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of Technology Transfer, 6011 Executive Blvd., Suite 325,
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(72) Inventors; and

(75) Inventors/Applicants (for US only): **DIMITROV, Di-
viter, S.** [US/US]; 12309 Braxfield Court, #16, Rockville,
MD 20852 (US). **ZHONGYU, Zhu** [CN/US]; 2501
Carrington Way, Frederick, MD 21702 (US). **BRODER,
Christopher, C.** [US/US]; 1717 Gruenther Avenue,
Rockville, MD 20851 (US).

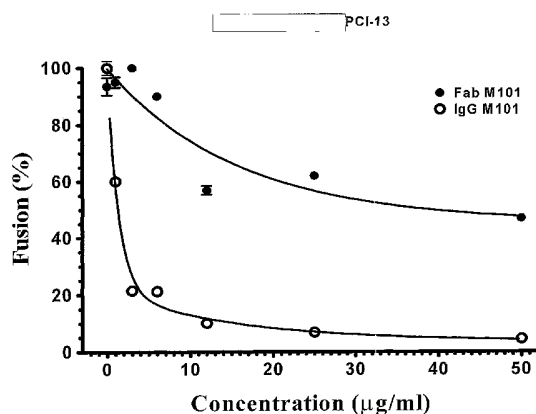
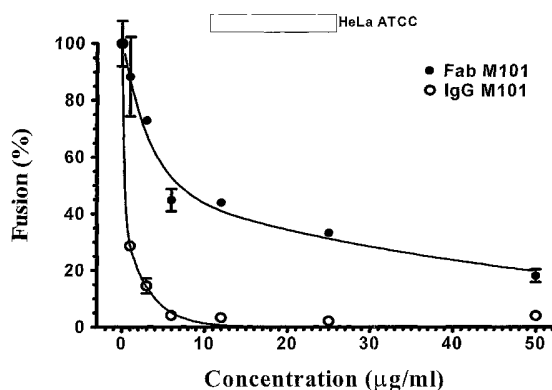
(74) Agent: **HART, Daniel**; Knobbe, Martens, Olson And
Bear, LLP, 550 West C Street, Suite 1200, San Diego, CA
92101 (US).

(71) Applicant (for all designated States except US): **THE
GOVERNMENT OF THE UNITED STATES OF
AMERICA, AS REPRESENTED BY THE SECRE-
TARY, DEPARTMENT OF HEALTH AND HUMAN
SERIVCES** [US/US]; National Institutes of Health, Office

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(54) Title: HUMAN MONOCLONAL ANTIBODIES AGAINST HENDRA AND NIPAH VIRUSES



(57) Abstract: The present invention relates to monoclonal antibodies that bind or neutralize Hendra or Nipah virus. The invention provides such antibodies, fragments of such antibodies retaining Hendra or Nipah virus-binding ability, fully human antibodies retaining Hendra or Nipah virus-binding ability, and pharmaceutical compositions including such antibodies. The invention further provides for isolated nucleic acids encoding the antibodies of the invention and host cells transformed therewith. Additionally, the invention provides for prophylactic, therapeutic, and diagnostic methods employing the antibodies and nucleic acids of the invention.



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HUMAN MONOCLONAL ANTIBODIES AGAINST HENDRA AND NIPAH VIRUSES

Related Applications

5 This application claims the benefit of U.S. Provisional Patent Application No: 60/661,766, filed March 14, 2005, U.S. Provisional Patent Application No: 60/678,547, filed May 5, 2005, and U.S. Provisional Patent Application No: 60/718,902, filed September 20, 2005, the disclosures of all of which are hereby expressly incorporated by reference in their entireties.

10 Field of the Invention

This invention relates generally to the field of immunology and specifically to monoclonal antibodies that bind or neutralize Hendra and Nipah viruses.

Background of the Invention

Nipah virus (NiV) and Hendra virus (HeV) are closely related emerging paramyxoviruses that comprise the *Henipavirus* genus (Anonymous 1999 *MMWR Morb Mortal Wkly Rep* Ward, J. W. ed. **48**:335-337; Chew, M. H. et al. 2000 *J Infect Dis* **181**:1760-1763; Chua, K. B. et al. 2000 *Ann Neurol* **48**:802-805; Eaton, B. T. 2001 *Microbes Infect* **3**:277-278; Goh, K. J. et al. 2000 *N Engl J Med* **342**:1229-1235; Lee, K. E. et al. 1999 *Ann Neurol* **46**:428-432; Lim, C. C. et al. 2000 *Am J Neuroradiol* **21**:455-461; Murray, K. et al. 1995 *Science* **268**:94-97). Paramyxoviruses are negative-sense RNA containing enveloped viruses and contain two major membrane-anchored envelope glycoproteins that are required for infection of a receptive host cell. All members contain an F glycoprotein which mediates pH-independent membrane fusion between the virus and its host cell, while the second attachment glycoprotein can be either a hemagglutinin-neuraminidase protein (HN), a hemagglutinin protein (H), or a G protein depending on the particular virus (reviewed in Lamb, R. A. and Kolakofsky, D. 2001 in Fields Virology, eds. Knippe, D. M. & Howley, P. M., Lippincott Williams & Wilkins, Philadelphia, pp. 1305-1340). As with all paramyxoviruses, these glycoproteins are also the principal antigens to which virtually all neutralizing antibodies are directed.

30 The broad species tropisms and the ability to cause fatal disease in both animals and humans distinguish HeV and NiV from all other known paramyxoviruses (reviewed in Eaton, B. T. 2001 *Microbes Infect* **3**:277-278). They are Biological Safety Level-4 (BSL-4)

pathogens, and are on the NIAID Biodefense research agenda as zoonotic emerging category C priority pathogens that could be used as bioterror agents. The henipaviruses can be amplified and cause disease in large animals and be aerosol transmitted to humans where disease can be a severe respiratory illness and febrile encephalitis. They can be readily grown in cell culture or embryonated chicken eggs, produce high un-concentrated titers (~10⁸ TCID₅₀/ml; Crameri, G. et al. 2002 *J Virol Methods* **99**:41-51), and are highly infectious (Field, H. et al. 2001 *Microbes Infect* **3**:307-314; Hooper, P. et al. 2001 *Microbes Infect* **3**:315-322).

NiV has recently re-emerged in Bangladesh. Two outbreaks of NiV in 2004 have been confirmed, and yet another one occurred in January of 2005 (Anonymous 2005 *Communicable Disease Report Weekly (CDR Weekly)* Vol. 15 No. 16). Several important observations in these most recent outbreaks have been made, including a higher incidence of acute respiratory distress syndrome, person-to-person transmission, and significantly higher case fatality rates (60-75%) than in Malaysia (about 40%) where the virus was discovered or suspected to have originated (Anonymous 2004 *Wkly Epidemiol Rec* **79**:168-171; Anonymous 2004 *Health and Science Bulletin (ICDDR,B)* **2**:5-9; Butler, D. 2004 *Nature* **429**:7; Enserink, M. 2004 *Science* **303**:1121; Hsu, V. P. et al. 2004 *Emerg Infect Dis* **10**:2082-2087). Currently, no therapeutics for NiV or HeV-infected individuals are available, and a vaccine for prevention of disease in human or livestock populations does not exist. Although antibody responses were detected in infections caused by these viruses, human monoclonal antibodies (hmAbs) have not been identified against either virus. A number of studies have shown the importance of neutralizing antibodies in recovery and protection from viral infections (Dimitrov, D. S. 2004 *Nat Rev Microbiol* **2**:109-122). Therefore, the development of neutralizing hmAbs against NiV and HeV could have important implications for prophylaxis and passive immunotherapy. In addition, the characterization of the epitopes of the neutralizing antibodies could provide helpful information for development of candidate vaccines and drugs. Finally, such antibodies could be used for diagnosis and as research reagents.

Segue to the Invention

Here, we report the identification of potent neutralizing hmAbs targeting the viral envelope glycoprotein G by using a highly purified, oligomeric, soluble HeV G (sG) glycoprotein as the antigen for screening of a large naïve human phage-display library. One of these antibodies exhibited exceptional potency against infectious HeV, and another one

neutralized both HeV and NiV. Because these antibodies are fully human antibodies, they serve as the basis for prophylaxis and treatment of humans infected with HeV or NiV.

Summary of the Invention

The present invention relates to monoclonal antibodies that bind or neutralize
5 Hendra or Nipah virus. The invention provides such antibodies, fragments of such antibodies retaining Hendra or Nipah virus-binding ability, fully human antibodies retaining Hendra or Nipah virus-binding ability, and pharmaceutical compositions including such antibodies. The invention further provides for isolated nucleic acids encoding the antibodies of the invention and host cells transformed therewith. Additionally, the
10 invention provides for prophylactic, therapeutic, and diagnostic methods employing the antibodies and nucleic acids of the invention.

Brief Description of the Drawings

Figure 1: Significantly higher inhibitory activity of IgG1 m101 than Fab m101 in HeV Env-mediated cell fusion. HeLa-USU cells were infected with vaccinia recombinants
15 encoding HeV F and G glycoproteins, and with a vaccinia recombinant encoding T7 RNA polymerase (effector cells). Each designated target cell type was infected with the *E.coli* LacZ-encoding reporter vaccinia virus vCB21R. IgG1 m101 and Fab m101 were pre-incubated with effector cells and then mixed with target cells. The cell fusion assay was performed for 2.5 hr at 37°C. Fusion was measured as described in Example 1. Inhibition
20 of HeV Env-mediated fusion by IgG1 m101 and Fab m101 in HeLa-ATCC cells is shown in A, and of PCI-13 cells - in B. Percentage of fusion is shown as function of the antibody concentration. The curves represent the best fit of the experimental data from which IC₅₀s were calculated using Prism GraphPad software.

Figure 2: Inhibition of HeV Env-mediated syncytia formation by m101. The
25 effector cells, prepared as described in Figure 1 legend were pre-incubated with IgG1 m101, Fab m101, or the control irrelevant antibody (X5 specific for HIV (Moulard, M. et al. 2002 *Proc Natl Acad Sci USA* 99:6913-6918)) for 20 min at room temperature, then 2 x 10⁵ cells in 200 µl were overlaid on 80% confluent monolayers of PCI-13 cells plated in a 48-well plate, and incubated for 3 h at 37°C in a humidified 5% CO₂ atmosphere.
30 Photographs were taken using phase contrast microscope with a 10x objective. Shown are illustrative portions of the original photographs that are electronically amplified for clarity. The top and bottom pictures of the left panel show formation of syncytia in the absence of antibody or in the presence of a control antibody; there were 17 or 20 giant fused cells

(syncytia) counted per complete photograph view, respectively. The top and bottom pictures of the right panel show complete inhibition of syncytia formation by IgG1 m101 or reduction in the number of syncytia by Fab m101 at 10 µg/ml, there were 0 or 9 syncytia per complete view, respectively.

5 Figure 3. Immunoprecipitation of HeV and NiV G glycoproteins by anti-G Fabs. HeLa cells were infected with WR, a control vaccinia virus, or recombinant vaccinia virus expressing myc-tagged HeV G or NiV G, and beginning at 6 h postinfection, labeled with [³⁵S] methionine-cysteine at 37°C overnight. Lysates were made in buffer containing Triton-X100 and incubated with various Fabs or mouse anti-myc 9E10 for at least 1 h at
10 4°C, then precipitated with Protein G Sepharose. Immunoprecipitated proteins were analyzed by 10% SDS-PAGE followed by autoradiography. WR denotes a control where the cells were infected with wild type vaccinia virus, X5 is a control antibody specific for gp120 of HIV, and 9E10 is an anti-c-Myc antibody serving as a positive control. Gels for m108 and m109 are also shown. The arrows next to G denote the position of the bands
15 corresponding to the monomeric G.

 Figure 4. Competition between anti-G antibodies and ephrin-B2 for binding to Hendra G. Serially diluted Fab m101, IgG1 m101 and Fab m106 were mixed with Hendra G, and added to the virus receptor ephrin-B2 coated on the bottom of a 96-well plate, and the amount of bound G measured as described in Example 1. An Fab specific for the
20 SARS-CoV S protein was used as control.

 Figure 5. Binding of m101 and m102 to alanine mutants of HeV G. HeLa cells transfected with wild type HeV G, various alanine mutants of HeV G, or pMC02 (empty vector) were infected with WR vaccinia virus to drive expression, radiolabeled with [³⁵S] methionine-cysteine overnight, lysed in buffer containing Triton X-100, and subjected to
25 immunoprecipitation by m101, m102, or rabbit polyclonal G antisera. Lysates were then precipitated with Protein G Sepharose and analyzed by 10% SDS-PAGE followed by autoradiography.

 Figure 6. Comparison of the inhibitory activity of m101, m102.4 Fab and IgG1, and m102 Fab in HeV Env-mediated cell fusion. HeLa-USU cells were infected with vaccinia recombinants encoding HeV F and G glycoproteins, and with a vaccinia recombinant
30 encoding T7 RNA polymerase (effector cells). Target cell U373 was infected with the *E.coli* LacZ-encoding reporter vaccinia virus vCB21R. Serial diluted antibodies were pre-incubated with effector cells for 0.5 hr and then mixed with target cells. The cell fusion

assay was performed for 2.5 hr at 37°C. Fusion was measured as described in Example 1. Antibodies concentrations were plotted against Beta-Gal assay reading at 595nm.

Figure 7. Significantly higher inhibitory activity of m102.4 Fab and IgG1 than m102 Fab in NiV-Env-mediated cell fusion. HeLa-USU cells were infected with vaccinia recombinants encoding NiV F and G glycoproteins, and with a vaccinia recombinant encoding T7 RNA polymerase (effector cells). Target cell U373 was infected with the *E.coli* LacZ-encoding reporter vaccinia virus vCB21R. Antibodies were pre-incubated with effector cells for 0.5 hr and then mixed with target cells. The cell fusion assay was performed for 2.5 hr at 37°C. Fusion was measured as described in Example 1. Antibodies concentrations were plotted against Beta-Gal assay reading at 595nm.

Figure 8. CDR1-3s and FR1-4s for m101-117 and m102 mutants.

Table A. Brief Description of m101-m117 SEQ ID NOs.

Fab/mab	Heavy Chain SEQ ID NOs								Light Chain SEQ ID NOs							
	V _H	FR1	CDR1	FR2	CDR2	FR3	CDR3	FR4	V _L	FR1	CDR1	FR2	CDR2	FR3	CDR3	FR4
m101	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
m102	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
m103	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
m104	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
m105	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
m106	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
m107	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112
m108	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128
m109	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144
m110	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160
m111	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176
m112	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192
m113	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208
m114	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224
m115	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240
m116	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256
m117	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272

Table B. Brief Description of Mutant m102 SEQ ID NOs.

Mutant	Heavy Chain SEQ ID NOs								Light Chain SEQ ID NOs							
	V _H	FR1	CDR1	FR2	CDR2	FR3	CDR3	FR4	V _L	FR1	CDR1	FR2	CDR2	FR3	CDR3	FR4
m102	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288
m102.2	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304
m102.4	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320
m102.5	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336
m102.11	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352
m102.12	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368
m102.13	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384
m102.15	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400
m102.16	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416

Detailed Description of the Preferred Embodiment

Hendra virus (HeV) and Nipah virus (NiV) are closely related emerging viruses comprising the *Henipavirus* genus of the *Paramyxovirinae*. Each has a broad species tropism and can cause high mortality disease in both animal and human hosts. These viruses infect cells by a pH-independent membrane fusion event mediated by their attachment (G) and fusion (F) envelope glycoproteins (Envs). Seven Fabs, m101-7, were selected for their significant binding to a soluble form of Hendra G (sG) which was used as the antigen for panning of a large naïve human antibody library. The selected Fabs inhibited to various degrees cell fusion mediated by the HeV or NiV Envs and virus infection. The conversion of the most potent neutralizer of infectious HeV, Fab m101, to IgG1 significantly increased its cell fusion inhibitory activity - the IC₅₀ was decreased more than 10-fold to approximately 1 µg/ml. The IgG1 m101 was also exceptionally potent in neutralizing infectious HeV; complete (100%) neutralization was achieved with 12.5 µg/ml and 98% neutralization required only 1.6 µg/ml. The inhibition of fusion and infection correlated with binding of the Fabs to full-length G as measured by immunoprecipitation, and less with binding to sG as measured by ELISA and Biacore. M101 and m102 competed with the ephrin-B2, which we recently identified as a functional receptor for HeV and NiV, indicating a possible mechanism of neutralization by these antibodies. The m101, m102 and m103 antibodies competed with each other indicating that they bind to overlapping epitopes which are distinct from the epitopes of m106 and m107. In an initial attempt to localize the epitopes of m101 and m102 we measured their binding to a panel of 10 G alanine scanning mutants, and identified one residue, G183, which decreases binding of both m101 and m102 to G; it is localized at the base of the globular head of the G protein according to a model structure, and could be part of the antibody epitope that does not overlap with the receptor binding site on G. These results indicate that m101-7 are specific for HeV or NiV or both, and exhibit various neutralizing activity; they are the first human monoclonal antibodies identified against these viruses and are contemplated for use in treatment, prophylaxis and diagnosis, and as research reagents and serving as the basis for vaccines.

Definitions

Unless defined otherwise, 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. See, e.g., Singleton P and Sainsbury D., Dictionary of Microbiology and

Molecular Biology 3rd ed., J. Wiley & Sons, Chichester, New York, 2001, and Fields Virology 4th ed., Knipe D.M. and Howley P.M. eds, Lippincott Williams & Wilkins, Philadelphia 2001.

As used herein, the term “antibody” means an immunoglobulin molecule or a
5 fragment of an immunoglobulin molecule having the ability to specifically bind to a
particular antigen. Antibodies are well known to those of ordinary skill in the science of
immunology. As used herein, the term “antibody” means not only full-length antibody
molecules but also fragments of antibody molecules retaining antigen binding ability. Such
fragments are also well known in the art and are regularly employed both *in vitro* and *in*
10 *vivo*. In particular, as used herein, the term “antibody” means not only full-length
immunoglobulin molecules but also antigen binding active fragments such as the well-
known active fragments F(ab')₂, Fab, Fv, and Fd.

As used herein, the terms “Hendra Virus Disease” and “Nipah Virus Disease” refer
to diseases caused, directly or indirectly, by infection with Hendra or Nipah virus. The
15 broad species tropisms and the ability to cause fatal disease in both animals and humans
have distinguished Hendra virus (HeV) and Nipah virus (NiV) from all other known
paramyxoviruses (Eaton B.T. 2001 *Microbes Infect* 3:277-278). These viruses can be
amplified and cause disease in large animals and can be transmitted to humans where
infection is manifested as a severe respiratory illness and/or febrile encephalitis.

20 As used herein with respect to polypeptides, the term “substantially pure” means
that the polypeptides are essentially free of other substances with which they may be found
in nature or *in vivo* systems to an extent practical and appropriate for their intended use. In
particular, the polypeptides are sufficiently pure and are sufficiently free from other
biological constituents of their host cells so as to be useful in, for example, generating
25 antibodies, sequencing, or producing pharmaceutical preparations. By techniques well
known in the art, substantially pure polypeptides may be produced in light of the nucleic
acid and amino acid sequences disclosed herein. Because a substantially purified
polypeptide of the invention may be admixed with a pharmaceutically acceptable carrier in
a pharmaceutical preparation, the polypeptide may comprise only a certain percentage by
30 weight of the preparation. The polypeptide is nonetheless substantially pure in that it has
been substantially separated from the substances with which it may be associated in living
systems.

As used herein with respect to nucleic acids, the term "isolated" means: (i) amplified *in vitro* by, for example, polymerase chain reaction (PCR); (ii) recombinantly produced by cloning; (iii) purified, as by cleavage and gel separation; or (iv) synthesized by, for example, chemical synthesis. An isolated nucleic acid is one which is readily
5 manipulable by recombinant DNA techniques well known in the art. Thus, a nucleotide sequence contained in a vector in which 5' and 3' restriction sites are known or for which polymerase chain reaction (PCR) primer sequences have been disclosed is considered isolated but a nucleic acid sequence existing in its native state in its natural host is not. An isolated nucleic acid may be substantially purified, but need not be. For example, a nucleic
10 acid that is isolated within a cloning or expression vector is not pure in that it may comprise only a tiny percentage of the material in the cell in which it resides. Such a nucleic acid is isolated, however, as the term is used herein because it is readily manipulable by standard techniques known to those of ordinary skill in the art.

As used herein, a coding sequence and regulatory sequences are said to be "operably
15 joined" when they are covalently linked in such a way as to place the expression or transcription of the coding sequence under the influence or control of the regulatory sequences. If it is desired that the coding sequences be translated into a functional protein, two DNA sequences are said to be operably joined if induction of a promoter in the 5' regulatory sequences results in the transcription of the coding sequence and if the nature of
20 the linkage between the two DNA sequences does not (1) result in the introduction of a frame-shift mutation, (2) interfere with the ability of the promoter region to direct the transcription of the coding sequences, or (3) interfere with the ability of the corresponding RNA transcript to be translated into a protein. Thus, a promoter region would be operably joined to a coding sequence if the promoter region were capable of effecting transcription
25 of that DNA sequence such that the resulting transcript might be translated into the desired protein or polypeptide.

The precise nature of the regulatory sequences needed for gene expression may vary between species or cell types, but shall in general include, as necessary, 5' non-transcribing and 5' non-translating sequences involved with initiation of transcription and translation
30 respectively, such as a TATA box, capping sequence, CAAT sequence, and the like. Especially, such 5' non-transcribing regulatory sequences will include a promoter region which includes a promoter sequence for transcriptional control of the operably joined gene.

Regulatory sequences may also include enhancer sequences or upstream activator sequences, as desired.

As used herein, a "vector" may be any of a number of nucleic acids into which a desired sequence may be inserted by restriction and ligation for transport between different genetic environments or for expression in a host cell. Vectors are typically composed of DNA although RNA vectors are also available. Vectors include, but are not limited to, plasmids and phagemids. A cloning vector is one which is able to replicate in a host cell, and which is further characterized by one or more endonuclease restriction sites at which the vector may be cut in a determinable fashion and into which a desired DNA sequence may be ligated such that the new recombinant vector retains its ability to replicate in the host cell. In the case of plasmids, replication of the desired sequence may occur many times as the plasmid increases in copy number within the host bacterium or just a single time per host before the host reproduces by mitosis. In the case of phage, replication may occur actively during a lytic phase or passively during a lysogenic phase. An expression vector is one into which a desired DNA sequence may be inserted by restriction and ligation such that it is operably joined to regulatory sequences and may be expressed as an RNA transcript. Vectors may further contain one or more marker sequences suitable for use in the identification and selection of cells which have been transformed or transfected with the vector. Markers include, for example, genes encoding proteins which increase or decrease either resistance or sensitivity to antibiotics or other compounds, genes which encode enzymes whose activities are detectable by standard assays known in the art (*e.g.*, β -galactosidase or alkaline phosphatase), and genes which visibly affect the phenotype of transformed or transfected cells, hosts, colonies or plaques. Preferred vectors are those capable of autonomous replication and expression of the structural gene products present in the DNA segments to which they are operably joined.

Novel Anti-HeV and NiV G Glycoprotein Monoclonal Antibodies

The present invention derives, in part, from the isolation and characterization of novel, fully human monoclonal antibodies that selectively bind to and neutralize Hendra and Nipah viruses. As described more fully below, these monoclonal antibodies have been shown to bind the G glycoprotein and to neutralize Hendra and Nipah viruses. The paratope of the anti-HeV and NiV Fab fragments associated with the neutralization epitope on the HeV and NiV glycoprotein G are defined by the amino acid (aa) sequences of the

immunoglobulin heavy and light chain V-regions described in Tables A and B and SEQ ID NO: 1 through SEQ ID NO: 416.

In one set of embodiments, the present invention provides the full-length, fully human Hendra and Nipah monoclonal antibodies in isolated form and in pharmaceutical preparations. Similarly, as described below, the present invention provides isolated nucleic acids, host cells transformed with nucleic acids, and pharmaceutical preparations including isolated nucleic acids, encoding the full-length, fully human Hendra and Nipah monoclonal antibodies. Finally, the present invention provides methods, as described more fully below, employing these antibodies and nucleic acids in the *in vitro* and *in vivo* diagnosis, prevention and therapy of Hendra Virus Disease or Nipah Virus Disease.

Significantly, as is well-known in the art, only a small portion of an antibody molecule, the paratope, is involved in the binding of the antibody to its epitope (see, in general, Clark, W.R. 1986 in The Experimental Foundations of Modern Immunology Wiley & Sons, Inc., New York; Roitt, I. 1991 in Essential Immunology, 7th Ed., Blackwell Scientific Publications, Oxford). The pFc' and Fc regions, for example, are effectors of the complement cascade but are not involved in antigen binding. An antibody from which the pFc' region has been enzymatically cleaved, or which has been produced without the pFc' region, designated an F(ab')₂ fragment, retains both of the antigen binding sites of a full-length antibody. Similarly, an antibody from which the Fc region has been enzymatically cleaved, or which has been produced without the Fc region, designated an Fab fragment, retains one of the antigen binding sites of a full-length antibody molecule. Proceeding further, Fab fragments consist of a covalently bound antibody light chain and a portion of the antibody heavy chain denoted Fd. The Fd fragments are the major determinant of antibody specificity (a single Fd fragment may be associated with up to ten different light chains without altering antibody specificity) and Fd fragments retain epitope-binding ability in isolation.

Within the antigen-binding portion of an antibody, as is well-known in the art, there are complementarity determining regions (CDRs), which directly interact with the epitope of the antigen, and framework regions (FRs), which maintain the tertiary structure of the paratope (see, in general, Clark, 1986, *supra*; Roitt, 1991, *supra*). In both the heavy chain Fd fragment and the light chain of IgG immunoglobulins, there are four framework regions (FR1 through FR4) separated respectively by three complementarity determining regions

(CDR1 through CDR3). The CDRs, and in particular the CDR3 regions, and more particularly the heavy chain CDR3, are largely responsible for antibody specificity.

The complete amino acid sequences of the antigen-binding Fab portions of the Hendra and Nipah monoclonal antibodies as well as the relevant FR and CDR regions are disclosed herein. SEQ ID NOs: 1, 17, 33, 49, 65, 81, 97, 113, 129, 145, 161, 177, 193, 209, 225, 241, 257, 273, 289, 305, 321, 337, 353, 369, 385, and 401 disclose the amino acid sequences of the Fd fragment of the Hendra and Nipah monoclonal antibodies. The amino acid sequences of the heavy chain FR1, CDR1, FR2, CDR2, FR3, CDR3 and FR4 regions are disclosed as (FR1, SEQ ID NOs: 2, 18, 34, 50, 66, 82, 98, 114, 130, 146, 162, 178, 194, 210, 226, 242, 258, 274, 290, 306, 322, 338, 354, 370, 386, and 402); (CDR1, SEQ ID NOs: 3, 19, 35, 51, 67, 83, 99, 115, 131, 147, 163, 179, 195, 211, 227, 243, 259, 275, 291, 307, 323, 339, 355, 371, 387, and 403); (FR2, SEQ ID NOs: 4, 20, 36, 52, 68, 84, 100, 116, 132, 148, 164, 180, 196, 212, 228, 244, 260, 276, 292, 308, 324, 340, 356, 372, 388, and 404); (CDR2, SEQ ID NOs: 5, 21, 37, 53, 69, 85, 101, 117, 133, 149, 165, 181, 197, 213, 229, 245, 261, 277, 293, 309, 325, 341, 357, 373, 389, and 405); (FR3, SEQ ID NOs: 6, 22, 38, 54, 70, 86, 102, 118, 134, 150, 166, 182, 198, 214, 230, 246, 262, 278, 294, 310, 326, 342, 358, 374, 390, and 406); (CDR3, SEQ ID NOs: 7, 23, 39, 55, 71, 87, 103, 119, 135, 151, 167, 183, 199, 215, 231, 247, 263, 279, 295, 311, 327, 343, 359, 375, 391, and 407); and (FR4, SEQ ID NOs: 8, 24, 40, 56, 72, 88, 104, 120, 136, 152, 168, 184, 200, 216, 232, 248, 264, 280, 296, 312, 328, 344, 360, 376, 392 and 408). SEQ ID NOs: 9, 25, 41, 57, 73, 89, 105, 121, 137, 153, 169, 185, 201, 217, 233, 249, 265, 281, 297, 313, 329, 345, 361, 377, 393 and 409 disclose the amino acid sequences of the light chains of the Hendra and Nipah monoclonal antibodies. The amino acid sequences of the light chain FR1, CDR1, FR2, CDR2, FR3, CDR3 and FR4 regions are disclosed as (FR1, SEQ ID NOs: 10, 26, 42, 58, 74, 90, 106, 122, 138, 154, 170, 186, 202, 218, 234, 250, 266, 282, 298, 314, 330, 346, 362, 378, 394, and 410); (CDR1, SEQ ID NOs: 11, 27, 43, 59, 75, 91, 107, 123, 139, 155, 171, 187, 203, 219, 235, 251, 267, 283, 299, 315, 331, 347, 363, 379, 395, and 411); (FR2, SEQ ID NOs: 12, 28, 44, 60, 76, 92, 108, 124, 140, 156, 172, 188, 204, 220, 236, 252, 268, 284, 300, 316, 332, 348, 364, 380, 396, and 412); (CDR2, SEQ ID NOs: 13, 29, 45, 61, 77, 93, 109, 125, 141, 157, 173, 189, 205, 221, 237, 253, 269, 285, 301, 317, 333, 349, 365, 381, 397, and 413); (FR3, SEQ ID NOs: 14, 30, 46, 62, 78, 94, 110, 126, 142, 158, 174, 190, 206, 222, 238, 254, 270, 286, 302, 318, 334, 350, 366, 382, 398, and 414); (CDR3, SEQ ID NOs: 15, 31, 47, 63, 79, 95, 111, 127, 143, 159, 175, 191, 207, 223, 239, 255, 271,

287, 303, 319, 335, 351, 367, 383, 399, and 415); (FR4, SEQ ID NOs: 16, 32, 48, 64, 80, 96, 112, 128, 144, 160, 176, 192, 208, 224, 240, 256, 272, 288, 304, 320, 336, 352, 368, 384, 400 and 416).

It is now well-established in the art that the non-CDR regions of a mammalian antibody may be replaced with similar regions of conspecific or heterospecific antibodies while retaining the epitopic specificity of the original antibody. This is most clearly manifested in the development and use of "humanized" antibodies in which non-human CDRs are covalently joined to human FR and/or Fc/pFc' regions to produce a functional antibody. Thus, for example, PCT International Publication Number WO 92/04381 teaches the production and use of humanized murine RSV antibodies in which at least a portion of the murine FR regions have been replaced by FR regions of human origin. Such antibodies, including fragments of full-length antibodies with antigen-binding ability, are often referred to as "chimeric" antibodies.

Thus, as will be apparent to one of ordinary skill in the art, the present invention also provides for F(ab')₂, Fab, Fv and Fd fragments of Hendra and Nipah monoclonal antibodies; chimeric antibodies in which the Fc and/or FR and/or CDR1 and/or CDR2 and/or light chain CDR3 regions of the Hendra and Nipah monoclonal antibodies have been replaced by homologous human or non-human sequences; chimeric F(ab')₂ fragment antibodies in which the FR and/or CDR1 and/or CDR2 and/or light chain CDR3 regions of the Hendra and Nipah monoclonal antibodies have been replaced by homologous human or non-human sequences; chimeric Fab fragment antibodies in which the FR and/or CDR1 and/or CDR2 and/or light chain CDR3 regions have been replaced by homologous human or non-human sequences; and chimeric Fd fragment antibodies in which the FR and/or CDR1 and/or CDR2 regions have been replaced by homologous human or non-human sequences. Thus, those skilled in the art may alter the Hendra and Nipah monoclonal antibodies by the construction of CDR grafted or chimeric antibodies or antibody fragments containing all, or part thereof, of the disclosed heavy and light chain V-region CDR aa sequences (Jones, P.T. et al. 1986 *Nature* **321**:522-525; Verhoeyen, M. et al. 1988 *Science* **39**:1534-1536; and Tempest, P.R. et al. 1991 *Biotechnology* **9**:266-271), without destroying the specificity of the antibodies for the G glycoprotein epitope. Such CDR grafted or chimeric antibodies or antibody fragments can be effective in prevention and treatment of Hendra or Nipah virus infection in animals (e.g., horses) and man.

In preferred embodiments, the chimeric antibodies of the invention are fully human monoclonal antibodies including at least the heavy chain CDR3 region of the Hendra and Nipah monoclonal antibodies. As noted above, such chimeric antibodies may be produced in which some or all of the FR regions of the Hendra and Nipah monoclonal antibodies have been replaced by other homologous human FR regions. In addition, the Fc portions may be replaced so as to produce IgA or IgM as well as IgG antibodies bearing some or all of the CDRs of the Hendra and Nipah monoclonal antibodies. Of particular importance is the inclusion of the Hendra and Nipah monoclonal antibodies heavy chain CDR3 region and, to a lesser extent, the other CDRs of the Hendra and Nipah monoclonal antibodies. Such fully human or chimeric antibodies will have particular utility in that they will not evoke an immune response against the antibody itself.

It is also possible, in accordance with the present invention, to produce chimeric antibodies including non-human sequences. Thus, one may use, for example, murine, ovine, equine, bovine or other mammalian Fc or FR sequences to replace some or all of the Fc or FR regions of the Hendra and Nipah monoclonal antibodies. Some of the CDRs may be replaced as well. Again, however, it is preferred that at least the heavy chain CDR3 of the Hendra and Nipah monoclonal antibodies, be included in such chimeric antibodies and, to a lesser extent, it is also preferred that some or all of the other CDRs of the Hendra and Nipah monoclonal antibodies be included. Such chimeric antibodies bearing non-human immunoglobulin sequences admixed with the CDRs of the human Hendra and Nipah monoclonal antibodies are not preferred for use in humans and are particularly not preferred for extended use because they may evoke an immune response against the non-human sequences. They may, of course, be used for brief periods or in immunosuppressed individuals but, again, fully human monoclonal antibodies are preferred. Because, however, Hendra and Nipah viruses also infect animals and because such antibodies may be used for brief periods or in immunosuppressed subjects, chimeric antibodies bearing non-human mammalian Fc and FR sequences but including at least the heavy chain CDR3 of the Hendra and Nipah monoclonal antibodies are contemplated as alternative embodiments of the present invention.

For inoculation or prophylactic uses, the antibodies of the present invention are preferably full-length antibody molecules including the Fc region. Such full-length antibodies will have longer half-lives than smaller fragment antibodies (*e.g.*, Fab) and are

more suitable for intravenous, intraperitoneal, intramuscular, intracavity, subcutaneous, or transdermal administration.

In some embodiments, Fab fragments, including chimeric Fab fragments, are preferred. Fabs offer several advantages over $F(ab')_2$ and whole immunoglobulin molecules for this therapeutic modality. First, because Fabs have only one binding site for their cognate antigen, the formation of immune complexes is precluded whereas such complexes can be generated when bivalent $F(ab')_2$ s and whole immunoglobulin molecules encounter their target antigen. This is of some importance because immune complex deposition in tissues can produce adverse inflammatory reactions. Second, because Fabs lack an Fc region they cannot trigger adverse inflammatory reactions that are activated by Fc, such as activation of the complement cascade. Third, the tissue penetration of the small Fab molecule is likely to be much better than that of the larger whole antibody. Fourth, Fabs can be produced easily and inexpensively in bacteria, such as *E. coli*, whereas whole immunoglobulin antibody molecules require mammalian cells for their production in useful amounts. The latter entails transfection of immunoglobulin sequences into mammalian cells with resultant transformation. Amplification of these sequences must then be achieved by rigorous selective procedures and stable transformants must be identified and maintained. The whole immunoglobulin molecules must be produced by stably transformed, high expression mammalian cells in culture with the attendant problems of serum-containing culture medium. In contrast, production of Fabs in *E. coli* eliminates these difficulties and makes it possible to produce these antibody fragments in large fermenters which are less expensive than cell culture-derived products.

In addition to Fabs, smaller antibody fragments and epitope-binding peptides having binding specificity for the epitopes defined by the Hendra and Nipah monoclonal antibodies are also contemplated by the present invention and can also be used to bind or neutralize the virus. For example, single chain antibodies can be constructed according to the method of U.S. Pat. No. 4,946,778, to Ladner et al. Single chain antibodies comprise the variable regions of the light and heavy chains joined by a flexible linker moiety. Yet smaller is the antibody fragment known as the single domain antibody or Fd, which comprises an isolated V_H single domain. Techniques for obtaining a single domain antibody with at least some of the binding specificity of the full-length antibody from which they are derived are known in the art.

It is possible to determine, without undue experimentation, if an altered or chimeric antibody has the same specificity as the Hendra and Nipah monoclonal antibodies by ascertaining whether the former blocks the latter from binding to G glycoprotein. If the monoclonal antibody being tested competes with the Hendra or Nipah monoclonal antibody as shown by a decrease in binding of the Hendra or Nipah monoclonal antibody, then it is likely that the two monoclonal antibodies bind to the same, or a closely spaced, epitope. Still another way to determine whether a monoclonal antibody has the specificity of the Hendra and Nipah monoclonal antibodies is to pre-incubate the Hendra or Nipah monoclonal antibody with G glycoprotein with which it is normally reactive, and then add the monoclonal antibody being tested to determine if the monoclonal antibody being tested is inhibited in its ability to bind G glycoprotein. If the monoclonal antibody being tested is inhibited then, in all likelihood, it has the same, or a functionally equivalent, epitope and specificity as the Hendra and Nipah monoclonal antibodies of the invention. Screening of Hendra and Nipah monoclonal antibodies also can be carried out by utilizing Hendra or Nipah viruses and determining whether the mAb neutralizes the virus.

By using the antibodies of the invention, it is now possible to produce anti-idiotypic antibodies which can be used to screen other monoclonal antibodies to identify whether the antibody has the same binding specificity as an antibody of the invention. In addition, such anti-idiotypic antibodies can be used for active immunization (Herlyn, D. et al. 1986 *Science* **232**:100-102). Such anti-idiotypic antibodies can be produced using well-known hybridoma techniques (Kohler, G. and Milstein, C. 1975 *Nature* **256**:495-497). An anti-idiotypic antibody is an antibody which recognizes unique determinants present on the monoclonal antibody produced by the cell line of interest. These determinants are located in the hypervariable region of the antibody. It is this region which binds to a given epitope and, thus, is responsible for the specificity of the antibody. An anti-idiotypic antibody can be prepared by immunizing an animal with the monoclonal antibody of interest. The immunized animal will recognize and respond to the idiotypic determinants of the immunizing antibody and produce an antibody to these idiotypic determinants. By using the anti-idiotypic antibodies of the immunized animal, which are specific for the monoclonal antibodies of the invention, it is possible to identify other clones with the same idio type as the antibody of the hybridoma used for immunization. Idiotypic identity between monoclonal antibodies of two cell lines demonstrates that the two monoclonal antibodies are the same with respect to their recognition of the same epitopic determinant.

Thus, by using anti-idiotypic antibodies, it is possible to identify other hybridomas expressing monoclonal antibodies having the same epitopic specificity.

It is also possible to use the anti-idiotypic technology to produce monoclonal antibodies which mimic an epitope. For example, an anti-idiotypic monoclonal antibody
5 made to a first monoclonal antibody will have a binding domain in the hypervariable region which is the image of the epitope bound by the first monoclonal antibody. Thus, the anti-idiotypic monoclonal antibody can be used for immunization, since the anti-idiotypic monoclonal antibody binding domain effectively acts as an antigen.

Nucleic Acids Encoding Anti-HeV and NiV G Glycoprotein Antibodies

Given the disclosure herein of the amino acid sequences of the heavy chain Fd and light chain variable domains of the Hendra and Nipah monoclonal antibodies, one of ordinary skill in the art is now enabled to produce nucleic acids which encode this antibody or which encode the various fragment antibodies or chimeric antibodies described above. It is contemplated that such nucleic acids will be operably joined to other nucleic acids forming a recombinant vector for cloning or for expression of the antibodies of the invention. The present invention includes any recombinant vector containing the coding sequences, or part thereof, whether for prokaryotic or eukaryotic transformation, transfection or gene therapy. Such vectors may be prepared using conventional molecular biology techniques, known to those with skill in the art, and would comprise DNA coding sequences for the immunoglobulin V-regions of the Hendra and Nipah monoclonal antibodies, including framework and CDRs or parts thereof, and a suitable promoter either with (Whittle, N. et al. 1987 *Protein Eng* 1:499-505 and Burton, D.R. et al. 1994 *Science* 266:1024-1027) or without (Marasco, W.A. et al. 1993 *Proc Natl Acad Sci USA* 90:7889-7893 and Duan, L. et al. 1994 *Proc Natl Acad Sci USA* 91:5075-5079) a signal sequence for export or secretion. Such vectors may be transformed or transfected into prokaryotic (Huse, W.D. et al. 1989 *Science* 246:1275-1281; Ward, S. et al. 1989 *Nature* 341:544-546; Marks, J.D. et al. 1991 *J Mol Biol* 222:581-597; and Barbas, C.F. et al. 1991 *Proc Natl Acad Sci USA* 88:7978-7982) or eukaryotic (Whittle, N. et al. 1987 *Protein Eng* 1:499-505 and Burton, D.R. et al. 1994 *Science* 266:1024-1027) cells or used for gene therapy (Marasco, W.A. et al. 1993 *Proc Natl Acad Sci USA* 90:7889-7893 and Duan, L. et al. 1994 *Proc Natl Acad Sci USA* 91:5075-5079) by conventional techniques, known to those with skill in the art.

The expression vectors of the present invention include regulatory sequences operably joined to a nucleotide sequence encoding one of the antibodies of the invention. As used herein, the term "regulatory sequences" means nucleotide sequences which are necessary for or conducive to the transcription of a nucleotide sequence which encodes a desired polypeptide and/or which are necessary for or conducive to the translation of the resulting transcript into the desired polypeptide. Regulatory sequences include, but are not limited to, 5' sequences such as operators, promoters and ribosome binding sequences, and 3' sequences such as polyadenylation signals. The vectors of the invention may optionally include 5' leader or signal sequences, 5' or 3' sequences encoding fusion products to aid in

protein purification, and various markers which aid in the identification or selection of transformants. The choice and design of an appropriate vector is within the ability and discretion of one of ordinary skill in the art. The subsequent purification of the antibodies may be accomplished by any of a variety of standard means known in the art.

5 A preferred vector for screening monoclonal antibodies, but not necessarily preferred for the mass production of the antibodies of the invention, is a recombinant DNA molecule containing a nucleotide sequence that codes for and is capable of expressing a fusion polypeptide containing, in the direction of amino- to carboxy-terminus, (1) a prokaryotic secretion signal domain, (2) a polypeptide of the invention, and, optionally, (3)
10 a fusion protein domain. The vector includes DNA regulatory sequences for expressing the fusion polypeptide, preferably prokaryotic, regulatory sequences. Such vectors can be constructed by those with skill in the art and have been described by Smith, G.P. et al. (1985 *Science* **228**:1315-1317); Clackson, T. et al. (1991 *Nature* **352**:624-628); Kang et al. (1991 in *Methods: A Companion to Methods in Enzymology*, vol. 2, R.A. Lerner and D.R.
15 Burton, ed. Academic Press, NY, pp 111-118); Barbas, C.F. et al. (1991 *Proc Natl Acad Sci USA* **88**:7978-7982); Roberts, B.L. et al. (1992 *Proc Natl Acad Sci USA* **89**:2429-2433).

A fusion polypeptide may be useful for purification of the antibodies of the invention. The fusion domain may, for example, include a poly-His tail which allows for purification on Ni⁺ columns or the maltose binding protein of the commercially available
20 vector pMAL (New England BioLabs, Beverly, MA). A currently preferred, but by no means necessary, fusion domain is a filamentous phage membrane anchor. This domain is particularly useful for screening phage display libraries of monoclonal antibodies but may be of less utility for the mass production of antibodies. The filamentous phage membrane anchor is preferably a domain of the cpIII or cpVIII coat protein capable of associating with
25 the matrix of a filamentous phage particle, thereby incorporating the fusion polypeptide onto the phage surface, to enable solid phase binding to specific antigens or epitopes and thereby allow enrichment and selection of the specific antibodies or fragments encoded by the phagemid vector.

The secretion signal is a leader peptide domain of a protein that targets the protein
30 to the membrane of the host cell, such as the periplasmic membrane of Gram-negative bacteria. A preferred secretion signal for *E. coli* is a pelB secretion signal. The leader sequence of the pelB protein has previously been used as a secretion signal for fusion proteins (Better, M. et al. 1988 *Science* **240**:1041-1043; Sastry, L. et al. 1989 *Proc Natl*

Acad Sci USA **86**:5728-5732; and Mullinax, R.L. et al., 1990 *Proc Natl Acad Sci USA* **87**:8095-8099). Amino acid residue sequences for other secretion signal polypeptide domains from *E. coli* useful in this invention can be found in Neidhard, F.C. (ed.), 1987 in *Escherichia coli* and *Salmonella Typhimurium*: Typhimurium Cellular and Molecular

5 *Biology*, American Society for Microbiology, Washington, D.C.

To achieve high levels of gene expression in *E. coli*, it is necessary to use not only strong promoters to generate large quantities of mRNA, but also ribosome binding sites to ensure that the mRNA is efficiently translated. In *E. coli*, the ribosome binding site includes an initiation codon (AUG) and a sequence 3-9 nucleotides long located 3-11

10 nucleotides upstream from the initiation codon (Shine J. and Dalgarno L. 1975 *Nature* **254**:34-38). The sequence, which is called the Shine-Dalgarno (SD) sequence, is complementary to the 3' end of *E. coli* 16S rRNA. Binding of the ribosome to mRNA and the sequence at the 3' end of the mRNA can be affected by several factors: the degree of complementarity between the SD sequence and 3' end of the 16S rRNA; the spacing lying

15 between the SD sequence and the AUG; and the nucleotide sequence following the AUG, which affects ribosome binding. The 3' regulatory sequences define at least one termination (stop) codon in frame with and operably joined to the heterologous fusion polypeptide.

In preferred embodiments with a prokaryotic expression host, the vector utilized

20 includes a prokaryotic origin of replication or replicon, *i.e.*, a DNA sequence having the ability to direct autonomous replication and maintenance of the recombinant DNA molecule extrachromosomally in a prokaryotic host cell, such as a bacterial host cell, transformed therewith. Such origins of replication are well known in the art. Preferred origins of replication are those that are efficient in the host organism. A preferred host cell

25 is *E. coli*. For use of a vector in *E. coli*, a preferred origin of replication is ColEI found in pBR322 and a variety of other common plasmids. Also preferred is the p15A origin of replication found on pACYC and its derivatives. The ColEI and p15A replicons have been extensively utilized in molecular biology, are available on a variety of plasmids and are described by Sambrook et al., 1989, in *Molecular Cloning: A Laboratory Manual*, 2nd

30 edition, Cold Spring Harbor Laboratory Press.

In addition, those embodiments that include a prokaryotic replicon preferably also include a gene whose expression confers a selective advantage, such as drug resistance, to a bacterial host transformed therewith. Typical bacterial drug resistance genes are those that

confer resistance to ampicillin, tetracycline, neomycin/kanamycin or chloramphenicol. Vectors typically also contain convenient restriction sites for insertion of translatable DNA sequences. Exemplary vectors are the plasmids pUC18 and pUC19 and derived vectors such as those commercially available from suppliers such as Invitrogen (San Diego, CA).

5 When the antibodies of the invention include both heavy chain and light chain sequences, these sequences may be encoded on separate vectors or, more conveniently, may be expressed by a single vector. The heavy and light chain may, after translation or after secretion, form the heterodimeric structure of natural antibody molecules. Such a heterodimeric antibody may or may not be stabilized by disulfide bonds between the heavy
10 and light chains.

 A vector for expression of heterodimeric antibodies, such as the full-length antibodies of the invention or the F(ab')₂, Fab or Fv fragment antibodies of the invention, is a recombinant DNA molecule adapted for receiving and expressing translatable first and second DNA sequences. That is, a DNA expression vector for expressing a heterodimeric
15 antibody provides a system for independently cloning (inserting) the two translatable DNA sequences into two separate cassettes present in the vector, to form two separate cistrons for expressing the first and second polypeptides of a heterodimeric antibody. The DNA expression vector for expressing two cistrons is referred to as a dicistronic expression vector.

20 Preferably, the vector comprises a first cassette that includes upstream and downstream DNA regulatory sequences operably joined via a sequence of nucleotides adapted for directional ligation to an insert DNA. The upstream translatable sequence preferably encodes the secretion signal as described above. The cassette includes DNA regulatory sequences for expressing the first antibody polypeptide that is produced when an
25 insert translatable DNA sequence (insert DNA) is directionally inserted into the cassette via the sequence of nucleotides adapted for directional ligation.

 The dicistronic expression vector also contains a second cassette for expressing the second antibody polypeptide. The second cassette includes a second translatable DNA sequence that preferably encodes a secretion signal, as described above, operably joined at
30 its 3' terminus via a sequence of nucleotides adapted for directional ligation to a downstream DNA sequence of the vector that typically defines at least one stop codon in the reading frame of the cassette. The second translatable DNA sequence is operably joined at its 5' terminus to DNA regulatory sequences forming the 5' elements. The second

cassette is capable, upon insertion of a translatable DNA sequence (insert DNA), of expressing the second fusion polypeptide comprising a secretion signal with a polypeptide coded by the insert DNA.

The antibodies of the present invention may additionally, of course, be produced by eukaryotic cells such as CHO cells, human or mouse hybridomas, immortalized B-lymphoblastoid cells, and the like. In this case, a vector is constructed in which eukaryotic regulatory sequences are operably joined to the nucleotide sequences encoding the antibody polypeptide or polypeptides. The design and selection of an appropriate eukaryotic vector is within the ability and discretion of one of ordinary skill in the art. The subsequent purification of the antibodies may be accomplished by any of a variety of standard means known in the art.

The antibodies of the present invention may furthermore, of course, be produced in plants. In 1989, Hiatt A. et al. 1989 *Nature* **342**:76-78 first demonstrated that functional antibodies could be produced in transgenic plants. Since then, a considerable amount of effort has been invested in developing plants for antibody (or "plantibody") production (for reviews see Giddings, G. et al. 2000 *Nat Biotechnol* 18:1151-1155; Fischer, R. and Emans, N. 2000 *Transgenic Res* **9**:279-299). Recombinant antibodies can be targeted to seeds, tubers, or fruits, making administration of antibodies in such plant tissues advantageous for immunization programs in developing countries and worldwide.

In another embodiment, the present invention provides host cells, both prokaryotic and eukaryotic, transformed or transfected with, and therefore including, the vectors of the present invention.

Diagnostic and Pharmaceutical Anti-HeV and NiV G Glycoprotein Antibody Preparations

The invention also relates to a method for preparing diagnostic or pharmaceutical compositions comprising the monoclonal antibodies of the invention or polynucleotide sequences encoding the antibodies of the invention or part thereof, the pharmaceutical compositions being used for immunoprophylaxis or immunotherapy of Hendra Virus Disease or Nipah Virus Disease. The pharmaceutical preparation includes a pharmaceutically acceptable carrier. Such carriers, as used herein, means a non-toxic material that does not interfere with the effectiveness of the biological activity of the active ingredients. The term "physiologically acceptable" refers to a non-toxic material that is compatible with a biological system such as a cell, cell culture, tissue, or organism. The

characteristics of the carrier will depend on the route of administration. Physiologically and pharmaceutically acceptable carriers include diluents, fillers, salts, buffers, stabilizers, solubilizers, and other materials which are well known in the art.

A preferred embodiment of the invention relates to monoclonal antibodies whose
5 heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 7, and/or whose light chains comprise in CDR3 the polypeptide having SEQ ID NO: 15; whose heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 23, and/or whose light chains comprise in CDR3 the polypeptide having SEQ ID NO: 31; whose heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 39, and/or whose light chains comprise in
10 CDR3 the polypeptide having SEQ ID NO: 47; whose heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 55, and/or whose light chains comprise in CDR3 the polypeptide having SEQ ID NO: 63; whose heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 71, and/or whose light chains comprise in CDR3 the polypeptide having SEQ ID NO: 79; whose heavy chains comprise in CDR3 the
15 polypeptide having SEQ ID NO: 87, and/or whose light chains comprise in CDR3 the polypeptide having SEQ ID NO: 95; whose heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 103, and/or whose light chains comprise in CDR3 the polypeptide having SEQ ID NO: 111; whose heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 119, and/or whose light chains comprise in CDR3 the
20 polypeptide having SEQ ID NO: 127; whose heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 135, and/or whose light chains comprise in CDR3 the polypeptide having SEQ ID NO: 143; whose heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 151, and/or whose light chains comprise in CDR3 the polypeptide having SEQ ID NO: 159; whose heavy chains comprise in CDR3 the
25 polypeptide having SEQ ID NO: 167, and/or whose light chains comprise in CDR3 the polypeptide having SEQ ID NO: 175; whose heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 183, and/or whose light chains comprise in CDR3 the polypeptide having SEQ ID NO: 191; whose heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 199, and/or whose light chains comprise in CDR3 the
30 polypeptide having SEQ ID NO: 207; whose heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 215, and/or whose light chains comprise in CDR3 the polypeptide having SEQ ID NO: 223; whose heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 231, and/or whose light chains comprise in CDR3 the

polypeptide having SEQ ID NO: 239; whose heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 247, and/or whose light chains comprise in CDR3 the polypeptide having SEQ ID NO: 255; whose heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 263, and/or whose light chains comprise in CDR3 the polypeptide having SEQ ID NO: 271; whose heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 279, and/or whose light chains comprise in CDR3 the polypeptide having SEQ ID NO: 287; whose heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 295, and/or whose light chains comprise in CDR3 the polypeptide having SEQ ID NO: 303; whose heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 311, and/or whose light chains comprise in CDR3 the polypeptide having SEQ ID NO: 319; whose heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 327, and/or whose light chains comprise in CDR3 the polypeptide having SEQ ID NO: 335; whose heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 343, and/or whose light chains comprise in CDR3 the polypeptide having SEQ ID NO: 351; whose heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 359, and/or whose light chains comprise in CDR3 the polypeptide having SEQ ID NO: 367; whose heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 375, and/or whose light chains comprise in CDR3 the polypeptide having SEQ ID NO: 383; whose heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 391, and/or whose light chains comprise in CDR3 the polypeptide having SEQ ID NO: 399; whose heavy chains comprise in CDR3 the polypeptide having SEQ ID NO: 407, and/or whose light chains comprise in CDR3 the polypeptide having SEQ ID NO: 415; and conservative variations of these peptides. The term "conservative variation" as used herein denotes the replacement of an amino acid residue by another, biologically similar residue. Examples of conservative variations include the substitution of one hydrophobic residue such as isoleucine, valine, leucine or methionine for another, or the substitution of one polar residue for another, such as the substitution of arginine for lysine, glutamic for aspartic acids, or glutamine for asparagine, and the like. The term "conservative variation" also includes the use of a substituted amino acid in place of an unsubstituted parent amino acid provided that antibodies having the substituted polypeptide also bind or neutralize Hendra or Nipah virus. Analogously, another preferred embodiment of the invention relates to polynucleotides which encode the above noted heavy chain polypeptides and to polynucleotide sequences which are

complementary to these polynucleotide sequences. Complementary polynucleotide sequences include those sequences that hybridize to the polynucleotide sequences of the invention under stringent hybridization conditions.

The anti-Hendra and Nipah antibodies of the invention may be labeled by a variety of means for use in diagnostic and/or pharmaceutical applications. There are many different labels and methods of labeling known to those of ordinary skill in the art. Examples of the types of labels which can be used in the present invention include enzymes, radioisotopes, fluorescent compounds, colloidal metals, chemiluminescent compounds, and bioluminescent compounds. Those of ordinary skill in the art will know of other suitable labels for binding to the monoclonal antibodies of the invention, or will be able to ascertain such, using routine experimentation. Furthermore, the binding of these labels to the monoclonal antibodies of the invention can be done using standard techniques common to those of ordinary skill in the art.

Another labeling technique which may result in greater sensitivity consists of coupling the antibodies to low molecular weight haptens. These haptens can then be specifically altered by means of a second reaction. For example, it is common to use haptens such as biotin, which reacts with avidin, or dinitrophenol, pyridoxal, or fluorescein, which can react with specific anti-hapten antibodies.

The materials for use in the assay of the invention are ideally suited for the preparation of a kit. Such a kit may comprise a carrier means being compartmentalized to receive in close confinement one or more container means such as vials, tubes, and the like, each of the container means comprising one of the separate elements to be used in the method. For example, one of the container means may comprise a monoclonal antibody of the invention that is, or can be, detectably labeled. The kit may also have containers containing buffer(s) and/or a container comprising a reporter-means, such as a biotin-binding protein, such as avidin or streptavidin, bound to a reporter molecule, such as an enzymatic or fluorescent label.

***In vitro* Detection and Diagnostics**

The monoclonal antibodies of the invention are suited for *in vitro* use, for example, in immunoassays in which they can be utilized in liquid phase or bound to a solid phase carrier. In addition, the monoclonal antibodies in these immunoassays can be detectably labeled in various ways. Examples of types of immunoassays which can utilize the monoclonal antibodies of the invention are competitive and non-competitive immunoassays

in either a direct or indirect format. Examples of such immunoassays are the radioimmunoassay (RIA) and the sandwich (immunometric) assay. Detection of antigens using the monoclonal antibodies of the invention can be done utilizing immunoassays which are run in either the forward, reverse, or simultaneous modes, including
5 immunohistochemical assays on physiological samples. Those of skill in the art will know, or can readily discern, other immunoassay formats without undue experimentation.

The monoclonal antibodies of the invention can be bound to many different carriers and used to detect the presence of Hendra or Nipah virus. Examples of well-known carriers include glass, polystyrene, polypropylene, polyethylene, dextran, nylon, amylase, natural
10 and modified cellulose, polyacrylamide, agarose and magnetite. The nature of the carrier can be either soluble or insoluble for purposes of the invention. Those skilled in the art will know of other suitable carriers for binding monoclonal antibodies, or will be able to ascertain such, using routine experimentation.

For purposes of the invention, Hendra or Nipah virus may be detected by the
15 monoclonal antibodies of the invention when present in biological fluids and tissues. Any sample containing a detectable amount of Hendra or Nipah virus can be used. A sample can be a liquid such as urine, saliva, cerebrospinal fluid, blood, serum or the like; a solid or semi-solid such as tissues, feces, or the like; or, alternatively, a solid tissue such as those commonly used in histological diagnosis.

20 ***In vivo* Detection of Hendra or Nipah Virus**

In using the monoclonal antibodies of the invention for the *in vivo* detection of antigen, the detectably labeled monoclonal antibody is given in a dose which is diagnostically effective. The term "diagnostically effective" means that the amount of detectably labeled monoclonal antibody is administered in sufficient quantity to enable
25 detection of the site having the Hendra or Nipah virus antigen for which the monoclonal antibodies are specific.

The concentration of detectably labeled monoclonal antibody which is administered should be sufficient such that the binding to Hendra or Nipah virus is detectable compared to the background. Further, it is desirable that the detectably labeled monoclonal antibody
30 be rapidly cleared from the circulatory system in order to give the best target-to-background signal ratio.

As a rule, the dosage of detectably labeled monoclonal antibody for *in vivo* diagnosis will vary depending on such factors as age, sex, and extent of disease of the

individual. The dosage of monoclonal antibody can vary from about 0.01 mg/kg to about 50 mg/kg, preferably 0.1 mg/kg to about 20 mg/kg, most preferably about 0.1 mg/kg to about 2 mg/kg. Such dosages may vary, for example, depending on whether multiple injections are given, on the tissue being assayed, and other factors known to those of skill in the art.

For *in vivo* diagnostic imaging, the type of detection instrument available is a major factor in selecting an appropriate radioisotope. The radioisotope chosen must have a type of decay which is detectable for the given type of instrument. Still another important factor in selecting a radioisotope for *in vivo* diagnosis is that the half-life of the radioisotope be long enough such that it is still detectable at the time of maximum uptake by the target, but short enough such that deleterious radiation with respect to the host is acceptable. Ideally, a radioisotope used for *in vivo* imaging will lack a particle emission but produce a large number of photons in the 140-250 keV range, which may be readily detected by conventional gamma cameras.

For *in vivo* diagnosis, radioisotopes may be bound to immunoglobulin either directly or indirectly by using an intermediate functional group. Intermediate functional groups which often are used to bind radioisotopes which exist as metallic ions are the bifunctional chelating agents such as diethylenetriaminepentaacetic acid (DTPA) and ethylenediaminetetra-acetic acid (EDTA) and similar molecules. Typical examples of metallic ions which can be bound to the monoclonal antibodies of the invention are ^{111}In , ^{97}Ru , ^{67}Ga , ^{68}Ga , ^{72}As , ^{89}Zr and ^{201}Tl .

The monoclonal antibodies of the invention can also be labeled with a paramagnetic isotope for purposes of *in vivo* diagnosis, as in magnetic resonance imaging (MRI) or electron spin resonance (ESR). In general, any conventional method for visualizing diagnostic imaging can be utilized. Usually gamma and positron emitting radioisotopes are used for camera imaging and paramagnetic isotopes for MRI. Elements which are particularly useful in such techniques include ^{157}Gd , ^{55}Mn , ^{162}Dy , ^{52}Cr and ^{56}Fe .

The monoclonal antibodies of the invention can be used *in vitro* and *in vivo* to monitor the course of Hendra Virus Disease or Nipah Virus Disease therapy. Thus, for example, by measuring the increase or decrease in the number of cells infected with Hendra or Nipah virus or changes in the concentration of Hendra or Nipah virus present in the body or in various body fluids, it would be possible to determine whether a particular therapeutic regimen aimed at ameliorating Hendra Virus Disease or Nipah Virus Disease is effective.

Prophylaxis and Therapy of Hendra Virus Disease and Nipah Virus Disease

The monoclonal antibodies can also be used in prophylaxis and as therapy for Hendra Virus Disease and Nipah Virus Disease in both humans and other animals. The terms, “prophylaxis” and “therapy” as used herein in conjunction with the monoclonal antibodies of the invention denote both prophylactic as well as therapeutic administration and both passive immunization with substantially purified polypeptide products, as well as gene therapy by transfer of polynucleotide sequences encoding the product or part thereof. Thus, the monoclonal antibodies can be administered to high-risk subjects in order to lessen the likelihood and/or severity of Hendra Virus Disease and Nipah Virus Disease or administered to subjects already evidencing active Hendra or Nipah virus infection. In the present invention, Fab fragments also bind or neutralize Hendra or Nipah virus and therefore may be used to treat infection but full-length antibody molecules are otherwise preferred.

As used herein, a “prophylactically effective amount” of the monoclonal antibodies of the invention is a dosage large enough to produce the desired effect in the protection of individuals against Hendra or Nipah virus infection for a reasonable period of time, such as one to two months or longer following administration. A prophylactically effective amount is not, however, a dosage so large as to cause adverse side effects, such as hyperviscosity syndromes, pulmonary edema, congestive heart failure, and the like. Generally, a prophylactically effective amount may vary with the subject's age, condition, and sex, as well as the extent of the disease in the subject and can be determined by one of skill in the art. The dosage of the prophylactically effective amount may be adjusted by the individual physician or veterinarian in the event of any complication. A prophylactically effective amount may vary from about 0.01 mg/kg to about 50 mg/kg, preferably from about 0.1 mg/kg to about 20 mg/kg, most preferably from about 0.2 mg/kg to about 2 mg/kg, in one or more administrations (priming and boosting).

As used herein, a “therapeutically effective amount” of the monoclonal antibodies of the invention is a dosage large enough to produce the desired effect in which the symptoms of Hendra Virus Disease or Nipah Virus Disease are ameliorated or the likelihood of infection is decreased. A therapeutically effective amount is not, however, a dosage so large as to cause adverse side effects, such as hyperviscosity syndromes, pulmonary edema, congestive heart failure, and the like. Generally, a therapeutically effective amount may vary with the subject's age, condition, and sex, as well as the extent

of the disease in the subject and can be determined by one of skill in the art. The dosage of the therapeutically effective amount may be adjusted by the individual physician or veterinarian in the event of any complication. A therapeutically effective amount may vary from about 0.01 mg/kg to about 50 mg/kg, preferably from about 0.1 mg/kg to about 20 mg/kg, most preferably from about 0.2 mg/kg to about 2 mg/kg, in one or more dose administrations daily, for one or several days. Preferred is administration of the antibody for 2 to 5 or more consecutive days in order to avoid "rebound" of virus replication from occurring.

The monoclonal antibodies of the invention can be administered by injection or by gradual infusion over time. The administration of the monoclonal antibodies of the invention may, for example, be intravenous, intraperitoneal, intramuscular, intracavity, subcutaneous, or transdermal. Techniques for preparing injectate or infusate delivery systems containing antibodies are well known to those of skill in the art. Generally, such systems should utilize components which will not significantly impair the biological properties of the antibodies, such as the paratope binding capacity (see, for example, Remington's Pharmaceutical Sciences, 18th edition, 1990, Mack Publishing). Those of skill in the art can readily determine the various parameters and conditions for producing antibody injectates or infusates without resort to undue experimentation.

Preparations for parenteral administration include sterile aqueous or non-aqueous solutions, suspensions, and emulsions. Examples of non-aqueous solvents are propylene glycol, polyethylene glycol, vegetable oils such as olive oil, and injectable organic esters such as ethyl oleate. Aqueous carriers include water, alcoholic/aqueous solutions, emulsions or suspensions, including saline and buffered media. Parenteral vehicles include sodium chloride solution, Ringer's dextrose, dextrose and sodium chloride, lactated Ringer's or fixed oils. Intravenous vehicles include fluid and nutrient replenishers, electrolyte replenishers (such as those based on Ringer's dextrose), and the like. Preservatives and other additives may also be present such as, for example, antimicrobials, anti-oxidants, chelating agents, and the like.

Potent Neutralization of Hendra and Nipah Viruses by Human Monoclonal Antibodies

Selection of phage-displayed Fabs (m101-7) specific for Hendra virus soluble G glycoprotein (sG)

Our initial efforts to develop G-specific human monoclonal antibodies (hmAbs) by using cell-associated G and synthetic antibody libraries as well as an immune library

constructed from frozen lymphocytes of a survivor from Nipah infection have not been successful. To develop hmAbs against the G envelope glycoprotein of HeV and NiV we used a large naïve human Fab library containing about 10^{10} different phage-displayed Fabs we have recently developed. Here, we have made use of a unique soluble and secreted form of the attachment (G) glycoprotein of HeV (sG) which we have recently produced and characterized (Bossart, K. N. et al. 2005 *J Virol* **79**:6690-6702). This protein was used as an antigen for screening of the antibody library. After four rounds of panning, screening of 380 individual phage clones was performed in phage ELISA with sG as described in Example 1. Of those, 71 clones that exhibited significant binding to sG were sequenced. Seventeen Fabs had unique sequences (Table 1). They were expressed in bacteria, purified and tested for binding activity. Seven Fabs, designated m101 through m107, exhibited significant ($A_{450} > 0.5$) binding to sG in ELISA (Table 1). Notably, on average, the heavy chain CDR3s (H3) of the binders (m101-7) were significantly longer than those of Fabs that bind weaker (m108-17) (Table 1). Interestingly, the heavy chains of m101 and m102 (the most potent HeV and NiV neutralizers – see below) were the most divergent from the germ line heavy chains indicating a certain level of maturation although they are IgM specific. The light chains were from all Ig classes and show greater variation as compared to the germ line light chains (Table 2).

Inhibition of HeV Env-mediated fusion by the selected Fabs

To test the neutralizing activity of the antibodies we first measured their ability to inhibit fusion mediated by HeV envelope glycoprotein (Env) expressing cells with cells that we had previously identified as fusion-competent. Fusion was measured by two assays – a reporter gene assay and a syncytia formation assay. The seven Fabs that bound strongly to sG (Table 1) also exhibited measurable inhibitory activity in the reporter gene assay (Table 3) and were selected for further characterization. They also inhibited syncytia formation to various degrees in general correlation with the inhibitory activity measured by the reporter gene assay. Interestingly, six of the seven Fabs also inhibited to various degrees NiV Env-mediated fusion (Table 3). One antibody, m101, was most active against HeV Env-mediated fusion, while another one, m102, exhibited the highest cross-inhibitory activity against both HeV- and NiV Env-mediated fusion.

Neutralization of HeV and NiV by Fabs

The inhibitory activity of these Fabs was further tested by using infectious HeV and NiV in a neutralization assay as described in the Example 1. When tested at concentrations

above 80 µg/ml, Fab m101 showed neutralizing activity against HeV but not against NiV, and Fab m102 exhibited weaker neutralizing activity against HeV as compared to m101. Interestingly, as in the cell fusion assay, m102 exhibited cross-neutralizing activity for both HeV and NiV. The other tested Fabs did not show measurable neutralizing activity when tested at concentrations up to 100 µg/ml. These results indicated that two of the selected Fabs could neutralize infectious HeV and NiV.

Potent inhibitory activity of IgG1 m101 against HeV Env-mediated fusion and live virus

..... In most cases, but not always, whole antibodies are better neutralizers than Fabs. Thus the most potent HeV-fusion inhibiting Fab, m101, was converted to a whole antibody format (IgG1) and tested in a cell fusion assay. The IgG1 m101 inhibitory activity was much higher than the activity of the Fab m101 (Figs. 1 and 2). The conversion of Fab m101 to IgG1 dramatically decreased its IC50s. For HeLa-ATCC cells which exhibit lower fusion rates, the IC50 decreased from 4.2 µg/ml to 0.5 µg/ml (Figure 1A). For the highly fusogenic PCI-13 cells, the IC50 decreased from 38 µg/ml to 1.2 µg/ml (Figure 1B). In another experiment the IgG1 m101 inhibited 95% of fusion at 3 µg/ml. IgG1 m101 also potently inhibited syncytia formation in correlation with its inhibitory activity measured by the reporter gene assay. An example using the highly fusogenic PCI-13 cells is shown in Figure 2. Here IgG1 m101 completely inhibited formation of syncytia at 10 µg/ml, whereas at the same concentration, Fab m101 inhibited approximately 50% of syncytia formation.

IgG1 m101 was also exceptionally potent in neutralizing infectious HeV. Complete (100 %) neutralization was achieved at 12.5 µg/ml, more than 99 % at 6 µg/ml, and 98% at 1.6 µg/ml (Table 4). These results demonstrated that IgG1 m101 is a very potent neutralizer of infectious HeV.

25 Mechanism of virus entry inhibition by the antibodies: correlation with binding to native G

To begin to elucidate the mechanisms of the inhibitory activity of the selected antibodies we measured their binding rate constants and affinities to sG in a Biacore assay. The antibodies bound with high (1 to 10³ nM range) affinity to sG as measured by Biacore (Table 5). The on rate constants varied significantly but there was no significant variation in the off rate constants except the very low dissociation rate constant of m102. The best inhibitors of HeV G-mediated fusion and infection, m101 and m102, exhibited the highest affinity. In this context there was correlation between binding to sG and fusion inhibition

by groups of antibodies divided into good (m101 and m102) and poor (the rest) neutralizers although direct mathematically calculated correlation between the Biacore measured affinity of each antibody to sG and fusion inhibitory activity was not found.

To find other possible correlations between binding and inhibition we measured
5 binding to native G which was immunoprecipitated from lysates of cells infected with recombinant vaccinia viruses. The extent of immunoprecipitation, which is proportional to the antibody binding affinity to native full-length G glycoprotein, was highest for m101 binding to HeV G (Fig. 3). Two of these antibodies, m102 and m106 demonstrated significant cross-reactivity to both HeV and NiV G (Fig. 3). The levels of
10 immunoprecipitation correlated with cell fusion (Table 3) indicating that binding to native G is a better correlate of fusion inhibitory activity than binding to soluble G.

Outcompeting the receptor ephrin-B2 as a mechanism of virus entry inhibition by m101 and m102

To further define the mechanism of virus entry inhibition by the most potent
15 neutralizer m101 we measured its competition with the recently identified receptor for Hendra and Nipah viruses, ephrin-B2 (Bonaparte M.I. et al. 2005 *Proc Natl Acad Sci USA* **102**:10652-10657). M101 competed with ephrin-B2 for binding to sG; IgG m101 was a much better competitor than Fab m101 (Fig. 4), which correlates with their inhibitory activity and is likely due to the multivalent nature of their interaction. Similar results were
20 obtained with m102 and by using Biacore (supplemental Fig. 2 in Bonaparte M.I. et al. 2005 *Proc Natl Acad Sci USA* **102**:10652-10657). These data indicate that m101 and m102 inhibit entry of Hendra virus and likely Nipah virus by preventing the access of these viruses to their receptor. They also indicate that the epitopes of m101 and m102 overlap with the receptor binding site on G. Interestingly, m106 competed with ephrin-B2 much
25 weaker than m101 and only at very high concentrations (Fig. 4).

Further characterization of the epitopes of the selected anti-G antibodies

To further characterize the epitopes of the newly identified antibodies we measured the competition of m101, m102, m103, m106 and m107 with one another by ELISA (presently, there are no anti-Hendra G antibodies with known epitopes). The m101, m102,
30 and m103 antibodies competed with each other indicating that they bind to overlapping epitopes that are distinct from the epitopes of m106 and m107. Interestingly, m103 appears to synergize with m106 leading to increased binding of one in the presence of the other. These results indicate that m101-3 may neutralize the virus by a different mechanism from

m106 and m107 but further studies with ephrin competition are needed to definitely elucidate the mechanism of their neutralizing activity.

In an initial attempt to localize the epitopes of m101 and m102 we measured their binding to a panel of 10 G alanine scanning mutants, selected to represent different portions
5 of the protein: G183A, L184A, P185A, (Q191, K192A), S195A, D289A, K324A, (I385, H386A), L517A, N570A, where the two double mutants are in parentheses. Of these mutants only one, G183A, decreases binding of both m101 and m102 to G; this mutant bound strongly to anti-G rabbit polyclonal antibodies and to the receptor ephrin-B2. (Fig. 5). The G183 residue is localized at the base of the globular head of the G protein
10 according to a model structure (Yu M. et al. 1998 *Virology* **251**:227-233), and could be a part of the antibody epitope that does not overlap with the receptor binding site on G. Another residue, N570, appears to decrease binding of m102 to G but not the binding of m101 and the receptor (Fig. 5). This residue could be a part of the m102 epitope that does not overlap with the epitope of m101 and the receptor binding site on G.

Table 1: Selection of phage clones with unique sequences that exhibit significant binding to sG

Fab	H3 Sequence	A ₄₅₀
m101	D P G G Y S Y G P Y Y Y Y Y G M D V	1.0
m102	G W G R E Q L A P H P S Q Y Y Y Y Y Y G M D V	1.4
m103	D S R Y H D A F D I	0.8
m104	E S S W L D A F D I	0.7
m105	V G G I T G T A D A F D I	0.9
m106	D Q L A G Y Y Y D S S G Y H Y Y Y Y G M D V	1.6
m107	D H V H G P D A F D I	0.6
m108	V G G A F D I	0.5
m109	G W F R D W Y F D L	0.0
m110	E G L P E T D D A F D I	0.0
m111	E G A D Y	0.0
m112	D G A D Y	0.4
m113	Y K L Q S D A F D I	0.1
m114	A G P V G A T T G T F D Y	0.0
m115	G S Q S Y D H Y Y Y Y	0.4
m116	D S A G L G A	0.3
m117	R E S G P E F F Q H	0.0

5 Screening of 380 individual phage clones was performed in phage ELISA with sG as described in Example 1. The sequences of the HC CDR3s (H3s) of phage-displayed Fabs that exhibited significant binding to sG in phage ELISA are shown as identified according to the IMGT database (<http://imgt.cines.fr>). Soluble Fabs were expressed, purified, and tested in ELISA for binding to sG. The solution absorbance at 450 nm (A₄₅₀) is shown as a measure of the strength of binding.

Table 2: V-gene families and number of amino acids changed compared to the germ line

Antibody	VH family	VL family	VH changes	VL changes
m101	VH1	Vk1	2	6
m102	VH1	Vk3	5	8
m103	VH3	Vk2	0	0
m104	VH1	Vk2	0	13
m105	VH3	Vk1	0	0
m106	VH1	Vk1	0	0
m107	VH1	V λ 1	1	3

Shown are the gene families for the V_H genes, which are IgM specific, and for the V_L genes, which are from all Ig classes, and their variations compared to germline sequences.

Table 3: Inhibition of HeV Env-mediated cell fusion by the selected Fabs

Fab	HeV	NiV
m101	+++	+
m102	++	++
m103	+	0
m104	+	+
m105	0	+
m106	+	++
m107	0	+
m108-17	0	0
X5	0	0

Anti-HeV G Fabs were used for inhibition of fusion as described in Example 1. A summary of four different experiments are shown where each + is a measure of increased inhibitory activity, and 0 means no measurable fusion activity compared to the background.

- 5 Fab X5 is a control antibody specific for the HIV-1 gp120 (Moulard, M. et al. 2002 *Proc Natl Acad Sci USA* **99**:6913-6918).

Table 4: Neutralization of infectious HeV by IgG1 m101

Antibody concentration (µg/ml)	Number of foci per well in each replica				Average number of foci (% neutralization)
25	0	0	0	0	0 (100)
12.5	0	0	0	0	0 (100)
6.2	0	0	1	0	0.25 (99)
3.1	1	0	1	0	0.5 (98)
1.6	1	1	0	0	0.5 (98)
0.8	5	2	2	2	2.75 (91)
0	30	37	34	30	33 (0)

5 IgG1 m101 was incubated with infectious HeV and the mixture added to plated Vero cells. After the 30 minute incubation, antibody-virus mixtures were removed, cells were washed and fresh EMEM-10 containing fresh antibody was added to the cells and incubated overnight. The average number of foci in the absence of antibody was 33. The percentage of neutralization shown below in parentheses was calculated by subtracting the number of foci in the wells with antibodies from the number of foci without antibodies and dividing the resulting number by the number of foci without antibodies, and multiplying by 100.

Table 5: Binding rate constants and affinities of selected Fabs

Antibody	k_a ($\times 10^4$) $M^{-1} s^{-1}$	k_d ($\times 10^{-3}$) s^{-1}	K_d , nM
m101	13	3.5	28
m102	5.7	0.068	1.2
m103	*	*	1800
m104	0.3	1.6	600
m105	7.4	5.1	69
m106	6.2	3.3	54
m107	30	2.2	78

Interaction between various Fabs and sG was analyzed at 25°C by surface plasmon resonance technology. Fabs at different concentrations were injected at flow rate of 30 μ l/min, and the association and dissociation phase data were fitted simultaneously to a 1:1 Langmuir global model by using the nonlinear data analysis program BIAevaluation 3.2. Individual association rate constant, k_a , dissociation rate constant, k_d , and equilibrium dissociation constant, K_d , were obtained from at least three separate experiments. The standard deviation was on average about 20%. * denotes that only steady state affinity was calculated due to fast kinetics.

10 Discussion

The major finding of this study is the identification of an antibody, m101, with exceptional potency against infectious HeV. Six other antibodies were also identified that are specific for HeV G and two of them significantly cross-reacted with NiV G. To our knowledge these antibodies are the first human monoclonal antibodies (hmAbs) identified against HeV and NiV. Interestingly, the only monoclonal antibody, Synagis (Pollack, P. and Groothuis, J. R. 2002 *J Infect Chemother* **8**:201-206) (palivizumab, MEDI-493), approved by FDA for clinical use against a viral disease (Dimitrov, D. S. 2004 *Nat Rev Microbiol* **2**:109-122), is also specific for a paramyxovirus, respiratory syncytial virus (RSV); it is a humanized version of a mouse antibody and is used for prevention of RSV infections in neonates and immune-compromised individuals. Synagis inhibits virus entry and cell fusion *in vitro* very potently, it appears that its efficacy *in vivo* is correlated to its potency *in vitro*, and it was proposed that its fusion-inhibiting activity could be a major determinant of its potency *in vivo* (Johnson, S. et al. 1999 *J Infect Dis* **180**:35-40). Because RSV and henipaviruses enter cells by the same pathway, fusion at the cell surface and not through endocytosis as most other enveloped viruses do (Dimitrov, D. S. 2004 *Nat Rev Microbiol* **2**:109-122), and are members of the same virus family, one predicts that m101 might be equally if not more effective against HeV as palivizumab is against RSV.

Each of the newly identified Fabs were examined in HeV and NiV-mediated cell fusion assays to evaluate their potential in blocking binding and/or the subsequent membrane fusion process. The Fab m101 demonstrated the most potent cell-fusion inhibitory activity, and m102 exhibited cross-reactive activity against both HeV and NiV.

5 The mechanism by which m101 and m102 inhibit HeV fusion and infection is by blocking the interaction of G with ephrin-B2, which we recently identified as a functional receptor for HeV and NiV (Bonaparte et al. 2005 *Proc Natl Acad Sci USA* **102**:10652-10657) (the receptor function of ephrin-B2 for NiV was also independently identified by using a different approach (Negrete O.A. et al. 2005 *Nature* **436**:401-405)). However, an

10 alternative possibility is that these antibodies bind to G and can also prevent its required interaction with the F glycoprotein to trigger the fusion process. There was a general correlation between their inhibitory activity and binding affinity of the Fabs to the G glycoprotein especially to the native membrane-associated protein as measured by immunoprecipitation.

15 Conversion of Fab m101 to IgG1 led to potent neutralization of infectious HeV where it neutralized more than 90% at concentration less than 1 µg/ml. One could speculate that this may be due to increased stability and avidity of the antibody and/or its ability to cross-link the oligomeric G glycoprotein on the surfaces of virus and infected cells. Nonetheless, the extreme potency of IgG1 m101 in infectious HeV neutralization

20 assays suggests that it may be important to convert other Fabs to IgG1 for evaluation as potent neutralizing hmAbs.

There is considerable amino acid homology between the F and G Envs of HeV and NiV (Harcourt, B. H. et al. 2000 *Virology* **271**:334-349; Wang, L. et al. 2001 *Microbes Infect* **3**:279-287). Previous studies have demonstrated that HeV and NiV antisera do cross

25 neutralize, with each serum being slightly less effective against the heterotypic virus (Cramer, G. et al. 2002 *J Virol Methods* **99**:41-51; Tamin, A. 2002 *Virology* **296**:190-200). Further, the HeV and NiV glycoproteins can functionally complement one another in mediating membrane fusion with wild-type efficiency (Bossart, K. N. and Broder, C. C. 2004 *Methods Mol Biol* **269**:309-332; Bossart, K. N. et al. 2002 *J Virol* **76**:11186-11198).

30 Thus, we anticipated that if antibodies were identified using sG from HeV some should display cross-reactive binding to shared epitopes between HeV and NiV. Indeed, two of the seven Fabs were capable of reacting equally well in immunoprecipitation of recombinant membrane-associated HeV and NiV G. In addition, m102 was capable of inhibiting HeV

and NiV-mediated fusion and may reflect a conserved epitope between these viruses that could be important not only for neutralization but also for the entry mechanism. Upon conversion to an IgG1, m102 might be capable of potentially neutralizing both HeV and NiV.

Antibody binding competition assays revealed that the panel of Fabs developed here, comprise two distinct groups and Fabs within each group possess overlapping epitopes. Analysis of the anti-G Fabs by Western-blotting revealed no reactivity to G, indicating that the epitopes recognized by these Fabs are likely conformation dependent. The most potent neutralizers, m101 and m102, bound to most of the alanine mutants tested except one which appears to be located at the base of the globular head of G according to a model of its structure (Yu M. et al. 1998 *Virology* **251**:227-233). Further studies are needed to precisely localize their epitopes.

Taken together, our results demonstrate new immuno-therapeutics against HeV and NiV. These human antibodies are also expected to be useful for diagnosis, as research reagents and serving as the basis for vaccines.

Example 1

Cells and culture conditions

HeLa-USU cells were provided by Anthony Maurelli, Uniformed Services University (USU). HeLa-ATCC was obtained from the American Tissue Culture Collection (ATCC #CCL 2). Vero cells were provided by Alison O'Brien, USU. The human glioblastoma cell line U373-MG was provided by Adam P. Geballe, Fred Hutchinson Cancer Research Center (Harrington R.D. 1993 *J Virol* **67**:5939-5947). The Human head and neck carcinoma PCI 13 cell line was the gift of Ernest Smith, Vaccinex, Inc. HeLa-USU, HeLa-ATCC, and U373 cells were maintained in Dulbecco's modified Eagle's medium (Quality Biologicals, Gaithersburg, MD.) supplemented with 10% cosmic calf serum (CCS) (HyClone, Logan, UT), and 2 mM L-glutamine (DMEM-10). PCI 13 cells were maintained in DMEM-10 supplemented with 1mM HEPES (Quality Bio.). Vero cells were maintained in Eagle's minimal essential medium (EMEM) (Quality Bio.) supplemented with 10% cosmic calf serum (CCS) (HyClone), and 2 mM L-glutamine (EMEM-10). All cell cultures were maintained at 37°C in a humidified 5% CO₂ atmosphere.

Alanine G mutants

Alanine mutations were made at specific residues in myc-tagged HeV G using site-directed mutagenesis (Stratagene). All mutants were sequenced and tested for expression.

Plasmids containing either mutant or wild type HeV Gmyc were transfected into HeLa USU monolayers using Fugene (Roche), and incubated overnight. The immunoprecipitation of the mutant G was performed as described below in the section Immunoprecipitation except that 3.0 µg of either m101 or m102 or 5 µL of rabbit polyclonal α-sHeV G sera was
5 incubated with 80 µL lysates overnight at 4°C, followed by precipitation at room temperature with 100 µL 20% Protein G-Sepharose for 45 minutes.

Selection of G-specific phage-displayed Fabs

A naïve human Fab phage display library (a total of about 10^{10} members), constructed from peripheral blood B cells of 10 healthy donors, was used for selection of
10 Fabs against purified, soluble and oligomeric HeV G glycoprotein (sG) (Bossart, K. N. et al. 2005 *J Virol* 79:6690-6702), conjugated to magnetic beads (Dynabeads M-270 Epoxy, DYNAL Inc., New Hyde Park, New York). Amplified libraries of 10^{12} phage-displayed Fabs were incubated with 5, 3, 3 and 1 µg of sG in 500 µl volume for 2 hours at room temperature during the 1st, 2nd, 3rd and 4th rounds of biopanning, respectively. After each
15 round of incubation the beads were washed 5 times for the first round and 15 times for the later rounds with PBST (PBS containing 0.05% Tween-20) to remove non-specifically bound phage, the bead-bound phage were mixed with TG1 cells for one hour at 37°C, the phage was amplified from the infected cells and used in the next round of biopanning. After the 4th round of biopanning 380 clones were randomly picked from the infected TG1
20 cells and each inoculated into 150 µl 2YT medium containing 100 µg/ml carbenicillin and 0.2% glucose in 96-well plates by using the automated BioRobotics BioPick colony picking system (Genomic Solutions, Ann Arbor, MI). After the bacterial cultures reached optical density (OD) 0.5 at 600 nm, helper phage M13K07 at 10 M.O.I. and kanamycin at 50 µg/ml final concentration were added to the medium, and the plates were further incubated at
25 30°C overnight in a shaker at 250 rpm. The phage supernatants were mixed with 3% nonfat milk in PBS at a 4:1 volume ratio and used for ELISA to identify clones of phage displaying Fabs with high sG-binding affinity. The supernatants were incubated for 2 hours at room temperature with sG protein coated at 50 ng per well in 96-well plates and washed 5 times with PBST. (sG was coated in 50 µl coating buffer (50mM NaHCO₃ pH 9.6); after
30 overnight incubation at 40°C it was blocked with 3% nonfat milk in PBS and washed 3 times with PBS containing 0.05% Tween-20). Soluble G-bound phage were detected by using horseradish-peroxidase-conjugated goat anti-M13 antibody. After incubation with the antibody, the non-specifically bound antibody was washed, the TMB substrate was

added and the solution absorbance at 450 nm (A_{450}) was measured. Clones that bound to sG with $A_{450} > 1.0$ were selected for further characterization.

Expression and purification of selected soluble Fabs

The V_H and V_L of the selected clones were sequenced, and the Fabs encoded by clones with unique sequences were expressed and purified as described below. Plasmids extracted from these clones were used for transformation of HB2151 cells. A single colony was picked from the plate containing freshly transformed cells, inoculated into 200 ml 2YT medium containing 100 μ g/ml ampicillin and 0.2% glucose, and incubated at 37°C with shaking at 250 rpm. When the culture OD at 600 nm reached 0.90, IPTG at 0.5 mM final concentration was added, and the culture was further incubated overnight at 30°C. Bacterial pellet was collected after centrifugation at 8000 g for 20 minutes and resuspended in PBS buffer containing 0.5 mU Polymixin B (Sigma-Aldrich, St. Louis, MO). After 30 min incubation with rotation at 50 rpm at room temperature, it was centrifuged at 25000 g for 25 min at 4°C, and the supernatant used for Fab purification with protein G column (Sigma-Aldrich, St. Louis, MO).

Conversion of Fab to IgG1, and IgG1 expression and purification

The Fab heavy and light chain were amplified and re-cloned in the PDR12 vector (provided by D. Burton, the Scripps Research Institute, La Jolla, CA) for whole IgG1 expression. The resulting construct was transfected and the IgG1 expressed using the FreeStyle™ 293 Expression Kit following the protocol from the manufacturer (Invitrogen, Carlsbad, CA). The IgG1 was purified from the culture medium with protein G column (Sigma-Aldrich, St. Louis, MO).

Affinity determination by surface plasmon resonance

Interactions between various Fabs and G were analyzed by surface plasmon resonance technology using a BIACORE 1000 instrument (Biacore, Pharmacia, Piscataway, NJ). sG was covalently immobilized onto a sensor chip (CM5) using carbodiimide coupling chemistry. A control reference surface was prepared for nonspecific binding and refractive index changes. For analysis of the kinetics of interactions, varying concentrations of Fabs (300, 100, 33, 11, and 3.7 nM) were injected at flow rate of 30 μ l/min using running buffer containing 150mM NaCl, 3 mM EDTA, and 0.005% P-20 (pH 7.4). The association and dissociation phase data were fitted simultaneously to a 1:1 Langmuir global model by using the nonlinear data analysis program BIAevaluation 3.2. All the experiments were performed at 25°C.

Competition ELISA

The Fabs m101, m102, m103, m106 and m107 were coated at 150, 50, 300, 300 and 100 ng per well, respectively in 50 μ l coating buffer as described above for sG, blocked with nonfat milk and washed. C-Myc tagged sG mixed with each of the Fabs in blocking buffer at final concentration 5 μ g/ml and 20 μ g/ml, respectively, were added to each of the Fab coated wells; sG (5 μ g/ml) without antibody was added to each of the coated Fabs as a positive control. Bound c-myc tagged sG protein was detected by an HRP conjugated anti-c-Myc antibody (Roche Diagnostics Corporation, Indianapolis, IN); the TMB substrate (Sigma-Aldrich, St. Louis, MO) was added and A_{450} measured.

Immunoprecipitation

HeLa-USU monolayers were infected with wild-type vaccinia (WR) or recombinant vaccinia expressing myc-tagged HeV G or NiV G at an MOI of 10 for 6 hours, then washed twice, and incubated overnight in methionine and cysteine-free essential medium plus 2.5% dialyzed fetal calf serum (Invitrogen) and 100 μ Ci of [^{35} S] ProMix/ml (Amersham Pharmacia Biotech, Piscataway, NJ). Cells were lysed in 100mM Tris-HCl (pH 8.0), 100mM NaCl, and 1% Triton X-100. Lysates were incubated with each Fab at a concentration of 1ug per 100 ul of lysate for at least one hour at 4°C, followed by precipitation at room temperature with 100 ul 20% Protein G-Sepharose (Amersham) for 45 minutes. Anti-myc antibody 9E10 (Roche Molecular Biochemicals) was used at a concentration of 2ug per 100 ul of lysate. Samples were washed twice with lysis buffer followed by one wash with DOC buffer containing 100 mM Tris-HCl (pH 8.0), 100 mM NaCl, 0.1% sodium deoxycholate, and 0.1% SDS. Samples were boiled in SDS-

Polyacrylamide gel electrophoresis (SDS-PAGE) sample buffer with 2-mercaptoethanol and analyzed by SDS-PAGE and autoradiography.

Cell-fusion assays

Fusion between HeV and NiV F and G envelope glycoprotein-expressing (effector cells) and target cells was measured by two assays: first, a reporter gene assay in which the cytoplasm of one cell population contained vaccinia virus-encoded T7 RNA polymerase and the cytoplasm of the other contained the *E. coli* lacZ gene linked to the T7 promoter; β -galactosidase (β -Gal) is synthesized only in fused cells (Bossart, K. N. and Broder, C. C. 2004 *Methods Mol Biol* **269**:309-332; Nussbaum, O. et al. 1994 *J Virol* **68**:5411-5422), and second, a syncytia assay. Typically, the expression of HeV and NiV F and G is performed in a HeV and NiV fusion and infection negative HeLa cell line derivative (HeLa-USU). Cytogenetic analysis has confirmed that the HeLa-USU cell line resistant to NiV and HeV mediated membrane fusion and live virus infection is derived from the ATCC (CCL-2) HeLa cell line. Vaccinia virus-encoded proteins (Bossart, K. N. et al. 2001 *Virology* **290**:121-135) were produced by infecting cells at a MOI of 10 and incubating infected cells at 31°C overnight. Cell-fusion reactions were conducted with the various cell mixtures in 96-well plates at 37°C. Typically, the ratio of envelope glycoprotein-expressing cells to target cells was 1:1 (2×10^5 total cells per well, 0.2-ml total volume). Cytosine arabinoside (40 μ g/ml) was added to the fusion reaction mixture to reduce nonspecific β -Gal production. For quantitative analyses, Nonidet P-40 was added (0.5% final) at 2.5 h and aliquots of the lysates were assayed for β -Gal at ambient temperature with the substrate chlorophenol red-D-galactopyranoside (CPRG; Roche Diagnostics Corp., Indianapolis, IN). For inhibition by antibodies, serial antibody dilutions were made and added to effector cell populations 30 min prior to the addition of target cell populations. All assays were performed in duplicate and fusion data were calculated and expressed as rates of β -Gal activity (change in OD at 570 nm per minute $\times$ 1,000) (Nussbaum, O. et al. 1994 *J Virol* **68**:5411-5422). They were normalized with respect to cell fusion in the absence of antibodies, and plotted as function of the antibody concentration.

The syncytia assay was performed in 48-well plates. Target PCI-13 cells were plated to reach 80% confluency at the time of the experiment. Effector cells, HeLa USU, which are non-permissive to HeV Env and NiV Env mediated fusion, were infected with recombinant vaccinia virus to express HeV G and F proteins. Three wells of a six-well plate 80% confluent HeLa-USU were incubated with both recombinant vaccinia viruses,

encoding HeV G and HeV F, MOI of 10 for each virus at 37°C for 3 h in DMEM-10 containing 2.5% cosmic calf serum, 1 ml per well, then washed once and dissociated from the plates by using 0.5 ml per well enzyme-free PBS-based cell dissociation buffer (Invitrogen Corp., Carlsbad, CA). The cells were gathered into 50 ml sterile centrifuge tube (Corning Inc., Corning, NY) and 20 ml DMEM-10 was added. The suspension was incubated 16 hours at 31°C in a humidified 5% CO₂ atmosphere. Before the experiment, the cells were centrifuged at 1200 rpm for 5 min and the pellet was re-suspended in DMEM-10. The cells were counted, centrifuged again and re-suspended at a concentration of 2×10^6 cells/ml. Cytosine arabinoside was added to a concentration of 80 µg/ml. One hundred-microliters of this cell suspension was mixed with the same amount DMEM-10 containing the antibody and incubated for 20 min at room temperature. The mixtures were added to the freshly washed (with DMEM-10) PCI-13 target cells in the 48-well plate and incubated for 3 h at 37°C in a humidified 5% CO₂ atmosphere. Photographs were taken by using phase contrast mode of an Olympus IX81 microscope with a 10x objective lens then electronically amplified whenever needed.

HeV and NiV neutralization assays

All live virus experiments were conducted under strict bio-containment procedures in a BSL-4 laboratory. 2×10^4 Vero cells were added to wells in 150 µl EMEM-10 in a 96-well plate and incubated at 37°C overnight in a humidified 5% CO₂ atmosphere. Antibodies were diluted in EMEM-10 by doubling dilution and an equal volume of either HeV or NiV was added to each dilution and incubated at 37°C for 30 min. The titer of HeV was 1.0×10^8 TCID₅₀/ml and NiV was 3.0×10^7 TCID₅₀/ml. Virus dilutions were done in EMEM-10 and chosen to generate 50 plaques following adsorption of virus for 30 min at 37°C to Vero cell monolayers (1.5×10^3 TCID₅₀/ml for HeV and 7.5×10^2 TCID₅₀/ml for NiV). Antibody-virus mixtures were added to Vero cell monolayers in quadruplicate and incubated for 30 minutes at 37°C in a humidified 5% CO₂ atmosphere. After 30 minute incubation, antibody-virus mixtures were removed and cells were washed 3 times with Ca⁺⁺/Mg⁺⁺-free PBS. Two different variations of this assay were conducted. In the first, EMEM-10 was added to Vero cells after washing and incubated overnight. In the second, the same antibody dilution as both the pre-incubation and virus incubation was added to the respective wells and incubated overnight. For both assays, the culture medium was discarded the next day, and plates immersed in ice-cold absolute methanol for 20 min prior to air-drying outside the biohazard level 4 facility. Fixed chamber slides were either stored

overnight at 4°C or immunolabeled immediately with anti-phosphoprotein (P) monospecific antiserum (Michalski, W. P. et al. 2000 *Virus Res* 69:83-93). Wells were washed in 0.01 M PBS, pH 7.2 containing 1% BSA for 5min. 40 µl of anti-P antiserum (1:200 in PBS-BSA) was applied to each well and incubated at 37°C for 30 min. Slides were rinsed with PBS containing 0.05% Tween 20 (PBS-T) and washed for 5 min in PBS-BSA. 40 µl of FITC labeled goat anti-rabbit antiserum (ICN Pharmaceuticals, Costa Mesa, USA) diluted 1:200 in PBS-BSA containing DAPI (10 µg/ml) was then applied to each well and incubated at 37°C for 30 min. Wells were rinsed again with PBS containing 0.05% Tween 20 (PBS-T) and washed for 5 min in PBS-BSA. Wells were overlaid with 100 µl Glycerol/PBS (9:1) containing DABCO (25 µg/ml) and stored in the dark prior to imaging. FITC immunofluorescence was visualized using an Olympus IX71 inverted microscope (Olympus Australia, Mt. Waverley, Australia). Percentage neutralization at a given antibody concentration was calculated as the ratio of the average number of foci per well due to cytopathic effect (CPE) to the same number for the positive control multiplied by 100.

Neutralization of HeV and NiV by Fabs was performed as follows. Fabs were diluted in EMEM-10 by doubling dilution and an equal volume of EMEM-10 containing 200 TCID₅₀ of either HeV or NiV was added to each dilution and incubated at 37°C for 30 min. The titer of HeV was 1.0×10^8 TCID₅₀/ml and NiV was 3.0×10^7 TCID₅₀/ml. 2×10^4 Vero cells were added to each Fab-virus mixture in six replicate wells and incubated for 5 days. Fab neutralization was determined by the level of cytopathic effect (CPE) in replicate wells at each Fab concentration.

Example 2

Affinity Maturation of m102

The original human Fab phage display library from which the antibodies m101-m107 were identified was used as the source of the VL repertoire in the shuffled library. The phagemid preparation from the original library was first digested with Nco I and Spe I and followed by electrophoresis on an agarose gel to separate the VH and CH1 gene fragments from the antibody light chain-containing backbone vector to delete the entire VH repertoire. The gene encoding the VH domain of clone m102 was amplified by error-prone PCR kit from Stratagene to introduce random mutations and then fused with CH1 gene fragment by SOE PCR. The fused fragment was digested with NcoI and Spe I and purified from gel and was then ligated into the purified backbone vector to create the VL-shuffled

Fab repertoire. *E. coli* TG1 cells were transformed with the ligation mixtures via electroporation. The transformed TG1 cells were plated on 2YT agar plates containing 100 µg/ml ampicillin and 2% glucose. After incubation overnight at 37°C, all of the colonies grown on the plates were scraped into 5 ml of 2YTAG medium, mixed with 1.2 ml of 50%
5 glycerol (final concentration 10%), aliquoted, and stored at -70°C as the library stock.

The library stock (100 µl) was grown to log phase in 20 ml of 2YT medium, rescued with M13K07 helper phage, and amplified overnight in 2YT medium (2YT containing 100 µg/ml of ampicillin and 50 µg/ml of kanamycin) at 30°C. The phage preparation was precipitated in 4% PEG, 0.5 M NaCl, resuspended in 1 ml of PBS as phage
10 library stock. Two round of biopanning were performed on Hendra G conjugated magnetic beads as described in the original library panning. 9 clones were identified as affinity matured antibodies and m102.4 was selected for further characterization.

While the present invention has been described in some detail for purposes of clarity
15 and understanding, one skilled in the art will appreciate that various changes in form and detail can be made without departing from the true scope of the invention. All figures, tables, and appendices, as well as patents, applications, and publications, referred to above, are hereby incorporated by reference.

WHAT IS CLAIMED IS:

1. A substantially pure polypeptide comprising an antibody selectively binding a Hendra or Nipah G glycoprotein epitope, wherein said antibody includes a heavy chain CDR3 region having the amino acid sequence selected from the group consisting of SEQ ID NO: 7, SEQ ID NO: 23, SEQ ID NO: 39, SEQ ID NO: 55, SEQ ID NO: 71, SEQ ID NO: 87, SEQ ID NO: 103, SEQ ID NO: 119, SEQ ID NO: 135, SEQ ID NO: 151, SEQ ID NO: 167, SEQ ID NO: 183, SEQ ID NO: 199, SEQ ID NO: 215, SEQ ID NO: 231, SEQ ID NO: 247, SEQ ID NO: 263, SEQ ID NO: 279, SEQ ID NO: 295, SEQ ID NO: 311, SEQ ID NO: 327, SEQ ID NO: 343, SEQ ID NO: 359, SEQ ID NO: 375, SEQ ID NO: 391 and SEQ ID NO: 407.
2. The substantially pure polypeptide of Claim 1 wherein said antibody comprises an Fd fragment.
3. The substantially pure polypeptide of Claim 1 wherein said antibody comprises an Fab fragment.
4. The substantially pure polypeptide of Claim 1 wherein said antibody includes a heavy chain CDR2 region having the amino acid sequence of :
 - a) SEQ ID NO: 5 (when heavy chain CDR3 region is SEQ ID NO: 7),
 - b) SEQ ID NO: 21 (when heavy chain CDR3 region is SEQ ID NO: 23),
 - c) SEQ ID NO: 37 (when heavy chain CDR3 region is SEQ ID NO: 39),
 - d) SEQ ID NO: 53 (when heavy chain CDR3 region is SEQ ID NO: 55),
 - e) SEQ ID NO: 69 (when heavy chain CDR3 region is SEQ ID NO: 71),
 - f) SEQ ID NO: 85 (when heavy chain CDR3 region is SEQ ID NO: 87),
 - g) SEQ ID NO: 101 (when heavy chain CDR3 region is SEQ ID NO: 103),
 - h) SEQ ID NO: 117 (when heavy chain CDR3 region is SEQ ID NO: 119),
 - i) SEQ ID NO: 133 (when heavy chain CDR3 region is SEQ ID NO: 135),
 - j) SEQ ID NO: 149 (when heavy chain CDR3 region is SEQ ID NO: 151),
 - k) SEQ ID NO: 165 (when heavy chain CDR3 region is SEQ ID NO: 167),
 - l) SEQ ID NO: 181 (when heavy chain CDR3 region is SEQ ID NO: 183),
 - m) SEQ ID NO: 197 (when heavy chain CDR3 region is SEQ ID NO: 199),
 - n) SEQ ID NO: 213 (when heavy chain CDR3 region is SEQ ID NO: 215),
 - o) SEQ ID NO: 229 (when heavy chain CDR3 region is SEQ ID NO: 231),
 - p) SEQ ID NO: 245 (when heavy chain CDR3 region is SEQ ID NO: 247),
 - q) SEQ ID NO: 261 (when heavy chain CDR3 region is SEQ ID NO: 263),

- 5 r) SEQ ID NO: 277 (when heavy chain CDR3 region is SEQ ID NO: 279),
 s) SEQ ID NO: 293 (when heavy chain CDR3 region is SEQ ID NO: 295),
 t) SEQ ID NO: 309 (when heavy chain CDR3 region is SEQ ID NO: 311),
 u) SEQ ID NO: 325 (when heavy chain CDR3 region is SEQ ID NO: 327),
 v) SEQ ID NO: 341 (when heavy chain CDR3 region is SEQ ID NO: 343),
 w) SEQ ID NO: 357 (when heavy chain CDR3 region is SEQ ID NO: 359),
 x) SEQ ID NO: 373 (when heavy chain CDR3 region is SEQ ID NO: 375),
 y) SEQ ID NO: 389 (when heavy chain CDR3 region is SEQ ID NO: 391),
 or
10 z) SEQ ID NO: 405 (when heavy chain CDR3 region is SEQ ID NO: 407).
5. The substantially pure polypeptide of Claim 4 wherein said antibody
includes a heavy chain CDR1 region having the amino acid sequence of :
- 15 a) SEQ ID NO: 3 (when heavy chain CDR3 region is SEQ ID NO: 7),
 b) SEQ ID NO: 19 (when heavy chain CDR3 region is SEQ ID NO: 23),
 c) SEQ ID NO: 35 (when heavy chain CDR3 region is SEQ ID NO: 39),
 d) SEQ ID NO: 51 (when heavy chain CDR3 region is SEQ ID NO: 55),
 e) SEQ ID NO: 67 (when heavy chain CDR3 region is SEQ ID NO: 71),
 f) SEQ ID NO: 83 (when heavy chain CDR3 region is SEQ ID NO: 87),
 g) SEQ ID NO: 99 (when heavy chain CDR3 region is SEQ ID NO: 103),
20 h) SEQ ID NO: 115 (when heavy chain CDR3 region is SEQ ID NO: 119),
 i) SEQ ID NO: 131 (when heavy chain CDR3 region is SEQ ID NO: 135),
 j) SEQ ID NO: 147 (when heavy chain CDR3 region is SEQ ID NO: 151),
 k) SEQ ID NO: 163 (when heavy chain CDR3 region is SEQ ID NO: 167),
 l) SEQ ID NO: 179 (when heavy chain CDR3 region is SEQ ID NO: 183),
25 m) SEQ ID NO: 195 (when heavy chain CDR3 region is SEQ ID NO: 199),
 n) SEQ ID NO: 211 (when heavy chain CDR3 region is SEQ ID NO: 215),
 o) SEQ ID NO: 227 (when heavy chain CDR3 region is SEQ ID NO: 231),
 p) SEQ ID NO: 243 (when heavy chain CDR3 region is SEQ ID NO: 247),
 q) SEQ ID NO: 259 (when heavy chain CDR3 region is SEQ ID NO: 263),
30 r) SEQ ID NO: 275 (when heavy chain CDR3 region is SEQ ID NO: 279),
 s) SEQ ID NO: 291 (when heavy chain CDR3 region is SEQ ID NO: 295),
 t) SEQ ID NO: 307 (when heavy chain CDR3 region is SEQ ID NO: 311),
 u) SEQ ID NO: 323 (when heavy chain CDR3 region is SEQ ID NO: 327),

- v) SEQ ID NO: 339 (when heavy chain CDR3 region is SEQ ID NO: 343),
w) SEQ ID NO: 355 (when heavy chain CDR3 region is SEQ ID NO: 359),
x) SEQ ID NO: 371 (when heavy chain CDR3 region is SEQ ID NO: 375),
y) SEQ ID NO: 387 (when heavy chain CDR3 region is SEQ ID NO: 391),
5 or
z) SEQ ID NO: 403 (when heavy chain CDR3 region is SEQ ID NO: 407).

6. The substantially pure polypeptide of Claim 1 wherein said antibody includes a heavy chain Fd region including the amino acid sequence of:

- a) SEQ ID NO: 1 (when heavy chain CDR3 region is SEQ ID NO: 7),
10 b) SEQ ID NO: 17 (when heavy chain CDR3 region is SEQ ID NO: 23),
c) SEQ ID NO: 33 (when heavy chain CDR3 region is SEQ ID NO: 39),
d) SEQ ID NO: 49 (when heavy chain CDR3 region is SEQ ID NO: 55),
e) SEQ ID NO: 65 (when heavy chain CDR3 region is SEQ ID NO: 71),
f) SEQ ID NO: 81 (when heavy chain CDR3 region is SEQ ID NO: 87),
15 g) SEQ ID NO: 97 (when heavy chain CDR3 region is SEQ ID NO: 103),
h) SEQ ID NO: 113 (when heavy chain CDR3 region is SEQ ID NO: 119),
i) SEQ ID NO: 129 (when heavy chain CDR3 region is SEQ ID NO: 135),
j) SEQ ID NO: 145 (when heavy chain CDR3 region is SEQ ID NO: 151),
k) SEQ ID NO: 161 (when heavy chain CDR3 region is SEQ ID NO: 167),
20 l) SEQ ID NO: 177 (when heavy chain CDR3 region is SEQ ID NO: 183),
m) SEQ ID NO: 193 (when heavy chain CDR3 region is SEQ ID NO: 199),
n) SEQ ID NO: 209 (when heavy chain CDR3 region is SEQ ID NO: 215),
o) SEQ ID NO: 225 (when heavy chain CDR3 region is SEQ ID NO: 231),
p) SEQ ID NO: 241 (when heavy chain CDR3 region is SEQ ID NO: 247),
25 q) SEQ ID NO: 257 (when heavy chain CDR3 region is SEQ ID NO: 263),
r) SEQ ID NO: 273 (when heavy chain CDR3 region is SEQ ID NO: 279),
s) SEQ ID NO: 289 (when heavy chain CDR3 region is SEQ ID NO: 295),
t) SEQ ID NO: 305 (when heavy chain CDR3 region is SEQ ID NO: 311),
u) SEQ ID NO: 321 (when heavy chain CDR3 region is SEQ ID NO: 327),
30 v) SEQ ID NO: 337 (when heavy chain CDR3 region is SEQ ID NO: 343),
w) SEQ ID NO: 353 (when heavy chain CDR3 region is SEQ ID NO: 359),
x) SEQ ID NO: 369 (when heavy chain CDR3 region is SEQ ID NO: 375),

y) SEQ ID NO: 385 (when heavy chain CDR3 region is SEQ ID NO: 391),
or

z) SEQ ID NO: 401 (when heavy chain CDR3 region is SEQ ID NO: 407).

7. The substantially pure polypeptide of Claim 1 wherein said antibody
5 includes a light chain CDR3 region having the amino acid sequence of:

- a) SEQ ID NO: 15 (when heavy chain CDR3 region is SEQ ID NO: 7),
- b) SEQ ID NO: 31 (when heavy chain CDR3 region is SEQ ID NO: 23),
- c) SEQ ID NO: 47 (when heavy chain CDR3 region is SEQ ID NO: 39),
- d) SEQ ID NO: 63 (when heavy chain CDR3 region is SEQ ID NO: 55),
- 10 e) SEQ ID NO: 79 (when heavy chain CDR3 region is SEQ ID NO: 71),
- f) SEQ ID NO: 95 (when heavy chain CDR3 region is SEQ ID NO: 87),
- g) SEQ ID NO: 111 (when heavy chain CDR3 region is SEQ ID NO: 103),
- h) SEQ ID NO: 127 (when heavy chain CDR3 region is SEQ ID NO: 119),
- i) SEQ ID NO: 143 (when heavy chain CDR3 region is SEQ ID NO: 135),
- 15 j) SEQ ID NO: 159 (when heavy chain CDR3 region is SEQ ID NO: 151),
- k) SEQ ID NO: 175 (when heavy chain CDR3 region is SEQ ID NO: 167),
- l) SEQ ID NO: 191 (when heavy chain CDR3 region is SEQ ID NO: 183),
- m) SEQ ID NO: 207 (when heavy chain CDR3 region is SEQ ID NO: 199),
- n) SEQ ID NO: 223 (when heavy chain CDR3 region is SEQ ID NO: 215),
- 20 o) SEQ ID NO: 239 (when heavy chain CDR3 region is SEQ ID NO: 231),
- p) SEQ ID NO: 255 (when heavy chain CDR3 region is SEQ ID NO: 247),
- q) SEQ ID NO: 271 (when heavy chain CDR3 region is SEQ ID NO: 263),
- r) SEQ ID NO: 287 (when heavy chain CDR3 region is SEQ ID NO: 279),
- s) SEQ ID NO: 303 (when heavy chain CDR3 region is SEQ ID NO: 295),
- 25 t) SEQ ID NO: 319 (when heavy chain CDR3 region is SEQ ID NO: 311),
- u) SEQ ID NO: 335 (when heavy chain CDR3 region is SEQ ID NO: 327),
- v) SEQ ID NO: 351 (when heavy chain CDR3 region is SEQ ID NO: 343),
- w) SEQ ID NO: 367 (when heavy chain CDR3 region is SEQ ID NO: 359),
- x) SEQ ID NO: 383 (when heavy chain CDR3 region is SEQ ID NO: 375),
- 30 y) SEQ ID NO: 399 (when heavy chain CDR3 region is SEQ ID NO: 391),
- or
- z) SEQ ID NO: 415 (when heavy chain CDR3 region is SEQ ID NO: 407).

8. The substantially pure polypeptide of Claim 7 wherein said antibody includes a light chain CDR2 region having the amino acid sequence of:

- a) SEQ ID NO: 13 (when heavy chain CDR3 region is SEQ ID NO: 7),
- b) SEQ ID NO: 29 (when heavy chain CDR3 region is SEQ ID NO: 23),
- 5 c) SEQ ID NO: 45 (when heavy chain CDR3 region is SEQ ID NO: 39),
- d) SEQ ID NO: 61 (when heavy chain CDR3 region is SEQ ID NO: 55),
- e) SEQ ID NO: 77 (when heavy chain CDR3 region is SEQ ID NO: 71),
- f) SEQ ID NO: 93 (when heavy chain CDR3 region is SEQ ID NO: 87),
- 10 g) SEQ ID NO: 109 (when heavy chain CDR3 region is SEQ ID NO: 103),
- h) SEQ ID NO: 125 (when heavy chain CDR3 region is SEQ ID NO: 119),
- i) SEQ ID NO: 141 (when heavy chain CDR3 region is SEQ ID NO: 135),
- j) SEQ ID NO: 157 (when heavy chain CDR3 region is SEQ ID NO: 151),
- k) SEQ ID NO: 173 (when heavy chain CDR3 region is SEQ ID NO: 167),
- 15 l) SEQ ID NO: 189 (when heavy chain CDR3 region is SEQ ID NO: 183),
- m) SEQ ID NO: 205 (when heavy chain CDR3 region is SEQ ID NO: 199),
- n) SEQ ID NO: 221 (when heavy chain CDR3 region is SEQ ID NO: 215),
- o) SEQ ID NO: 237 (when heavy chain CDR3 region is SEQ ID NO: 231),
- p) SEQ ID NO: 253 (when heavy chain CDR3 region is SEQ ID NO: 247),
- q) SEQ ID NO: 269 (when heavy chain CDR3 region is SEQ ID NO: 263),
- 20 r) SEQ ID NO: 285 (when heavy chain CDR3 region is SEQ ID NO: 279),
- s) SEQ ID NO: 301 (when heavy chain CDR3 region is SEQ ID NO: 295),
- t) SEQ ID NO: 317 (when heavy chain CDR3 region is SEQ ID NO: 311),
- u) SEQ ID NO: 333 (when heavy chain CDR3 region is SEQ ID NO: 327),
- v) SEQ ID NO: 349 (when heavy chain CDR3 region is SEQ ID NO: 343),
- 25 w) SEQ ID NO: 365 (when heavy chain CDR3 region is SEQ ID NO: 359),
- x) SEQ ID NO: 381 (when heavy chain CDR3 region is SEQ ID NO: 375),
- y) SEQ ID NO: 397 (when heavy chain CDR3 region is SEQ ID NO: 391),
- or
- z) SEQ ID NO: 413 (when heavy chain CDR3 region is SEQ ID NO: 407).

30 9. The substantially pure polypeptide of Claim 8 wherein said antibody includes a light chain CDR1 region having the amino acid sequence of:

- a) SEQ ID NO: 11 (when heavy chain CDR3 region is SEQ ID NO: 7),
- b) SEQ ID NO: 27 (when heavy chain CDR3 region is SEQ ID NO: 23),

- c) SEQ ID NO: 43 (when heavy chain CDR3 region is SEQ ID NO: 39),
- d) SEQ ID NO: 59 (when heavy chain CDR3 region is SEQ ID NO: 55),
- e) SEQ ID NO: 75 (when heavy chain CDR3 region is SEQ ID NO: 71),
- f) SEQ ID NO: 91 (when heavy chain CDR3 region is SEQ ID NO: 87),
- 5 g) SEQ ID NO: 107 (when heavy chain CDR3 region is SEQ ID NO: 103),
- h) SEQ ID NO: 123 (when heavy chain CDR3 region is SEQ ID NO: 119),
- i) SEQ ID NO: 139 (when heavy chain CDR3 region is SEQ ID NO: 135),
- j) SEQ ID NO: 155 (when heavy chain CDR3 region is SEQ ID NO: 151),
- k) SEQ ID NO: 171 (when heavy chain CDR3 region is SEQ ID NO: 167),
- 10 l) SEQ ID NO: 187 (when heavy chain CDR3 region is SEQ ID NO: 183),
- m) SEQ ID NO: 203 (when heavy chain CDR3 region is SEQ ID NO: 199),
- n) SEQ ID NO: 219 (when heavy chain CDR3 region is SEQ ID NO: 215),
- o) SEQ ID NO: 235 (when heavy chain CDR3 region is SEQ ID NO: 231),
- p) SEQ ID NO: 251 (when heavy chain CDR3 region is SEQ ID NO: 247),
- 15 q) SEQ ID NO: 267 (when heavy chain CDR3 region is SEQ ID NO: 263),
- r) SEQ ID NO: 283 (when heavy chain CDR3 region is SEQ ID NO: 279),
- s) SEQ ID NO: 299 (when heavy chain CDR3 region is SEQ ID NO: 295),
- t) SEQ ID NO: 315 (when heavy chain CDR3 region is SEQ ID NO: 311),
- u) SEQ ID NO: 331 (when heavy chain CDR3 region is SEQ ID NO: 327),
- 20 v) SEQ ID NO: 347 (when heavy chain CDR3 region is SEQ ID NO: 343),
- w) SEQ ID NO: 363 (when heavy chain CDR3 region is SEQ ID NO: 359),
- x) SEQ ID NO: 379 (when heavy chain CDR3 region is SEQ ID NO: 375),
- y) SEQ ID NO: 395 (when heavy chain CDR3 region is SEQ ID NO: 391),
- or
- 25 z) SEQ ID NO: 411 (when heavy chain CDR3 region is SEQ ID NO: 407).

10. The substantially pure polypeptide of Claim 1 wherein said antibody includes a light chain region including the amino acid sequence of :

- a) SEQ ID NO: 9 (when heavy chain CDR3 region is SEQ ID NO: 7),
- b) SEQ ID NO: 25 (when heavy chain CDR3 region is SEQ ID NO: 23),
- 30 c) SEQ ID NO: 41 (when heavy chain CDR3 region is SEQ ID NO: 39),
- d) SEQ ID NO: 57 (when heavy chain CDR3 region is SEQ ID NO: 55),
- e) SEQ ID NO: 73 (when heavy chain CDR3 region is SEQ ID NO: 71),
- f) SEQ ID NO: 89 (when heavy chain CDR3 region is SEQ ID NO: 87),

- g) SEQ ID NO: 105 (when heavy chain CDR3 region is SEQ ID NO: 103),
h) SEQ ID NO: 121 (when heavy chain CDR3 region is SEQ ID NO: 119),
i) SEQ ID NO: 137 (when heavy chain CDR3 region is SEQ ID NO: 135),
j) SEQ ID NO: 153 (when heavy chain CDR3 region is SEQ ID NO: 151),
5 k) SEQ ID NO: 169 (when heavy chain CDR3 region is SEQ ID NO: 167),
l) SEQ ID NO: 185 (when heavy chain CDR3 region is SEQ ID NO: 183),
m) SEQ ID NO: 201 (when heavy chain CDR3 region is SEQ ID NO: 199),
n) SEQ ID NO: 217 (when heavy chain CDR3 region is SEQ ID NO: 215),
o) SEQ ID NO: 233 (when heavy chain CDR3 region is SEQ ID NO: 231),
10 p) SEQ ID NO: 249 (when heavy chain CDR3 region is SEQ ID NO: 247),
q) SEQ ID NO: 265 (when heavy chain CDR3 region is SEQ ID NO: 263),
r) SEQ ID NO: 281 (when heavy chain CDR3 region is SEQ ID NO: 279),
s) SEQ ID NO: 297 (when heavy chain CDR3 region is SEQ ID NO: 295),
t) SEQ ID NO: 313 (when heavy chain CDR3 region is SEQ ID NO: 311),
15 u) SEQ ID NO: 329 (when heavy chain CDR3 region is SEQ ID NO: 327),
v) SEQ ID NO: 345 (when heavy chain CDR3 region is SEQ ID NO: 343),
w) SEQ ID NO: 361 (when heavy chain CDR3 region is SEQ ID NO: 359),
x) SEQ ID NO: 377 (when heavy chain CDR3 region is SEQ ID NO: 375),
y) SEQ ID NO: 393 (when heavy chain CDR3 region is SEQ ID NO: 391),
20 or
z) SEQ ID NO: 409 (when heavy chain CDR3 region is SEQ ID NO: 407).

11. The substantially pure polypeptide of Claim 1 wherein said antibody includes a heavy chain Fd region including the CDR amino acid sequences of:

- a) SEQ ID NO: 1 (when heavy chain CDR3 region is SEQ ID NO: 7),
25 b) SEQ ID NO: 17 (when heavy chain CDR3 region is SEQ ID NO: 23),
c) SEQ ID NO: 33 (when heavy chain CDR3 region is SEQ ID NO: 39),
d) SEQ ID NO: 49 (when heavy chain CDR3 region is SEQ ID NO: 55),
e) SEQ ID NO: 65 (when heavy chain CDR3 region is SEQ ID NO: 71),
f) SEQ ID NO: 81 (when heavy chain CDR3 region is SEQ ID NO: 87),
30 g) SEQ ID NO: 97 (when heavy chain CDR3 region is SEQ ID NO: 103),
h) SEQ ID NO: 113 (when heavy chain CDR3 region is SEQ ID NO: 119),
i) SEQ ID NO: 129 (when heavy chain CDR3 region is SEQ ID NO: 135),
j) SEQ ID NO: 145 (when heavy chain CDR3 region is SEQ ID NO: 151),

- k) SEQ ID NO: 161 (when heavy chain CDR3 region is SEQ ID NO: 167),
 l) SEQ ID NO: 177 (when heavy chain CDR3 region is SEQ ID NO: 183),
 m) SEQ ID NO: 193 (when heavy chain CDR3 region is SEQ ID NO: 199),
 n) SEQ ID NO: 209 (when heavy chain CDR3 region is SEQ ID NO: 215),
 5 o) SEQ ID NO: 225 (when heavy chain CDR3 region is SEQ ID NO: 231),
 p) SEQ ID NO: 241 (when heavy chain CDR3 region is SEQ ID NO: 247),
 q) SEQ ID NO: 257 (when heavy chain CDR3 region is SEQ ID NO: 263),
 r) SEQ ID NO: 273 (when heavy chain CDR3 region is SEQ ID NO: 279),
 s) SEQ ID NO: 289 (when heavy chain CDR3 region is SEQ ID NO: 295),
 10 t) SEQ ID NO: 305 (when heavy chain CDR3 region is SEQ ID NO: 311),
 u) SEQ ID NO: 321 (when heavy chain CDR3 region is SEQ ID NO: 327),
 v) SEQ ID NO: 337 (when heavy chain CDR3 region is SEQ ID NO: 343),
 w) SEQ ID NO: 353 (when heavy chain CDR3 region is SEQ ID NO: 359),
 x) SEQ ID NO: 369 (when heavy chain CDR3 region is SEQ ID NO: 375),
 15 y) SEQ ID NO: 385 (when heavy chain CDR3 region is SEQ ID NO: 391),
 or
 z) SEQ ID NO: 401 (when heavy chain CDR3 region is SEQ ID NO: 407).

12. The substantially pure polypeptide of Claim 11 wherein said antibody includes a light chain region including the CDR amino acid sequences of:

- 20 a) SEQ ID NO: 9 (when heavy chain CDR3 region is SEQ ID NO: 7),
 b) SEQ ID NO: 25 (when heavy chain CDR3 region is SEQ ID NO: 23),
 c) SEQ ID NO: 41 (when heavy chain CDR3 region is SEQ ID NO: 39),
 d) SEQ ID NO: 57 (when heavy chain CDR3 region is SEQ ID NO: 55),
 e) SEQ ID NO: 73 (when heavy chain CDR3 region is SEQ ID NO: 71),
 25 f) SEQ ID NO: 89 (when heavy chain CDR3 region is SEQ ID NO: 87),
 g) SEQ ID NO: 105 (when heavy chain CDR3 region is SEQ ID NO: 103),
 h) SEQ ID NO: 121 (when heavy chain CDR3 region is SEQ ID NO: 119),
 i) SEQ ID NO: 137 (when heavy chain CDR3 region is SEQ ID NO: 135),
 j) SEQ ID NO: 153 (when heavy chain CDR3 region is SEQ ID NO: 151),
 30 k) SEQ ID NO: 169 (when heavy chain CDR3 region is SEQ ID NO: 167),
 l) SEQ ID NO: 185 (when heavy chain CDR3 region is SEQ ID NO: 183),
 m) SEQ ID NO: 201 (when heavy chain CDR3 region is SEQ ID NO: 199),
 n) SEQ ID NO: 217 (when heavy chain CDR3 region is SEQ ID NO: 215),

- o) SEQ ID NO: 233 (when heavy chain CDR3 region is SEQ ID NO: 231),
p) SEQ ID NO: 249 (when heavy chain CDR3 region is SEQ ID NO: 247),
q) SEQ ID NO: 265 (when heavy chain CDR3 region is SEQ ID NO: 263),
r) SEQ ID NO: 281 (when heavy chain CDR3 region is SEQ ID NO: 279),
5 s) SEQ ID NO: 297 (when heavy chain CDR3 region is SEQ ID NO: 295),
t) SEQ ID NO: 313 (when heavy chain CDR3 region is SEQ ID NO: 311),
u) SEQ ID NO: 329 (when heavy chain CDR3 region is SEQ ID NO: 327),
v) SEQ ID NO: 345 (when heavy chain CDR3 region is SEQ ID NO: 343),
w) SEQ ID NO: 361 (when heavy chain CDR3 region is SEQ ID NO: 359),
10 x) SEQ ID NO: 377 (when heavy chain CDR3 region is SEQ ID NO: 375),
y) SEQ ID NO: 393 (when heavy chain CDR3 region is SEQ ID NO: 391),
or
z) SEQ ID NO: 409 (when heavy chain CDR3 region is SEQ ID NO: 407).
13. An isolated nucleic acid comprising
15 a nucleotide sequence encoding a polypeptide selected from the group
consisting of the polypeptide of Claim 1, the polypeptide of Claim 2, the
polypeptide of Claim 3, the polypeptide of Claim 4, the polypeptide of Claim 5, the
polypeptide of Claim 6, the polypeptide of Claim 7, the polypeptide of Claim 8, the
polypeptide of Claim 9, the polypeptide of Claim 10, the polypeptide of Claim 11,
20 and the polypeptide of Claim 12.
14. An isolated nucleic acid as in Claim 13 wherein
said nucleic acid comprises a vector including a regulatory sequence
operably joined to said nucleic acid.
15. A host cell including a vector comprising a nucleic acid of Claim 13.
- 25 16. A pharmaceutical preparation comprising
a pharmaceutically acceptable carrier; and
a substantially pure polypeptide selected from the group consisting of the
polypeptide of Claim 1, the polypeptide of Claim 2, the polypeptide of Claim 3, the
polypeptide of Claim 4, the polypeptide of Claim 5, the polypeptide of Claim 6, the
30 polypeptide of Claim 7, the polypeptide of Claim 8, the polypeptide of Claim 9, the
polypeptide of Claim 10, the polypeptide of Claim 11, and the polypeptide of Claim
12.
17. A diagnostic preparation comprising

a pharmaceutically acceptable carrier; and

a substantially pure polypeptide selected from the group consisting of the polypeptide of Claim 1, the polypeptide of Claim 2, the polypeptide of Claim 3, the polypeptide of Claim 4, the polypeptide of Claim 5, the polypeptide of Claim 6, the polypeptide of Claim 7, the polypeptide of Claim 8, the polypeptide of Claim 9, the polypeptide of Claim 10, the polypeptide of Claim 11, and the polypeptide of Claim 12.

18. A method for the treatment of Hendra Virus Disease or Nipah Virus Disease comprising

administering to a patient a therapeutically effective amount of the pharmaceutical preparation of Claim 16.

19. A method for prophylaxis against Hendra Virus Disease or Nipah Virus Disease comprising

administering to a patient a prophylactically effective amount of the pharmaceutical preparation of Claim 16.

20. A method for the diagnosis of Hendra Virus Disease or Nipah Virus Disease comprising

administering to a patient an effective amount of the diagnostic preparation of Claim 17, and

detecting binding of the substantially pure polypeptide as a determination of the presence of Hendra Virus Disease or Nipah Virus Disease.

21. A method of detecting the presence of Hendra or Nipah virus in a biological sample comprising

contacting said sample with the diagnostic preparation of Claim 17, and

assaying binding of the substantially pure polypeptide as a determination of the presence of said Hendra or Nipah virus.

22. A substantially pure polypeptide comprising a monoclonal antibody that binds the antigen to which an antibody selectively binding a Hendra or Nipah G glycoprotein epitope binds, wherein said antibody includes a heavy chain CDR3 region having the amino acid sequence selected from the group consisting of SEQ ID NO: 7, SEQ ID NO: 23, SEQ ID NO: 39, SEQ ID NO: 55, SEQ ID NO: 71, SEQ ID NO: 87, SEQ ID NO: 103, SEQ ID NO: 119, SEQ ID NO: 135, SEQ ID NO: 151, SEQ ID NO: 167, SEQ ID NO: 183, SEQ ID NO: 199, SEQ ID NO: 215, SEQ ID NO: 231, SEQ ID NO: 247, SEQ ID

NO: 263, SEQ ID NO: 279, SEQ ID NO: 295, SEQ ID NO: 311, SEQ ID NO: 327, SEQ ID NO: 343, SEQ ID NO: 359, SEQ ID NO: 375, SEQ ID NO: 391 and SEQ ID NO: 407.

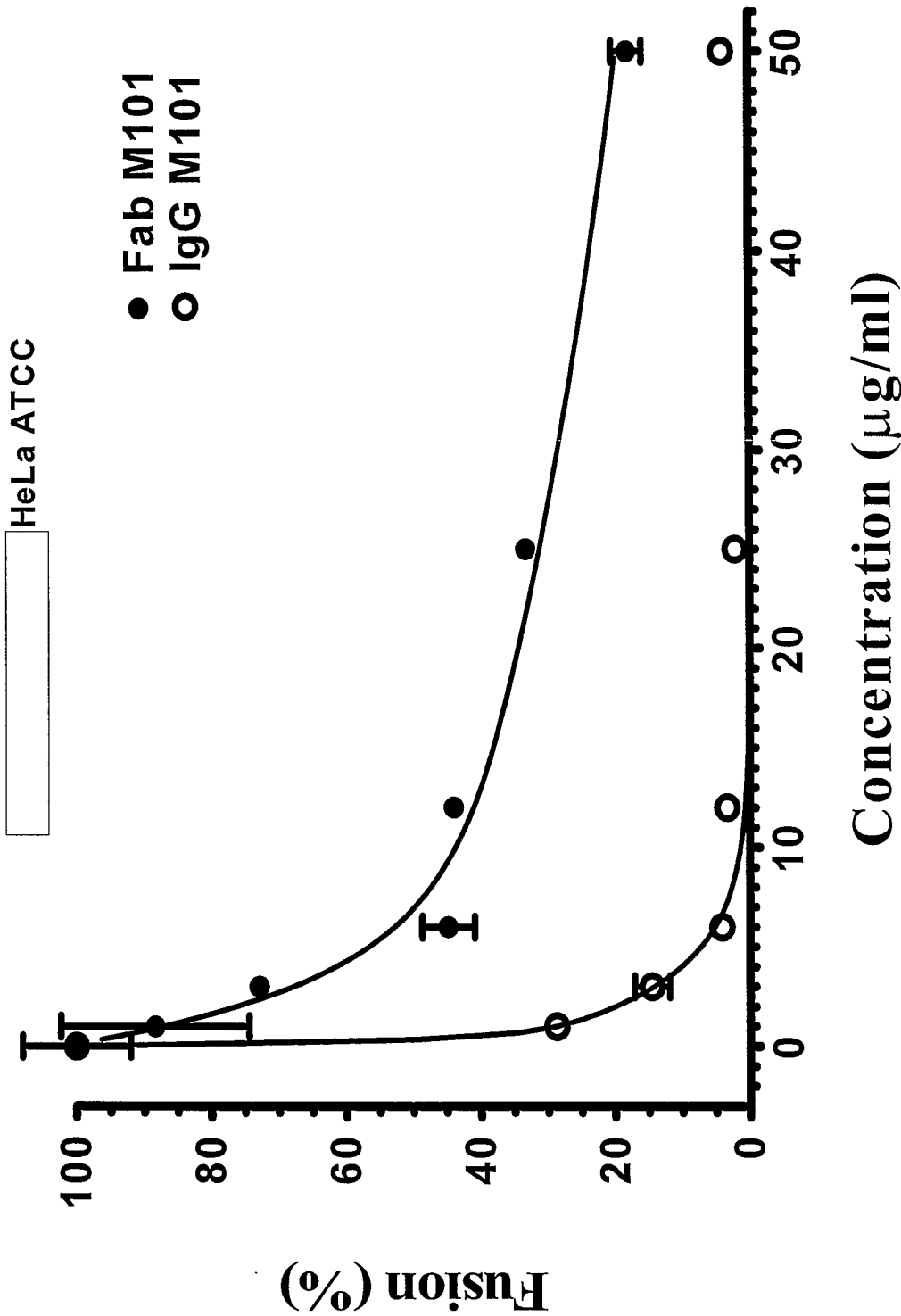


Fig. 1A

PCI-13

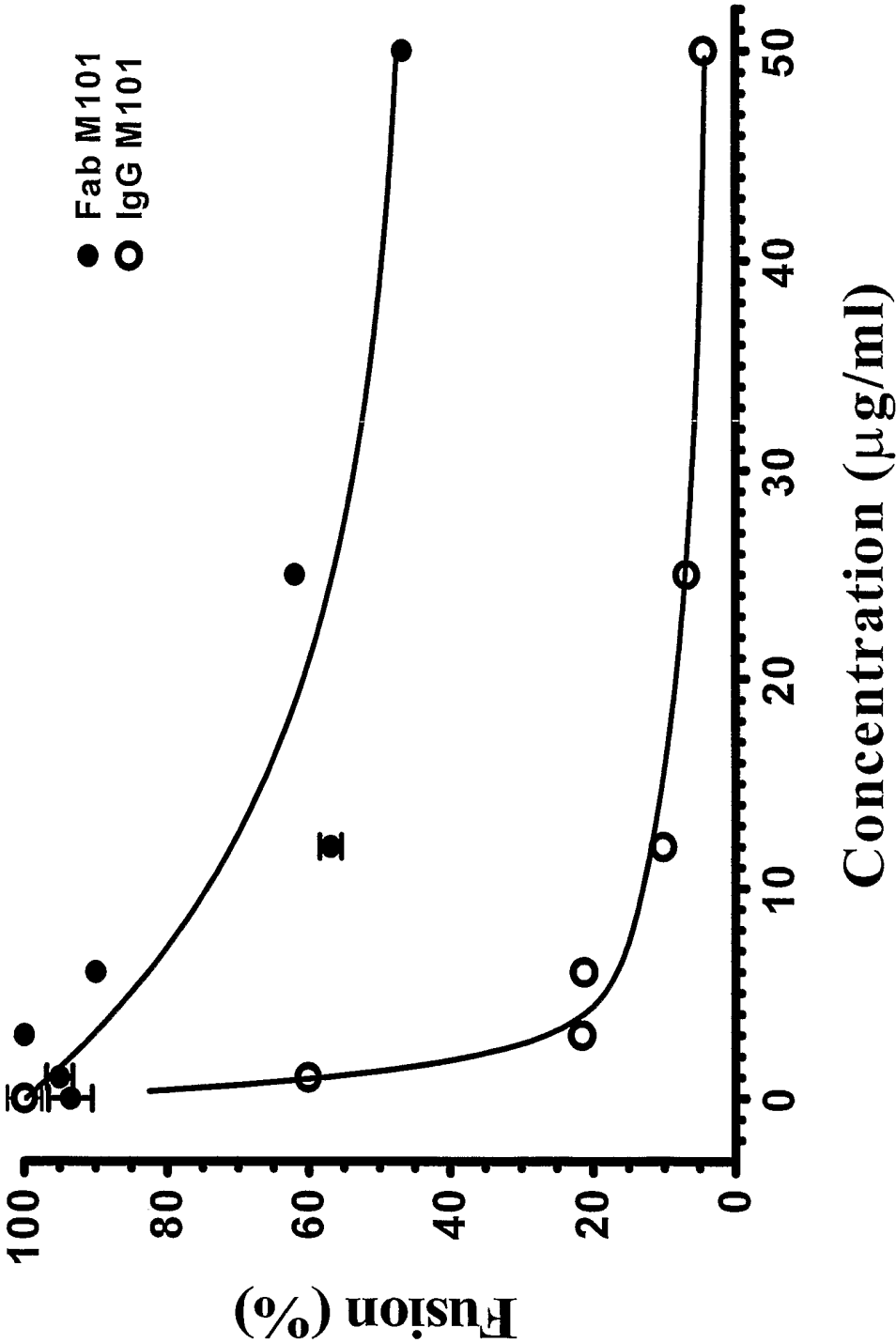
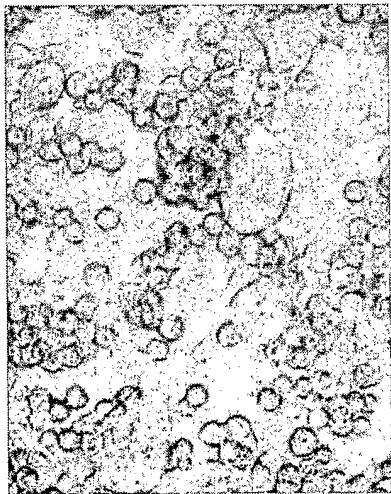


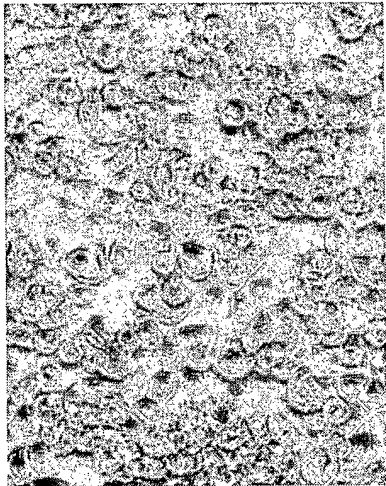
Fig. 1B

Fig. 2

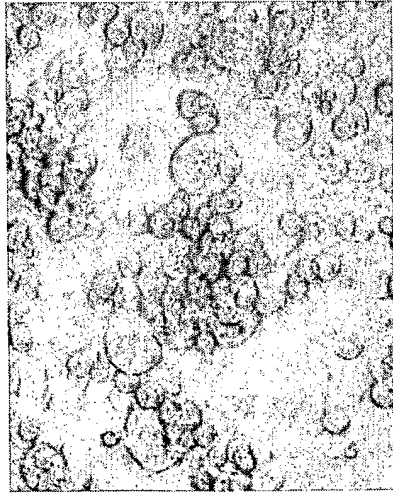
No Antibody



IgG1 m101 (10 µg/ml)



Control Antibody



Fab m101 (10 µg/ml)

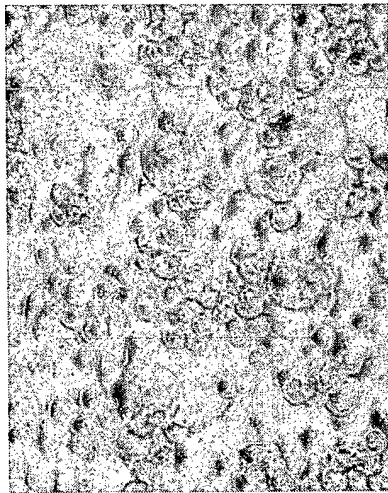


Fig. 3

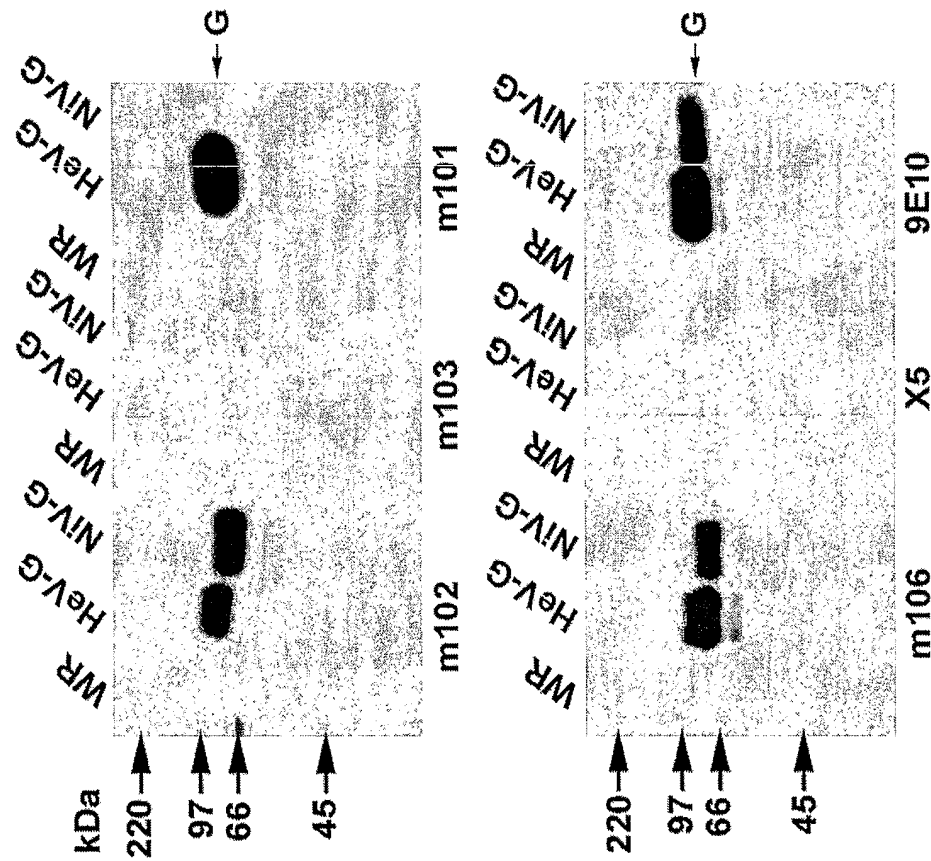


Fig. 4

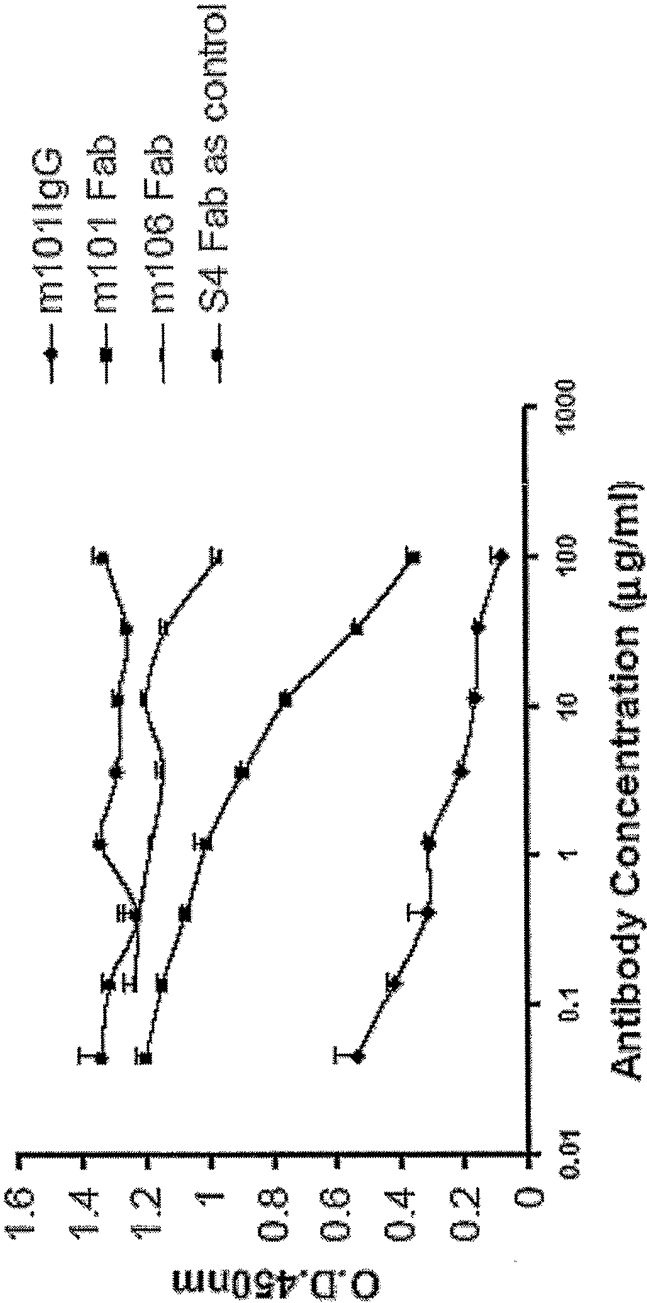
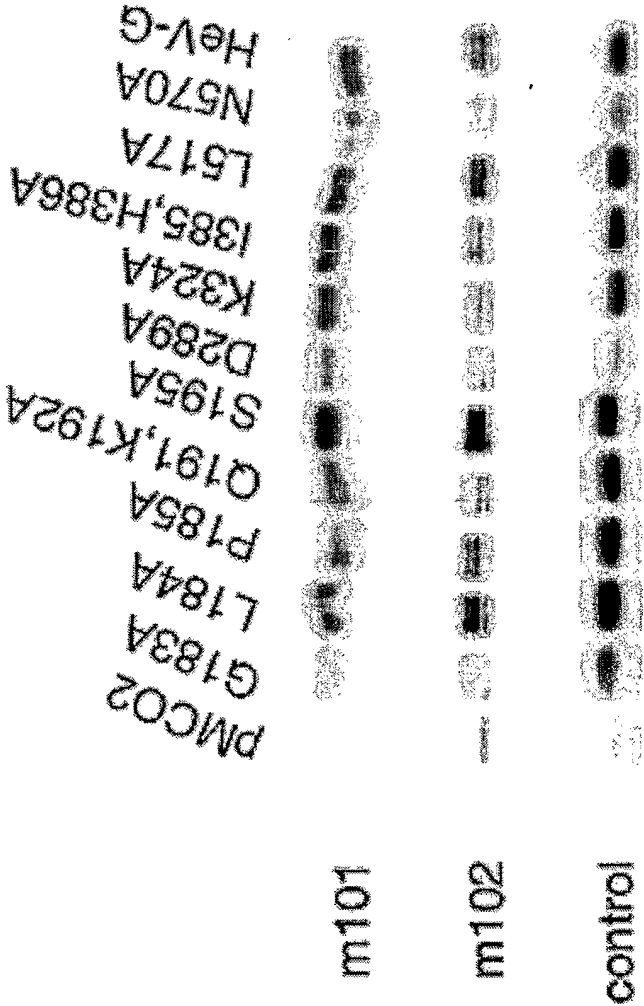
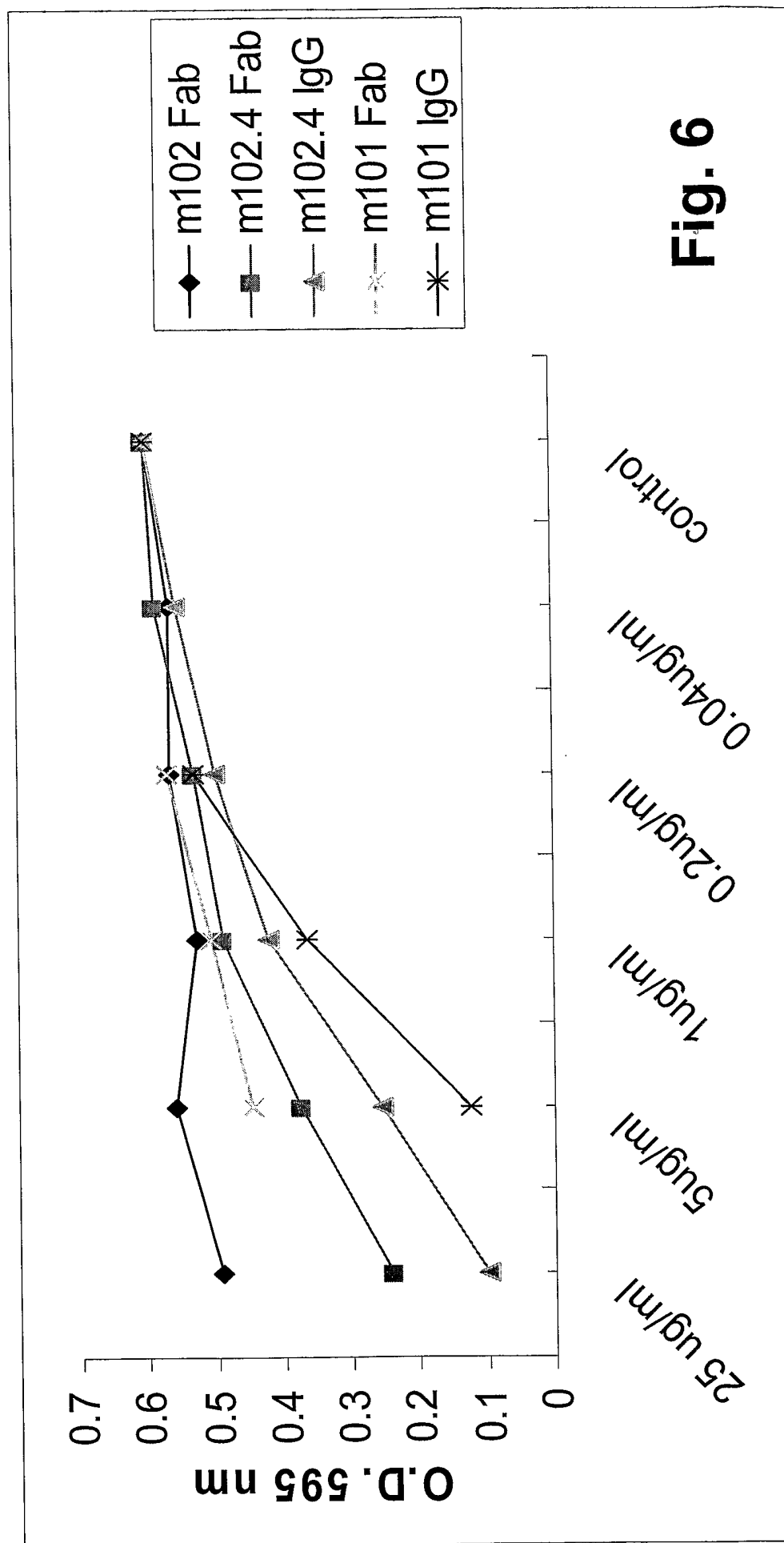


Fig. 5



Inhibition of HeV Env-Mediated Fusion by Affinity Matured IgG m102.4: Weaker Activity than IgG m101



Inhibition of NiV Env-Mediated Fusion by Affinity Matured IgG m102.4: Exceptional Potency

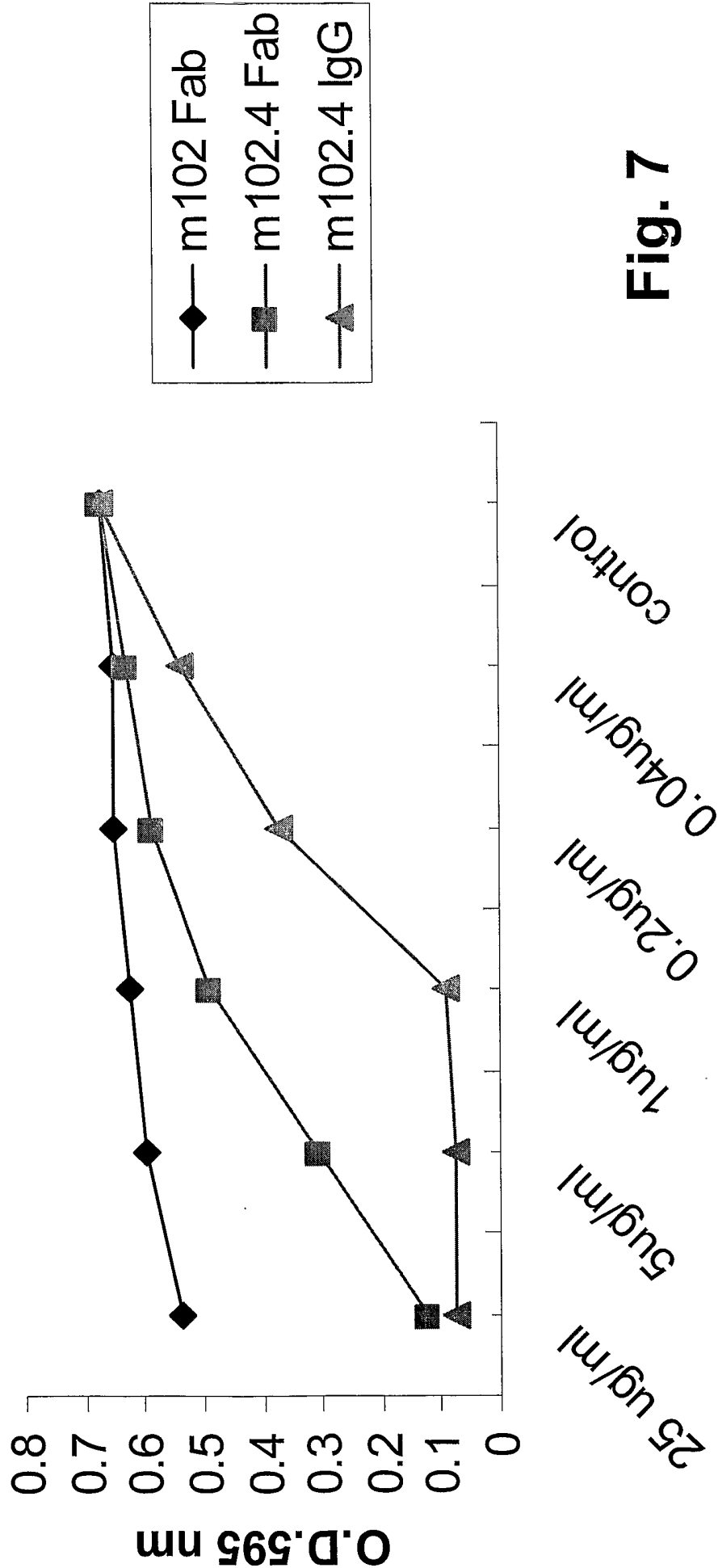


Fig. 7

For all the VH and VL sequences, the CDR1-3s were underlined and the FR1-4s were the fragments divided by the three CDRs. The following example can be applied to all the sequences.

Example:

```

      FR1          FR2          FR3          FR4
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
      CDR1          CDR2          CDR3

```

m101-m107 Sequences:

m101 VH3

QVQLVQSGAEVKKPGASVKVSCKASGGTFSSYAISWVRQAPGQ
GLEWMGGIIPFGTANYAQKFQGRVTITADESTSTAYME
LSSLRSGDTAVYYCARDPGGYSGPYYYYYYGMDVWGQ
GTTVTVSS

m101 Vk1

DIQMTQSPSSVSASVGDRVITICRASQGIGPWLA WYQQKPGKAP
KFLIYRASTLQSGVPSRFSGSGSGTDFTLTISSLQPEDFAT
YYCQQAHSFPFTFGPGTKVDIKRTVA

m102 VH1

EVQLVQSGAEVKKPGSSVKVSCKSSGGTFSSNYAINW
VRQAPGQGLEWMGGIIPILGIANYA QKFQGR
VTITTDESTSTAYMELSSLRSED TAVYYCARG
WGREQLAPHPSQYYYYYYGMDVWGQGTTVT
VSS

m102 Vk3

EIVLTQSPGTLSLSPGERATLSCRASQSITNGRLAWY
QQKPGQAPRLLIYGVSSRASGIPERFSGSGSGT
DFTLTISRLEPEDFAVYYCQQYGSSVLFGPGT
KVDIKRTVA

m103 VH3

EVQLVESGGGLIQPGGSLRLSCAASGFTVSSNYMSW
VRQAPGKGLEWVSVIYSGGSTYYADSVKGRF
TISRDN SKNTLYLQMNSLRAED TAVYYCARD
SRYHDAFDIWGQGTMTVTVSS

Fig. 8

m103 **Vk2**

D V V M T Q S P L S L P V T P G E P A S I S C R S S Q S L L H S N G Y N Y
L D W Y L Q K P G Q S P Q L L I Y L G S N R A S G V P D R F S G
S G S G T D F T L K I S R V E A E D V G V Y Y C M Q A L Q T L
Y T F G Q G T K L E I K R T V A

m104 **VH1**

Q V Q L Q Q S G A E V K K P G S S V K V S C K A S G G T F S S Y A I S W
V R Q A P G Q G L E W M G G I I P I F G T A N Y A Q K F Q G R
V T I T A D E S T S T A Y M E L S S L R S E D T A V Y Y C A R E
S S W L D A F D I W G Q G T M V T V S S

m104 **Vk2**

D V V M T Q S P L S L S V T A G E P A S I S C R S S Q S L L H S N G H I Y
L D W Y L Q K P G Q S P Q L L I Y M A S N R A S G V P D R F S
G S G S G T D F T L R I N R V E T E D V G I Y Y C M Q S L H T T
R T F G Q G T K V E I K R T V A

m105 **VH3**

Q V Q L V Q S G G G V V Q P G R S L R L S C A A S G F T F S S Y A M H
W V R Q A P G K G L E W V A V I S Y D G S N K Y Y A D S V K
G R F T I S R D N S K N T L Y L Q M N S L R A E D T A V Y Y C
A R V G G I T G T A D A F D I W G Q G T M V T V S S

m105 **Vk1**

D V V M T Q S P L S L P V T L G Q P A S I S C R S S Q S L V Y S D G N T
Y L N W F Q Q R P G Q S P R R L I Y K V S N R D S G V P D R F S
G S G S G T D F T L K I S R V E A E D V G V Y Y C M Q G T H W
P F T F G P G T K V D I K R T V A

m106 **VH1**

Q V Q L Q Q S G A E V K K P G S S V K V S C K A S G G T F S S Y A I S W
V R Q A P G Q G L E W M G G I I P I F G T A N Y A Q K F Q G R
V T I T A D K S T S T A Y M E L S S L R S E D T A V Y Y C A R D
Q L A G Y Y Y D S S G Y H Y Y Y Y G M D V W G Q G T T V T V
S S

m106 **Vk1**

D I Q M T Q S P S S L S A S V G D R V T I T C R A S Q S I S S Y L N W Y Q
Q K P G K A P K L L I Y A A S S L Q S G V P S R F S G S G S G T
D F T L T I S S L Q P E D F A T Y Y C Q Q S Y S T P I T F G Q G T
R L E I K R T V A

Fig 8 (continued¹)

m107 VH1

EVQLVQSGAEVKKPGASVKVSCKASGYTFTGYYMH
WVRQAPGQGLEWMGIINPSGGSTSYAQKFQG
RVTMTRDTSTSTVYMELSLRSEDTAVYYCAR
DHVHGPDAFDIWGQGTMTVTVSS

m107 VL1

SYELTQPPSASGTPGQRVTISCSGSSSNIGSNTVNWY
QQLPGTAPKLLIYRNNQRPSGVPDRFSGSKSG
TSASLAISGLQSEDEADYYCAAWDDSLHVVF
GGGTKLTVLGQPKA

m108-117 mabs VH +VL protein sequences:

M108

VH

EVQLVESGGGLVKPGGSLRLSCAASGFTFSD
YYMSWIRQAPGKGLEWVSYISSSGSTIYYADS
VKGRFTISRDNAKNSLYLQMNSLRAEDTAVY
YCARVGGAFDIWGQGTMTVTVSS

VL

NFMLTQPHSVSGSPGKTVTISCTRSSGSIASNYVQWYRQS
PGSAPTTVIYEGYQRPSGVPDRFSGSIDSSSNSASLTISGL
ETEDEADYYCQSYDATNHQVVFGGGTKLTVL

M109

VH

QMQLQQWGAGLLKPSETLSLTCAVYGGSFSG
YYWSWIRQPPGKGLEWIGEINHSGSTNYNPS
LKSRVTISVDTSKNQFSLKLSSVTAADTAVYY
CARGWFRDWYFDLWGRGTLVTVSS

VL

DIQMTQSPSSLSASVGDRVTITCRASQDIRNDLGWYQQRPG
KAPKLLIYAAASSLQSGVPSRFSSGSGGTDFTLTISLQPED
SATYFCLQDYQYPWTFGQGTKVEIKR

Fig. 8 (continued²)

M110

VH

E V Q L V Q S G G G L V Q P G R S L R L S C A A S G F T F D D
Y A M H W V R Q A P G K G L E W V S A I S G S G G S T Y Y A
D S V K G R F T I S R D N S K N T L Y L Q M N S L R A E D T A
V Y Y C A S E G L P E T D D A F D I W G Q G T M V T V S S

VL

D V V M T Q S P L S L P V T P G E P A S I S C R S S Q S L L Y S D G Y N Y L D W
Y L Q K P G Q S P Q L L I Y L G S R R A S G V P D R F S G S G S G T D F T L K I
N T V E A E D V G V Y Y C M Q G V E I P F T F G P G T K V E I K R

M111

VH

Q V Q L V Q S G A E V K K P G A T V K I S C K V S G Y T F T D
Y Y M H W V Q Q A P G K G L E W M G L V D P E D G E T I Y A
E K F Q G R V T I T A D T S T D T A Y M E L S S L R S E D T A V
Y Y C A T E G A D Y W G Q G T L V T V S S

VL

D V V M T Q S P L S L P V A L G Q P A S I S C R S S Q S L V H S D G N T Y L N
W F Q Q R P G Q S P R R L L Y K V S N R E S G V P D R F S G S G S G S D F T L K
I S R V E A E D V G I Y Y C M Q G T H W P P I T F G Q G T R L E I K R

M112

VH

Q V Q L V Q S G A E V K K P G A T V K I S C K V S G Y T F T D
Y Y M H W V Q Q A P G K G L E W M G L V D P E D G E T I Y A
Q K F Q G R V T I T A D T S T N T A Y M E L S S L R S E D T A V
Y Y C A T D G A D Y W D Q G T L G T V S T

VL

Q S V L T Q P P S V S G A P G Q T V T I S C T G S S S N I G G D S D V H W Y Q Q
L P G S A P K L L I Y G N R N R P S G V P D R F S G S R S G T S A S L A V I G V
Q A D D E A D Y Y C Q C Y D S S L N G Y V F G P G T K V I V L

M113

VH

Q V Q L Q Q S G A E V K K P G S S V K V S C K A S G G T F S S
Y A I S W V R Q A P G Q G L E W M G W T N P N S G G T N Y A
Q K L Q G R V T M T T D T S T S T A Y M E L R S L R S D D T A
V Y Y C A N Y K L Q S D A F D I W G Q G T M V T V S S

VL

DIQM TQSPSSLSASVGDRVITICRASQDIGNFLVWFQQKP
GKAPKSLIYAASRLQSGVPSRFSGSGSGTDFTLTISLQPE
DFATYYCQHYSYPLTFGGGTKVEIKR

M114

VH

QVQLVQSGAEVKKPGSSVKVSCKASGGTFSS
YAISWVRQAPGQGLEWMGGIIPFGTANYAQ
KFQGRVTITADESTSTAYMELSSLRSEDTAVY
YCARAGPVGATTGTFDYWGQGTLVTVSS

VL

DIVM TQSPGTLSPGERATLSCRASQSVSSSYLAWYQQ
KPGQAPRLLIYGASSRATGIPDRFSGSGSGTDFTLTISRLE
PEDFAVYYCQQYGSSFTFGPGTKVDIKR

M115

VH

QVQLQQSGAEVKKPGSSVKVSCKASGGTFRS
YAISWVRQAPGQGLEWMGGIIPFGTANYAQ
KFQGRVTITADESTSTAYMELSSLRSEDTAVY
YCARGSQSYDHYYYGYGMDVWGQGTTVTVSS

VL

QSALTQPASVSGSPGQSITISCTGTSSDVGGYNYVSWYQQ
HPGKAPKLMIFDVSNRPSGVSNRLSGSKSGNTASLTISGL
QAEDEADYYCSSYTSNTVVFGGGTKLTVL

M116

VH

EVQLVQSGAEVKKPGSSVKVSCKASGGAFSS
YAISWVRQAPGQGLEWMGGIIPFGTANYAQ
KFQGRVTITADESTSTAYMELSSLRSEDTAVY
YCARD SAGLGA WGQGTLVAVSS

VL

DIQM TQSPSSLSASVGDRVITICRASQGISSALAWYQQKP
GKAPKLLIYDASSLESGVPSRFSGSGSGTDFTLTISLQPE
DFATYYCQQFNSYPLTFGQGTRLEIKR

M117

VH

Q I T L K E S G P T L V K P T Q T L T L T C T F S G F S L S T S G
V G V G W I R Q P P G K A L E W L A L I Y W D D D K R Y S P S
L K S R L T I T K D T S K N Q V V L T M T N M D P V D T A T Y
Y C A H R E S G P E F F Q H W G Q G T L V T V S S

VL

D V V M T Q S P L S L P V T L G Q P A S I S C N S S Q S L V Y S N G I T Y L N W
F H Q R P G Q S P R R L I Y Q V S N W D S E V P D R F S G S G S A T D F T L K I
S R V E A D D V G I Y Y C M Q G T H W P P T F G Q G T R L E I K R

9 m102 mutants Sequences:

M102.2

VH

E V Q V I Q S G A D V K K P G S S V K V S C K S S G G T F S K Y A I N W V R Q
A P G Q G L E W M G G I I P I L G I A N Y A Q K F Q G R V T I T T D E S T S T A
Y M E L S S L R S E D T A V Y Y C A R G G W G R E Q L A P H P S Q Y Y Y Y Y Y
G M D V W G Q G T T V T V S S

VL

E I V M T Q S P G T L S L S P G E R A T L S C R A S Q S V A S R Y L A W Y Q H
K P G L A P R L L I Y G A S T R A T G I P D R F S G S G S G T D F T L T I S R L E
P E D F A V Y Y C Q Q Y G R T P S V T F G G G T K V E I K R

M102.3

VH

E V Q V I Q S G A D V K K P G S S V K V S C K S S G G T F S K Y A I N W V R Q
A P G Q G L E W M G G I I P I L G I A N Y A Q K F Q G R V T I T T D E S T S T A
Y M E L S S L R S E D T A V Y Y C A R G G W G R E Q L A P H P S Q Y Y Y Y Y Y
G M D V W G Q G T T V T V S S

VL

E I V M T Q S P G T P S L S P G E R A T L S C R A S Q S I R S T Y L A W Y Q Q K
P G Q A P R L L I Y G A S S R A T G I P D R F S G S G S G T D F T L T I S R L E P
E D F A V Y Y C Q Q Y G R S P S F G Q G T K V E I K R

M102. 4

VH

EVQVIQSGADVKKPGSSVKVSCKSSGGTFSKYAINWVRQ
APGQGLEWMGGIIPILGIANYAQKFQGRVTITTDESTSTA
YMESSLRSED~~TAVYYCARGWG~~REQLAPHPSQYYYYYY
GMDVWGQGTTVTVSS

VL

EIVMTQSPGTL~~SLAPGERATLSC~~WASQSVRNNYLAWYQQ
KPGQAPRLVIYNGSTRATGIPDRFSGSGSGTDFTLTISRLD
PEDFAVYYCQQYGN~~SRRT~~TFGGGTKVEIKR

M102. 5

VH

EVQVIQSGADVKKPGSSVKVSCKSSGGTFSKYAINWVRQ
APGQGLEWMGGIIPILGIANYAQKFQGRVTITTDESTSTA
YMESSLRSED~~TAVYYCARGWG~~REQLAPHPSQYYYYYY
GMDVWGQGTTVTVSS

VL

EIVLTQSPGTL~~SLSPGERATLSC~~RASQSVSSSYLAWYQQK
PGQAPRLLIYGTSTRATGIPDRFSGSGSGTDFTLTISRLEP
EDFAVYYCQRYGSSPAFGQG~~GT~~TKVEIKR

M102.11

VH

EVQVIQSGADVKKPGSSVKVSCKSSGGTFSKYAINWVRQ
APGQGLEWMGGIIPILGIANYAQKFQGRVTITTDESTSTA
YMESSLRSED~~TAVYYCARGWG~~REQLAPHPSQYYYYYY
GMDVWGQGTTVTVSS

VL

DIQMTQSPATLSASIGDRV~~TITCRASQSISKW~~LAWYQQKP
GKAPKLLIYKASTLES~~GVPSR~~FSGSGSGTDFTLTIS~~SLQPD~~
DFATYYCQQYIN~~YATF~~GQG~~GT~~TKVEIKR

M102.12

VH

EVQVIQSGADVKKPGSSVKVSCKSSGGTFSKYAINWVRQ
APGQGLEWMGGIIPILGIANYAQKFQGRVTITTDESTSTA
YMESSLRSED~~TAVYYCARGWG~~REQLAPHPSQYYYYYY
GMDVWGQGTTVTVSS

VL

EIVM TQSPGTL SLAPGERATL SCWAS QSVRNNYLAWYQQ
KPGQAPRLVIY NGSTRATGIPDRFSGSGSGTDFTLTISRLD
PEDFAVYYC QQYGNSRRVTFGGGTKVEIKR

M102.13

VH

EVQVIQSGADVKKPGSSVKV SCKSS GGTFSKYA INWVRQ
APGQGLEWMGGI IPILGIANYA QKFQGRVTITTTDESTSTA
YME LSSLRSEDTAVYYCARG WGREQLAPHPSQYYYYYY
GMDVWGQGTTTVTVSS

VL

EIVLTQSPATLSLSPGERATL SCRAS QSVSSYLAWYQQKPGQ
APRLLIYD ASNRATGIPARFSGSGSGTDFTLTIS SLEPEDFAV
YYC QQRSNWPTFGQGTKVEIKR

M102.15

VH

EVQVIQSGADVKKPGSSVKV SCKSS GGTFSKYA INWVRQ
APGQGLEWMGGI IPILGIANYA QKFQGRVTITTTDESTSTA
YME LSSLRSEDTAVYYCARG WGREQLAPHPSQYYYYYY
GMDVWGQGTTTVTVSS

VL

EIVLTQSPGTL SLSPGERATL SCRAS QSVSSSYLAWYQQKP
GQAPRLLIY GASSRATGIPDRFSGSGSGTDFTLTISRLEPEDF
AVYYC QQYGSSPTITFGQGTRLEIKR

M102.16

VH

EVQVIQSGADVKKPGSSVKV SCKSS GGTFSKYA INWVRQ
APGQGLEWMGGI IPILGIANYA QKFQGRVTITTTDESTSTA
YME LSSLRSEDTAVYYCARG WGREQLAPHPSQYYYYYY
GMDVWGQGTTTVTVSS

VL

EIVLTQSPGTL SLSPGERATL SCRAS QSVSSSYLAWYQQKP
GQAPRLLIY GASSRATGIPDRFSGSGSGTDFTLTISRLEPEDF
AVYYC QQYGSSPVFGQGTKLEIKR