Antibodies Against Influenza Virus and Methods of Use Thereof

RELATED APPLICATIONS

This application claims the benefit of USSN 61/005,725 filed December 6, 2007 and USSN 61/091,599 filed August 25, 2008 the contents of which are incorporated herein by reference in their entireties.

GRANT SUPPORT

This invention was made with United States Government support under National Institutes of Health Grants U01 AI074518-01. The United States Government has certain rights in the invention.

FIELD OF THE INVENTION

This invention relates generally to anti-viral antibodies as well as to methods for use thereof.

BACKGROUND

An influenza pandemic represents one of the greatest acute infectious threats to human health. The 1918-1919 influenza pandemic caused an estimated 500,000 deaths in the United States, making it the most fatal event in all of US history. The spread of highly pathogenic avian influenza (HPAI) H5N1 influenza across Asia and now to the middle east and northern Africa creates a substantial risk for a new pandemic to arise.

Natural variation as well as escape mutants suggests that continued evolution of the virus should impact the decision on which strain(s) should be used for passive and active immunization. Although a number of important epitope mapping and neutralization escape studies have been reported new neutralizing antibodies and related structural studies are needed to develop immunization strategies against HPAI H5N1. The challenges to developing a protective vaccine against HPAI H5N1 are formidable and new approaches are needed to prevent and treat human infection by an ever changing enemy. There is a need to rapidly develop therapeutic strategies to elicit protective hosts immunity, both passively and actively.

Tremendous advances in the field of human antibody (Ab) engineering have been made. Monoclonal antibody (Mab) based immunotherapies are now becoming standard of care in an increasing number of human diseases including RSV. The shift toward *de novo* human Mab isolation and their clinical use is in part due to new antibody display and other library screening techniques that are now be exploited to build human antibodies with high affinity and specificity. Human Mab immunotherapies can provide an increasingly important role in clinical management of human diseases.

SUMMARY OF THE INVENTION

The invention is based upon the discovery of monoclonal antibodies which neutralize the influenza virus, e.g. influenza A virus. The influenza A virus is a Group I influenza A virus such as a H1 cluster influenza virus, The H1 cluster influenza virus is an H1a cluster or an H1b cluster. The monoclonal antibody is fully human. In various aspects, the monoclonal antibody is a bivalent antibody, a monovalent antibody, a single chain antibody or fragment thereof. Specifically, such monoclonal bind to an epitope on the stem region of the hemagglutinin protein (HA), such as HA1 or HA2 polypeptide. The epitope is non-linear.

Optionally, the epitope comprises both the HA-1 and HA-2. The epitope is non-linear. In some embodiments the epitope comprises the amino acid position 18, 38, 40, 291 of the HA1 polypeptide and the amino acid at position 18, 19, 20, 21, 38, 41, 42, 45, 49, 52, 53 and 56 of the HA2 polypeptide.

Exemplary monoclonal antibodies include monoclonal antibody D7, D8, F10, G17, H40, A66, D80, E88, E90, or H98 or an antibody that binds to the same epitope as D7, D8, F10, G17, H40, A66, D80, E88, E90, or H98.

The monoclonal antibodies of the invention can have the binding affinity of monoclonal antibody D7, D8, F10, G17, H40, A66, D80, E88, E90, or H98. Alternatively, the binding affinity can range about 1pM to about 200 mM. The monoclonal antibodies of the invention function to inhibit viral and cell membrane fusion.

The monoclonal antibody has a heavy chain variable amino acid sequence containing SEQ ID NOS: 2, 6, 12, 18, 24, 28, 32, and 36 and/or a light chain variable amino acid sequence containing SEQ ID NOS: 4, 8, 14, 16, 20, 22, 26, 30, 34, and 38.

The monoclonal antibody, has a heavy chain variable nucleic acid sequence containing SEQ ID NOS: 1, 5, 13, 15, 21, 23, 29, 33, 37, and 40 and or a light chain variable nucleic acid sequence containing SEQ ID NOS: 3, 9, 11, 17, 19, 25, 27, 31, 35, 39, and 42

Also provided by the invention is an monoclonal anti-influenza hemagglutinin protein antibody or fragment thereof, where the antibody has a V_H CDR1 region having the amino acid sequence SYAFS, TNAFS, AYAFT, SFAIS, SYAIS, GYYIH, MTAFT, or DNAIS; a V_H CDR2 region having the amino acid sequence GIIPMFGTPNYAQKFQG, GVIPLFRTASYAQNVQG, GIIGMFGTANYAQKFQG, GISPMFGTPNYAQKFQG, GIIGVFGVPKYAQKFQG, WINPMTGGTNYAQKFQV, GISPIFRTPKYAQKFQG, or GIIPIFGKPNYAQKFQG; a V_H CDR3 region having the amino acid sequence SSGYYYG GGFDV, SSGYHFGRSHFDS, GLYYYESSLDY, SPSYICSGGTCVFDH, EPGYYVGKNGFDV, GASVLRYFDWQPEALDI, TLSSYQPNNDAFAI, or DSDAYYYGSGGMDV; V_L CDR1 region having amino acid sequence TGSSSNIGNYVA, TGSSSNIAANYVQ, TGTSSDVGGYNSVS, TGNSNNVGNQGAA, TGDSNNVGHQGTA, GGNNIGGYSVH, RASQSVSSYLA, RASQSLSSKYLA, TGSSSNIGNYVA, SGSSSNIGSNTVN, RASQSISSYLN, or TLSSGHSNYIIA; a V_L CDR2 region having the amino acid sequence SNSDRPS, EDDRRPS, EVTKRPS, RNNDRPS, RNGNRPS, DDKDRPS, DASNRAT, GASSRAT, SNNQRPS, AASSLQR, SNEQRPS, or VNSDGSHTKGD and/or a V_L CDR3 region having the amino acid sequence QSYDSLSAYV, QSYDTNNHAV, CSYAGHSAYV, STWDSSLSAVV, SVWDSSLSAWV, QVWDSGNDRPL, QQYGSSPQV, QQYDGVPRT, QSYDSRLSASL, QQYDSSPYT, ASWDDNLSGWV, or ETWDTKIHV.

In a further aspect, the invention provides An isolated an monoclonal anti-influenza hemagglutinin protein antibody or fragment thereof where the antibody has a VH amino acid sequence encoded by the VH germline gene IGHV1-69*01 and the the amino acid at position: a) 27 is a valine; b) 28 is threonine; c) 30 is serine; d) 31 is serine; e) 54 is methionine; f) 55 is phenylalanine; g) 58 is threonine; h) 100 is proloine; i) 101 is serine; j) 102 is tyrosine; k)103 is isoleucine and 105 is serine.

In another aspect, the invention provides a method of preventing or treating a disease or disorder caused by an influenza virus by administering to a person at risk of suffering from said disease or disorder, a therapeutically effective amount of a monoclonal antibody or scFV antibody described herein. The monoclonal antibody or scFV antibody is administered at a dose sufficient to neutralize the influenza virus. In embodiments of the invention, the method also includes administering an anti-viral drug, a viral entry inhibitor or a viral attachment inhibitor. The anti-viral drug is neuraminidase inhibitor such as zanamivir, or oseltamivir phosphate, a HA inhibitor, a sialic acid inhibitor or an M2 ion channel such as amantadine or rimantadine. The antibody is administered prior t or after exposure to an influenza virus

In another aspect, the invention provides a method of detecting the presence of a an influenza virus in a sample by contacting the sample with a monoclonal antibody as described herein, and detecting the presence or absence of an antibody-antigen complex, thereby detecting the presence of a influenza virus in a sample. The test sample is generally obtained from blood, hair, cheek scraping or swab, saliva, biopsy, urine, feces, sputum, nasal aspiration, or semen.

The invention is further based upon the discovery of a protocol for generating broadly neutralizing human antibodies that target a highly conserved epitope in the stem region of HA. By using the trimeric H5 ectodomain expressed in baculovirus which produces shorter N-glycans and uncharged mannoses absorbed on a plastic surface, allowed for the dominant presentation of the stem epitope while masking the normally immunodominat globular head.

Accordingly, also included in the invention is a method of producing an isolated antibody that specifically binds a pathogenic enveloped virus by exposing a single chain or Fab expression library to a membrane fusion protein of the virus, identifying an antibody in the library that specifically binds said protein; and isolating the antibody from the library. Preferably, the fusion protein is immobilized on a solid surface, e.g. plastic. In various aspects the fusion protein has modified glycosylations compared to a wild type fusion protein. For example, the fusion is produced in a non-mammalian cell, such as an insect cell. The fusion protein is for example a trimeric hemagglutinin (HA) protein

The invention further provides a method of vaccinating a subject against pathogenic enveloped virus such as an influenza virus by administering to the subject a membrane fusion protein (e.g., a trimeric hemagglutinin (HA) protein coated) or embedded in a biologically compatible matrix. In various aspects the fusion protein has modified glycosylations compared to a wild type fusion protein.

In another aspect, the invention provides a composition comprising a monoclonal antibody as described herein and kits containing the composition in one or more containers and instructions for use.

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present invention, suitable methods and materials are described below. All publications, patent applications, patents, and other references mentioned herein are incorporated by reference in their entirety. In the case of conflict, the

present specification, including definitions, will control. In addition, the materials, methods, and examples are illustrative only and are not intended to be limiting.

Other features and advantages of the invention will be apparent from the following detailed description and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 A is an illustration of the structure of the A/Vietnam 1203/04 trimer. The receptor binding site and antigenic variation sites are highlighted on the monomer.

Figure 1B is an illustration showing the location of amino acid residues in the HA of H5N1 influenza viruses that are under positive selection

Figure 2 is a schematic illustration of convergent combination Immunotherapy for H5N1.

Figure 3 is an illustration showing an amino acid sequence comparison of the framework regions 1-4 (FR1-4) and the complementary-determining regions 1-3(CDR1-3) for both the VH and VL of the anti-influenza antibodies of the invention.. FR and CDR regions are defined using Kabat database. The VH and VL gene name are shown on the right (using IMGT database). Dots show sequence identity to the consensus sequence. Hyphens represent gaps.

Figure 4 shows *in vitro* neutralization of anti-H5 antibodies. (a) (Top panel) The 10 nAbs were converted to soluble scFv-Fcs (single chain fragment of variable region linked with Hinge, CH2 and CH3) and evaluated for neutralizing activity against H5-TH04-pseudotyped viruses. The percentage neutralization at 2 concentrations is shown with standard error bars. The mAb $80R^{16}$ was used as the control (Ctrl.). (Middle and bottom panels), Neutralization of wild type H5-VN04 and H5-IN05 by the 10 scFv-Fcs at three concentrations using a plaque reduction assay. Results are consistent with those obtained from a microneutralization assay (data not shown). (b) Cross subtype neutralization. nAbs D8, F10 and A66 all neutralized H5-TH04, H1-SC1918 ((A/South Carolina/1/1918 (H1N1)), H1-PR34 (A/Puerto Rico/8/34 (H1N1)), H2-JP57 (A/Japan/305/57(H2N2)) and H6-NY98 (A/chicken/New York/14677-13/1998(H6N2)) pseudotyped viruses. **(c)** Microneutralization assay. Neutralization titers of F10 against wild-type H5N1, H1N1 (A/Ohio/83 ("H1-OH83")) and H2N2 (A/Ann Arbor/6/60 ('H2-AA60")) compared with a murine mAb 21G8.6 raised against H5N1 and Ctrl. 80R (1 mg/mL Ab stock solution). "<" indicates a titer of less than 20. Results represent two independent experiments.

Figure 5 shows the Neutralization mechanism. (a) Virus binding inhibition assay using full-length HA of H5-TH04-pseudotyped HIV-1 viruses. The binding of virus to cells in Ab-treated groups were compared with binding to cells in the absence of Ab (defined as 100%). None of the three nAbs (D8, F10 and A66) inhibited virus binding to cells, while a mouse anti-H5 mAb, 17A2.1.2, and ferret anti-H5N1 serum, both of which inhibit haemagglutination and presumably bind to the head, reduced binding significantly. (b) Inhibition of syncytia formation by nAbs. HeLa cells were transfected with H5-TH04-expressing plasmid. Syncytia formation induced by brief exposure to pH 5.0 buffer was completely inhibited by nAbs D8, F10 and A66, at 20 μg/ml, whereas control and an anti-HA1 mAb (2A) at the same concentration had no effect.

Figure 6 show the Structure of the H5-F10 epitope, and sequence/structural conservation. (a) Structure of the H5 trimer bound to F10 (scFv). H5 is very similar to the uncomplexed structure[21] (pairwise RMSD (Cα) = 1.0 and 0.63 Å for 2 independent trimers). HA1, HA2, the αA-helix of HA2, the "fusion peptide" (FP), and F10 (VH and VL) are colour-coded. The third F10 is hidden behind the stem. Note that VL makes no contacts with H5. (b) Surface of the central stem region. One monomer is coloured by chain; the path of FP through the epitope (red) is outlined; mutations not affecting binding are in cyan. The fusion peptide (FP and FP') is visible in two monomers. Epitope residues are labeled white (HA2) or yellow (HA1). (c) Close-up of the epitope showing the tip of F10 (red ribbon) and selected CDR side-chains. Of 1500 $Å^2$ buried surface at the interface, 43% involves hydrophobic interactions. (d) Overlay of HA subtypes: H1, H5 and H9 (Group 1) in shades of red/yellow (1RU7, 2IBX and 1JSD); H3 and H7 (Group 2) in shades of blue (1MQL and 1TI8). RMSDs for pairwise overlays are 0.56±0.11 Å (observed range, Group 1); 0.75 Å (Group 2); and 1.21±0.12 Å between groups. Consistent differences between groups include the orientation of $W21_2$, which is linked to alternate side-chain directions at 18_1 and 38_1, the burial of the larger tyrosine (Group 1) versus histidine (Group 2) at 17_1, and the packing of buried $His111_2$ (Group 1) against $W21_1$. Other epitope residues are indicated by numbered white circles. $N38_1$ is glycosylated in H3 and the H7 cluster. (e) Sequences of the 16 HA subtypes. Circles indicate calculated binding energies: strong=blue, intermediate=orange; weak=blue; unfavorable=black. Coloured highlighting indicates sequence conservation within clusters and groups. The network of inter-helical contacts that stabilize the fusogenic structure[29] are indicated below the sequences.

Figure 7 shows the prophylactic and therapeutic efficacy of anti-H5 nAbs in mice. Mice were treated with different doses of nAb either before or after lethal viral challenge.

Prophylactic efficiacy (a, b, g and h). Mice were treated with anti-H5 nAbs or control mAb 24 hour before lethal challenge by intranasally (i.n.) with 10 median lethal doses (MLD_{50}) of the H5N1 or H1N1s. (a) Intra-peritoneal (i.p.) injection of 10 mg/kg of any of the three nAbs provided complete protection of mice challenged with H5-VN04 (A/Vietnam/1203/04 (H5N1), Clade 1). A lower antibody dose (2.5 mg/kg) was also highly protective. (b) Prophylactic protection against H5-HK97 (A/HongKong/483/97 (H5N1), Clade 0) virus was observed in 80-100% of the mice treated with 10 mg/kg of any of the three nAbs. (g) Any of the three nAbs (at 10 mg/kg of single injection) provided complete protection of mice challenged with H1-WSN33 (A/WSN/1933(H1N1)) viruses. (h) D8 and F10 completely protected mice challenged with H1-PR34 (A/Puerto Rico/8/34 (H1N1)) when given at 10mg/kg of single injection. A66 provided complete protection of mice when 25mg/kg of antibody was given as a single injection. Therapeutic efficacy (c-f). Mice were inoculated with H5-VN04 and injected with nAbs at 24, 48, 72 hpi (c, e and f) or with H5-HK97 at 24 hpi (d). I.p. treatment with 15 mg/kg (a therapeutically achievable dose in humans) of any of the 3 nAbs at 24h post-inoculation (hpi) protected 80-100% of mice challenged with 10-times the MLD_{50} of either H5-VN04 or H5-HK97 virus.

Figure 8 illustrates SDS-PAGE and gel filtration analysis of HA proteins. (a) Antibody 2A was obtained from a separate HA1-targeted selection against the HA1 (residues 11-325) fragment of H5-TH04 (left panel). . H5 HA (H5-VN04 strain) used for library selection is shown in the right panel, (b) H5-VN04 (H5) and scFv F10 complex. HA0 was fully cleaved into HA1 and HA2 by co-expression with furin (left panel). Complexes were formed by first mixing H5 and F10 at a molar ratio of 1:10, and then purified by gel filtration.

Figure 9 show the binding of anti-H5 scFv-Fcs to H5 or HA1 by ELISA and competition ELISA. (a) 1 μg/mL of anti-H5 scFv-Fcs followed by HRP-anti-human IgG1 were used to detect the binding of anti-H5 scFv-Fcs to HA1 (H5-TH04) or H5 (H5-VN04) coated on an ELISA plate. An antibody selected against the HA1 subunit, mAb 2A scFv-Fc, bound to both HA1 and H5. The 10 potent neutralizing scFv-Fcs bound to H5 but not HA1. (b) 10^{12} pfu of anti-H5 phage-scFvs were mixed with 5 μg/mL of anti-H5 scFv-Fcs and added to H5 (H5-VN04)-coated plates, washed, and followed by HRP-anti-M13 to detect phage-scFvs bound to H5. mAb 2A-Fc did not compete for the epitope recognized by the 10 H5-selected Abs. All H5-selected scFv-Fcs cross-competed. Of these, Ab F10 (phage-scFv) binding to the H5 trimer was the least inhibited by the other scFv-Fcs suggesting that it has the highest affinity among all Abs tested.

Figure 10 shows the kinetic and thermodynamic characterization of the binding of H5 to nAbs D8, F10 and A66-IgG1s. nAbs were captured on a CM4 chip via anti-human IgG1; trimeric H5 (H5-VN04) at various concentrations (20, 10, 5, 2.5, 2.5, 1.25, 0.625 nM) was injected over the chip surface. Binding kinetics were evaluated using a 1:1 Langmuir binding model. The recorded binding curves (with blank reference subtracted) and the calculated curves are closely superimposable. Each *ka, kd* and K_D value represents the mean and standard error of three experiments.

Figure 11 shows the phylogenetic relationships and sequence comparison among HA subtypes. Phylogenetic tree of the 16 HA subtypes of influenza A viruses based on amino-acid sequences. Four clusters of HA subtypes are shaded in different colors. The sequences used for analysis were: H1 (A/South Carolina/1/1918), H2 (A/Japan/305/1957), H3 (A/Aichi/2/1968), H4 (A/duck/Czechoslovakia/56), H5 (A/VietNam1203/2004), H6 (A/chicken/California/431/00), H7 (A/Netherland/219/03), H8 (A/turkey/Ontario/6118/68), H9 (A/swine/HK/9/98), H10 (A/chicken/Germany/N49), H11 (A/duck/England/56), H12 (A/duck/Alberta/60/76), H13 (A/gull/Maryland/704/77), H14 (A/mallard/Astrakhan/263/1982), H15 (A/shearwater/West Australia/2576/79) and H16 (A/black-headed gull/Sweden/2/99).

Figure 12 shows viral titers in lung, spleen and brain of mice treated with anti-H5 nAbs after H5-VN04 challenge. BALB/c mice (n=5) were treated by i.p. injection of 15 mg/kg of mAb at 24, 48 or 72 hrs after i.n. infection with 10 MLD_{50} of H5-VN04. Viral titers were determined in lung, brain, and spleen collected at 96 hpi. Data are displayed in box-and-whiskers form in which the box extends from the 25th to the 75th percentile, with a horizontal line at the median. Whiskers above and below the box indicate the extreme values. Results of Student T-test statistic analysis are noted with a single star (*) for $p<0.05$, and double stars (**) for $p<0.01$. The arrows crossing the Y axis indicate the detection limit of the titration.

Figure 13 shows FACS analysis of anti-H5 nAbs binding to all H1 Cluster HAs including H1, H2, H5, H6, H11, H13 and H16. 293T cells were transiently transfected with different HA-expressing plasmids, and mAb binding to the HA-expressing cells was analyzed by FACS. The anti-SARS mAb 80R was used as a control. 2A-Fc is an H5 HA specific antibody. Lack of binding to a Group 2 HA, H7, was also shown. Viral strain details of H11, H13 and H16 are: H11-MP74 (A/Duck/memphis/546/74 (H11N9)), H13-MD77 (A/Gull/MD/704/77 (H13N6)) and H16-DE06 (A/Shorebird/DE/172/06 (H16N3)).

DETAILED DESCRIPTION OF THE INVENTION

Influenza A is a negative-sense, single-stranded RNA virus, with an eight-segment genome encoding 10 proteins. It belongs to the family Orthomyxoviridae which includes the genera of influenza virus A, B and C as defined by the antigenicity of the nucleocapsid and matrix proteins. Generally, influenza A virus is associated with more severe disease in humans. Influenza A virus is further subtyped by two surface proteins, hemagglutinin (HA) which attaches the virion to the host cell for cell entry, and neuraminidase (NA) which facilitates the spread of the progeny virus by cleaving the host sialic acid attached to the progeny virus or cell surface.

There are 16 HA subtypes and 9 NA subtypes which make up all subtypes of influenza A viruses by various combinations of HA and NA. All combinations of the 16 HA and 9 NA virus subtypes are found in water fowl. Of the hundreds of strains of avian influenza A viruses, only four are known to have caused human infections: H5N1, H7N3, H7N7 and H9N2. In general, human infection with these viruses has resulted in mild symptoms and very little severe illness: there has been only one fatal case of pneumonia caused by H7N7. However, the exception is the highly pathogenic H5N1 virus, for which there is no natural immunity in humans. The infidelity of the RNA polymerase and the selective pressure of host immunity can lead to the accumulation of mutations and change in surface antigenicity of these proteins. This antigenic change is called antigenic drift. In addition, as a result of its segmented genome, shuffling of gene segments can occur if two different subtypes of influenza A virus infect the same cell. For example, if a human H3N2 virus and an avian H5N1 virus co-infect a human or other member of a mammalian species, such an event can produce a novel H5N2. This novel virus can then be efficiently transmitted from human to human because all of most of the gene segments come from the human virus. Such genetic reassortment would lead to a major antigen change, a so-called antigenic shift, which would mean that most of the global population would not have any neutralizing antibodies against the reassortant virus. Such a situation, coupled with the high mortality of influenza H5N1 pneumonia, is one of the most feared scenarios in the field of public health.

Influenza virus hemagglutinin (HA) is the most variable antigen of influenza virus, and is responsible for virus entry into cells. It is synthesized as a trimeric precursor polypeptide HA0 which is post-translationally cleaved to two polypeptides HA1 and HA2 linked by a single disulphide bond. The HA1 chain of HA is responsible for the attachment of virus to the cell surface. HA2 mediates the fusion of viral and cell membranes in endosomes,

allowing the release of the ribonucleoprotein complex into the cytoplasm. In contrast to HA1, the HA2 molecule represents a relatively conserved part of HA. A second immunogenic influenza protein is neuraminidase (NA). This tetrameric glycoprotein is responsible for releasing virions from surface sialic acid on producer cells, and may also have a role in promoting access to target cells in the airways. Although neutralizing antibodies against NA are protective in animals and man, there is a paucity of data on their mechanisms of action. A recent report on the crystal structure of N1 neuraminidase demonstrated the presence of a cavity adjacent to its active site that may be exploited to develop new anti-influenza drugs, including antibodies. This finding is particularly important in light of the reports of emergence of drug resistance to oseltamivir (Tamiflu) and zanamivir (Relenza) for H5N1 viruses.

Both the HA1 and HA2 chains of HA are immunogenic and antibodies reactive with both chains have been demonstrated after natural infection in humans. While antibodies specific to HA1 are mostly neutralizing, different mechanism of virus neutralization by HA1 specific Mabs *in vitro* have been described including blocking the receptor site on HA1, intracellular inhibition of virus-cell fusion, or simultaneous attachment inhibition and virus-cell fusion inhibition, depending on antibody concentration. Although less well studied, inhibition of cell fusion by anti-HA2 antibodies has been reported .

More than two decades ago, the HA molecule of the H3 subtype was characterized by sequencing the HA of antigenic drift variants and escape mutants, and the antigenic epitopes were mapped on the molecule's three-dimensional structure. Since then, the antigenic sites on H1, H2 and H5 of an avian pathogenic virus were mapped on the three-dimensional structures of H3. After the outbreak of H5N1 infection in humans in Hong Kong in 1997 and the isolation of H9N2 virus from human cases in 1999, the X-ray structures of both proteins were solved. However, antigenic drift of the 1997 swine isolate (A/Duck/Singapore/3/97) that was used to solve the structure, and more recently isolated highly pathogenic strains, is significant. Indeed, there are 28 minor changes and two potentially major changes between the swine isolate (A/Duck/Singapore/3/97) and the HPAI H5N1 strain (A/Vietnam1203/04).

Phylogenetic analyses of the H5 HA genes from the 2004-2005 outbreak have shown two different lineages of HA genes, termed clades 1 and 2 . HPAI H5N1 strain (A/Vietnam1203/04) is a member of clade 1. Viruses in each of these clades are distributed in non-overlapping geographic regions of Asia. The H5N1 viruses from Indochina are tightly clustered within clade 1, whereas H5N1 isolated from several surrounding countries are

distinct from clade 1 isolates, and belong in a more divergent clade 2. Clade 1 viruses were isolated from humans and birds in Vietnam, Thailand and Cambodia but only from birds in Laos and Malaysia. The clade 2 viruses were found in viruses isolated exclusively from birds in China, Indonesia, Japan, and South Korea. The most recent epidemiologic studies analyzed 82 H5N1 viruses isolated from poultry throughout Indonesia and Vietnam, as well as 11 human isolates from southern Vietnam together with sequence data available in public databases, to address questions relevant to virus introduction, endemicity and evolution[36]. Phylogenetic analysis showed that all viruses from Indonesia form a distinct sublineage of H5N1 genotype Z viruses, suggesting that this outbreak likely originated from a single introduction via spread throughout the country during the past two years. Continued virus activities in Indonesia were attributed to transmission via poultry movement within the country, rather than through repeated introductions by bird migration. Within Indonesia and Vietnam, H5N1 viruses have evolved over time into geographically distinct groups within each country.

Recently, the structure of HA from A/Vietnam1203/4 was solved. Comparison of its amino acid sequences with the HA genes from HPAI 2004 and 2005 isolates from clade 1 and 2 viruses identified 13 positions of antigenic variation that are mainly clustered around the receptor binding domain, while the rest are within the vestigual esterase domain . Regions of antigenic variation have been identified in H1 and H3 serotypes (Figure 1A). For H1, these sites are designated Sa, Sb, Ca and Cb while for H3, sites are designated A, B, C and D. Escape mutants of H5 HAs can be clustered into three epitopes; site 1: an exposed loop (HA1 140-145) that overlaps antigenic sites A of H3 and Ca2 of H^2 ; site 2: HA1 residues 156 and 157 that corresponds to antigenic site B in H3 serotypes; and 3) HA1 129-133, which is restricted to the Sa site in H1 HAsand H9 serotypes. In the recent studies by Smith, detection of positive selection at the amino acid level indicated that eight residues in the HA proteins were under positive selection (Figure 1B). These residues include five in antigenic sites A and E (positions 83, 86, 138, 140 and 141); two involved in receptor binding (positions 129 and 175); and positions 156 is a site for potential N-linked glycosylation that is near the receptor-binding site. The results further revealed that three residues in HA (Val 86, Ser 129 and Thr 156) were more frequently observed in human isolates than in chicken or duck isolates and likely represented early adaptation of H5N1 genotype Z to humans. Another important finding from these studies is that the phylogenetic differences between the Indonesian and Vietnamese sub-lineages was also reflected in significant differences in antigenic cross-reactivity between these two group of viruses. Specifically, viruses from

Indonesia did not react to ferret antisera against A/Vietnam1203/04, and representative viruses from Vietnam did not react with ferret antisera against Indonesian viruses IDN/5/06 and Dk/IDN/MS/04. These findings are in agreement with earlier studies with immune human serum and human 1997 and 2003 H5N1 viruses that these strains were not only phylogenetically but also antigenically distinct. Thus, natural variation as well as escape mutants suggests that continued evolution of the virus should impact the decision on which strain(s) should be used for passive and active immunization.

The instant invention provides methods for the identification, production and characterization of human anti-influenza monoclonal antibodies

Identification and Characterization of scFvs and Monoclonal Antibodies

High affinity, cross-subtype, broadly-neutralizing human anti-HA mAbs have been identified. These nAbs inhibit the post-attachment fusion process by recognizing a novel and highly conserved neutralizing epitope within the stem region at a point where key elements of the conformational change – the fusion peptide and the exposed surface of helix αA – are brought into close apposition. Structural and sequence analysis of all 16 HA subtypes points to the existence of only two variants of this epitope, corresponding to the two phylogenetic groupings of HA (Groups 1 and 2). These results raise the possibility that a small cocktail of nAbs derived from a subset of each group could provide broad protection against both seasonal and pandemic influenza.

A recent report utilized immune cells from H5N1-infected patients to isolate anti-HA nAbs. However, their epitopes and modes of action were not reported. Remarkably, we repeatedly isolated nAbs that utilizes the same VH germline gene, IGHV1-69*01, and encodes a CDR3 loop containing a tyrosine at an equivalent position to Y102, from a non-immune library. This suggests that broad anti-HA cross-immunity pre-exists in the H5-naive population, possibly due to previous exposure to H1, and, for library donors born before 1968, H2 subtypes. The recurrent use of this germline VH segment, the commonality of the CDR3 tyrosine introduced through N insertion and/or germline D gene assembly, and the promiscuous use of VL genes by the nAbs discovered in both studies, suggest that the precursor frequency of rearranged VH segments that could recognize this epitope is significant. This raises the possibility that with suitable exposure to the F10 epitope identified here, these broad-spectrum nAbs may be readily induced *in vivo*. While the genetic and structural complexity of nAbs required to provide universal protection against virus subtypes in both groups is still unknown, our data would seem to point to a surprisingly simple solution.

Three unique anti-HA-1 scFvs were identified by sequencing analysis of the 58 HA-1 positive clones. These scFvs were designated as 38 B and 1C. The VH and VL amino acid sequence of 2A is shown in Figure 4.

Ten unique anti-HA0 scFvs were identified by sequencing analysis of the 97 HA0 positive clones. These scFvs were designated as 7, 8, 10, 17, 40, 66, 80, 88, 90, and 98. Six different VH and 10 diffferent VL genes were revealed. Some scFvs shared the same VH gene. Five out of the six different VH genes belonged to the IGHV1-69 gene family. Three out of ten VL genes were kappa chain.

2A scFv is an moderate neutralizing antibody, 38B and 1C are non-nuetralizing antibodies. Ten scFvs, 7, 8, 10, 17, 40, 66, 80, 88, 90, and 98 are potent neutralizing antibodies. (Figure 6)

The nucleic acid and amino acid sequence of the neutralizing influenza antibodies are provided below:

Table 1A. Antibody 2AVariable Region nucleic acid sequences
V_H chain of 2A (SEQ ID NO:1)
CAGGTGCAGCTGGTGCAGTCTGGGGCTGAGGTGAAGAAGCCTGGGTCCTCGGTGAAGGTCTCCTGCAAGGCTTCTGGAGG CACCTTCAGTGACAATGCTATCAGCTGGGTGCGACAGGCCCCAGGACAAGGGCTTGAGTGGATGGGGGGGCATCATTCCTA TCTTTGGAAAACCAAACTACGCACAGAAGTTCCAGGGCAGAGTCACGATTACTGCGGACGAATCCACGAGCACAGCCTAC ATGGACCTGAGGAGCCTGAGATCTGAGGACACGGCCGTTTATTACTGTGCGAGAGATTCAGACGCGTATTACTATGGTTC GGGGGGTATGGACGTCTGGGGCCAAGGCACCCTGGTCACCGTCTCCTCA
V_L chain of 2A (SEQ ID NO:3)
CTGCCTGTGCTGACTCAATCATCCTCTGCCTCTGCTTCCCTGGGATCCTCGGTCAAGCTCACCTGCACTCTGAGCAGTGG GCATAGTAACTACATCATCGCATGGCATCAACAGCAGCCAGGGAAGGCCCCTCGGTACTTGATGAAGGTTAATAGTGATG GCAGCCACACCAAGGGGGACGGGATCCCTGATCGCTTCTCAGGCTCCAGCTCTGGGGCTGACCGCTACCTCACCATCTCC AACCTCCAGTCTGAGGATGAGGCTAGTTATTTCTGTGAGACCTGGGACACTAAGATTCATGTCTTCGGAACTGGGACCAA GGTCTCCGTCCTCAG

Table 1B. Antibody 2A Variable Region amino acid sequences
V_H chain of 2A (SEQ ID NO: 2)
QVQLVQSGAEVKKPGSSVKVSCKASGGTFSDNAISWVRQAPGQGLEWMGGIIPIFGKPNYAQKFQGRVTITADESTSTAY MDLRSLRSEDTAVYYCARDSDAYYYGSGGMDVWGQGTLVTVSS
V_L chain of 2A (SEQ ID NO:4)
LPVLTQSSSASASLGSSVKLTCTLSSGHSNYIIAWHQQQPGKAPRYLMKVNSDGSHTKGDGIPDRFSGSSSGADRYLTIS NLQSEDEASYFCETWDTKIHVFGTGTKVSVL

Table 1C. Antibody D7 Variable Region nucleic acid sequences
V_H chain of D7 (SEQ ID NO:5)
CAGGTGCAGCTGGTGCAGTCTGGGGCTGAGGTGAAGAAGCCTGGGTCCTCGGTGAAGGTCTCCTGCAAGGCTCCTGGAGG TATCTTCAACACCAATGCTTTCAGCTGGGTCCGACAGGCCCCTGGACAAGGTCTTGAGTGGGTGGGAGGGGTCATCCCTT TGTTTCGAACAGCAAGCTACGCACAGAACGTCCAGGGCAGAGTCACCATTACCGCGGACGAATCCACGAACACAGCCTAC ATGGAGCTTACCAGCCTGAGATCTGCGGACACGGCCGTGTATTACTGTGCGAGAAGTAGTGGTTACCATTTTAGGAGTCA CTTTGACTCCTGGGGCCTGGGAACCCTGGTCACCGTCTCCTCA

V_L chain of D7 (SEQ ID NO:9)
AATTTTATGCTGACTCAGCCCCACTCTGTGTCGGCGTCTCCGGGGAAGACGGTGACCATCTCCTGCACCGGCAGCAGTGG CAACATTGCCGCCAACTATGTGCAGTGGTACCAACAACGTCCGGGCAGTGCCCCCACTACTGTGATCTATGAGGATGACC GAAGACCCTCTGGGGTCCCTGATCGGTTCTCTGGCTCCATCGACAGGTCCTCCAACTCTGCCTCCCTCACCATCTCAGGA CTGAAGACTGAGGACGAGGCTGACTACTACTGTCAGACTTATGATACCAACAATCATGCTGTGTTCGGAGGAGGCACCCA CCTGACCGTCCTC

Table 1D. Antibody H98 Variable Region nucleic acid sequences
V_H chain of H98 (SEQ ID NO:7)
CAGGTGCAGCTGGTGCAATCTGGGGCTGAGGTGAAGAAGCCTGGGTCCTCGGTGAAGGTCTCCTGCAAGGCTCCTGGAGG TATCTTCAACACCAATGCTTTCAGCTGGGTCCGACAGGCCCCTGGACAAGGTCTTGAGTGGGTGGGAGGGGTCATCCCTT TGTTTCGAACAGCAAGCTACGCACAGAACGTCCAGGGCAGAGTCACCATTACCGCGGACGAATCCACGAACACAGCCTAC ATGGAGCTTACCAGCCTGAGATCTGCGGACACGGCCGTGTATTACTGTGCGAGAAGTAGTGGTTACCATTTTAGGAGTCA CTTTGACTCCTGGGGCCTGGGAACCCTGGTCACCGTCTCCTCA
V_L chain of H98 (SEQ ID NO:11)
TCCTATGAGCTGACTCAGCCACCCTCAGCGTCTGGGAAACACGGGCAGAGGGTCACCATCTCTTGTTCTGGAGGCACCTC CAACATCGGACGTAATCATGTTAACTGGTACCAGCAACTCCCAGGAACGGCCCCCAAACTCCTCATCTATAGTAATGAAC AGCGGCCCTCAGGGGTCCCTGACCGATTCTCTGGCTCCAAATCTGGCACCTCCGCCTCCCTGGCCGTGAGTGGGCTCCAG TCTGAGGATGAGGCTGATTATTACTGTGCATCATGGGATGACAACTTGAGTGGTTGGGTGTTCGGCGGAGGGACCAAGCT GACCGTCCTA

Table 1E. Antibody D7 and H98 Variable Region chain amino acid sequences
V_H chain of D7 and H98 (SEQ ID NO:6)
QVQLVQSGAEVKKPGSSVKVSCKAPGGIFNTNAFSWVRQAPGQGLEWVGGVIPLFRTASYAQNVQGRVTITADESTNTAY MELTSLRSADTAVYYCARSSGYHFRSHFDSWGLGTLVTVSS
V_L chain of D7 (SEQ ID NO:8)
NFMLTQPHSVSASPGKTVTISCTGSSGNIAANYVQWYQQRPGSAPTTVIYEDDRRPSGVPDRFSGSIDRSSNSASLTISG LKTEDEADYYCQTYDTNNHAVFGGGTHLTVL
V_L chain of H98 (SEQ ID NO:10)
SYELTQPPSASGKHGQRVTISCSGGTSNIGRNHVNWYQQLPGTAPKLLIYSNEQRPSGVPDRFSGSKSGTSASLAVSGLQ SEDEADYYCASWDDNLSGWVFGGGTKLTVL

Table 1F. Antibody D8 Variable Region nucleic acid sequences
V_H chain of D8 (SEQ ID NO:13)
CAGGTGCAGCTGGTGCAGTCTGGGGCTGAGGTGAAGAAGCCTGGGTCCTCGGTGAAGGTCTCCTGCAAGGCTTCTGGAGG CACCTTCAGCGCTTATGCTTTCACCTGGGTGCGGCAGGCCCCTGGACAAGGGCTTGAGTGGATGGGAGGCATCACCGGAA TGTTTGGCACAGCAAACTACGCACAGAAGTTCCAGGGCAGAGTCACGATTACCGCGGACGAACTCACGAGCACAGCCTAC ATGGAGTTGAGCTCCCTGACATCTGAAGACACGGCCCTTTATTATTGTGCGAGAGGATTGTATTACTATGAGAGTAGTCT TGACTATTGGGGCCAGGGAACCCTGGTCACCGTCTCCTCAG
V_L chain of D8 (SEQ ID NO:17)
CAGTCTGTGCTGACTCAGCCACCCTCCGCGTCCGGGTCTCCTGGACAGTCAGTCACCATCTCCTGCACTGGAACCAGCAG TGACGTTGGTGGTTATAACTCTGTCTCCTGGTACCAACAGCACCCAGGCAAAGCCCCCAAACTCATGATTTATGAGGTCA CTAAGCGGCCCTCAGGGGTCCCTGATCGCTTCTCTGCCTCCAAGTCTGGCAACACGGCCTCCCTGACCGTCTCTGGGCTC CAGGCTGAGGATGAGGCTGATTATTTCTGCTGCTCATATGCAGGCCACAGTGCTTATGTCTTCGGAACTGGGACCAAGGT CACCGTCCTG

Table 1G. Antibody D80 Variable Region nucleic acid sequences
V_H chain of D80 (SEQ ID NO:15)
CAGGTGCAGCTGGTGCAGTCTGGGGCTGAGGTGAAGAAGCCTGGGTCCTCGGTGAAGGTCTCCTGCAGGGCTTCTGGAGG CACCTTCAGCGCTTATGCTTTCACCTGGGTGCGGCAGGCCCCTGGACAAGGGCTTGAGTGGATGGGAGGCATCACCGGAA TGTTTGGCACAGCAAACTACGCACAGAAGTTCCAGGGCAGAGTCACGATTACCGCGGACGAACTCACGAGCACAGCCTAC ATGGAGTTGAGCTCCCTGACATCTGAAGACACGGCCCTTTATTATTGTGCGAGAGGATTGTATTACTATGAGAGTAGTCT

TGACTATTGGGGCCAGGGAACCCTGGTCACCGTCTCCTCAG
V_K chain of D80 (SEQ ID NO:19)
GAAATTGTGCTGACTCAGTCTCCAGGCACCCTGTCTTTGTCTCCAGGGGAAAGAGCCACCCTCTCCTGCAGGGCCAGTCA GAGTCTTAGCAGCAAGTACTTAGCCTGGTATCAGCAGAAACCTGGCCAGGCTCCCAGGCTCCTCATCTATGGTGCATCCA GCAGGGCCACTGGCATCCCAGACAGGTTCAGTGGCAGTGGGTCTGGGACAGACTTCACCCTCACCATCAGTAGACTGGAG CCTGAAGATTTTGCAGTGTATTCCTGTCAGCAGTATGATGGCGTACCTCGGACGTTCGGCCAAGGGACCACGGTGGAAAT CAAA

Table 1H. Antibody D8 and D80 Variable Region chain amino acid sequences
V_H chain of D8 and D80 (SEQ ID NO:12)
QVQLVQSGAEVKKPGSSVKVSCKASGGTFSAYAFTWVRQAPGQGLEWMGGITGMFGTANYAQKFQGRVTITADELTSTAY MELSSLTSEDTALYYCARGLYYYESSLDYWGQGTLVTVSS
V_L chain of D8 (SEQ ID NO:14)
QSVLTQPPSASGSPGQSVTISCTGTSSDVGGYNSVSWYQQHPGKAPKLMIYEVTKRPSGVPDRFSASKSGNTASLTVSGL QAEDEADYFCCSYAGHSAYVFGTGTKVTVL
V_K chain of D80 (SEQ ID NO:16)
EIVLTQSPGTLSLSPGERATLSCRASQSLSSKYLAWYQQKPGQAPRLLIYGASSRATGIPDRFSGSGSGTDFTLTISRLE PEDFAVYSCQQYDGVPRTFGQGTTVEIK

Table 1I . Antibody F10 Variable Region nucleic acid sequences
V_H chain of F10 (SEQ ID NO:21)
CAGGTGCAGCTGGTGCAGTCAGGGGCTGAGGTGAAGAAGCCTGGGTCCTCGGTGAAGGTCTCCTGCACGTCCTCTGAAGT CACCTTCAGTAGTTTTGCTATCAGCTGGGTGCGACAGGCCCCTGGACAAGGGCTTGAGTGGCTGGGAGGGATCAGCCCTA TGTTTGGAACACCTAATTACGCGCAGAAGTTCCAAGGCAGAGTCACCATTACCGCGGACCAGTCCACGAGGACAGCCTAC ATGGACCTGAGGAGCCTGAGATCTGAGGACACGGCCGTGTATTATTGTGCGAGATCTCCTTCTTACATTTGTTCTGGTGG AACCTGCGTCTTTGACCATTGGGGCCAGGGAACCCTGGTCACCGTCTCCTCA
V_L chain of F10 (SEQ ID NO:25)
CAGCCTGGGCTGACTCAGCCACCCTCGGTGTCCAAGGGCTTGAGACAGACCGCCACACTCACCTGCACTGGGAACAGCAA CAATGTTGGCAACCAAGGAGCAGCTTGGCTGCAGCAGCACCAGGGCCACCCTCCCAAACTCCTATCCTACAGGAATAATG ACCGGCCCTCAGGGATCTCAGAGAGATTCTCTGCATCCAGGTCAGGAAACACAGCCTCCCTGACCATTACTGGACTCCAG CCTGAGGACGAGGCTGACTATTACTGCTCAACATGGGACAGCAGCCTCAGTGCTGTGGTATTCGGCGGAGGGACCAAGCT GACCGTCCTA

Table 1J . Antibody E90 Variable Region nucleic acid sequences
V_H chain of E90 (SEQ ID NO:23)
CAGGTACAGCTGCAGCAGTCAGGGGCTGAGGTGAAGAAGCCTGGGTCCTCGGTGAAGGTCTCCTGCACGTCCTCTGAAGT CACCTTCAGTAGTTTTGCTATCAGCTGGGTGCGACAGGCCCCTGGACAAGGGCTTGAGTGGCTGGGAGGGATCAGCCCTA TGTTTGGAACACCTAATTACGCGCAGAAGTTCCAAGGCAGAGTCACCATTACCGCGGACCAGTCCACGAGGACAGCCTAC ATGGACCTGAGGAGCCTGAGATCTGAGGACACGGCCGTGTATTATTGTGCGAGATCTCCTTCTTACATTTGTTCTGGTGG AACCTGCGTCTTTGACCATTGGGGCCAGGGAACCCTGGTCACCGTCTCCTCA
V_L chain of E90 (SEQ ID NO:27)
GACATCCAGATGACCCAGTCTCCATCCTCCCTGTCTGCATCTGTAGGAGACAGAGTCACCATCACTTGCCGGGCAAGTCA GAGCATTAGCAGCTATTTAAATTGGTATCAGCAGAAACCAGGGAAAGCCCCTAAGCTCCTGATCTATGCTGCATCCAGTT TGCAAAGAGGGGTCCCATCAAGGTTCAGTGGCAGTGGATCTGGGACAGACTTCACTCTCACCATTAGCAGCCTGCAGCCT GAAGATTTTGCAGTGTATTACTGTCAGCAGTATGATAGTTCACCGTACACTTTTGGCCAGGGGACCAAGGTAGAGATCAA A

Table 1K. Antibody F10 and E90 Variable Region amino acid sequences
V_H chain of F10 and E90 (SEQ ID NO:18)
QVQLVQSGAEVKKPGSSVKVSCTSSEVTFSSFAISWVRQAPGQGLEWLGGISPMFGTPNYAQKFQGRVTITADQSTRTAY MDLRSLRSEDTAVYYCARSPSYICSGGTCVFDHWGQGTLVTVSS

V_L chain of F10 (SEQ ID NO:20)
QPGLTQPPSVSKGLRQTATLTCTGNSNNVGNQGAAWLQQHQGHPPKLLSYRNNDRPSGISERFSASRSGNTASLTITGLQ PEDEADYYCSTWDSSLSAVVFGGGTKLTVL
V_L chain of E90 (SEQ ID NO:22)
DIQMTQSPSSLSASVGDRVTITCRASQSISSYLNWYQQKPGKAPKLLIYAASSLQRGVPSRFSGSGSGTDFTLTISSLQP EDFAVYYCQQYDSSPYTFGQGTKVEIK

Table 1L. Antibody G17 Variable Region nucleic acid sequences

V_H chain of G17 (SEQ ID NO:29)
CAGGTGCAGCTGGTGCAATCTGGGGCTGAAGTGAAGAAGCCTGGGGCCTCAGTGAAGGTCTCCTGCAAGACTTCTGGAGT CACCTTCAGCAGCTATGCTATCAGTTGGGTGCGACAGGCCCCTGGACAAGGGCTTGAGTGGATGGGAGGGATCATCGGTG TCTTTGGTGTACCAAAGTACGCGCAGAACTTCCAGGGCAGAGTCACAATTACCGCGGACAAACCGACGAGTACAGTCTAC ATGGAGCTGAACAGCCTGAGAGCTGAGGACACGGCCGTGTATTACTGTGCGAGAGAGCCCGGGTACTACGTAGGAAAGAA TGGTTTTGATGTCTGGGGCCAAGGGACAATGGTCACCGTCTCTTCA
V_L chain of G17 (SEQ ID NO:31)
TCCTATGAGCTGACTCAGCCACCCTCGGTGTCCAAGGGCTTGAGACAGACCGCCATACTCACCTGCACTGGAGACAGCAA CAATGTTGGCCACCAAGGTACAGCTTGGCTGCAACAACACCAGGGCCACCCTCCCAAACTCCTATCCTACAGGAATGGCA ACCGGCCCTCAGGGATCTCAGAGAGATTCTCTGCATCCAGGTCAGGAAATACAGCCTCCCTGACCATTATTGGACTCCAG CCTGAGGACGAGGCTGACTACTACTGCTCAGTATGGGACAGCAGCCTCAGTGCCTGGGTGTTCGGCGGAGGGACCAAGCT GACCGTCCTA

Table 1M. Antibody G17 Variable Region amino acid sequences

V_H chain of G17 (SEQ ID NO:24)
QVQLVQSGAEVKKPGASVKVSCKTSGVTFSSYAISWVRQAPGQGLEWMGGIIGVFGVPKYAQNFQGRVTITADKPTSTVY MELNSLRAEDTAVYYCAREPGYYVGKNGFDVWGQGTMVTVSS
V_L chain of G17 (SEQ ID NO:26)
SYELTQPPSVSKGLRQTAILTCTGDSNNVGHQGTAWLQQHQGHPPKLLSYRNGNRPSGISERFSASRSGNTASLTIIGLQ PEDEADYYCSVWDSSLSAWVFGGGTKLTVL

Table 1N. Antibody H40 Variable Region nucleic acid sequences

V_H chain of H40 (SEQ ID NO:33)
CAGGTGCAGCTGGTGCAGTCTGGGGCTGAGGTGAGGAAGCCTGGGGCCTCAGTGAAGGTCTCATGTAAGGCTTCTGGATA CACCTTCACCGGTTATTATATTCACTGGGTGCGACAGGCCCCTGGACAAGGACTTGAGTGGATGGGTTGGATCAACCCTA TGACTGGTGGCACAAACTATGCACAGAAGTTTCAGGTCTGGGTCACCATGACCCGGGACACGTCCATCAACACAGCCTAC ATGGAGGTGAGCAGGCTGACATCTGACGACACGGCCGTGTATTACTGTGCGAGGGGGGCTTCCGTATTACGATATTTTGA CTGGCAGCCCGAGGCTCTTGATATCTGGGGCCTCGGGACCACGGTCACCGTCTCCTCA
V_L chain of H40 (SEQ ID NO:35)
CAGCCTGTGCTGACTCAGCCACCCTCGGTGTCAGTGGCCCCAGGACAGACGGCCAGCATTCCCTGTGGGGGGAACAACAT TGGAGGCTACAGTGTACACTGGTACCAACAAAAGCCGGGCCAGGCCCCCCTCTTGGTCATTTATGACGATAAAGACCGGC CCTCAGGGATCCCTGAGCGATTCTCTGGCGCCAACTCTGGGAGCACGGCCACCCTGACAATCAGCAGGGTCGAAGCCGGG GATGAGGGCGACTACTACTGTCAGGTGTGGGATAGTGGTAATGATCGTCCGCTGTTCGGCGGAGGGACCAAGCTGACCGT CCTA

Table 1O. Antibody H40 Variable Region amino acid sequences

V_H chain of H40 (SEQ ID NO:28)
QVQLVQSGAEVRKPGASVKVSCKASGYTFTGYYIHWVRQAPGQGLEWMGWINPMTGGTNYAQKFQVWVTMTRDTSINTAY MEVSRLTSDDTAVYYCARGASVLRYFDWQPEALDIWGLGTTVTVSS

V_L chain of H40 (SEQ ID NO:30)
QPVLTQPPSVSVAPGQTASIPCGGNNIGGYSVHWYQQKPGQAPLLVIYDDKDRPSGIPERFSGANSGSTATLTISRVEAG DEGDYYCQVWDSGNDRPLFGGGTKLTVL

Table 1P. Antibody A66 Variable Region nucleic acid sequences
V_H chain of A66 (SEQ ID NO:37)
CAGGTGCAGCTGGTGCAGTCTGGGGCTGAAGTGAAGAAGCCTGGCTCCTCGGTGAAGGTTTCCTGCAAGGCTTCTGGAGG CCCCTTCAGCATGACTGCTTTCACCTGGCTGCGACAGGCCCCTGGACAAGGGCTTGAGTGGATGGGTGGGATCAGCCCTA TCTTTCGTACACCGAAGTACGCACAGAAGTTCCAGGGCAGAGTCACGATTACCGCGGACGAATCCACGAACACAGCCAAC ATGGAGCTGACCAGCCTGAAATCTGAGGACACGGCCGTGTATTACTGTGCGAGAACCCTTTCCTCCTACCAACCGAATAA TGATGCTTTTGCTATCTGGGGCCAAGGGACAATGGTCACCGTCTCTTCA
V_K chain of A66(SEQ ID NO:39)
GAAATTGTGTTGACGCAGTCTCCAGCCACCCTGTCTTTGTCTCCAGGGGAAAGAGCCACCCTCTCCTGCAGGGCCAGTCA GAGTGTTAGCAGCTACTTAGCCTGGTACCAACAGAAACCTGGCCAGGCTCCCAGGCTCCTCATCTATGATGCATCCAACA GGGCCACTGGCATCCCAGCCAGGTTCAGTGGCAGTGGGTCTGGGACAGACTTCACTCTCACCATCAGCAGACTGGAGCCT GAAGATTTTGCAGTCTATTTCTGTCAGCAGTATGGTAGCTCACCTCAATTCGGCCAAGGGACACGACTGGAGATTAAA

Table 1Q. Antibody A66 Variable Region amino acid sequences
V_H chain of A66 (SEQ ID NO:32)
QVQLVQSGAEVKKPGSSVKVSCKASGGPFSMTAFTWLRQAPGQGLEWMGGISPIFRTPKYAQKFQGRVTITADESTNTAN MELTSLKSEDTAVYYCARTLSSYQPNNDAFAIWGQGTMVTVSS
V_K chain of A66 (SEQ ID NO:34)
EIVLTQSPATLSLSPGERATLSCRASQSVSSYLAWYQQKPGQAPRLLIYDASNRATGIPARFSGSGSGTDFTLTISRLEP EDFAVYFCQQYGSSPQFGQGTRLEIK

Table 1R. Antibody E88 Variable Region nucleic acid sequences
V_H chain of E88 (SEQ ID NO:40)
CAGGTGCAGCTGGTGCAGTCTGGGGCTGAAGTGAAGAAGCCTGGCTCCTCGGTGAAGGTTTCCTGCAAGGCTTCTGGAGG CCCCTTCAGCATGACTGCTTTCACCTGGCTGCGACAGGCCCCTGGACAAGGGCTTGAGTGGATGGGTGGGATCAGCCCTA TCTTTCGTACACCGAAGTACGCACAGAAGTTCCAGGGCAGAGTCACGATTACCGCGGACGAATCCACGAACACAGCCAAC ATGGAGCTGACCAGCCTGAAATCTGAGGACACGGCCGTGTATTACTGTGCGAGAACCCTTTCCTCCTACCAACCGAATAA TGATGCTTTTGCTATCTGGGGCCAAGGGACAATGGTCACCGTCTCTTCA
V_L chain of E88 (SEQ ID NO:42)
CTGCCTGTGCTGACTCAGCCACCCTCAGCGTCTGGGACCCCCGGGCAGAGGGTCACCATCTCTTGTTCTGGAAGCAGCTC CAACATCGGAAGTAATACTGTAAACTGGTACCAGCAGCTCCCAGGAACGGCCCCCAAACTCCTCATCTATAGTAATAATC AGCGGCCCTCAGGGGTCCCTGACCGATTCTCTGGCTCCAGGTCAGGCACCTCAGCCTCCCTGGCCATCATTGGACTCCGG CCTGAGGATGAAGCTGATTATTACTGTCAGTCGTATGACAGCAGGCTCAGTGCTTCTCTCTTCGGAACTGGGACCACGGT CACCGTCCTC

Table 1S. Antibody E88 Variable Region amino acid sequences
V_H chain of E88 (SEQ ID NO:36)
QVQLVQSGAEVKKPGSSVKVSCKASGGPFSMTAFTWLRQAPGQGLEWMGGISPIFRTPKYAQKFQGRVTITADESTNTAN MELTSLKSEDTAVYYCARTLSSYQPNNDAFAIWGQGTMVTVSS
V_L chain of E88 (SEQ ID NO:38)
LPVLTQPPSASGTPGQRVTISCSGSSSNIGSNTVNWYQQLPGTAPKLLIYSNNQRPSGVPDRFSGSRSGTSASLAIIGLR PEDEADYYCQSYDSRLSASLFGTGTTVTVL

The amino acid sequences of the heavy and light chain complementary determining regions of the neutralizing influenza antibodies are shown in Table 2 below and Figure 4.

Table 2

Antibody	CDR1	CDR2	CDR3
CONSENSUS	SYAFS (SEQ ID NO: 43)	GIIPMFGTPNYAQKFQG (SEQ ID NO: 51)	SSGYYYG GGFDV (SEQ ID NO: 59)
D7/H98VH	TNAFS (SEQ ID NO: 44)	GVIPLFRTASYAQNVQG (SEQ ID NO: 52)	SSGYHFGRSHFDS (SEQ ID NO: 60)
D8/D80VH	AYAFT (SEQ ID NO: 45)	GIIGMFGTANYAQKFQG (SEQ ID NO: 53)	GLYYYESSLDY (SEQ ID NO: 61)
F10/90VH	SFAIS (SEQ ID NO: 46)	GISPMFGTPNYAQKFQG (SEQ ID NO: 54)	SPSYICSGGTCVFDH (SEQ ID NO: 62)
G17VH	SYAIS (SEQ ID NO: 47)	GIIGVFGVPKYAQKFQG (SEQ ID NO: 55)	EPGYYVGKNGFDV (SEQ ID NO: 63)
H40VH	GYYIH (SEQ ID NO: 48)	WINPMTGGTNYAQKFQ* (SEQ ID NO: 56)	GASVLRYFDWQPEALDI (SEQ ID NO: 64)
A66VH	MTAFT (SEQ ID NO: 49)	GISPIFRTPKYAQKFQG (SEQ ID NO: 57)	TLSSYQPNNDAFAI (SEQ ID NO: 65)
2AVH	DNAIS (SEQ ID NO: 50)	GIIPIFGKPNYAQKFQG (SEQ ID NO: 58)	DSDAYYYGSGGMDV (SEQ ID NO: 66)
CONSENSUS	TGSSSNIGNYVA (SEQ ID NO: 67)	SNSDRPS (SEQ ID NO: [illegible])	QSYDSLSAYV (SEQ ID NO: 91)
D7VL	TGSSSNIAANYVQ (SEQ ID NO: 68)	EDDRRPS (SEQ ID NO: [illegible])	QSYDTNNHAV (SEQ ID NO: 92)
DD8VL	TGTSSDVGGYNSVS (SEQ ID NO: 69)	EVTKRPS (SEQ ID NO: [illegible])	CSYAGHSAYV (SEQ ID NO: 93)
F10VL	TGNSNNVGNQGAA (SEQ ID NO: 70)	RNNDRPS (SEQ ID NO: [illegible])	STWDSSLSAVV (SEQ ID NO: 94)
G17VH	TGDSNNVGHQGTA (SEQ ID NO: 71)	RNGNRPS (SEQ ID NO: [illegible])	SVWDSSLSAWV (SEQ ID NO: 95)
H40VH	GGNNIGGYSVH (SEQ ID NO: 72)	DDKDRPS (SEQ ID NO: [illegible])	QVWDSGNDRPL (SEQ ID NO: 96)
A66VH	RASQSVSSYLA (SEQ ID NO: 73)	DASNRAT (SEQ ID NO: [illegible])	QQYGSSPQV (SEQ ID NO: 97)
D80VL	RASQSLSSKYLA (SEQ ID NO: 74)	GASSRAT (SEQ ID NO: [illegible])	QQYDGVPRT (SEQ ID NO: 98)
E88VL	TGSSSNIGNYVA (SEQ ID NO: 75)	SNNQRPS (SEQ ID NO: [illegible])	QSYDSRLSASL (SEQ ID NO: 99)
E90VK	SGSSSNIGSNTVN (SEQ ID NO: 76)	AASSLQR (SEQ ID NO: [illegible])	QQYDSSPYT (SEQ ID NO: 100)
H98VL	RASQSISSYLN (SEQ ID NO: 77)	SNEQRPS (SEQ ID NO: [illegible])	ASWDDNLSGWV (SEQ ID NO: 101)
2AVL	TLSSGHSNYIIA (SEQ ID NO: 78)	VNSDGSHTKGD (SEQ ID NO: 90)	ETWDTKIHV (SEQ ID NO: 102)

Those skilled in the art will recognize that additional scFvs and monoclonal antibodies having different binding affinities may also be therapeutically effective. For example, antibodies and scFvs having binding affinities ranging from about 1 pM to about 200 mM may also be therapeutically effective.

Neutralization of H5N1 with anti- influenza antibodies.

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H-5 pseudotyped viruses were incubated with bivalent scFv and full length antibodies and the antibody-virus mixture was contacted with 293T cells. Infectivity was quantified by measuring luciferase activity in the target cells. The D8, D8, F10, G17, H40, A66, D80, E88, E90, and H98, antibodies have potent neutralization activity against H5. D8, F1C and A66 antibodies also crossed neutralized H1N1, potently neutralized strain H1-SC/1918 and moderately neutralized strain H1-PR-34 (Figure 6)

Characterization of the 8, 10 and 66 epitope.

Primary epitope mapping of 8,10 and 66 binding to the influenza hemagglutinin (HA) protein showed that epitopes of these three antibodies were similar and are located at positions 307 on HA1 and at positions 52, 59, 65, and 93 on HA2. This epitope is comprised.

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of the hemagglutinin protein which is not shed by the virus. This is unlike most other known ant- influenza antibodies which bind the neuraminidase protein which is shed by the virus.

Structural characterization of the nAb epitope

The epitope and mode of binding of one of the nAbs, F10, by solving the crystal structure of its scFv fragment in complex with HA (H5-VN04) at 3.2 Å resolution, and by mutagenesis. (Fig. 6 and Table 4)

In the complex, each H5 trimer binds three molecules of F10, at symmetry-related sites, burying ~1500 $Å^2$ of protein surface per antibody; the structure of H5 itself is not significantly altered by F10 binding. HA is synthesized as a single chain, HA0, that is activated by proteolytic cleavage into two subunits, HA1 and HA2. Cleavage leads to the burial of the "fusion peptide" (comprising the first ~21 residues of HA2) into the membrane-proximal stem. F10 binding occurs exclusively in this region (Fig. 6), making intimate contacts with the fusion peptide, elements of HA1 and HA2 (both of which are integral to the structure of this region) that lock the peptide into place in the neutral pH conformation, as well as the large helical hairpin of HA2 that undergoes a massive conformation change at acidic pH in order to propel the fusion peptide from its viral membrane-proximal pocket to the distal surface of the virus, where it can trigger fusion with the endosomal membrane.

The heavy chain of F10 plays the major role in H5 binding, utilizing the tips of its three complementarity-determining regions (CDRs). Each F10 molecule make contacts with both the HA1 and HA2 subunits within a single monomer of the HA trimer (Fig 6). The contact region comprises a pocket formed by part of the HA2 fusion peptide, with elements of HA1 on one side and an exposed face of helix αA of HA2 on the other (Figs. 4 and 6). A triad of antibody residues - F55 and M54 from CDR H2, and Y102 from CDR H3 - form major contact points. The phenyl ring of F55 lies across a flat surface formed by a prominent loop of the fusion peptide loop (HA2 residues DGW 19_2-21_2 (H3 numbering scheme; subscripts 1 and 2 refer to HA1 and HA2 chains)) and the aromatic side-chains of two flanking histidines (residues 18_1 and 38_1) and a tryptophan, $W21_2$, which forms the back of the pocket. The side-chain of M54 also contacts the aromatic rings of $W21_2$ and $H38_1$, as well as the side-chain of $I45_2$ from helix αA, while its main-chain carbonyl oxygen hydrogen-bonds with the side-chain of $H38_1$. Y102 inserts its side-chain into a hydrophobic crevice created by four side-chains of the αA helix, and also hydrogen-bonds to a backbone carbonyl ($D19_2$) of the fusion peptide. The CDR H1 loop makes multiple contacts with the C-terminal end of helix αA and a loop of HA1 at the base of the head region (Fig.12d,e).

In parallel, mutagenesis experiments were carried out on helix αA to help define the epitope (Fig. 6). Mutations in 3 residues that directly contact the antibody: V52A/E, N53A and I56A, significantly reduced or ablated antibody binding, while the conservative mutation, V52L, had no effect. As controls, mutations on a different exposed face of the helix, which does not contact the antibody, had no effect on antibody binding (Fig.12b-c). Thus, mutagenesis of the αA helix is fully consistent with the epitope defined crystallographically for F10. Furthermore, the other two nAbs, for which no structural data exist, showed an almost identical mutant-nAb binding profile, indicative of a closely overlapping epitope and consistent with competitive binding (Fig. 6, Fig. 9). Taken together, we conclude that all three nAbs neutralize virus by stabilizing the neutral pH conformation of HA in a region that provides the trigger (most likely release of the fusion peptide from its pocket) for conformational changes that lead to the fusogenic state.

Antibodies

As used herein, the term "antibody" refers to immunoglobulin molecules and immunologically active portions of immunoglobulin (Ig) molecules, *i.e.*, molecules that contain an antigen binding site that specifically binds (immunoreacts with) an antigen. By "specifically binds" or "immunoreacts with" is meant that the antibody reacts with one or more antigenic determinants of the desired antigen and does not react with other polypeptides. Antibodies include, but are not limited to, polyclonal, monoclonal, chimeric, dAb (domain antibody), single chain, F_{ab}, $F_{ab'}$ and $F_{(ab')2}$ fragments, scFvs, and F_{ab} expression libraries.

A single chain Fv ("scFv") polypeptide molecule is a covalently linked V_H : :V_L heterodimer, which can be expressed from a gene fusion including V_H- and V_L-encoding genes linked by a peptide-encoding linker. (*See* Huston et al. (1988) Proc Nat Acad Sci USA 85(16):5879-5883). A number of methods have been described to discern chemical structures for converting the naturally aggregated, but chemically separated, light and heavy polypeptide chains from an antibody V region into an scFv molecule, which will fold into a three dimensional structure substantially similar to the structure of an antigen-binding site. *See, e.g.,* U.S. Patent Nos. 5,091,513; 5,132,405; and 4,946,778.

Very large naïve human scFv libraries have been and can be created to offer a large source of rearranged antibody genes against a plethora of target molecules. Smaller libraries can be constructed from individuals with infectious diseases in order to isolate disease-specific antibodies. (*See* Barbas et al., Proc. Natl. Acad. Sci. USA 89:9339-43 (1992); Zebedee et al., Proc. Natl. Acad. Sci. USA 89:3175-79 (1992)).

In general, antibody molecules obtained from humans relate to any of the classes IgG, IgM, IgA, IgE and IgD, which differ from one another by the nature of the heavy chain present in the molecule. Certain classes have subclasses as well, such as IgG_1, IgG_2, and others. Furthermore, in humans, the light chain may be a kappa chain or a lambda chain.

The term "antigen-binding site," or "binding portion" refers to the part of the immunoglobulin molecule that participates in antigen binding. The antigen binding site is formed by amino acid residues of the N-terminal variable ("V") regions of the heavy ("H") and light ("L") chains. Three highly divergent stretches within the V regions of the heavy and light chains, referred to as "hypervariable regions," are interposed between more conserved flanking stretches known as "framework regions," or "FRs". Thus, the term "FR" refers to amino acid sequences which are naturally found between, and adjacent to, hypervariable regions in immunoglobulins. In an antibody molecule, the three hypervariable regions of a light chain and the three hypervariable regions of a heavy chain are disposed relative to each other in three dimensional space to form an antigen-binding surface. The antigen-binding surface is complementary to the three-dimensional surface of a bound antigen, and the three hypervariable regions of each of the heavy and light chains are referred to as "complementarity-determining regions," or "CDRs." CDRs for the VH and VL regions of the 11A and 256 antibody are shown in Figure 1 and Figure 6 respectively .

As used herein, the term “epitope” includes any protein determinant capable of specific binding to an immunoglobulin, an scFv, or a T-cell receptor. Epitopic determinants usually consist of chemically active surface groupings of molecules such as amino acids or sugar side chains and usually have specific three dimensional structural characteristics, as well as specific charge characteristics. For example, antibodies may be raised against N-terminal or C-terminal peptides of a polypeptide.

As used herein, the terms "immunological binding," and "immunological binding properties" refer to the non-covalent interactions of the type which occur between an immunoglobulin molecule and an antigen for which the immunoglobulin is specific. The strength, or affinity of immunological binding interactions can be expressed in terms of the dissociation constant (K_d) of the interaction, wherein a smaller K_d represents a greater affinity. Immunological binding properties of selected polypeptides can be quantified using methods well known in the art. One such method entails measuring the rates of antigen-binding site/antigen complex formation and dissociation, wherein those rates depend on the concentrations of the complex partners, the affinity of the interaction, and geometric parameters that equally influence the rate in both directions. Thus, both the "on rate constant"

(K_{on}) and the "off rate constant" (K_{off}) can be determined by calculation of the concentrations and the actual rates of association and dissociation. (*See* Nature 361:186-87 (1993)). The ratio of K_{off} /K_{on} enables the cancellation of all parameters not related to affinity, and is equal to the dissociation constant K_d. (*See, generally*, Davies et al. (1990) Annual Rev Biochem 59:439-473). An antibody of the present invention is said to specifically bind to a influenza epitope when the equilibrium binding constant (K_d) is ≤1 μM, preferably ≤ 100 nM, more preferably ≤ 10 nM, and most preferably ≤ 100 pM to about 1 pM, as measured by assays such as radioligand binding assays or similar assays known to those skilled in the art.

A influenza protein (*e.g.*, HA or neuramindase) of the invention, or a derivative, fragment, analog, homolog or ortholog thereof, may be utilized as an immunogen in the generation of antibodies that immunospecifically bind these protein components.

Those skilled in the art will recognize that it is possible to determine, without undue experimentation, if a human monoclonal antibody has the same specificity as a human monoclonal antibody of the invention by ascertaining whether the former prevents the latter from binding to the HA protein of the influenza virus. If the human monoclonal antibody being tested competes with the human monoclonal antibody of the invention, as shown by a decrease in binding by the human monoclonal antibody of the invention, then it is likely that the two monoclonal antibodies bind to the same, or to a closely related, epitope.

Another way to determine whether a human monoclonal antibody has the specificity of a human monoclonal antibody of the invention is to pre-incubate the human monoclonal antibody of the invention with the influenza HA protein, with which it is normally reactive, and then add the human monoclonal antibody being tested to determine if the human monoclonal antibody being tested is inhibited in its ability to bind the HA protein. If the human monoclonal antibody being tested is inhibited then, in all likelihood, it has the same, or functionally equivalent, epitopic specificity as the monoclonal antibody of the invention. Screening of human monoclonal antibodies of the invention, can be also carried out by utilizing the influenza virus and determining whether the test monoclonal antibody is able to neutralize the influenza virus.

Various procedures known within the art may be used for the production of polyclonal or monoclonal antibodies directed against a protein of the invention, or against derivatives, fragments, analogs homologs or orthologs thereof. (*See, for example,* Antibodies: A Laboratory Manual, Harlow E, and Lane D, 1988, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, NY, incorporated herein by reference).

Antibodies can be purified by well-known techniques, such as affinity chromatography using protein A or protein G, which provide primarily the IgG fraction of immune serum. Subsequently, or alternatively, the specific antigen which is the target of the immunoglobulin sought, or an epitope thereof, may be immobilized on a column to purify the immune specific antibody by immunoaffinity chromatography. Purification of immunoglobulins is discussed, for example, by D. Wilkinson (The Scientist, published by The Scientist, Inc., Philadelphia PA, Vol. 14, No. 8 (April 17, 2000), pp. 25-28).

The term "monoclonal antibody" or "MAb" or "monoclonal antibody composition", as used herein, refers to a population of antibody molecules that contain only one molecular species of antibody molecule consisting of a unique light chain gene product and a unique heavy chain gene product. In particular, the complementarity determining regions (CDRs) of the monoclonal antibody are identical in all the molecules of the population. MAbs contain an antigen binding site capable of immunoreacting with a particular epitope of the antigen characterized by a unique binding affinity for it.

Monoclonal antibodies can be prepared using hybridoma methods, such as those described by Kohler and Milstein, Nature, 256:495 (1975). In a hybridoma method, a mouse, hamster, or other appropriate host animal, is typically immunized with an immunizing agent to elicit lymphocytes that produce or are capable of producing antibodies that will specifically bind to the immunizing agent. Alternatively, the lymphocytes can be immunized *in vitro*.

The immunizing agent will typically include the protein antigen, a fragment thereof or a fusion protein thereof. Generally, either peripheral blood lymphocytes are used if cells of human origin are desired, or spleen cells or lymph node cells are used if non-human mammalian sources are desired. The lymphocytes are then fused with an immortalized cell line using a suitable fusing agent, such as polyethylene glycol, to form a hybridoma cell (Goding, Monoclonal Antibodies: Principles and Practice, Academic Press, (1986) pp. 59-103). Immortalized cell lines are usually transformed mammalian cells, particularly myeloma cells of rodent, bovine and human origin. Usually, rat or mouse myeloma cell lines are employed. The hybridoma cells can be cultured in a suitable culture medium that preferably contains one or more substances that inhibit the growth or survival of the unfused, immortalized cells. For example, if the parental cells lack the enzyme hypoxanthine guanine phosphoribosyl transferase (HGPRT or HPRT), the culture medium for the hybridomas typically will include hypoxanthine, aminopterin, and thymidine ("HAT medium"), which substances prevent the growth of HGPRT-deficient cells.

Preferred immortalized cell lines are those that fuse efficiently, support stable high level expression of antibody by the selected antibody-producing cells, and are sensitive to a medium such as HAT medium. More preferred immortalized cell lines are murine myeloma lines, which can be obtained, for instance, from the Salk Institute Cell Distribution Center, San Diego, California and the American Type Culture Collection, Manassas, Virginia. Human myeloma and mouse-human heteromyeloma cell lines also have been described for the production of human monoclonal antibodies. (*See* Kozbor, J. Immunol., 133:3001 (1984); Brodeur et al., Monoclonal Antibody Production Techniques and Applications, Marcel Dekker, Inc., New York, (1987) pp. 51-63)).

The culture medium in which the hybridoma cells are cultured can then be assayed for the presence of monoclonal antibodies directed against the antigen. Preferably, the binding specificity of monoclonal antibodies produced by the hybridoma cells is determined by immunoprecipitation or by an *in vitro* binding assay, such as radioimmunoassay (RIA) or enzyme-linked immunoabsorbent assay (ELISA). Such techniques and assays are known in the art. The binding affinity of the monoclonal antibody can, for example, be determined by the Scatchard analysis of Munson and Pollard, Anal. Biochem., 107:220 (1980). Moreover, in therapeutic applications of monoclonal antibodies, it is important to identify antibodies having a high degree of specificity and a high binding affinity for the target antigen.

After the desired hybridoma cells are identified, the clones can be subcloned by limiting dilution procedures and grown by standard methods. (*See* Goding, Monoclonal Antibodies: Principles and Practice, Academic Press, (1986) pp. 59-103). Suitable culture media for this purpose include, for example, Dulbecco's Modified Eagle's Medium and RPMI-1640 medium. Alternatively, the hybridoma cells can be grown *in vivo* as ascites in a mammal.

The monoclonal antibodies secreted by the subclones can be isolated or purified from the culture medium or ascites fluid by conventional immunoglobulin purification procedures such as, for example, protein A-Sepharose, hydroxylapatite chromatography, gel electrophoresis, dialysis, or affinity chromatography.

Monoclonal antibodies can also be made by recombinant DNA methods, such as those described in U.S. Patent No. 4,816,567. DNA encoding the monoclonal antibodies of the invention can be readily isolated and sequenced using conventional procedures (*e.g.*, by using oligonucleotide probes that are capable of binding specifically to genes encoding the heavy and light chains of murine antibodies). The hybridoma cells of the invention serve as a preferred source of such DNA. Once isolated, the DNA can be placed into expression

vectors, which are then transfected into host cells such as simian COS cells, Chinese hamster ovary (CHO) cells, or myeloma cells that do not otherwise produce immunoglobulin protein, to obtain the synthesis of monoclonal antibodies in the recombinant host cells. The DNA also can be modified, for example, by substituting the coding sequence for human heavy and light chain constant domains in place of the homologous murine sequences (*see* U.S. Patent No. 4,816,567; Morrison, Nature 368, 812-13 (1994)) or by covalently joining to the immunoglobulin coding sequence all or part of the coding sequence for a non-immunoglobulin polypeptide. Such a non-immunoglobulin polypeptide can be substituted for the constant domains of an antibody of the invention, or can be substituted for the variable domains of one antigen-combining site of an antibody of the invention to create a chimeric bivalent antibody.

Fully human antibodies are antibody molecules in which the entire sequence of both the light chain and the heavy chain, including the CDRs, arise from human genes. Such antibodies are termed "human antibodies", or "fully human antibodies" herein. Human monoclonal antibodies can be prepared by using trioma technique; the human B-cell hybridoma technique (*see* Kozbor, et al., 1983 Immunol Today 4: 72); and the EBV hybridoma technique to produce human monoclonal antibodies (*see* Cole, et al., 1985 In: MONOCLONAL ANTIBODIES AND CANCER THERAPY, Alan R. Liss, Inc., pp. 77-96). Human monoclonal antibodies may be utilized and may be produced by using human hybridomas (*see* Cote, et al., 1983. Proc Natl Acad Sci USA 80: 2026-2030) or by transforming human B-cells with Epstein Barr Virus *in vitro* (see Cole, et al., 1985 In: MONOCLONAL ANTIBODIES AND CANCER THERAPY, Alan R. Liss, Inc., pp. 77-96).

In addition, human antibodies can also be produced using additional techniques, including phage display libraries. (*See* Hoogenboom and Winter, J. Mol. Biol., 227:381 (1991); Marks et al., J. Mol. Biol., 222:581 (1991)). Similarly, human antibodies can be made by introducing human immunoglobulin loci into transgenic animals, *e.g.*, mice in which the endogenous immunoglobulin genes have been partially or completely inactivated. Upon challenge, human antibody production is observed, which closely resembles that seen in humans in all respects, including gene rearrangement, assembly, and antibody repertoire. This approach is described, for example, in U.S. Patent Nos. 5,545,807; 5,545,806; 5,569,825; 5,625,126; 5,633,425; 5,661,016, and in Marks et al., Bio/Technology 10, 779-783 (1992); Lonberg et al., Nature 368 856-859 (1994); Morrison, Nature 368, 812-13 (1994); Fishwild et al, Nature Biotechnology 14, 845-51 (1996); Neuberger, Nature

Biotechnology 14, 826 (1996); and Lonberg and Huszar, Intern. Rev. Immunol. 13 65-93 (1995).

Human antibodies may additionally be produced using transgenic nonhuman animals which are modified so as to produce fully human antibodies rather than the animal's endogenous antibodies in response to challenge by an antigen. (*See* PCT publication WO94/02602). The endogenous genes encoding the heavy and light immunoglobulin chains in the nonhuman host have been incapacitated, and active loci encoding human heavy and light chain immunoglobulins are inserted into the host's genome. The human genes are incorporated, for example, using yeast artificial chromosomes containing the requisite human DNA segments. An animal which provides all the desired modifications is then obtained as progeny by crossbreeding intermediate transgenic animals containing fewer than the full complement of the modifications. The preferred embodiment of such a nonhuman animal is a mouse, and is termed the Xenomouse™ as disclosed in PCT publications WO 96/33735 and WO 96/34096. This animal produces B cells which secrete fully human immunoglobulins. The antibodies can be obtained directly from the animal after immunization with an immunogen of interest, as, for example, a preparation of a polyclonal antibody, or alternatively from immortalized B cells derived from the animal, such as hybridomas producing monoclonal antibodies. Additionally, the genes encoding the immunoglobulins with human variable regions can be recovered and expressed to obtain the antibodies directly, or can be further modified to obtain analogs of antibodies such as, for example, single chain Fv (scFv) molecules.

An example of a method of producing a nonhuman host, exemplified as a mouse, lacking expression of an endogenous immunoglobulin heavy chain is disclosed in U.S. Patent No. 5,939,598. It can be obtained by a method, which includes deleting the J segment genes from at least one endogenous heavy chain locus in an embryonic stem cell to prevent rearrangement of the locus and to prevent formation of a transcript of a rearranged immunoglobulin heavy chain locus, the deletion being effected by a targeting vector containing a gene encoding a selectable marker; and producing from the embryonic stem cell a transgenic mouse whose somatic and germ cells contain the gene encoding the selectable marker.

One method for producing an antibody of interest, such as a human antibody, is disclosed in U.S. Patent No. 5,916,771. This method includes introducing an expression vector that contains a nucleotide sequence encoding a heavy chain into one mammalian host cell in culture, introducing an expression vector containing a nucleotide sequence encoding a

light chain into another mammalian host cell, and fusing the two cells to form a hybrid cell. The hybrid cell expresses an antibody containing the heavy chain and the light chain.

In a further improvement on this procedure, a method for identifying a clinically relevant epitope on an immunogen, and a correlative method for selecting an antibody that binds immunospecifically to the relevant epitope with high affinity, are disclosed in PCT publication WO 99/53049.

The antibody can be expressed by a vector containing a DNA segment encoding the single chain antibody described above.

These can include vectors, liposomes, naked DNA, adjuvant-assisted DNA, gene gun, catheters, *etc*. Vectors include chemical conjugates such as described in WO 93/64701, which has targeting moiety (*e.g.* a ligand to a cellular surface receptor), and a nucleic acid binding moiety (*e.g.* polylysine), viral vector (*e.g.* a DNA or RNA viral vector), fusion proteins such as described in PCT/US 95/02140 (WO 95/22618) which is a fusion protein containing a target moiety (*e.g.* an antibody specific for a target cell) and a nucleic acid binding moiety (*e.g.* a protamine), plasmids, phage, etc. The vectors can be chromosomal, non-chromosomal or synthetic.

Preferred vectors include viral vectors, fusion proteins and chemical conjugates. Retroviral vectors include moloney murine leukemia viruses. DNA viral vectors are preferred. These vectors include pox vectors such as orthopox or avipox vectors, herpesvirus vectors such as a herpes simplex I virus (HSV) vector (*see* Geller, A. I. et al., J. Neurochem, 64:487 (1995); Lim, F., et al., in DNA Cloning: Mammalian Systems, D. Glover, Ed. (Oxford Univ. Press, Oxford England) (1995); Geller, A. I. et al., Proc Natl. Acad. Sci.: U.S.A. 90:7603 (1993); Geller, A. I., et al., Proc Natl. Acad. Sci USA 87:1149 (1990), Adenovirus Vectors (*see* LeGal LaSalle et al., Science, 259:988 (1993); Davidson, et al., Nat. Genet 3:219 (1993); Yang, et al., J. Virol. 69:2004 (1995) and Adeno-associated Virus Vectors (*see* Kaplitt, M. G.. et al., Nat. Genet. 8:148 (1994).

Pox viral vectors introduce the gene into the cells cytoplasm. Avipox virus vectors result in only a short term expression of the nucleic acid. Adenovirus vectors, adeno-associated virus vectors and herpes simplex virus (HSV) vectors are preferred for introducing the nucleic acid into neural cells. The adenovirus vector results in a shorter term expression (about 2 months) than adeno-associated virus (about 4 months), which in turn is shorter than HSV vectors. The particular vector chosen will depend upon the target cell and the condition being treated. The introduction can be by standard techniques, *e.g.* infection, transfection, transduction or transformation. Examples of modes of gene transfer include *e.g.*, naked DNA,

$CaPO_4$ precipitation, DEAE dextran, electroporation, protoplast fusion, lipofection, cell microinjection, and viral vectors.

The vector can be employed to target essentially any desired target cell. For example, stereotaxic injection can be used to direct the vectors (*e.g.* adenovirus, HSV) to a desired location. Additionally, the particles can be delivered by intracerebroventricular (icv) infusion using a minipump infusion system, such as a SynchroMed Infusion System. A method based on bulk flow, termed convection, has also proven effective at delivering large molecules to extended areas of the brain and may be useful in delivering the vector to the target cell. (*See* Bobo et al., Proc. Natl. Acad. Sci. USA 91:2076-2080 (1994); Morrison et al., Am. J. Physiol. 266:292-305 (1994)). Other methods that can be used include catheters, intravenous, parenteral, intraperitoneal and subcutaneous injection, and oral or other known routes of administration.

These vectors can be used to express large quantities of antibodies that can be used in a variety of ways. For example, to detect the presence ofan influenza virus in a sample. The antibody can also be used to try to bind to and disrupt influenza virus cell membrane fusion.

Techniques can be adapted for the production of single-chain antibodies specific to an antigenic protein of the invention (*see e.g.*, U.S. Patent No. 4,946,778). In addition, methods can be adapted for the construction of F_{ab} expression libraries (*see e.g.*, Huse, et al., 1989 Science 246: 1275-1281) to allow rapid and effective identification of monoclonal F_{ab} fragments with the desired specificity for a protein or derivatives, fragments, analogs or homologs thereof. Antibody fragments that contain the idiotypes to a protein antigen may be produced by techniques known in the art including, but not limited to: (i) an $F_{(ab')2}$ fragment produced by pepsin digestion of an antibody molecule; (ii) an F_{ab} fragment generated by reducing the disulfide bridges of an $F_{(ab')2}$ fragment; (iii) an F_{ab} fragment generated by the treatment of the antibody molecule with papain and a reducing agent and (iv) F_v fragments.

Heteroconjugate antibodies are also within the scope of the present invention. Heteroconjugate antibodies are composed of two covalently joined antibodies. Such antibodies have, for example, been proposed to target immune system cells to unwanted cells (*see* U.S. Patent No. 4,676,980), and for treatment of HIV infection (*see* WO 91/00360; WO 92/200373; EP 03089). It is contemplated that the antibodies can be prepared *in vitro* using known methods in synthetic protein chemistry, including those involving crosslinking agents. For example, immunotoxins can be constructed using a disulfide exchange reaction or by forming a thioether bond. Examples of suitable reagents for this purpose include

iminothiolate and methyl-4-mercaptobutyrimidate and those disclosed, for example, in U.S. Patent No. 4,676,980.

It can be desirable to modify the antibody of the invention with respect to effector function, so as to enhance, *e.g.*, the effectiveness of the antibody in treating influenza. For example, cysteine residue(s) can be introduced into the Fc region, thereby allowing interchain disulfide bond formation in this region. The homodimeric antibody thus generated can have improved internalization capability and/or increased complement-mediated cell killing and antibody-dependent cellular cytotoxicity (ADCC). (*See* Caron et al., J. Exp Med., 176: 1191-1195 (1992) and Shopes, J. Immunol., 148: 2918-2922 (1992)). Alternatively, an antibody can be engineered that has dual Fc regions and can thereby have enhanced complement lysis and ADCC capabilities. (*See* Stevenson et al., Anti-Cancer Drug Design, 3: 219-230 (1989)).

The invention also pertains to immunoconjugates comprising an antibody conjugated to a cytotoxic agent such as a toxin (*e.g.*, an enzymatically active toxin of bacterial, fungal, plant, or animal origin, or fragments thereof), or a radioactive isotope (*i.e.*, a radioconjugate).

Enzymatically active toxins and fragments thereof that can be used include diphtheria A chain, nonbinding active fragments of diphtheria toxin, exotoxin A chain (from Pseudomonas aeruginosa), ricin A chain, abrin A chain, modeccin A chain, alpha-sarcin, Aleurites fordii proteins, dianthin proteins, Phytolaca americana proteins (PAPI, PAPII, and PAP-S), momordica charantia inhibitor, curcin, crotin, sapaonaria officinalis inhibitor, gelonin, mitogellin, restrictocin, phenomycin, enomycin, and the tricothecenes. A variety of radionuclides are available for the production of radioconjugated antibodies. Examples include ^{212}Bi, ^{131}I, ^{131}In, ^{90}Y, and ^{186}Re.

Conjugates of the antibody and cytotoxic agent are made using a variety of bifunctional protein-coupling agents such as N-succinimidyl-3-(2-pyridyldithiol) propionate (SPDP), iminothiolane (IT), bifunctional derivatives of imidoesters (such as dimethyl adipimidate HCL), active esters (such as disuccinimidyl suberate), aldehydes (such as glutareldehyde), bis-azido compounds (such as bis (p-azidobenzoyl) hexanediamine), bis-diazonium derivatives (such as bis-(p-diazoniumbenzoyl)-ethylenediamine), diisocyanates (such as tolyene 2,6-diisocyanate), and bis-active fluorine compounds (such as 1,5-difluoro-2,4-dinitrobenzene). For example, a ricin immunotoxin can be prepared as described in Vitetta et al., Science 238: 1098 (1987). Carbon-14-labeled 1-isothiocyanatobenzyl-3-methyldiethylene triaminepentaacetic acid (MX-DTPA) is an

exemplary chelating agent for conjugation of radionucleotide to the antibody. (*See* WO94/11026).

Those of ordinary skill in the art will recognize that a large variety of possible moieties can be coupled to the resultant antibodies or to other molecules of the invention. (*See, for example*, "Conjugate Vaccines", Contributions to Microbiology and Immunology, J. M. Cruse and R. E. Lewis, Jr (eds), Carger Press, New York, (1989), the entire contents of which are incorporated herein by reference).

Coupling may be accomplished by any chemical reaction that will bind the two molecules so long as the antibody and the other moiety retain their respective activities. This linkage can include many chemical mechanisms, for instance covalent binding, affinity binding, intercalation, coordinate binding and complexation. The preferred binding is, however, covalent binding. Covalent binding can be achieved either by direct condensation of existing side chains or by the incorporation of external bridging molecules. Many bivalent or polyvalent linking agents are useful in coupling protein molecules, such as the antibodies of the present invention, to other molecules. For example, representative coupling agents can include organic compounds such as thioesters, carbodiimides, succinimide esters, diisocyanates, glutaraldehyde, diazobenzenes and hexamethylene diamines. This listing is not intended to be exhaustive of the various classes of coupling agents known in the art but, rather, is exemplary of the more common coupling agents. (*See* Killen and Lindstrom, Jour. Immun. 133:1335-2549 (1984); Jansen et al., Immunological Reviews 62:185-216 (1982); and Vitetta et al., Science 238:1098 (1987)). Preferred linkers are described in the literature. (*See, for example*, Ramakrishnan, S. et al., Cancer Res. 44:201-208 (1984) describing use of MBS (M-maleimidobenzoyl-N-hydroxysuccinimide ester). *See also*, U.S. Patent No. 5,030,719, describing use of halogenated acetyl hydrazide derivative coupled to an antibody by way of an oligopeptide linker. Particularly preferred linkers include: (i) EDC (1-ethyl-3-(3-dimethylamino-propyl) carbodiimide hydrochloride; (ii) SMPT (4-succinimidyloxycarbonyl-alpha-methyl-alpha-(2-pridyl-dithio)-toluene (Pierce Chem. Co., Cat. (21558G); (iii) SPDP (succinimidyl-6 [3-(2-pyridyldithio) propionamido]hexanoate (Pierce Chem. Co., Cat #21651G); (iv) Sulfo-LC-SPDP (sulfosuccinimidyl 6 [3-(2-pyridyldithio)-propianamide] hexanoate (Pierce Chem. Co. Cat. #2165-G); and (v) sulfo-NHS (N-hydroxysulfo-succinimide: Pierce Chem. Co., Cat. #24510) conjugated to EDC.

The linkers described above contain components that have different attributes, thus leading to conjugates with differing physio-chemical properties. For example, sulfo-NHS esters of alkyl carboxylates are more stable than sulfo-NHS esters of aromatic carboxylates.

NHS-ester containing linkers are less soluble than sulfo-NHS esters. Further, the linker SMPT contains a sterically hindered disulfide bond, and can form conjugates with increased stability. Disulfide linkages, are in general, less stable than other linkages because the disulfide linkage is cleaved *in vitro*, resulting in less conjugate available. Sulfo-NHS, in particular, can enhance the stability of carbodimide couplings. Carbodimide couplings (such as EDC) when used in conjunction with sulfo-NHS, forms esters that are more resistant to hydrolysis than the carbodimide coupling reaction alone.

The antibodies disclosed herein can also be formulated as immunoliposomes. Liposomes containing the antibody are prepared by methods known in the art, such as described in Epstein et al., Proc. Natl. Acad. Sci. USA, 82: 3688 (1985); Hwang et al., Proc. Natl Acad. Sci. USA, 77: 4030 (1980); and U.S. Pat. Nos. 4,485,045 and 4,544,545. Liposomes with enhanced circulation time are disclosed in U.S. Patent No. 5,013,556.

Particularly useful liposomes can be generated by the reverse-phase evaporation method with a lipid composition comprising phosphatidylcholine, cholesterol, and PEG-derivatized phosphatidylethanolamine (PEG-PE). Liposomes are extruded through filters of defined pore size to yield liposomes with the desired diameter. Fab' fragments of the antibody of the present invention can be conjugated to the liposomes as described in Martin et al., J. Biol. Chem., 257: 286-288 (1982) via a disulfide-interchange reaction.

Use of Antibodies Against Influenza Virus

Methods for the screening of antibodies that possess the desired specificity include, but are not limited to, enzyme linked immunosorbent assay (ELISA) and other immunologically mediated techniques known within the art.

Antibodies directed against a influenza virus protein such as HA (or a fragment thereof) may be used in methods known within the art relating to the localization and/or quantitation of a influenza virus protein (*e.g.*, for use in measuring levels of the influenza virus protein within appropriate physiological samples, for use in diagnostic methods, for use in imaging the protein, and the like). In a given embodiment, antibodies specific to an influenza virus protein, or derivative, fragment, analog or homolog thereof, that contain the antibody derived antigen binding domain, are utilized as pharmacologically active compounds (referred to hereinafter as "Therapeutics").

An antibody specific for an influenza virus protein of the invention can be used to isolate an influenza virus polypeptide by standard techniques, such as immunoaffinity, chromatography or immunoprecipitation. Antibodies directed against an influenza virus protein (or a fragment thereof) can be used diagnostically to monitor protein levels in tissue

as part of a clinical testing procedure, *e.g.*, to, for example, determine the efficacy of a given treatment regimen. Detection can be facilitated by coupling (*i.e.*, physically linking) the antibody to a detectable substance. Examples of detectable substances include various enzymes, prosthetic groups, fluorescent materials, luminescent materials, bioluminescent materials, and radioactive materials. Examples of suitable enzymes include horseradish peroxidase, alkaline phosphatase, β-galactosidase, or acetylcholinesterase; examples of suitable prosthetic group complexes include streptavidin/biotin and avidin/biotin; examples of suitable fluorescent materials include umbelliferone, fluorescein, fluorescein isothiocyanate, rhodamine, dichlorotriazinylamine fluorescein, dansyl chloride or phycoerythrin; an example of a luminescent material includes luminol; examples of bioluminescent materials include luciferase, luciferin, and aequorin, and examples of suitable radioactive material include ^{125}I, ^{131}I, ^{35}S or ^{3}H.

Antibodies of the invention, including polyclonal, monoclonal, humanized and fully human antibodies, may used as therapeutic agents. Such agents will generally be employed to treat or prevent an influenza virus -related disease or pathology (*e.g.,* bird flu) in a subject. An antibody preparation, preferably one having high specificity and high affinity for its target antigen, is administered to the subject and will generally have an effect due to its binding with the target. Administration of the antibody may abrogate or inhibit or interfere with the internalization of the virus into a cell In this case, the antibody binds to the target and masks a binding site of the naturally occurring ligand, thereby blocking fusion the virus to the cell membrane inhibiting internalization of the virus.

A therapeutically effective amount of an antibody of the invention relates generally to the amount needed to achieve a therapeutic objective. As noted above, this may be a binding interaction between the antibody and its target antigen that, in certain cases, interferes with the functioning of the target. The amount required to be administered will furthermore depend on the binding affinity of the antibody for its specific antigen, and will also depend on the rate at which an administered antibody is depleted from the free volume other subject to which it is administered. Common ranges for therapeutically effective dosing of an antibody or antibody fragment of the invention may be, by way of nonlimiting example, from about 0.1 mg/kg body weight to about 50 mg/kg body weight. Common dosing frequencies may range, for example, from twice daily to once a week.

Antibodies specifically binding an influenza virus protein or a fragment thereof of the invention, as well as other molecules identified by the screening assays disclosed herein, can be administered for the treatment of an influenza virus -related disorders in the form of

pharmaceutical compositions. Principles and considerations involved in preparing such compositions, as well as guidance in the choice of components are provided, for example, in Remington: The Science And Practice Of Pharmacy 19th ed. (Alfonso R. Gennaro, et al., editors) Mack Pub. Co., Easton, Pa., 1995; Drug Absorption Enhancement: Concepts, Possibilities, Limitations, And Trends, Harwood Academic Publishers, Langhorne, Pa., 1994; and Peptide And Protein Drug Delivery (Advances In Parenteral Sciences, Vol. 4), 1991, M. Dekker, New York.

Where antibody fragments are used, the smallest inhibitory fragment that specifically binds to the binding domain of the target protein is preferred. For example, based upon the variable-region sequences of an antibody, peptide molecules can be designed that retain the ability to bind the target protein sequence. Such peptides can be synthesized chemically and/or produced by recombinant DNA technology. (*See*, *e.g.*, Marasco et al., Proc. Natl. Acad. Sci. USA, 90: 7889-7893 (1993)). The formulation can also contain more than one active compound as necessary for the particular indication being treated, preferably those with complementary activities that do not adversely affect each other. Alternatively, or in addition, the composition can comprise an agent that enhances its function, such as, for example, a cytotoxic agent, cytokine, chemotherapeutic agent, or growth-inhibitory agent. Such molecules are suitably present in combination in amounts that are effective for the purpose intended.

The active ingredients can also be entrapped in microcapsules prepared, for example, by coacervation techniques or by interfacial polymerization, for example, hydroxymethylcellulose or gelatin-microcapsules and poly-(methylmethacrylate) microcapsules, respectively, in colloidal drug delivery systems (for example, liposomes, albumin microspheres, microemulsions, nano-particles, and nanocapsules) or in macroemulsions.

The formulations to be used for *in vivo* administration must be sterile. This is readily accomplished by filtration through sterile filtration membranes.

Sustained-release preparations can be prepared. Suitable examples of sustained-release preparations include semipermeable matrices of solid hydrophobic polymers containing the antibody, which matrices are in the form of shaped articles, *e.g.*, films, or microcapsules. Examples of sustained-release matrices include polyesters, hydrogels (for example, poly(2-hydroxyethyl-methacrylate), or poly(vinylalcohol)), polylactides (U.S. Pat. No. 3,773,919), copolymers of L-glutamic acid and γ ethyl-L-glutamate, non-degradable ethylene-vinyl acetate, degradable lactic acid-glycolic

acid copolymers such as the LUPRON DEPOT ™ (injectable microspheres composed of lactic acid-glycolic acid copolymer and leuprolide acetate), and poly-D-(-)-3-hydroxybutyric acid. While polymers such as ethylene-vinyl acetate and lactic acid-glycolic acid enable release of molecules for over 100 days, certain hydrogels release proteins for shorter time periods.

An antibody according to the invention can be used as an agent for detecting the presence of an influenza virus (or a protein or a protein fragment thereof) in a sample. Preferably, the antibody contains a detectable label. Antibodies can be polyclonal, or more preferably, monoclonal. An intact antibody, or a fragment thereof (*e.g.*, F_{ab}, scFv, or $F_{(ab)2}$) can be used. The term "labeled", with regard to the probe or antibody, is intended to encompass direct labeling of the probe or antibody by coupling (*i.e.*, physically linking) a detectable substance to the probe or antibody, as well as indirect labeling of the probe or antibody by reactivity with another reagent that is directly labeled. Examples of indirect labeling include detection of a primary antibody using a fluorescently-labeled secondary antibody and end-labeling of a DNA probe with biotin such that it can be detected with fluorescently-labeled streptavidin. The term "biological sample" is intended to include tissues, cells and biological fluids isolated from a subject, as well as tissues, cells and fluids present within a subject. Included within the usage of the term "biological sample", therefore, is blood and a fraction or component of blood including blood serum, blood plasma, or lymph. That is, the detection method of the invention can be used to detect an analyte mRNA, protein, or genomic DNA in a biological sample *in vitro* as well as *in vivo*. For example, *in vitro* techniques for detection of an analyte mRNA include Northern hybridizations and *in situ* hybridizations. *In vitro* techniques for detection of an analyte protein include enzyme linked immunosorbent assays (ELISAs), Western blots, immunoprecipitations, and immunofluorescence. *In vitro* techniques for detection of an analyte genomic DNA include Southern hybridizations. Procedures for conducting immunoassays are described, for example in "ELISA: Theory and Practice: Methods in Molecular Biology", Vol. 42, J. R. Crowther (Ed.) Human Press, Totowa, NJ, 1995; "Immunoassay", E. Diamandis and T. Christopoulus, Academic Press, Inc., San Diego, CA, 1996; and "Practice and Theory of Enzyme Immunoassays", P. Tijssen, Elsevier Science Publishers, Amsterdam, 1985. Furthermore, *in vivo* techniques for detection of an analyte protein include introducing into a subject a labeled anti-analyte protein antibody. For example, the antibody can be labeled with a radioactive marker whose presence and location in a subject can be detected by standard imaging techniques.

Pharmaceutical compositions

The antibodies or agents of the invention (also referred to herein as "active compounds"), and derivatives, fragments, analogs and homologs thereof, can be incorporated into pharmaceutical compositions suitable for administration. Such compositions typically comprise the antibody or agent and a pharmaceutically acceptable carrier. As used herein, the term "pharmaceutically acceptable carrier" is intended to include any and all solvents, dispersion media, coatings, antibacterial and antifungal agents, isotonic and absorption delaying agents, and the like, compatible with pharmaceutical administration. Suitable carriers are described in the most recent edition of Remington's Pharmaceutical Sciences, a standard reference text in the field, which is incorporated herein by reference. Preferred examples of such carriers or diluents include, but are not limited to, water, saline, ringer's solutions, dextrose solution, and 5% human serum albumin. Liposomes and non-aqueous vehicles such as fixed oils may also be used. The use of such media and agents for pharmaceutically active substances is well known in the art. Except insofar as any conventional media or agent is incompatible with the active compound, use thereof in the compositions is contemplated. Supplementary active compounds can also be incorporated into the compositions.

A pharmaceutical composition of the invention is formulated to be compatible with its intended route of administration. Examples of routes of administration include parenteral, *e.g.*, intravenous, intradermal, subcutaneous, oral (*e.g.*, inhalation), transdermal (*i.e.,* topical), transmucosal, and rectal administration. Solutions or suspensions used for parenteral, intradermal, or subcutaneous application can include the following components: a sterile diluent such as water for injection, saline solution, fixed oils, polyethylene glycols, glycerine, propylene glycol or other synthetic solvents; antibacterial agents such as benzyl alcohol or methyl parabens; antioxidants such as ascorbic acid or sodium bisulfite; chelating agents such as ethylenediaminetetraacetic acid (EDTA); buffers such as acetates, citrates or phosphates, and agents for the adjustment of tonicity such as sodium chloride or dextrose. The pH can be adjusted with acids or bases, such as hydrochloric acid or sodium hydroxide. The parenteral preparation can be enclosed in ampoules, disposable syringes or multiple dose vials made of glass or plastic.

Pharmaceutical compositions suitable for injectable use include sterile aqueous solutions (where water soluble) or dispersions and sterile powders for the extemporaneous preparation of sterile injectable solutions or dispersion. For intravenous administration, suitable carriers include physiological saline, bacteriostatic water, Cremophor EL™ (BASF, Parsippany, N.J.) or phosphate buffered saline (PBS). In all cases, the composition must be

sterile and should be fluid to the extent that easy syringeability exists. It must be stable under the conditions of manufacture and storage and must be preserved against the contaminating action of microorganisms such as bacteria and fungi. The carrier can be a solvent or dispersion medium containing, for example, water, ethanol, polyol (for example, glycerol, propylene glycol, and liquid polyethylene glycol, and the like), and suitable mixtures thereof. The proper fluidity can be maintained, for example, by the use of a coating such as lecithin, by the maintenance of the required particle size in the case of dispersion and by the use of surfactants. Prevention of the action of microorganisms can be achieved by various antibacterial and antifungal agents, for example, parabens, chlorobutanol, phenol, ascorbic acid, thimerosal, and the like. In many cases, it will be preferable to include isotonic agents, for example, sugars, polyalcohols such as manitol, sorbitol, sodium chloride in the composition. Prolonged absorption of the injectable compositions can be brought about by including in the composition an agent which delays absorption, for example, aluminum monostearate and gelatin.

Sterile injectable solutions can be prepared by incorporating the active compound in the required amount in an appropriate solvent with one or a combination of ingredients enumerated above, as required, followed by filtered sterilization. Generally, dispersions are prepared by incorporating the active compound into a sterile vehicle that contains a basic dispersion medium and the required other ingredients from those enumerated above. In the case of sterile powders for the preparation of sterile injectable solutions, methods of preparation are vacuum drying and freeze-drying that yields a powder of the active ingredient plus any additional desired ingredient from a previously sterile-filtered solution thereof.

Oral compositions generally include an inert diluent or an edible carrier. They can be enclosed in gelatin capsules or compressed into tablets. For the purpose of oral therapeutic administration, the active compound can be incorporated with excipients and used in the form of tablets, troches, or capsules. Oral compositions can also be prepared using a fluid carrier for use as a mouthwash, wherein the compound in the fluid carrier is applied orally and swished and expectorated or swallowed. Pharmaceutically compatible binding agents, and/or adjuvant materials can be included as part of the composition. The tablets, pills, capsules, troches and the like can contain any of the following ingredients, or compounds of a similar nature: a binder such as microcrystalline cellulose, gum tragacanth or gelatin; an excipient such as starch or lactose, a disintegrating agent such as alginic acid, Primogel, or corn starch; a lubricant such as magnesium stearate or Sterotes; a glidant such as colloidal silicon dioxide;

a sweetening agent such as sucrose or saccharin; or a flavoring agent such as peppermint, methyl salicylate, or orange flavoring.

For administration by inhalation, the compounds are delivered in the form of an aerosol spray from pressured container or dispenser which contains a suitable propellant, *e.g.*, a gas such as carbon dioxide, or a nebulizer.

Systemic administration can also be by transmucosal or transdermal means. For transmucosal or transdermal administration, penetrants appropriate to the barrier to be permeated are used in the formulation. Such penetrants are generally known in the art, and include, for example, for transmucosal administration, detergents, bile salts, and fusidic acid derivatives. Transmucosal administration can be accomplished through the use of nasal sprays or suppositories. For transdermal administration, the active compounds are formulated into ointments, salves, gels, or creams as generally known in the art.

The compounds can also be prepared in the form of suppositories (*e.g.*, with conventional suppository bases such as cocoa butter and other glycerides) or retention enemas for rectal delivery.

In one embodiment, the active compounds are prepared with carriers that will protect the compound against rapid elimination from the body, such as a controlled release formulation, including implants and microencapsulated delivery systems. Biodegradable, biocompatible polymers can be used, such as ethylene vinyl acetate, polyanhydrides, polyglycolic acid, collagen, polyorthoesters, and polylactic acid. Methods for preparation of such formulations will be apparent to those skilled in the art. The materials can also be obtained commercially from Alza Corporation and Nova Pharmaceuticals, Inc. Liposomal suspensions (including liposomes targeted to infected cells with monoclonal antibodies to viral antigens) can also be used as pharmaceutically acceptable carriers. These can be prepared according to methods known to those skilled in the art, for example, as described in U.S. Patent No. 4,522,811.

It is especially advantageous to formulate oral or parenteral compositions in dosage unit form for ease of administration and uniformity of dosage. Dosage unit form as used herein refers to physically discrete units suited as unitary dosages for the subject to be treated; each unit containing a predetermined quantity of active compound calculated to produce the desired therapeutic effect in association with the required pharmaceutical carrier. The specification for the dosage unit forms of the invention are dictated by and directly dependent on the unique characteristics of the active compound and the particular therapeutic

effect to be achieved, and the limitations inherent in the art of compounding such an active compound for the treatment of individuals.

The pharmaceutical compositions can be included in a container, pack, or dispenser together with instructions for administration.

Screening Methods

The invention provides methods (also referred to herein as "screening assays") for identifying modulators, *i.e.*, candidate or test compounds or agents (*e.g.*, peptides, peptidomimetics, small molecules or other drugs) that modulate or otherwise interfere with the fusion of an influenza virus to the cell membrane. Also provided are methods of indentifying compounds useful to treat influenza infection. The invention also encompasses compounds identified using the screening assays described herein.

For example, the invention provides assays for screening candidate or test compounds which modulate the interaction between the influenza virus and the cell membrane. The test compounds of the invention can be obtained using any of the numerous approaches in combinatorial library methods known in the art, including: biological libraries; spatially addressable parallel solid phase or solution phase libraries; synthetic library methods requiring deconvolution; the "one-bead one-compound" library method; and synthetic library methods using affinity chromatography selection. The biological library approach is limited to peptide libraries, while the other four approaches are applicable to peptide, non-peptide oligomer or small molecule libraries of compounds. (*See, e.g.,* Lam, 1997. Anticancer Drug Design 12: 145).

A "small molecule" as used herein, is meant to refer to a composition that has a molecular weight of less than about 5 kD and most preferably less than about 4 kD. Small molecules can be, *e.g.*, nucleic acids, peptides, polypeptides, peptidomimetics, carbohydrates, lipids or other organic or inorganic molecules. Libraries of chemical and/or biological mixtures, such as fungal, bacterial, or algal extracts, are known in the art and can be screened with any of the assays of the invention.

Examples of methods for the synthesis of molecular libraries can be found in the art, for example in: DeWitt, et al., 1993. Proc. Natl. Acad. Sci. U.S.A. 90: 6909; Erb, et al., 1994. Proc. Natl. Acad. Sci. U.S.A. 91: 11422; Zuckermann, et al., 1994. J. Med. Chem. 37: 2678; Cho, et al., 1993. Science 261: 1303; Carrell, et al., 1994. Angew. Chem. Int. Ed. Engl. 33: 2059; Carell, et al., 1994. Angew. Chem. Int. Ed. Engl. 33: 2061; and Gallop, et al., 1994. J. Med. Chem. 37: 1233.

Libraries of compounds may be presented in solution (*see e.g.*, Houghten, 1992. Biotechniques 13: 412-421), or on beads (*see* Lam, 1991. Nature 354: 82-84), on chips (*see* Fodor, 1993. Nature 364: 555-556), bacteria (*see* U.S. Patent No. 5,223,409), spores (*see* U.S. Patent 5,233,409), plasmids (*see* Cull, et al., 1992. Proc. Natl. Acad. Sci. USA 89: 1865-1869) or on phage (*see* Scott and Smith, 1990. Science 249: 386-390; Devlin, 1990. Science 249: 404-406; Cwirla, *et al.*, 1990. Proc. Natl. Acad. Sci. U.S.A. 87: 6378-6382; Felici, 1991. J. Mol. Biol. 222: 301-310; and U.S. Patent No. 5,233,409.).

In one embodiment, a candidate compound is introduced to an antibody-antigen complex and determining whether the candidate compound disrupts the antibody-antigen complex, wherein a disruption of this complex indicates that the candidate compound modulates the interaction between an influenza virus and the cell membrane. For example, the antibody may be monoclonal antibody D7, D8, F10, G17, H40, A66, D80, E88, E90, and H98 and the antigen may be located on the HA protein of an influenza virus.

In another embodiment, at least one HA protein is provided, which is exposed to at least one neutralizing monoclonal antibody. Formation of an antibody-antigen complex is detected, and one or more candidate compounds are introduced to the complex. If the antibody-antigen complex is disrupted following introduction of the one or more candidate compounds, the candidate compounds is useful to treat a an influenza virus -related disease or disorder, *e.g.* bird flu. For example, the at least one influenza virus protein may be provided as an influenza virus molecule.

Determining the ability of the test compound to interfere with or disrupt the antibody-antigen complex can be accomplished, for example, by coupling the test compound with a radioisotope or enzymatic label such that binding of the test compound to the antigen or biologically-active portion thereof can be determined by detecting the labeled compound in a complex. For example, test compounds can be labeled with ^{125}I, ^{35}S, ^{14}C, or ^{3}H, either directly or indirectly, and the radioisotope detected by direct counting of radioemission or by scintillation counting. Alternatively, test compounds can be enzymatically-labeled with, for example, horseradish peroxidase, alkaline phosphatase, or luciferase, and the enzymatic label detected by determination of conversion of an appropriate substrate to product.

In one embodiment, the assay comprises contacting an antibody-antigen complex with a test compound, and determining the ability of the test compound to interact with the antigen or otherwise disrupt the existing antibody-antigen complex. In this embodiment, determining the ability of the test compound to interact with the antigen and/or disrupt the antibody-

antigen complex comprises determining the ability of the test compound to preferentially bind to the antigen or a biologically-active portion thereof, as compared to the antibody.

In another embodiment, the assay comprises contacting an antibody-antigen complex with a test compound and determining the ability of the test compound to modulate the antibody-antigen complex. Determining the ability of the test compound to modulate the antibody-antigen complex can be accomplished, for example, by determining the ability of the antigen to bind to or interact with the antibody, in the presence of the test compound.

Those skilled in the art will recognize that, in any of the screening methods disclosed herein, the antibody may be a an influenza virus neutralizing antibody, such as monoclonal antibody D7, D8, F10, G17, H40, A66, D80, E88, E90, and H98. Additionally, the antigen may be a HA protein, or a portion thereof In any of the assays described herein, the ability of a candidate compound to interfere with the binding between the D7, D8, F10, G17, H40, A66, D80, E88, E90, and H98 monoclonal antibody and the HA protein indicates that the candidate compound will be able to interfere with or modulate the fusion of the influenza virus and the cell membrane Moreover, because the binding of the HA protein to cell is responsible for influenza virus entry into cells such candidate compounds will also be useful in the treatment of a influenza virus related disease or disorder, *e.g.* bird flu..

The screening methods disclosed herein may be performed as a cell-based assay or as a cell-free assay. The cell-free assays of the invention are amenable to use of both the soluble form or the membrane-bound form of the HA proteins and fragments thereof. In the case of cell-free assays comprising the membrane-bound forms of the HA proteins, it may be desirable to utilize a solubilizing agent such that the membrane-bound form of the proteins are maintained in solution. Examples of such solubilizing agents include non-ionic detergents such as n-octylglucoside, n-dodecylglucoside, n-dodecylmaltoside, octanoyl-N-methylglucamide, decanoyl-N-methylglucamide, Triton® X-100, Triton® X-114, Thesit®, Isotridecypoly(ethylene glycol ether)$_n$, N-dodecyl--N,N-dimethyl-3-ammonio-1-propane sulfonate, 3-(3-cholamidopropyl) dimethylamminiol-1-propane sulfonate (CHAPS), or 3-(3-cholamidopropyl)dimethylamminiol-2-hydroxy-1-propane sulfonate (CHAPSO).

In more than one embodiment, it may be desirable to immobilize either the antibody or the antigen to facilitate separation of complexed from uncomplexed forms of one or both following introduction of the candidate compound, as well as to accommodate automation of the assay. Observation of the antibody-antigen complex in the presence and absence of a candidate compound, can be accomplished in any vessel suitable for containing the reactants.

Examples of such vessels include microtiter plates, test tubes, and micro-centrifuge tubes. In one embodiment, a fusion protein can be provided that adds a domain that allows one or both of the proteins to be bound to a matrix. For example, GST-antibody fusion proteins or GST-antigen fusion proteins can be adsorbed onto glutathione sepharose beads (Sigma Chemical, St. Louis, MO) or glutathione derivatized microtiter plates, that are then combined with the test compound, and the mixture is incubated under conditions conducive to complex formation (*e.g.*, at physiological conditions for salt and pH). Following incubation, the beads or microtiter plate wells are washed to remove any unbound components, the matrix immobilized in the case of beads, complex determined either directly or indirectly. Alternatively, the complexes can be dissociated from the matrix, and the level of antibody-antigen complex formation can be determined using standard techniques.

Other techniques for immobilizing proteins on matrices can also be used in the screening assays of the invention. For example, either the antibody or the antigen (*e.g.* the can be immobilized utilizing conjugation of biotin and streptavidin. Biotinylated antibody or antigen molecules can be prepared from biotin-NHS (N-hydroxy-succinimide) using techniques well-known within the art (*e.g.*, biotinylation kit, Pierce Chemicals, Rockford, Ill.), and immobilized in the wells of streptavidin-coated 96 well plates (Pierce Chemical). Alternatively, other antibodies reactive with the antibody or antigen of interest, but which do not interfere with the formation of the antibody-antigen complex of interest, can be derivatized to the wells of the plate, and unbound antibody or antigen trapped in the wells by antibody conjugation. Methods for detecting such complexes, in addition to those described above for the GST-immobilized complexes, include immunodetection of complexes using such other antibodies reactive with the antibody or antigen.

The invention further pertains to novel agents identified by any of the aforementioned screening assays and uses thereof for treatments as described herein.

Diagnostic Assays

Antibodies of the present invention can be detected by appropriate assays, *e.g.*, conventional types of immunoassays. For example, a an assay can be performed in which a influenza protein (*e.g.*, HA1, HA 2 or neurominidase) or fragment thereof is affixed to a solid phase. Incubation is maintained for a sufficient period of time to allow the antibody in the sample to bind to the immobilized polypeptide on the solid phase. After this first incubation, the solid phase is separated from the sample. The solid phase is washed to remove unbound materials and interfering substances such as non-specific proteins which may also be present in the sample. The solid phase containing the antibody of interest bound to the immobilized

polypeptide is subsequently incubated with a second, labeled antibody or antibody bound to a coupling agent such as biotin or avidin. This second antibody may be another anti-influenza antibody or another antibody. Labels for antibodies are well-known in the art and include radionuclides, enzymes (*e.g.* maleate dehydrogenase, horseradish peroxidase, glucose oxidase, catalase), fluors (fluorescein isothiocyanate, rhodamine, phycocyanin, fluorescarmine), biotin, and the like. The labeled antibodies are incubated with the solid and the label bound to the solid phase is measured. These and other immunoassays can be easily performed by those of ordinary skill in the art.

An exemplary method for detecting the presence or absence of a influenza virus (in a biological sample involves obtaining a biological sample from a test subject and contacting the biological sample with a labeled monoclonal or scFv antibody according to the invention such that the presence of the influenza virus is detected in the biological sample.

As used herein, the term "labeled", with regard to the probe or antibody, is intended to encompass direct labeling of the probe or antibody by coupling (*i.e.*, physically linking) a detectable substance to the probe or antibody, as well as indirect labeling of the probe or antibody by reactivity with another reagent that is directly labeled. Examples of indirect labeling include detection of a primary antibody using a fluorescently-labeled secondary antibody and end-labeling of a DNA probe with biotin such that it can be detected with fluorescently-labeled streptavidin. The term "biological sample" is intended to include tissues, cells and biological fluids isolated from a subject, as well as tissues, cells and fluids present within a subject. That is, the detection method of the invention can be used to detect an influenza virus in a biological sample *in vitro* as well as *in vivo*. For example, *in vitro* techniques for detection of an influenza virus include enzyme linked immunosorbent assays (ELISAs), Western blots, immunoprecipitations, and immunofluorescence. Furthermore, *in vivo* techniques for detection of an influenza virus include introducing into a subject a labeled anti-influenza virus antibody. For example, the antibody can be labeled with a radioactive marker whose presence and location in a subject can be detected by standard imaging techniques.

In one embodiment, the biological sample contains protein molecules from the test subject. One preferred biological sample is a peripheral blood leukocyte sample isolated by conventional means from a subject.

The invention also encompasses kits for detecting the presence of an influenza virus in a biological sample. For example, the kit can comprise: a labeled compound or agent capable of detecting an influenza virus (*e.g.*, an anti-influenza scFv or monoclonal antibody)

in a biological sample; means for determining the amount of an influenza virus in the sample; and means for comparing the amount of an influenza virus in the sample with a standard. The compound or agent can be packaged in a suitable container. The kit can further comprise instructions for using the kit to detect an influenza virus in a sample.

Passive Immunization

Passive immunization has proven to be an effective and safe strategy for the prevention and treatment of viral diseases. (*See* Keller et al., Clin. Microbiol. Rev. 13:602-14 (2000); Casadevall, Nat. Biotechnol. 20:114 (2002); Shibata et al., Nat. Med. 5:204-10 (1999); and Igarashi et al., Nat. Med. 5:211-16 (1999), each of which are incorporated herein by reference)). Passive immunization using neutralizing human monoclonal antibodies could provide an immediate treatment strategy for emergency prophylaxis and treatment of influenza such as bird flu while the alternative and more time-consuming development of vaccines and new drugs in underway.

Subunit vaccines potentially offer significant advantages over conventional immunogens. They avoid the safety hazards inherent in production, distribution, and delivery of conventional killed or attenuated whole-pathogen vaccines. Furthermore, they can be rationally designed to include only confirmed protective epitopes, thereby avoiding suppressive T epitopes (*see* Steward et al., J. Virol. 69:7668 (1995)) or immunodominant B epitopes that subvert the immune system by inducing futile, non-protective responses (*e.g.* "decoy" epitopes). (*See* Garrity et al., J. Immunol. 159:279 (1997)).

Moreover, those skilled in the art will recognize that good correlation exists between the antibody neutralizing activity *in vitro* and the protection *in vivo* for many different viruses, challenge routes, and animal models. (*See* Burton, Natl. Rev. Immunol. 2:706-13 (2002); Parren et al., Adv. Immunol. 77:195-262 (2001)). The data presented herein demonstrate that the D7, D8, F10, G17, H40, A66, D80, E88, E90, and H98 human monoclonal antibodies can be further developed and tested in *in vivo* animal studies to determine its clinical utility as a potent viral entry inhibitor for emergency prophylaxis and treatment of influenza.

Antigen-Ig chimeras in vaccination

It has been over a decade since the first antibodies were used as scaffolds for the efficient presentation of antigenic determinants to the immune systems. (*See* Zanetti, Nature 355:476-77 (1992); Zaghouani et al., Proc. Natl. Acad. Sci. USA 92:631-35 (1995)). When a peptide is included as an integral part of an IgG molecule (*e.g.*, the 11A or 256 IgG1 monoclonal antibody described herein), the antigenicity and immunogenicity of the peptide

epitopes are greatly enhanced as compared to the free peptide. Such enhancement is possibly due to the antigen-IgG chimeras longer half-life, better presentation and constrained conformation, which mimic their native structures.

Moreover, an added advantage of using an antigen-Ig chimera is that either the variable or the Fc region of the antigen-Ig chimera can be used for targeting professional antigen-presenting cells (APCs). To date, recombinant Igs have been generated in which the complementarity-determining regions (CDRs) of the heavy chain variable gene (V_H) are replaced with various antigenic peptides recognized by B or T cells. Such antigen-Ig chimeras have been used to induce both humoral and cellular immune responses. (*See* Bona et al., Immunol. Today 19:126-33 (1998)).

Chimeras with specific epitopes engrafted into the CDR3 loop have been used to induce humoral responses to either HIV-1 gp120 V3-loop or the first extracellular domain (D1) of human CD4 receptor. (*See* Lanza et al., Proc. Natl. Acad. Sci. USA 90:11683-87 (1993); Zaghouani et al., Proc. Natl. Acad. Sci. USA 92:631-35 (1995)). The immune sera were able to prevent infection of CD4 SupT1 cells by HIV-1MN (anti-gp120 V3C) or inhibit syncytia formation (anti-CD4-D1). The CDR2 and CDR3 can be replaced with peptide epitopes simultaneously, and the length of peptide inserted can be up to 19 amino acids long.

Alternatively, one group has developed a "troybody" strategy in which peptide antigens are presented in the loops of the Ig constant (C) region and the variable region of the chimera can be used to target IgD on the surface of B-cells or MHC class II molecules on professional APCs including B-cells, dendritic cells (DC) and macrophages. (*See* Lunde et al., Biochem. Soc. Trans. 30:500-6 (2002)).

An antigen-Ig chimera can also be made by directly fusing the antigen with the Fc portion of an IgG molecule. You et al., Cancer Res. 61:3704-11 (2001) were able to obtain all arms of specific immune response, including very high levels of antibodies to hepatitis B virus core antigen using this method.

DNA vaccination

DNA vaccines are stable, can provide the antigen an opportunity to be naturally processed, and can induce a longer-lasting response. Although a very attractive immunization strategy, DNA vaccines often have very limited potency to induce immune responses. Poor uptake of injected DNA by professional APCs, such as dendritic cells (DCs), may be the main cause of such limitation. Combined with the antigen-Ig chimera vaccines, a promising new DNA vaccine strategy based on the enhancement of APC antigen presentation has been reported (*see* Casares, et al., Viral Immunol. 10:129-36 (1997); Gerloni et al., Nat.

Biotech. 15:876-81 (1997); Gerloni et al., DNA Cell Biol. 16:611-25 (1997); You et al., Cancer Res. 61:3704-11 (2001)), which takes advantage of the presence of Fc receptors (FcγRs) on the surface of DCs.

It is possible to generate a DNA vaccine encoding an antigen (Ag)-Ig chimera. Upon immunization, Ag-Ig fusion proteins will be expressed and secreted by the cells taking up the DNA molecules. The secreted Ag-Ig fusion proteins, while inducing B-cell responses, can be captured and internalized by interaction of the Fc fragment with FcγRs on DC surface, which will promote efficient antigen presentation and greatly enhance antigen-specific immune responses. Applying the same principle, DNA encoding antigen-Ig chimeras carrying a functional anti-MHC II specific scFv region gene can also target the immunogens to all three types of APCs. The immune responses could be further boosted with use of the same protein antigens generated *in vitro* (*i.e.*,"prime and boost"), if necessary. Using this strategy, specific cellular and humoral immune responses against infection of influenza virus were accomplished through intramuscular (i.m.) injection of a DNA vaccine. (*See* Casares et al., Viral. Immunol. 10:129-36 (1997)).

Vaccine compositions

Therapeutic or prophylactic compositions are provided herein, which generally comprise mixtures of one or more monoclonal antibodies or ScFvs and combinations thereof. The prophylactic vaccines can be used to prevent an influenza virus infection and the therapeutic vaccines can be used to treat individuals following an influenza virus infection. Prophylactic uses include the provision of increased antibody titer to an influenza virus in a vaccination subject. In this manner, subjects at high risk of contracting influenza can be provided with passive immunity to an influenza virus

These vaccine compositions can be administered in conjunction with ancillary immunoregulatory agents. For example, cytokines, lymphokines, and chemokines, including, but not limited to, IL-2, modified IL-2 (Cys125 → Ser125), GM-CSF, IL-12, γ-interferon, IP-10, MIP1β, and RANTES.

Methods of Immunization

The vaccines of the present invention have superior immunoprotective and immunotherapeutic properties over other anti-viral vaccines

The invention provides a method of immunization, e.g., inducing an immune response, of a subject. A subject is immunized by administration to the subject a composition containing a membrane fusion protein of a pathogenic enveloped virus. The fusion protein is coated or embedded in a biologically compatible matrix.

The fusion protein is glycosylated, e.g. contains acarbohydrate moiety. The carbohydrate moiety may be in the form of a monosaccharide, disaccharide(s). oligosaccharide(s), polysaccharide(s), or their derivatives (e.g. sulfo- or phospho-substituted). The carbohydrate is linear or branched. The carbohydrate moiety is N-linked or O-linked to a polypeptide. N-linked glycosylation is to the amide nitrogen of asparagine side chains and O-linked glycosylation is to the hydroxy oxygen of serine and threonine side chains.

The carbohydrate moiety is endogenous to the subject being vaccinated. Alternatively, the carbohydrate moiety is exogenous to the subject being vaccinated. The carbohydrate moiety are carbohydrate moieties that are not typically expressed on polypeptides of the subject being vaccinated. For example, the carbohydrate moieties are plant-specific carbohydrates. Plant specific carbohydrate moieties include for example N-linked glycan having a core bound α1,3 fucose or a core bound β 1,2 xylose. Alternatively, the carbohydrate moiety are carbohydrate moieties that are expressed on polypeptides or lipids of the subject being vaccinate. For example many host cells have been genetically engineered to produce human proteins with human-like sugar attachments.

For example, the fusion protein is a trimeric hemagglutinin protein. Optionally, the hemagglutinin protein is produced in a non-mammalian cell such as a plant cell.

The subject is at risk of developing or suffering from a viral infection. Enveloped viruses include for example, epstein-barr virus, herpes simplex virus, type 1 and 2, human cytomegalovirus, human herpesvirus, type 8, varicella zoster virus, hepatitis B virus, hepatitis C virus, human immunodeficiency virus, influenza virus, measles virus, mumps virus, parainfluenza virus, respiratory syncytial virus, rabies virus, and rubella virus

The methods described herein lead to a reduction in the severity or the alleviation of one or more symptoms of a viral infection. Infections are diagnosed and or monitored, typically by a physician using standard methodologies A subject requiring immunization is identified by methods know in the art. For example subjects are immunized as outlined in the CDC's General Recommendation on Immunization (51(RR02) pp1-36) Cancer is diagnosed for example by physical exam, biopsy, blood test, or x-ray.

The subject is *e.g.*, any mammal, *e.g.*, a human, a primate, mouse, rat, dog, cat, cow, horse, pig, a fish or a bird. The treatment is administered prior to diagnosis of the infection. Alternatively, treatment is administered after diagnosis.

Efficaciousness of treatment is determined in association with any known method for diagnosing or treating the particular disorder or infection. Alleviation of one or more symptoms of the disorder indicates that the compound confers a clinical benefit.

Evaluation of Antigenic Protein Fragments (APFs) for Vaccine Potential

A vaccine candidate targeting humoral immunity must fulfill at least three criteria to be successful: it must provoke a strong antibody response ("immunogenicity"); a significant fraction of the antibodies it provokes must cross-react with the pathogen ("immunogenic fitness"); and the antibodies it provokes must be protective. While immunogenicity can often be enhanced using adjuvants or carriers, immunogenic fitness and the ability to induce protection (as evidenced by neutralization) are intrinsic properties of an antigen which will ultimately determine the success of that antigen as a vaccine component.

Evaluation of Immunogenic Fitness

"Immunogenic fitness" is defined as the fraction of antibodies induced by an antigen that cross-react with the pathogen. (*See* Matthews et al., J. Immunol. 169:837 (2002)). It is distinct from immunogenicity, which is gauged by the titer of all of the antibodies induced by an antigen, including those antibodies that do not cross-react with the pathogen. Inadequate immunogenic fitness has probably contributed to the disappointing track record of peptide vaccines to date. Peptides that bind with high affinity to antibodies and provoke high antibody titers frequently lack adequate immunogenic fitness, and, therefore, they fail as potential vaccine components. Therefore, it is important to include immunogenic fitness as one of the criteria for selecting influenza vaccine candidates.

A common explanation for poor immunogenic fitness is the conformational flexibility of most short peptides. Specifically, a flexible peptide may bind well to antibodies from patients, and elicit substantial antibody titers in naïve subjects. However, if the peptide has a large repertoire of conformations, a preponderance of the antibodies it induces in naïve subjects may fail to cross-react with the corresponding native epitope on intact pathogen.

Like short peptides, some APFs may be highly flexible and, therefore may fail as vaccine components. The most immunogenically fit APFs are likely to consist of self-folding protein subdomains that are intrinsically constrained outside the context of the whole protein.

Because immunogenic fitness is primarily a property of the APF itself, and not of the responding immune system, immunogenic fitness can be evaluated in an animal model (*e.g.* in mice) even though ultimately the APF will have to perform in humans.

The immunogenic fitness achieved by APFs is evaluated by immunosorption of anti-APF sera with purified spike or membrane protein, in a procedure analogous to that described in Matthews et al., J. Immunol. 169:837 (2002). IgG is purified from sera collected from mice that have been immunized. Purified, biotinylated proteins (as appropriate, depending on the particular APF with which the mice were immunized) are mixed with the mouse IgG and

incubated. Streptavidin-coated sepharose beads are then added in sufficient quantity to capture all of the biotinylated protein, along with any bound IgG. The streptavidin-coated beads are removed by centrifugation at 13,000 rpm in a microcentrifuge, leaving IgG that has been depleted of antibodies directed against the protein, respectively. Mock immunoabsorptions are performed in parallel in the same way, except that biotinylated BSA will be substituted for influenza protein as a mock absorbent.

To measure the immunogenic fitness of APFs, the absorbed antibodies and the mock-absorbed antibodies are titered side-by-side in ELISA against the immunizing APF. For APFs affinity selected from a phage display NPL, the antigen for these ELISAs will be purified APF-GST fusion proteins. For the potentially glycosylated APFs from the mammalian cell display NPL, the antigen for these ELISAs will be APF-Fc fusion proteins secreted by mammalian cells and purified with protein A. The percentage decrease in the anti-APF titer of absorbed antibodies compared with the mock-absorbed antibodies will provide a measure of the immunogenic fitness of the APF.

Methods of Treatment

The invention provides for both prophylactic and therapeutic methods of treating a subject at risk of (or susceptible to) an influenza virus-related disease or disorder. Such diseases or disorders include but are not limited to, *e.g.*, bird flu.

Prophylactic Methods

In one aspect, the invention provides methods for preventing an influenza virus -related disease or disorder in a subject by administering to the subject a monoclonal antibody or scFv antibody of the invention or an agent identified according to the methods of the invention. For example, scFv and/or monoclonal antibody D7, D8, F10, G17, H40, A66, D80, E88, E90, and H98 may be administered in therapeutically effective amounts. Optionally, two or more anti-influenza antibodies are co-administered

Subjects at risk for an influenza virus -related diseases or disorders include patients who have come into contact with an infected person or who have been exposed to the influenza virus in some other way. Administration of a prophylactic agent can occur prior to the manifestation of symptoms characteristic of the influenza virus -related disease or disorder, such that a disease or disorder is prevented or, alternatively, delayed in its progression.

The appropriate agent can be determined based on screening assays described herein. Alternatively, or in addition, the agent to be administered is a scFv or monoclonal antibody

that neutralizes an influenza virus that has been identified according to the methods of the invention.

Therapeutic Methods

Another aspect of the invention pertains to methods of treating an influenza virus-related disease or disorder in a patient. In one embodiment, the method involves administering an agent (*e.g.*, an agent identified by a screening assay described herein and/or an scFv antibody or monoclonal antibody identified according to the methods of the invention), or combination of agents that neutralize the influenza to a patient suffering from the disease or disorder.

Combinatory Methods

The invention provides treating an influenza-related disease or disorder, such as bird flu, in a patient by administering two or more antibodies, such as D7, D8, F10, G17, H40, A66, D80, E88, E90, and H98 that bind to the same epitope of the HA protein.

The invention will be further described in the following examples, which do not limit the scope of the invention described in the claims.

EXAMPLES

Example 1: General Methods

Expression and preparation of various panning antigens for selection of phage display antibody library.

HA1. HA1 is the N-terminal fragment (aa17-338) of (A/Thailand/2(SP-33)/2004(H5N1). The gene was codon-optimized and expressed as fusion protein with a C-terminal 9 amino-acids tag (C9-tag:GTETSQVAPA). The fusion protein HA1-C9 was expressed in 293T cells transiently and the secreted protein was purified from supernatant by affinity chromatography. Protein A Sepharose covalently coupled with anti-C9 antibody 1D4 (National Cell Culture Center) was used for purification of HA1-C9.

Trimeric HA0. The ectodomain (HA0) of hamagglutinin (HA) gene of A/Viet Nam/1203/2004 was expressed in insect cells as a fusion protein by adapting the protocol described previously[33]. This construct contains a C-terminal trimerizing 'foldon' sequence from the bacteriophage T4 fibritin to stabilize the trimeric structure, followed by a thrombin site and a His6 tag. The cDNA of the fusion protein was cloned into the baculovirus transfer vector, pAcGP67A (BD Biosciences, Bedford, MA) to allow for efficient secretion of

recombinant protein. $9x10^6$ cells were infected with the viral stock. 3 days after infection, the cells were spun down and the supernatant was incubated with 6 ml Ni-NTA beads (Qiagen Inc,, Valencia, CA). The beads were washed with TBS buffer (10 mM Tris.HCl/ 80 mM NaCl, pH8.0) with 10 mM imidazole and eluted with TBS with 250 mM Imidazole. The eluted HA5 protein was dialyzed against TBS buffer and further purified by ion-exchange using Mono Q HR10/10 column (GE Healthcare, Piscataway, NJ). The purified HA5 were digested by thrombin overnight. The integrity and property of HA0 trimer was examined using Gel filtration (Superdex 200 column) and SDS-PAGE.

Selection of phage antibody libraries and screening of antibodies against H5.

Two human non-immune scFv libraries (a total of $2.7x10^{10}$ members) constructed from B-cells of 57 un-immunized donors were used for selection of scFvs against the purified HA1 or trimeric HA0. $5x10^{11}$ pfu of phage-scFvs prepared from each library were incubated with immunotubes (Nunc, Naperville, IL) coated with 10 μg of HA1 or HA0, separately. The selection procedures were the same as described previously. After two rounds of selection, randomly picked single phage-scFv clones were screened for specific binding to HA1 or HA0 by enzyme-linked immunosorbent assay (ELISA) as described previously. Clones that bound to HA1 or HA0 with A_{450} values of >1.0 were scored as positive, whereas negative clones gave values of <0.1. For HA1or HA0 specific binding clones, the genes of variable regions of heavy (VH) and light (VL) chain were sequenced and their corresponding amino acid sequences were aligned to identify antibodies with different sequence for further characterization.

Expression and purification of soluble scFv-Fcs and full-length human IgG1.

Phage-scFvs of individual clones were produced for neutralization assay using the same method as making phage library. Phage particles were concentrated 25 times by using PEG/NaCl precipitation. scFv-Fcs and whole human IgG1s were produced as described previously. In brief, selected scFvs were converted to scFv-Fcs by subcloning the scFv into a Fc expression vector pcDNA 3.1-Hinge which contains the hinge, CH2, and CH3 domains of human IgG1 but lacks CH1. For whole human IgG1s, the VH and VL gene fragments of scFv were separately subcloned into human IgG1 kappa light chain or lambda light chain expression vector TCAE5 or TCAE6. scFv-Fcs or IgG1s were expressed in 293T or 293F cells (Invitrogen) by transient transfection and purified by protein A sepharose affinity chromatography.

Surface Plasmon Resonance (SPR) analysis

Kinetic analyses of H5 HA Mabs binding to recombinant HA0 (VietNam1203/04) trimer were performed on a Biacore T100 (Biacore) at 25 °C. Anti-human IgG Fc antibody (Biacore) was covalently coated to individual flow cell surfaces of a CM4 sensor chip by amine-coupling using the amine coupling kit (Biacore). HA Mabs were captured onto anti-human IgG Fc surfaces at the flow rate of 10ul/min in HBS buffer (Biacore) to ensure that the Mab-HA0 binding occurred as a homogenous 1:1 Langmuir interaction. HA0 was injected over each flow cell at the flow rate of 30ul/min in HBS buffer, and at concentrations ranging from to 0.31 to 20 nM. A buffer injection served as a negative control. All experiments contained an additional anti-human IgG Fc antibody control surface that served to account for changes in the buffer refractive index and to test for potential nonspecific interactions between HA0 and anti-human IgG Fc. Upon completion of each association and dissociation cycle, surfaces were regenerated with 3M $MgCl_2$ solution. The association rates (*ka*), dissociation rate constants (*kd*), and affinity constants (*KD*) were calculated using Biacore T100 evaluation software. The goodness of each fit was based on the agreement between experimental data and the calculated fits, where the Chi^2 values were below 1.0. Surface densities of Mabs against HA0 were optimized to minimize mass transfer and avoid any contribution of avidity effects. All *ka, kd, KD* reported here represent the means and standard errors of three experiments.

Viruses and cells

Wild type influenza A/Vietnam/1203/2004 (H5N1; H5-VN04), A/HongKong/483/1997 (H5N1; H5-HK97), A/Netherlands/219/2003 (H7N7; H7-NL03), and A/Ohio/4/1983 (H1N1; H1-OH83) viruses as well as a cold-adapted vaccine strain of A/Ann Arbor/6/1960 (H2N2) were obtained from the WHO Global Influenza Surveillance Network and provided by Alexander Klimov (CDC, Atlanta, USA). H1-PR34 and Madin-Darby canine kidney (MDCK) cells were obtained from the American Type Culture Collection and propagated in Dulbecco's Modification of Eagle's Medium with 10% fetal bovine serum. Viral infectivity was determined by plaque assay on MDCK cells. Live wildtype H5N1 viruses were handled in biosafety level 3 containment, including enhancements required by the U.S. Department of Agriculture and the Select Agents program http://www.cdc.gov/od/ohs/biosfty/bmbl5/bmbl5toc.htm.

Neutralization assay with HA-pseudotyped viruses

Plasmids and constructs

The full length HA gene of A/Thailand/2(SP-33)/2004(H5N1)), H5-SP33, and neuramidase gene of A/Vietnam 1203/2004, N1, were codon-optimized and cloned into pcDNA3.1 vector to obtain the pcDNA3.1-H5-SP33 and pcDNA3.1-N1 expression plasmid, separately. The pCAGGS-H1(SC) plasmid encoding A/South Carolina/1/1918 (H1N1) full length HA protein was kindly provided by form Dr. P.Palese (Mount Sinai School of Medicine, US). The pCAGGS-H1(PR) plasmid encoding A/Puerto Rico/8/34 (H1N1) HA protein was a generous gift from Dr. M. Farzan (Harvard Medical School, US).

Making the HA-pseudotyped viruses.

The single-round HIV luciferase reporter viruses of H5N1 or H1N1 pseudotyped by H5-SP33, H1-SC/1918 or H1-PR/34 were made by co-transfection of 293T cells with 4 plasmids that are pcDNA3.1-H5-SP33, HIV packaging vector pCMVΔR 8.2 encoding HIV-1 Gag-Pol[57], transfer vector pHIV-Luc encoding the firefly luciferase reporter gene under control of the HIV-1 LTR, and expressing plasmid pcDNA3.1-N1. 36 hours post-transfection, viral supernatants were harvested and stored at 4°C.

Neutralization assay.

Before transducing cells, viral supernatant of H1-SC/1918 or H1-PR/34F pseudotyped viruses was incubated with 16μg/mL TPCK-treated trpsin for one hour at 25°C and then neutralized with trypsin neutralizing solution (TNS, Cambrex) at the ratio of 1:1 (V/V). Testing antibodies or sera were incubated with adequate amount of H5-SP33 pseudotyped or trpsin-treated H1 pseudotyped viruses for 30mins at RT. The mixture was then added to 293T cells in 96 well plates and continued the culture for 48 hours. Viral entry level was evaluated by measuring the luciferase activity in the target cells with a microplate luminometer.

Epitope mapping of antibody 8, 10 and 66

Plasmids and constructs. pcDNA3.1-H5-SP33, pCAGGS-H1(SC) and pCAGGS-H1(PR) were described as above. pCAGGS-H7 (FPV) which encodes HA proteins for A/FPV/Rostock/34 (H7N1) was kindly provided by Dr. X. Yang (Beth Israel Deaconess Medical Center). All the mutants of pcDNA3.1-H5-SP33 or pCAGGS-H7 (FPV) were constructed by the QuikChange method (Stratagene). Flow cytometry analysis of the binding of anti-H5 antibodies to HA expressing cells. Various full-length wild type HA and HA mutants expressing plasmids for H1, H5 or H7 were transfected transiently into 293T cells. 48 hours after transfection, anti-H5 antibodies (10ug/ml) were incubated with transfected 293T cells at 4 °C for 1 hour. Cells were then washed three times with PBS containing 0.5%

BSA and 0.1% NaN3. For the detection of anti-H5 antibodies' binding to HA transfected cells, FITC-labeled goat anti-human IgG (Pierce) was used as secondary antibody and incubated with cells at 4 °C for 30 min. Cells were washed again as above and analyzed using a Becton Dickinson FACScaliber with CellQuest software.

Microneutralization assay

The method was performed as described previously[48]. Briefly, 100 $TCID_{50}$ (median tissue culture infectious doses) of virus were mixed in equal volume with log2 dilutions of antibody stock solution (1 mg/ml) in 96-well tissue culture plates, and incubated for 1h at 37°C. Indicator MDCK cells (1.5 x 10^4 cells/well) were added to the plates, followed by incubation at 37°C for 20 hours. To establish the endpoint, cell monolayers were then washed with PBS, fixed in acetone, and viral antigen detected by indirect ELISA with a mAb against influenza A NP (A-3, Accurate).

Plaque Reduction Assay

A/Viet Nam 1203/2004 (H5N1) or A/Netherland/219/03 (H7N7) viruses (10,000 pfu) were incubated with anti-H5 scFv-Fcs at three different concentrations 100ug/ml, 10ug/ml and 1ug/ml at 37 °C for 30 mins. The virus-antibody mixture was transferred onto MDCK cell monolayers in 12-well plates and incubated at 37°C for 1 h and cells were then washed and overlaid with agar. After 4 days of incubation, the agar overlay was discarded, and plaques were visualized by crystal violet staining.

Hemagglutination inhibition (HI) assay

Avian influenza viruses preferentially bind to sialic acid receptors that contain N-acteylneuraminic acid α2,3-galactose (α2,3Gal) linkages while human viruses preferentially bind to those containing N-acetylneuaminic acid α2,6-galactose ((α2,6Gal) linkages. The molecular basis for receptor specificity is most likely determined by a complex set of residues in the viral HA. Hemagglutination-inhibition (HI) tests are a simple and widely used method to assess antibody responses to influenza hemagglutinin. Stephenson et al. reported that by using horse erythrocytes and thereby increasing the proportion of α2,3Gal linkages available for binding, the sensitivity of the hemagglutination assay was improved. In addition, the titers of the HI assay correlated well with the titers of the micro-neutralization assay. The pseudotyped viruses will be first titered using hemagglutination of horse erythrocytes as described . The initial high-throughput screens will be similarly performed using horse erythrocyte suspensions and assaying for the ability of the phage antibodies to inhibit the HI endpoint of the titered H5/N1 viruses. More detailed secondary screens for inhibition of H5N1 reporter virus entry and HI will be preformed using dose response studies with soluble

scFvFc proteins produced by transiently transfected 293T cells and purified by protein A beads.

Viral binding inhibition assay

$0.5x10^6$ 293T cells were incubated with H5-TH04-pseudotyped HIV viruses (~ 500 ng of p24) in the presence of anti-H5 mAbs, control mAbs, or in the absence of antibodies, in a buffer of PBS containing 0.5% BSA and 0.02% NaN_3 at 4°C. After an hour of incubation, cells were spun down. Supernatants were collected and tested for p24 levels using a HIV-1 $p24^{CA}$ capture ELISA kit (NCI, Frederick, NIH) to quantify the unbound viruses. The cells were then washed one or two times and lysed to quantify the cell-bound virus using the same method.

Cell fusion inhibition assay

293T cells, ~90% confluent in six-well plates, were transfected with pcDNA3.1-H5-TH04 plasmid and pcDNA 3.1-N1 at a ratio of 4:1 (3 μg total DNA/ well) using lipofectamine 2000 (Invitrogen). The culture medium was supplemented with 1 ml of anti-H5, control or mock mAbs at 6 hours post-transfection, and cells cultured for 36 hours. Cells were observed for syncytia formation with a phase-contrast microscope. Photomicrographs were taken at 10x magnification.

Expression and preparation of various HA proteins for panning

HA1 is an N-terminal fragment of HA of H5N1 A/Thailand/2(SP-33)/2004 (H5-TH04), residues 11 to 325 (H3 numbering). The gene was codon-optimized and expressed as fusion protein with a C-terminal 9 amino-acids tag (C9-tag:GTETSQVAPA). The fusion protein HA1-C9 was expressed in 293T cells transiently and the secreted proteins in supernatant were harvested 48 hours after transfection and purified from the supernatant by affinity chromatography using Protein A Sepharose that coupled covalently with anti-C9 antibody 1D4 (National Cell Culture Center). The method to produce HA0 protein of H5-VN04 is the same as described below for crystallization of H5-F10 complex but without the baculovirus coinfection for furin-cleavage.

ELISA

0.2μg of pure H5 HA proteins was coated onto 96-well Maxisorb ELISA plate (Nunc, NY) at 2μg/mL in PBS at 4°C overnight. The plate was washed with PBS for 3 times to remove uncoated proteins. For regular ELISA, 1 μg/mL of anti-H5 scFv-Fcs followed by HRP-anti-human IgG1 were used to detect the binding of anti-H5 scFv-Fcs to H5 HA proteins. For competition ELISA, 50 μL(10^{12}pfu) of anti-H5 phage-scFvs were mixed with 5 μg/mL of anti-H5 scFv-Fcs and applied to H5-VN04 HA coated ELISA plate. The

competition of scFv-Fcs for the binding of phage-scFvs to HA0 were determined by measuring the remaining binding of phage-scFvs using HRP-anti-M13. The optical density at 450 nm was measured after incubation of peroxidase tetramethylbenzidine (TMB) substrate system (KPL, Gaithersburg MD).

Expression, purification, and crystallization of the H5-F10 complex

The gene encoding single chain (VH-linker-VL) F10 (scFv) was cloned into pSynI vector containing an N-terminal periplasmic secretion signal pelB, and a C-terminal 6xHis tag. F10 scFv was expressed in XL10 cells in 2YT media containing 0.1% glucose (w/v) at 25°C for 15 hours with 0.5 mM IPTG. Protein was purified first by Hisbind Ni-NTA (Novagen) according to the manufacturer's instructions, and then by Superdex 200 (Amersham Biosciences) in 50 mM Tris-HCl, 0.5 M NaCl, pH 8.

The ectodomain of H5-VN04 HA gene was expressed in insect cells as a fusion protein by adapting the protocol described previously[6]. This construct contains a C-terminal trimerizing 'foldon' sequence from the bacteriophage T4 fibritin to stabilize the trimeric structure, followed by a thrombin site and a His_6 tag. The cDNA of the fusion protein was cloned into the baculovirus transfer vector, pAcGP67A (BD Biosciences, Bedford, MA), to allow for efficient secretion of recombinant protein. To obtain fully cleaved HA (as HA1-HA2 trimers), sf9 cells were co-infected with baculovirus stocks of HA0 and furin at an empirically derived ratio. The furin cDNA was a gift from Dr. Robert Fuller (University of Michigan). Three days after infection, the cells were spun down and the supernatant was incubated with Ni-NTA beads (Qiagen Inc., Valencia, CA). The beads were washed with TBS buffer (10 mM Tris.HCl, 80 mM NaCl, pH8.0) with 10 mM imidazole, and eluted with TBS with 250 mM Imidazole. The eluted H5 protein was dialyzed against TBS buffer and further purified by ion-exchange using Mono Q HR10/10 column (GE Healthcare, Piscataway, NJ). The purified H5 was digested by thrombin overnight and further purified by Superdex 200 column in TBS buffer.

H5-F10 complexes were formed by mixing the two purified components, and isolated by Superdex 200 in TBS buffer (Supplementary Figure 1b). Peak fractions were pooled and concentrated to ~11 mg/ml. The integrity of the H5 trimer was examined using Gel filtration (Superdex 200 column) and SDS-PAGE. Crystals grew by the hanging drop vapor diffusion method at 22°C. Two μL of H5-F10 were mixed with an equal volume of 12.5% PEG 1K, 25% ethylene glycol, 100 mM Tris, pH 8.5. Crystals were flash-frozen in liquid nitrogen prior to data collection.

Co-crystallization of the H5-F10 complex

For co-crystallization of the H5-F10 complex, F10 was expressed in *E. coli* and purified by Ni-NTA and gel filtration. H5 was expressed by co-infection of H5 and furin baculovirus stocks in sf9 cells, and purified by Ni-NTA, anion ion exchange, and gel filtration chromatography. H5-F10 complexes were obtained by mixing H5 with an excess of F10 and isolated by gel filtration. Crystals were grown by mixing 2 □L of complex (~11 mg/ml) with an equal volume of 12.5% PEG 1K, 25% ethylene glycol, 100 mM Tris, pH 8.5 using the hanging drop vapor diffusion method at 22°C. The crystal structure was determined at 3.2 Å resolution by Molecular Replacement and refined to an R_{FREE} of .29 with excellent geometry.

Data collection, structure determination, and refinement

X-ray diffraction data were collected at the Stanford Synchrotron Radiation Laboratory (SSRL) beam-lines 7.1 and 9.2. Data were processed with XDS[7] and the HKL2000 package.

The structure of the H5-F10 complex was determined by molecular replacement with PHASER using the structure of H5 (A/Vietnam/1194/04; PDB code 2IBX) and the scFv structure of SARS nAb 80R (PDB code 2GHW) as search models. The scFv structure homology model was build with WHATIF[9]. The asymmetric unit contains two H5 trimers and six F10 molecules.

Solutions from molecular replacement were subjected to several rounds of refinement with the program REFMAC5 with simulated annealing in CNS and manual model rebuilding with Coot and Xtalview. The final model includes 506/503/503/496/495/496 residues for 6 independent copies of HA, respectively, 233 residues for each nAb10, 24 N-acetyl-d-glucosamine and 6 β-d-mannose, 0 water molecules. Geometric parameters were assessed with PROCHECK and Rampage.

Protection of mice with hMabs against H5

All mouse studies were performed in USDA and CDC accredited biosafety level 3 (BSL3) animal facility in accordance with protocols approved by the CDC Animal Care and Use Committee. Female 8-10 weeks old Balb/C mice (5 per group) were used in all experiments. For all groups, mice were observed for 2 weeks, weighted and deaths noted daily.

Prophylactic mouse study. Three hMabs (D8-IgG1, F10-IgG1 and A66-IgG1) or control hMab 80R-IgG1 at 2 doses of 10 mg/kg and 2.5 mg/kg [53] were administered into mice intraperitoneally (i.p.). 24 hours after hMabs administration, all groups of mice were

challenged with A/Vietnam/1203/04(H5N1) or A/HK/483/97 (H5N1) intranasally (i.n.) at dose of 10 MLD_{50} (50% mouse lethal dose) viruses under light anesthesia.

Therapeutic mouse study. Mice were first infected i.n. with 10 MLD_{50} of A/Vietnam/1203/04(H5N1) or A/HK/483/97 (H5N1). Three hMabs againt H5 or control hMab at 10 mg/kg were then i.p. administered into mice 24, 48 and 72 hours after A/Vietnam/1203/04(H5N1) infection. For A/HK/483/97 (H5N1) infected mice, hMabs were only injected 24 hours after viral challenge.

Identification of anti-H5 phage antibodies

Antibodies against HA1. Purified recombinant HA1 was used to select antibodies from two non-immune human scFv libraries separately. After two rounds of selection on HA1, 58 out of 96 clones screened by ELISA were HA1 specific positive clones. Three unique anti-HA1 scFvs were identified (38B and 1C) by sequencing analysis of the 58 HA1-positive clones. Similar selection and screening experiments were repeated; no new clones were identified but obtained the same three scFvs as described above. Amino acid sequence of 2A is showed in Figure 4

Antibodies against ectodomain of H5 (HA0). Purified recombinant trimeric HA0 was used to select the same antibody libraries as that used for HA1. After two rounds of selection on HA0, a total of 392 clones were screened for HA0 specific binding by ELISA. 97 clones recognized HA0 protein specifically. Ten unique anti-HA0 scFvs (7, 8, 10, 17, 40, 66, 80, 88, 90 and 98) were identified by sequence analysis. Six different VH and 10 different VL genes were revealed (some scFvs shared the same VH gene). Five out of the six different VH belong to one gene family, IGHV1-69. The VL genes were much diverse than the VH genes, three out of the 10 VL are Kappa chain. (Figure 4).

Establishment of a reliable single-round reporter virus system

The single-round HIV luciferase reporter viruses of H5N1 or H1N1 pseudotyped by H5-SP33, H1-SC/1918 or H1-PR/34 were made by co-transfection of 293T cells with 4 plasmids that are pcDNA3.1-H5-SP33, HIV packaging vector pCMVΔR 8.2 encoding HIV-1 Gag-Pol, transfer vector pHIV-Luc encoding the firefly luciferase reporter gene under control of the HIV-1 LTR, and expressing plasmid pcDNA3.1-N1. 36 hours post-transfection, viral supernatants were harvested and stored at 4°C. The titer of HA0-pseudotyped viruses was measured by infecting 293T cells. Including the N1 expressing plasmid in the tranfection of making pseudotyped viruses can dramatically increase the titer of H5-pseudotyped viruses The proper behavior of the H5-pseudotyped viruses was examined by using ferret immune serum against H5N1 (A/VietNam/ 2004). These viruses can be neutralized potently by anti-

serum, while not by pre-bleeding serum. Thus a reliable single-round high efficient reporter virus system was established for efficient screening of neutralizing antibody

Example 2: Identification of neutralizing antibodies against H5N1 using viruses pseudotyped with H5-SP33 and microneutralization assay.

Results of neutralization assay using pseudotyped viruses.

Bivalent scFvFcs of anti-H5 antibodies were produced and tested for neutralization activities against HA0-pseudotyped viruses. We found that 2A is a moderate neutralizing antibody, 38B and 1C are non-neutralizing antibodies (data not shown). The 2A antibody has been used as a useful anti-HA reagent for other assays (epitope mapping) described below.) By using HA0 trimer as a target, we have identified 10 new unique antibodies against HA0. These Abs were screened for neutralization activity by using a novel high-throughput phage-scFvs screening method that has been recently set up in our lab. Briefly, the phage-scFvs of individual clones were directly used in a neutralization assay immediately following being screened by ELISA for positive clones in 96-well plates. In this schema, neutralization activity will be known in 48 hours. By doing this, we bypass steps of subcloning and expressing of soluble Abs which are time-consuming.

As shown in the figure, neutralizing Abs that were indicated by phage-scFvs (Figure 6 top left panel) turned out to be potent neutralizing when confirmed with soluble scFvFc Abs (Figure 6 top middle panel). All the 10 antibodies screened by phage-scFvs are potent neutralizing Abs. We also converted three of the 10 antibodies (D8, F10 and A66) into full-length human IgG1, the potent neutralization activity were again seen with H5-SP33 pseudotyped viruses (Figure 6 bottom left panel). The three antibodies also cross-neutralized H1N1: potently neutralized stain of H1-SC/1918 (Figure 6 bottom left panel) and moderately neutralized strain of H1-PR/34 (Figure 6 bottom right panel).

Results of microneutralization assay. As shown in Figure 6 the top right panel, the 10 anti-H5 antibodies exhibited different levels of neutralization. F10-Fc, A66-Fc, E88-Fc and E90-Fc appeared to be the most potent inhibitors, which neutralize more than 95% of 10,000pfu virus at 10ug/ml and more than 50% at 1ug/ml. We also have seen complete plaque reduction when 100pfu was used for these four antibodies at 10ug/ml or 1ug/ml (data not shown).

The 10 antibodies (scFv-Fcs) were found to neutralize H5 pseudo-viruses (virus-like particles with HIV-1 only cores that display H5 on their surface), in this case from the clade 1 virus, A/Thailand/2-SP-33/2004 (H5N1) ("H5-TH04"). All 10 antibodies also exhibited high but distinct levels of neutralization against H5-VN04 (Clade 1) and A/Indonesia/5/2005

("H5-IN05", Clade 2.1) viruses in a stringent plaque reduction assay (Fig.9), suggesting that the neutralization epitope(s) is conserved across different H5 clades. However, none of the Abs neutralized a Group 2 virus, HPAI H7N7 strain, A/Netherlands/219/03 (H7N7) (H7-NL03) (Figure 4).

All 10 nAbs bound to trimeric H5 and cross-competed against each other (Fig.16), indicating that they recognize an overlapping epitope. Based on this finding as well as VH sequence diversity and neutralization potency, three nAbs (D8, F10 and A66) were selected and converted into full-length human IgG1. All three nAb IgG1s bound to recombinant H5 (H5-VN04) *in vitro* with high affinity (Kd~100-200 pM) and very slow dissociation rates (kd ~ 10^{-4} s^{-1}) (Fig.17).

Example 3: Kinetic characterization of the binding of HA0 (the ectodomain of HA of A/Vietnam1203/04) to D8-IgG1, F10-IgG1 and A66-IgG1 by using BIAcore T-100

Mabs were captured on a CM4 chip via anti-human IgG1, and trimeric HA0 at various concentrations (20, 10, 5, 2.5, 2.5, 1.25, 0.625 nM) was injected over the chip surface. Binding kinetics was evaluated using a 1:1 Laugmuir binding model. The recorded binding curves (with blank reference subtracted) are shown in black and the calculated curves in red. All *ka, kd, KD* represent the means and standard errors of three experiments. Using Biacore T100 and Biacore T100 evaluation software, we determined the kinetic rates and affinity constants for the three anti-HA MAbs by fitting to a 1:1 Langmuir model. As shown in the figure below, similar *ka*, *kd*, and *KD* of D8 and F10 were observed, and A66 had a 1.8 fold lower KD than 8 and 10 due to a relative faster dissociation rate than the other two antibodies. The complexes between Mabs and HA0 were stable as illustrated by a very slow dissociation rate ($8.8\pm1.1x10^{-5}$ s^{-1}~ $1.8\pm0.3x10^{-4}$ s^{-1}) and high affinity binding with H5 trimer at pM level. (Figure 7)

Example 4: Prophylactic and therapeutic effect of anti-H5 antibodies

The protective efficacy of human nAbs against H5N1 and H1N1 virus infection was evaluated in a BALB/c mouse model. Mice were treated with different doses of nAb either before or after lethal viral challenge.

Prophylactic efficiacy (Figure 7 a, b, g and h). Mice were treated with anti-H5 nAbs or control mAb 24 hour before lethal challenge by intranasally (i.n.) with 10 median lethal doses (MLD_{50}) of the H5N1 or H1N1s. Intra-peritoneal (i.p.) injection of 10 mg/kg of any of the three nAbs provided complete protection of mice challenged with H5-VN04 (A/Vietnam/1203/04 (H5N1), Clade 1). A lower antibody dose (2.5 mg/kg) was also highly

protective.(Figure 7a) Prophylactic protection against H5-HK97 (A/HongKong/483/97 (H5N1), Clade 0) virus was observed in 80-100% of the mice treated with 10 mg/kg of any of the three nAbs. (Figure 7b) Any of the three nAbs (at 10 mg/kg of single injection) provided complete protection of mice challenged with H1-WSN33 (A/WSN/1933(H1N1)) viruses. (Figure 7g) D8 and F10 completely protected mice challenged with H1-PR34 (A/Puerto Rico/8/34 (H1N1)) when given at 10mg/kg of single injection. A66 provided complete protection of mice when 25mg/kg of antibody was given as a single injection. (Figure 7h) Therapeutic efficacy (Figure 7c-f). Mice were inoculated with H5-VN04 and injected with nAbs at 24, 48, 72 hpi (Figure 7 c, e and f) or with H5-HK97 at 24 hpi (Figure 7 d). I.p. treatment with 15 mg/kg (a therapeutically achievable dose in humans) of any of the 3 nAbs at 24h post-inoculation (hpi) protected 80-100% of mice challenged with 10-times the MLD_{50} of either H5-VN04 or H5-HK97 virus (Figure 7c-d). Mice treated with the same dose of nAbs at 48 or 72 hpi with H5-VN04 showed similar or higher levels of protection (Figure 7 2e-f). Surviving mice in all anti-H5 nAb treatment groups remained healthy and showed minimal body weight loss over the 2-week observation period (data not shown).

Example 5: Suppression of viral titer in tissues by anti-H5 antibodies in a therapeutic animal study

The anti-viral effect of nAbs used therapeutically was further investigated by measuring virus titer 4 days post-challenge either in lungs, as an indicator of inhibition of local replication, or in spleen and brain, indicative of the systemic spread that is characteristic of H5N1 infection. The nAbs mediated a significant suppression of viral replication in lungs of H5 nAb treated mice as compared to controls when given within 48 hours of challenge (Fig. 12). Notably, two of the nAbs, D8 and F10, also showed antiviral effect when given at 72 hpi. Systemic virus spread to the brain was low in control animals, obscuring any effect of nAb treatment. However, the impact of nAb therapy on systemic spread was dramatically demonstrated by ≥1000-fold suppression of virus spread to the spleen even when the three nAbs were given within 72 hpi.

Example 6: Initial Epitope mapping of antibody D8, F10 and A66.

Various full-length wild type HA and HA mutants expressing plasmids for H5-SP33 were transfected transiently into 293T cells. 48 hours after transfection, anti-H5 antibodies (10ug/ml) were incubated with transfected 293T cells at 4 °C for 1 hour. Cells were then washed three times with PBS containing 0.5% BSA and 0.1% NaN3. For the detection of anti-H5 antibodies' binding to HA transfected cells, FITC-labeled goat anti-human IgG

(Pierce) was used as secondary antibody and incubated with cells at 4 °C for 30 min. Antibody 2A was used as a control antibody to indicate the expression of each mutant. As we can see from the table below, the epitopes for Mab D8, 1F0 and A66 are similar and they are located at positions of 307 on HA1 and 52, 59, 65, 93 on HA2. The position of these amino acids were highlighted in the crystal structure of H5 (A/Vietnam/1203/04(H5N1))

Example 7: Binding and neutralization of Cluster H1 viruses.

The cross-clade neutralization of H5N1 viruses (Figure 4) prompted testing for neutralization of other HA subtypes within the Group 1 H1 cluster (Figure 11). All three nAbs bound to cells expressing full-length H1 ((A/South Carolina/1/1918 (H1N1) ("H1-SC1918") and A/Puerto Rico/8/34 (H1N1) ("H1-PR34")), H2 (A/Japan/305/57(H2N2)) ("H2-JP57"), H6 (A/chicken/New York/14677-13/1998(H6N2)) (H6-NY98), but not a Group 2 subtype, H7 ((A/FPV/Rostock/34 (H7N1) ("H7-FP34")) (Figure 4). They also neutralized H1-SC1918- and H1-PR34-pseudotyped virus infection (Figure 4); and in addition, F10 neutralized PR34 (H1N1), A/Ohio/83 (H1N1) ("H1-OH83") and A/Ann Arbor/6/60 (H2N2) infection (Fig. 4). These results suggest that these nAbs recognize an epitope on HA that is not only highly conserved among H5 clades, but is also present on H1, H2 and H6 subtypes, and potentially subtypes within other clusters. We therefore decided to investigate the mechanism of virus neutralization in detail.

Example 8: nAbs inhibit cell fusion but not virus binding.

Two ways in which anti-HA Abs can mediate neutralization are blocking HA binding to its cellular receptor, and inhibition of virus-host membrane fusion by interfering with low-pH induced conformational changes of HA. We found that the three nAbs neither affected virus binding to cells nor inhibited haemagglutination (binding and cross-linking of red blood cells), while a mouse anti-H5 nAb, 17A2.1.2, and ferret anti-H5N1 serum, both of which inhibit haemagglutination, reduced binding to background levels.

We next tested the ability of the nAbs to inhibit fusion of host cell membranes using a model system in which 293T cells at high density were co-transfected with H5- and N1-expressing plasmids from H5-TH04. Surface-expressed viral proteins cause cells to fuse and form syncytia, which occurs spontaneously within 36-48hrs post-transfection under normal culture conditions. When nAbs were added 6hrs post-transfection and observed 36hrs later, complete inhibition of syncytia formation was observed in all 3 cases In the absence of nAbs, cells exposed briefly (3-4 minutes) to an acidic medium (pH 5) 30hrs post-transfection form extensive syncytia. The nAbs (5 μg/ml) also completely blocked syncytia formation

under these conditions (data not shown). Together, these results indicate that all three nAbs inhibit membrane fusion without interfering with receptor binding.

Example 9: Structural characterization of the nAb epitope

We next determined the epitope and mode of binding of one of the nAbs, F10, by solving the crystal structure of its scFv fragment in complex with HA (H5-VN04) at 3.2 Å resolution, and by mutagenesis. (Fig. 6 and Table 4)

In the complex, each H5 trimer binds three molecules of F10, at symmetry-related sites, burying ~1500 $Å^2$ of protein surface per antibody; the structure of H5 itself is not significantly altered by F10 binding. HA is synthesized as a single chain, HA0, that is activated by proteolytic cleavage into two subunits, HA1 and HA2. Cleavage leads to the burial of the "fusion peptide" (comprising the first ~21 residues of HA2) into the membrane-proximal stem. F10 binding occurs exclusively in this region (Fig. 6), making intimate contacts with the fusion peptide, elements of HA1 and HA2 (both of which are integral to the structure of this region) that lock the peptide into place in the neutral pH conformation, as well as the large helical hairpin of HA2 that undergoes a massive conformation change at acidic pH in order to propel the fusion peptide from its viral membrane-proximal pocket to the distal surface of the virus, where it can trigger fusion with the endosomal membrane.

The heavy chain of F10 plays the major role in H5 binding, utilizing the tips of its three complementarity-determining regions (CDRs). Each F10 molecule make contacts with both the HA1 and HA2 subunits within a single monomer of the HA trimer (Fig 6). The contact region comprises a pocket formed by part of the HA2 fusion peptide, with elements of HA1 on one side and an exposed face of helix αA of HA2 on the other (Figs. 4 and 6). A triad of antibody residues - F55 and M54 from CDR H2, and Y102 from CDR H3 - form major contact points. The phenyl ring of F55 lies across a flat surface formed by a prominent loop of the fusion peptide loop (HA2 residues DGW 19_2-21_2 (H3 numbering scheme; subscripts 1 and 2 refer to HA1 and HA2 chains)) and the aromatic side-chains of two flanking histidines (residues 18_1 and 38_1) and a tryptophan, $W21_2$, which forms the back of the pocket. The side-chain of M54 also contacts the aromatic rings of $W21_2$ and $H38_1$, as well as the side-chain of $I45_2$ from helix αA, while its main-chain carbonyl oxygen hydrogen-bonds with the side-chain of $H38_1$. Y102 inserts its side-chain into a hydrophobic crevice created by four side-chains of the αA helix, and also hydrogen-bonds to a backbone carbonyl ($D19_2$) of the fusion peptide. The CDR H1 loop makes multiple contacts with the C-terminal end of helix αA and a loop of HA1 at the base of the head region (Fig.12d,e).

In parallel, mutagenesis experiments were carried out on helix αA to help define the epitope (Fig. 6). Mutations in 3 residues that directly contact the antibody: V52A/E, N53A and I56A, significantly reduced or ablated antibody binding, while the conservative mutation, V52L, had no effect. As controls, mutations on a different exposed face of the helix, which does not contact the antibody, had no effect on antibody binding (Fig.12b-c). Thus, mutagenesis of the αA helix is fully consistent with the epitope defined crystallographically for F10. Furthermore, the other two nAbs, for which no structural data exist, showed an almost identical mutant-nAb binding profile, indicative of a closely overlapping epitope and consistent with competitive binding (Fig. 6, Fig. 9). Taken together, we conclude that all three nAbs neutralize virus by stabilizing the neutral pH conformation of HA in a region that provides the trigger (most likely release of the fusion peptide from its pocket) for conformational changes that lead to the fusogenic state.

Example 10: Structural basis of broad-spectrum neutralization

The region of HA defined by the F10 epitope is highly conserved among the 16 HA subtypes (Fig.6 and Table 5). The fusion peptide must adopt a well-defined structure, both in the neutral pH conformation and during the process of membrane fusion, and mutagenesis studies have shown that few sequence changes are tolerated. The exposed helical face of HA2 αA is also nearly invariant across both groups, presumably because it must reorganize to form the inner surface of the long trimeric coiled-coil in the fusogenic state. Thus, the requirement of these segments to adopt two very different structures in two distinct environments presumably imparts strong evolutionary constraints on the sequences, providing a clear rationale for their conservation across the 16 HA subtypes.

Crystal structures have been determined for subtypes H1, H5, and H9 from Group 1 and H3 and H7 from Group 2, and the structures fall into two distinct classes, coincident with the two groups defined by phylogenetic analysis. Further comparisons show that the two classes are also readily distinguishable at the detailed 3-dimensional level within the region defined by the F10 epitope. Sequence differences in a few key amino acids buried in the core that are characteristic of each class (e.g. at 17_1 and 111_2) lead to consistent differences in the orientation of several side-chains within the epitope, as well as the disposition of the pocket with respect to helix αA.

Within each group/class, the epitope region is highly conserved, with very few differences in a given cluster, and only a few changes, generally conservative, between clusters (e.g., at positions 18_1 and 38_1, Fig.6a). Our observation that the 3 nAbs can recognize all 4 members of the H1 cluster demonstrates that amino-acid differences at the

periphery of the epitope (such as at residue 40_1, which is K, Q or V in this cluster) may not be critical for binding.

The 10 antibodies we selected have 5 different sets of VH CDR1-3, which vary substantially in sequence and length. Nevertheless, the three key residues in CDR2 (M54, F55) and CDR3 (Y102) that insert into the pocket are conserved. The conservation of key residues within a varied CDR context may expand the range of HA subtype/cluster recognition by this group of nAbs beyond those tested here. However, it should be noted that 4 out of 6 Group 2 subtypes are glycosylated at position 38_1, which lies at the periphery of the F10 epitope. Modeling studies predict steric clashes (but only with the CDR H1 loop), which likely contributes to the observed lack of binding/neutralization of H7 viruses.

Example 11: Anti-H5 nAbs bind to a broad range of Group 1 HA subtypes

Group 1 viruses contains 10 of the total 16 subtypes of Influenza A virus, and is further classified into 3 "clusters", H1a, H1b, and H9. We tested our nAbs for binding to all seven HA subtypes of Clusters H1a and H1b, which include avian H5 as well as the most common human influenza subtypes, with the exception of the Group 2 subtype, H3. In addition to H5, we found that all three nAb IgG1s bound to cells expressing full-length H1 from 2 different strains of H1N1, including the 1918 "Spanish flu"; H2 from H2N2; and H6 from H6N2; as well as the Cluster 1b subtypes: H11 from H11N9; H13 from H13N6; and H16 from H16N3. However, none of them bound to a Group 2 subtype, H7 from H7N1 (Fig. 13). More details about Fig. 13 are as follows. FACS analysis of anti-H5 nAbs binding to H1, H2, H5, H6 (cluster H1a) and H11, H13 and H16 (Cluster H1b). 293T cells were transiently transfected with different HA-expressing plasmids. NAb binding to the cells was analyzed by FACS. H5-specific antibody 2A and 80R are negative control. Lack of binding to a Group 2 HA, H7, is also shown. Detail on viral strains are: H1-SC1918 ((A/South Carolina/1/1918 (H1N1)), H1-PR34 (A/Puerto Rico/8/34 (H1N1)), H2-JP57 (A/Japan/305/57(H2N2)), H5-TH04 (A/Thailand/2-SP-33/2004 (H5N1)), H6-NY98 (A/Chicken/New York/14677-13/1998 (H6N2)), H7-FP34 (A/FPV/Rostock/34 (H7N1)), H11-MP74 (A/Duck/memphis/546/74 (H11N9)), H13-MD77 (A/Gull/MD/704/77 (H13N6)) and H16-DE06 (A/Shorebird/DE/172/06 (H16N3)).

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Table 3. Contact residues at the H5-F10 interface

	FRH1	CDRH1				CDRH2			CDRH3				
10	S25	V27	T28	S30	S31	**M54**	**F55**	T57	P100	S101	**Y102**	I103	**S105**
A1	S291	S291 M292		**Q40**		H38	H18 **H38**						
A2		I56	V52 N53		I45 T49	W21 I45	V18 **D19** G20 **W21**	V18	Q42	Q42	D19 K38 T41 Q42 I45	D19 K38	K38

Contact residues defined by having a closest interatomic distance of < 4.5 Å. The color scheme indicates contributions of individual residues to the binding free energy: very favorable (red(V27,T28,I45,D19,W21)),
favorable (orange(S25,S291,M292,I56,V52,N53,T49,H18,V18,G20,T57,T41)), negligible (blue (S30,S31,Q40,H38), unfavorable (black), very unfavorable (bold black). Based on energy calculations using the server at http://structure.pitt.edu/servers/fastcontact[1].

Table 4. Data collection and refinement statistics.

	H5-F10
Data Collection	
Cell parameters	a=205.3, b=118.5, c=338.9 β=99.6°
Space group	C2
Resolution (Å)*	3.2(3.28-3.20)
Total reflections	509705
Unique reflections	112570
Completeness (%)*	85.0 (68.4)
Average I/σ(I)*	9.5 (2.0)
R_{MERGE} (%)*	12.8 (81.0)
Redundancy*	4.5 (4.5)
σ cutoff	-3
Refinement	
Resolution	50-3.2(3.28-3.20)
R_{WORK}*	0.23 (0.32)
R_{FREE} (5% data)*	0.29 (0.38)
RMSD bond distance (Å)	0.01
RMSD bond angle (°)	1.31
Average B value	75.7
Solvent atoms	0
σ cutoff	none
Ramachandran plot	
Residues in favored regions (%)	90.0
Residues in allowed regions (%)	9.5
Residues in outlier regions (%)	0.5

*Numbers in parentheses correspond to the highest resolution shell.

Table 5*. Sequence comparison of F10 epitope among 16 HA subtypes.

Group	Cluster	Subtype	# Full-length sequence	# Unique sequence	HA1					HA2												
					17	18	38	40	291	18	19	20	21	38	41	42	45	49	52	53	56	111
Group 1	H1a	H2	100	95	Y	H	H	(Q,E)/K (18)/77	T	(I)/V (20)/75	D	G	W	K	T	Q	(F,V)/I (39)/56	T	(I)/V (1)/94	N	I	H
		H5	1620	1178	(S,T,F)/Y (4)/1174	(Y,M)/H (2)/1176	(Q,Y)/H (4)/1174	(K)/Q (2)/1176	(I,N,T,R)/S (6)/1172	(I)/V (6)/1172	(N,H,Y,X)/D (5)/1173	G	(R)/W (1)/1177	(Q,R,N)/K (23)/1155	(S)/T (3)/1175	P/Q (1)/1177	(M,L,T)/I (8)/1170	(I)/T (1)/1177	V	N	(F)/ V (1)/1177	H
		H1	1211	701	Y	H	H	(I)/V (2)/699	(S)/N 16(686)	(V,M)/I (137)/546	D	G	W	(K,R,L)/Q (60)/641	T	Q	(V)/I (2)/699	(S,N,X)/T (19)/682	(M,I)/V (2)/699	N	(V)/I (1)/700	H
		H6	278	230	Y	H	H	V	(I)/N (1)/229	(V)/I (43)/187	D	G	(R)/W (1)/229	(R)/K (102)/128	T	Q	(V)/I (78)/152	(I)/T (1)/229	(I)/V (3)/227	N	I	H
	H1b	H13	16	16	Y	L	S	(V)/I (6)/16	N	I	N	G	W	K	T	Q	I	T	V	N	I	H
		H16	8	6	Y	L	S	(I)/V (2)/6	N	I	N	G	W	K	T	Q	I	T	V	N	I	H
		H11	64	64	Y	L	S	(I)/V (1)/64	(T)/S (1)/63	(L)/I (1)/63	N	G	W	(R)/K (5)/59	T	Q	(V)/I (3)/61	(I)/T (1)/63	V	N	(I,A)/V (17)/47	H
	H9	H8	10	10	Y	Q	Q	M	S	I	D	G	W	Q	T	Q	I	T	(D)/V (1)/9	N	I	H
		H12	19	18	Y	Q	Q	E	S	V	A	G	W	R	T	Q	I	Q	L	N	I	H
		H9	252	234	(H)/Y (33)/201	(L)/Q (1)/233	(D)/H (1)/233	(R,E)/K (5)/229	(I)/T (1)/233	V	(S)/A (1)/233	G	(G)/W (1)/233	(K,G)/R (14)/220	T	Q	(V,F,M,R)/I (43)/191	(I)/T (1)/233	V	(S,T,D)/N (3)/231	(I)/V (55)/179	(C)/H 1/233
Group 2	H3	H4	105	90	H	H	(A)/T (1)/89	(R)Q (1)/89	(A,I,S,N)/T (10)/82	I	D	G	(G)/W (1)/91	L	T	Q	I	(N)/T (1)/89	L	N	I	(A)/T (2)/90
		H14	2	2	H	H	S	K	D	I	D	G	W	L	T	Q	I	N	L	N	I	T
		H3	2302	1228	H	H	N	(N)/T (1)/1227	(N,Y,E,G)/D (35)/1193	(M)/(V/I) (149)/70%/30	(N)/D (15)/1213	G	W	(F)/L (1)/1227	T	Q	(V,T,L)/I (5)/1223	(D,S,T,A)/N (22)/1206	(M)/L (1)/1227	(D)/N (1)/1227	(V,T,F)/I (19)/1209	(A)/T (7)/1221
	H7	H15	8	6	H	H	N	T	P	I	D	G	W	Y	T	Q	I	T	L	N	I	A
		H7	334	273	H	H	N	T	(S,R,P)/N (131)/142	(V)/I (41)/232	(N)/D (57)/213	G	W	(H)/Y (1)/272	T	(P)/Q (2)/271	(V)/I (3)/270	T	L	N	I	(T)/A (35)/238
		H10	31	28	H	H	N	T	(E)/K (1)/27	V	(N,E)/D (2)/26	(A)/G (1)/27	w	Y	T	Q	I	T	L	N	(V)/I (1)/27	A

* This table represents sequences available in public influenza sequence databases (http://www.ncbi.nlm.nih.gov/genomes/FLU/FLU.html) as of April. 17, 2008. Light blue highlights: top '( )/ ', (amino acid variant(s)) / amino acid consensus at the position; bottom '( )/ ', (number of amino acid variants)/ number of consensus amino acids. Non-highlighted amino acids are 100% conserved or variants are observed ≤ 5 times at those positions for subtypes H4, H6, H9, H10, H11. Histidines H17 (HA1) and H111 (HA2) that may play a role in pH-trigger are highlighted in green.

OTHER EMBODIMENTS

Although particular embodiments have been disclosed herein in detail, this has been done by way of example for purposes of illustration only, and is not intended to be limiting with respect to the scope of the appended claims, which follow. In particular, it is contemplated by the inventors that various substitutions, alterations, and modifications may be made to the invention without departing from the spirit and scope of the invention as defined by the claims. Other aspects, advantages, and modifications considered to be within the scope of the following claims. The claims presented are representative of the inventions disclosed herein. Other, unclaimed inventions are also contemplated. Applicants reserve the right to pursue such inventions in later claims.

CLAIMS

We claim:

1. An isolated monoclonal antibody, wherein said monoclonal antibody binds to an epitope in the stem region of the hemagglutinin (HA) protein of an influenza virus, and neutralizes influenza A virus.

2. The monoclonal antibody of claim 1, wherein said influenza virus is a Group I influenza virus.

3. The monoclonal antibody of claim 1, wherein said influenza virus is H1 cluster influenza virus.

4. The monoclonal antibody of claim 3, wherein said H1 cluster influenza virus is an H1a cluster influenza virus or an H1b cluster influenza virus.

5. The monoclonal antibody of claim 1, wherein said epitope is non-linear.

6. The monoclonal antibody of claim 1, wherein said epitope comprises the HA1and the HA2 polypeptide

7. The monoclonal antibody of claim 1, wherein the epitope comprises the amino acid at position 18, 38, 40, 291 of the HA1 polypeptide and the amino acid at position 18, 19, 20, 21, 38, 41, 42, 45, 49, 52, 53 and 56 of the HA2 polypeptide.

8. The monoclonal antibody of claim 1, wherein said monoclonal antibody inhibits viral and cell membrane fusion.

9. The monoclonal antibody of claim 1, wherein said monoclonal antibody competes with the binding of monoclonal antibody D7, D8, F10, G17, H40, A66, D80, E88, E90, or H98 to the HA protein.

10. The monoclonal antibody of claim 1 wherein said monoclonal antibody is a fully human antibody.

11. An isolated scFv antibody, wherein said antibody binds to an epitope the hemagglutinin (HA) protein of an influenza virus, and neutralizes influenza A virus.

12. The antibody of claim 11, wherein said influenza virus is a Group I influenza virus.

13. The antibody of claim 11, wherein said influenza virus is H1 cluster influenza virus.

14. The antibody of claim 13, wherein said H1 cluster influenza virus is an H1a cluster influenza virus.

15. The antibody of claim 11, wherein said epitope is non-linear.

16. The antibody of claim 11, wherein epitope comprises the HA1 and HA2 polypeptide

17. The antibody of claim 11, wherein the epitope comprises the amino acid at position 18, 38, 40, 291 of the HA1 polypeptide and the amino acid at position 18, 19, 20, 21, 38, 41, 42, 45, 49, 52, 53 and 56 of the HA2 polypeptide.

18. The antibody of claim 11, wherein said antibody inhibits viral and cell membrane fusion.

19. The monoclonal antibody of claim 11, wherein said antibody competes with the binding of monoclonal antibody D7, D8, F10, G17, H40, A66, D80, E88, E90, or H98 to the HA protein.

20. A method of preventing a disease or disorder caused by an influenza virus, the method comprising administering to a person at risk of suffering from said disease or disorder, a therapeutically effective amount of the monoclonal antibody of claim 1 or the scFv antibody of claim 11.

21. The method of claim 20, wherein the method further comprises administering an anti-viral drug, a viral entry inhibitor or a viral attachment inhibitor.

22. The method of claim 21, wherein said anti-viral drug is a neuraminidase inhibitor, a HA inhibitor, a sialic acid inhibitor or an M2 ion channel.

23. The method of claim 22 wherein said M2 ion channel inhibitor is amantadine or , rimantadine.

24. The method of claim 22, wherein said neuraminidase inhibitor is zanamivir, or oseltamivir phosphate.

25. The method of claim 20 or claim 21, wherein the method comprises administering two or more antibodies specific to a Group I influenza virus

26. The method of claim 20, claim 21 or claim 25, wherein the method further comprises administering an antibody specific to a Group II influenza virus.

27. The method of claim 20, wherein said antibody is administered prior to or after exposure to influenza virus.

28. The method of claim 20, wherein said antibody is administered at a dose sufficient to neutralize said influenza virus.

29. A method of treating a disease or disorder caused by an influenza virus, the method comprising administering to a person at risk of suffering from said disease or disorder, a therapeutically effective amount of the monoclonal antibody of claim 1 or the scFv antibody of claim 11.

30. The method of claim 29, wherein the method further comprises administering an anti-viral drug, a viral entry inhibitor or a viral attachment inhibitor.

31. The method of claim 30, wherein said anti-viral drug is a neuraminidase inhibitor, a HA inhibitor, a sialic acid inhibitor or an M2 ion channel.

32. The method of claim 31, wherein said M2 ion channel inhibitor is amantadine or , rimantadine.

33. The method of claim 31, wherein said neuraminidase inhibitor zanamivir, or oseltamivir phosphate.

34. The method of claim 29 or claim 30, wherein the method comprises administering two or more antibodies specific to a Group I influenza virus

35. The method of claim 29, claim 30 or claim 34, wherein the method further comprises administering an antibody specific to a Group II influenza virus.

36. The method of claim 29, wherein said antibody is administered prior to or after exposure to influenza virus.

37. The method of claim 29, wherein said antibody is administered at a dose sufficient to neutralize said influenza virus.

38. A composition comprising the monoclonal antibody of claim 1 or the scFv antibody of claim 11 and a carrier.

39. The composition of claim 38, further comprising an anti-viral drug, a viral entry inhibitor or a viral attachment inhibitor.

40. The composition of claim 39, wherein said anti-viral drug is a neuraminidase inhibitor, a HA inhibitor, a sialic acid inhibitor or an M2 ion channel.

41. The method of claim 40, wherein said M2 ion channel inhibitor is amantadine or , rimantadine.

42. The method of claim 40, wherein said neuraminidase inhibitor zanamivir, or oseltamivir phosphate.

43. The composition of claim 38, further comprising one or more antibodies specific to a Group I influenza virus

44. The composition of claim 38, claim 39 or claim 42, further comprising an antibody specific to a Group II influenza virus.

45. A method identifying an antibody specific for an influenza virus comprising: contacting a trimeric hemagglutinin (HA) protein, wherein said HA protein is immobilized on a solid surface with a test antibody and detecting a HA protein-antibody complex.

46. The method of claim 45 wherein said solid surface is plastic.

47. The method of claim 45, wherein said HA protein is produced in a non-mammalian cell.

48. The method of claim 45, wherein said HA protein is produced in insect cells.

49. The method of claim 45, wherein said HA protein comprising modified glycosylations compared to a wild type HA protein.

50. The method of claim 45 wherein said HA protein is immobilized on said solid surface as to mask the globular head of said HA protein.

51. A method of producing an isolated antibody that specifically binds a trimeric hemagglutinin (HA) protein, (a) exposing a single chain or Fab expression library to said HA protein wherein said HA protein is immobilized on a solid surface; (b) identifying an antibody in said library that specifically binds said protein; and (c) isolating the antibody from the library.

52. The method of claim 51, wherein said solid surface is plastic.

53. The method of claim 51, wherein said HA protein is produced in a non-mammalian cell.

54. The method of claim 51, wherein said HA protein comprising modified glycosylations compared to a wild type HA protein.

55. The method of claim 51, wherein said HA protein is immobilized on said solid surface as to mask the globular head of said HA protein.

56. The method of claim 51, wherein said expression library is a non-immune library.

57. The method of claim 51, wherein said expression library is H5 naïve library.

58. A method of vaccinating a subject against an influenza virus comprising administering to said subject an trimeric hemagglutinin (HA) protein coated or embedded in a biologically compatible matrix.

59. The method of claim 58, wherein said HA protein has non-mammalian carbohydrate structures.

60. The method of claim 58, wherein said HA protein comprising modified glycosylations compared to a wild type HA protein.

61. The method of claim 58, wherein said HA protein is coated or embedded in said biologically compatible matrix as to mask the globular head of said HA protein.

62. A method of producing an isolated antibody that specifically binds a pathogenic enveloped virus, (a) exposing a single chain or Fab expression library to a membrane fusion protein of said virus wherein said protein is immobilized on a solid surface; (b) identifying an antibody in said library that specifically binds said protein; and (c) isolating the antibody from the library.

63. The method of claim 62, wherein said solid surface is plastic.

64. The method of claim 62, wherein said membrane fusion protein is produced in a non-mammalian cell.

65. The method of claim 62, wherein said membrane fusion protein has non-mammalian carbohydrate structures.

66. The method of claim 62, wherein said membrane fusion protein comprising modified glycosylations compared to a wild type membrane fusion protein.

67. The method of claim 62, wherein said expression library is a non-immune library.

68. The method of claim 62, wherein said expression library is H5 naïve library.

69. A method of vaccinating a subject against pathogenic enveloped virus comprising administering to said subject a membrane fusion protein of said virus coated or embedded in a biologically compatible matrix.

70. The method of claim 69, wherein said fusion protein has non-mammalian carbohydrate structures.

71. The method of claim 69, wherein said fusion protein comprising modified glycosylations compared to a wild type membrane fusion protein.

72. A method of detecting the presence of an influenza virus in a sample, the method comprising:

a) contacting the sample with the monoclonal antibody of claim; and

b) detecting the presence or absence of an antibody-antigen complex,

thereby detecting the presence of an influenza virus in a sample.

73. The method of claim 72, wherein the detecting occurs *in vivo*.

74. The method of claim 72, wherein the sample is obtained from blood, hair, cheek scraping, saliva, biopsy, or semen.

75. An isolated monoclonal antibody, wherein said monoclonal antibody comprise a VH amino acid sequence encoded by the VH germline gene IGHV1-69*01 wherein the amino acid at position: a) 27 is a valine; b) 28 is threonine; c) 30 is serine; d) 31 is

serine; e) 54 is methionine; f) 55 is phenylalanine; g) 58 is threonine; h) 100 is proloine; i) 101 is serine; j) 102 is tyrosine; k)103 is isoleucine and 105 is serine, wherein said monoclonal antibody binds to an epitope in the stem region of the hemagglutinin (HA) protein of an influenza virus, and neutralizes influenza A virus.