 14, an HBV polymerase antigen comprising an amino acid sequence that is at least 90% identical to SEQ ID NO: 4, an HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to the SEQ ID NO: 29, an HBV surface antigen consisting of an amino acid sequence that is at least 98% identical to SEQ ID NO: 27, a vector comprising the isolated or non-naturally occurring nucleic acid molecule, and/or an isolated or non-naturally occurring polypeptide encoded by the isolated or non-naturally occurring nucleic acid molecule.

- 15 In an embodiment of the application, a composition comprises an isolated or non-naturally occurring nucleic acid molecule (DNA or RNA) encoding a truncated HBV core antigen consisting of an amino acid sequence that is at least 90% identical to SEQ ID NO: 2 or SEQ ID NO: 14, preferably 100% identical to SEQ ID NO: 2 or SEQ ID NO: 14.

- 20 In an embodiment of the application, a composition comprises an isolated or non-naturally occurring nucleic acid molecule (DNA or RNA) encoding an HBV Pol antigen comprising an amino acid sequence that is at least 90% identical to SEQ ID NO: 4, preferably 100% identical to SEQ ID NO: 4.

- 25 In an embodiment of the application, a composition comprises an isolated or non-naturally occurring nucleic acid molecule (DNA or RNA) encoding an S-surface antigen consisting of an amino acid sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 27, preferably 100% identical to SEQ ID NO: 27.

- 30 In an embodiment of the application, a composition comprises an isolated or non-naturally occurring nucleic acid molecule (DNA or RNA) encoding an HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to the amino acid sequence of SEQ ID NO: 29, preferably 100% identical to SEQ ID NO: 29.

- In an embodiment of the application, a composition comprises an isolated or non-naturally occurring nucleic acid molecule (DNA or RNA) comprising a polynucleotide sequence encoding a truncated HBV core antigen consisting of an amino acid sequence that is at least 90% identical to SEQ ID NO: 2 or SEQ ID NO: 14, preferably 100% identical to SEQ ID NO: 2 or SEQ ID NO: 14; and an isolated or non-naturally occurring nucleic acid molecule (DNA or

RNA) comprising a polynucleotide sequence encoding a HBV Pol antigen comprising an amino acid sequence that is at least 90% identical to SEQ ID NO: 4, preferably 100% identical to SEQ ID NO: 4. The coding sequences for the truncated HBV core antigen and the HBV Pol antigen can be present in the same isolated or non-naturally occurring nucleic acid molecule (DNA or RNA), or in two different isolated or non-naturally occurring nucleic acid molecules (DNA or RNA).

In an embodiment of the application, a composition comprises an isolated or non-naturally occurring nucleic acid molecule (DNA or RNA) comprising a polynucleotide sequence encoding an HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to SEQ ID NO: 29, preferably 100% identical to SEQ ID NO: 29; and an isolated or non-naturally occurring nucleic acid molecule (DNA or RNA) comprising a polynucleotide sequence encoding an S-surface antigen consisting of an amino acid sequence that is at least 98% identical to 27, preferably 100% identical to SEQ ID NO: 27. The coding sequences for different HBV surface antigen described herein can be present in the same isolated or non-naturally occurring nucleic acid molecule (DNA or RNA), or in two different isolated or non-naturally occurring nucleic acid molecules (DNA or RNA). Preferably, the coding sequences for the HBV surface antigens described herein (e.g., coding sequence for HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to SEQ ID NO: 29 and coding sequence for HBV surface antigen consisting of an amino acid sequence that is at least 98% identical to SEQ ID NO: 27) are present in two different isolated or non-naturally occurring nucleic acid molecules (DNA or RNA).

In an embodiment of the application, a composition comprises an isolated or non-naturally occurring nucleic acid molecule (DNA or RNA) comprising a polynucleotide sequence encoding an HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to SEQ ID NO: 29, preferably 100% identical to SEQ ID NO: 29; an isolated or non-naturally occurring nucleic acid molecule (DNA or RNA) comprising a polynucleotide sequence encoding an S-surface antigen consisting of an amino acid sequence that is at least 98% identical to 27, preferably 100% identical to SEQ ID NO: 27; and optionally at least one of an isolated or non-naturally occurring nucleic acid molecule (DNA or RNA) comprising a polynucleotide sequence encoding a truncated HBV core antigen consisting of an amino acid sequence that is at least 90% identical to SEQ ID NO: 2 or SEQ ID NO: 14, preferably 100% identical to SEQ ID NO: 2 or SEQ ID NO: 14; and an isolated or non-naturally occurring nucleic acid molecule (DNA or RNA) comprising a polynucleotide sequence encoding a HBV Pol antigen comprising an amino acid sequence that is at least 90% identical to SEQ ID NO: 4, preferably 100%

identical to SEQ ID NO: 4. The coding sequences for the HBV surface antigens, truncated HBV core antigen and the HBV Pol antigen can be present in the same isolated or non-naturally occurring nucleic acid molecule (DNA or RNA), or in two or more different isolated or non-naturally occurring nucleic acid molecules (DNA or RNA), preferably in two or more different isolated or non-naturally occurring nucleic acid molecules.

In an embodiment of the application, a composition comprises a vector, preferably a DNA plasmid or a viral vector (such as an adenoviral vector) comprising a polynucleotide encoding a truncated HBV core antigen consisting of an amino acid sequence that is at least 90% identical to SEQ ID NO: 2 or SEQ ID NO: 14, preferably 100% identical to SEQ ID NO: 2 or SEQ ID NO: 14.

In an embodiment of the application, a composition comprises a vector, preferably a DNA plasmid or a viral vector (such as an adenoviral vector), comprising a polynucleotide encoding a HBV Pol antigen comprising an amino acid sequence that is at least 90% identical to SEQ ID NO: 4, preferably 100% identical to SEQ ID NO: 4.

In an embodiment of the application, a composition comprises a vector, preferably a DNA plasmid or viral vector (such as an adenoviral vector), comprising a polynucleotide encoding an S-surface antigen consisting of an amino acid sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 27, preferably 100% identical to SEQ ID NO: 27.

In an embodiment of the application a composition comprises a vector, preferably a DNA plasmid or viral vector (such as an adenoviral vector), comprising a polynucleotide encoding an HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to the amino acid sequence of SEQ ID NO: 29, preferably 100% identical to SEQ ID NO: 29.

In an embodiment of the application, a composition comprises a vector, preferably a DNA plasmid or a viral vector (such as an adenoviral vector), comprising a polynucleotide encoding a truncated HBV core antigen consisting of an amino acid sequence that is at least 90% identical to SEQ ID NO: 2 or SEQ ID NO: 14, preferably 100% identical to SEQ ID NO: 2 or SEQ ID NO: 14; and a vector, preferably a DNA plasmid or a viral vector (such as an adenoviral vector), comprising a polynucleotide encoding a HBV Pol antigen comprising an amino acid sequence that is at least 90% identical to SEQ ID NO: 4, preferably 100% identical to SEQ ID NO: 4. The vector comprising the coding sequence for the truncated HBV core antigen and the vector comprising the coding sequence for the HBV Pol antigen can be in the same vector, or two different vectors.

In an embodiment of the application, a composition comprises a vector, preferably a DNA plasmid or a viral vector (such as an adenoviral vector), comprising a polynucleotide

encoding an HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to SEQ ID NO: 29, preferably 100% identical to SEQ ID NO: 29; and a vector, preferably a DNA plasmid or a viral vector (such as an adenoviral vector), comprising a polynucleotide sequence encoding an S-surface antigen consisting of an amino acid sequence that is at least 98% identical to SEQ ID NO: 27, preferably 100% identical to SEQ ID NO: 27. The vector comprising the coding sequence for the different HBV surface antigens can be in the same vector, or two different vectors. Preferably, the vector comprising the coding sequence for an HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to SEQ ID NO: 29 and the vector comprising the coding sequence for the S-surface antigen consisting of an amino acid sequence that is at least 98% identical to SEQ ID NO: 27 are in two different vectors, particularly when the vector is a DNA plasmid. However, embodiments in which the coding sequence for the aforementioned surface antigens are present in the same vector, particularly when the vector is a viral vector, e.g., adenoviral vector, are also contemplated by the application.

In an embodiment of the application, a composition comprises a vector, preferably a DNA plasmid or a viral vector (such as an adenoviral vector), comprising a polynucleotide sequence encoding an HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to SEQ ID NO: 29, preferably 100% identical to SEQ ID NO: 29; a vector, preferably a DNA plasmid or a viral vector (such as an adenoviral vector), comprising a polynucleotide sequence encoding an S-surface antigen consisting of an amino acid sequence that is at least 98% identical to SEQ ID NO: 27, preferably 100% identical to SEQ ID NO: 27; and optionally at least one of a vector, preferably a DNA plasmid or a viral vector (such as an adenoviral vector), comprising a polynucleotide sequence encoding a truncated HBV core antigen consisting of an amino acid sequence that is at least 90% identical to SEQ ID NO: 2 or SEQ ID NO: 14, preferably 100% identical to SEQ ID NO: 2 or SEQ ID NO: 14; and a vector, preferably a DNA plasmid or a viral vector (such as an adenoviral vector), comprising a polynucleotide sequence encoding a HBV Pol antigen comprising an amino acid sequence that is at least 90% identical to SEQ ID NO: 4, preferably 100% identical to SEQ ID NO: 4. The vector comprising the coding sequence for the HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to SEQ ID NO: 29, the vector comprising the coding sequence for the S-surface antigen consisting of an amino acid sequence that is at least 98% identical to SEQ ID NO: 27, the vector comprising the coding sequence for the truncated HBV core antigen and the vector comprising the coding sequence for the HBV Pol antigen can be present in the same vector or in two or more different vectors.

In an embodiment of the application, a composition comprises a vector, preferably a DNA plasmid or a viral vector (such as an adenoviral vector), comprising a polynucleotide encoding a fusion protein comprising a truncated HBV core antigen consisting of an amino acid sequence that is at least 90% identical to SEQ ID NO: 2 or SEQ ID NO: 14, preferably 100% identical to SEQ ID NO: 2 or SEQ ID NO: 14, operably linked to a HBV Pol antigen comprising an amino acid sequence that is at least 90% identical to SEQ ID NO: 4, preferably 100% identical to SEQ ID NO: 4, or *vice versa*. Preferably, the fusion protein further comprises a linker that operably links the truncated HBV core antigen to the HBV Pol antigen, or *vice versa*. Preferably, the linker has the amino acid sequence of (AlaGly)_n, wherein n is an integer of 2 to 5.

In an embodiment of the application, a composition comprises an isolated or non-naturally occurring truncated HBV core antigen consisting of an amino acid sequence that is at least 90% identical to SEQ ID NO: 2 or SEQ ID NO: 14, preferably 100% identical to SEQ ID NO: 2 or SEQ ID NO: 14.

In an embodiment of the application, a composition comprises an isolated or non-naturally occurring HBV Pol antigen comprising an amino acid sequence that is at least 90% identical to SEQ ID NO: 4, preferably 100% identical to SEQ ID NO: 4.

In an embodiment of the application, a composition comprises an isolated or non-naturally occurring truncated HBV core antigen consisting of an amino acid sequence that is at least 90% identical to SEQ ID NO: 2 or SEQ ID NO: 14, preferably 100% identical to SEQ ID NO: 2 or SEQ ID NO: 14; and an isolated or non-naturally occurring HBV Pol antigen comprising an amino acid sequence that is at least 90% identical to SEQ ID NO: 4, preferably 100% identical to SEQ ID NO: 4.

In an embodiment of the application, a composition comprises an isolated or non-naturally occurring fusion protein comprising a truncated HBV core antigen consisting of an amino acid sequence that is at least 90% identical to SEQ ID NO: 2 or SEQ ID NO: 14, preferably 100% identical to SEQ ID NO: 2 or SEQ ID NO: 14, operably linked to a HBV Pol antigen comprising an amino acid sequence that is at least 90% identical to SEQ ID NO: 4, preferably 100% identical to SEQ ID NO: 4, or *vice versa*. Preferably, the fusion protein further comprises a linker that operably links the truncated HBV core antigen to the HBV Pol antigen, or *vice versa*. Preferably, the linker has the amino acid sequence of (AlaGly)_n, wherein n is an integer of 2 to 5.

In an embodiment of the application, a composition comprises an isolated or non-naturally occurring HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to SEQ ID NO: 29, preferably 100% identical to SEQ ID NO: 29.

In an embodiment of the application a composition comprises an isolated or non-naturally occurring S-surface antigen consisting of an amino acid sequence that is at least 98% identical to the SEQ ID NO: 27, preferably 100% identical to SEQ ID NO: 27.

5 In an embodiment of the application, a composition comprises an isolated or non-naturally occurring HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to SEQ ID NO: 29, preferably 100% identical to SEQ ID NO: 29; and an isolated or non-naturally occurring S-surface antigen consisting of an amino acid sequence that is at least 98% identical to the SEQ ID NO: 27, preferably 100% identical to SEQ ID NO: 27.

10 In an embodiment of the application, a composition comprises an isolated or non-naturally occurring HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to SEQ ID NO: 29, preferably 100% identical to SEQ ID NO: 29; an isolated or non-naturally occurring S-surface antigen consisting of an amino acid sequence that is at least 98% identical to the SEQ ID NO: 27, preferably 100% identical to SEQ ID NO: 27; and optionally at least one of an isolated or non-naturally occurring truncated HBV core antigen
15 consisting of an amino acid sequence that is at least 90% identical to SEQ ID NO: 2 or SEQ ID NO: 14, preferably 100% identical to SEQ ID NO: 2 or SEQ ID NO: 14; and an isolated or non-naturally occurring HBV Pol antigen comprising an amino acid sequence that is at least 90% identical to SEQ ID NO: 4, preferably 100% identical to SEQ ID NO: 4.

20 The application also relates to an immunogenic or vaccine combination or a kit comprising polynucleotides expressing HBV antigens according to embodiments of the application. Any polynucleotides and/or vectors encoding HBV antigens of the application described herein can be used in the immunogenic combinations or kits of the application.

According to embodiments of the application, an immunogenic or vaccine combination or kit comprises:

- 25 (a) a first non-naturally occurring nucleic acid molecule comprising a first polynucleotide encoding a first HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to SEQ ID NO: 29;
- (b) a second non-naturally occurring nucleic acid molecule comprising a second polynucleotide encoding a second HBV surface antigen consisting of an amino acid
30 sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 27; and
- (c) a pharmaceutically acceptable carrier,
wherein the first non-naturally occurring nucleic acid molecule and the second non-naturally occurring nucleic acid molecule are present in the same non-naturally

occurring nucleic acid molecule or in two different non-naturally occurring nucleic acid molecules, preferably in two different non-naturally occurring nucleic acid molecules.

According to embodiments of the application, the polynucleotides in an immunogenic or vaccine combination or kit can be linked or separate, such that the HBV antigens expressed from such polynucleotides are fused together or produced as separate proteins, whether expressed from the same or different polynucleotides. In an embodiment, the first and second polynucleotides are present in separate vectors, e.g., DNA plasmids or viral vectors, used in combination either in the same or separate compositions, such that the expressed proteins are also separate proteins, but used in combination. In another embodiment, the HBV antigens encoded by the first and second polynucleotides can be expressed from the same vector, such that a fusion antigen is produced. Optionally, the HBV antigens can be joined or fused together by a short linker. Alternatively, the HBV antigens encoded by the first and second polynucleotides can be expressed independently from a single vector using a ribosomal slippage site (also known as cis-hydrolase site) between the core and pol antigen coding sequences. This strategy results in a bicistronic expression vector in which individual antigens are produced from a single mRNA transcript. The antigens produced from such a bicistronic expression vector can have additional N or C-terminal residues, depending upon the ordering of the coding sequences on the mRNA transcript. Examples of ribosomal slippage sites that can be used for this purpose include, but are not limited to, the FA2 slippage site from foot-and-mouth disease virus (FMDV). Another possibility is that the HBV antigens encoded by the first and second polynucleotides can be expressed independently from two separate vectors, one encoding the first HBV surface antigen and one encoding the second HBV surface antigen.

In a preferred embodiment, the first and second polynucleotides are present in separate vectors, e.g., DNA plasmids or viral vectors. Preferably, the separate vectors are present in the same composition.

According to preferred embodiments of the application, an immunogenic or vaccine combination or kit comprises a first polynucleotide present in a first vector and a second polynucleotide present in a second vector. The first and second vectors can be the same or different. Preferably the vectors are DNA plasmids.

In a particular embodiment of the application, an immunogenic or vaccine combination or kit comprises: a first vector comprising a polynucleotide encoding a first HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to SEQ ID NO: 29, preferably 100% identical to SEQ ID NO: 29; and a second vector comprising a polynucleotide encoding a

second HBV surface antigen consisting of an amino acid sequence that is at least 98% identical to SEQ ID NO: 27, preferably 100% identical to SEQ ID NO: 27.

In a particular embodiment of the application, the first vector is a first DNA plasmid and the second vector is a second DNA plasmid. Each of the first and second DNA plasmids comprises an origin of replication, preferably pUC ORI of SEQ ID NO: 10, and an antibiotic resistance cassette, preferably comprising a codon optimized Kan^r gene having a polynucleotide sequence that is at least 90% identical to SEQ ID NO: 12, preferably under control of a bla promoter, for instance the bla promoter shown in SEQ ID NO: 9. Each of the first and second DNA plasmids independently further comprises at least one of a promoter sequence, enhancer sequence, and a polynucleotide sequence encoding a signal peptide sequence operably linked to the first polynucleotide sequence or the second polynucleotide sequence. Preferably, each of the first and second DNA plasmids comprises an upstream sequence operably linked to the first polynucleotide or the second polynucleotide, wherein the upstream sequence comprises, from 5' end to 3' end, a promoter sequence of SEQ ID NO: 7 or SEQ ID NO: 25, an enhancer sequence of SEQ ID NO: 8, and a polynucleotide sequence encoding a signal peptide sequence having the amino acid sequence of SEQ ID NO: 6. Each of the first and second DNA plasmids can also comprise a polyadenylation signal located downstream of the coding sequence of the HBV antigen, such as the bGH polyadenylation signal of SEQ ID NO: 11.

In another particular embodiment of the application, the first vector is a first viral vector and the second vector is a second viral vector. Preferably, each of the first and second viral vector is an adenoviral vector, more preferably an Ad26 or Ad35 vector, comprising an expression cassette including the polynucleotide encoding an HBV surface antigen of the application; an upstream sequence operably linked to the polynucleotide encoding the HBV surface antigen comprising, from 5' end to 3' end, a promoter sequence, preferably a CMV promoter sequence of SEQ ID NO: 17, an enhancer sequence, preferably an ApoAI gene fragment sequence of SEQ ID NO: 23, and a polynucleotide sequence encoding a signal peptide sequence, preferably an immunoglobulin secretion signal having the amino acid sequence of SEQ ID NO: 19; and a downstream sequence operably linked to the polynucleotide encoding the HBV antigen comprising a polyadenylation signal, preferably a SV40 polyadenylation signal of SEQ ID NO: 24.

In another embodiment, the first and second polynucleotides are present in a single vector, e.g., DNA plasmid or viral vector. Preferably, the single vector is viral vector, e.g., an adenoviral vector such as an Ad26 vector, comprising an expression cassette including a polynucleotide encoding a first HBV surface antigen capable of inducing an immune response

against L-surface antigen and M-surface antigen and a second HBV surface antigen capable of inducing an immune response against S-surface antigen of the application; an upstream sequence operably linked to the polynucleotide encoding the first and second HBV surface antigens comprising, from 5' end to 3' end, a promoter sequence, preferably a CMV promoter sequence of SEQ ID NO: 17, an enhancer sequence, preferably an ApoAI gene fragment sequence of SEQ ID NO: 23, and a polynucleotide sequence encoding a signal peptide sequence, preferably an immunoglobulin secretion signal having the amino acid sequence of SEQ ID NO: 19; and a downstream sequence operably linked to the polynucleotide encoding the HBV antigen comprising a polyadenylation signal, preferably a SV40 polyadenylation signal of SEQ ID NO: 24.

In some embodiments, an immunogenic or vaccine combination or kit further comprises a third non-naturally occurring nucleic acid molecule comprising a third polynucleotide sequence encoding an HBV polymerase antigen comprising an amino acid sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 4, preferably 100% identical to the amino acid sequence of SEQ ID NO: 4.

In some embodiments, an immunogenic or vaccine combination or kit further comprises a fourth non-naturally occurring nucleic acid molecule comprising a fourth polynucleotide sequence encoding a truncated HBV core antigen consisting of the amino acid sequence of SEQ ID NO: 2 or SEQ ID NO: 14.

In some embodiments, an immunogenic or vaccine combination or kit further comprises a third non-naturally occurring nucleic acid molecule comprising a third polynucleotide sequence encoding an HBV polymerase antigen comprising an amino acid sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 4, preferably 100% identical to the amino acid sequence of SEQ ID NO: 4; and a fourth non-naturally occurring nucleic acid molecule comprising a fourth polynucleotide sequence encoding a truncated HBV core antigen consisting of the amino acid sequence of SEQ ID NO: 2 or SEQ ID NO: 14.

In preferred embodiments, the third and fourth polynucleotides are present in separate vectors, e.g., DNA plasmids or vectors, from the first and second polynucleotides. Preferably the separate vectors are present in the same composition.

According to preferred embodiments of the application, an immunogenic or vaccine combination or kit comprises a first polynucleotide present in a first vector, a second polynucleotide present in a second vector, a third polynucleotide present in a third vector, and a fourth polynucleotide present in a fourth vector. The first, second, third, and fourth vectors can be the same or different. Preferably the vectors are DNA plasmids.

In a particular embodiment of the application, an immunogenic or vaccine combination or kit comprises: a first vector comprising a polynucleotide encoding a first HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to SEQ ID NO: 29, preferably 100% identical to SEQ ID NO: 29; a second vector comprising a polynucleotide encoding a
5 second HBV surface antigen consisting of an amino acid sequence that is at least 98% identical to SEQ ID NO: 27, preferably 100% identical to SEQ ID NO: 27; and third vector comprising a polynucleotide encoding an HBV polymerase antigen comprising an amino acid sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 4, preferably 100% identical to the amino acid sequence of SEQ ID NO: 4; and a fourth vector comprising a polynucleotide
10 encoding a truncated HBV core antigen consisting of the amino acid sequence of SEQ ID NO: 2 or SEQ ID NO: 14.

In a particular embodiment of the application, the first vector is a first DNA plasmid, the second vector is a second DNA plasmid, the third vector is a third DNA plasmid, and the fourth vector is a fourth DNA plasmid. Each of the first, second, third and fourth DNA plasmids
15 comprises an origin of replication, preferably pUC ORI of SEQ ID NO: 10, and an antibiotic resistance cassette, preferably comprising a codon optimized Kan^r gene having a polynucleotide sequence that is at least 90% identical to SEQ ID NO: 12, preferably under control of a bla promoter, for instance the bla promoter shown in SEQ ID NO: 9. Each of the first, second, third and fourth DNA plasmids independently further comprises at least one of a promoter sequence,
20 enhancer sequence, and a polynucleotide sequence encoding a signal peptide sequence operably linked to the first polynucleotide sequence, the second polynucleotide sequence, the third polynucleotide sequence, or the fourth polynucleotide sequence. Preferably, each of the first, second, third and fourth DNA plasmids comprises an upstream sequence operably linked to the first polynucleotide or the second polynucleotide, wherein the upstream sequence comprises,
25 from 5' end to 3' end, a promoter sequence of SEQ ID NO: 7 or SEQ ID NO: 25, an enhancer sequence of SEQ ID NO: 8, and a polynucleotide sequence encoding a signal peptide sequence having the amino acid sequence of SEQ ID NO: 6. Each of the first, second, third and fourth DNA plasmids can also comprise a polyadenylation signal located downstream of the coding sequence of the HBV antigen, such as the bGH polyadenylation signal of SEQ ID NO: 11.

30 In another particular embodiment of the application, the first vector is a first viral vector, the second vector is a second viral vector, the third vector is a third viral vector, and the fourth vector is a fourth viral vector. Preferably, each of the first, second, third, and fourth viral vectors is an adenoviral vector, more preferably an Ad26 or Ad35 vector, comprising an expression cassette including the polynucleotide encoding an HBV antigen of the application; an upstream

sequence operably linked to the polynucleotide encoding the HBV antigen comprising, from 5' end to 3' end, a promoter sequence, preferably a CMV promoter sequence of SEQ ID NO: 17, an enhancer sequence, preferably an ApoAI gene fragment sequence of SEQ ID NO: 23, and a polynucleotide sequence encoding a signal peptide sequence, preferably an immunoglobulin secretion signal having the amino acid sequence of SEQ ID NO: 19; and a downstream sequence operably linked to the polynucleotide encoding the HBV antigen comprising a polyadenylation signal, preferably a SV40 polyadenylation signal of SEQ ID NO: 24.

When an immunogenic or vaccine combination or kit of the application comprises a first vector, such as a DNA plasmid or viral vector, and a second vector, such as a DNA plasmid or viral vector, the amount of each of the first and second vectors is not particularly limited. For example, the first DNA plasmid and the second DNA plasmid can be present in a ratio of 10:1 to 1:10, by weight, such as 10:1, 9:1, 8:1, 7:1, 6:1, 5:1, 4:1, 3:1, 2:1, 1:1, 1:2, 1:3, 1:4, 1:5, 1:6, 1:7, 1:8, 1:9, or 1:10, by weight. Preferably, the first and second DNA plasmids are present in a ratio of 1:1, by weight. Likewise, when an immunogenic or vaccine combination or kit of the application comprises additional vectors, such as additional DNA plasmids or viral vectors, for instance, a third and fourth vector, the amount of each of the first, second, third, and fourth vectors is not particularly limited. In a particular embodiment, the first, second, third, and fourth vectors (e.g., DNA plasmids) can be present in a ratio of 1:1:1:1 by weight.

Compositions, immunogenic or vaccine combinations, and kits of the application can comprise additional polynucleotides or vectors encoding additional HBV antigens and/or additional HBV antigens or immunogenic fragments thereof and/or additional anti-HBV agents.

As used herein, an "anti-HBV agent" refers to any molecule (e.g., small molecule, antigen, protein, antibody, nucleic acid, etc.) capable of achieving at least one of the following effects: (i) reduce or ameliorate the severity of an HBV infection or a symptom associated therewith; (ii) reduce the duration of an HBV infection or symptom associated therewith; (iii) prevent the progression of an HBV infection or symptom associated therewith; (iv) cause regression of an HBV infection or symptom associated therewith; (v) prevent the development or onset of an HBV infection, or symptom associated therewith; (vi) prevent the recurrence of an HBV infection or symptom associated therewith; (vii) reduce hospitalization of a subject having an HBV infection; (viii) reduce hospitalization length of a subject having an HBV infection; (ix) increase the survival of a subject with an HBV infection; (x) eliminate an HBV infection in a subject; (xi) inhibit or reduce HBV replication in a subject; and/or (xii) inducing a protective and/or therapeutic immune response against HBV. An anti-HBV agent includes antigens capable of inducing a protective and/or therapeutic immune response against HBV. Other

examples of anti-HBV agents suitable for use with compositions and immunogenic combinations of the application are described in more detail below.

Compositions, immunogenic or vaccine combinations, and kits of the application can also comprise a pharmaceutically acceptable carrier. A pharmaceutically acceptable carrier is non-toxic and should not interfere with the efficacy of the active ingredient. Pharmaceutically acceptable carriers can include one or more excipients such as binders, disintegrants, swelling agents, suspending agents, emulsifying agents, wetting agents, lubricants, flavorants, sweeteners, preservatives, dyes, solubilizers and coatings. Pharmaceutically acceptable carriers can include vehicles, such as lipid (nano)particles. The precise nature of the carrier or other material can depend on the route of administration, e.g., intramuscular, intradermal, subcutaneous, oral, intravenous, cutaneous, intramucosal (e.g., gut), intranasal or intraperitoneal routes. For liquid injectable preparations, for example, suspensions and solutions, suitable carriers and additives include water, glycols, oils, alcohols, preservatives, coloring agents and the like. For solid oral preparations, for example, powders, capsules, caplets, gelcaps and tablets, suitable carriers and additives include starches, sugars, diluents, granulating agents, lubricants, binders, disintegrating agents and the like. For nasal sprays/inhalant mixtures, the aqueous solution/suspension can comprise water, glycols, oils, emollients, stabilizers, wetting agents, preservatives, aromatics, flavors, and the like as suitable carriers and additives.

Compositions, immunogenic or vaccine combinations, and kits of the application can be formulated in any matter suitable for administration to a subject to facilitate administration and improve efficacy, including, but not limited to, oral (enteral) administration and parenteral injections. The parenteral injections include intravenous injection or infusion, subcutaneous injection, intradermal injection, and intramuscular injection. Compositions of the application can also be formulated for other routes of administration including transmucosal, ocular, rectal, long acting implantation, sublingual administration, under the tongue, from oral mucosa bypassing the portal circulation, inhalation, or intranasal.

In a preferred embodiment of the application, compositions, immunogenic or vaccine combinations and kits of the application are formulated for parental injection, preferably subcutaneous, intradermal injection, or intramuscular injection, more preferably intramuscular injection.

According to embodiments of the application, compositions, immunogenic or vaccine combinations and kits for administration will typically comprise a buffered solution in a pharmaceutically acceptable carrier, e.g., an aqueous carrier such as buffered saline and the like, e.g., phosphate buffered saline (PBS). The compositions, immunogenic or vaccine combinations

and kits can also contain pharmaceutically acceptable substances as required to approximate physiological conditions such as pH adjusting and buffering agents. For example, a composition or immunogenic combination of the application comprising plasmid DNA can contain phosphate buffered saline (PBS) as the pharmaceutically acceptable carrier. The plasmid DNA can be present in a concentration of, e.g., 0.5 mg/mL to 5 mg/mL, such as 0.5 mg/mL, 1 mg/mL, 2 mg/mL, 3 mg/mL, 4 mg/mL, or 5 mg/mL, preferably at 1 mg/mL.

Compositions and immunogenic combinations of the application can be formulated as a vaccine (also referred to as an “immunogenic composition”) according to methods well known in the art. Such compositions can include adjuvants to enhance immune responses. The optimal ratios of each component in the formulation can be determined by techniques well known to those skilled in the art in view of the present disclosure.

In a particular embodiment of the application, a composition or immunogenic combination is a DNA vaccine. DNA vaccines typically comprise bacterial plasmids containing a polynucleotide encoding an antigen of interest under control of a strong eukaryotic promoter. Once the plasmids are delivered to the cell cytoplasm of the host, the encoded antigen is produced and processed endogenously. The resulting antigen typically induces both humoral and cell-mediated immune responses. DNA vaccines are advantageous at least because they offer improved safety, are temperature stable, can be easily adapted to express antigenic variants, and are simple to produce. Any of the DNA plasmids of the application can be used to prepare such a DNA vaccine.

In other particular embodiments of the application, a composition or immunogenic combination is an RNA vaccine. RNA vaccines typically comprise at least one single-stranded RNA molecule encoding an antigen of interest, e.g., HBV antigen such as an HBV surface antigen of the application. Once the RNA is delivered to the cell cytoplasm of the host, the encoded antigen is produced and processed endogenously, inducing both humoral and cell-mediated immune responses, similar to a DNA vaccine. The RNA sequence can be codon optimized to improve translation efficiency. The RNA molecule can be modified by any method known in the art in view of the present disclosure to enhance stability and/or translation, such by adding a polyA tail, e.g., of at least 30 adenosine residues; and/or capping the 5-end with a modified ribonucleotide, e.g., 7-methylguanosine cap, which can be incorporated during RNA synthesis or enzymatically engineered after RNA transcription. An RNA vaccine can also be a self-replicating RNA vaccine developed from an alphavirus expression vector. Self-replicating RNA vaccines comprise a replicase RNA molecule derived from a virus belonging to the

alphavirus family with a subgenomic promoter that controls replication of the HBV antigen RNA followed by an artificial poly A tail located downstream of the replicase.

In certain embodiments, an adjuvant is included in a composition or immunogenic combination of the application, or co-administered with a composition or immunogenic combination of the application. Use of an adjuvant is optional, and can further enhance immune responses when the composition is used for vaccination purposes. Adjuvants suitable for co-administration or inclusion in compositions in accordance with the application should preferably be ones that are potentially safe, well tolerated and effective in humans. An adjuvant can be a small molecule or antibody including, but not limited to, immune checkpoint inhibitors (e.g., anti-PD1, anti-TIM-3, etc.), toll-like receptor agonists (e.g., TLR7 agonists and/or TLR8 agonists), RIG-1 agonists, IL-15 superagonists (Altor Bioscience), mutant IRF3 and IRF7 genetic adjuvants, STING agonists (Aduro), FLT3L genetic adjuvant, IL-12 genetic adjuvant, and IL-7-hyFc. Adjuvants can also e.g., be chosen from among the following anti-HBV agents: HBV DNA polymerase inhibitors; immunomodulators; toll-like receptor 7 modulators; toll-like receptor 8 modulators; toll-like receptor 3 modulators; interferon alpha receptor ligands; hyaluronidase inhibitors; modulators of IL-10; HBsAg inhibitors; toll-like receptor 9 modulators; cyclophilin inhibitors; HBV prophylactic vaccines; HBV therapeutic vaccines; HBV viral entry inhibitors; antisense oligonucleotides targeting viral mRNA, more particularly anti-HBV antisense oligonucleotides; short interfering RNAs (siRNA), more particularly anti-HBV siRNA; endonuclease modulators; inhibitors of ribonucleotide reductase; hepatitis B virus E antigen inhibitors; HBV antibodies targeting the surface antigens of the hepatitis B virus; HBV antibodies; CCR2 chemokine antagonists; thymosin agonists; cytokines, such as IL12; capsid assembly modulators, nucleoprotein inhibitors (HBV core or capsid protein inhibitors); nucleic acid polymers (NAPs); stimulators of retinoic acid-inducible gene 1; stimulators of NOD2; recombinant thymosin alpha-1; hepatitis B virus replication inhibitors; PI3K inhibitors; cccDNA inhibitors; immune checkpoint inhibitors, such as PD-L1 inhibitors, PD-1 inhibitors, TIM-3 inhibitors, TIGIT inhibitors, Lag3 inhibitors, and CTLA-4 inhibitors; agonists of co-stimulatory receptors that are expressed on immune cells (more particularly T cells), such as CD27, CD28, etc.; BTK inhibitors; other drugs for treating HBV; IDO inhibitors; arginase inhibitors; and KDM5 inhibitors.

The application also provides methods of making compositions and immunogenic or vaccine combinations of the application. A method of producing a composition or immunogenic or vaccine combination comprises mixing an isolated polynucleotide encoding an HBV antigen, vector, and/or polypeptide of the application with one or more pharmaceutically acceptable

carriers. One of ordinary skill in the art will be familiar with conventional techniques used to prepare such compositions.

Methods of Inducing an Immune Response

The application also provides methods of inducing an immune response against hepatitis B virus (HBV) in a subject in need thereof, comprising administering to the subject an immunogenically effective amount of a composition or immunogenic or vaccine combinations of the application. Any of the compositions and immunogenic or vaccine combinations of the application described herein can be used in the methods of the application.

As used herein, the term “infection” refers to the invasion of a host by a disease causing agent. A disease causing agent is considered to be “infectious” when it is capable of invading a host, and replicating or propagating within the host. Examples of infectious agents include viruses, e.g., HBV and certain species of adenovirus, prions, bacteria, fungi, protozoa and the like. “HBV infection” specifically refers to invasion of a host organism, such as cells and tissues of the host organism, by HBV.

The phrase “inducing an immune response” when used with reference to the methods described herein encompasses causing a desired immune response or effect in a subject in need thereof against an infection, e.g., an HBV infection. “Inducing an immune response” also encompasses providing a therapeutic immunity for treating against a pathogenic agent, e.g., HBV. As used herein, the term “therapeutic immunity” or “therapeutic immune response” means that the vaccinated subject is able to control an infection with the pathogenic agent against which the vaccination was done, for instance immunity against HBV infection conferred by vaccination with an HBV vaccine. In an embodiment, “inducing an immune response” means producing an immunity in a subject in need thereof, e.g., to provide a therapeutic effect against a disease, such as HBV infection. In certain embodiments, “inducing an immune response” refers to causing or improving cellular immunity, e.g., T cell response, against HBV infection. In certain embodiments, “inducing an immune response” refers to causing or improving a humoral immune response against HBV infection. In certain embodiments, “inducing an immune response” refers to causing or improving a cellular and a humoral immune response against HBV infection.

As used herein, the term “protective immunity” or “protective immune response” means that the vaccinated subject is able to control an infection with the pathogenic agent against which the vaccination was done. Usually, the subject having developed a “protective immune response” develops only mild to moderate clinical symptoms or no symptoms at all. Usually, a subject

having a “protective immune response” or “protective immunity” against a certain agent will not die as a result of the infection with said agent.

Typically, the administration of compositions and immunogenic or vaccine combinations of the application will have a therapeutic aim to generate an immune response against HBV after
5 HBV infection or development of symptoms characteristic of HBV infection, e.g., for therapeutic vaccination.

As used herein, “an immunogenically effective amount” or “immunologically effective amount” means an amount of a composition, polynucleotide, vector, or antigen sufficient to induce a desired immune effect or immune response in a subject in need thereof. An
10 immunogenically effective amount can be an amount sufficient to induce an immune response in a subject in need thereof. An immunogenically effective amount can be an amount sufficient to produce immunity in a subject in need thereof, e.g., provide a therapeutic effect against a disease such as HBV infection. An immunogenically effective amount can vary depending upon a
15 variety of factors, such as the physical condition of the subject, age, weight, health, etc.; the particular application, e.g., providing protective immunity or therapeutic immunity; and the particular disease, e.g., viral infection, for which immunity is desired. An immunogenically effective amount can readily be determined by one of ordinary skill in the art in view of the present disclosure.

In particular embodiments of the application, an immunogenically effective amount
20 refers to the amount of a composition or immunogenic or vaccine combination which is sufficient to achieve one, two, three, four, or more of the following effects: (i) reduce or ameliorate the severity of an HBV infection or a symptom associated therewith; (ii) reduce the duration of an HBV infection or symptom associated therewith; (iii) prevent the progression of an HBV infection or symptom associated therewith; (iv) cause regression of an HBV infection or
25 symptom associated therewith; (v) prevent the development or onset of an HBV infection, or symptom associated therewith; (vi) prevent the recurrence of an HBV infection or symptom associated therewith; (vii) reduce hospitalization of a subject having an HBV infection; (viii) reduce hospitalization length of a subject having an HBV infection; (ix) increase the survival of a subject with an HBV infection; (x) eliminate an HBV infection in a subject; (xi) inhibit or reduce
30 HBV replication in a subject; and/or (xii) enhance or improve the prophylactic or therapeutic effect(s) of another therapy.

An immunogenically effective amount can also be an amount sufficient to reduce HBsAg levels consistent with evolution to clinical seroconversion; achieve sustained HBsAg clearance associated with reduction of infected hepatocytes by a subject’s immune system; induce HBV-

antigen specific activated T-cell populations; and/or achieve persistent loss of HBsAg within 12 months. Examples of a target index include lower HBsAg below a threshold of 500 copies of HBsAg international units (IU) and/or higher CD8 counts.

As general guidance, an immunogenically effective amount when used with reference to a DNA plasmid can range from about 0.1 mg/mL to 10 mg/mL of DNA plasmid total, such as 0.1 mg/mL, 0.25 mg/mL, 0.5 mg/mL, 0.75 mg/mL, 1 mg/mL, 1.5 mg/mL, 2 mg/mL, 3 mg/mL, 4 mg/mL, 5 mg/mL, 6 mg/mL, 7 mg/mL, 8 mg/mL, 9 mg/mL, or 10 mg/mL. Preferably, an immunogenically effective amount of DNA plasmid is less than 8 mg/mL, more preferably less than 6 mg/mL, even more preferably 3-4 mg/mL. An immunogenically effective amount can be from one vector or plasmid, or from multiple vectors or plasmids, e.g., 2, 3, 4, or more vectors or plasmids. An immunogenically effective amount can be administered in a single composition, or in multiple compositions, such as 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10 compositions (e.g., tablets, capsules or injectables, or any composition adapted to intradermal delivery, e.g., to intradermal delivery using an intradermal delivery patch), wherein the administration of the multiple capsules or injections collectively provides a subject with an immunogenically effective amount. For example, when two DNA plasmids are used, an immunogenically effective amount can be 3-4 mg/mL, with 1.5-2 mg/mL of each plasmid. As another illustrative example, when four DNA plasmids are used, an immunogenically effective amount can be 3-4 mg/mL total, with 0.75-1 mg/mL of each plasmid. It is also possible to administer an immunogenically effective amount to a subject, and subsequently administer another dose of an immunogenically effective amount to the same subject, in a so-called prime-boost regimen. This general concept of a prime-boost regimen is well known to the skilled person in the vaccine field. Further booster administrations can optionally be added to the regimen, as needed.

An immunogenic or vaccine combination comprising two DNA plasmids, e.g., a first DNA plasmid encoding a first HBV surface antigen capable of eliciting an immune response against an L-surface antigen and M-surface antigen and a second DNA plasmid encoding a second HBV surface antigen capable of eliciting an immune response against S-surface antigen can be administered to a subject by mixing both plasmids and delivering the mixture to a single anatomic site. Alternatively, two separate immunizations each delivering a single expression plasmid can be performed. In such embodiments, whether both plasmids are administered in a single immunization as a mixture or in two separate immunizations, the first DNA plasmid and the second DNA plasmid can be administered in a ratio of 10:1 to 1:10, by weight, such as 10:1, 9:1, 8:1, 7:1, 6:1, 5:1, 4:1, 3:1, 2:1, 1:1, 1:2, 1:3, 1:4, 1:5, 1:6, 1:7, 1:8, 1:9, or 1:10, by weight. Preferably, the first and second DNA plasmids are administered in a ratio of 1:1, by weight.

Preferably, a subject to be treated according to the methods of the application is an HBV-infected subject, particularly a subject having chronic HBV infection. Acute HBV infection is characterized by an efficient activation of the innate immune system complemented with a subsequent broad adaptive response (e.g., HBV-specific T-cells, neutralizing antibodies), which usually results in successful suppression of replication or removal of infected hepatocytes. In contrast, such responses are impaired or diminished due to high viral and antigen load, e.g., HBV envelope proteins are produced in abundance and can be released in sub-viral particles in 1,000-fold excess to infectious virus.

Chronic HBV infection is described in phases characterized by viral load, liver enzyme levels (necroinflammatory activity), HBeAg, or HBsAg load or presence of antibodies to these antigens. cccDNA levels stay relatively constant at approximately 10 to 50 copies per cell, even though viremia can vary considerably. The persistence of the cccDNA species leads to chronicity. More specifically, the phases of chronic HBV infection include: (i) the immune-tolerant phase characterized by high viral load and normal or minimally elevated liver enzymes; (ii) the immune activation HBeAg-positive phase in which lower or declining levels of viral replication with significantly elevated liver enzymes are observed; (iii) the inactive HBsAg carrier phase, which is a low replicative state with low viral loads and normal liver enzyme levels in the serum that may follow HBeAg seroconversion; and (iv) the HBeAg-negative phase in which viral replication occurs periodically (reactivation) with concomitant fluctuations in liver enzyme levels, mutations in the pre-core and/or basal core promoter are common, such that HBeAg is not produced by the infected cell.

As used herein, "chronic HBV infection" refers to a subject having the detectable presence of HBV for more than 6 months. A subject having a chronic HBV infection can be in any phase of chronic HBV infection. Chronic HBV infection is understood in accordance with its ordinary meaning in the field. Chronic HBV infection can for example be characterized by the persistence of HBsAg for 6 months or more after acute HBV infection. For example, a chronic HBV infection referred to herein follows the definition published by the Centers for Disease Control and Prevention (CDC), according to which a chronic HBV infection can be characterized by laboratory criteria such as: (i) negative for IgM antibodies to hepatitis B core antigen (IgM anti-HBc) and positive for hepatitis B surface antigen (HBsAg), hepatitis B e antigen (HBeAg), or nucleic acid test for hepatitis B virus DNA, or (ii) positive for HBsAg or nucleic acid test for HBV DNA, or positive for HBeAg two times at least 6 months apart.

Preferably, an immunogenically effective amount refers to the amount of a composition or immunogenic or vaccine combination of the application which is sufficient to treat chronic HBV infection.

In some embodiments, a subject having chronic HBV infection is undergoing nucleoside analog (NUC) treatment, and is NUC-suppressed. As used herein, "NUC-suppressed" refers to a subject having an undetectable viral level of HBV and stable alanine aminotransferase (ALT) levels for at least six months. Examples of nucleoside/nucleotide analog treatment include HBV polymerase inhibitors, such as entecavir and tenofovir. Preferably, a subject having chronic HBV infection does not have advanced hepatic fibrosis or cirrhosis. Such subject would typically have a METAVIR score of less than 3 for fibrosis and a fibroscan result of less than 9 kPa. The METAVIR score is a scoring system that is commonly used to assess the extent of inflammation and fibrosis by histopathological evaluation in a liver biopsy of patients with hepatitis B. The scoring system assigns two standardized numbers: one reflecting the degree of inflammation and one reflecting the degree of fibrosis.

It is believed that elimination or reduction of chronic HBV may allow early disease interception of severe liver disease, including virus-induced cirrhosis and hepatocellular carcinoma. Thus, the methods of the application can also be used as therapy to treat HBV-induced diseases. Examples of HBV-induced diseases include, but are not limited to cirrhosis, cancer (e.g., hepatocellular carcinoma), and fibrosis, particularly advanced fibrosis characterized by a METAVIR score of 3 or higher for fibrosis. In such embodiments, an immunogenically effective amount is an amount sufficient to achieve persistent loss of HBsAg within 12 months and significant decrease in clinical disease (e.g., cirrhosis, hepatocellular carcinoma, etc.).

Methods according to embodiments of the application further comprise administering to the subject in need thereof another immunogenic agent (such as another HBV antigen or other antigen) or another anti-HBV agent (such as a nucleoside analog or other anti-HBV agent) in combination with a composition of the application. For example, another anti-HBV agent or immunogenic agent can be a small molecule or antibody including, but not limited to, immune checkpoint inhibitors (e.g., anti-PD1, anti-TIM-3, etc.), toll-like receptor agonists (e.g., TLR7 agonists and/or TLR8 agonists), RIG-1 agonists, IL-15 superagonists (Altor Bioscience), mutant IRF3 and IRF7 genetic adjuvants, STING agonists (Aduro), FLT3L genetic adjuvant, IL-12 genetic adjuvant, IL-7-hyFc; CAR-T which bind HBV env (S-CAR cells); capsid assembly modulators; cccDNA inhibitors, HBV polymerase inhibitors (e.g., entecavir and tenofovir). The one or more other anti-HBV active agents can be, for example, a small molecule, an antibody or antigen binding fragment thereof, a polypeptide, protein, or nucleic acid. The one or more other

anti-HBV agents can e.g., be chosen from among HBV DNA polymerase inhibitors; immunomodulators; toll-like receptor 7 modulators; toll-like receptor 8 modulators; toll-like receptor 3 modulators; interferon alpha receptor ligands; hyaluronidase inhibitors; modulators of IL-10; HBsAg inhibitors; toll-like receptor 9 modulators; cyclophilin inhibitors; HBV prophylactic vaccines; HBV therapeutic vaccines; HBV viral entry inhibitors; antisense oligonucleotides targeting viral mRNA, more particularly anti-HBV antisense oligonucleotides; short interfering RNAs (siRNA), more particularly anti-HBV siRNA; endonuclease modulators; inhibitors of ribonucleotide reductase; hepatitis B virus E antigen inhibitors; HBV antibodies targeting the surface antigens of the hepatitis B virus; HBV antibodies; CCR2 chemokine antagonists; thymosin agonists; cytokines, such as IL12; capsid assembly modulators, nucleoprotein inhibitors (HBV core or capsid protein inhibitors); nucleic acid polymers (NAPs); stimulators of retinoic acid-inducible gene 1; stimulators of NOD2; recombinant thymosin alpha-1; hepatitis B virus replication inhibitors; PI3K inhibitors; cccDNA inhibitors; immune checkpoint inhibitors, such as PD-L1 inhibitors, PD-1 inhibitors, TIM-3 inhibitors, TIGIT inhibitors, Lag3 inhibitors, and CTLA-4 inhibitors; agonists of co-stimulatory receptors that are expressed on immune cells (more particularly T cells), such as CD27, CD28, etc.; BTK inhibitors; other drugs for treating HBV; IDO inhibitors; arginase inhibitors; and KDM5 inhibitors.

Methods of Delivery

Compositions and immunogenic or vaccine combinations of the application can be administered to a subject by any method known in the art in view of the present disclosure, including, but not limited to, parenteral administration (e.g., intramuscular, subcutaneous, intravenous, or intradermal injection), oral administration, transdermal administration, and nasal administration. Preferably, compositions and immunogenic or vaccine combinations are administered parenterally (e.g., by intramuscular injection or intradermal injection) or transdermally.

In some embodiments of the application in which a composition or immunogenic or vaccine combination comprises one or more DNA plasmids, administration can be by injection through the skin, e.g., intramuscular or intradermal injection, preferably intramuscular injection. Intramuscular injection can be combined with electroporation, i.e., application of an electric field to facilitate delivery of the DNA plasmids to cells. As used herein, the term “electroporation” refers to the use of a transmembrane electric field pulse to induce microscopic pathways (pores) in a bio-membrane. During *in vivo* electroporation, electrical fields of appropriate magnitude and duration are applied to cells, inducing a transient state of enhanced cell membrane

permeability, thus enabling the cellular uptake of molecules unable to cross cell membranes on their own. Creation of such pores by electroporation facilitates passage of biomolecules, such as plasmids, oligonucleotides, siRNAs, drugs, etc., from one side of a cellular membrane to the other. *In vivo* electroporation for the delivery of DNA vaccines has been shown to significantly
5 increase plasmid uptake by host cells, while also leading to mild-to-moderate inflammation at the injection site. As a result, transfection efficiency and immune response are significantly improved (e.g., up to 1,000 fold and 100 fold respectively) with intradermal or intramuscular electroporation, in comparison to conventional injection.

In a typical embodiment, electroporation is combined with intramuscular injection.

10 However, it is also possible to combine electroporation with other forms of parenteral administration, e.g., intradermal injection, subcutaneous injection, etc.

Administration of a composition, immunogenic combination or vaccine of the application via electroporation can be accomplished using electroporation devices that can be configured to deliver to a desired tissue of a mammal a pulse of energy effective to cause reversible pores to
15 form in cell membranes. The electroporation device can include an electroporation component and an electrode assembly or handle assembly. The electroporation component can include one or more of the following components of electroporation devices: controller, current waveform generator, impedance tester, waveform logger, input element, status reporting element, communication port, memory component, power source, and power switch. Electroporation can
20 be accomplished using an *in vivo* electroporation device. Examples of electroporation devices and electroporation methods that can facilitate delivery of compositions and immunogenic combinations of the application, particularly those comprising DNA plasmids, include CELLECTRA® (Inovio Pharmaceuticals, Blue Bell, PA), Elgen electroporator (Inovio Pharmaceuticals, Inc.), Tri-Grid™ delivery system (Ichor Medical Systems, Inc., San Diego, CA
25 92121) and those described in U.S. Patent No. 7,664,545, U.S. Patent No. 8,209,006, U.S. Patent No. 9,452,285, U.S. Patent No. 5,273,525, U.S. Patent No. 6,110,161, U.S. Patent No. 6,261,281, U.S. Patent No. 6,958,060, and U.S. Patent No. 6,939,862, U.S. Patent No. 7,328,064, U.S. Patent No. 6,041,252, U.S. Patent No. 5,873,849, U.S. Patent No. 6,278,895, U.S. Patent No. 6,319,901, U.S. Patent No. 6,912,417, U.S. Patent No. 8,187,249, U.S. Patent No. 9,364,664,
30 U.S. Patent No. 9,802,035, U.S. Patent No. 6,117,660, and International Patent Application Publication WO2017172838, all of which are herein incorporated by reference in their entireties. Other examples of *in vivo* electroporation devices are described in U.S. Patent Application No. 16/223,318 entitled "Method and Apparatus for the Delivery of Hepatitis B Virus (HBV) Vaccines," filed on December 18, 2018, the contents of which is hereby

incorporated by reference in its entirety. Also contemplated by the application for delivery of the compositions and immunogenic combinations of the application are use of a pulsed electric field, for instance as described in, e.g., U.S. Patent No. 6,697,669, which is herein incorporated by reference in its entirety.

5 In other embodiments of the application in which a composition or immunogenic or vaccine combination comprises one or more DNA plasmids, the method of administration is transdermal. Transdermal administration can be combined with epidermal skin abrasion to facilitate delivery of the DNA plasmids to cells. For example, a dermatological patch can be used for epidermal skin abrasion. Upon removal of the dermatological patch, the composition or
10 immunogenic combination can be deposited on the abraded skin.

Methods of delivery are not limited to the above described embodiments, and any means for intracellular delivery can be used. Other methods of intracellular delivery contemplated by the methods of the application include, but are not limited to, liposome encapsulation, nanoparticles, etc.

15 Adjuvants

In some embodiments of the application, a method of inducing an immune response against HBV further comprises administering an adjuvant. The terms "adjuvant" and "immune stimulant" are used interchangeably herein, and are defined as one or more substances that cause stimulation of the immune system. In this context, an adjuvant is used to enhance an immune
20 response to HBV antigens and antigenic HBV polypeptides of the application.

According to embodiments of the application, an adjuvant can be present in an immunogenic combination or composition of the application, or administered in a separate composition. An adjuvant can be, e.g., a small molecule or an antibody. Examples of adjuvants suitable for use in the application include, but are not limited to, immune checkpoint inhibitors
25 (e.g., anti-PD1, anti-TIM-3, etc.), toll-like receptor agonists (e.g., TLR7 and/or TLR8 agonists), RIG-1 agonists, IL-15 superagonists (Altor Bioscience), mutant IRF3 and IRF7 genetic adjuvants, STING agonists (Aduro), FLT3L genetic adjuvant, IL-12 genetic adjuvant, and IL-7-hyFc. Examples of adjuvants can e.g., be chosen from among the following anti-HBV agents: HBV DNA polymerase inhibitors; immunomodulators; toll-like receptor 7 modulators; toll-like
30 receptor 8 modulators; toll-like receptor 3 modulators; interferon alpha receptor ligands; hyaluronidase inhibitors; modulators of IL-10; HBsAg inhibitors; toll-like receptor 9 modulators; cyclophilin inhibitors; HBV prophylactic vaccines; HBV therapeutic vaccines; HBV viral entry inhibitors; antisense oligonucleotides targeting viral mRNA, more particularly anti-HBV antisense oligonucleotides; short interfering RNAs (siRNA), more particularly anti-HBV siRNA;

endonuclease modulators; inhibitors of ribonucleotide reductase; hepatitis B virus E antigen inhibitors; HBV antibodies targeting the surface antigens of the hepatitis B virus; HBV antibodies; CCR2 chemokine antagonists; thymosin agonists; cytokines, such as IL12; capsid assembly modulators, nucleoprotein inhibitors (HBV core or capsid protein inhibitors); nucleic acid polymers (NAPs); stimulators of retinoic acid-inducible gene 1; stimulators of NOD2; recombinant thymosin alpha-1; hepatitis B virus replication inhibitors; PI3K inhibitors; cccDNA inhibitors; immune checkpoint inhibitors, such as PD-L1 inhibitors, PD-1 inhibitors, TIM-3 inhibitors, TIGIT inhibitors, Lag3 inhibitors, and CTLA-4 inhibitors; agonists of co-stimulatory receptors that are expressed on immune cells (more particularly T cells), such as CD27, CD28, etc.; BTK inhibitors; other drugs for treating HBV; IDO inhibitors; arginase inhibitors; and KDM5 inhibitors.

Compositions and immunogenic combinations of the application can also be administered in combination with at least one other anti-HBV agent. Examples of anti-HBV agents suitable for use with the application include, but are not limited to small molecules, antibodies, and/or CAR-T therapies which bind HBV env (S-CAR cells), capsid assembly modulators, TLR agonists (e.g., TLR7 and/or TLR8 agonists), cccDNA inhibitors, HBV polymerase inhibitors (e.g., entecavir and tenofovir), and/or immune checkpoint inhibitors, etc. The at least one anti-HBV agent can e.g., be chosen from among HBV DNA polymerase inhibitors; immunomodulators; toll-like receptor 7 modulators; toll-like receptor 8 modulators; toll-like receptor 3 modulators; interferon alpha receptor ligands; hyaluronidase inhibitors; modulators of IL-10; HBsAg inhibitors; toll-like receptor 9 modulators; cyclophilin inhibitors; HBV prophylactic vaccines; HBV therapeutic vaccines; HBV viral entry inhibitors; antisense oligonucleotides targeting viral mRNA, more particularly anti-HBV antisense oligonucleotides; short interfering RNAs (siRNA), more particularly anti-HBV siRNA; endonuclease modulators; inhibitors of ribonucleotide reductase; hepatitis B virus E antigen inhibitors; HBV antibodies targeting the surface antigens of the hepatitis B virus; HBV antibodies; CCR2 chemokine antagonists; thymosin agonists; cytokines, such as IL12; capsid assembly modulators, nucleoprotein inhibitors (HBV core or capsid protein inhibitors); nucleic acid polymers (NAPs); stimulators of retinoic acid-inducible gene 1; stimulators of NOD2; recombinant thymosin alpha-1; hepatitis B virus replication inhibitors; PI3K inhibitors; cccDNA inhibitors; immune checkpoint inhibitors, such as PD-L1 inhibitors, PD-1 inhibitors, TIM-3 inhibitors, TIGIT inhibitors, Lag3 inhibitors, and CTLA-4 inhibitors; agonists of co-stimulatory receptors that are expressed on immune cells (more particularly T cells), such as CD27, CD28, etc.; BTK inhibitors; other drugs for treating HBV; IDO inhibitors; arginase inhibitors; and KDM5

inhibitors. Such anti-HBV agents can be administered with the compositions and immunogenic combinations of the application simultaneously or sequentially.

Methods of Prime/Boost Immunization

Embodiments of the application also contemplate administering an immunogenically effective amount of a composition or immunogenic or vaccine combination to a subject, and subsequently administering another dose of an immunogenically effective amount of a composition or immunogenic or vaccine combination to the same subject, in a so-called prime-boost regimen. Thus, in an embodiment, a composition or immunogenic combination of the application is a primer vaccine used for priming an immune response. In another embodiment, a composition or immunogenic combination of the application is a booster vaccine used for boosting an immune response. The priming and boosting vaccines of the application can be used in the methods of the application described herein. This general concept of a prime-boost regimen is well known to the skilled person in the vaccine field. Any of the compositions and immunogenic combinations of the application described herein can be used as priming and/or boosting vaccines for priming and/or boosting an immune response against HBV.

In some embodiments of the application, a composition or immunogenic combination of the application can be administered for priming immunization. The composition or immunogenic combination can be re-administered for boosting immunization. Further booster administrations of the composition or vaccine combination can optionally be added to the regimen, as needed. An adjuvant can be present in a composition of the application used for boosting immunization, present in a separate composition to be administered together with the composition or immunogenic combination of the application for the boosting immunization, or administered on its own as the boosting immunization. In those embodiments in which an adjuvant is included in the regimen, the adjuvant is preferably used for boosting immunization.

An illustrative and non-limiting example of a prime-boost regimen includes administering a single dose of an immunogenically effective amount of a composition or immunogenic combination of the application to a subject to prime the immune response; and subsequently administering another dose of an immunogenically effective amount of a composition or immunogenic combination of the application to boost the immune response, wherein the boosting immunization is first administered about two to six weeks, preferably four weeks after the priming immunization is initially administered. Optionally, about 10 to 14 weeks, preferably 12 weeks, after the priming immunization is initially administered, a further boosting immunization of the composition or immunogenic combination, or other adjuvant, is administered.

Kits

Also provided herein is a kit comprising an immunogenic or vaccine combination of the application. A kit can comprise the first polynucleotide and the second polynucleotide in separate compositions, or a kit can comprise the first polynucleotide and the second
5 polynucleotide in a single composition. A kit can further comprise at least one of a third polynucleotide and a fourth polynucleotide, wherein the first, second, third, and fourth polynucleotides are present in a single composition or in two or more separate compositions. A kit can also further comprise one or more adjuvants or immune stimulants, and/or other anti-HBV agents.

10 The ability to induce or stimulate an anti-HBV immune response upon administration in an animal or human organism can be evaluated either *in vitro* or *in vivo* using a variety of assays which are standard in the art. For a general description of techniques available to evaluate the onset and activation of an immune response, see for example Coligan et al. (1992 and 1994, Current Protocols in Immunology; ed. J Wiley & Sons Inc, National Institute of Health).

15 Measurement of cellular immunity can be performed by measurement of cytokine profiles secreted by activated effector cells including those derived from CD4+ and CD8+ T-cells (e.g. quantification of IL-10 or IFN gamma-producing cells by ELISPOT), by determination of the activation status of immune effector cells (e.g. T cell proliferation assays by a classical [³H] thymidine uptake or flow cytometry-based assays), by assaying for antigen-specific T
20 lymphocytes in a sensitized subject (e.g. peptide-specific lysis in a cytotoxicity assay, etc.).

The ability to stimulate a cellular and/or a humoral response can be determined by antibody binding and/or competition in binding (see for example Harlow, 1989, Antibodies, Cold Spring Harbor Press). For example, titers of antibodies produced in response to administration of a composition providing an immunogen can be measured by enzyme-linked immunosorbent
25 assay (ELISA). The immune responses can also be measured by neutralizing antibody assay, where a neutralization of a virus is defined as the loss of infectivity through reaction/inhibition/neutralization of the virus with specific antibody. The immune response can further be measured by Antibody-Dependent Cellular Phagocytosis (ADCP) Assay.

EMBODIMENTS

Embodiments Section 1

Embodiment 1 is a non-naturally occurring nucleic acid molecule comprising a first polynucleotide sequence encoding a first HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to the amino acid sequence of SEQ ID NO: 29.

Embodiment 2 is the non-naturally occurring nucleic acid molecule of embodiment 1, wherein the first HBV surface antigen consists of the amino acid sequence of SEQ ID NO: 29.

Embodiment 3 is the non-naturally occurring nucleic acid molecule of embodiment 1 or 2, wherein the first polynucleotide sequence is at least 90% identical to the polynucleotide
5 sequence of SEQ ID NO: 28.

Embodiment 4 is the non-naturally occurring nucleic acid molecule of embodiment 3, wherein the first polynucleotide sequence consists of the polynucleotide sequence of SEQ ID NO: 28.

Embodiment 5 is the non-naturally occurring nucleic acid molecule of any one of
10 embodiments 1 to 4, further comprising a polynucleotide sequence encoding a signal sequence operably linked to the first HBV surface antigen.

Embodiment 6 is the non-naturally occurring nucleic acid molecule of embodiment 5, wherein the signal sequence comprises the amino acid sequence of SEQ ID NO: 6 or SEQ ID NO: 19.

Embodiment 7 is the non-naturally occurring nucleic acid molecule of embodiment 6,
15 wherein the signal sequence is encoded by the polynucleotide sequence of SEQ ID NO: 5 or SEQ ID NO: 18.

Embodiment 8 is the non-naturally occurring nucleic acid molecule of any one of
embodiments 1 to 7, wherein the first HBV surface antigen is capable of inducing an immune
20 response against at least one of L-surface antigen and M-surface antigen, preferably capable of inducing an immune response against both L-surface antigen and M-surface antigen in a subject.

Embodiment 9 is the non-naturally occurring nucleic acid molecule of any one of
embodiments 1 to 8, wherein the first HBV surface antigen is capable of inducing a T cell
response in a mammal against at least HBV genotypes B, C and D, more preferably a T cell
25 response in a mammal against at least HBV genotypes A, B, C, and D.

Embodiment 10 is the non-naturally occurring nucleic acid molecule of embodiment 9, wherein the T-cell response comprises a CD8 T-cell response.

Embodiment 11 is a non-naturally occurring nucleic acid molecule comprising a second
polynucleotide sequence encoding a second HBV surface antigen consisting of an amino acid
30 sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 27.

Embodiment 12 is the non-naturally occurring nucleic acid molecule of embodiment 11, wherein the second HBV surface antigen consists of the amino acid sequence of SEQ ID NO: 27.

Embodiment 13 is the non-naturally occurring nucleic acid molecule of embodiment 11 or 12, wherein the second polynucleotide sequence is at least 90% identical to the polynucleotide sequence of SEQ ID NO: 26.

5 Embodiment 14 is the non-naturally occurring nucleic acid molecule of embodiment 13, wherein the second polynucleotide sequence comprises the polynucleotide sequence of SEQ ID NO: 26.

Embodiment 15 is the non-naturally occurring nucleic acid molecule of any one of embodiments 11 to 14, wherein the second HBV surface antigen further comprises a signal sequence, preferably the signal sequence comprises the amino acid sequence of SEQ ID NO: 6 or
10 SEQ ID NO: 19.

Embodiment 16 is the non-naturally occurring nucleic acid molecule of embodiment 15, wherein the signal sequence is encoded by the polynucleotide sequence of SEQ ID NO: 5 or SEQ ID NO: 18.

Embodiment 17 is the non-naturally occurring nucleic acid molecule of any one of
15 embodiments 11 to 16, wherein the second HBV surface antigen is capable of inducing an immune response against S-surface antigen in a subject.

Embodiment 18 is the non-naturally occurring nucleic acid molecule of any one of
embodiments 11 to 17, wherein the second HBV surface antigen is capable of inducing a T cell response in a mammal against at least HBV genotypes B, C and D, more preferably a T cell
20 response in a mammal against at least HBV genotypes A, B, C, and D.

Embodiment 19 is the non-naturally occurring nucleic acid molecule of embodiment 18, wherein the T-cell response comprises a CD8 T-cell response.

Embodiment 20 is the non-naturally occurring nucleic acid molecule of any one of
embodiments 1 to 19 further comprising a promoter sequence, and optionally one or more
25 additional regulatory sequences.

Embodiment 21 is the non-naturally occurring nucleic acid molecule of embodiment 20, wherein the promoter sequence comprises the polynucleotide sequence of SEQ ID NO: 7.

Embodiment 22 is the non-naturally occurring nucleic acid molecule of embodiment 20, wherein the promoter sequence comprises the polynucleotide sequence of SEQ ID NO: 25.

30 Embodiment 23 is the non-naturally occurring nucleic acid molecule of any one of embodiments 20 to 23, wherein the additional regulatory sequence is at least one of a triple enhancer, an ApoAI gene fragment, and a polyadenylation signal sequence.

Embodiment 24 is the non-naturally occurring nucleic acid molecule of embodiment 23, wherein the polyadenylation signal is a BGH polyadenylation signal or an SV40 polyadenylation signal.

5 Embodiment 25 is the non-naturally occurring nucleic acid molecule of embodiment 23 or 24, wherein the triple enhancer has the sequence of SEQ ID NO: 8, the ApoAI gene fragment has the sequence of SEQ ID NO: 23, the BGH polyadenylation signal has the sequence of SEQ ID NO: 11 and the SV40 polyadenylation signal has the sequence of SEQ ID NO: 24.

10 Embodiment 26 is the non-naturally occurring nucleic acid molecule of any one of embodiments 1 to 10, wherein the non-naturally occurring nucleic acid molecule does not encode an HBV surface antigen capable of inducing an immune response against S-surface antigen.

Embodiment 27 is the non-naturally occurring nucleic acid molecule of any one of embodiments 11 to 19, wherein the non-naturally occurring nucleic acid molecule does not encode an HBV surface antigen capable of inducing an immune response against L-surface antigen and/or M-surface antigen.

15 Embodiment 28 is a vector comprising the non-naturally occurring nucleic acid molecule of any one of embodiments 1 to 27

Embodiment 29 is the vector of embodiment 28, wherein the non-naturally occurring nucleic acid molecule comprises, from 5' end to 3' end, a promoter sequence, an enhancer sequence, a signal peptide coding sequence, the first polynucleotide sequence, and a
20 polyadenylation signal sequence.

Embodiment 30 is the vector of embodiment 29, further comprising the second polynucleotide sequence.

Embodiment 31 is the vector of embodiment 28, wherein the non-naturally occurring nucleic acid molecule comprises, from 5' end to 3' end, a promoter sequence, an enhancer
25 sequence, a signal peptide coding sequence, the second polynucleotide sequence, and a polyadenylation signal sequence.

Embodiment 32 is the vector of embodiment 31, further comprising the first polynucleotide sequence.

30 Embodiment 33 is the vector of any one of embodiments 28 to 32, wherein the vector is a plasmid DNA vector.

Embodiment 34 is the vector of embodiment 33, wherein the plasmid DNA vector further comprises an origin of replication and an antibiotic resistance gene.

Embodiment 35 is the vector of claim 34, wherein the plasmid DNA vector contains the origin of replication comprising the polynucleotide sequence of SEQ ID NO: 10, the antibiotic

resistance gene comprising the polynucleotide sequence of SEQ ID NO: 12, the promoter sequence comprising the polynucleotide sequence of SEQ ID NO: 7 or SEQ ID NO: 25, the enhancer sequence comprising the polynucleotide sequence of SEQ ID NO: 8, the signal peptide coding sequence comprising the polynucleotide sequence of SEQ ID NO: 5, the first
5 polynucleotide sequence comprising the polynucleotide sequence of SEQ ID NO: 28, and the polyadenylation signal sequence comprising the polynucleotide sequence of SEQ ID NO: 11.

Embodiment 36 is the vector of any one of embodiments 28 to 32, wherein the vector is an adenoviral vector.

10 Embodiment 37 is the vector of embodiment 36, wherein the adenoviral vector is an Ad26 or Ad35 vector.

Embodiment 38 is the vector of embodiment 36 or 37, wherein the adenoviral vector contains the promoter sequence comprising the polynucleotide sequence of SEQ ID NO: 17, the regulatory sequence comprising the polynucleotide sequence of SEQ ID NO: 23, the signal peptide coding sequence comprising the polynucleotide sequence of SEQ ID NO: 18, the linker
15 coding sequence comprising the polynucleotide sequence of SEQ ID NO: 22, and the polyadenylation signal sequence comprising the polynucleotide sequence of SEQ ID NO: 24.

Embodiment 39 is a non-naturally occurring first HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to the amino acid sequence of SEQ ID NO: 29.

20 Embodiment 40 is the non-naturally occurring polypeptide of embodiment 39, wherein the polypeptide consists of the amino acid sequence of SEQ ID NO: 29.

Embodiment 41 is a non-naturally occurring second HBV surface antigen consisting of an amino acid sequence that is at least 98% identical to the amino acid sequence SEQ ID NO: 27.

25 Embodiment 42 is the non-naturally occurring polypeptide of embodiment 41, wherein the polypeptide consists of the amino acid sequence of SEQ ID NO: 27.

Embodiment 43 is a host cell comprising the non-naturally occurring nucleic acid molecule of any one of embodiments 1 to 27 or the vector of any one of embodiments 28 to 38.

30 Embodiment 44 is a composition comprising the non-naturally occurring nucleic acid molecule of any one of embodiments 1-27, the vector of any one of embodiments 28 to 38, or the non-naturally occurring first HBV surface antigen and second HBV surface antigen of any one of claims 39-42, and a pharmaceutically acceptable carrier.

Embodiment 45 is the composition of embodiment 44, comprising the first polynucleotide of any one of embodiments 1-10, the second polynucleotide of any one of embodiments 11-19, and a pharmaceutically acceptable carrier, wherein the first and second

polynucleotides are not comprised in the same nucleic acid molecule or in the same nucleic acid vector.

Embodiment 46 is a vaccine combination comprising:

- (a) a first non-naturally occurring nucleic acid molecule comprising a first polynucleotide encoding a first HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to the amino acid sequence of SEQ ID NO: 29;
 - (b) a second non-naturally occurring nucleic acid molecule comprising a second polynucleotide encoding a second HBV surface antigen consisting of an amino acid sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 27; and
 - (c) a pharmaceutically acceptable carrier,
- wherein the first non-naturally occurring nucleic acid molecule and the second non-naturally occurring nucleic acid molecule are present in the same non-naturally occurring nucleic acid molecule or two different non-naturally occurring nucleic acid molecules.

Embodiment 47 is the vaccine combination of embodiment 46, wherein the first non-naturally occurring nucleic acid molecule and the second non-naturally occurring nucleic acid molecule are present in two different non-naturally occurring nucleic acid molecules.

Embodiment 48 is the vaccine combination of embodiment 46 or 47, wherein the first HBV surface antigen consists of the amino acid sequence of SEQ ID NO: 29.

Embodiment 49 is the vaccine combination of any one of embodiments 46 to 48, wherein the second HBV surface antigen consists of the amino acid sequence of SEQ ID NO: 27.

Embodiment 50 is the vaccine combination of any one of embodiments 46 to 49, wherein at least one of the first non-naturally occurring nucleic acid molecule and the second non-naturally nucleic acid molecule further comprises a polynucleotide sequence encoding a signal sequence operably linked to at least one of the first HBV surface antigen and the second HBV surface antigen.

Embodiment 51 is the vaccine combination of embodiment 50, wherein the signal sequence independently comprises the amino acid sequence of SEQ ID NO: 6 or SEQ ID NO: 19, preferably the signal sequence is independently encoded by the polynucleotide sequence of SEQ ID NO: 5 or SEQ ID NO: 18.

Embodiment 52 is the vaccine combination of any one of embodiments 46 to 51, wherein the first polynucleotide sequence is at least 90% identical to SEQ ID NO: 28.

Embodiment 53 is the vaccine combination of embodiment 52, wherein the first polynucleotide sequence comprises the polynucleotide sequence of SEQ ID NO: 28.

Embodiment 54 is the vaccine combination of any one of embodiments 46 to 53, wherein the second polynucleotide sequence is at least 90% identical to the polynucleotide sequence of
5 SEQ ID NO: 26.

Embodiment 55 is the vaccine combination of embodiment 54, wherein the second polynucleotide sequence comprises the polynucleotide sequence of SEQ ID NO: 26.

Embodiment 56 is the vaccine combination of any one of embodiments 46 to 55, wherein at least one of the first non-naturally occurring nucleic acid molecule and the second non-naturally nucleic acid molecule further comprises a promoter sequence, optionally an enhancer
10 sequence, and further optionally a polyadenylation signal sequence, preferably the promoter sequence has the polynucleotide sequence of SEQ ID NO: 7 or SEQ ID NO: 25, the enhancer sequence independently has the polynucleotide sequence of SEQ ID NO: 8 or SEQ ID NO: 23, and the polyadenylation signal sequence independently has the polynucleotide sequence of SEQ
15 ID NO: 11 or SEQ ID NO: 24.

Embodiment 57 is the vaccine combination of any one of claims 46 to 58, wherein the first non-naturally occurring nucleic acid molecule is present in a first vector, preferably a first plasmid DNA vector, and the second non-naturally occurring nucleic acid molecule is present in a second vector, preferably a second plasmid DNA vector.

Embodiment 58 is the vaccine combination of embodiment 57, wherein each of the first and second plasmid DNA vectors comprises an origin of replication, an antibiotic resistance gene, and from 5' end to 3' end, a promoter sequence, a regulatory sequence, a signal peptide coding sequence, the first polynucleotide sequence or the second polynucleotide sequence, and a polyadenylation signal sequence.
20

Embodiment 59 is the vaccine combination of embodiment 58, wherein the antibiotic resistance gene is a kanamycin resistance gene having a polynucleotide sequence at least 90% identical to the polynucleotide sequence of SEQ ID NO: 12, preferably 100% identical to the polynucleotide sequence of SEQ ID NO: 12.
25

Embodiment 60 is the vaccine combination of embodiment 59, comprising:

(a) a first vector, preferably a first plasmid DNA vector, comprising the promoter sequence comprising the polynucleotide sequence of SEQ ID NO: 25, the regulatory sequence comprising the polynucleotide sequence of SEQ ID NO: 8, the signal peptide coding sequence comprising the polynucleotide sequence of SEQ ID NO: 5, the first polynucleotide sequence comprising the polynucleotide sequence of SEQ ID
30

NO: 28, and the polyadenylation signal sequence comprising the polynucleotide sequence of SEQ ID NO: 11;

(b) a second vector, preferably a second plasmid DNA vector, comprising the promoter sequence comprising the polynucleotide sequence of SEQ ID NO: 25, the regulatory sequence comprising the polynucleotide sequence of SEQ ID NO: 8, the signal peptide coding sequence comprising the polynucleotide sequence of SEQ ID NO: 5, the second polynucleotide sequence comprising the polynucleotide sequence of SEQ ID NO: 26, and the polyadenylation signal sequence comprising the polynucleotide sequence of SEQ ID NO: 11; and

(c) a pharmaceutically acceptable carrier, wherein each of the first plasmid DNA vector and the second plasmid DNA vector further comprises a kanamycin resistance gene having the polynucleotide sequence of SEQ ID NO: 12, and an origin of replication having the polynucleotide sequence of SEQ ID NO: 10, and

wherein the first plasmid DNA vector and the second plasmid DNA vector are present in the same composition or two different compositions.

Embodiment 61 is the vaccine combination of any one of embodiments 46 to 60, further comprising a third non-naturally occurring nucleic acid molecule comprising a third polynucleotide sequence encoding an HBV polymerase antigen comprising an amino acid sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 4.

Embodiment 62 is the vaccine combination of embodiment 61, wherein the HBV polymerase antigen comprises the amino acid sequence of SEQ ID NO: 4.

Embodiment 63 is the vaccine combination of embodiment 61 or 62, wherein the third polynucleotide sequence is at least 90% identical to the polynucleotide sequence of SEQ ID NO: 3 or SEQ ID NO: 16, preferably SEQ ID NO: 3.

Embodiment 64 is the vaccine combination of embodiment 63, wherein the third polynucleotide sequence comprises the polynucleotide sequence of SEQ ID NO: 3 or SEQ ID NO: 16, preferably SEQ ID NO: 3.

Embodiment 65 is the vaccine combination of any one of embodiments 46 to 64, further comprising a fourth non-naturally occurring nucleic acid molecule comprising a fourth polynucleotide sequence encoding a truncated HBV core antigen consisting of the amino acid sequence of SEQ ID NO: 2 or SEQ ID NO: 14.

Embodiment 66 is the vaccine combination of embodiment 65, wherein the fourth polynucleotide sequence is at least 90% identical to the polynucleotide sequence of SEQ ID NO: 1 or SEQ ID NO: 15.

5 Embodiment 67 is the vaccine combination of embodiment 66, wherein the fourth polynucleotide sequence comprises the polynucleotide sequence of SEQ ID NO: 1 or SEQ ID NO: 15.

Embodiment 68 is the vaccine combination of any one of embodiments 61, wherein the third non-naturally occurring nucleic acid molecule and the fourth non-naturally occurring nucleic acid molecule are present in non-naturally occurring nucleic acid molecules separate
10 from the first and second non-naturally occurring nucleic acid molecules.

Embodiment 69 is the vaccine combination of embodiment 68, wherein the third non-naturally occurring nucleic acid molecule is present in a third plasmid DNA vector and the fourth non-naturally occurring nucleic acid molecule is present in a fourth plasmid DNA vector.

Embodiment 70 is the vaccine combination of embodiment 69, wherein each of the first, second, third and fourth plasmid DNA vectors comprises an origin of replication, an antibiotic resistance gene, and from 5' end to 3' end, a promoter sequence, a regulatory sequence, a signal peptide coding sequence, the first polynucleotide sequence, the second polynucleotide sequence, the third polynucleotide sequence, or the fourth polynucleotide sequence, and a polyadenylation signal sequence.
15

20 Embodiment 71 is the vaccine combination of embodiment 70, comprising:

(a) a first plasmid DNA vector comprising the promoter sequence comprising the polynucleotide sequence of SEQ ID NO: 25, the regulatory sequence comprising the polynucleotide sequence of SEQ ID NO: 8, the signal peptide coding sequence comprising the polynucleotide sequence of SEQ ID NO: 5, the first polynucleotide sequence comprising the polynucleotide sequence of SEQ ID NO: 28, and the polyadenylation signal sequence comprising the polynucleotide sequence of SEQ ID NO: 11;
25

(b) a second plasmid DNA vector comprising the promoter sequence comprising the polynucleotide sequence of SEQ ID NO: 25, the regulatory sequence comprising the polynucleotide sequence of SEQ ID NO: 8, the signal peptide coding sequence comprising the polynucleotide sequence of SEQ ID NO: 5, the second polynucleotide sequence comprising the polynucleotide sequence of SEQ ID NO: 26, and the polyadenylation signal sequence comprising the polynucleotide sequence of SEQ ID NO: 11;
30

(c) a third plasmid DNA vector comprising the promoter sequence comprising the polynucleotide sequence of SEQ ID NO: 7, the regulatory sequence comprising the polynucleotide sequence of SEQ ID NO: 8, the signal peptide coding sequence comprising the polynucleotide sequence of SEQ ID NO: 5, the third polynucleotide sequence comprising the polynucleotide sequence of SEQ ID NO: 3, and the polyadenylation signal sequence comprising the polynucleotide sequence of SEQ ID NO: 11;

(d) a fourth plasmid DNA vector comprising the promoter sequence comprising the polynucleotide sequence of SEQ ID NO: 7, the regulatory sequence comprising the polynucleotide sequence of SEQ ID NO: 8, the signal peptide coding sequence comprising the polynucleotide sequence of SEQ ID NO: 5, the fourth polynucleotide sequence comprising the polynucleotide sequence of SEQ ID NO: 1, and the polyadenylation signal sequence comprising the polynucleotide sequence of SEQ ID NO: 11; and

(e) a pharmaceutically acceptable carrier, wherein each of the first plasmid DNA vector, the second plasmid DNA vector, the third plasmid DNA vector, and the fourth plasmid DNA vector further comprises a kanamycin resistance gene having the polynucleotide sequence of SEQ ID NO: 12, and an origin of replication having the polynucleotide sequence of SEQ ID NO: 10, and

wherein the first plasmid DNA vector, the second plasmid DNA vector, the third plasmid DNA vector, and the fourth plasmid DNA vector are present in the same composition or two or more different compositions.

Embodiment 72 is the composition of embodiments 44-45 or the vaccine combination of any one of embodiments 46 to 71 for use in inducing an immune response against a hepatitis B virus (HBV) in a subject in need thereof, preferably the subject has chronic HBV infection.

Embodiment 73 is a combination of another immunogenic agent, preferably another anti-HBV agent, with the composition of embodiments 44-45 or the vaccine combination of any one of embodiments 46 to 71 for use in inducing an immune response against a hepatitis B virus (HBV) in a subject in need thereof, preferably the subject has chronic HBV infection.

Embodiment 74 is the composition of embodiments 44-45 or the vaccine combination of any one of embodiments 46 to 71 for use in treating a hepatitis B virus (HBV)-induced disease in a subject in need thereof, preferably the subject has chronic HBV infection, and preferably the

HBV-induced disease is selected from the group consisting of advanced fibrosis, cirrhosis and hepatocellular carcinoma (HCC)

5 Embodiment 75 is a combination of another therapeutic agent, preferably another anti-HBV agent, with the composition of embodiments 44-45 or the vaccine combination of any one of embodiments 46 to 71 for use in treating a hepatitis B virus (HBV)-induced disease in a subject in need thereof, preferably the subject has chronic HBV infection, and preferably the HBV-induced disease is selected from the group consisting of advanced fibrosis, cirrhosis and hepatocellular carcinoma (HCC).

10 Embodiment 76 is a method of inducing an immune response against a hepatitis B virus (HBV) in a subject in need thereof, preferably the subject has chronic HBV infection, the method comprising administering to the subject the composition of embodiments 44-45 or the vaccine combination of any one of embodiments 46 to 71.

15 Embodiment 77 is a method of treating a hepatitis B virus (HBV)-induced disease in a subject in need thereof, preferably the subject has chronic HBV infection, the method comprising administering to the subject the composition of embodiments 44-45 or the vaccine combination of any one of embodiments 46 to 71.

20 Embodiment 78 is the method of embodiment 77, wherein the HBV-induced disease is selected from the group consisting of advanced fibrosis, cirrhosis and hepatocellular carcinoma (HCC).

 Embodiment 79 is the method of any one of embodiments 76 to 78, further comprising administering to the subject an additional therapeutic agent, preferably an additional anti-HBV agent.

25 Embodiment 80 is use of the composition of embodiments 44-45 or the vaccine combination of any one of embodiments 46 to 71 in the manufacture of a medicament for inducing an immune response against a hepatitis B virus, or for treating a hepatitis B virus (HBV)-induced disease.

Embodiments Section 2

30 Embodiment 1 is a non-naturally occurring nucleic acid molecule comprising a first polynucleotide sequence encoding a first HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to the amino acid sequence of SEQ ID NO: 29.

 Embodiment 2 is the non-naturally occurring nucleic acid molecule of embodiment 1, wherein the first HBV surface antigen consists of the amino acid sequence of SEQ ID NO: 29.

Embodiment 3 is the non-naturally occurring nucleic acid molecule of embodiment 1 or 2, wherein the first polynucleotide sequence is at least 90% identical to the polynucleotide sequence of SEQ ID NO: 28.

5 Embodiment 4 is the non-naturally occurring nucleic acid molecule of embodiment 3, wherein the first polynucleotide sequence consists of the polynucleotide sequence of SEQ ID NO: 28.

Embodiment 5 is the non-naturally occurring nucleic acid molecule of any one of embodiments 1 to 4, further comprising a polynucleotide sequence encoding a signal sequence operably linked to the first HBV surface antigen.

10 Embodiment 6 is the non-naturally occurring nucleic acid molecule of embodiment 5, wherein the signal sequence comprises the amino acid sequence of SEQ ID NO: 6 or SEQ ID NO: 19, preferably the signal sequence is encoded by the polynucleotide sequence of SEQ ID NO: 5 or SEQ ID NO: 18.

15 Embodiment 7 is a non-naturally occurring nucleic acid molecule comprising a second polynucleotide sequence encoding a second HBV surface antigen consisting of an amino acid sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 27.

Embodiment 8 is the non-naturally occurring nucleic acid molecule of embodiment 7, wherein the second HBV surface antigen consists of the amino acid sequence of SEQ ID NO: 27.

20 Embodiment 9 is the non-naturally occurring nucleic acid molecule of embodiment 8, wherein the second polynucleotide sequence is at least 90% identical to the polynucleotide sequence of SEQ ID NO: 26.

Embodiment 10 is the non-naturally occurring nucleic acid molecule of embodiment 9, wherein the second polynucleotide sequence comprises the polynucleotide sequence of SEQ ID NO: 26.

25 Embodiment 11 is the non-naturally occurring nucleic acid molecule of any one of embodiments 8 to 10, wherein the second HBV surface antigen further comprises a signal sequence, preferably the signal sequence comprises the amino acid sequence of SEQ ID NO: 6 or SEQ ID NO: 19, more preferably the signal sequence is encoded by the polynucleotide sequence of SEQ ID NO: 5 or SEQ ID NO: 18.

30 Embodiment 12 is the non-naturally occurring nucleic acid molecule of any one of embodiments 1 to 11 further comprising a promoter sequence, optionally one or more additional regulatory sequences, preferably the promoter sequence comprises the polynucleotide sequence of SEQ ID NO: 7, and the additional regulatory sequence is selected from the group consisting of

SEQ ID NO: 8 or SEQ ID NO: 23, and a polyadenylation signal sequence of SEQ ID NO: 11 or SEQ ID NO: 24.

Embodiment 13 is a vector comprising the non-naturally occurring nucleic acid molecule of any one of embodiments 1 to 12.

5 Embodiment 14 is the vector of embodiment 13, wherein the non-naturally occurring nucleic acid molecule comprises, from 5' end to 3' end, a promoter sequence, an enhancer sequence, a signal peptide coding sequence, the first polynucleotide sequence, and a polyadenylation signal sequence, optionally, the non-naturally occurring nucleic acid molecule further comprises the second polynucleotide sequence.

10 Embodiment 15 is the vector of embodiment 13 or 14, wherein the vector is a plasmid DNA vector, and the plasmid DNA vector further comprises an origin of replication and an antibiotic resistance gene.

15 Embodiment 16 is the vector of embodiment 15, wherein the plasmid DNA vector contains the origin of replication comprising the polynucleotide sequence of SEQ ID NO: 10, the antibiotic resistance gene comprising the polynucleotide sequence of SEQ ID NO: 12, the promoter sequence comprising the polynucleotide sequence of SEQ ID NO: 7, the enhancer sequence comprising the polynucleotide sequence of SEQ ID NO: 8, the signal peptide coding sequence comprising the polynucleotide sequence of SEQ ID NO: 5, the first polynucleotide sequence comprising the polynucleotide sequence of SEQ ID NO: 28, and the polyadenylation
20 signal sequence comprising the polynucleotide sequence of SEQ ID NO: 11.

Embodiment 17 is the vector of embodiment 13 or 14, wherein the vector is an adenoviral vector, preferably an Ad26 or Ad35 vector.

Embodiment 18 is a non-naturally occurring first HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to the amino acid sequence of SEQ ID NO: 29.

25 Embodiment 19 is the non-naturally occurring polypeptide of embodiment 18, wherein the polypeptide consists of the amino acid sequence of SEQ ID NO: 29.

Embodiment 20 is a non-naturally occurring second HBV surface antigen consisting of the amino acid sequence of SEQ ID NO: 27.

30 Embodiment 21 is a host cell comprising the non-naturally occurring nucleic acid molecule of any one of claims 1 to 12 or the vector of any one of embodiments 13 to 17.

Embodiment 22 is a composition comprising the non-naturally occurring nucleic acid molecule of any one of embodiments 1 to 12, the vector of any one of embodiments 13 to 17, or the non-naturally occurring first HBV surface antigen and second HBV surface antigen of any one of embodiments 18 to 20, and a pharmaceutically acceptable carrier.

Embodiment 23 is the composition of embodiment 22, comprising the first polynucleotide of any one of embodiments 1 to 6, the second polynucleotide of any one of embodiments 7 to 11, and a pharmaceutically acceptable carrier, wherein the first and second polynucleotides are not comprised in the same nucleic acid molecule or in the same nucleic acid vector.

Embodiment 24 is a vaccine combination comprising:

(a) a first non-naturally occurring nucleic acid molecule comprising a first polynucleotide encoding a first HBV surface antigen consisting of an amino acid sequence that is at least 95% identical to the amino acid sequence of SEQ ID NO: 29;

(b) a second non-naturally occurring nucleic acid molecule comprising a second polynucleotide encoding a second HBV surface antigen consisting of an amino acid sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 27; and

(c) a pharmaceutically acceptable carrier,

wherein the first non-naturally occurring nucleic acid molecule and the second non-naturally occurring nucleic acid molecule are present in the same non-naturally occurring nucleic acid molecule or two different non-naturally occurring nucleic acid molecules, preferably in two different non-naturally occurring nucleic acid molecules.

Embodiment 25 is the vaccine combination of embodiment 24, wherein the first HBV surface antigen consists of the amino acid sequence of SEQ ID NO: 29 and the second HBV surface antigen consists of the amino acid sequence of SEQ ID NO: 27.

Embodiment 26 is the vaccine combination of embodiment 24 or 25, wherein at least one of the first non-naturally occurring nucleic acid molecule and the second non-naturally nucleic acid molecule further comprises a polynucleotide sequence encoding a signal sequence operably linked to at least one of the first HBV surface antigen and the second HBV surface antigen.

Embodiment 27 is the vaccine combination of embodiment 26, wherein the signal sequence independently comprises the amino acid sequence of SEQ ID NO: 6 or SEQ ID NO: 19, preferably the signal sequence is independently encoded by the polynucleotide sequence of SEQ ID NO: 5 or SEQ ID NO: 18.

Embodiment 28 is the vaccine combination of any one of embodiments 24 to 27, wherein the first polynucleotide sequence is at least 90% identical to SEQ ID NO: 28.

Embodiment 29 is the vaccine combination of embodiment 28, wherein the first polynucleotide sequence comprises the polynucleotide sequence of SEQ ID NO: 28.

Embodiment 30 is the vaccine combination of any one of embodiments 24 to 29, wherein the second polynucleotide sequence is at least 90% identical to the polynucleotide sequence of SEQ ID NO: 26.

Embodiment 31 is the vaccine combination of embodiment 30, wherein the second
5 polynucleotide sequence comprises the polynucleotide sequence of SEQ ID NO: 26.

Embodiment 32 is the vaccine combination of any one of embodiments 24 to 31, wherein at least one of the first non-naturally occurring nucleic acid molecule and the second non-naturally nucleic acid molecule further comprises a promoter sequence, optionally an enhancer sequence, and further optionally a polyadenylation signal sequence, preferably the promoter
10 sequence has the polynucleotide sequence of SEQ ID NO: 7 or SEQ ID NO: 25, the enhancer sequence independently has the polynucleotide sequence of SEQ ID NO: 8 or SEQ ID NO: 23, and the polyadenylation signal sequence independently has the polynucleotide sequence of SEQ ID NO: 11 or SEQ ID NO: 24.

Embodiment 33 is the vaccine combination of any one of embodiments 24 to 32, wherein
15 the first non-naturally occurring nucleic acid molecule is present in a first vector, preferably a first plasmid DNA vector, and the second non-naturally occurring nucleic acid molecule is present in a second vector, preferably a second plasmid DNA vector.

Embodiment 34 is the vaccine combination of embodiment 33, wherein each of the first and second plasmid DNA vectors comprises an origin of replication, an antibiotic resistance gene, and from 5' end to 3' end, a promoter sequence, a regulatory sequence, a signal peptide
20 coding sequence, the first polynucleotide sequence or the second polynucleotide sequence, and a polyadenylation signal sequence.

Embodiment 35 is the vaccine combination of embodiment 34, wherein the antibiotic resistance gene is a kanamycin resistance gene having a polynucleotide sequence at least 90%
25 identical to the polynucleotide sequence of SEQ ID NO: 12, preferably 100% identical to the polynucleotide sequence of SEQ ID NO: 12.

Embodiment 36 is the vaccine combination of embodiment 35, comprising:

(a) a first vector, preferably a first plasmid DNA vector, comprising the promoter sequence comprising the polynucleotide sequence of SEQ ID NO: 25, the regulatory
30 sequence comprising the polynucleotide sequence of SEQ ID NO: 8, the signal peptide coding sequence comprising the polynucleotide sequence of SEQ ID NO: 5, the first polynucleotide sequence comprising the polynucleotide sequence of SEQ ID NO: 28, and the polyadenylation signal sequence comprising the polynucleotide sequence of SEQ ID NO: 11;

(b) a second vector, preferably a second plasmid DNA vector, comprising the promoter sequence comprising the polynucleotide sequence of SEQ ID NO: 25, the regulatory sequence comprising the polynucleotide sequence of SEQ ID NO: 8, the signal peptide coding sequence comprising the polynucleotide sequence of SEQ ID NO: 5, the second polynucleotide sequence comprising the polynucleotide sequence of SEQ ID NO: 26, and the polyadenylation signal sequence comprising the polynucleotide sequence of SEQ ID NO: 11; and

(c) a pharmaceutically acceptable carrier,

wherein each of the first plasmid DNA vector and the second plasmid DNA vector further comprises a kanamycin resistance gene having the polynucleotide sequence of SEQ ID NO: 12, and an origin of replication having the polynucleotide sequence of SEQ ID NO: 10, and

wherein the first plasmid DNA vector and the second plasmid DNA vector are present in the same composition or two different compositions.

Embodiment 37 is the vaccine combination of any one of embodiments 24 to 36, further comprising a third non-naturally occurring nucleic acid molecule comprising a third polynucleotide sequence encoding an HBV polymerase antigen comprising an amino acid sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 4.

Embodiment 38 is the vaccine combination of embodiment 37, wherein the HBV polymerase antigen comprises the amino acid sequence of SEQ ID NO: 4.

Embodiment 39 is the vaccine combination of embodiment 37 or 38, wherein the third polynucleotide sequence is at least 90% identical to the polynucleotide sequence of SEQ ID NO: 3 or SEQ ID NO: 16, preferably SEQ ID NO: 3.

Embodiment 40 is the vaccine combination of embodiment 39, wherein the third polynucleotide sequence comprises the polynucleotide sequence of SEQ ID NO: 3 or SEQ ID NO: 16, preferably SEQ ID NO: 3.

Embodiment 41 is the vaccine combination of any one of embodiments 24 to 40, further comprising a fourth non-naturally occurring nucleic acid molecule comprising a fourth polynucleotide sequence encoding a truncated HBV core antigen consisting of the amino acid sequence of SEQ ID NO: 2 or SEQ ID NO: 14.

Embodiment 42 is the vaccine combination of embodiment 41, wherein the fourth polynucleotide sequence is at least 90% identical to the polynucleotide sequence of SEQ ID NO: 1 or SEQ ID NO: 15.

Embodiment 43 is the vaccine combination of embodiment 42, wherein the fourth polynucleotide sequence comprises the polynucleotide sequence of SEQ ID NO: 1 or SEQ ID NO: 15.

Embodiment 44 is the vaccine combination of any one of embodiments 37 to 43, wherein the third non-naturally occurring nucleic acid molecule and the fourth non-naturally occurring nucleic acid molecule are present in non-naturally occurring nucleic acid molecules separate from the first and second non-naturally occurring nucleic acid molecules.

Embodiment 45 is the vaccine combination of embodiment 44, wherein the third non-naturally occurring nucleic acid molecule is present in a third plasmid DNA vector and the fourth non-naturally occurring nucleic acid molecule is present in a fourth plasmid DNA vector.

Embodiment 46 is the vaccine combination of embodiment 45, comprising:

- (a) a first plasmid DNA vector comprising the promoter sequence comprising the polynucleotide sequence of SEQ ID NO: 25, the regulatory sequence comprising the polynucleotide sequence of SEQ ID NO: 8, the signal peptide coding sequence comprising the polynucleotide sequence of SEQ ID NO: 5, the first polynucleotide sequence comprising the polynucleotide sequence of SEQ ID NO: 28, and the polyadenylation signal sequence comprising the polynucleotide sequence of SEQ ID NO: 11;
- (b) a second plasmid DNA vector comprising the promoter sequence comprising the polynucleotide sequence of SEQ ID NO: 25, the regulatory sequence comprising the polynucleotide sequence of SEQ ID NO: 8, the signal peptide coding sequence comprising the polynucleotide sequence of SEQ ID NO: 5, the second polynucleotide sequence comprising the polynucleotide sequence of SEQ ID NO: 26, and the polyadenylation signal sequence comprising the polynucleotide sequence of SEQ ID NO: 11;
- (c) a third plasmid DNA vector comprising the promoter sequence comprising the polynucleotide sequence of SEQ ID NO: 7, the regulatory sequence comprising the polynucleotide sequence of SEQ ID NO: 8, the signal peptide coding sequence comprising the polynucleotide sequence of SEQ ID NO: 5, the third polynucleotide sequence comprising the polynucleotide sequence of SEQ ID NO: 3, and the polyadenylation signal sequence comprising the polynucleotide sequence of SEQ ID NO: 11;
- (d) a fourth plasmid DNA vector comprising the promoter sequence comprising the polynucleotide sequence of SEQ ID NO: 7, the regulatory sequence comprising the

polynucleotide sequence of SEQ ID NO: 8, the signal peptide coding sequence comprising the polynucleotide sequence of SEQ ID NO: 5, the fourth polynucleotide sequence comprising the polynucleotide sequence of SEQ ID NO: 1, and the polyadenylation signal sequence comprising the polynucleotide sequence of SEQ ID NO: 11; and

(e) a pharmaceutically acceptable carrier,

wherein each of the first plasmid DNA vector, the second plasmid DNA vector, the third plasmid DNA vector, and the fourth plasmid DNA vector further comprises a kanamycin resistance gene having the polynucleotide sequence of SEQ ID NO: 12, and an origin of replication having the polynucleotide sequence of SEQ ID NO: 10, and

wherein the first plasmid DNA vector, the second plasmid DNA vector, the third plasmid DNA vector, and the fourth plasmid DNA vector are present in the same composition or two or more different compositions.

Embodiment 47 is the composition of embodiment 22 or embodiment 23 or the vaccine combination of any one of embodiments 24 to 46 for use in inducing an immune response against a hepatitis B virus (HBV) in a subject in need thereof, preferably the subject has chronic HBV infection.

Embodiment 48 is a combination of another immunogenic agent, preferably another anti-HBV agent, with the composition of embodiment 22 or embodiment 23 or the vaccine combination of any one of embodiments 24 to 46 for use in inducing an immune response against a hepatitis B virus (HBV) in a subject in need thereof, preferably the subject has chronic HBV infection.

Embodiment 49 is the composition of embodiment 22 or embodiment 23 or the kit of any one of embodiments 24 to 46 for use in treating a hepatitis B virus (HBV)-induced disease in a subject in need thereof, preferably the subject has chronic HBV infection, and the HBV-induced disease is selected from the group consisting of advanced fibrosis, cirrhosis and hepatocellular carcinoma (HCC).

Embodiment 50 is a combination of another therapeutic agent, preferably another anti-HBV agent, with the composition of embodiment 22 or embodiment 23 or the kit of any one of embodiments 24 to 46 for use in treating a hepatitis B virus (HBV)-induced disease in a subject in need thereof, preferably the subject has chronic HBV infection, and the HBV-induced disease is selected from the group consisting of advanced fibrosis, cirrhosis and hepatocellular carcinoma (HCC).

EXAMPLES

The following examples of the application are to further illustrate the nature of the application. It should be understood that the following examples do not limit the application and the scope of the application is to be determined by the appended claims.

Example 1: Generation of HBV Core and Pol Antigen Sequences and Plasmid Optimization

T-cell epitopes on the hepatitis core protein are considered important for elimination of hepatitis B infection and hepatitis B viral proteins, such as polymerase, may serve to improve the breadth of the response. Thus, hepatitis B core and polymerase proteins were selected as antigens for the design of a therapeutic hepatitis B virus (HBV) vaccine.

Derivation of HBV Core and Polymerase Antigen Consensus Sequences

HBV pol and core antigen consensus sequences were generated based on HBV genotypes B, C, and D. Different HBV sequences were obtained from different sources and aligned separately for core and polymerase proteins. Original sequence alignments for all subtypes (A to H) were subsequently limited to HBV genotypes, B, C, and D. Consensus sequences were defined for each protein alignment in each subtype separately and in all joint BCD sequences. In variable alignment positions, the most frequent amino acid was used in the consensus sequence.

Optimization of HBV Core Antigen

The HBV core antigen consensus sequence was optimized by a deletion in the native viral protein. In particular, a deletion of thirty-four amino acids corresponding to the C-terminal highly positively charged segment was made, which is required for pre-genomic RNA encapsidation.

Optimization of the HBV Pol Antigen

The HBV pol antigen consensus sequence was optimized by changing four residues to remove reverse transcriptase and RNaseH enzymatic activities. In particular, the aspartate residues (D) were changed to asparagine residues (N) in the "YXDD" motif of the reverse transcriptase domain to eliminate any coordination function, and thus nucleotide/metal ion binding. Additionally, the first aspartate residue (D) was changed to an asparagine residue (N) and the first glutamate residue (E) was changed to a glutamine residue (A) in the "DEDD" motif of the RNaseH domain to eliminate Mg^{2+} coordination. Additionally, the sequence of the HBV pol antigen was codon optimized to scramble the internal open reading frames for the envelope proteins, including the S protein and versions of the S protein with the N-terminal extensions pre-S1 and pre-S2. As a result, open reading frames for the envelope proteins (pre-S1, pre-S2, and S protein) and the X protein were removed.

Optimization of HBV Core and Pol Antigen Expression Strategies

Three different strategies were tested to obtain maximum and equal expression of both core and pol antigens from plasmid vectors: (1) fusion of HBV core and pol antigens in frame with a small AGAG inserted between the coding sequences to produce a single Core-Pol fusion protein (**FIG. 2A**); (2) expression of both core and pol antigens from one plasmid by means of a ribosomal slippage site, particularly the FA2 slippage site from foot-and-mouth disease (FMDV) to produce a bicistronic expression vector expressing individual core and pol proteins from a single mRNA (**FIG. 2B**); and (3) two separate plasmids encoding for HBV core and pol antigens, respectively (**FIG. 2C**).

In vitro Expression Analysis

The coding sequences of consensus HBV core and pol antigens according to each of the above three expression strategies were cloned into the commercially available expression plasmid pcDNA3.1. HEK-293T cells were transfected with the vectors and protein expression was evaluated by Western blot using a HBV core-specific antigen.

Optimization of Post-Transcriptional Regulatory Elements

Four different post-transcriptional regulatory elements were evaluated for enhancement of protein expression by stabilizing the primary transcript, facilitating its nuclear export, and/or improving transcriptional-translational coupling: (1) Woodchuck HBV post-transcriptional regulatory element (WPRE) (GenBank: J04514.1); (2) intron/exon sequence derived from human apolipoprotein A1 precursor (GenBank: X01038.1); (3) untranslated R-U5 domain of the human T-cell leukemia virus type 1 (HTLV-1) long terminal repeat (LTR) (GenBank: KM023768.1); and (4) composite sequence of the HTLV-1 LTR, synthetic rabbit β -globin intron (GenBank: V00882.1), and a splicing enhancer (triple composite sequence). The enhancer sequences were introduced between a CMV promoter and the HBV antigen coding sequences in the plasmids. No significant difference was observed by Western blot in the expression of the core antigen when expressed from a plasmid in the presence and absence of the WPRE element (**FIG. 2D**). However, when core antigen expression in HEK293T transfected cells from plasmids having the other three post-transcriptional regulatory sequences was evaluated by Western blot, the triple enhancer sequence resulted in the strongest core antigen expression (**FIG. 2E**).

Selection of Signal Peptide for Efficient Protein Secretion

Three different signal peptides introduced in frame at the N-terminus of the HBV core antigen were evaluated: (1) Ig heavy chain gamma signal peptide SPIgG (BAA75024.1); (2) the Ig heavy chain epsilon signal peptide SPIgE (AAB59424.1); and (3) the Cystatin S precursor signal peptide SPCS (NP_0018901.1). Signal peptide cleavage sites were optimized *in silico* for

core fusion using the Signal P prediction program. Secretion efficiency was determined by analyzing core protein levels in the supernatant. Western blot analysis of core antigen secretion using the three different signal peptides fused at the N-terminus demonstrated that the Cystatin S signal peptide resulted in the most efficient protein secretion (**FIG. 2F**).

DNA Vaccine Vector Optimization

The optimized expression cassettes containing the triple composite enhancer sequence upstream of the HBV antigen coding sequence with an N-terminal Cystatin S signal peptide sequence were cloned in the DNA vaccine vector pVax-1 (Life Technologies, Thermo Fisher Scientific, Waltham, MA). The expression cassette in pVax-1 contains a human CMV-IE promoter followed by the bovine growth hormone (BGH)-derived polyadenylation sequence (pA). Bacterial propagation is driven by the pUC ori replicon and kanamycin resistance gene (Kan R) driven by a small eukaryotic promoter. The pUC ori replication, KanR expression cassette, and expression cassette driven by the CMV-IE promoter are all in the same orientation within the plasmid backbone. However, a marked reduction in core antigen expression was observed in the pVax-1 vector as compared to the expression level observed in the pcDNA3.1 vector.

Several strategies were employed to improve protein expression: (1) reversal of the entire pUCori-KanR cassette into counterclockwise orientation (pVD-core); and (2) changing the codon usage of the KanR gene along with replacement of the Kan promoter with the Amp promoter from the pcDNA3.1 vector (pDK-core). Both strategies restore core antigen expression, but core antigen expression was highest with the pDK vector, which contained the codon-adjusted Kan R gene, AmpR promoter (instead of KanR promoter), and inverse orientation of the pUCori-KanR cassette.

The four different HBV core/pol antigen optimized expression cassettes as shown in **FIG. 2G** were introduced into the pDK plasmid backbone to test each of the three expression strategies illustrated in **FIGS. 2A-2C**. The plasmids were tested *in vitro* for core and pol antigen expression by Western blot analysis using core and pol specific antibodies. The most consistent expression profile for cellular and secreted core and pol antigens was achieved when the core and pol antigens were encoded by separate vectors, namely the individual DNA vectors pDK-core and pDK-pol (**FIG. 2H**). A schematic representation of the pDK-pol and pDK-core vectors is shown in **FIGS. 3A and 3B**, respectively.

Example 2: Generation of Adenoviral Vectors Expressing a Fusion of Truncated HBV Core Antigen with HBV Pol Antigen

The creation of an adenovirus vector has been designed as a fusion protein or core and pol antigens expressed from a single open reading frame. Additional configurations for the expression of the two proteins, e.g. using two separate expression cassettes, or using a 2A-like sequence to separate the two sequences, can also be envisaged.

5 Design of expression cassettes for adenoviral vectors

The expression cassettes (diagrammed in **FIG. 8A** and **FIG. 8B**) are comprised of the CMV promoter (SEQ ID NO: 17), an intron (SEQ ID NO: 23) (a fragment derived from the human ApoAI gene - GenBank accession X01038 base pairs 295 – 523, harboring the ApoAI second intron), followed by the optimized coding sequence – either core alone or the core and polymerase fusion protein preceded by a human immunoglobulin secretion signal coding sequence (SEQ ID NO: 18), and followed by the SV40 polyadenylation signal (SEQ ID NO: 24).

A secretion signal was included because of past experience showing improvement in the manufacturability of some adenoviral vectors harboring secreted transgenes, without influencing the elicited T-cell response (mouse experiments).

15 The last two residues of the Core protein (VV) and the first two residues of the Polymerase protein (MP) if fused results in a junction sequence (VVMP) that is present on the human dopamine receptor protein (D3 isoform), along with flanking homologies.

The interjection of an AGAG linker between the core and the polymerase sequences eliminates this homology and returned no further hits in a Blast of the human proteome.

20 **Example 3: *In Vivo* Immunogenicity Study of DNA Vaccine in Mice**

An immunotherapeutic DNA vaccine containing DNA plasmids encoding an HBV core antigen or HBV polymerase antigen was tested in mice. The purpose of the study was designed to detect T-cell responses induced by the vaccine after intramuscular delivery via electroporation into BALB/c mice. Initial immunogenicity studies focused on determining the cellular immune responses that would be elicited by the introduced HBV antigens.

In particular, the plasmids tested included a pDK-Pol plasmid and pDK-Core plasmid, as shown in **FIGS. 3A** and **3B**, respectively, and as described above in Example 1. The pDK-Pol plasmid encoded a polymerase antigen having the amino acid sequence of SEQ ID NO: 4, and the pDK-Core plasmid encoded a Core antigen having the amino acid sequence of SEQ ID NO: 2. First, T-cell responses induced by each plasmid individually were tested. The DNA plasmid (pDNA) vaccine was intramuscularly delivered via electroporation to Balb/c mice using a commercially available TriGridTM delivery system-intramuscular (TDS-IM) adapted for application in the mouse model in cranialis tibialis. See International Patent Application Publication WO2017172838, and U.S. Patent Application No. 16/223,318 entitled “Method and

Apparatus for the Delivery of Hepatitis B Virus (HBV) Vaccines,” filed on December 18, 2018 for additional description on methods and devices for intramuscular delivery of DNA to mice by electroporation, the disclosures of which are hereby incorporated by reference in their entireties. In particular, the TDS-IM array of a TDS-IM v1.0 device having an electrode array with a 2.5 mm spacing between the electrodes and an electrode diameter of 0.030 inch was inserted percutaneously into the selected muscle, with a conductive length of 3.2 mm and an effective penetration depth of 3.2 mm, and with the major axis of the diamond configuration of the electrodes oriented in parallel with the muscle fibers. Following electrode insertion, the injection was initiated to distribute DNA (e.g., 0.020 ml) in the muscle. Following completion of the IM injection, a 250 V/cm electrical field (applied voltage of 59.4 -65.6 V, applied current limits of less than 4 A, 0.16 A/sec) was locally applied for a total duration of about 400 ms at a 10% duty cycle (i.e., voltage is actively applied for a total of about 40 ms of the about 400 ms duration) with 6 total pulses. Once the electroporation procedure was completed, the TriGrid™ array was removed and the animals were recovered. High-dose (20 µg) administration to Balb/c mice was performed as summarized in Table 1. Six mice were administered plasmid DNA encoding the HBV core antigen (pDK-core; Group 1), six mice were administered plasmid DNA encoding the HBV pol antigen (pDK-pol; Group 2), and two mice received empty vector as the negative control. Animals received two DNA immunizations two weeks apart and splenocytes were collected one week after the last immunization.

Table 1: Mouse immunization experimental design of the pilot study.

Group	N	pDNA	Unilateral Admin Site (alternate sides)	Dose	Vol	Admin Days	Endpoint (spleen harvest) Day
1	6	Core	CT + EP	20 µg	20 µL	0, 14	21
2	6	Pol	CT + EP	20 µg	20 µL	0, 14	21
3	2	Empty Vector (neg control)	CT + EP	20 µg	20 µL	0, 14	21

CT, cranialis tibialis muscle; EP, electroporation.

Antigen-specific responses were analyzed and quantified by IFN-γ enzyme-linked immunospot (ELISPOT). In this assay, isolated splenocytes of immunized animals were incubated overnight with peptide pools covering the Core protein, the Pol protein, or the small

peptide leader and junction sequence (2µg/ml of each peptide). These pools consisted of 15 mer peptides that overlap by 11 residues matching the Genotypes BCD consensus sequence of the Core and Pol vaccine vectors. The large 94 kDa HBV Pol protein was split in the middle into two peptide pools. Antigen-specific T cells were stimulated with the homologous peptide pools and IFN-γ-positive T cells were assessed using the ELISPOT assay. IFN-γ release by a single antigen-specific T cell was visualized by appropriate antibodies and subsequent chromogenic detection as a colored spot on the microplate referred to as spot-forming cell (SFC).

Substantial T-cell responses against HBV Core were achieved in mice immunized with the DNA vaccine plasmid pDK-Core (Group 1) reaching 1,000 SFCs per 10⁶ cells (FIG. 4). Pol T-cell responses towards the Pol 1 peptide pool were strong (~1,000 SFCs per 10⁶ cells). The weak Pol-2-directed anti-Pol cellular responses were likely due to the limited MHC diversity in mice, a phenomenon called T-cell immunodominance defined as unequal recognition of different epitopes from one antigen. A confirmatory study was performed confirming the results obtained in this study (data not shown).

The above results demonstrate that vaccination with a DNA plasmid vaccine encoding HBV antigens induces cellular immune responses against the administered HBV antigens.

Example 4: Dose-finding study of combined pDK-Core / pDK-Pol plasmids in Mice

The purpose of this dose-finding study with combined plasmids was to evaluate the immune responses in mice of a mixture of DNA plasmid (pDNA) vectors encoding HBV core and pol antigens applied in one site using different DNA doses. In this study, an immunotherapeutic DNA vaccine containing a 1:1 (w/v) mixture of two plasmids, the pDK-pol and pDK-core plasmids described in Example 1, was tested in mice. The DNA vaccine was delivered to Balb/c mice in one anatomic site intramuscularly via electroporation as described above in Example 3. Vaccination of the combined *Core*- and *Pol*-expressing plasmids at 10 µg, 1 µg, and 0.1 µg DNA of each plasmid per site was performed as summarized in Table 2. Eight mice were tested in each group, and two mice were administered empty vector as the negative control. Animals received two DNA immunizations three weeks apart and splenocytes were collected one week after the last immunization.

Table 2: Mouse immunization experimental design of the dose-finding study with combined plasmids.

Group	N	pDNA		Unilateral admin site (alternate sides)	Dose of each pDNA per site	Dose total pDNA per site	Admin days	Endpoint (spleen harvest) Day
1	8	Core Pol	and	CT + EP	10 µg	20 µg	0, 21	28
2	8	Core Pol	and	CT + EP	1 µg	2 µg	0, 21	28
3	8	Core Pol	and	CT + EP	0.1 µg	0.2 µg	0, 21	28
4	2	Empty Vector (neg. control)		CT + EP	20 µg	20 µg	0, 21	28

pDNA, plasmid DNA; CT, cranialis tibialis muscle; EP, electroporation.

Antigen-specific responses were analyzed and quantified by IFN- γ enzyme-linked immunospot (ELISPOT) as described in Example 1. Considerable T-cell responses against Core and Pol were achieved in BALB/c mice immunized with the combined DNA vaccine consisting of plasmid pDK-Core and pDK-Pol (FIG. 5). There was no statistical difference in terms of the magnitude of immune responses between Group 1, immunized with 10 µg of each plasmid, and Group 2, immunized with only 1 µg of each plasmid. This result suggested that T-cell responses reached a maximum level at around 1 µg Core- and Pol-antigen-expressing plasmids. However, at 10-fold lower DNA exposure, i.e., at 0.1 µg of each plasmid, a significant decrease in SFCs was observed. Pol T-cell responses towards the Pol-1 peptide pool were dominant. The weak Pol-2-directed anti-Pol cellular responses were likely due to the limited MHC diversity in inbred mice, a phenomenon called T-cell immunodominance defined as unequal recognition of different epitopes from one antigen.

The above results demonstrate that in mice immunized with a combination of DNA plasmids expressing HBV core and pol antigens, considerable T-cell responses were found at doses of 1 µg of each plasmid, and some immune response was still observed at a dose 0.1 µg per plasmid.

Example 5: Immune Interference Study in Mice

For practical reasons, it would be desirable to develop the combination HBV core and pol antigen DNA vaccine as a combined (mixed) vector formulation. However, immunodominance might occur with multivalent vaccines and immune responses against subdominant antigens could be blunted. Therefore, immune interference, i.e., decreased Core- and/or Pol-specific cellular responses from administration of a combination of the two antigen-expression plasmids mixed together when compared to immunization of either vector in different anatomic sites, was assessed.

Balb/c mice were vaccinated with the pDK-core and/or pDK-pol DNA plasmids intramuscularly via electroporation as described in Example 3. The DNA plasmids (pDNA) were administered at a dose of 5 µg per site applied either individually, combined (mixed) at one site, or combined in separate sites, as summarized in Table 3. Animals received two DNA immunizations three weeks apart and splenocytes were collected one week after the last immunization.

Table 3: Mouse immunization experimental design of the immune interference study.

Group	N	pDNA	Unilateral admin site (alternate sides)	Dose each pDNA per site	Dose total pDNA per site	Admin days	Endpoint (spleen harvest) Day
1	6	Core	Bilateral CT	5 µg	10 µg	0, 21	28
2	6	Pol	Bilateral CT	5 µg	10 µg	0, 21	28
3	6	Core and Pol <i>mixed</i>	Bilateral CT	10 µg	20 µg	0, 21	28
4	6	Core and Pol <i>individual</i>	Core in left CT Pol in right CT	10 µg	20 µg	0, 21	28
5	2	Empty Vector (neg. control)	Bilateral CT	10 µg	20 µg	0, 21	28

CT, cranialis tibialis muscle.

Antigen-specific responses were analyzed and quantified by IFN- γ enzyme-linked immunospot (ELISPOT) as described in Example 1. Strong Core- and Pol-specific antigen responses were confirmed in BALB/c mice in this experiment (**FIG. 6**). No significant immune interference was observed based on the substantially identical T-cell responses obtained for Group 3, in which both plasmids were mixed and applied in the same site, and Group 4, in which pDNA expressing core and pol antigens were individually electroporated in two different sites. One animal in Group 1 showed a low abnormal Pol-2-pool-directed response. The same experiment was repeated in C57/Bl6 mice with comparable results.

The above results demonstrate that substantially no immune interference was observed when combining the two HBV antigen-expression plasmids pDK-Core and pDK-Pol.

Example 6: Evaluation of the Efficacy of a DNA Vaccine in Non-Human Primates

The purpose of this study was to evaluate the efficacy of a therapeutic HBV DNA vaccine delivered intramuscularly with electroporation, and to induce and measure a HBV-specific T cell response/cell activation in Cynomolgus monkeys (*Macaca fascicularis*).

Vaccine

The vaccine used in this study was a combination of two separate DNA plasmids encoding an HBV core antigen and HBV polymerase antigen, respectively. In particular, the DNA plasmids were pDK-Pol plasmid (encoding an HBV polymerase antigen having the amino acid sequence of SEQ ID NO: 4) and pDK-Core plasmid (encoding an HBV core antigen having the amino acid sequence of SEQ ID NO: 2), as shown in **FIGS. 3A and 3B**, respectively, and described in Example 1.

The DNA plasmids were administered in a 1:1 (w/w) mixture of both plasmids delivered in one anatomic site. Non-human Primates (NHP) were electroporated with a TriGrid™ delivery system-intramuscular (TDS-IM) adapted for application in the NHP model. See U.S. Patent Application No. 16/223,318 entitled “Method and Apparatus for the Delivery of Hepatitis B Virus (HBV) Vaccines,” filed on December 18, 2018 for additional description on methods and devices for intramuscular delivery of DNA to NHP by electroporation, the disclosure of which is hereby incorporated by reference. In particular, the TDS-IM array of a TDS-IM v1.0 or TDS-IM v2.0 having an electrode array with a 6.0 mm spacing between the electrodes and an electrode diameter of 0.021 or 0.023 inch, respectively, was inserted percutaneously into the selected muscle with the major axis of the diamond configuration of the electrodes oriented in parallel with the muscle fibers. The conductive length was 5.0 mm for TDS-IM v1.0 or TDS-IM v2.0, while the effective penetration depth was 15.5 mm for TDS-IM v1.0 and 9.0 mm for TDS-IM v2.0. Following electrode insertion, the injection was initiated to distribute DNA (e.g., 1.0 ml) in

the muscle. Following completion of the IM injection, a 250 V/cm electrical field (applied voltage of 142.4 – 157.6 V, applied current limits of 0.6 - 4 A, 0.16 A/sec) was locally applied for a total duration of about 400 ms at a 10% duty cycle (i.e., voltage is actively applied for a total of about 40 ms of the about 400 ms duration) with 6 total pulses. Once the electroporation procedure was completed, the TriGrid™ array was removed and the animals were recovered. The initial immunogenicity study focused on determining the cellular immune responses that would be elicited by the introduced HBV antigens.

Non-human primates

Cynomolgus macaques (n=30) were sourced from China (Covance Research Products Inc. USA), at 2.5 to 5 years of age and weighing 3.0 to 5.0 kg at start of study. They were socially housed in enriched environment according to veterinary guidelines and National Research Council, *Guide for the Care and Use of Laboratory Animals*, 8th Edition, Washington DC: National Academies Press (2011). Animals were acclimatized for a period of 2 weeks before starting the study. Monkeys were anesthetized with ketamine prior to each plasmid electroporation administration. Blood was collected 2 weeks after each immunization in vials containing sodium heparin. PBMCs were isolated using ficoll gradient and stored in liquid nitrogen tanks until analysis.

Intramuscular/Electroporation Administration in the Non-Human Primates

Plasmid administration was performed three times (group 1) at days 0, 36 and 62, as summarized in Table 4. pDK-Core (1.0 mg) and pDK-Pol (1.0 mg) were administered via electroporation with the delivery system set to 19 mm (short) injection depth in the quadriceps (*vastus lateralis*) muscle. For each injection, an alternate leg muscle was administered. The syringe containing DNA plasmid was equipped with an injection depth limiter suitable for NHP quadriceps muscle, for an injection target depth of about 10 mm into the muscle, with the major axis of the diamond configuration oriented in parallel with the muscle fibers. Immediately after the IM injection was completed, the electroporation apparatus was activated, resulting in the electrical stimulation of the muscle at an amplitude of up to 250 V per cm of electrode spacing for a total of up to 40 mS duration over a 400 mS interval. Samples were collected on days 0, 14, 50, and 76, and analyzed by ELISPOT and intracellular cytokine staining.

Table 4: NHP vaccination experimental design

Group	N	pDNA	Unilateral admin site (alternate sides)	Dose each pDNA per site	Dose total pDNA per site	Admin days	Sample days
1	5	pDK-Core & pDK-Pol	CT + EP	1.0 mg	2.0 mg	0, 36 and 62	0, 14, 50 and 76

ELISPOT Analysis

Antigen-specific responses were analyzed and quantified by IFN- γ enzyme-linked immunospot (ELISPOT) using Primate IFN- γ ELISpot kit (R&D Systems, USA, Cat No.

5 EL961). In this assay, isolated PBMCs of immunized animals were incubated in triplicate wells overnight with peptide pools (2 μ g/ml) covering the Core protein and the Pol protein. These pools consist of 15 mer peptides that overlap by 11 residues matching the Genotypes ABCD consensus sequence of the Core and Pol vaccine vectors. The peptides were synthesized at 90% purity (JPT, Germany). The large 94 kDa HBV Pol protein was split in the middle into two peptide
10 pools. IFN- γ release by a single antigen-specific T cell was visualized by appropriate antibodies and subsequent chromogenic detection as a colored spot on the microplate referred to as spot-forming cell (SFC). The results are shown in FIG. 7A.

Intracellular Cytokine Staining (ICS)

Intracellular cytokine staining (ICS) was used to study the vaccine-induced T-cell

15 responses. Frozen PBMCs were thawed and rested overnight in 10% FBS, RPMI medium before stimulation with vaccine-insert matched Core, Pol-1 or Pol-2 peptide pools (2 μ g/ μ l), DMSO or Leukocyte Activation cocktail for 6 hours in 10% FBS, RPMI medium containing Golgiplug Protein Transport Inhibitor (1 μ g/ μ l). Stimulated cells were stained with fixable viability dye eFluor 780 (65-0865-14, eBioscience), and treated for 20 minutes with Fixation/Permeabilization
20 solution (554714, BD Biosciences) before staining for 30 minutes with intracellular stain mix as shown in Table 5 below. Stained cells were acquired using Fortessa flowcytometer with the appropriate single color compensation controls. Response magnitudes were reported as the percentage of CD4⁺ or CD8⁺ T cells expressing IFN- γ , TNF- α or IL-2 after stimulation. The results are shown in FIG. 7B.

Table 5: Antibody panel used for intracellular cytokine staining assay**BD****Biosciences**

Cat no	Antibody	Fluorescence	Clone
557705	CD3	Alexa fluor 488	SP34
563823	CD8	BUV786	RPA-T8
564107	CD4	BUV395	L200
554701	IFN γ	PE	B27
554514	TNF	APC	MAb11
564164	IL-2	BV421	MQ1- 17H12

Results

5 ELISPOT data (**FIG. 7A**) showed strong Core and Pol-2 responses after two immunizations. A third immunization greatly increased the IFN- γ magnitude. The Pol-1 peptide pool elicited an intermediate response that was also improved with a third immunization, although not as greatly improved as with Core and Pol-2. Day 76 data includes only the results from four NHPs, as blood draw from the fifth monkey was not successful. The high variation within each group is due to the NHPs being sourced from an outbred stock, and genetic diversity could account for the differing immune response.

10 The ICS assay data (**FIG. 7B**) showed that cytokine response from HBV peptide stimulation is CD8 driven and is specific to the Core and Pol-2 peptide pools, as previously observed with ELISPOT. The responding NHPs in the ICS assay are the same responding individuals as with the ELISPOT assay. Although a few individual ICS responses do not show positive as seen in the ELISPOT data, this may be attributed to the higher sensitivity of the ELISPOT assay.

Conclusion

20 The above results demonstrate that in NHPs immunized with a combination of pDK-Core and pDK-Pol vaccine by intramuscular injection via electroporation, considerable T-cell responses were found at doses of 1.0 mg of each plasmid, with peptide specific responses detected after two immunizations and even greater responses after three immunizations. At Day 76, ELISPOT assay results showed that peptide pools Core, Pol-1 and Pol-2 induced positive

IFN- γ T cell responses in every tested NHP (4/5 NHP). The ICS assay on PBMCs from immunized NHPs show that the HBV peptide specific response is CD8 driven, with the highest responses against Core and Pol-2 peptide pools.

Example 7: Evaluation of the Efficacy of a DNA Vaccine in Human Subjects

5 The efficacy of a therapeutic HBV DNA vaccine delivered intramuscularly with electroporation is evaluated in human subjects.

Human Subjects

The human subjects are adult patients having chronic HBV infection that are HBsAg-positive. The human subjects are being treated with an HBV polymerase inhibitor (entecavir or
10 tenofovir).

Vaccine

Human patients are administered a combination of two separate DNA plasmids encoding an HBV core antigen and HBV polymerase antigen, respectively. In particular, the DNA plasmids were pDK-Pol plasmid (encoding an HBV polymerase antigen having the amino acid
15 sequence of SEQ ID NO: 4) and pDK-Core plasmid (encoding an HBV core antigen having the amino acid sequence of SEQ ID NO: 2), as shown in FIGS. 3A and 3B, respectively, and described in Example 1. The DNA plasmids are administered in a 1:1 mixture of both plasmids at different dosages, particularly dosages of 0.25 mg, 1 mg, and 6 mg of total plasmid according to a randomized, placebo-controlled escalating dose trial.

20 Intramuscular/Electroporation Administration in the Human Subjects

The DNA plasmids are administered to the human subjects by electroporation in 2 to 3 intramuscular immunizations using a TriGridTM delivery system-intramuscular (TDS-IM) adapted for application in humans. Some patients are administered placebo (i.e., plasmids lacking the coding sequences for HBV antigens) as control. A TriGridTM delivery system-
25 intramuscular (TDS-IM) adapted for application in the human is used for the delivery of the plasmid DNA by electroporation. See International Patent Application Publication WO2017172838, and U.S. Patent Application No. 16/223,318 entitled "Method and Apparatus for the Delivery of Hepatitis B Virus (HBV) Vaccines," filed on December 18, 2018 for additional description on methods and devices for intramuscular delivery of DNA to humans by
30 electroporation, the disclosures of which are hereby incorporated by reference in their entireties. For example, the TDS-IM array of TDS-IM v2.0 having an electrode array with a 6.0 mm spacing between the electrodes and an electrode diameter of 0.023 inch, respectively, can be inserted percutaneously into the selected muscle with the major axis of the diamond configuration of the electrodes oriented in parallel with the muscle fibers. The conductive length

can be 5.0 mm, while the effective penetration depth can be 19 mm. Following electrode insertion, the injection is initiated to distribute DNA (e.g., 1.0 ml) in the muscle. Following completion of the IM injection, a 250 V/cm electrical field (applied voltage of 142.4 – 157.6 V, applied current limits of 0.6 - 4 A, 0.16 A/sec) is locally applied for a total duration of about 400 ms at a 10% duty cycle (i.e., voltage is actively applied for a total of about 40 ms of the about 400 ms duration) with 6 total pulses. Once the electroporation procedure is completed, the TriGrid™ array is removed and the human subject is recovered.

Blood samples are collected from the patients at various time points post-immunization. The development of HBsAg levels post immunization, particularly for levels consistent with evolution to clinical seroconversion are evaluated in the patients 3 to 6 months post-immunization. The persistent loss of HBsAg and a decrease in clinical disease (e.g., cirrhosis, hepatocellular carcinoma) are evaluated in the patients 6 to 12 months post-immunization.

Example 8: *In Vivo* Immunogenicity Study of Adenoviral Vectors in Mice

An immunotherapeutic vaccine containing adenoviral vectors encoding an HBV core antigen or an HBV polymerase antigen was tested in mice. The purpose of the study was to detect T-cell responses induced by the vaccine after intramuscular delivery into F1 mice (C57BL/6 x Balb/C). Initial immunogenicity studies focused on determining the cellular immune responses that would be elicited by the introduced HBV antigens. In particular, the adenovectors tested contained the expression cassettes as shown in FIGS. 8A and 8B.

***In vivo* Immunogenicity Study**

To evaluate the *in vivo* immunogenicity of the adenoviral vaccine, HBV adenoviral vectors were administered intramuscularly into F1 mice. These immunogenicity studies focused on determining the cellular immune responses elicited by the HBV antigens Core and Polymerase. The administration to F1 mice was performed as summarized in Table 6. Animals received one HBV adenoviral vector immunization. Splenocytes were collected nine weeks later.

Table 6: Experimental Design for Mouse Immunization with Adenoviral Vectors

Group	N	Prime Day 0	R	Dose (vp)	Endpt Day
1	4	Core Pol fusion + Core	IM	10 ⁸	63
2	4	Core Pol fusion + Core	IM	10 ⁹	63
3	4	Core Pol fusion +	IM	10 ¹⁰	63

Group	N	Prime Day 0	R	Dose (vp)	Endpt Day
		Core			
7	4	Core Pol fusion	IM	10^8	63
8	4	Core Pol fusion	IM	10^9	63
9	4	Core Pol fusion	IM	10^{10}	63

IM: intramuscular; vp: viral particles;

Evaluation of immunogenicity of HBV adenoviral vectors

Antigen-specific responses were analyzed and quantified by IFN- γ enzyme-linked immunospot (ELISPOT). In this assay, isolated splenocytes of immunized animals were incubated with peptide pools covering the Core and the Pol protein (2 μ g/ml of each peptide). The pools consist of 15-mer peptides that overlap by 11 residues matching the genotypes ABCD consensus sequences of the Core and Pol adenoviral vectors. The large 94 kDa HBV Pol protein was split in the middle into two peptide pools. In ELISPOT, IFN- γ release by a single antigen-specific T-cell was visualized by appropriate antibodies and subsequent chromogenic detection as a colored spot on the microplate referred to as spot-forming cell (SFC).

The results are shown in FIG. 9. From the results, it can be seen that HBV adenoviral vectors, especially the combination of Core Pol fusion and Core adenovectors gave rise to Core and Pol specific T cell responses. These data indicate that adenoviral vectors encoding HBV core and pol antigens give rise to robust T cell responses against core and pol in F1 mice.

Example 9: *In Vivo* Immunogenicity Study of DNA Vaccine in Mice

An immunotherapeutic DNA vaccine containing DNA plasmids encoding an S-surface antigen or surface antigen containing the L- and M-surface antigen domains was tested in mice. The purpose of the study was designed to detect T-cell responses induced by the vaccine after intramuscular delivery via electroporation into BALB/c mice. Initial immunogenicity studies focused on determining the cellular immune responses that would be elicited by the introduced HBV antigens.

In particular, the plasmids tested included a pDK-S plasmid and pDK-LM plasmid, as shown in FIGS. 3C and 3D, respectively. The pDK-S and pDK-LM plasmids contained the codon-adjusted KanR gene, AmpR promoter, and inverse orientation of the pUCori-KanR cassette as described above in Example 1 with respect to the pDK-pol and pDK-core plasmids. The pDK-S and pDK-LM plasmids contained further contained optimized expression cassettes containing the triple composite enhancer sequence upstream of the HBV antigen coding sequence with an N-terminal Cystatin S signal peptide sequence. The expression cassette

contains a human CMV-IE promoter followed by the bovine growth hormone (BGH)-derived polyadenylation sequence (pA). The pDK-S plasmid encoded an S-surface antigen having the amino acid sequence of SEQ ID NO: 27, and the pDK-LM plasmid encoded a protein containing the L- and M-surface antigen domains having the amino acid sequence of SEQ ID NO: 29. T-cell responses induced by each plasmid individually were tested as well as T-cell responses induced by the two plasmids administered in combination. The DNA plasmid (pDNA) vaccine was intramuscularly delivered via electroporation to Balb/c mice in one anatomic site as described above in Example 3.

Administration to Balb/C mice was performed as summarized in Table 7. Each plasmid was tested at two different doses (10 μ g and 1.0 μ g). Six mice were administered plasmid DNA encoding the S-surface antigen at a dose of 10 μ g (pDK-S; Group 1), six mice were administered plasmid DNA encoding the S-surface antigen at a dose of 1.0 μ g (pDK-S; Group 2), six mice were administered plasmid DNA encoding the protein containing the L- and M-surface antigen domains at a dose of 10 μ g (pDK-LM; Group 3), six mice were administered plasmid DNA encoding the protein containing the L- and M-surface antigen domains at a dose of 1.0 μ g (pDK-LM; Group 4), six mice were administered a combination of plasmid DNA encoding the protein containing the L- and M-surface antigen domains and plasmid DNA encoding the S-surface antigen each at a dose of 10 μ g (pDK-S + pDK-LM; Group 5), six mice were administered a combination of plasmid DNA encoding the protein containing the L- and M-surface antigen domains and plasmid DNA encoding the S-surface antigen each at a dose of 1.0 μ g (pDK-S + pDK-LM; Group 6), and two mice received empty vector as the negative control. Animals received two DNA immunizations three weeks apart and splenocytes were collected one week after the last immunization.

Table 7: Mouse immunization experimental design

Group	N	pDNA	Unilateral Admin Site (alternate sides)	Dose	Vol	Admin Days	Endpoint (spleen harvest) Day
1	6	pDK-S	CT + EP	10 µg	20 µL	0, 21	28
2	6	pDK-S	CT + EP	1.0 µg	20 µL	0, 21	28
3	6	pDK-LM	CT + EP	10 µg	20 µL	0, 21	28
4	6	pDK-LM	CT + EP	1.0 µg	20 µL	0, 21	28
5	6	pDK-S + pDK-LM	CT + EP	10 µg each plasmid	20 µL	0, 21	28
6	6	pDK-S + pDK-LM	CT + EP	1.0 µg each plasmid	20 µL	0, 21	28
7	2	Empty Vector (neg control)	CT + EP	20 µg	20 µL	0, 21	28

CT, cranialis tibialis muscle; EP, electroporation.

- 5 Antigen-specific responses were analyzed and quantified by IFN- γ enzyme-linked immunospot (ELISPOT). Isolated splenocytes of immunized animals were incubated overnight with peptide pools covering the surface antigens, including L-, M-, and S-surface antigens (2 µg/ml of each peptide). These pools consisted of 15 mer peptides that overlap by 11 residues matching the genotypes ABCD consensus sequence of the surface antigen vaccine vectors. Antigen-
- 10 specific T cells were stimulated with the homologous peptide pools and IFN- γ -positive T cells were assessed using the ELISPOT assay. IFN- γ release by a single antigen-specific T cell was visualized by appropriate antibodies and subsequent chromogenic detection as a colored spot on the microplate referred to as spot-forming cell (SFC). The results are shown in FIG. 10.

- 15 Substantial T-cell responses were achieved in mice immunized with the DNA vaccine plasmid pDK-S (Groups 1 and 2). Weaker T-cell responses were achieved in mice immunized with the DNA vaccine plasmid pDK-LM (Groups 3 and 4). However, substantial T-cell responses were achieved in mice immunized with the DNA vaccine plasmid pDK-S in combination with the DNA vaccine plasmid pDK-LM (Groups 5 and 6).

The above results demonstrate that vaccination with a DNA plasmid vaccine encoding HBV antigens induces cellular immune responses against the administered HBV antigens.

It is understood that the examples and embodiments described herein are for illustrative purposes only, and that changes could be made to the embodiments described above without
5 departing from the broad inventive concept thereof. It is understood, therefore, that this invention is not limited to the particular embodiments disclosed, but it is intended to cover modifications within the spirit and scope of the invention as defined by the appended claims.

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CLAIMS

We claim:

- 5 1. A non-naturally occurring nucleic acid molecule comprising a polynucleotide encoding an HBV surface antigen consisting of an amino acid sequence that is at least 98% identical to the amino acid sequence of SEQ ID NO: 27, such as at least 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8% or 99.9% or 100% identical to the amino acid sequence of SEQ ID NO: 27.
- 10 2. The non-naturally occurring nucleic acid molecule according to claim 1, further comprising a polynucleotide encoding at least one of a truncated HBV core antigen and an HBV polymerase antigen, wherein:
- 15 a) the truncated HBV core antigen consists of an amino acid sequence that is at least 90% identical to SEQ ID NO: 2 or SEQ ID NO: 14, such as at least 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 2; and
- 20 b) the HBV polymerase antigen comprises an amino acid sequence that is at least 90% identical to SEQ ID NO: 4, such as at least 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 4.
- 25 3. The non-naturally occurring nucleic acid molecule according to claim 2, wherein
- a) the HBV surface antigen consists of an amino acid sequence that is at least 99% identical to the amino acid sequence of SEQ ID NO: 27;
- b) the truncated HBV core antigen consists of an amino acid sequence that is at least 99% identical to SEQ ID NO: 2; and
- 30 c) the HBV polymerase antigen comprises an amino acid sequence that is at least 99% identical to SEQ ID NO: 4.
4. The non-naturally occurring nucleic acid molecule according to claim 2, wherein
- a) the polynucleotide sequence encoding the HBV surface antigen is at least 90% identical to SEQ ID NO: 26, such as at least 90%, 91%, 92%, 93%, 94%, 95%,

95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 26;

b) the polynucleotide sequence encoding the truncated HBV core antigen is at least 90% identical to SEQ ID NO: 1 or SEQ ID NO: 15, such as at least 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 1 or SEQ ID NO: 15; and

c) the polynucleotide sequence encoding the HBV polymerase antigen is at least 90% identical to SEQ ID NO: 3 or SEQ ID NO: 16, such as at least 90%, 91%, 92%, 93%, 94%, 95%, 95.5%, 96%, 96.5%, 97%, 97.5%, 98%, 98.5%, 99%, 99.1%, 99.2%, 99.3%, 99.4%, 99.5%, 99.6%, 99.7%, 99.8%, 99.9% or 100% identical to SEQ ID NO: 3 or SEQ ID NO: 16.

5. The non-naturally occurring nucleic acid molecule according to claim 4, wherein

a) the polynucleotide sequence encoding the truncated HBV core antigen is 100% identical to SEQ ID NO: 1 or SEQ ID NO: 15; and

b) the polynucleotide sequence encoding the HBV polymerase antigen is 100% identical to SEQ ID NO: 3 or SEQ ID NO: 16.

6. The non-naturally occurring nucleic acid molecule according to any one of the preceding claims, wherein the polynucleotide is DNA or RNA.

7. The non-naturally occurring nucleic acid molecule according to any one of the preceding claims, wherein the HBV surface antigen is capable of inducing a T cell response, such as a CD8 T cell response, in a human subject against at least HBV genotypes A, B, C and D.

8. A vector comprising the non-naturally occurring nucleic acid molecule according to any one of the preceding claims.

9. The vector according to claim 8, wherein the vector is a non-viral vector or a viral vector.

10. The vector according to any one of claims 8-9, wherein the non-viral vector is a DNA plasmid or an RNA replicon.

11. The vector according to any one of claims 8-9, wherein the viral vector is an adenoviral vector, such as an Ad26 or Ad35 vector.
12. The vector according to any one of claims 8-11, comprising one or more regulatory elements operably linked to the polynucleotide encoding the HBV surface antigen and the at least one of the truncated HBV core antigen and the HBV polymerase antigen.
13. A host cell comprising the non-naturally occurring nucleic acid molecule according to any one of claims 1-7 or the vector according to any one of claims 8-12.
14. A composition comprising the non-naturally occurring nucleic acid molecule of any one of claims 1-7 or the vector according to any one of claims 8-12, and a pharmaceutically acceptable carrier.
15. The composition according to claim 14 for use in inducing an immune response against a hepatitis B virus (HBV) in a subject in need thereof, preferably the subject has chronic HBV infection, optionally in combination with another immunogenic agent, preferably another anti-HBV agent.
16. The composition for use in treating a hepatitis B virus (HBV)-induced disease in a subject in need thereof, preferably the subject has chronic HBV infection, and the HBV-induced disease is selected from the group consisting of advanced fibrosis, cirrhosis and hepatocellular carcinoma (HCC), optionally in combination with another therapeutic agent, preferably another anti-HBV agent.
17. A vaccine comprising the non-naturally occurring nucleic acid molecule of any one of claims 1-7 or the vector according to any one of claims 8-12.
18. The vaccine according to claim 17, wherein the vaccine is a DNA or an RNA vaccine.
19. The vaccine according to any one of claims 17-18, wherein the vaccine is an RNA vaccine, such as a self-replicating RNA vaccine.

20. The vaccine according to any one of claims 17-19, wherein the vaccine further comprises an adjuvant.

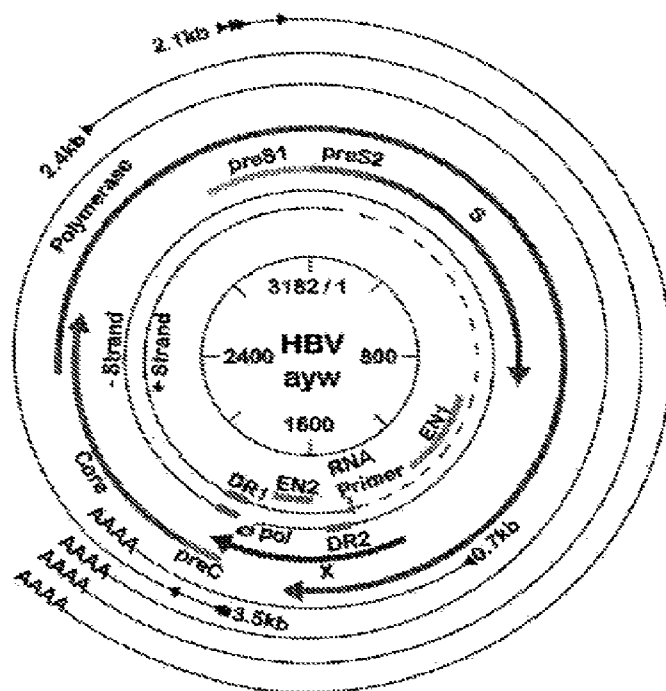


FIG 1A

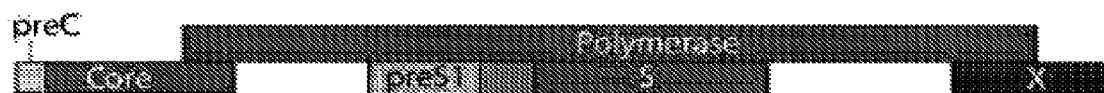


FIG 1B

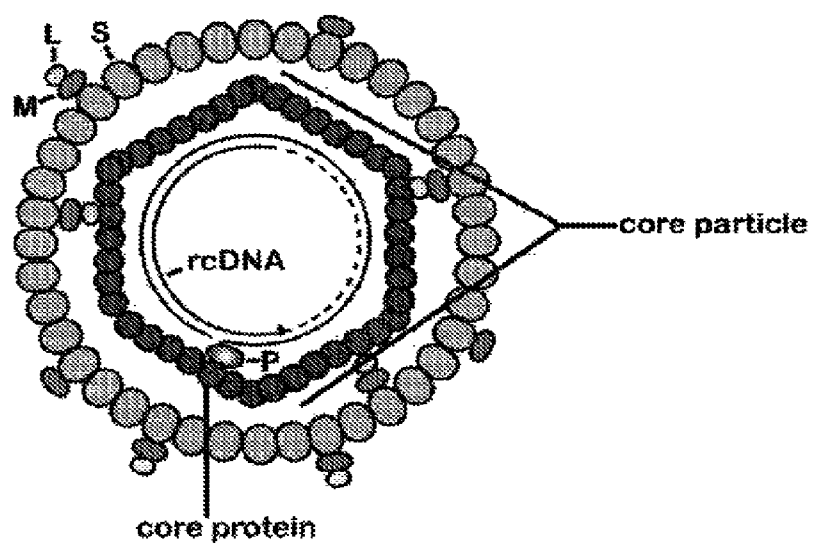


FIG 1C

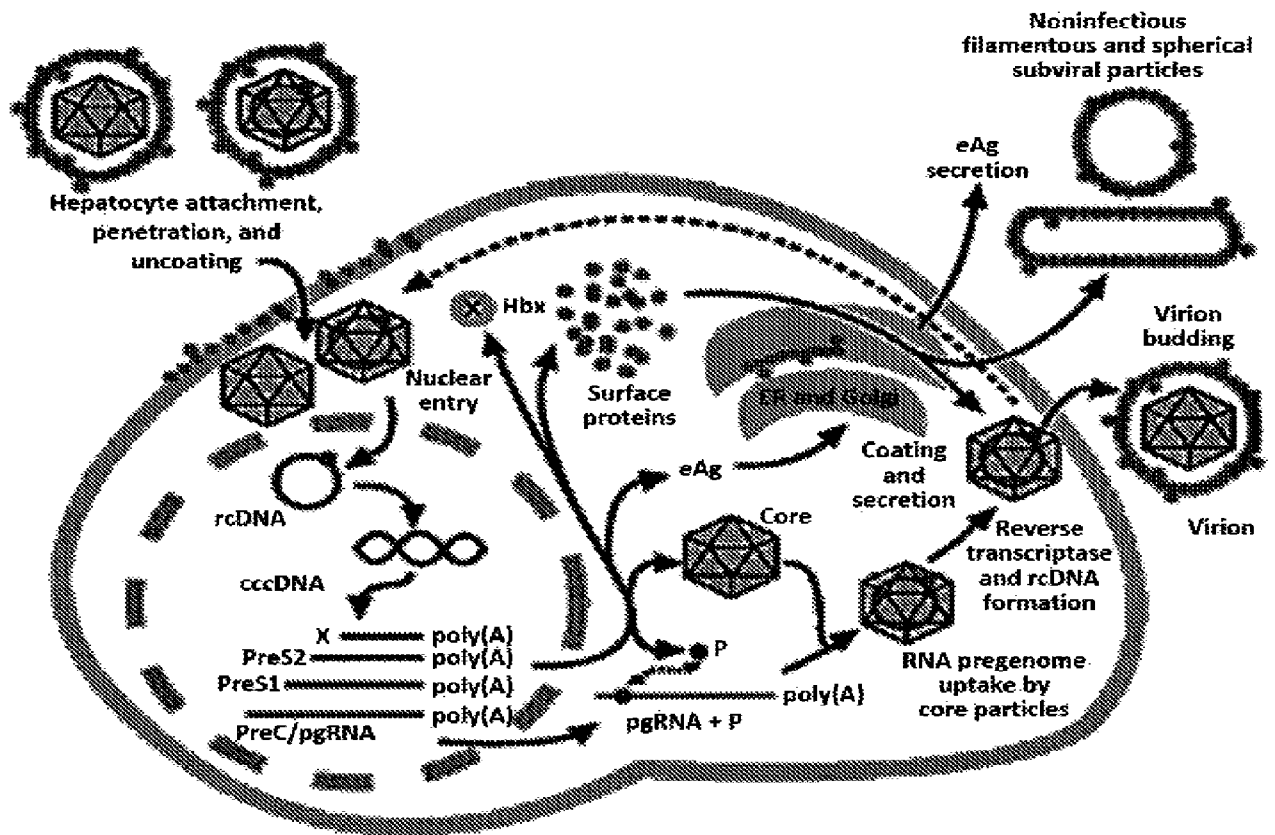


FIG 1D

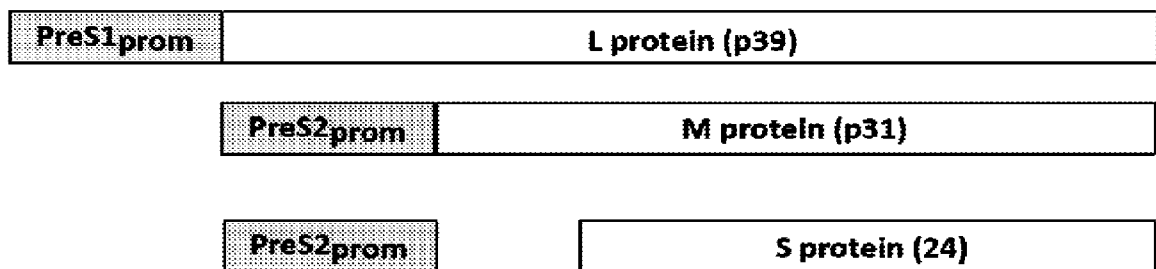
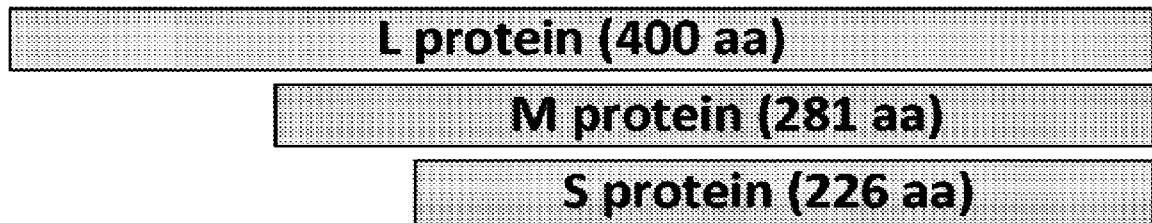


FIG 1E



MGGWSSKPRKGMGTNLSVPNPLGFFPDHQLDPAFGANSNNPDWDFNPNKDTWPDANKV
GAGAFGPGFTPPHGGLLGWSPQAQGILTTVPAAPPPASTNRQSGRQPTLSPPLRDTHPQAM
QWNSTTFHQTLQDPRVRGLYFPAGGSSSGTVNPVPTTASPISSIFSRTGDPAPNMENITSGFLG
PLLVLOAGFFLLTRILTIPQSLDSWWTSLNFLGGTPVCLGQNSQSPTSNNHSPTSCPPICPGYRWMC
LRRFIIFLFIILLCLIFLLVLLDYQGMLPVCPLIPGSSTTSTGPCKTCTTPAQGTSMFPSCCCTKPSDGN
CTCIPSSWAFKFLWEWASVRFSWLSLLVPFVQWFEVGLSPTVWLSVIWMMWYWGPSLYNIL
SPFLPLLPIFFCLWVYI (SEQ ID NO: 31)

L-surface antigen domain
M-surface antigen domain
S-surface antigen domain

FIG 1F



FIG 2A

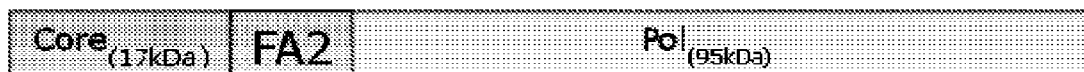


FIG 2B

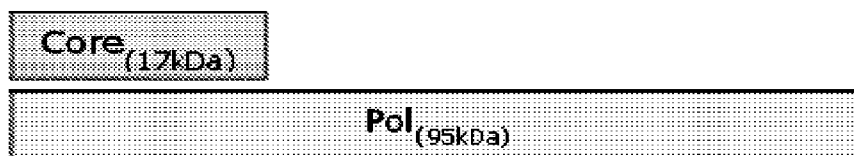


FIG 2C

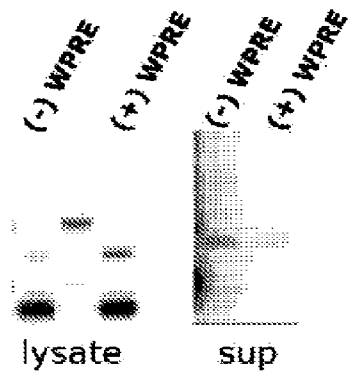


FIG 2D

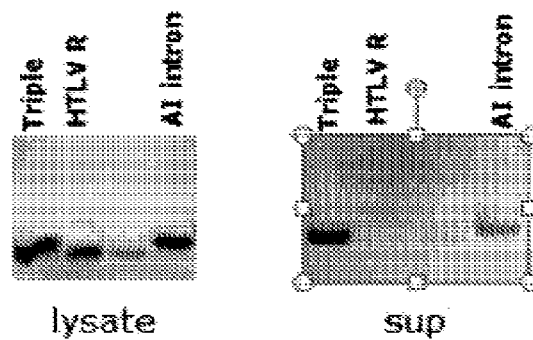


FIG 2E

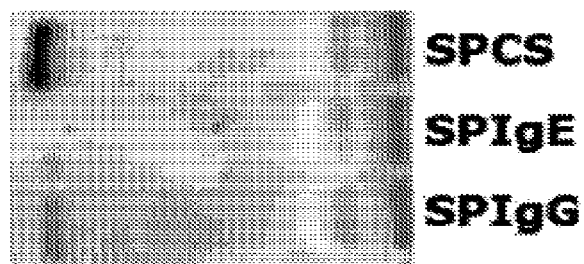


FIG 2F

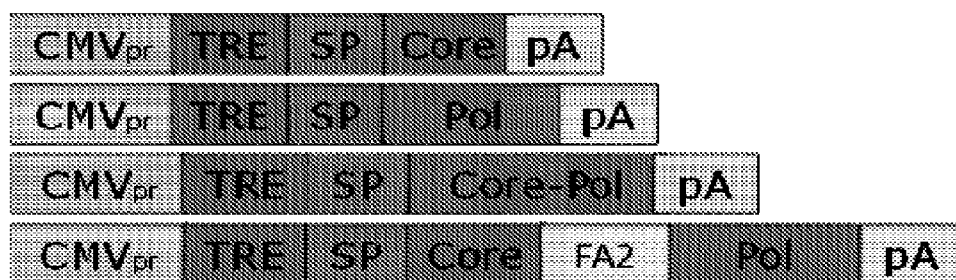


FIG 2G

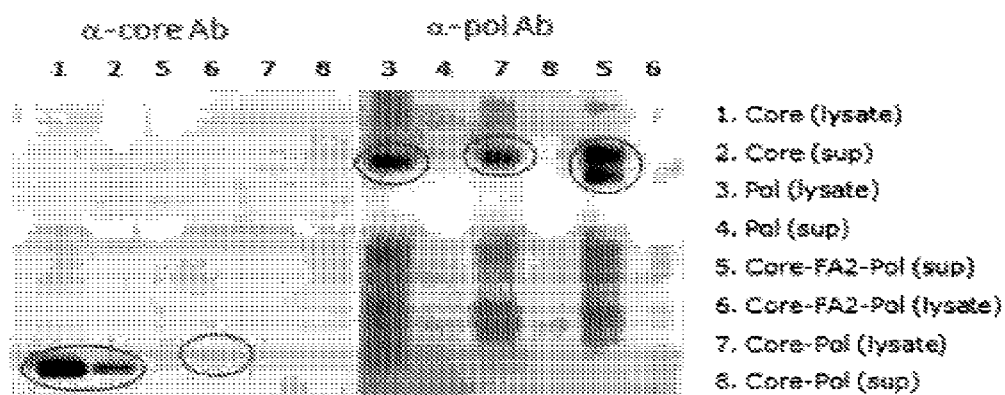


FIG 2H

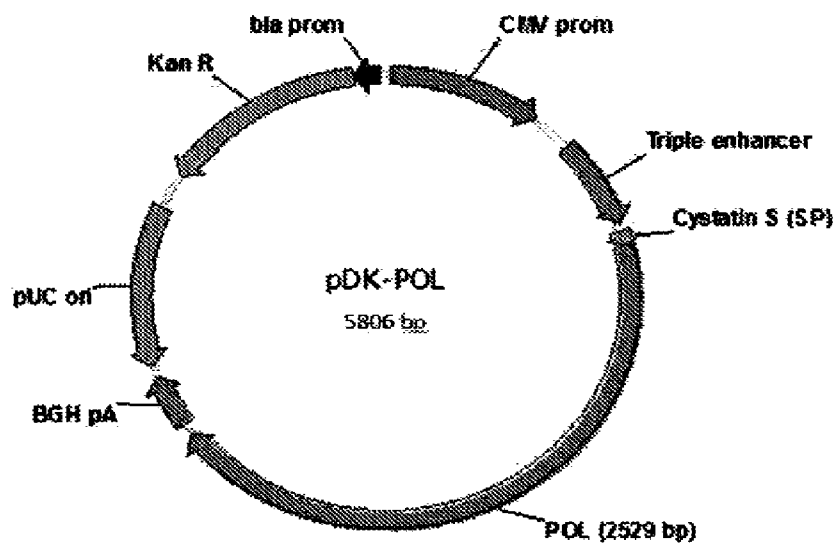


FIG 3A

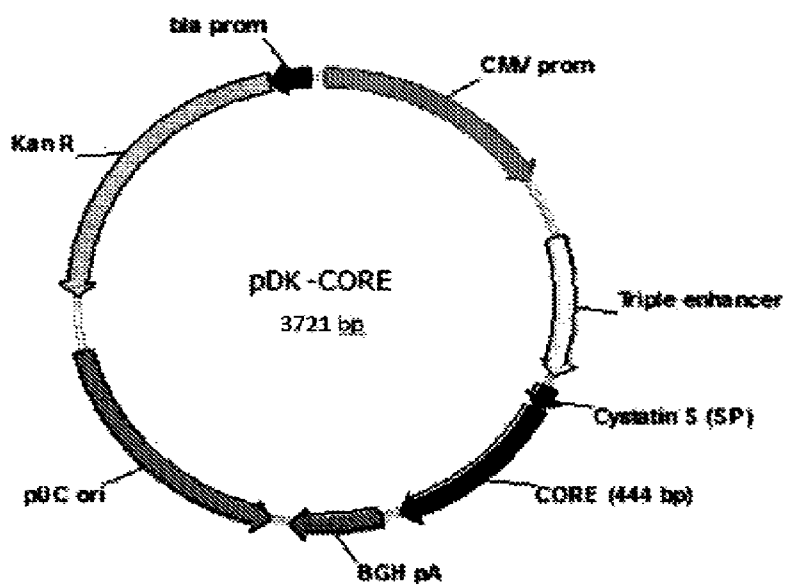


FIG 3B

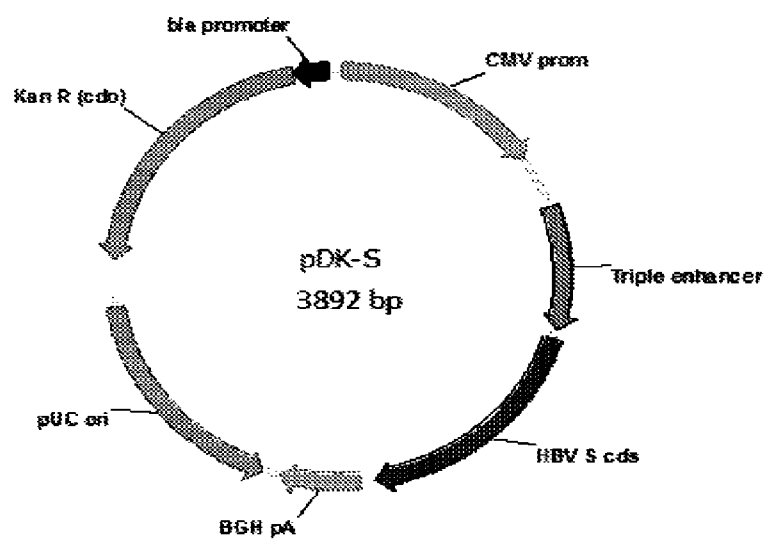


FIG 3C

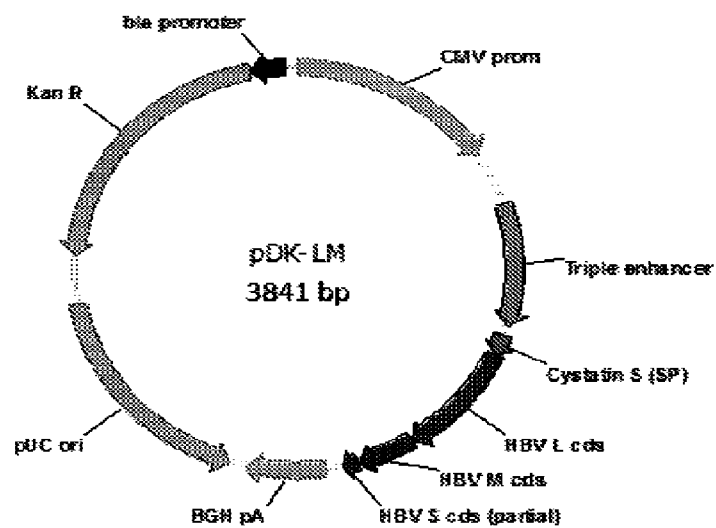


FIG 3D

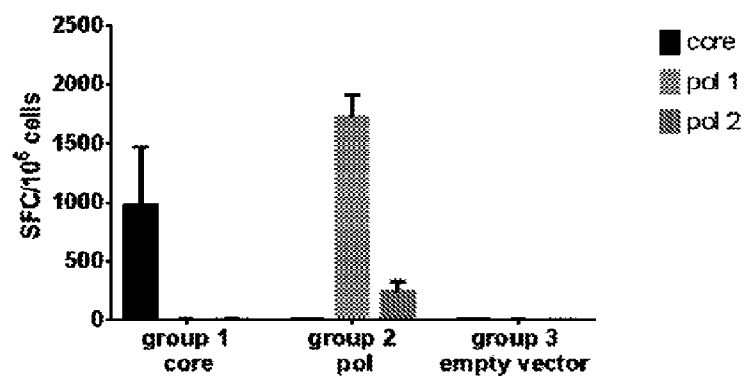


FIG 4

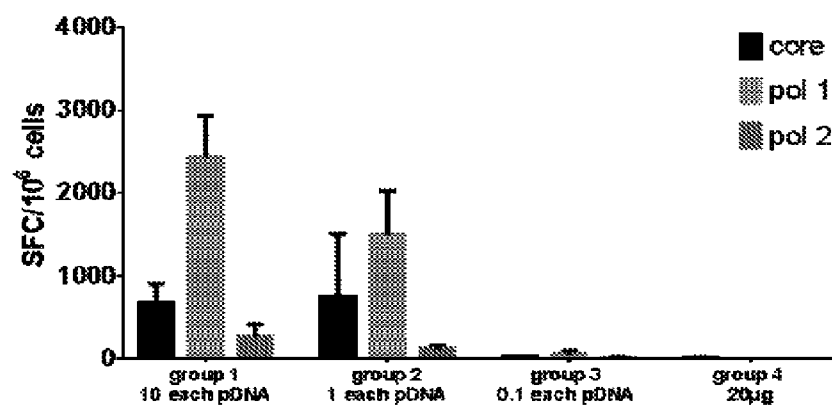


FIG 5

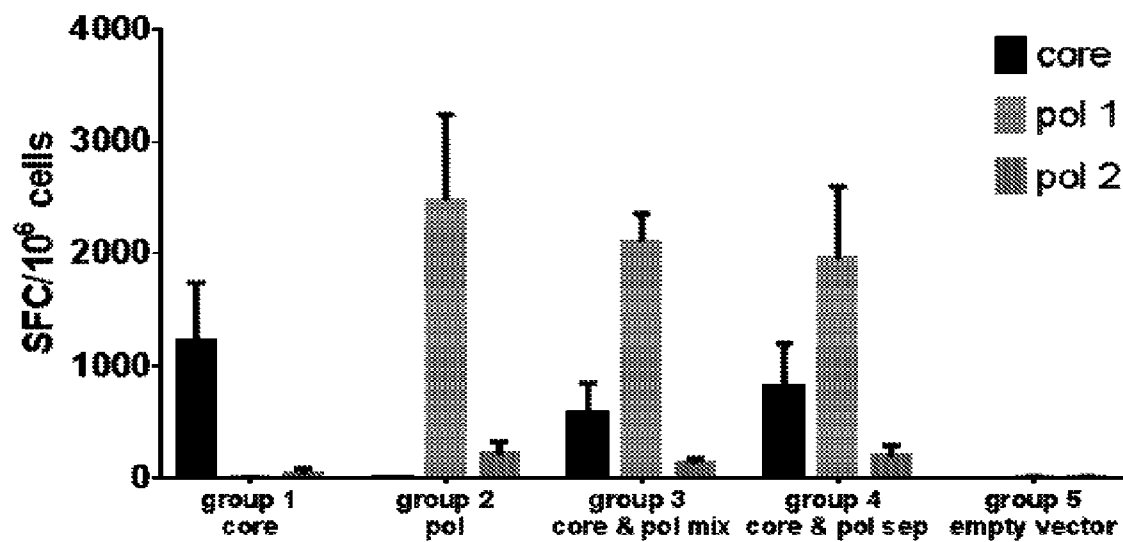


FIG 6

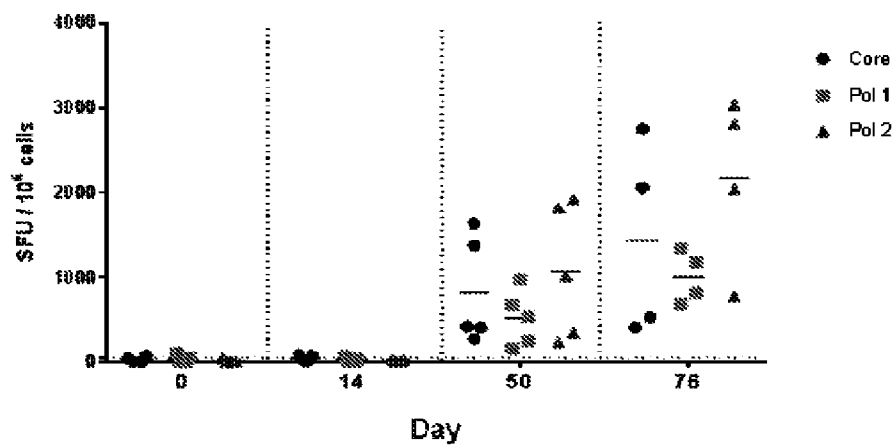


FIG 7A

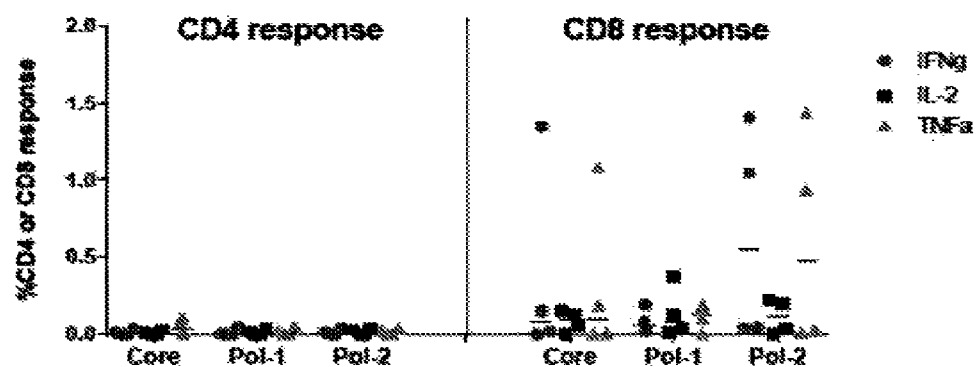


FIG 7B

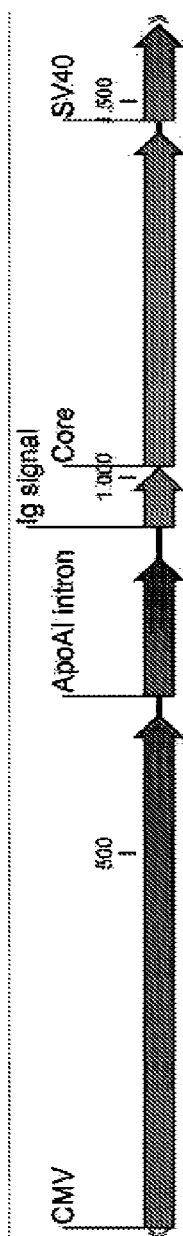


FIG 8A

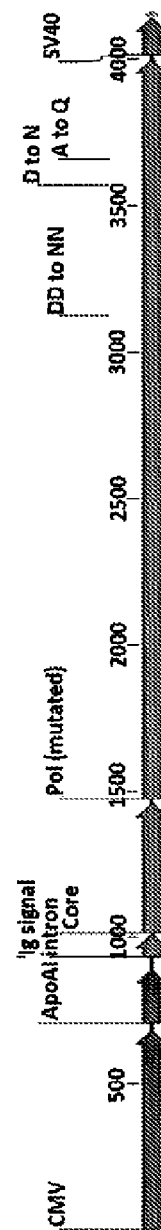


FIG 8B

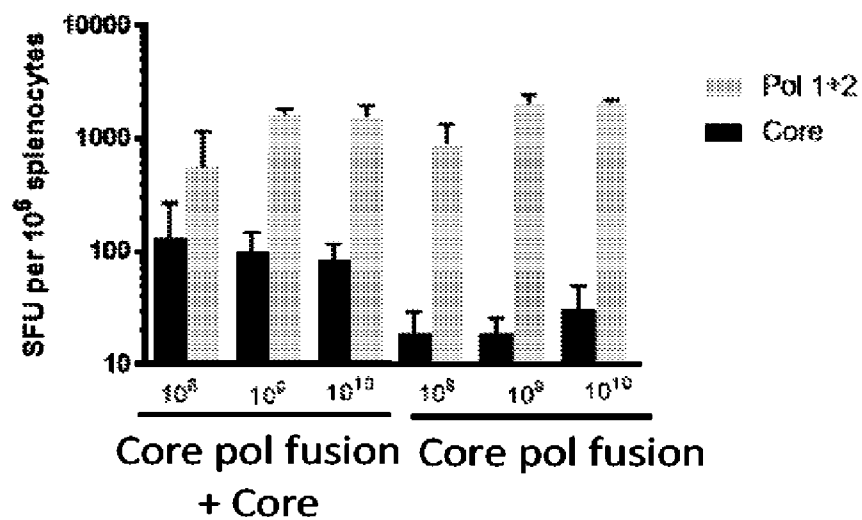


FIG 9

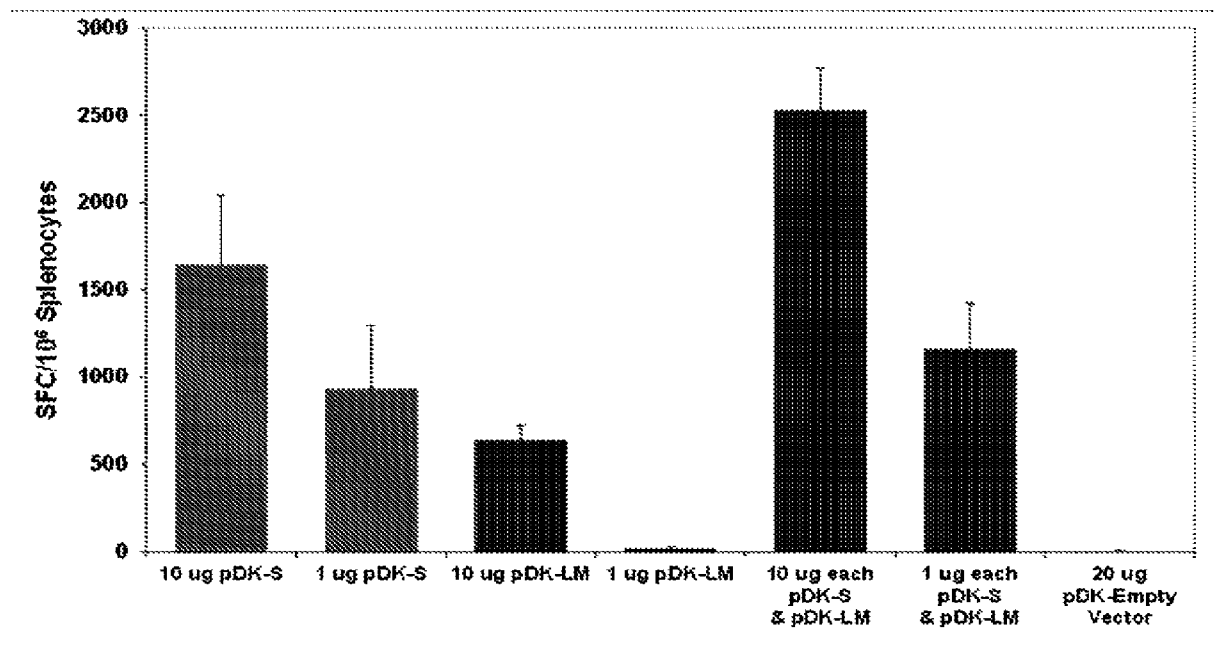


FIG 10

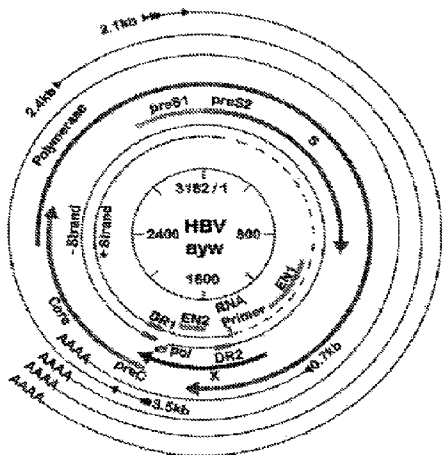


FIG 1A